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"The DEMETER Program: A Pathfinder to a High Performance Micro Satellite Line"

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Abstract

The DEMETER satellite is scheduled for launch in early 2004, from Baikonour, aboard a Dnepr launcher.
Its main scientific objectives are the detection and characterization of ionospheric electrical and magnetic disturbances in connection with a telluric activity.
The DEMETER program is the first application of the MYRIADE program conducted by CNES, in partnership with the two leading European space companies ASTRIUM and ALCATEL SPACE.
The joint effort is directed to the definition of a product able to implement either scientific missions, demonstrators or operational applications in different areas: earth observation, astronomy, fundamental physics, or telecommunications, within limited financial budget. These various missions led to the design of a system with a very high level of performances in terms of power, AOCS, propulsion, data storage and transmission, robustness and availability as well as flexibility.
Capacity to implement technological innovations is also a cornerstone of MYRIADE endeavor.
Beyond DEMETER, 3 other missions representing 6 additional satellites are today fully funded and under development for launch in 2004 and further.
The paper will introduce DEMETER and the other different missions under development or analysis.
It will then focus on the description of the performances offered, which appear to be unique for this size of spacecraft, the design and the validation process. The organization set for the development will finally be presented as well as the progress status.

1. Introduction.

The DEMETER satellite will be launched in early 2004, from Baikonour. This satellite will be the first of the MYRIADE micro satellite family whose development was decided by CNES in 1998. At that time it was clearly identified that micro satellite had could offer sufficient performance in order to be an answer to the scientific request for faster and cheaper access to space. The choice was made to design a satellite with a high level of performances, superseding the performances strictly required by DEMETER, being stated that it would then be easier and more cost effective to degrade the scope of performances for missions with less demanding requirements rather than enhancing the design. A set of specification was then established taking into account the requirements of future missions. The design and performances of MYRIADE are presented in part 2 as well as the status of development. A system description is provided in part 3. From the beginning, CNES associated ALCATEL SPACE and ASTRIUM to the effort of development of MYRIADE, thus permitting to both companies to use the design for commercial applications. Those choices now appear to be adequate, and several on going programs take benefit from Myriad design with minimum modifications. These programs together with the required adaptations will be presented in part 4.

2. DEMETER Description.

2.1 The Demeter mission.

The main mission of DEMETER is scientific and dedicated to the detection of electro magnetic signals associated with telluric activity.

Various observations made at the ground level or from space have pointed out the existence of low intensity magnetic and electrical effects in connection with seism or volcanic activities. They reveal increases of the signals intensity during the final step of preparation of earthquakes, that is between a few tens of minutes and a few hours prior to the seism. These observations are yet too limited to permit to bring a clear evidence of a direct correlation between the observed signals and the seismic activity. Additional observations need to be performed and some statistics established. DEMETER is then entirely dedicated to these observations, through i) continuous data collection, ii) in the appropriate frequency ranges, and iii) in the different components of the electro magnetic field. The purpose of the measurement performed by DEMETER will then be to study systematically the emissions of electro magnetic waves observed during earthquakes and volcano eruptions, the disturbances of the ionosphere and high atmosphere, as well as the precipitations of associated particles.

Table 1 gives the Measured Parameters:

▪ Frequency range, B	10 Hz - 18 kHz
▪ Frequency range, E	DC - 4 MHz
▪ Sensibility B :	$2\ 10^{-5}$ nT $Hz^{-1/2}$ at 1 kHz
▪ Sensibility E :	0.2 µV $Hz^{-1/2}$ at 500 kHz
▪ Particles: Electrons :	30 keV - 10 MeV
▪ Ionic density:	$5\ 10^{2}$ - $5\ 10^{6}$ ions/cm^{3}
▪ Ionic temperature:	1000 K - 5000 K
▪ Ionic composition:	H^{+}, He^{+}, O^{+}, NO^{+}
▪ Electron density:	10^{2} - $5\ 10^{6}$ cm-3
▪ Electron temperature:	500 K - 3000 K

Table 1 : DEMETER Measured Parameters.

The secondary mission of DEMETER is technological. The purpose is to perform in flight validation of i) an advanced system of payload telemetry incorporating a solid state mass memory of 8 Gbits and an X band transmitter at 16,8 Mbits/s, ii) a system of autonomous orbit control relying on a GPS receiver and a navigator, iii) pyro device firing by laser, and thermal protections performance.

Finally, DEMETER being the first of the MYRIADE micro satellite it will permit the in-flight validation of the concept and the verification of the expected performances.

