

**PROBA: ESA's AUTONOMY AND TECHNOLOGY DEMONSTRATION MISSION**

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**ABSTRACT:** *Proba is an ESA mission conceived for the purpose of demonstrating the opportunities and benefits of on-board autonomy. To this end, it offers a flight opportunity centered around the validation of the associated technological capabilities. The Proba spacecraft is equipped with a selected set of technologies providing advanced on-board functions for performing a number of mission operations functions with minimum ground involvement. The autonomy is exercised in realistic scenarios through the accommodation of four payload instruments.*

**INTRODUCTION**

In the framework of demonstrating the feasibility of small and low-cost missions by increasing operational autonomy, ESA is undertaking two main activities: one is the design, development, and operations of an actual mission dedicated to autonomy performed by Verhaert D&D as Prime contractor and called **PROBA** (**PR**oject for **On-Board Autonomy**) and the other is a research activity performed by MMS (Matra Marconi Space) which aims at the production of flight software for supporting on-board autonomy.

Proba is an approved project under ESA's General Study Program (which is part of the Technological Demonstration Program). The project has been kicked-off in February 1998, for a two years development. It is being performed by an industrial consortium led by Verhaert Design and Development (Belgium). The cost of the Proba mission is targeted at below 10 MECU.

The project will realized by following consortium :

PROBA consortium and responsibilities :

- Verhaert Design and Development (Belgium) : prime contractor, system tasks, structure and launch
- Space Innovations Ltd (UK) : Data handling, power and communication system
- Spacebel Informatique (Belgium) : On-board software
- SAS (Belgium) : Ground segment and operations
- UdS (Ca) : AOCS system
- SSF (Finland) : Software Validation Facility
- FIAR (Italy) : Solar cells

Other European companies participate as unit suppliers (e.g. Technical University of Denmark for the Star Tracker and SSTL in UK for the GPS).

Proba's System Design Review has been held in June '98. The main scientific payload consists of an Earth observation instrument. In addition, two instruments are taken on-board for the purpose of radiation and space debris monitoring. A fourth instrument for high-resolution pictures (10m) will be flown as well.

Proba intends to demonstrate the benefits of autonomy and to validate the supporting advanced technologies in orbit. In particular, the following autonomy functions are being implemented:

1. commanding for management of on-board resource and house-keeping functions;
2. scheduling, preparation and execution of scientific observations (for instance: slew, attitude pointing, instrument settings);
3. scientific data collection, storage, processing, and distribution;
4. data communications management between Proba, the scientific users, and the ground station;
5. performance evaluation and estimation of drifts, trends;
6. failure detection, reconfigurations and software exchanges.

This paper presents a description of the Proba mission, including programmatic aspects, system design, payload instruments, selected technology demonstrations, and the baseline mission operations concept.

## **PROBA MISSION SUMMARY**

### **Launch and Orbit**

Proba is planned to be launched in mid 2000 on PSLV. However, the spacecraft design is compatible with many of the current launch vehicles. It will be injected directly into its final polar, sun-synchronous orbit at an altitude of 817 km, 98.7 degrees inclination. On-board propulsion is not provided, so the orbit can not be corrected or maintained during the planned two years of operational lifetime of the spacecraft. The orbital drift (away from sun-synchronism) amounts to about 2 degrees per year and is acceptable.

Navigation of the spacecraft is performed autonomously on-board by a combination of GPS measurements and orbit propagation. NORAD two-line elements are used for on-ground navigation and as a back-up in case of a GPS unit failure. The spacecraft is kept three-

axis stabilized by means of attitude measurements provided by an autonomous star tracker, a GPS-based attitude sensor and a three-axis magnetometer and by on-board control through a set of reaction wheels and magneto-torquers.

### **Payload Instruments**

An **Earth Observation Instrument**, CHRIS, has been chosen as the primary payload instrument on the basis of its strength of autonomy demonstration and its associated scientific merit. This instrument will require a specific attitude (pointing and rates) of the spacecraft in order to be able to perform its mission. It will be the prime driver for Proba operations since observations are prepared on-ground by the scientist and the amount of data generated is relatively high. The observation request itself should be 'goal oriented' (for instance, in terms of target location and time of observation). This request will then be translated into a schedule of activities, resource management decisions and satellite pointing commands.

