LEOSTAR™ Development and Validation

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Abstract. The LEOSTAR generic avionics development currently in progress at Matra Marconi Space Toulouse center can be easily adapted to a variety of small satellites in LEO, with specific sensor and equipment suite selected according to the mission needs. A generic avionics bench has been set up and proto-flight equipment procured for a comprehensive configuration. The development and validation are performed along an incremental process for the two AOCS main modes, Acquisition and Safe Hold mode (ASH) and Normal mode. The functional and dynamics behavior is analyzed and compared with the results of the SIMULEO simulation software, with any potential deviation investigated and accounted for. The validation is proceeding as planned, with flight software and equipment at flight standard running in closed loop and real time. The successful validation of the ASH mode has been completed in early 1998 and will be followed later this year by the validation of the Normal Mode.

Introduction

LEOSTAR™ is a family of platforms (Fig.1) proposed by Matra Marconi Space for Low Earth Orbit (LEO) missions, including small Earth observation and science satellites, as well as communication constellations. This family is designed around a generic core avionics.

The fully centralised and optimised architecture enables the use of existing flight proven equipment as-is (COTS approach). It is versatile thanks to the current definition and easy evolution, if needed, of the modular and evolutive On Board Management Unit (OBMU) and to the initial identification of options taken into account since the start of the development.

The mechanical aspects are not considered generic, being dependent on customer requirements as launcher compatibility and payload mechanical characteristics.

System analyses are based on the LEOSTAR™ 200 and LEOSTAR™ 500 platforms, defined for missions which can be implemented with a standard, affordable product.

The geometric lay-out frame for the validation of the core avionics is based on LEOSTAR™ 500 (Fig. 2).

LEOSTAR™ Core Avionics

The LEOSTAR™ core avionics (Fig. 3) is based on a centralised architecture involving the On Board Management Unit (OBMU), fully redunded, which comprises the processor and all the interfaces with the AOCS sensors, actuators and the Telecommand and Telemetry equipment. The OBMU (Fig. 4) presents a modular architecture with optional functions such as mass memory modules or payload dedicated module for additional services to the basic services already offered : among them, 1553 bus, RS 422 serial lines, power and thermal lines.

The LEOSTAR™ power bus is directly connected to the NiCd battery, leading to an unregulated power bus. The battery regulation and generally all unit On/Off switching is performed through actuation of Solid State Power Controllers (SSPC) located within the Distribution and Regulation Box (DRB).