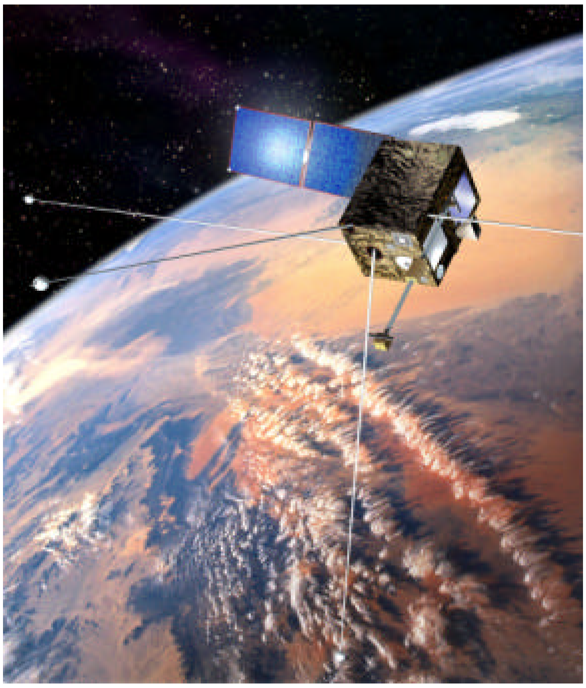

Fig.2: Demeter in flight

2.2 DEMETER satellite description.

2.2.1 Plat form general performances.

Orbit	• 700 km, SSO
Pointing	• Earth
Stabilisation	• 3 axis. • Typical accuracy: coarse mode < 5° Fine mode < 0,1 °. • Stability: < 3'/s.
Telemetry Telecommand	• CCSDS, convolutionnal & R- S coding. • S -Band Transmission. • Useful TM rate: 400 kbits/s. • Useful TC rate : 20 kbit/s.
Localisation	• Doppler measurement • Accuracy: 1 km (LEO), 10 km (GTO).
Date	• Ground synchronization. • On board accuracy :< 1 s.
Power	• Steerable sun generator • AsGa solar cells(200 W EOL) • Li Ion battery: 14 Ah • Payload: around 70 W permanent .
Weight *Propulsion*	• Total: 135 kg. • Payload weight: 50 kg. • *Hydrazine* • *4 thrusters 1 N* • *Dv : 100 m/s*
High rate TM	• *X-Band emitter 16,8 Mbits/s* • *Memory : 8 Gbits (Flash)*
GPS	• *Topstar 3000*

Table 3: DEMETER performances

2.2.2 Payload description.

The DEMETER scientific payload is constituted by a 3 axis magnetic search coil instrument (IMSC), 4 electrical sensors (ICE), a langmuir probe (ISL), a plasma analyzer (IAP), a particles detector (IDP) and an electronic unit (BANT).
The IMSC captor is set at the end of a 2 m long deployable boom, while the ICE captors are set at the extremity of 8 m long expendable booms.
For this mission, the system is supplemented by a high data rate telemetry chain with an on board 8Gbits memory (using 128Mbits flash EEPROM chips), a X band transmitter and a X band ground station needed by the high volume of scientific data produced during the payload burst measurement mode.
DEMETER includes also some technological experiments as on board autonomous orbit control system, pyrotechnic priming by a laser system, thermal materials ageing monitoring (THERME) and a technological solar cell string (ASPI experiment).

2.2.3 Functional chains description

2.2.3.1 Structural and thermal architecture.

MYRIADE was initially designed to be compatible with a launch on the auxiliary structure ASAP on board Ariane V, which implies maximum dimensions of 60x60x80 cm and a maximum mass of 120 kg. After decision of launching DEMETER with DNEPR, those constraints were relaxed and overall dimensions are 60x85x110, with a mass of 135 kg.

The structure is based on a massive rigid low plate made of alloy, which provides the interface with the launcher and supports the propulsion system. This plate provides the vertical stiffness required by the launcher. The structure is completed by four vertical struts at each angle of the satellite and by four lateral panels made of alloy honeycomb, which concur to the lateral stiffness. These panels receive the plat form equipment. They are opened for integration. This architecture was chosen for its ability to maximise the use of the authorised volume and also because it lets the room for the central hydrazine tank