The main instrument, CHRIS, was selected through an Announcement of Opportunity.

**CHRIS** (Compact High Resolution Imaging Spectrometer) is an imager proposed by SIRA electro-optics (UK) which works in the spectral range 450 nm to 1050 nm, targeted in particular towards directional reflectance of land areas. It has a spatial resolution of 25m at nadir, and a spectral resolution of 5 nm to 12nm..

In addition to its scientific interest, CHRIS puts severe requirements on the spacecraft autonomy in terms of AOCS, data handling and resources management. For example, CHRIS uses the spacecraft slewing capabilities to perform multiple images of the same scene on Earth from different viewing angles.

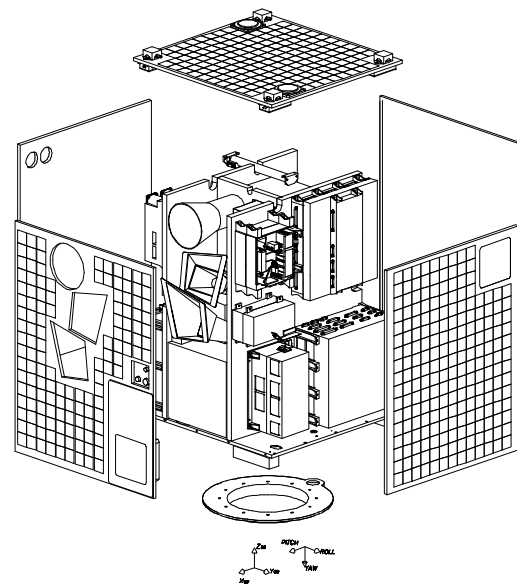
In addition to the main Earth Observation Instrument, Proba will have three secondary

payloads: one is the **Space Radiation Environment Monitoring (SREM)**, proposed by Contraves (CH), instrument providing measurements of electron and proton fluences and of the total radiation dose received [Ref. 1]. SREM is a standard off-the-shelf unit contained in a box of 9/12/22 cm, weighting 2.5 kg.

The second one is **DEBIE (DEBris In orbit Evaluator)** proposed by Finnavittec (Finland) which measures mass, impact speed and penetration power of the dust environment around the spacecraft using 2 impact detectors located on the panel looking in the flight direction and on the panel looking to deep space of the satellite. These instruments enhance Proba's mission objectives because of their specific accommodation and operations requirements and by their generation of valuable scientific data.

The standard instrument units SREM and DEBIE are beneficial to any satellite which requires autonomous reactions to radiation or debris flux levels. For instance, SREM is foreseen on ESA's Integral spacecraft whose payload instruments must be switched off when the level of radiation exceeds a certain specified limit and then switched on again when the level drops below the limit again.

The third one is **HRC (High Resolution Camera)** built by OIP (Belgium), which allows the demonstration of taking high resolution pictures (10m) with a small three-axis stabilized satellite.



**Figure 1 - PROBA Exploded View**  
(Courtesy of Verhaert Design and Development nv)

### Spacecraft Characteristics

Proba has a weight of about 100 kg with dimensions 600 x 600 x 800 mm (ASAP5 / PSLV compatible) and belongs to the class of mini-satellites. Its structure (Figure 1) is built in a classical manner using aluminum honeycomb panels. The carrying part of the structure is composed of 3 panels mounted in a H-structure carrying the different units.

The satellite's outside panels have body-mounted Gallium Arsenide solar cells with integrated diode, providing power to the spacecraft (90 W peak), a 7Ah NiCd battery is used for energy storage. A centrally switched and protected 28 V regulated bus distributes the power to the units and instruments.

The spacecraft has passive thermal control,

A high-performance redundant central computer performs all computing tasks and interfaces to every unit of the spacecraft with high-speed data links and house-keeping data acquisition links. The telecommunications subsystem provides quasi omni-directional CCSDS-compatible up-link and down-link

for S-band communications with the ground. The link capacities are 4 Kbit/s for the packet telecommanding and a maximum of 1 Mb/s for the packet telemetry.

