Leostar : lessons learnt and perspectives

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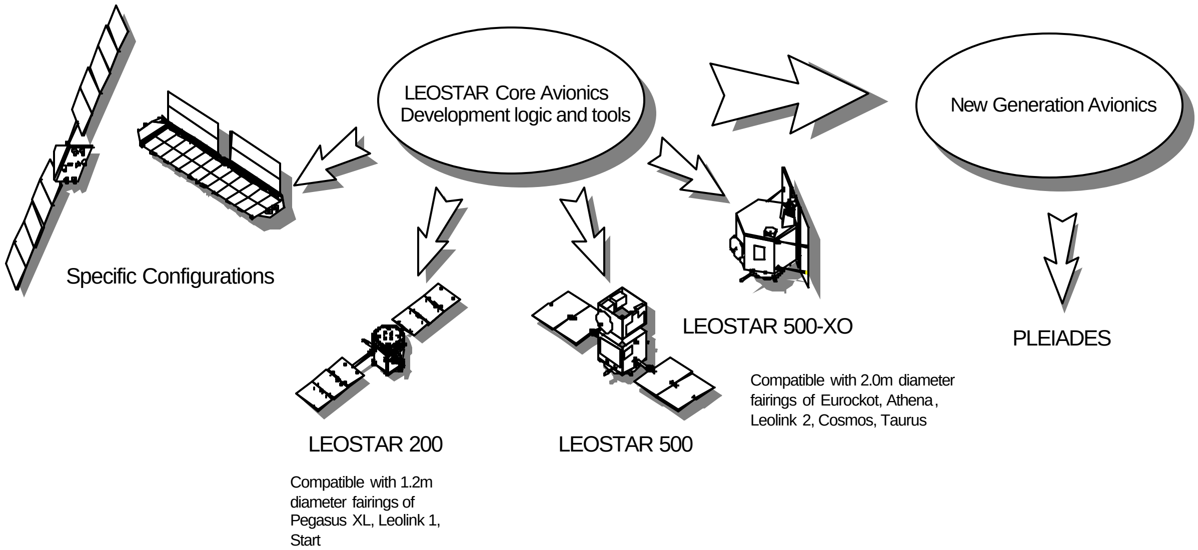
Abstract
In 1996, Matra Marconi Space (now Astrium) has started the design of Leostar, a family of small platforms capable of supporting Earth observation, science and communication missions for a large range of Low Earth Orbits. This internal initiative has been triggered by the Faster/Better/Cheaper (FBC) tendency appearing among institutional customers and obvious on the export market. Hence, Astrium strategy was to provide standard qualified platforms relying upon a generic core avionics, as well as customized elements to be used for specific applications. To achieve these FBC goals, Astrium implemented innovative design and validation incremental methods, coupled with the maximum use of off-the-shelf equipment.
The validation of the Leostar generic core avionics is now terminated and turned out successful w.r.t the FBC approach. Indeed, significant cost and time reduction could be observed not to the detriment of performance since the family now includes the Leostar 500-XO bus dedicated to very demanding high resolution observation missions. For a recent export program awarded end 99, Astrium is relying upon the Leostar concept to answer the needs of an Earth observation mission while coping with the challenging schedule requirement of delivery of satellite to final Customer in 30 months. Moreover, thanks to this Leostar heritage, Astrium has started to study for the French Space Agency (CNES) the new generation of agile bus which will support PLEIADES, the Spot follow-on program.

This paper gives a brief overview of the Leostar family and its current and planned applications, describes the lessons learnt throughout the validation phase, and discusses how adequate aspects of the Leostar development approach have been applied to an interplanetary mission such as Mars Express.