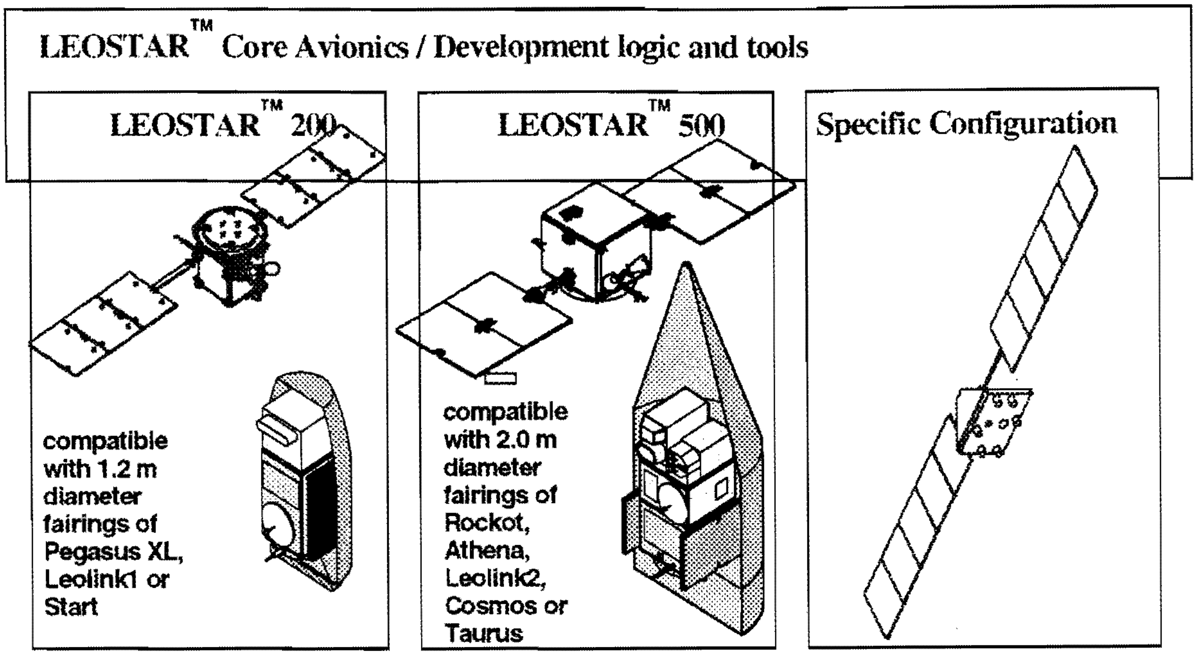


Fig. 1 : The LEOSTAR™ Family

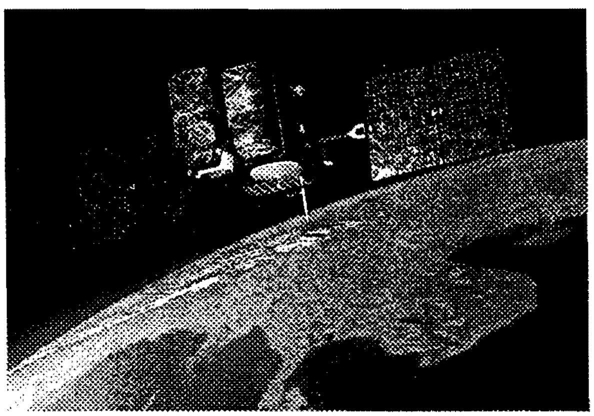


Figure 2 : Earth Observation Satellite based on LEOSTAR™ 500 Platform

The LEOSTAR™ AOCS has two main modes :

- the Acquisition and Safe Hold mode used for initial stabilisation and acquisition after launcher separation and as safe attitude in case of anomaly ; its MMS patented design is purely magnetic, leading to a robust, autonomous and non-time limited mode without resource consumption nor orbit degradation.
- the Normal mode using autonomous Star Sensors, an Inertial Reference Unit and GPS receivers for attitude and orbit determination. The choice of these state-of-the art sensors leads to a high degree of autonomy for the platform as well as high performance.

The Normal mode control relies on a four reaction wheel cluster, with magnetic off-loading. The orbit control is performed with hydrazine propulsion.

Core Avionics Development approach

The validation of LEOSTAR™ core avionics functions enables a protoflight qualification approach for the satellites based on LEOSTAR™ platform family.

Thanks to the modularity of both the OBMU and the on-board software, the development and validation can be performed along a "spiral" (Fig. 5) in an incremental process : the two main modes (ASH and Normal mode) being clearly separated in terms of software, actuators, sensors and OBMU interface modules, their development and validation are performed independently and in sequence.

After the development and validation of the ASH mode in 1997, the Normal mode is now under validation and will be followed by system tests dedicated to the validation of the full flight domain, from launcher separation to the operational phase, including reconfigurations and recovery tests after failure simulation.

