Denmark's Second Small Scientific Satellite

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Abstract

Denmark is now planning its second scientific satellite after the first successful mission "Ørsted". The new satellite has been named Rømer after the Danish astronomer Ole Rømer (1644-1710). The 2 scientific experiments, which will be implemented, are **MONS** with the primary science objective of observing some 20 nearby, solar-like stars by measuring tiny oscillations in intensity and colour by precision photometry. This is done to probe the stellar interior for determination of its temperature, composition, age and internal rotation, and **Ballerina** with the primary science objective of tracing and monitoring short "Gamma-Ray Bursts". The current mass of the combined satellite is estimated to be $\approx$ 120 kg and the envelope is $60 \times 60 \times 80$ cm. It is proposed to launch the satellite into a so-called Molniya orbit ($\approx$ 500 km $\times \approx$ 40.000 km, 63.4°) using the Russian Soyuz launch vehicle with the new Fregat upper stage. The launch date is currently foreseen to be late 2003.

Introduction

The first Danish Satellite was successfully launched on 23 February 1999 as a secondary payload with US Air Force ARGOS on a Delta-II launch vehicle. The main objective of the 61 kg ØRSTED-satellite is to map the Earth's magnetic field and the charged particle environment from a near-Sun synchronous low-Earth orbit (650 km x 850 km, 96.5°). The satellite continues to function perfectly in orbit and has already provided the most intriguing new insight into the changes of the Earth's magnetic field since the NASA MAGSAT mission in 1979-80. The first concrete data product from the ØRSTED-satellite was the International Geomagnetic Reference Field Model IGRF-2000, with unprecedented precision, based entirely on the ØRSTED-data.

The ØRSTED-satellite has, since the completion of the Flight Model in 1997, raised a considerable interest for small scientific satellites in Denmark and in the beginning of 1998, a Danish Small Satellite Programme was initiated. The first mission, which is carried out in this context, is the Danish contribution to the Argentine SAC-C mission, also denoted ØRSTED-2. 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 during the ØRSTED-mission. SAC-C is expected to be launched in October 2000.

In February 2000, after several technical and scientific evaluation rounds, it was decided which mission should be implemented as the second Danish small scientific satellite. This paper briefly presents the scientific goals and the satellite technical baseline. The satellite has been named Rømer after the Danish astronomer Ole Rømer (1644-1710) and the plan is to launch the satellite late 2003.

The Rømer Satellite

The RØMER mission is the result of a call for proposals and the consecutive evaluation and down-selection process during 1998 and 1999, resulting in a mission based on a combination of 2 of the original proposals. **MONS - Measuring Oscillations in Nearby Stars**, proposed by the Institute of Physics and Astronomy, University of Aarhus and **Ballerina - Pirouettes in search of Gamma-Ray Bursts** proposed by the Danish Space Research Institute.

The current mass of the combined satellite is estimated to be $\approx$120 kg and the envelope is $60 \times 60 \times 80$ cm. Fig. 1 shows the proposed satellite configuration mounted with solar panels and the deployable cover on the top for protection of the on-board optics.
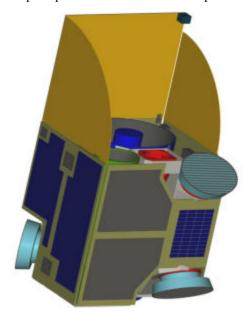

Fig. 1: Rømer satellite
(Peer Taarup Clausen, DSRI)

RØMER Science Mission

MONS - Measuring Oscillations in Nearby Stars.

The primary science objective of the MONS experiment is to observe nearby, solar-like stars by measuring tiny oscillations in intensity and colour by precision photometry. This is done to probe the stellar interior for determination of its temperature, composition, age and internal rotation.

Today, the only star, which has been subject to such measurements, is our own sun and the group behind the MONS project has contributed substantially to these *helio-seismic* studies of the Sun. The experience from this, and from the wide-ranging observations of stars done by this group, creates a firm foundation for the MONS project.

The main telescope of MONS (40 cm) will concentrate on observing about 20 stars with oscillations corresponding to those of the Sun, observing each star for 1 - 2 months. These stars will be chosen to represent an appropriate selection of masses and ages; 1 possible candidate is a star, which closely corresponds to the future state of the Sun, in about 3 billion years. Observations of a large number of other stars will be undertaken with the 2 onboard star trackers, which are used to control and point the satellite. Even though the precision is lower than it is for the main telescope, these observations will nevertheless be far better than Earth-based observations, for a large number of variable stars of many different types. The Australian company AUSPACE, in co-operation with University of Sydney and the Institute for Physics and Astronomy at the Danish Aarhus University, which is also the principle responsible for the science part of the MONS mission, develops the telescope. Fig. 2 shows an example on how such oscillations can look like.
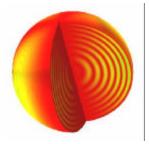

Fig. 2: Example of light oscillation patterns of a star with periodic wave motion on the surface as well as in the interior. (Source: Institute for Physics and Astronomy, Aarhus University)

Ballerina - The search for gamma-ray bursts and X-ray transients.