Leostar Family

Leostar constitutes the family of platforms proposed by Astrium SAS for Low Earth Orbit (LEO) missions including Earth Observation satellites, Science satellites and Telecommunication satellites for LEO constellations.
This family is designed around a generic core avionics, which can be accommodated in various physical ways:

- either a standard platform, such as the Leostar 200 dedicated to 1.2m diameter launcher fairing (Pegasus XL, Leolink 1, Start) or Leostar 500/500-XO dedicated to 2.0 m diameter launcher fairing (Rockot, Athena 2, Leolink 2, Cosmos, Taurus) ; the Leostar 500-XO is more specifically optimised for high resolution observation mission.
- or a customised mechanical configuration, for spacecraft overall optimisation : configuration optimised for efficient SAR antenna for a radar mission, configuration optimised for multiple launches in the case of a telecommunication constellation, etc.



The Leostar Family

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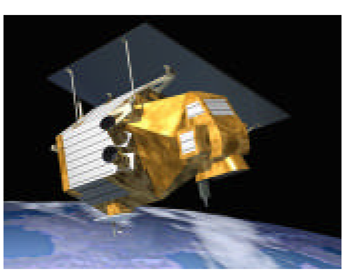
Leostar Family Key Characteristics

The heart of the Leostar family, including the core avionics and also the generic development logic and tools, features the following key characteristics :

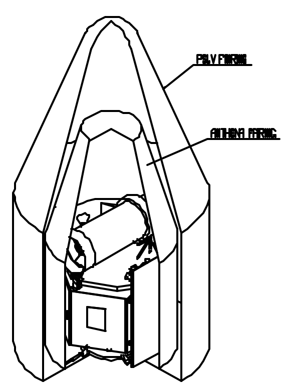
- low cost because of fully centralised and optimised architecture enabling the use of existing flight proven equipment as-is ("Off-The-Shelf" approach)
- versatility through the current definition and easy evolution, if needed, of the modular On Board Management Unit and through the initial identification of options taken into account since the start of the development
- high performance (agility, pointing accuracy, location and stability) with the use of advanced sensors (gyroscopes, star trackers, GPS)

The new Leostar 500-XO bus



Within the frame of the 1999 competition organised by CNES for the initial 3S Spot Follow-On program, Astrium has derived from the Leostar generic avionics a dedicated bus (so called Leostar 500-XO) which provides, in addition to the above described general Leostar family characteristics, high agility, stability and localisation leading to a high performance bus for high resolution optical observation missions.

This bus, which includes also the Payload storage and downlink functions, is currently under development for an earth observation export program which was awarded to Astrium end of 1999 after world wide competition.



Satellite based on Leostar 500-XO bus Launch configuration

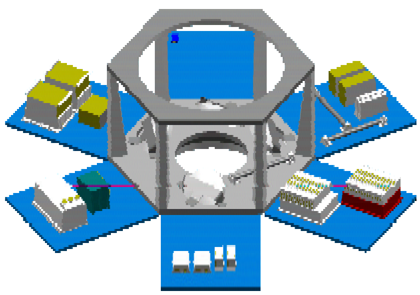
Leostar 500-XO overview

The Leostar 500-XO bus has been specifically designed for High Resolution observation missions. Low inertia and high stiffness provides for a very agile spacecraft, while enhancing Line Of Sight pointing performances.

As the other standard platforms of the Leostar family, the Leostar 500-XO bus provides a multi-mission potential. It features easy accommodation of any type of payload with typical mass of 500 kg. Thanks to its modular design, a number of options can be selected to best suit to the mission needs in terms of orbit, mass, power, propulsion and data transmission capabilities.

Mechanical Architecture

The overall shape is an hexagon, 1.5m height, included in a 1.5m diameter. Structural aluminium honeycomb panels provide support to the equipment. The attachment to the launcher is ensured by an adaptable frame bolted to the lower face of the bus.



On the upper face, the Payload Interface Panel (PIP) carries the payload. For pointing performances, the PIP is made of CFRP, quasi iso-staticaly mounted on the bus; furthermore, attitude sensors are accommodated directly on the PIP.