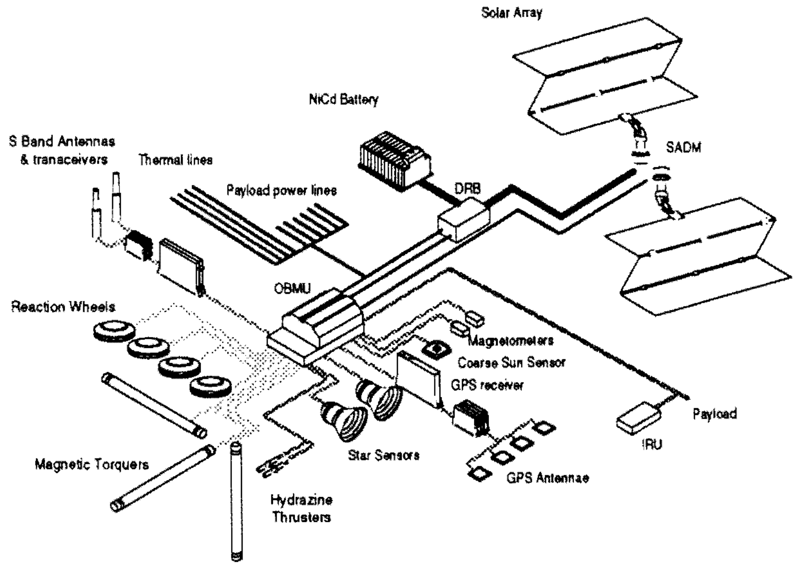


Fig. 3 : LEOSTAR™ Core Avionics Architecture

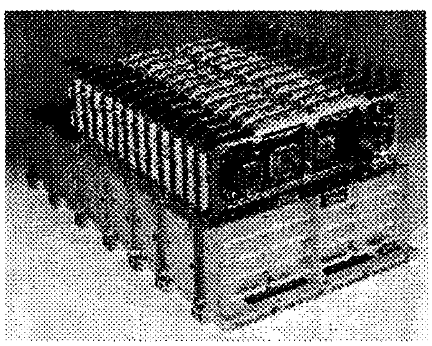
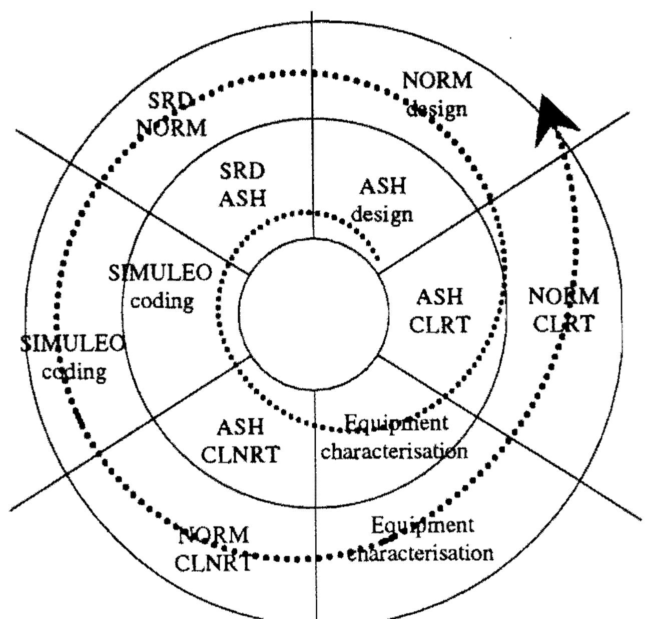


Fig. 4 : On Board Management Unit (OBMU)

The LEOSTAR™ avionics validation comprises:

- a simulation phase (using SIMULEO dedicated simulator) for Closed Loop Non Real Time (CLNRT) validation of AOCS control laws definition. SIMULEO includes the ADA flight software and numerical models for dynamics and environment as well as fine correlated models of AOCS units. This phase of system simulation covers the overall platform flight domain and enables to assess the actual performance of the satellite : pointing accuracy and stability, energy budget, etc.
- a phase of unit characterisation for the AOCS sensors and actuators, which enables to refine, if needed, the unit models used in the simulations and allows an early validation of units operating procedures.
- a global validation phase using selected reference cases, in Closed Loop Real Time environment (CLRT), the flight software running on the actual processor and with the real units in the loop.



CLNRT : Closed Loop Non Real Time
CLRT : Cosed Loop Real time
SRD : Software Requirement Document

Fig. 5 : LEOSTAR ™ Spiral Development and Validation Approach

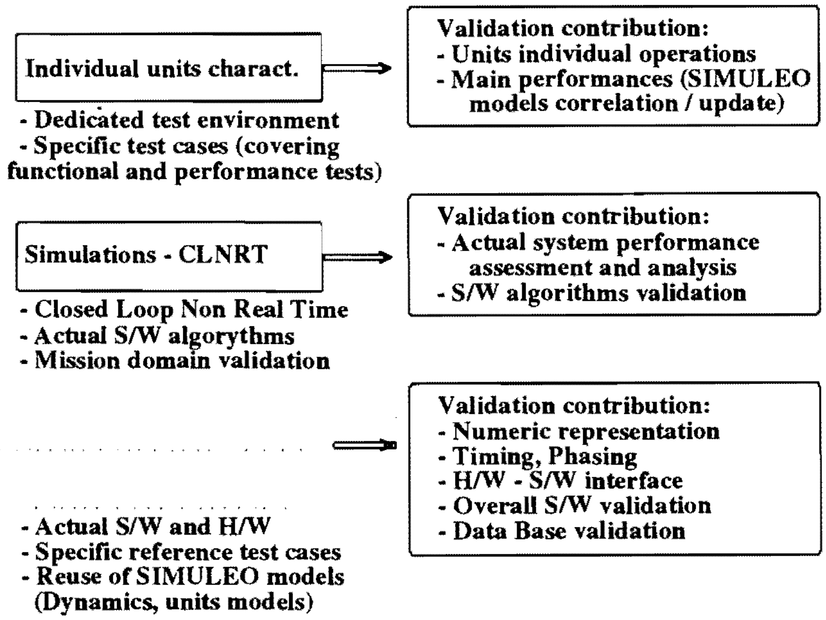


Fig. 6 : LEOSTAR ™ Validation Approach

This phase complements SIMULEO through the introduction of the flight representativity in terms of :

- processor (numeric representation)
- hardware/software interfaces
- timing and phasing
- actual sensors and actuators

The test results are compared to those obtained with SIMULEO on the same test cases.