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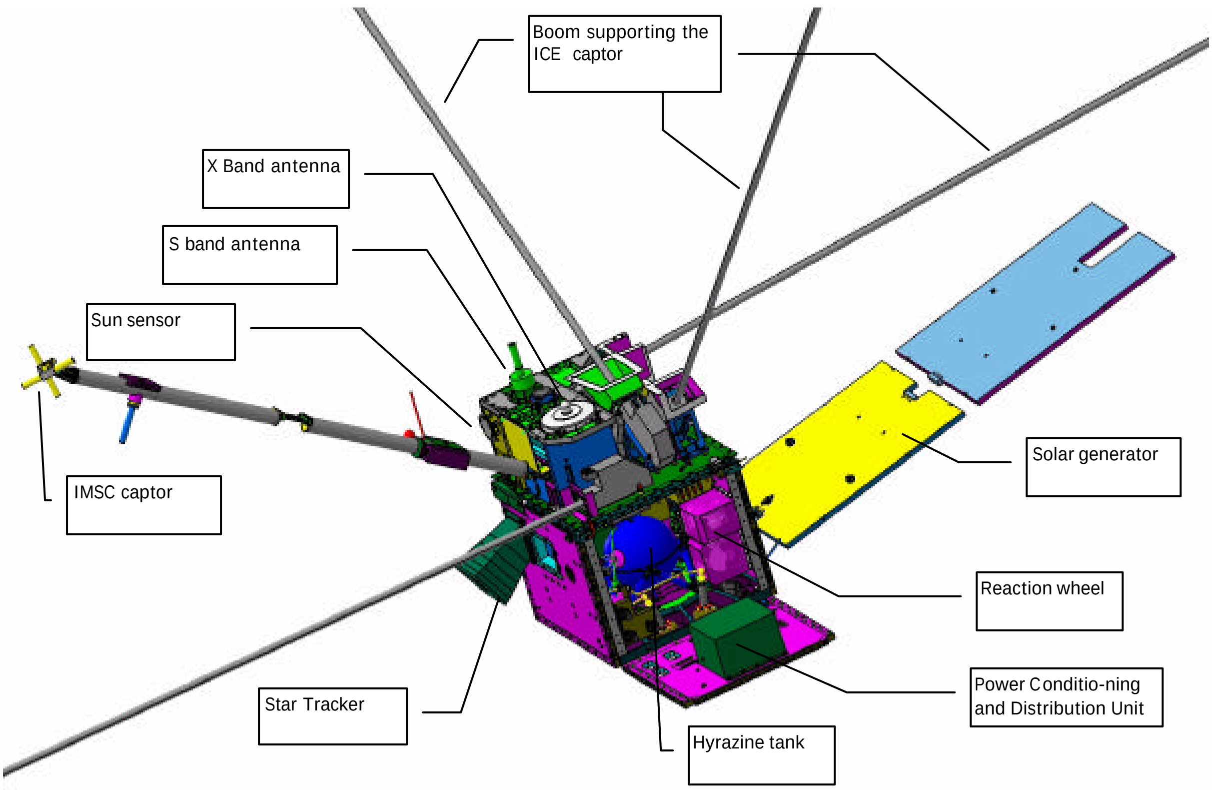


Fig. 4: DEMETER View

For launch, the 2 solar array panels are folded and stowed on the -Y face, opposite to battery and stellar sensor +Y face.
The payload is independent and supported by an upper plate, also made of ally honeycomb.
The general design concept allows to systematically have a satellite face in the shadow. This face supports low temperature equipment (battery, IDP sensor) and the star sensor which requires not only low temperature but also a field of view without any sun parasitic illumination.
The thermal architecture is partly passive, relying on use of painting, MLI and SSM and partly active.

2.2.3.2 *Propulsion module.*

The propulsion module is a blow down system using hydrazine.
It carries 4,5 kg of hydrazine, which corresponds to speed increment Δv = 100 m/s for a launch mass of 100 kg. (mean Isp = 210 s)
It uses 4 thrusters with a 1N thrust each.
Figure x below displays a functional sketch of the system.
It was designed as a modular system, which can be carried as an option on a given satellite.

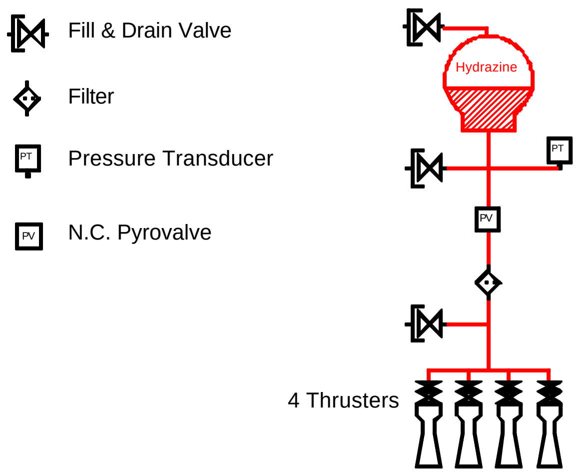


Fig.5: Propulsion sketch

2.2.3.3 *AOCS architecture*

AOCS overview

In order to accommodate the large range of possible pointing requirements, the architecture selected is based on a 3-axes stabilisation.
Although DEMETER requires only nadir pointing, the AOCS was designed in order to be able to cope with inertial or sun pointing.