The propulsion assembly used for orbit control is constituted by an independent module grouping four thrusters, the tubes and the hydrazine tank of 80 kg, and directly mated to the lower floor.

The solar array is fixed and modular, with two (600W) or three panels (900W) with GaAs cells.

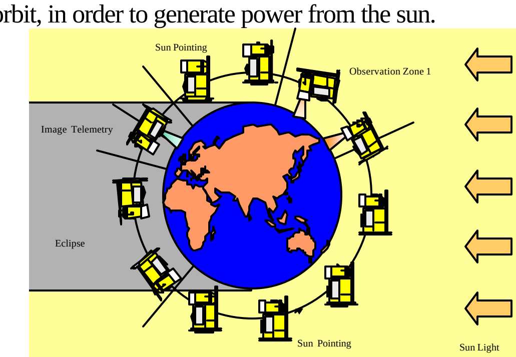
The spacecraft modes

➢ The Acquisition and Safe Hold (ASH) mode, used for initial stabilisation and acquisition after launcher separation, and for safe attitude in case of anomaly; its Astrium patented design is purely magnetic, leading to a robust, autonomous and non time-limited mode without resource consumption nor orbit degradation.

➢ The solar pointing of the fixed solar array is autonomously provided by spacecraft attitude strategy.

Three phases can be defined on an observation orbit

- The observation phase, with potential roll/tilt manoeuvres for cross-track and along-track imaging capability (multi-strip acquisition, stereo imaging…) and direct payload data down-linking
- The eclipse phase, with Nadir pointing, especially for payload data down-linking during night and Scientific observation
- The sun pointing phase, for the remaining part of the orbit, in order to generate power from the sun.



The Autonomous Sun Pointing

	Main features	Main performances
Design lifetime	5 years	
Reliability	0.8 over 5 years	
Mass		
Buss dry mass	350 – 400kg	
Payload mass capability		150-600 kg
Power		
Modular fixed solar array panels	600 – 900 W	
Bus power consumption	150 – 350 W	
Power available to payload		Typically 250W mean & 450 W peak
Line of Sight		
Pointing		100-250m @ 700km
Localisation		20 – 70m @ 700km
Stability		Better than 10^{-4} °/s

Leostar 500-XO Main features

Leostar generic core avionics validation

The development and validation of the generic Leostar avionics has been achieved from 1996 to 1998 through internal funding by Astrium. This internal initiative has been triggered by the Faster/Better/Cheaper tendency appearing among institutional customers and by actual opportunities on export market.

The objective was to get enough development maturity w.r.t the most innovative Leostar concepts so as to demonstrate to potential customers the design credibility and improve the development schedule of the first mission.

Hence, the effort was focused on the avionics and in particular on the data-handling/AOCS/software/ operation aspects.

Using innovative methods, among which incremental development and concurrent engineering, the whole avionics development was achieved in less than two years.

Leostar Methodologies

In addition to the end-product interest, the context of an internal funding was appropriate to implement and test the following innovative development and management methodologies :

Keep the system design simple

In order to lead to a robust product, Leostar design has been kept as simple as possible with clear principles for FDIR (Failure Detection, Isolation and Recovery) ; this guarantees a full design control by the design team and leads to an easy and comprehensive system validation. Main characteristics in this domain are :

- only two AOCS modes :
  - one single ASH mode gathering initial Acquisition after launcher separation and Safe Hold mode in case of failure; the failure isolation and reconfiguration is a ground task. To be noted that this ASH mode is very robust as relying only on magnetometer measurement and magnetic actuators (no propulsion)
  - the normal mode covering the payload operational mode (imaging for example) and the orbit control mode; this mode relies on autonomous sensors (as GPS and Star Tracker) allowing to decrease the system complexity and ease the validation process.

- Centralised architecture around two main units:
  - the OBMU (On Board Management Unit) supporting the computer function and all data handling IF with AOCS sensors/actuators as well as TM/TC units
  - the DRU (Distribution and Regulation Unit) in charge of all units switch on /off and battery management /solar array string connection as well as implementing the first electrical protection.

