The Project Test Bed and Its Application to Future Missions

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This article presents the concept of the Project Test Bed (PTB) and its application in support of two ESA missions — the PROBA (Project for On-Board Autonomy) technology mission and the Land Surface Processes and Interactions Mission — during their early project phases. As a multi-purpose simulation and verification platform, the PTB includes a system simulator, an Electrical Ground Support Equipment and Monitoring Control System (EMCS) and real flight hardware like the on-board computer. It therefore has the potential to support systems-engineering activities throughout the spacecraft-development life cycle and of being reused from one mission to another, as reported here.

Introduction

In ESA projects, a number of different simulation and test facilities have traditionally been used in support of different activities like mission analysis, design and development, assembly, integration and verification (AIV) and flight-operations preparation and training. Simulation is used extensively in design verification and operation preparation, but it is also required for test benches involving real flight-hardware elements. The Electrical Ground Support Equipment (EGSE) is used to verify the spacecraft's functionality whilst still on the ground, by stimulating it with test signals/ procedures and analysing its responses.

Simulators are normally developed to support specific tasks during the various phases of spacecraft development. The different simulation requirements at the different stages and the often different responsibilities for procurement mean that simulators still tend to be developed in isolation and with little or no reuse foreseen. Simulation in the early phases is normally not carried forward to later phases, and verification test benches often include their own simulation systems. Simulators supporting mission operations and training are developed independently of those used during the development. Flight operations procedures are developed and tested using these simulators, which in turn are not applied for validating the test procedures.

The PTB concept

The PTB concept seeks to rationalise the development of ground simulation and test facilities within a space project and to minimise duplication of effort. The new approach consists of establishing an infrastructure early in the project, which can evolve and be adapted to the needs of the different development and verification tasks along the way.

The PTB is thus a space-engineering development and test facility that, whilst including specific components for a particular project phase or mission, has a general design such that it can be used across many project phases and for different missions (Fig. 1).

The PTB is composed of three main elements (Fig. 2):

- The real-time simulator, containing models of the spacecraft hardware and environment. At the start of the project the models are fairly simple, but are able to provide an overview of the complete mission to assist with the systems-engineering tasks related to mission and system definition.
- The EGSE and Monitoring Control System (EMCS), consisting of telemetry, telecommand and special command interfaces, a master test processor and a suite of test/operational procedures.
- A hardware emulation of the On-Board Computer (OBC) running the flight software.

Some of the specific components may be reusable for other projects depending on the degree of similarity between the two missions. At the beginning of the project, the system prototype is composed mainly of the software simulation and reusable components from other projects, but in the later phases other components can be added. In order to allow the different components to be developed independently and in parallel, it is important to ensure an early and accurate definition of the interfaces between PTB components.