Control is then achieved by reaction wheels, which are unloaded by magneto torquers.
For the attitude measurement, a trade-off led to select a measurement based on the star tracker: earth sensor is not compatible with all the foreseen orientation; GPS attitude is not accurate enough. Considering that the star tracker could give continuous accurate measurement, the attitude is not filtered by gyros measurement in operational mode.
Hydrazine thrusters perform orbit manoeuvres. Any loss of attitude measurement must be avoided during either the slew manoeuvres or the thrust phase. As a consequence, in this mode, attitude will be derived from the integration of gyro.
For the safehold and acquisition mode, the main requirements were to use, as far as possible, equipment, which was not used in other modes, and to be autonomous from the ground. Magnetic measurement, associated to a wide field of view solar measurement, was selected to fulfil these requirements.

AOCS modes description

The DEMETER AOCS consists in 4 modes:
- acquisition and safehold mode MAS
- coarse transition mode MGT
- normal mode MNO
- orbit control mode MCO

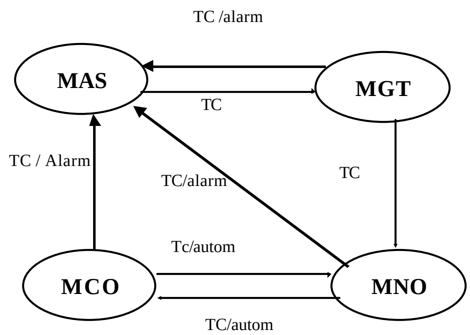


Figure 6: Demeter AOCS modes and transitions

Table 7 below gives the list of equipment used in each mode.
The sensors can be divided into two categories:
- low accuracy sensors : 3 axes magnetometer (MAG) and 3 wide range sun sensors (SAS) allowing a 4π steradians field of view (coarse sensors used in the acquisition mode or the coarse pointing mode). Medium range gyro FOG (GYR) are used to steer and control the thrust, as their accuracy is compatible with the relatively relaxed performances. The MCO mode duration is

then limited and correlated with the gyro drift.

- high accuracy sensor : autonomous 3 axes star sensor (SST) delivering attitude measurement with a high availability

The actuators can be divided into

- 4 reaction wheels (RWS), used as well as kinetic wheels (two on the same axis to increase the kinetic momentum) in coarse pointing mode or used as reaction wheels in fine pointing mode
- 3 magnetotorquer bars (MTB): they are the main actuator in coarse pointing mode and they are used to unload the wheels in the other modes,
- 4x1N thrusters (THR) used for attitude control during the thrust phase,

	Number	MAS	MGT	MNO	MCO
MAG	1 *	X	X		
SAS	3	X			
SST	1		X *(4)*	X	
GYR	3 * *(1axis)*				X
RWS	4	X *(1)*	X *(2)*	X *(3)*	X *(3)*
MTB	3	X	X	X	X
THR	4				X

Table 7: Use of equipment

Acquisition and safehold mode (MAS).

The Acquisition and safehold mode is used after separation from the launcher and later in case of anomaly detection.

It consists in an orientation of the satellite in the direction of the sun, with a slow rotation around the X-axis for thermal reasons.

It is based on :

- the angular rate estimation based on MAG measurements and on the sun direction when available
- the estimation of the sun direction and the detection of eclipse, whatever the spacecraft attitude is, using three two axes wide field of view sun sensors.
- A Gyroscopic stiffness around X-axis provided by the X-axis wheel in order to insure dynamic stability despite disturbing torque especially in eclipse
- MTB (magnetotorquer bars) used to control the direction of X-axis with respect to the Sun. The magnetic momentum order is defined thanks to the magnetic field direction provided by the magnetometer.

Coarse pointing mode (MGT)

MGT is a transition mode from acquisition to normal mode.

Its objectives are:

- to reach an attitude close to the nominal one in order to enable the acquisition of stars in the star sensor's field of view. This is a recovery condition to switch-over to normal mode
- to cope with power supply and thermal subsystems constraints,
- to insure pointing performances compatible with MNO capacities.