The spacecraft provides nadir and inertial off-nadir pointing capabilities. Three-axis attitude control and fine pointing are provided by a high-accuracy autonomous double-head star tracker, a GPS receiver and a set of reaction wheels. Two three-axis magnetometers complements the attitude sensing, and four magneto-torquers are available for momentum management. A set of gyroscopes may be accommodated for improving the short-term pointing stability. A propulsion capability is not foreseen.

Whereas commonly available units and well-proven concepts are used for the power and the communication subsystems, the system design of Proba is innovative in many respects, especially in the areas of attitude control and avionics.

## **TECHNOLOGIES for AUTONOMY**

A core of technologies aiming at the demonstration of spacecraft autonomy is accommodated in the attitude control and the avionics subsystems and forms an integral part of the Proba system design. Others will be implemented as 'technological experiments' since their use for autonomy is optional or their novelty would present a relatively high risk.

The technologies flown on Proba as part of the system are a GPS receiver for navigation and attitude determination, an autonomous star tracker for attitude determination and a high-performance computer.

Further hardware technological experiments will be accommodated in a 'PPU' box (Payload Processing Unit) or as stand-alone units. The PPU also contains a Digital Signal Processor for on-board scientific data processing and analysis, and a mass memory.

Software experiments may be accommodated as well since the on-board software will be entirely re-programmable. However, software updates for in-flight testing of new functions or algorithms will be introduced only in the later phase of the mission.

## **On-Board Computer**

Proba's high-performance on-board computer (built around components sponsored by ESA) provides sufficient performances to support spacecraft autonomy. It is able to support the processing normally performed on-ground (and also migrated on-board in Proba's case) as well as the on-board scientific data processing. The latter capability enhances the spacecraft autonomy with respect to data distribution through the selective use of the downlink and the on-board mass memory.

A high-performance RISC processor, the ERC 32, performs the spacecraft management including guidance, navigation, control, housekeeping and monitoring, on-board scheduling and resource management. The development of this processor which is a space version of standard commercial processors have been initiated by ESA to establish and validate a computing core for future spacecraft.

The ERC 32 [Ref. 2] is a radiation tolerant (> 80 Krad) SPARC V7 processor providing 10 MIPS and 2 MFLOPS with a floating-point unit. A memory controller includes all the peripheral functions needed by the processor, such as the address decoders, the bus arbiter, the EDAC, 2 UARTS, 3 timers and a watchdog. The chip set is manufactured with the MHS 0.8 micron CMOS/EPI radiation tolerant technology.

## **Autonomous Star Tracker**

The main attitude determination sensor is an autonomous star tracker which provides the full-sky coverage and achieves the high-pointing accuracy required in Earth observation and in astronomy. The sensor

can autonomously reconstruct the spacecraft's inertial attitude starting from a 'lost in space' attitude. This is done with a typical performance of a few arcseconds to an arcminute, depending on the sensor's characteristics and the measurement conditions. The attitude can be reconstructed even at relatively high inertial rates. Several star trackers with adequate characteristics and performances for the Proba mission have been evaluated during the feasibility study. Finally, the Advanced Star Tracker (double-head) from DTU was selected because of its superior performances and its novelty.

### **GPS (Global Positioning System)**

Proba will accommodate a GPS L1, a C/A receiver, and 4 antennae for position and medium-accuracy attitude determination. This is considered a crucial technology for autonomy demonstration because this single unit is able to provide all essential AOCS measurements without any ground intervention for a low-altitude orbiting spacecraft. Autonomy in low-Earth orbit depends on the accurate on-board knowledge of the satellite position in ground coordinates. This knowledge is required for Earth observation purposes, for data downlink transmissions, as well as for spacecraft control functions. Furthermore, it is required for high-precision attitude determination in the Earth-orbital frame using star tracker measurements. Autonomous operations also require adequate time accuracy on-board: the GPS time determination is used for on-board time keeping and correlation with UTC.

Most of these GPS functions are actually somewhat redundant: the attitude estimation may also be provided by the star tracker and the spacecraft position may be obtained by orbit propagation using the Norad two-line elements. This 'redundancy' may in fact allow interesting accuracy comparisons and calibrations.