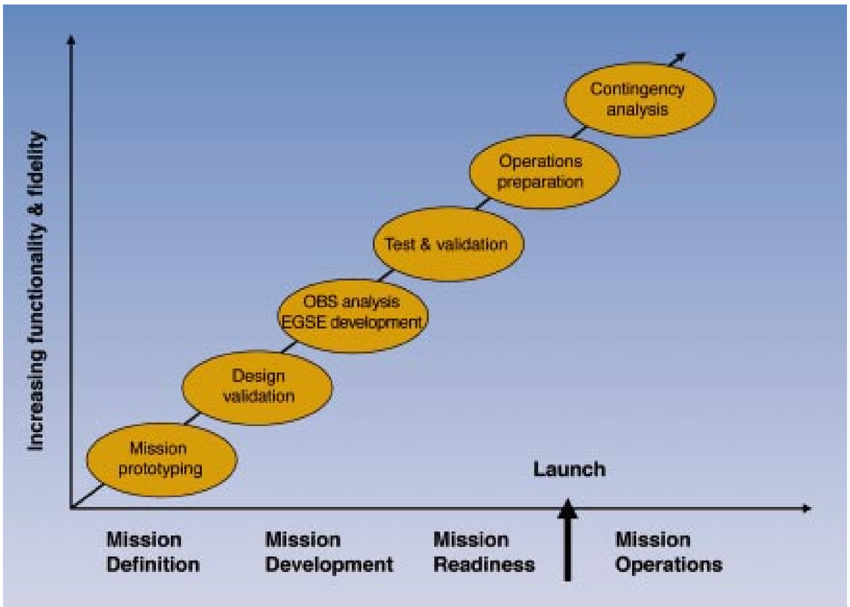


Figure 1. Evolution of the Project Test Bed (PTB)

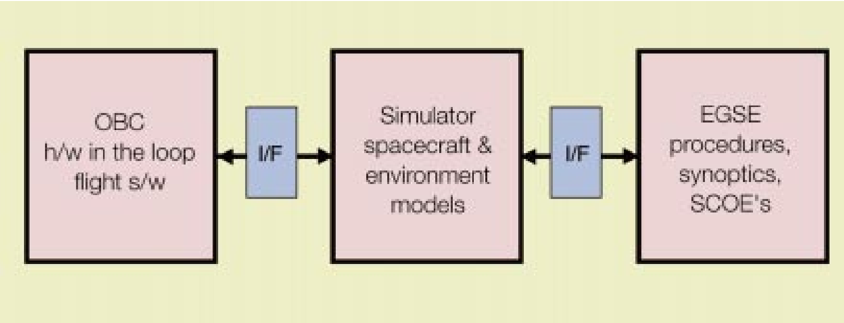


Figure 2. The PTB concept

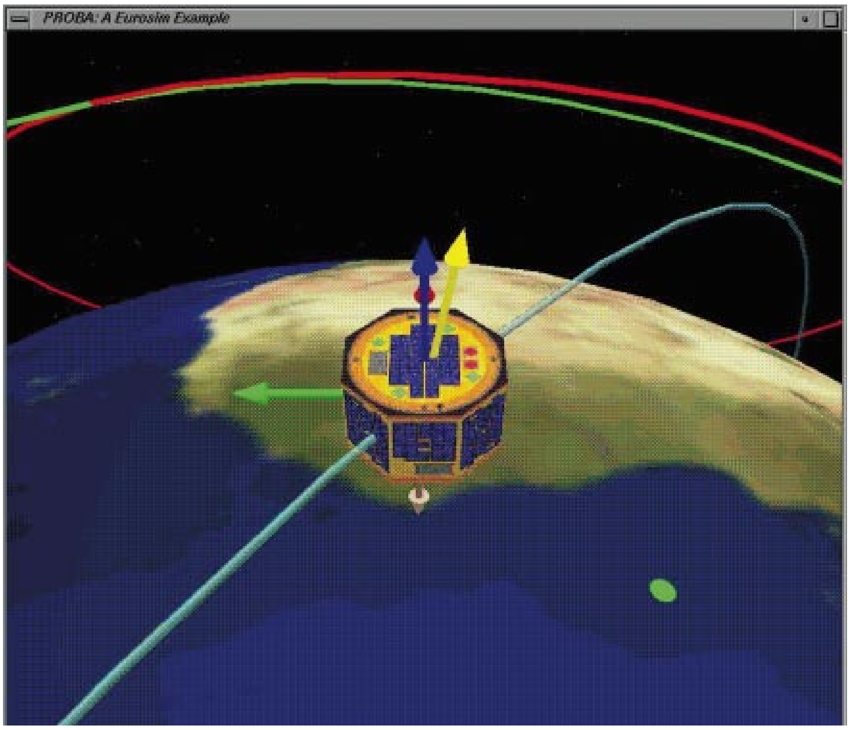


Figure 3. The PROBA mission

PTB applications

A first version of the PTB concept, covering only the simulation element, has been developed at ESTEC for the PROBA (PRoject for On Board Autonomy) mission and then partially reused for the Land mission PTB prototype. The purpose of such a simulation is to support early project phases by providing:

- Mission simulation to monitor the performances of the chosen platform and its predefined control system, to verify in a visual and intuitive way that the mission requirements are fulfilled at system level, and to identify feasible control strategies.
- System simulation to achieve a better understanding of configuration options and to support trade-offs at system level by providing quantitative performance results for different spacecraft options.