The control during this mode does not need any attitude measurement (the star tracker data are not used) but the satellite pointing requires knowing the orbit position. The attitude control is based on:

- a kinetic momentum provided by two reaction wheels which remains aligned with the normal to the orbit
- a "compass law" based on the on board knowledge of the earth magnetic field $\underline{b}_0$ and on the magnetometer measurement $\underline{b}$. The compass law is composed of:
    - a magnetic stiffness created by magnetic momentum
    - a damping of the oscillations.

Nota: This mode can be sufficient for missions which do not require a high pointing performances (see § 6.1.1).

Normal Mode (MNO)

The Normal mode is the mode in which the scientific mission will be carried out. The satellite is 3-axes stabilized by three reaction wheels (one of the 2 Y-axis wheel is switched off). Attitude is just given by the star sensor, which imposes some strategy to cope with possible dropouts of measurement. The guidance profile is given like in the MGT mode by sending commands either as harmonical series or as polynomial functions. During the normal mode, the kinetic momentum of the wheels is controlled by the magneto-torquers.

The control laws have been designed using robust control methods in order to take into account flexible modes induced in particular by the 4-meter booms.

Orbit control mode (MCO)

This mode is dedicated to perform the orbit manoeuvres. During the thrust, the attitude control is performed using the 4 specifically tilted thrusters, in off-modulation, to create torque around the 3 axes. Attitude is just provided by integration of the gyro.

The thrust manoeuvres are preceded by an attitude manoeuvre in order to steer the thrusters along the direction of the thrust. The attitude manoeuvres are performed using the reaction wheels as actuators and the gyros for attitude measurement.

AOCS performances

MAS mode

Main performances of the MAS mode are
- time durations of the convergence towards the sun (with an accuracy better than 30°) either in first acquisition or in safe configuration, are compatible with the thermal and power supply requirements,
- only one wheel used in common with the other modes.

MGT mode

The difficulty in the tuning of this mode is due to the large inertia with respect to the low wheel momentum capacity which leads to a coarse pointing accuracy of 17° around X, Z axes and less than 8° around Y-axis. These performances fit nevertheless the requirements for the star acquisition and for the transition to MNO.

MNO mode

The MNO is robust to uncertainties on flexible modes, or to drop outs of SST measurement.

Typical performances are described in the table 7

		X	Y	Z
Pointing accuracy	Without bias	0.02	0.025	0.02
	Bias including guidance	0,013	0.08	0.012
Pointing stability over 1sec (*)		0.0009	0.0016	0.0002
Attitude restitution (*)		0,008	0.033	0.007

Table 8: MNO pointing performance (deg.)

(*): no SADM rotation and no MTB actuation

2.2.3.4 *Power architecture.*

The solar generator (SG) is made of two foldable panels.

Each panel is covered by 7 strings of 18 cells each. The cells, provided by Spectrolab (US) are triple junction AsGa, with an efficiency of 26%. The total delivered power reaches 200 W

The SG is steered by a µ step Drive mechanism, with a resolution of 1/64°.

The battery has a capacity of 15 Ah. It is formed by 10x8 Li Ion elements (selected commercial SONY elements)

Regulation and distribution of the power is controlled by the PCDU (Power Control and Distribution Unit) whose other functions are the following:
- Automatically switch on the satellite after separation (the satellite is off during launch),
- DC/DC conversion and regulation (for equipment requeting regulated voltage)
- Distribution of power (regulated or not regulated) up to 44 lines. Each line is controlled by way of LCL (Latchable Current Limiter) and can deliver nominally 0,6 A. The PCDU can then be configured by merging together several lines when power greater than 0,6 A is required.
- The PCDU directs controls the MTB, the thrusters, and pyro devices.

2.2.3.5 *Data handling architecture.*

The Data handling architecture is based on a central computer (OBC).

This computer is the result of an in-house development effort

Emphasis was put to develop a product with low power, use of commercial parts for low cost, radiation tolerance, and flexibility.

The result is a highly integrated product with the following features:
- Processor: transputer T805 @ 20 MHz, with four high speed data exchange links @ 5 Mbits/s, and a processing capacity of 2 Mips
- Radiation hardened: 15 krad , SEL and SEU immune,
- TM and TC coding and decoding according to CCSDS
- 1 Gbits RAM protected by EDAC
- Input and output: configurable by micro software and addition of boards. A standard configuration includes 10 serial link RS422/ RS485, acquisition of 16 analog input 12-bit coded, control signals.