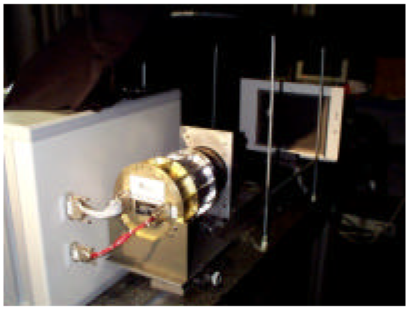
Re-use of COTS

In order to lead to an affordable product, Leostar design has been made compatible with Commercial Off The Shelf units, ie units previously developed for other programs and potentially already qualified or with in-orbit heritage.

This approach is made possible and competitive thanks to the concentration within one unit (the OBMU, internally developed within Astrium) of all the interfaces and thanks to the OBMU design modularity which allow modifications to one module without challenging the whole OBMU qualification.

This principle is associated to the retro-specification concept where the unit supplier own specification is used as the contractual requirement after review and potential addition by Astrium of missing information or Leostar specificities to take into account. This approach of re-use (after review and Astrium approval) of supplier own documentation is also implemented for Product Assurance and Product Management plans, as a principle of limiting the specific documentation to the minimum.

A key validation aspect on Leostar is the introduction of some unit characterisation tests at Astrium after acceptance tests at supplier premises.

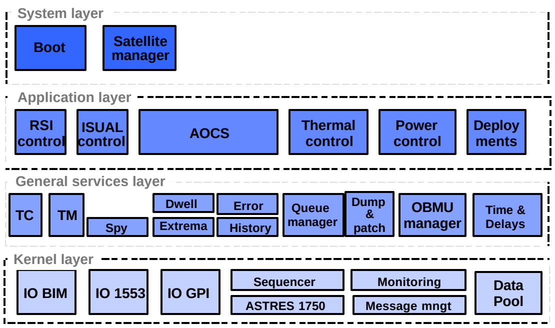


Star tracker characterisation tests

With the COTS concept, the unit acceptance tests are often pre-defined according to the units generic requirement . The characterisation tests are the occasion to fully operate the units according to Leostar operating modes, to validate the system interface and through specific tests to correlate the units numerical models used for system simulation and validation

Software design, development and validation

The software also presents modularity with successive layers implementing higher and higher level command/algorithms. Thanks to this architecture, modifications (as AOCS unit change) can be implemented while keeping the rest of the software unchanged and hence limiting the need for validation to the modified areas and to a global non-regression test at system level.



Leostar software architecture

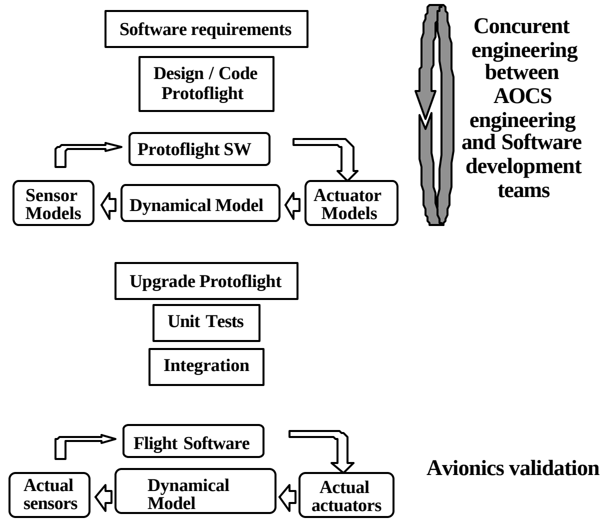
One of the key issues of a challenging development schedule is the ability to test very early the flight software in closed loop, in order to gain confidence in the system design, but also in the software, much sooner than usually done. It is well-known that errors which are detected early can be corrected with very little cost.