The primary science objective of the Ballerina experiment is to trace and monitor short "gamma-ray bursts", which due to their random occurrence and transient nature are very difficult to observe in detail, and the origin of which are very poorly understood.

Establishing the cosmological distances to gamma-ray bursts and understanding their nature will provide us with a new and independent probe of the structure of the Universe - complementary to supernovae, quasars and clusters of galaxies.

On the experimental side, it remains a challenge to ensure the earliest detection of the X-ray afterglow. For the first time, this experiment allows for systematic studies of the soft X-ray emission in the time interval from only a few minutes after the onset of the burst to a few hours later. Thus, in addition to accurate source positions essential for follow-up work with larger telescopes, Ballerina will independently provide observations in an uncharted region of parameter space. In addition to the autonomous observations of events detected on board, Ballerina may on short notice be commanded from the ground to execute observations on objects identified by other observatories. Fig. 3 shows a gamma-ray burst observed in 1992 with WATCH on EURECA. Both times the history of the burst and a sky map with the source position is shown.
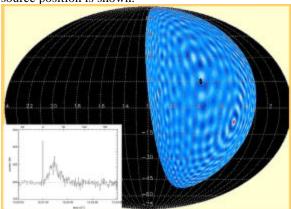

Fig. 4: gamma-ray burst (Source DSRI)

The Ballerina experiment consists of a system of 4 wide-angle x-ray monitors developed by DSRI (Fig. 4), which will trace the bursts. When the X-ray signature of a gamma-ray burst has been detected, the satellite will turn autonomously to point an X-ray telescope (developed by the Max Planck Institute, Germany) towards the source for detailed observations.

Fig. 4: Wide angle gamma-ray detector
(WATCH-EURECA version)

RØMER Mission Concept

Orbit Considerations

The science mission requirements call for a spacecraft in an orbit spending most of its time outside the proton radiation belts. The instruments of both the MONS- and the Ballerina experiments are sensitive to proton irradiation, implying that either a geo-stationary or highly elliptical orbit is desirable.

To reach a geo-stationary orbit an apogee kick motor is required and this is deemed an undesirable driver of cost, mass, complexity and risk. This leaves back highly elliptical orbits, including the geo-stationary transfer orbit (GTO), the Molniya orbit employed by Russian communication satellites or seldom frequented orbits like those of the XMM/Newton, Cluster-II, Chandra and other scientific satellites.

Based on a survey of available orbit options in the 2003 timeframe, a launch as a secondary payload on board a Russian Soyuz/Fregat launcher to the Molniya orbit (≈40.000 km x ≈500 km, 63.4°) has been chosen as the initial baseline.

The Molniya orbit with a period of revolution of 12 hours allows 8-10 hours of uninterrupted observations outside the radiation belts. It also has the convenient feature that the apogee stays above the Northern Hemisphere, allowing full TM/TC coverage from a single ground station in Denmark, during the entire 2-year mission period. The Molniya orbit also satisfies the requirement for continuous availability of the TM down-link during the observation period from the Ballerina experiment.
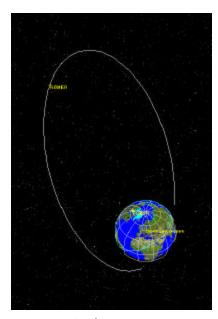

Fig. 5: Picture of RØMER in Molniya orbit

Operations Scenario

The 12-hour orbit period will consist of 8-10 hours of observations while outside the radiation belts, 1-2 hours of high-speed telemetry down-link and 2-4 hour maintenance period. The TM down-link will overlap the observation and maintenance period. During the maintenance period excess momentum on the WATCH rotors will be dumped, using magnetorquers while maintaining an attitude around the perigee pass that minimises the thermal disturbances.

The primary instrument complex on Rømer is the MONS experiment and the secondary is Ballerina. The MONS primary observation scenario is to continuously monitor a selected target star up to 30 days, but interrupting this observation for shorter periods of time will not affect the scientific goals of the mission. Thus, it has been proposed to include the Ballerina instrument complex, which from time to time (approx. 70 times/year) autonomously will detect a gamma-ray burst with its WATCH all-sky X-ray monitors to an accuracy of approximately 1° and interrupt the MONS measurements, and autonomously swing the satellite around to monitor the burst using the X-ray telescope for a few hours. The x-ray telescope will measure the burst intensity and spectrum, afterglow etc. and determine the position of the source to an accuracy of approx. 1 arc-minute. The exact position of the source will be down-linked to the ground within minutes of its detection. This is a very important feature in order to ensure that larger and more advanced ground based telescopes also has the opportunity of investigating the burst source while it is still bright. Having completed the gamma-ray burst monitoring phase, the satellite will then swing back to its original target star and continue the MONS observation using its optical telescope. Scientifically, it has been verified that this approach is feasible without degradation of the science goals. However, technically, the mission is very challenging and it may be necessary to de-scope the science goals to ensure a feasible mission. A quite unique feature of the satellite is the proposal to use the rotating WATCH wide angle monitors as momentum wheels for attitude control and stabilisation. This approach has been investigated in some detail and it has been verified that this approach is feasible.