The selected GPS receiver is from SSTL.

### **On-Board Software**

Autonomy requires larger and more reactive software than is the case on conventional spacecraft. The software development time and its validation are therefore key aspects to be taken into consideration in the system design. Open standards have been considered in order to ease the development effort. A standard commercial off-the-shelf kernel will be used: this will allow the support of custom, re-usable, and automatically-generated software. The first category of software should normally be in Ada while the second type is often in C language. Furthermore, when Proba will be subjected to the in-orbit testing of additional autonomous functions, openness will facilitate the development and the uplink of the supporting software.

For verification and validation of the software a set of tools will be implemented, the Software Validation Facility [Ref. 3] allows to exercise and validate the software in a realistic environment.

### **Additional Opportunities for Demonstration**

During the system feasibility study, several companies have indicated their interest in in-flight testing of some of their new technology developments. Technologies supported by hardware are included in a 'Payload Processing Unit (PPU)' or accommodated as stand-alone units. The PPU box provides the mechanical, electrical and functional interfaces with the spacecraft. The envisaged technological demonstrations are, a new advanced autonomous star tracker, a set of Smart Sensors (called DIP) measuring temperature and radiation, and solid state gyroscopes. Another candidate is a high resolution camera (approx. 10m), in order to evaluate the platform stability and pointing accuracy. Final accommodation depends on the available mass left for additional payloads.

Technological experiments supported by software alone will be tested on the

spacecraft in the later phase of the mission after the first year in orbit. These experiments will be validated on-ground using the software validation facility before being uplinked to the spacecraft. It is planned that the spacecraft software will use a standard programming language and a real-time kernel so that the uplink of new software is facilitated.

## **IMAGER DATA PROCESSING**

The Chris imager data (main payload) is processed by a DSP and stored in a MMU, both located in the Payload Processing Unit.

### **DSP**

The DSP is a space qualified ASDP21020 device which is used to perform image processing on the acquired image both, post acquisition and during acquisition. Typical image processing tasks include image compression.

### **Memory Management Unit**

Autonomy requires the accommodation of a large telemetry buffer in order to be able to decouple the data generation during periods of observation from the data transmission during ground contacts. Fast random access will be used for supporting autonomous data transmissions directly to a user's station. Appropriate memory management will allow the efficient usage of the storage area by the on-board scientific data analysis and compression software. Although relatively small at 1 Gbit, the mass memory is adequate for fulfilling Proba's mission requirements. The Mass memory is located into the PPU and is part of the Main instrument. Data stored in the MMU can be accessed from both the DSP and the DHS.

## **MISSION OPERATIONS CONCEPT**

It is generally expected that, in the near future, mission operations activities will evolve from ground-based control towards on-board monitoring and control. This will clearly be the case for the so-called 'routine' functions requiring relatively straightforward and low-risk decision-making.

In the future, more complex functions may gradually be migrated to the on-board computer. On-ground operations spacecraft activities by humans will essentially be limited to the initialization phase (establishing the routine operations) and to emergency support. In order to be able to arrive at an effective overall system design (both from performance and cost points of view!), it is essential that the design of spacecraft and the associated operations are performed together in an overall system-level concept rather than in isolation (Ref. 4).

Proba provides considerable flexibility in the allocation of on-board resources and in scheduling of operations when compared to the relatively rigid concepts used in conventional missions. By its nature, Proba offers an excellent opportunity for validating and demonstrating novel operations concepts which may then be applied in future missions. In particular, the following operations functions are being planned for implementation on Proba:

**1. On-board housekeeping:** Proba will autonomously take care of all routine housekeeping and resource management tasks. This includes also the decision-making process in the case of (foreseeable only!) anomalies, i.e. failure detection, failure identification and first-level recovery actions. A summary of the information available on-board is downlinked to the control centre at regular intervals. More detailed information may be downlinked on specific request by the control centre.