Power consumption is limited to 6 W maximum, and mass to 3 kg

The standard bus used on the plat-form is a serial asynchronous link. The OBC can be configures to accept other protocols, depending on each equipment specific interface.

2.2.3.6 Telecommunication architecture.

Telecommunications use S band transmission.
Two omni directional and wide band antenna are set one on the face directed towards the earth, the other on the opposite face. Each antenna permits both emission of TM and reception of TC
The receivers and transmitters are redounded.
The receivers are in hot redundancy, the OBC being locked on the first equipment from which a signal is received.
The receivers are in cold redundancy.
2 diplexers and a coupler complete the system.

S band	
TM Modulation and coding	QPSK (1/2 Nyquist filter) Viterbi RS concatenated coding
TM Modulation and coding	QPSK (1/2 Nyquist filter) Viterbi
Maximum telemetry rate Safe mode Nominal mode	 25 kbits/s 400 kbits/s
Telecommand rate	20 kbits/s

Table 9: S-Band characteristics

2.2.3.7 Equipment characteristics

Equipment	Mass/Power	Performance	Supplier
Magnetometer	.18 kg/ .8 W		TAMAM
Magneto torquer	.25 kg/ .8 W	12 Am²	TAMAM
Gyrometer	.15 kg/ 2 W	Drift < 6°/h	LITEF
Sun Sensor	.07kg		ASTRIUM
Star Sensor	1,4 kg/ 7 W	Autonomous Accurracy < 12 arcsec	DTU
Reaction wheel	.7 kg/ 4 W	5 mNm 0,12 Nms	TELDIX
Battery	4,2 kg	13.5 Ah	AEA
PCDU	4,5 kg		ETCA
Solar Generator	7 kg*	200 W	ALCATEL SPACE
SADM	1.5 kg/5 W	µstep: 1/64°	SNECMA
Tank	1.2 kg	4,5 l	RAFAEL
Propulsion	5.5 kg	100 m/s	SNECMA
OBC	3 kg/ 6 W	1 Gbits CPU: T805 2 Mips	STEEL
S band receiver	.45 kg/ 1.5 W	25 kb/s	THALES
S band transmitter	.45 kg/ 8 W	400 kb/s.	THALES
X band transmitter	1.5 kg/30 W	16.8 Mbits/s	ALCATEL SPACE
GPS	1.6 kg/ 8W		ALCATEL SPACE
Payload computer solid state memory	4.2 kg/ 5 W	8 Gbits**	STEEL

*: Mass specific to DEMETER configuration.
**: expendable to 16 Gbits

2.2.4 Accomodation of MYRIADE to DEMETER.

The high level of electro magnetic sensibility required by the payload brought specific constraints on DEMETER:

- Captors mounted at end of boom, bringing high inertia and low natural modes of the satellite: AOCS laws had to be optimized,
- Equipotentality of the surface of the satellite: MLI are covered with specific conductive black painting, Solar generator is protected by ITO (Indium Tin Oxyde), coverglasses are interconnected, any current loop is compensated in order to reduce any generation of magnetic field
- Magnetic shielding of equipment. The reaction wheels are placed in double shells made of µ metal. The electronic box of the star tracker was wrapped in a single sheet of µ metal. Finally local shielding of the OBC was developped.

- Magneto-torquers activation limited to orbital period free from scientific measurements (terrestrial high latitudes > 60° and <-60°)
- Specific control and filtering of the Solar generator current, by the software.

2.2.5 DEMETER progress status.

DEMETER satellite is presently in integration at LATÉCOÈRE premises in Toulouse.
Integration of the payload on the platform was completed in April, 2003. The first system tests have also demonstrated the compatibility between the ground and the space segments.
Environmental testing will take place in automn.
The spacecraft will then be shipped to Baikonour for a launch on DNEPR schedule for March, 30th.
Validation of the software is in progress using the System Validation bench.
Development of the ground segment is completed.
Qualification of the operations will be conducted from August to end of 2003.