The PROBA mission

The PROBA mission (Fig. 3) is an ESA Technology Demonstration Programme conceived to prove the feasibility of a small and low-cost mission optimising operational autonomy. It will therefore fly advanced technologies which can contribute to enhanced autonomy for satellite systems. The baseline orbit for the 100 kg (approx.) spacecraft is Sun-synchronous, with an altitude of 817 km and an inclination of 98.7°. Its main scientific payload will be the Compact High-Resolution Imaging Spectrometer (CHRIS). The baseline satellite attitude will be Earth-pointing, with a roll and pitch/yaw steering capability allowing BRDF (Bi-Directional Reflectance Distribution Function) images to be taken repeatedly of the same Earth scene. The ground station will be at ESTEC, with the multiple user stations at a variety of sites.

The Land mission

The Land Surface Processes and Interactions mission (Fig. 4) is one of the proposed future generation of Earth-Explorer missions. It is dedicated to the study of land-surface processes and interactions with the atmosphere, including the energy and water fluxes and the biomedical fluxes like photosynthesis and plant respiration.

The mission features a single hyper-spectral imaging instrument known as PRISM (Process Research for Imaging Space Missions). The mission calls for the acquisition of directional measurements over a scene (site), thus requiring across-track (roll) pointing performances of ± 30° and along-track (pitch) pointing performances of ± 60°, in order to measure the BRDF of the observed site.

Pre-Phase-A analyses have demonstrated the advantages of an instrument concept without a pointing capability, accommodated on an agile spacecraft allowing the required pointing to be achieved with the platform itself. According to the preliminary studies, the spacecraft will have a mass of about 700 kg. Its configuration features fixed solar arrays, and its baseline attitude is Sun-pointing. It will use yaw steering in order to minimise image distortion due to the pointing and the Earth's rotation. The baseline orbit is a Sun-synchronous polar orbit (97.8º) with an altitude of 670 km. The main ground station is to be located at Kiruna, in Sweden, and the options for 'local users' are also being studied.

PTB prototype implementation

The PTB simulator has been designed with a modular approach in mind such that in the later phases of a project not only can additional mission-specific software and hardware be added to the PTB, but the existing subsystem models can be independently upgraded with minimal impact on the rest of the PTB.

The simulator contains models of the spacecraft, its subsystems, the spacecraft environment and the ground segment. Its purpose is to provide a virtual spacecraft and environment in which to refine the mission concepts and to assist system design and later verification and validation, mission operations and training. Its design must be flexible enough to support changes in and the evolution of performance requirements. In fact, the simulator models the overall system (space and ground) to such a level of detail that the mission objectives can be demonstrated, with the option of incorporating the actual flight software.