Radiation Environment

Compared to the environment in low-Earth orbit (LEO), the radiation in Molniya orbit is very harsh. Dose-depth curves have been calculated using the ESA SPENVIS software and models. Fig. 6 shows the dose-depth curves for the Molniya orbit during a 2-year lifetime, assuming solar maximum conditions and for various particle species and sources.
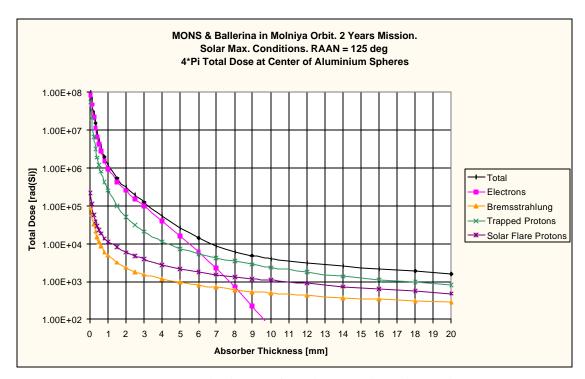
Fig.6: Dose-depth curves for radiation in the Molniya orbit

At 2.5-mm absorption thickness, the total dose becomes 190 krad (Si). This radiation level would dictate rad-herd semi-conductor parts, which severely impacts the parts expenses for narrows the availability of such parts. By increasing the shielding thickness to 6-7 mm, the dose is brought within the 10-20 krad (Si) range, for which a great part of commercial of-the-shelf (COTS) devices are applicable. Still, the radiation tolerance of the proposed devices must be documented before being accepted for this dose level. Based on these considerations it becomes mandatory to design the spacecraft structure to provide shielded compartments with a minimum of 6 mm aluminium shielding for the electronics.

Spacecraft Design Considerations

The mass of a secondary payload that can be accommodated on board the Soyuz/Fregat launcher is around 130 kg. The physical dimension is not yet determined in detail, but the ARIANE-5 ASAP envelope of 600 x 600 x 800 mm has been adopted for the RØMER satellite.

The structural design and accommodation of instruments and platform equipment is driven by several factors and constraints:

- The WATCH X-ray monitors needs a tetrahedral arrangement for full-sky coverage and needs un-obscured FOV-zones.
- The spacecraft structure must be able to carry instruments, equipment, solar panels, etc. and also to provide radiation shielding to the electric circuits.

- The satellite must be very compact in order to minimise the moment of inertia, allowing fast attitude slews for quick gamma-ray burst source acquisition.
- The focal planes of the MONS and X-ray telescopes need to be cooled passively to about 170 K, necessitating short distance from the shadow-side radiator surfaces to the focal planes.
- The apertures of the MONS telescope must be shadowed from the sun during observations.
- Heavy equipment and instruments should be positioned as close as possible to the separation interface, in order to lower the center of mass.
- The magnetometer must be placed as far away from the spacecraft body as possible, in order to be useful for scientific purposes.
- The TM/TC antennas must be positioned on 2 opposite faces, in order to ensure omni-directional coverage.
- The satellite should have solar cells on 3 faces or more, in order to ensure adequate power during the early operation phases, while the attitude is not fully controlled.
- It is desired to keep the platform and payload electronics separated as far as possible, allowing the prime contractor to provide the platform as a recurring unit for other missions.

These and other design considerations lead to the proposed spacecraft configuration shown in Fig. 7 & 8.
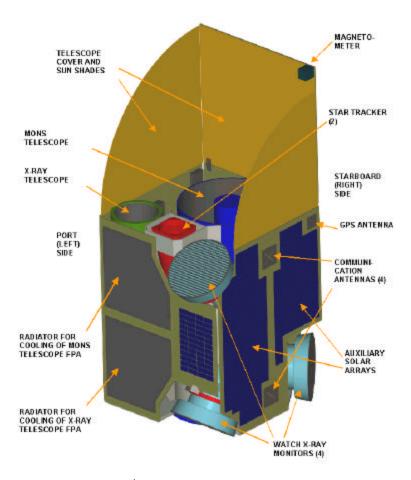
TELESCOPE COVER AND SUN SHADES