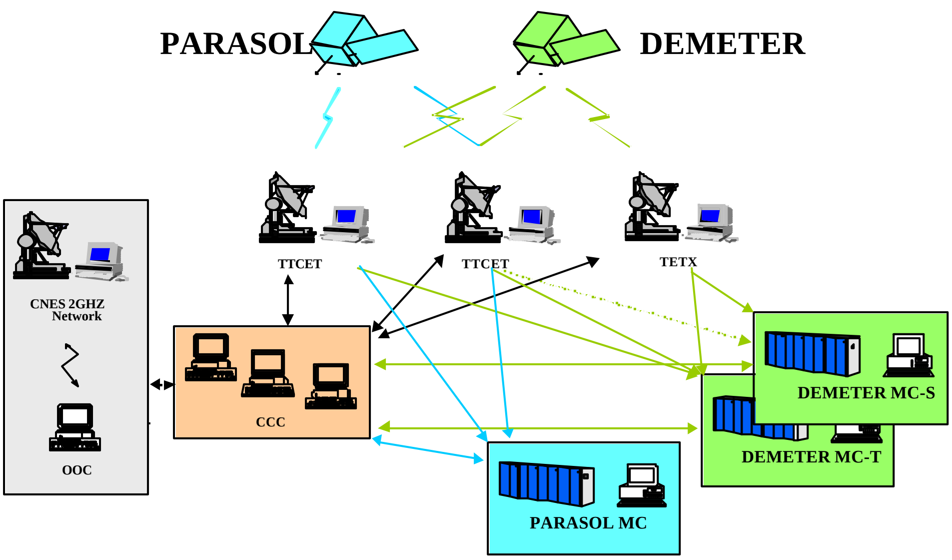
3. Ground segment

3.1 Constitution

A MYRIAD ground system for multi-mission control (MIGS) was developped, based on the heritage of the PROTEUS Generic Ground System.
It is composed of:

- A command control ground segment with:
  - a Command Control Center (CCC),
  - some Data Remote Processing PC,
  - one Telemetry and TeleCommand Earth Terminals (TTCET)
  - a Data Communication Network (DCN)
- An X band Telemetry Earth Terminal (TETX)
- Two Mission Centers (MC), one for the scientific part of the mission (MC-S) and the other for the technological one (MC-T). These CM are specific to each mission.

In addition this system has the capability to use CNES multi-mission resources (the CNES S band stations network and the Orbitography Operational Center). These resources can be used for the first station acquisition and in case of anomaly.



.Figure10: MYRIADE Multi mission Ground Segment

This system has the additional capability to use CNES multi-mission resources (CNES S-band stations network and the Orbitography Operational Center). These resources can be used for orbital station acquisition and in case of anomaly.

3.2 Command and Control Ground Segment (MIGS).

The CCC (Command Control Center) is in charge of:

- Preparing the programming messages taking into account the payload part which is built in the Mission Centers,
- Preparing and monitoring the communication with the satellite using a TTCET,
- Reconciling the TM for a quick look and for alarm generation,
- Evaluating the functioning of the spacecraft bus,
- Orbit and attitude monitoring.

The CCC performs the orbit restitution using Doppler measurements acquired by the TTCET. The Data Remote Processing PC (DRPPC) is a PC which can be used in the CCC or outside, in order to process real time housekeeping telemetry, or to work with the archive data that are stored in the CCC databases.

From an labour point of view, the ground operators work only during administrative hours. This requires:

- The capability of performing automatic loading of programming messages in the absence of any operator, using an agenda function,
- An automatic anomaly detection.

The TTCET are automatic S-Band stations, in charge of:

- Establishing and maintaining the satellite to ground radio-frequency link for all programmed visibility passes (transits),
- Receiving and temporarily storing the received telemetry during a transit. This function concerns the House Keeping Telemetry to be Recorded, but also a part of the Payload Telemetry,
- Receiving and transmitting to CCC the Passage House Keeping Telemetry during a transit,
- Accepting the connection with CCC or a Mission Center for transmission of payload data and a part of the received spacecraft bus data,
- Transmission of command to the satellite for the transit in progress,
- Doing Doppler measurements during the transit, for orbit calculation and antenna positioning,
- Compensating Doppler effect on Command link,
- Contributing to the on board with UTC time synchronization.

The TTCET is equipped with a 3.1 meters diameter antenna.

The last component of the MIGS is the Data Communication Network (DCN). Its main characteristics are:

- The interfaces of the MIGS are based on Internet Protocol (IP), for real time transfer via service sockets, or file transfer using ftp

The MIGS subsystems are connected to the IP network by standard routers.

3.3 Ground Satellite Interface

The communication between the ground segment and the satellite is performed through two links: the S band, and the X band. The S band link is fully compliant to the CCSDS standard, whereas the X band link complies with this standard at the packet level.