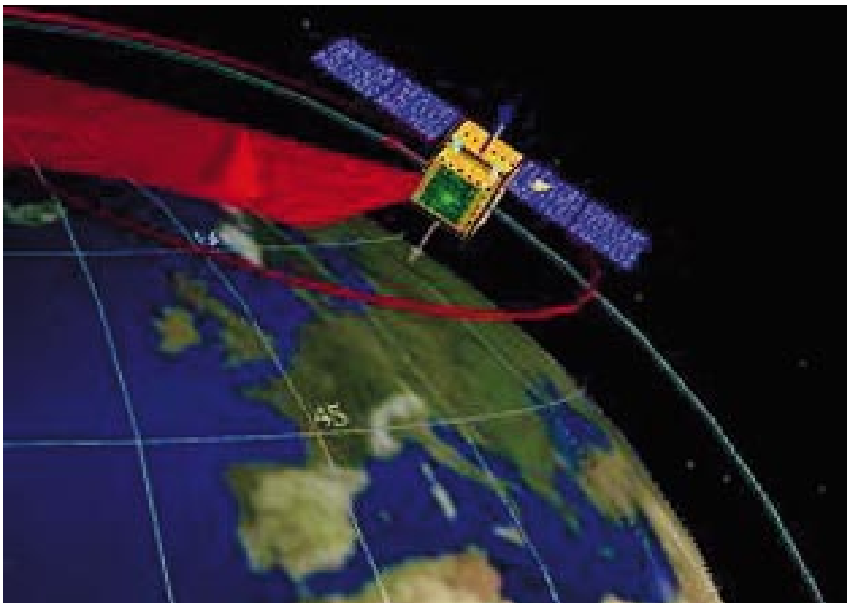


Figure 4. The Land mission

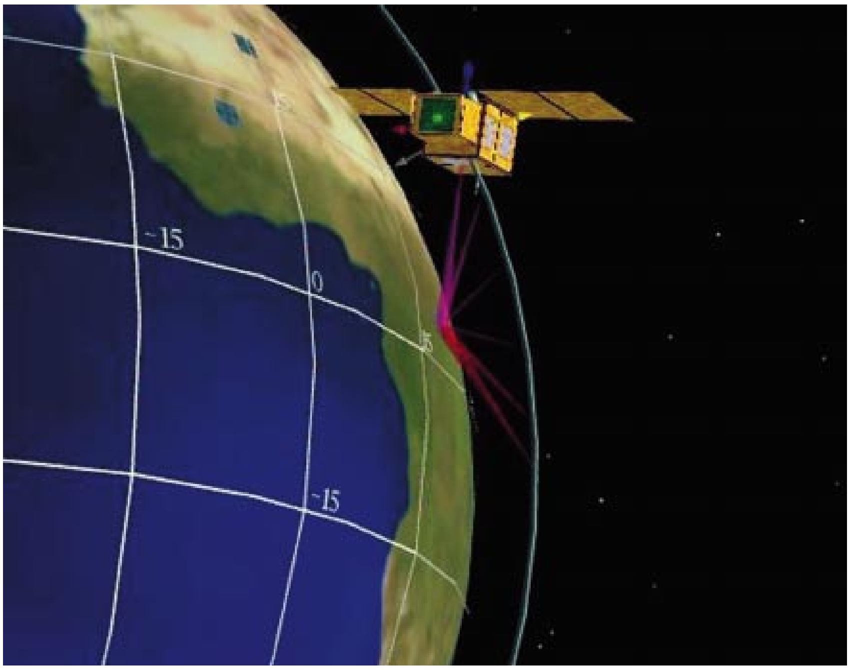


Figure 5. BRDF imaging

Capabilities of the PTB Mission Simulator

- Uplinking of telecommands and downlinking of housekeeping data when the spacecraft is in contact with the ground station
- Downlinking of user-requested images
- Maintenance of an event table containing the housekeeping history from the last ground-station contact (Fig. 11)
- Computation and 3D display of spacecraft position, orbital track, ground-station visibility zones and transmitter and imager coverage
- Realistic geometric modelling of the spacecraft, overlaid with its body vectors as well as Sun and Earth pointing vectors
- Simulation and 3D display of pointing manoeuvres required during the mission lifetime, such as Earth-pointing and BRDF manoeuvres (Fig. 5)
- Computation and 2D display of an Earth map with spacecraft position, ground stations, target images and image swath with zoom capability (Fig. 8)
- Simulation of electrical power generation and consumption
- On-board scheduling of image requests/downloads to the user station