MAGNETO-METER

MONS TELESCOPE

STAR TRACKER (2)

X-RAY TELESCOPE

STARBOARD (RIGHT) SIDE

PORT (LEFT) SIDE

GPS ANTENNA

COMMUNI-CATION ANTENNAS (4)

RADIATOR FOR COOLING OF MONS TELESCOPE FPA

RADIATOR FOR COOLING OF X-RAY TELESCOPE FPA

AUXILIARY SOLAR ARRAYS

WATCH X-RAY MONITORS (4)

Fig. 7: The RØMER satellite. View from the shadow side

STAR TRACKER

MONS TELESCOPE

X-RAY TELESCOPE

STAR TRACKER
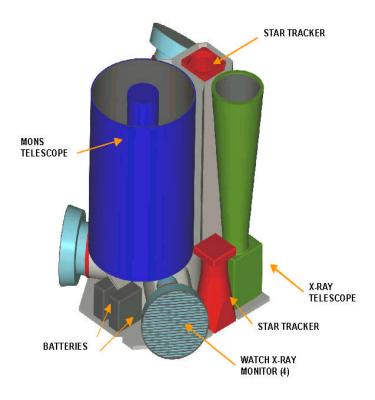
BATTERIES

WATCH X-RAY MONITOR (4)

Fig. 8: The RØMER satellite with the solar panels removed

The body dimensions comply with the ARIANE-5 ASAP envelope of 600 x 600 x 800 mm. The WATCH rotors protrude beyond this, making the gross envelope 750 x 750 x 800 mm, which was accepted by the launch provider.

Spacecraft Structure

The spacecraft structure with all instruments removed is shown in Fig. 9.

The bottom cylinder is the platform electronics compartment and houses the command- and data handling sub-system (CDH), the attitude control electronics (ACS), the electrical power sub-system (EPS) and the
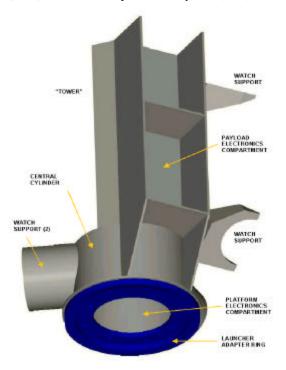

Fig. 9: Spacecraft structure

communications sub-system (COM) in a configuration which can be adopted for future small spacecrafts, according to the platform in a box concept.

The box-shaped compartment in the "tower" structure contains the payload electronics, except the focal plane electronics of the telescopes, star trackers and WATCH-units. The interconnections in the platform and payload compartments will be based on a motherboard to eliminate internal harness.

The proposed structure is made of 6 mm thick aluminium walls, bringing the radiation level down to <20 krad (Si) during the 2-year mission lifetime, cf. Fig. 6 (radiation dose-depth curve).

The proposed structure also allows derivation of a recurring spacecraft platform with a moderate re-design effort.

Mechanisms

The satellite will be stored and handled on a structure, which apart from acting as a structure to hold the spacecraft during integration and test, also acts as the interface between the launcher and the satellite. The structure will hold the satellites during launch and the detailed design of this separation structure depends on the launch loads and on the mass properties of the satellite.

Fig. 10: The ØRSTED separation system

The current baseline is to use a separation system similar to the separation system used for ØRSTED (Fig. 10), where a clamp-band holds together the launch vehicle side of the separation ring and the ring placed on the satellite. Pyro-actuators cuts the bolts holding the clamp-band in place, springs ensures the removal of the band away from the separation inter-face and 4 separation springs pushes the satellite away from the launch vehicle. Once the mechanical separation is complete, separation switches turns on the satellite electrical power system and then the basic on-board systems turn on automatically. The ring proposed for RØMER has a diameter of about 32 cm, which is larger than the one used on the ØRSTED-
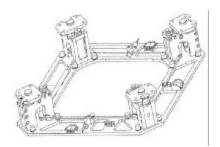

Fig. 11: Separation system by Swedish Space Corporation

which is larger than the one used on the ØRSTED satellite, due to the higher mass of the RØMER spacecraft. A second option would be to use the off-the-shelf separation system provided by Swedish Space Corporation, which is illustrated in Fig. 11.

Hinges and release mechanism for the telescope dust cover

To prevent dust and particles from polluting the MONS and X-ray telescope- and top star imager optics, a cover plate is proposed (Fig. 7). The cover plate covers the cameras during the integration and launch. Shortly after satellite separation, a command is sent to deploy this cover. Apart from acting as a cover, solar cells are also mounted on the top surface. This will provide additional power input when the plate is deployed. The deployment mechanisms for such cover-plates are well known from past missions. Either a design from one of those missions can be adopted, or a design can be developed and used as a product for future missions. One option would be to rely on the shape memory metal thermal actuators, which was used with success on the ØRSTED mission to release the boom from the boom canister.