**2. On-board data management:** Proba will also autonomously take care of all management tasks related to the on-board data handling, storage, and downlinks. The spacecraft

accommodates in the PPU a 1 Gbit mass memory for data recording and a tuneable 2 Kbit/s to 1 Mbit/s down-link. As a worst case, two passes of about 10 min every 12 hours are available for downlink of telemetry data (as well as for command uplinks). Therefore, the complete mass memory contents can be dumped to ground every 12 hours if desired. It is intended to downlink only a synthetic house-keeping report (unless specific data are explicitly requested) so the full down-link will normally be available for science data.

**3. On-board resources usage:** Proba will autonomously take care of all management tasks related to the on-board power usage. Any excess power and energy (above the basic spacecraft control requirements during daylight and eclipse phases) will be allocated to the instruments and to the spacecraft subsystems supporting the specific operations of the instruments, for instance to the wheels for attitude manoeuvres. The allocation will be performed on a dynamic basis, resolving task constraints and priorities. Constraints include for each activity the power and data storage area needed, the pointing requested, etc.

Because of the criticality of this function precautions will be introduced as follows:

- ◇ the scheduling of on-board activities obtained after solving the constraints and priorities may either be done on-ground or on-board with ground acknowledgement; since this scheduling may also be programmed in on-board software, fully autonomous scheduling is feasible in principle; however, this step should be taken very carefully and only after a build-up of operational experience has been established;
- ◇ a safety function will continuously monitor the spacecraft ensuring that sufficient energy will be available during the following eclipse phase based on a specified depth-of-discharge of the battery, while guaranteeing that also enough energy is available for the down-link of house-keeping data.

**4. Instrument commanding:** all preparatory, commanding, and data processing activities related to the instrument operations are planned to be performed on-board (after an appropriate initialization period). This includes the planning, scheduling, resource management, navigation, and instrument pointing as well as the downlinks of the processed data. In the case of the main Earth Observation Instrument, a specific attitude (pointing and rates) of the spacecraft will be required to perform its Earth observation function. The calculations of the relevant slew characteristics will be based on a request file (containing the coordinates of the target area and the observation duration) which is uplinked from ground.

The planning and scheduling of the instrument requests together with other spacecraft activities will be resolved on-board using a combination of constraints solver and optimiser to achieve the best possible mission data return.

**5. Science data distribution:** the collected science data are normally downlinked to the (nominal) ground station from where they may be routed automatically or on request to a user's site using Internet links. Furthermore, it is planned to demonstrate an automatic direct data distribution capability to different user ground antennae upon their requests without human involvement and with minimum possible delay. The optimal downlink times may be uplinked in the request file or calculated on-board.

## CONDUCT of MISSION OPERATIONS

### Ground Segment

With the ground station located in a mid-latitude region (Belgium) about 4 time 10 minutes of visibility per day will be available in average. The station consists of a portable 2.4 m dish with RF front-end and a control centre with relatively limited facilities. The centre will be directly connected to the ground antenna; it will also be connected to a communications

network (using the Internet) for easy remote access by the users.

The ground station will provide the following functions:

1. automatic link acquisition based on Norad elements and spacecraft navigation data;
2. communications set-up protocol for the types of data (and their bit rates) to be received;
3. automatic uplink of previously screened observation requests and spacecraft planning commands;
4. automated call of ground staff in case of detection of on board anomaly;
5. science data filing, notification of scientists, and data distribution.

The spacecraft may also be accessed by other standard S-band ground stations (for instance: ESA, CNES). For what concerns the telemetry, it is planned that science data can be transmitted directly to a 'user station' as specified in the observation request.

The user request shall also specify the data transmission type: if it is a 'send and forget' type, the data will be removed from the mass memory after transmission; if it is a 'confirmed delivery' type, the data will be removed from the mass memory only after a positive acknowledgement of receipt has been received from ground. The handling of transmission anomalies, i.e. re-transmissions and time-outs, will follow a pre-programmed algorithm.

### **LEOP Operations**

The spacecraft is launched in a powered-off configuration. Five seconds after the spacecraft detects the separation, the avionics and attitude acquisition units are powered on, as well as the spacecraft receivers. The spacecraft separation rates are damped first by magnetometers/magneto-torquers and then by star tracker/wheels. Subsequently, the spacecraft acquires a rough nadir pointing attitude until the first ground contact. When ground contact is established the transmitter is switched on and

a check-out of the spacecraft status is performed. After the spacecraft health has been confirmed and a first fix of navigation data is achieved, the GPS receiver is switched on and the AOCS is commanded into a nominal (Earth-pointing) mode.