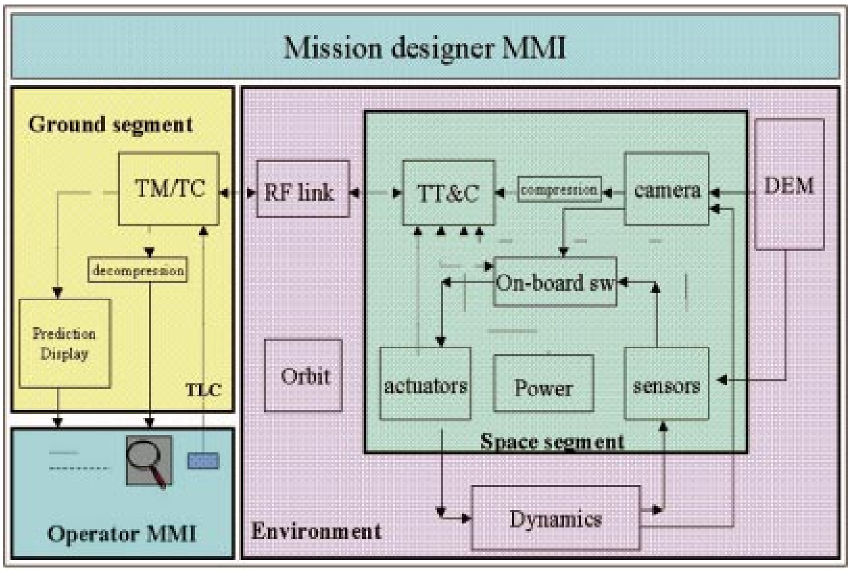


Figure 6. Simulator architecture

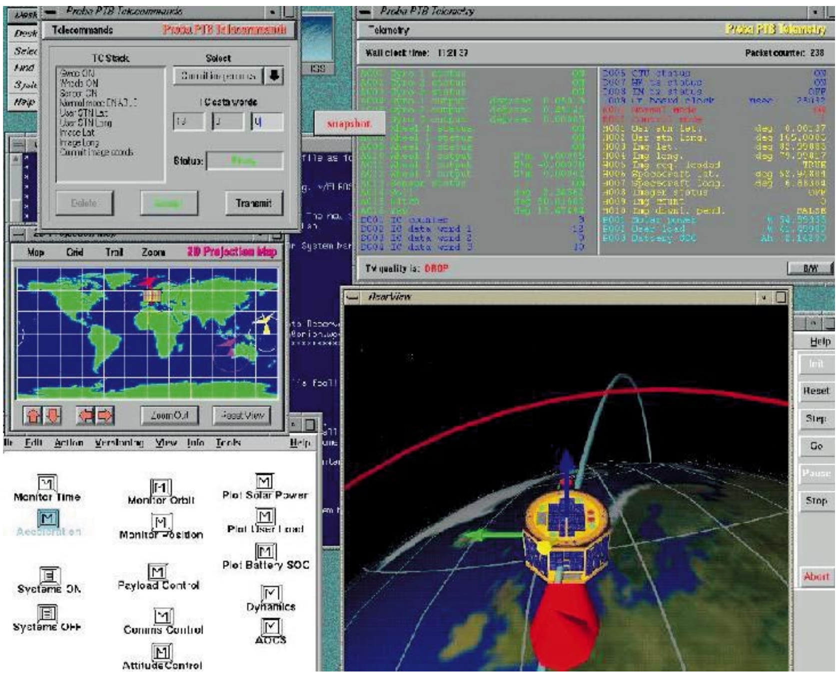
Simulator architecture

The simulator is based on the EuroSim real-time simulation environment, which supports model development and integration, simulation execution and analysis of results. The basic components (Fig. 6) of the PROBA and Land mission PTBs are the same, except for the spacecraft graphical models and the operational scenarios.

The simulator's four main components are:
- the spacecraft models
- the environment models
- the ground-segment models
- the display.