For Leostar AOCS software, this has been possible thanks to the SIMULEO tool, which includes functional models of AOCS equipment, as well as dynamics and environment models. The AOCS module of the flight software can be included without modification in SIMULEO, in order to perform closed loop tests.

The early validation phase requires a very close co-operation (or concurrent engineering) between the AOCS engineering team and the software team. The first step is to write the first version of the Software Requirements Document (SRD).

As soon as it is available, the first version of the flight software is coded, and integrated in SIMULEO with very few preliminary tests.

Then begins the early validation phase in itself. Closed loop SIMULEO tests are run, and both teams investigate together the anomalies. Quick iterations on the design, as well software bugs corrections, are performed. This phase requires maximum co-operation between both teams, and a very good reactivity, in order to be able to perform very quick changes.

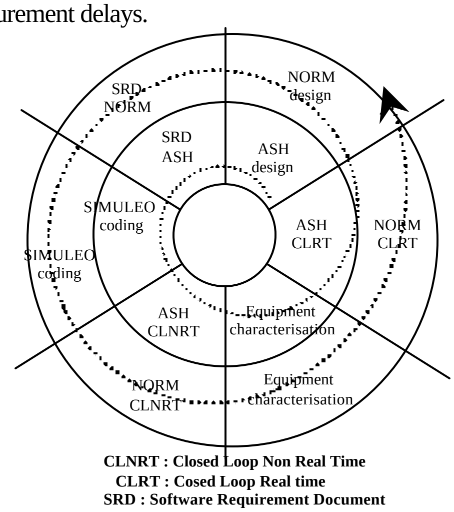


Leostar software development and validation principle

This method proved to be very efficient during the Leostar generic avionics development. At the end of this phase, which lasted typically two months for each AOCS mode, the SRD could be considered as validated. Moreover, the confidence in the software was very good. No anomaly was actually discovered, neither in the design nor in the software, after this phase.

Incremental development process

Thanks to the Leostar design modularity implemented both at OBMU hardware level and at software level, an incremental development and validation process has been implemented for AOCS function, which revealed to be particularly efficient in term of gradual system validation and schedule flexibility w.r.t unit availability due to procurement delays.

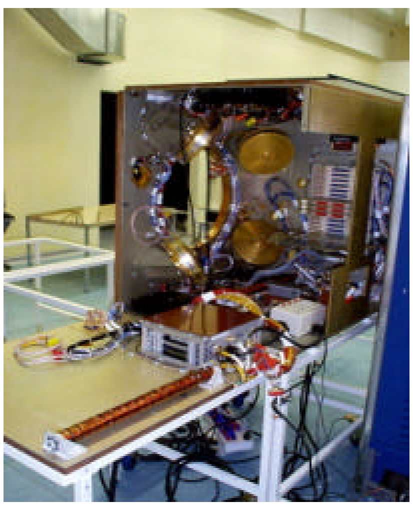


Leostar Spiral Development and Validation Approach

One AOCS mode validation includes:

- Early validation of the Flight Software in closed loop (using the SIMULEO dedicated tool), with quick iterations between design and software.
- Characterisation of AOCS sensors and actuators, to allow early validation of the units operating procedures, and to refine their numerical models if needed.
- Closed Loop Real Time validation on an avionics test bench, with real hardware and software in the loop.

Using these incremental methods, combined with maximum concurrent engineering practices, the whole Leostar avionics concept has been validated within two years, hence demonstrating a saving ratio of 2 in terms of schedule and cost w.r.t previous SPOT programs.