The RØMER System Architecture

Attitude Control Sub-System

The attitude control system for RØMER uses the rotating WATCH X-ray camera modulators for short term attitude control (seconds to hours) and a set of magnetic coils or rods for angular momentum off-loading for long term control (days).

The attitude sensors are 2 star trackers for autonomous attitude determination and a vector magnetometer for coarse attitude determination. Further, it has to be investigated if the solar panels can be utilised as attitude sensors or if we have to include sun sensors in the system configuration as well. During eclipses, only the data from the magnetometer will be available and this may not be sufficient to assure a satisfactory value of the sun incidence angle upon exit of eclipse (the magnetometer cannot detect a drift of the attitude around the local field direction). In such cases, the star tracker system continues to be activated.

There is some redundancy both in the attitude sensors (double star tracker and magnetometer) and in the actuators (4 WATCH units; 3 will suffice for attitude control and 3 torque coils or rods, where also only 2 are required). Also the insertion of sun sensors or the solar panels as attitude sensors will include some level of redundancy.

Also the MONS telescope and the X-ray telescope are proposed to be in the control loop for fine tuning the attitude in observation modes and to keep better control of the error budget. Table 1 summarises the different modes of the attitude control software:

Item	Description	Requirement
Initial acquisition	The phase right after release. The satellite is tumbling with up to 3°/s	The attitude control system must be able to absorb the angular momentum and orient the solar panels towards the Sun within 10 minutes.
Reference tracking	The orientation of the reference co-ordinate system (RCS) is given by the on-board computer, according to the position of the source to be observed.	The satellite must be aligned with the RCS with accuracy better than 0.5 arc-min RMS about all axes.
Attitude determination	Determination of the orientation of the satellite with respect to the stellar reference frame	Outside the radiation belts: The attitude must be determined with an accuracy better than 2 arc-sec RMS around the pitch/yaw (Star Tracker RCS)
Momentum dumping	In order to keep the rotation speed of the WATCH modulators within the defined limits (0.5 – 2 Hz) it is necessary to regulate the units at regular intervals.	When the satellite is near its perigee the torque coils or rods shall offload the imbalance of the angular momentum of the rotating WATCH modulators.
Slew manoeuvres	Requirements for the orientation and change of orientation of the satellite.	The satellite must be able to slew 180° in less than 50 sec. (autonomously)
Safe mode	If a failure occurs or the normal operation is disabled this mode is used.	The ACS orients the solar panels towards the sun within 10°.

Table 1: The different modes of the attitude control system

Mode changes can be commanded from the ground. However, the spacecraft will normally be in an autonomous state, where the CDH will execute an observation programme according to an up-linked schedule. Once a gamma-ray burst is detected by one of the WATCH units, the on-board ACS software will perform

an autonomous re-orientation of the satellite to point the X-ray telescope towards the burst.

GPS

RØMER will employ a GPS receiver for position and orbit determination and for maintaining a precise timing on board.

Most of the time in the proposed Molniya orbit is spent outside the orbit shell of the GPS satellites. Even outside the GPS orbit shell intermittent position fixes will be available when 4 or more satellites on the far side of the Earth have favourable antenna pointing towards RØMER.

Accurate orbit predictions can be obtained with only relatively sparse position and velocity measurements using off-the-shelf prediction software, such as BAHN. When the satellite is in the area near to the orbit perigee the GPS receiver is foreseen to track the GPS satellites for a period of more than 1 hour, long enough to generate sufficient data for the orbit modelling.

The GPS will also be used as accurate time reference, linking the master on-board time base located in the CDHs with the UTC. Science data time stamping is foreseen to be performed using a so-called timing correlation pulse distributed to all relevant instruments. The CDH initiates the timing correlation pulse, time-stamped locally in each science instrument. At the same time the CDH time-stamp the pulse, using the master on-board time base, and by merging time-stamps from instruments and CDH, accurate timing can be performed at the science data center.

As baseline the GPS will be procured as a COTS unit, equipped with a standard RS-422 interface.
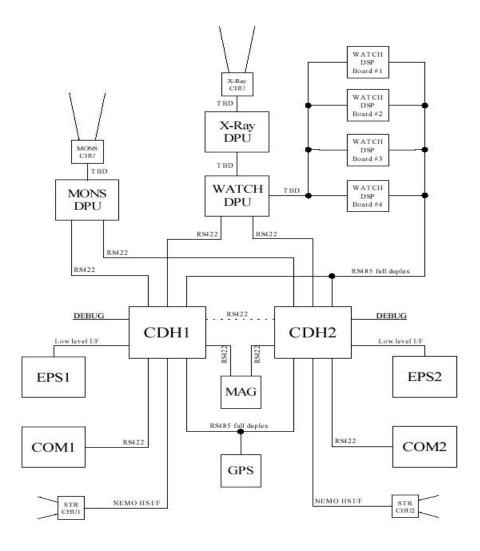

Fig. 12: Data system architecture

Command- & Data Handling

The command- & data handling (CDH) architecture is still under consideration, but the current CDH-system block diagram is shown in Fig. 12.