### **Commissioning Phase**

The spacecraft is kept pointing towards nadir (or nadir plus an offset in case of a specific target) by means of a star tracker, on-board navigation data and the set of wheels. During the spacecraft commissioning the performances of the spacecraft subsystems and the autonomy support will be checked, for instance:

- Star tracker accuracy in inertial and nadir-pointing mode;
- GPS attitude measurement accuracy using the star tracker as a reference;
- Navigation accuracy;
- Wheels performances (perturbations);
- Magneto-meter accuracy, using magnetic field model;
- Power generation performances;
- Thermal and thermo-elastic performances, using the double head star tracker;
- RF link performance;
- Avionics performance (time accuracy, SEU);
- Instruments performances;
- Operations functions.

### **Nominal Phase**

Nominal spacecraft-to-ground interfaces are limited to the downlink of the spacecraft health status and house-keeping data. Specific operations activities, however, are required to support the demonstration objectives of the spacecraft (e.g., switch to GPS attitude, software uploads). Emergency and specific operations are the only periods when human interaction is required; during the remainder of the time, operations will be performed automatically by the control centre and ground



staff can have remote access to downlinked data whenever they wish.

The nominal instrument operations are limited to observation requests remotely transmitted from the scientists to the control centre. The requests are automatically checked, a preliminary schedule of the requested operations is prepared, and the scientists are informed about the results. The requests are then uplinked to the spacecraft which may re-schedule them in accordance with its more precise on-board knowledge. After the scientific data are collected they are downlinked to ground at the first possible opportunity and the scientist is notified of the data availability.

### Spacecraft Contingency Phase

Whenever a failure is detected on-board, the ground staff is automatically warned (by means of a pager, telephone, or e-mail). The station triggers the warning procedure through monitoring of the telemetry data or when it fails to receive the spacecraft's periodic status report.

The detection of on-board anomalies and failures is performed autonomously using the following parameters:

1. Unit technological parameters are monitored by the central computer for hard errors (as usual);
2. Drifts, biases, and systematic errors may be detected by simple coherency checks and by analytical redundancy techniques;
3. Failure of the central software performing these functions is detected by conventional mechanisms (such as watch-dogs and processor alarms) or perhaps by a monitoring function in the redundant processor;
4. In case of a failure which can not be recovered autonomously, ground is informed by the absence of the 'alive' signal from the spacecraft and will be able to access the spacecraft using direct commands.

For cases (1), (2), (3) the recovery is performed autonomously on-board, with priority given first to the safety of the spacecraft and the downlink capability to ground, and secondly to the recovery of the complete mission. For case (4), the spacecraft is designed to be recoverable even if left uncontrolled by the provision of passive thermal control, and a quasi-omni-directional link coverage from ground. In addition, built-in protections are provided to ensure that the computer and receivers are always powered on. The handling of on-board failures and recoveries relies either on redundant identical units or on functional redundancies.

### Mission Planning and Scheduling

Three options will be provided for mission planning and scheduling featuring different allocations between on-ground and on-board activities. In this manner, a gradual progression towards an increased on-board autonomy may be implemented during the course of the mission:

- 1) **conventional**: mission planning and scheduling are done manually on-ground; checks of the proposed planning are performed by both the on-ground and the On-Board Mission Manager (OBMM) mission planning tools;
- 2) **semi-autonomous**: the on-ground and the OBMM mission planning tools are used to schedule the activities, but the resulting schedule must be confirmed on-ground prior to its execution on board;
- 3) **completely autonomous**: the operations requests are evaluated on-ground by the mission planning tool and then uplinked to the spacecraft which schedules the activities in the most efficient way while accounting for the relevant constraints.

The commanding of the spacecraft is performed using synthetic and goal-oriented commands. In order to accomplish autonomous mission management, goal-oriented commands are first expanded into elementary tasks, then these

tasks are merged with all other operations to be performed, and finally, the constraint problem is resolved. Each task has its own associated constraints, resource requirements, and priority parameters. In addition, cost functions are introduced in order to allow for optimisation of the long-term planning, in contrast to the scheduling task which has a shorter-term view and does accommodate (but not optimise) a possible sequence of tasks.