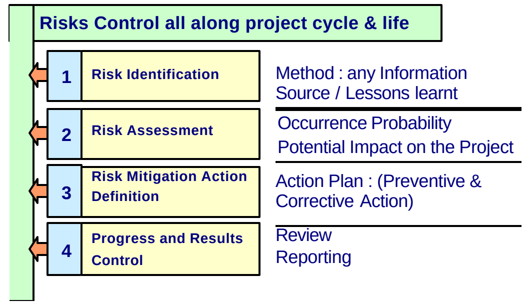
Leostar Avionics Test Bench

Implementation of Risk Management methodology

The Leostar generic avionics development program has been the occasion to implement and practice the Risk Management methodology. Risk management is a continuous process which ensures project control and advanced project monitoring for technical definition, cost and schedule.

This Risk Assessment & Mitigation methodology allows identification, assessment and definition of all necessary preventive or curative actions to mitigate Risks or cancel Risks.

It is processed in 4 main steps, as presented hereunder :



Risk Assessment Methodology

- Step 1 : Identify Risk

This is a collective result from Project Team which allows :

- Critical point identification with their associated risks,
- Analysis of causes with identification of associated triggering factors and activation period.

- Step 2 : Assess Risk

This step consists in the assessment of criticality at project level :

The Criticality results from independent assessment of seriousness of risk consequence and assessment of risk occurrence probability .

- Step 3 : Risk Mitigation Action Plan

There are 2 types of actions :

- Preventive Action : raised in order to mitigate the occurrence probability by killing root causes.
- Corrective Action : raised in order to mitigate the consequences.

The Risk Mitigation Action Plan describes the actions and for each action, the name of the Actionnee, the foreseen date of action closure, the action status.

- Step 4 : Progress & Results Control

Each Risk is reported on a “Risk Sheet” which collects all necessary information. All Risk Sheets are collected together to form the “Risk Mitigation Plan” of the Project which is regularly reviewed and updated by the project team under the responsibility of the Project manager.

When all preventive actions have been closed, the residual (if any) associated risk is assessed and if judged acceptable, the Risk Sheet is closed, otherwise new mitigation actions are raised.

Lessons learnt implemented on Mars Express/Leostar 500-XO export program

From the experimentation of the above described methodologies, during the Leostar generic avionics development and validation program completed from 96 to 98, the following lessons have been learnt and have enabled

Astrium to tune these methodologies for the benefit of Mars Express and now the on-going Leostar 500-XO export program ; this experience will also be of prime importance for the new CNES programs : PLEIADES for Earth observation or MSRO for Mars exploration.

Avionics is generic, satellite configuration is subject to mission optimisation

The Leostar generic avionics development and validation program took place from 96 to 98 with the Leostar 500 platform as system definition. It has been a sound Astrium decision to focus the internal funding on the avionics only (ie not to develop the Structure, Propulsion, Solar Array, etc) in the absence of actual contract on the Leostar 500 configuration. As a matter of fact, the satellite configuration is always a subject of mission optimisation and the first Leostar contract is actually related to a new system configuration (Leostar 500-XO) which has been fully optimised for SSO earth observation missions. Although the resulting mechanical configuration is new, the development and validation activities achieved during the Leostar 96-98 program are fully re-usable and enable Astrium to cope with the challenging schedule requirement of satellite delivery to final Customer in 30 months.

Re-use Off the shelf units but review qualification status carefully

Re-using Off-the-shelf units is an efficient way to decrease the costs of a program. This approach has also been applied to Mars Express program with the re-use of many ROSETTA units and of the Globalstar solar array for example. Obviously, such approach implies to take as system constraint the existing recurring interfaces. However, reviewing the interfaces is a natural and necessary task for system design ; what is more complex, and some emphasis shall be put on this aspect when re-using equipment, is the review of the Qualification status w.r.t the mission needs. Some aspects as the mechanical environmental requirements (which can vary a lot from a launcher to another, and often not very mature at program kick-off) or EMC requirements have proved to be very difficult to handle within Leostar 96-98 program.