The avionics validation approach implemented for LEOSTAR™ (Fig. 6) comprises key innovative characteristics which have led to a significant reduction in development schedule and costs :

- the characterisation tests are performed early in the development thanks to the quick availability of the selected equipment (COTS approach); this enables to be rapidly familiar with the equipment operation and to reflect it properly in the flight software ; the EGSE interfaces are also validated very early with anticipation with respect to the next phase of integrated system validation .
- maximum concurrent engineering practices are implemented. No software User Requirement Document is used ; the software requirements are directly formalised by a joint AOCS/ software team into a Software Requirement Document (SRD).
- as soon as designed, the AOCS control algorithms are coded as a protoflight software in ADA (Fig. 7); hence SIMULEO includes the actual flight software (AOCS application) instead of classically a high level language description, and constitutes the first step of flight software validation ; this integrated AOCS/ software validation allows very quick iterations between AOCS engineers and the software team in the critical early design stage.

- the test environment, called **Avionics Test Bench** (Fig. 8) presents a modular architecture allowing various configurations dedicated to :
  - Flight software validation with the actual OBMU processor module
  - Closed Loop Real Time tests (CLRT) with actual units (flight models)
  - Assembly, Integration and Test of the platform.

The Avionics Test Bench re-uses also :

- the AOCS units specific interface EGSE used for the characterisation tests
- the SIMULEO models for AOCS units and for the satellite dynamics and environment.

For the tests, the AOCS sensors or actuators, as well as OBMU interface modules, are either actual hardware or simulation models. The units are systematically simulated for dry run tests first, in order to avoid any potential stress to actual hardware in early phase.

- A significant effort has been devoted to develop on the Avionics Test Bench, 3D visualisation tools for easy interpretation of satellite attitude for both CLNRT and CLRT tests .
- The platform units used on the Avionics Test Bench are assembled on a foldable structure (Fig. 9) representative in terms of geometric lay-out, together with a representative electrical harness. This provides easy access to units in deployed configuration, while tests are performed with the folded configuration for proper magnetic and EMC representativity.

LEOSTAR™ ASH and Normal Mode Validation Campaigns

ASH mode campaign

- ***SIMULEO phase***

This simulation phase has covered 32 reference cases (standard selection for non-regression tests) complemented by more than 200 other cases with system parameters random setting.
These 32 reference cases cover the LEOSTAR™ 500 flight domain made of various orbit and satellite assumptions (SSO, equatorial or inclined orbits ; satellite configurations with Solar Array up to 4 panels ; satellite mass between 330 kg and 1200 kg).
Each simulation lasts typically about 30 minutes (depending on the workstation processor performance) compared to real time simulations which lasts about 8 hours.

To get the first conclusive SIMULEO results, 32 bugs had to be corrected : 15 linked to AOCS control laws design and 17 due to software coding. These 32 bugs have been solved in less than three weeks thanks to the integrated AOCS/software team approach (Fig. 7). Furthermore, no additional bug was found during CLRT phase, highlighting the interest of such a validation approach.

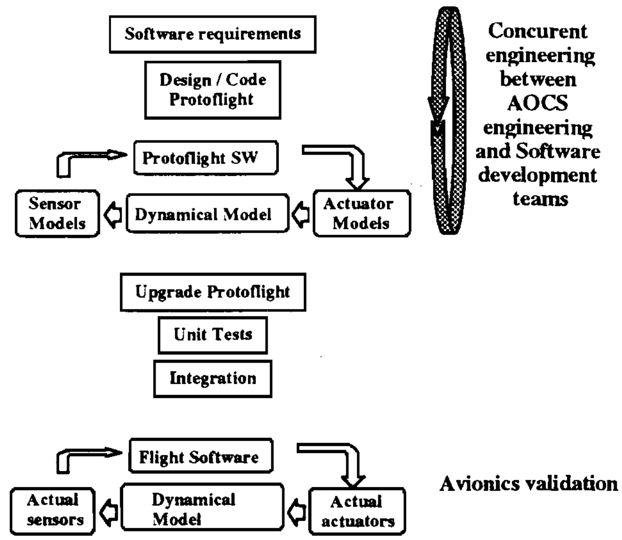


Fig. 7 : LEOSTAR ™ software development

The first conclusive SIMULEO results have demonstrated that the convergence duration for the acquisition mode was too long on some equatorial orbits, in worst case initial velocities condition, and could lead to complete battery discharge before proper pointing of the solar array.