The spacecraft models implemented are:
- TT&C, which models the communications link between the spacecraft and the ground station
- OBSW, which models the telemetry and telecommand handling, the control laws and the autonomous payload-management software (different models for the two missions)
- POWER, which models power generation via body-mounted solar panels, battery state of charge and loads during the mission
- AOCS, which models the sensors and actuators
- Camera model.

Figure 7. Typical PTB user interface



The environment models are:
- the orbit model (PEM), developed by ESOC, which supports Keplerian orbits with first-order perturbations, (terrestrial spherical mass distribution, residual atmospheric drag, solar radiation pressure and Moon gravitational influence)
- the dynamics model, using a simple single rigid-body approximation of the spacecraft structure.

The ground segment models are:
- estimation algorithms (tbd)
- prediction algorithms (tbd).

The display capabilities of the PTB consist of a 3D Image Generation System (IGS; Figs. 3 – 5), 2D map and telemetry/telecommand man/machine interfaces (MMIs). A typical PTB user interface (Fig. 7) also includes the test conductor MMI provided by EuroSim.

Two commercial tools are used for the graphical implementation: MultiGen and Vega. MultiGen is used to create new models and edit existing ones, and Vega was employed to animate the models. A number of highly detailed models were required, including a texture mapped Earth, a textured spacecraft model and transmitter cones that can be switched on and off. BRDF sequences are shown in terms of past and present viewing angles.

Vega has also been used to provide the simulator user with different viewing options, including a ground- or user-station view, tracer view and overall view of the Earth and orbit

The 2D Map (Fig. 8) consists of an Earth map, displaying ground stations, target images, and spacecraft position, with the possibility of zooming in on the computation of the image swath to be taken by the instrument.

Three MMIs – one for telecommanding (TC) and two for telemetry (TM) – have been developed using Xforms, a public-domain tool kit. The TC MMI (Fig.9) presents the user with a list of telecommands which can be selected and stacked for later uploading. The transmission of the spacecraft telemetry data is handled in two different ways:

- when a link is established with the ground station, the spacecraft transmits the instantaneous housekeeping data, which is displayed by the TM MMI (Fig.10)
- when the spacecraft is not in contact with the ground station, it stores a history of major events, which it downloads when next in contact with the station (Event MMI) (Fig.11).

Further work

The analysis and implementation of the interface between the PTB simulator and the on-board computer is still in progress. The development of a full PTB and its application in the context of end-to-end validation and operations preparation for a real mission is foreseen as the next step. Application of the PTB concept to the SMART-1 mission (described elsewhere in this Bulletin) is presently being investigated via the development of an appropriate prototype.

Conclusions

The prototype version of the PTB implemented for the PROBA and Land missions is proving to be a useful tool. It has been designed using a modular approach, so that in the later phases of a project not only is it possible to add mission-specific software and hardware, but also the existing subsystem models can be independently upgraded with minimal impact on the rest of the PTB. Although the two PTBs developed so far are only prototypes for early mission phases, they have served to demonstrate clearly the validity and benefits of the concept of test-bed reusability across projects.

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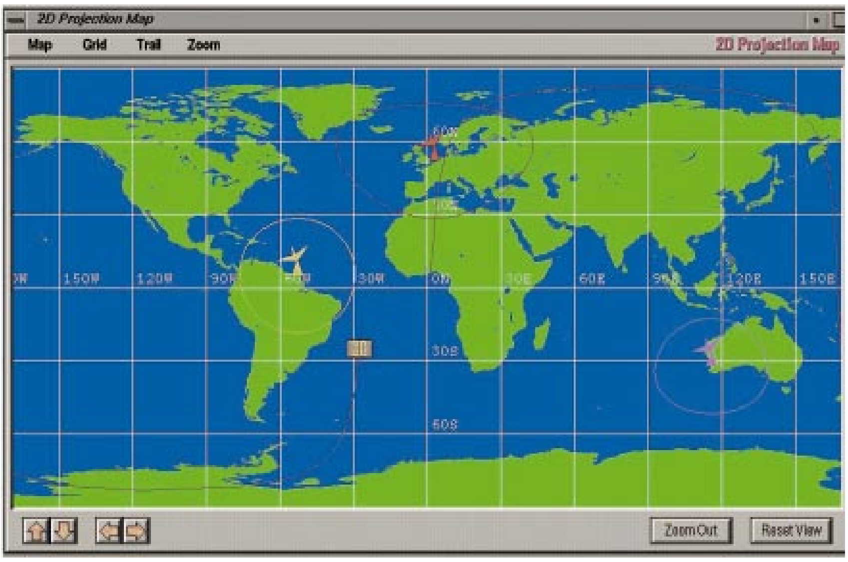