The system is partially redundant, based on the reasoning that the satellite must be able to survive one major failure and that it must be possible to identify the failure from ground. It is, however, acceptable that the mission is degraded after a major failure.
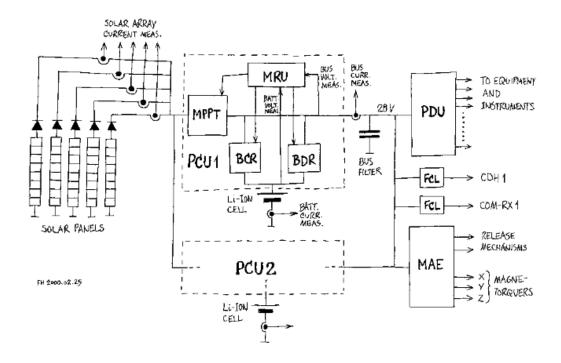
Fig.13: The RØMER power sub-system

This philosophy requires that the on-board computers, the communication sub-system (COM), the electrical power sub-system (EPS) and the star trackers are redundant. The systems are not fully cross-strapped and thus a major failure may cause loss of on-board functionality and degrading of the mission.

As the system is not fully cross-strapped, both on-board computers will be active all the time (not re-dundant). However, the COM sub-system will be cold redundant.

In our current thinking, the data interfaces are based on either RS-422 or enhanced (full-duplex) RS-485 buses. However, we are seriously considering a CAN-bus architecture, which will simplify both the harness design and testing.

The type of processor for the CDH sub-system has not been selected, but the PowerPC 603 seems very attractive (rad-hard version available, flight proven). Other candidate processors include the SPARC ETC-32 from TEMIC, the MIPS R3000, Analogue Devices ADSP-21020, Texas Instruments, Intel 80C386EX or 80C486.

Electrical Power Sub-System

The electrical power sub-system is sketched in Fig. 13

The EPS is proposed to employ a regulated 28 V bus. This facilitates the integration of off-the-shelf equipment. It eases the design of the DC/DC-converters for

the platform and payload units and significantly alleviates the EMC control procedures.

To extract maximum power from the solar arrays, a maximum power tracker (MPPT) is proposed. A MPPT is currently being developed for the ESA ROSETTA-mission at Terma Elektronik AS, Denmark. It is desired to employ lithium-ion batteries to save mass. The inherent charge control hassles of a multi-cell lithium-ion battery can be overcome by using only a single cell per redundant branch. However, this pushes the discharge current into the 15 A-range, which requires special design considerations for the battery discharge regulator (BDR). An intermediate solution with 2-4 cells is also being considered.

The 2 power control units (PCU) shown in the diagram are cold redundant during normal operation.

A power distribution unit (PDU) will enable turning instruments and units on and off, according to operational requirements. It is presently being studied whether to employ fully protected or only partially protected solid-state switches in the PDU.

The mechanisms and actuator electronics section (MAE) includes switches to activate the release mechanisms and drivers for the magnetorquercoils.

As shown in Fig. 7 solar arrays are placed on 3 sides plus the deployable top cover. A small, fifth array may be placed on the shadow side, cf. Fig. 7 to pro-

vide extra power while the satellite is tumbling, following the separation from the launcher.

For the solar arrays we consider using triple-junction GaAs/Ge cells to maximise power, but the final choice will depend on the power requirements, the most adverse pointing required during observations, ITAR-regulations (no European manufacturer available) and last, but not least, the cost.

Assuming that triple-junction cells with a BoL efficiency of 25%, BoL-EoL degradation of 20%, 90% arraying efficiency, the sun-facing panels will produce 123 W at normal incidence.

Considering the current average power requirement during observations, including power for charging the battery after a worst-case 1-hour eclipse, a sun-angle of 45° is possible without jeopardising the power margin.

Communication Sub-System

The design considerations for the RØMER communication sub-system is in close lieu with those of the ØRSTED-satellite, i.e. S-bands are used for TM/TC down- and up-link, TM- and TC-formatting, modulation and encoding adhere strictly to ESA PSS- and CCSDS-standards for packet telemetry and packet telecommands.

The main difference between RØMER and ØRSTED, in terms of link design, is that RØMER at apogee is separated by ≈42.500 km from the ground station compared to ≈3.400 km for ØRSTED at the horizon. This implies a ≈22 dB penalty in the link budget for RØMER.