As a return of experience, for Mars Express and Leostar 500-XO programs, as part of the selection process of COTS supplier, a detailed compliance matrix to a project URD (Unit Requirement Document) is now requested. This URD addresses all non-functional requirements for the unit (ie design levels and margin, environmental conditions, test requirements). The objective is not to modify recurring units to make them compliant to this project URD, but rather to identify which requirements are not met at recurring unit levels so as to assess the corresponding risk for the project and decide if a modification is mandatory. As a matter of fact, the experience shows also that major problems with pseudo recurring units are often related to modifications imposed to the unit and which are not implemented with sufficient design rigour and assessment of resulting qualification status.

The return of experience has also led to introduce for recurring units on Mars Express and Leostar 500-XO programs, and very early after supplier kick-off, a dedicated formal review to address those specific subjects : the Equipment Suitability Review. As part of this ESR review, the documentation justifying the qualification shall be made available. So as to respect the low level documentation approach, recurring unit "generic" documentation is fully accepted (rather than program specific documentation).

Even for a recurring unit, a minimum of supplier follow-on is necessary, to be adapted depending on supplier maturity

Another return of experience from Leostar 96-98 program is related to supplier follow-on, in particular for recurring units. In general, space industry is not in the context of series production, though telecommunication constellation projects push towards this direction. As a result, the processes are not so frozen and documented so as to expect a recurring production to be an easy task. In addition, some problems as EEE parts obsolescence can add complexity. The result of experience is that sufficient procurement and PA resources shall be put in place even for a recurring unit.

Design modularity and incremental validation are success factors for on-schedule delivery

A key lesson learnt from Leostar 96-98 program is that the modularity given by the OBMU and the software has enabled partial hardware and software development releases and has lead to a large flexibility in the system development and validation process. This has enabled to optimise the scope of work w.r.t the available internal funding and to give priority to the critical technical issues.

The incremental process of validation has enabled to divide the system global complexity in few steps well defined with validation milestones indicating clear progress towards system validation.

The characterisation tests of units have shown to be particularly efficient as enabling to validate the supplier operation documentation or to debug, in advance to the system tests, the unit system interfaces, thus enabling to focus the attention on system levels during systems tests in case of problems.

The new methodology for software design and development has proved also to be very efficient and is now the Astrium baseline methodology for all new programs ; It has been implemented with the same success on Mars Express as well as the concept of avionics test bench which enables real time closed loop testing involving actual flight software and flight (or flight representative) hardware, well in advance to PFM testing during AIT.

Risk analysis is a key tool for team spirit development and anticipation

The Leostar 96-98 program was one of the first program to implement within Astrium the Risk Management methodology described above .

This experience was globally positive and has been implemented also on Mars Express as for more and more projects in Astrium. This kind of exercise takes all its interest when it is performed as a collective work in particular for the risk identification step. The internal communication associated to the exercise is an efficient “team spirit” development tool. A key lesson learnt is that some actions at no extra cost can be implemented early in the project development, which can save a lot afterwards when the risk occurs. This anticipation aspect is usually not properly covered if the risk analysis exercise is not formalised.

Conclusion

The Leostar 96-98 program dedicated to the generic development and validation of the Leostar core avionics has experienced new development and management methodologies belonging to the principles of Faster/Better/Cheaper. For Astrium, the key success factor of these programs shall be to decrease the system complexity and associated design effort ; in particular, the re-use of recurring units, with associated system adaptation, is a major way to shorten the development schedule and reduce the costs. However, the final validation is the key step which guarantee the mission success ; hence, even for missions with small budgets, the validation phase shall be as rigorous as known to be necessary for space systems. Moreover, re-using recurring units can lead to more system validation to be sure that the change of mission definition and context does not impact the final performance of the units at system level. For software development and validation as well as for system global validation, Astrium has gained a valuable experience from the Leostar 96-98 program. The lessons learnt through this program have been implemented on recent programs such as Mars Express and the on-going export program based on Leostar 500-XO bus. Such development methodologies and this Leostar heritage enable Astrium to commit on mission success within a delivery schedule of 30 months for a high performance earth observation satellite.