As a consequence, the AOCS control algorithms have been refined and a second phase of tests has demonstrated a correct behaviour for the overall flight domain (Fig. 8).

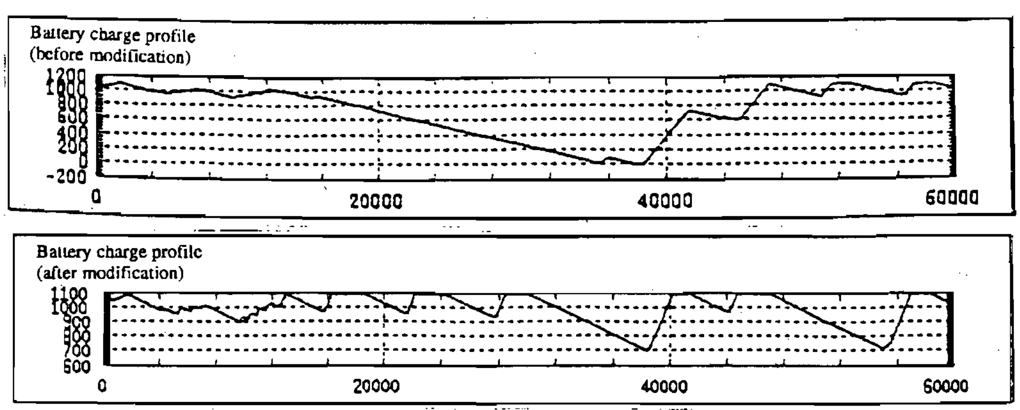


Fig. 8 : Comparison of Battery Charge Profiles in ASH, Before and After Modification

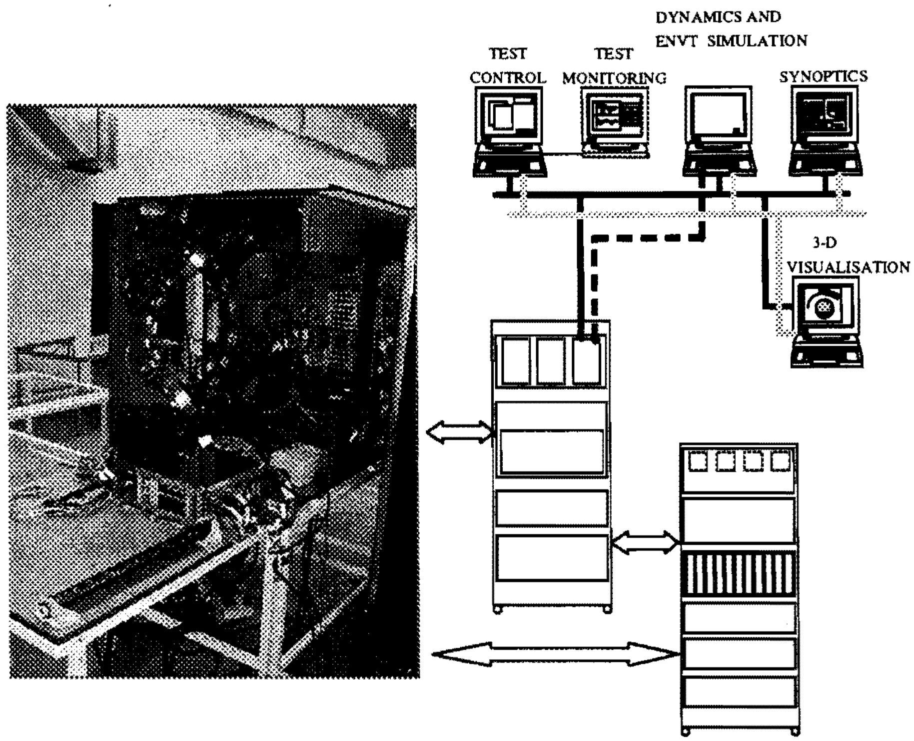


Fig. 9 : LEOSTAR ™ Avionics Test Bench

Characterisation tests

The AOCS sensors and actuators used during the ASH mode have been characterised in parallel to the development of the Avionics Test Bench facility and integration and test of the OBMU.
In addition to the above mentioned AOCS model correlation aspects, these tests have enabled :
- to measure the micro-dynamics performance of the Reaction Wheels (RWA) through tests on a Kistler table ; the performance was found excellent and compatible with high resolution imagery requirements
- to validate the Solar Array Drive design for the full LEOSTAR ™ range of solar array inertia ; the impact of SADA rotation on the platform stability has also been characterised.
- to validate the principle of use of the magnetic torquers and magnetometers and derive fine model for magnetic interaction.