In order to mitigate this penalty without requiring a larger antenna than the present 1.8-m ØRSTED ground station, several measures are proposed:

1. Increase on-board transmitting power from 1 W to 2 W (+3 dB). This is possible within the present power budget.

2. Apply antennas on the opposite faces of the satellite. This will ensure a minimum gain of about -10 dBi over 4π steradian. A RF-switch in front of the transponder selects the antenna with the most favourable pointing. The proposed antenna type is a cavity-packed, crossed-slot antenna, which levels with the exterior surface and protrudes ≈ 40 mm into the spacecraft interior.

3. Select the highest sustainable bid rate at any time by the link based on continuous monitoring of link performance, instead of just using the minimum sustainable bid rate at apogee at the most adverse antenna pointing.

4. Use state-of-the-art encoding schemes, such as the Turbo-coding recently included in a draft standard by CCSDS. This will provide a minimum gain of 2 dB over traditional concatenated R=½, K=7 convolutional and (255,223) Reed-Solomon codes.

Presently 1. and 2. are being drawn up, while 3. and 4. are under consideration. The antenna selection algorithm in item 2 could be based on either a trial-and-error scheme or an orbit-, attitude- and antenna pattern model on board, regularly calculating the gain from the 2 on-board antennas and selecting the best. In any case the first option should be a part of the communications failure recovery scheme.

Based on these considerations a worst-case TM down-link rate of 500 bits/s (219 bits/s information rate) can be sustained at apogee and a 64.000 bits/s (28.000 bits/s information rate) can be sustained near Earth for a high-speed science data down-link. Assuming sufficient hours of high-speed down-link per orbit and 500 bits/s in the remaining visibility period, 24 Mbytes of data can be down-linked every day, satisfying the present requirements.

One problem remains, though. At an interleaving factor of I=5 the composite CCSDS TM transfer frame, Reed-Solomon encoded, becomes 10.232 bits long, incl. sync. marker.

Convolutionally encoded, the total frame length becomes 20.464 bits. At a 500 bits/s channel rate the down-link time becomes 41 seconds. This is not compliant with fast dissemination of a gamma-ray burst position, which should reach robotic telescopes in seconds, rather than in minutes.

To mitigate this problem, turbo-coding could be used, unaccounted system margins (conservative sizing has been applied so far) could be exploited and some attitude control freedom around the roll axis could take the antenna radiation pattern out of the most adverse pointing. The interleaving factor could also be decreased at the expense of CCSDS compatibility. Finally, a larger ground station could be deployed, which in fact is a realistic possibility without busting the overall budget.

Ground Segment

The present ØRSTED 1.8-m ground station, situated in Copenhagen, needs to be upgraded with a new indoor electronics unit (modulator/de-modulator, encoder/decoder, frame formatter/synchroniser, etc.) in order to cope with the new data rates and provide better remote control, monitoring functions and Internet capabilities. This is a modest investment.

There is an option, however, to commission a 4-m ground station based on an old X-band weather radar. This would improve the link budget by 7 dB, corresponding to a 5-fold increase in the data rate.

The remaining 2 components of the ground segment are the control center and the science data center.

The science data center will be located at the University of Aarhus with the MONS project group. The architecture of the science data center is not yet defined, except that it is certain that data access and dissemination will be based on the Internet.

The control center will be physically located at the Danish Space Research Institute in Copenhagen. Here, a room with 3-4 computers (preferably PCs), a large wall-mounted colour display and adequate room for visitors will be build. It turned out during the ØRSTED early operations phase that the lack of room for visitors (some 10-12 persons were stuffed into a very small office) and a common large screen display complicated the monitoring and assessment of the spacecraft status.

More challenging for the control center architecture is the concept of the "virtual control room", meaning that the control room functionality should be accessible anywhere, at any computer connected to the Internet, either hard-wired or by radio. This means that e.g. a Java applet running in a browser window, appropriately serviced by a web-enabled control center software system, should allow the operator to perform all or at least a sub-set of the control- and monitoring functions. Wireless access will be based on the GSM mobile communications system, the recently inaugurated wireless applications protocol (WAP) and new high-speed data services, such as general packet radio service (GPRS, up to 115 kbits/s) soon to be available. Thus, the control room will ultimately be a WAP-enabled mobile phone, a laptop PC with a GSM mobile phone plug-in or an integrated device like the NOKIA Communicator. To eliminate unauthorised access, a secure protocol will be used, preferably using a hardware key, such as a PC-card or the subscriber identity module (SIM), used in GSM mobile phones.

In case of anomalies when using a mobile phone may easily be sent to the operator on duty, using the short message service (SMS) of the GSM-system. The virtual control room concept then allows the operator to immediately begin diagnosing and mitigating the problem.