### **Operational Language and Software**

For executing a science request on-board, the following information should be provided:

1. which area shall be observed;
2. which instrument configuration shall be selected;
3. where shall the data be sent.

These are the only items of information that will be contained in a spacecraft command. The on-board computer will translate item (1) into a time sequence of activities with the aid of (in particular) the on-board navigation function; item (2) will be expanded into a configuration sequence and item (3) will be translated into a downlink sequence.

Specific pre-defined operations procedures are called up as required by specifying items (2) and (3). These procedures will be resident on-board, or may be uplinked from ground. Therefore, a spacecraft command language will need to be implemented on-board on top of the basic telecommand execution module.

One of two radically different options (which are still being evaluated) may be selected for implementing operations procedures, while taking account of the fact that complex operations procedures as well as on-board software updates need to be executed:

- complex operations are considered as on-board software updates so that any complex ground interaction is executed by the uplink of an on-board software task which is scheduled by the on-board scheduler and

which has access to a library of on-board services;

- software updates are seen as complex operational procedures, and any ground interaction is executed through a dedicated spacecraft command language and an on-board interpreter.

For what concerns the lower-level commanding design, packet telecommanding is supported using the COP-1 protocol. Commands are interpreted at spacecraft computer level or at instrument level. Direct priority commands are supported for emergency recovery situations.

### **CONCLUSIONS**

Proba is an ESA mission aiming to demonstrate the opportunities and benefits of on-board autonomy. It offers a flight opportunity for the validation of the associated technological capabilities.

The on-board autonomy is exercised in realistic scenarios through the accommodation of three payload instruments: an Earth Observation instrument, a space radiation monitoring instrument, and a debris detector. The autonomy capabilities focus on the following operations functions:

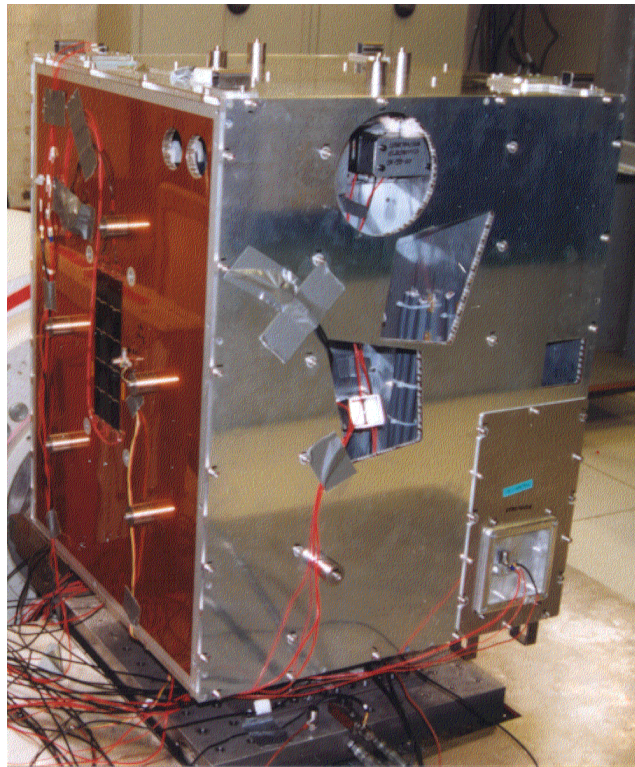
- scheduling, preparation and execution of scientific observations;
- scientific data collection, storage, and processing;
- data communications management between Proba, the scientific users and the ground station;
- management of on-board resources and house-keeping functions;
- state estimation and trend monitoring.
- failure detection, reconfigurations and software exchanges.

The Proba spacecraft provides a unique opportunity for the in-orbit demonstration of a number of new technologies, such as for instance:

- a double-head autonomous star tracker for high-accuracy attitude estimation;
- GPS receiver for position and attitude estimation;
- novel, high-performance, and space-hardened on-board computer;
- high-integration solid state recorder;
- GaAs solar panels with integrated diode.

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