Closed Loop Real Time tests

The Closed Loop Real Time tests have been performed on SIMULEO cases selected to cover the overall flight domain and satellite potential configurations.
The results have been found to be extremely well correlated to SIMULEO simulations (Fig. 10).

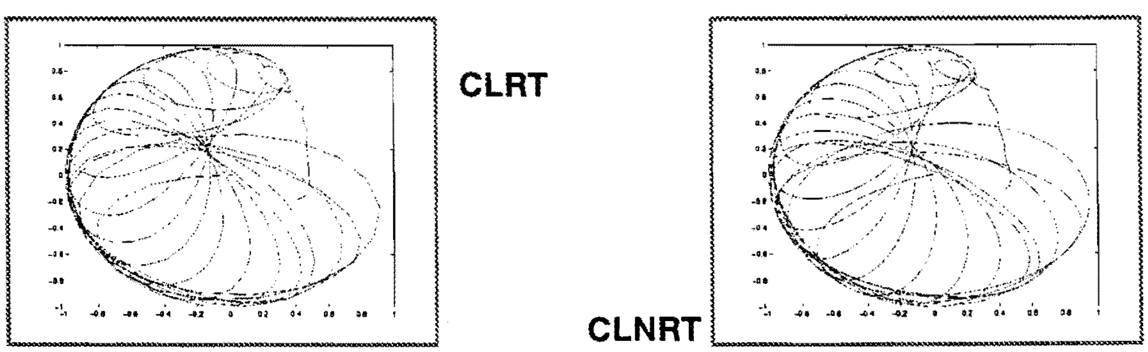


Fig. 10 : Comparison of CLRT and CLNRT Tests Results for the Initial ASH Convergence (Roll-Yaw plane)

Normal mode campaign

The Normal mode validation campaign is under progress and is organised as the ASH validation campaign with :

- Characterisation tests for the Inertial Reference Unit (IRU), the GPS receiver and the Star sensor (SST)
- Closed Loop Non Real Time simulations (with an enhanced SIMULEO configuration integrating the normal mode AOCS laws and the new equipment models)
- Closed Loop Real Time on the Avionics Test Bench with additional units (flight models for IRU and GPS, EM for SST)

Static and dynamic tests on IRU demonstrate that the very high performance expected for the will be met in terms of noise, random drift as well as scale factor stability.

An early validation of a GPS based attitude measurement concept was performed in 1996 in order to take into account the impacts of multi-path effects for the LEOSTAR™ design. The characterisation tests performed in 1998 on a representative model of LEOSTAR™ GPS have demonstrated the successful initialisation of the GPS receiver for the overall LEOSTAR™ flight domain, when using the warm start option.

A dynamic stimulator developed by MMS for the star tracker end-to-end tests is used to validate the tracking mode as well as to check the initial star pattern recognition algorithms on various star configurations.

SIMULEO phase and closed loop tests

The Simuleo phase (Closed Loop in Non Real Time) and the Closed Loop Real Time tests are planned during summer 98. The validation will cover the attitude estimation function and the control laws used for the Normal mode as well as for Orbit Control. As for the ASH mode, the test cases will cover the overall LEOSTAR ™ platform flight domain and the satellite potential configurations.

Conclusion

The development and validation of the LEOSTAR ™ avionics are proceeding as planned, with flight software and equipment at flight standard running in closed loop and real time.

The validation process is characterised by :

- parallelism of activities and extensive concurrent engineering practices between AOCS, Operations, software and OBMU developments
- early operation of the actual units through the characterisation tests
- incremental process thanks to the modular architecture of the OBMU and the flexible Avionics Test Bench used both for simulation and actual hardware tests.

The successful validation of the Acquisition and Safe Hold mode has been completed. The innovative development methodologies applied to the ASH mode are currently re-used for the validation of the Normal mode.