Model Philosophy, AIV Approach

To reduce cost and schedule, a critical re-examination of the classical ESA/NASA build- and test philosophy is being performed. E.g. this means that only one

Flight Model will be built and enough spare sub-systems should be available in case of minor failures on the flight equipment. Hence, the RØMER-satellite should be built and tested as a proto-flight satellite. This means, that one complete satellite unit will be fully assembled and tested for flight. This proto-flight satellite unit will be tested in accordance with the environmental system test specification, consistent with the launch vehicle proto-flight test requirements. The satellite will be tested to qualification levels for acceptance time. The various satellite models, which currently are foreseen to be essential for the success of the project, are described in the following. This approach will also be further elaborated during the system definition phase and requirements for the individual development models will be determined.

Engineering Models

Each sub-system will be required to develop an engineering model that should be as close to the flight configuration as possible, to be used during design, integration, verification and as a simulator during the operational phase of the mission.

RF Model

The purpose of this mechanical mock-up is to define all the outer dimensions and electrical characteristics, in order to simulate the antenna environment. The mock-up consists of a satellite structure with aluminium side walls and will be used to measure the antenna radiation pattern using a radio anechoic chamber.

Modal Survey Test Model and
Wiring Harness Mock-up

This is a structural model to facilitate static finite element load analysis, coupled with a modal survey test and to design and route the wiring harness. The results from the modal test are used to correlate the finite element analysis. The final dynamic model is integrated into the launch vehicle dynamic model and a coupled load analysis can then be performed, if required, to verify the structural stability of the satellite and the launch vehicle structures. The modal test unit consists of the mechanical structure mounted with dummy masses of the sub-system units and with the correct connector placements. It is important that the hardware is close to being "flight like", i.e. that the structural and mechanical behaviour is close to the flight equipment.

Proto-flight Model

It is suggested to adopt a proto-flight approach to the RØMER satellite development, i.e. use a proto-flight model satellite with verification by environmental testing. This means, that only one complete satellite

unit is fully assembled and tested. Care shall be taken not to over-test the proto-flight unit and thus risk inadvertent stress/damage to the flight hardware, which would then require costly refurbishment and re-test.

Satellite Simulator/Bench Test Model

This can be partially assembled during the satellite integration using a combination of engineering models and flight spare models. This unit can be assembled to a point where it will function as a satellite simulator for troubleshooting during ground testing and in-orbit operations.

Flight Spare Equipment

Each sub-system consists of one or more individual equipment boxes/items, which in general are built/procured and delivered separately for satellite integration and testing. Whenever feasible, one extra unit should be built/procured, thus providing one extra flight spare unit. The units will be made using flight grade parts, materials and processes. Non-critical flight equipment may have all parts and materials available but not assembled, i.e. resources will be saved by not assembling and testing specific hardware. In case of a major failure in one of these sub-systems, it is possible to quickly produce a flight spare if deemed necessary.

Planning

Fig. 14 indicates the foreseen schedule for the implementation of the mission. The current phase of the mission is crucial, in order to consolidate the mission consortium, to evaluate the organisational structures and to prepare a technical baseline, which enables the establishment of the detailed planning and a reliable financial budget.

To the foreign partners, involved companies and institutions the initiation of this phase indicates that Denmark is committed to fly the selected mission, that the project is moving ahead and that the involved parties needs to seek the necessary support from their superiors to commit themselves to the project.

Upon the system definition phase the project will proceed with the detailed design phase using the funding already allocated for the Small Satellite Programme by the Danish Research Councils. During the detailed design phase, the funding for the implementation phase, the operations phase including the science utilisation will be finally negotiated. Before the end of the detailed design phase it is expected that the total funding of the mission be in place.

Conclusion

The primary objective for the parties involved in defining and carrying-out of the programme is of course to ensure that Denmark, within the next few years, are able to put the RØMER-satellite in orbit. A follow-on mission to the ØRSTED-satellite, for which we, 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 of the Danish programme, hence, that the programme is continuously funded. Thus, it is very important at all times to have new and exiting projects, which can form the basis of the programme. Projects, which continuously can improve the technological and scientific return and which can ensure a continued political interest in our programme.

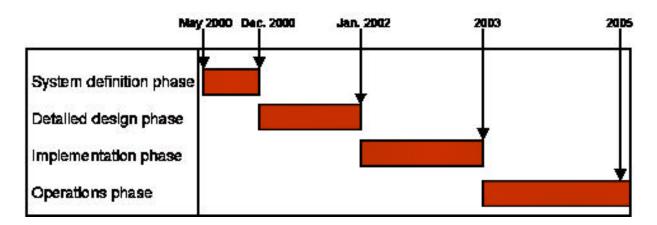You can read more about RØMER and the rest of the small satellite programme on **http//:www.dsri.dk.**

Fig.14: The RØMER time schedule