Figure 8 . The two-dimensional map

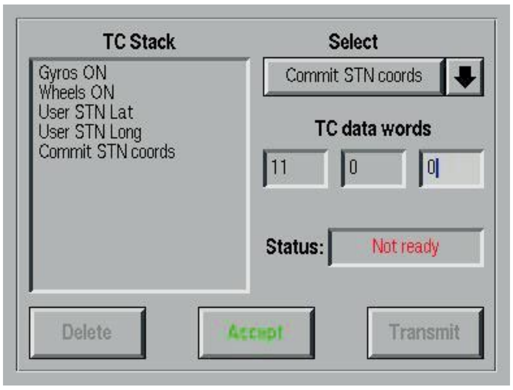

Figure 9. The telecommanding (TC) man/machine interface (MMI)

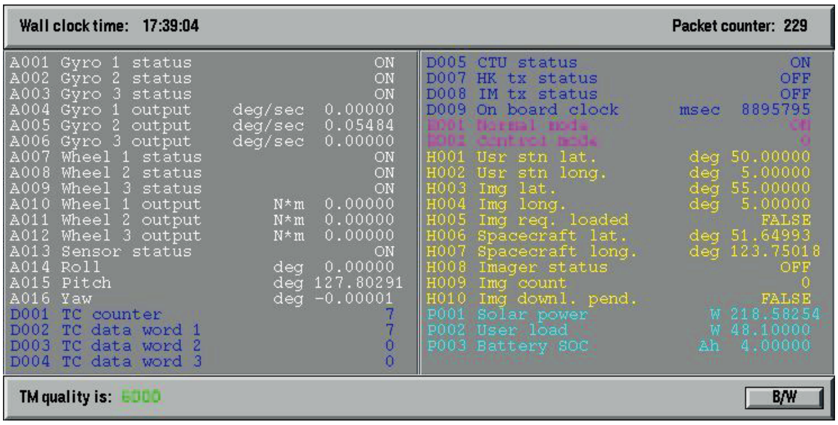

Figure 10. The telemetry (TM) man/machine interface (MMI)

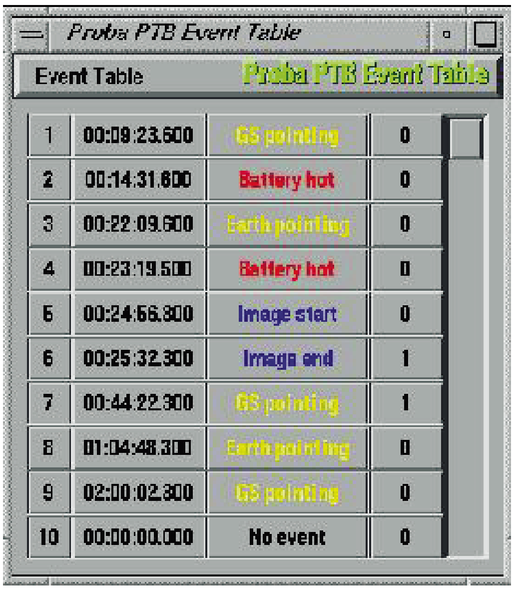

Figure 11. The event man/machine interface (MMI)