The X band is devoted to scientific telemetry, whereas the S band is used for housekeeping and technological telemetry or to scientific missions with limited data transmission needs (up to 600 Mbytes/day). All the TC are transmitted through the S band, using a protocol which guarantees automatic re-transmission of TC frames detected as erroneous or lost by the board peer.

For the S band, the specified performance objectives must be guaranteed for a minimum elevation of 10deg with a system margin of 3 dB for TM and 10 dB for TC.

For the X band, the specified performance objectives must be guaranteed for a minimum elevation of 15deg with the X-band ground station. The maximum data coded rate is 18 Mb/s. The modulation and coding used is a Multidimensional Trellis Coded Modulation Concatenated with Reed-Solomon bloc code (MCTMCRS).

3.4 *The SCAO and System Validation Bench.*

The SSVB is designed in order to simulate the performance of the satellite. It includes a breadboard of the On Board Computer and the In flight Software. The star tracker can be either simulated or an actual Star tracker can be included in the loop and optically stimulated by a screen displaying sky views, updated in function of the attitude and dynamics of the satellite. All the other aspects are numerically simulated. Data exchanges with the payload are also simulated. The SSVB integrates a simulation of the flight environment, simulations of the different on-board functional chains and equipment and of the behavior (dynamics, ..) of the satellite. A gateway with the tools used for the design of the AOCS is made available in order to share the results.

The SSVB is used :

- For the qualification of the spacecraft: validation of the performance of the functional chains, in particular the AOCS, validation of the on-board software,
- For the validation of ground/satellite command/control interface,
- For the preparation of the operations: validation of the procedures and operators training,
- During flight for the investigation in case of anomaly.

It is configurable in order to be easily adapted to new missions.

4. Launch Means

DEMETER was initially designed to be compatible with a launch on Ariane V ASAP.

With the lack of launch opportunity in the period of end2003/beginning of 2004, it was decided to turn to another launch. DNEPR then appeared as the best choice. In addition, this choice permitted to relax the constraints on volume and mass of the satellite.

The basic design, as well as the mechanical qualification remains compatible with ASAP, as well as other launchers such as PSLV (ANTRIX). Other launchers such as ROKOT (EUROKOT) or SOYOUZ (STARSEM) could also be considered if some launch opportunity appears.

ASAP 5 can accommodate up to eight auxiliary passengers.

PSLV has the capacity to launch up to two micro-satellites in addition to the main passenger.

DNEPR, in its basic configuration, has a capability to launch typically four to five micro-satellites together.

ROKOT has recently entered the commercial trade for up to six auxiliary payloads.

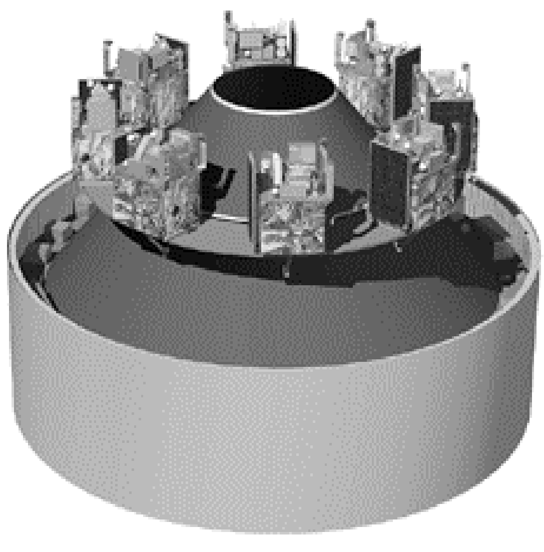


Figure 10: ARIANE 5 ASAP configuration.

Some obvious differences can be noticed in the mechanical interfaces and umbilical links capabilities from one launcher to another. We have however found that adaptation to any of those can quite easily be done. As the other launchers requirements are similar to the requirements for an ASAP 5 micro-satellite launch but with lower environmental loads (e.g. shock and random), dimensioning was therefore done on the basis of ARIANE 5 requirements.

5. Industrial organization.

CNES is prime contractor for the MYRIAD line of product development:
Engineering of the MYRIAD System is performed and led by CNES with some links with the PROTEUS product line development.
Depending on the scientific mission CNES may also performs engineering and AIT of the payload. Otherwise this is a task for the Laboratory.
Spacecraft engineering is also performed by CNES which specifies, contracts for and oversees the R$D effort. This engineering is done in partnership with ASTRIUM and ALCATEL

ASTRIUM is involved in:

- Software specification and validation,
- System test bench development,
- Some of the AOCS modes studies and development.

ALCATEL SPACE is involved in:

- PCDU (Power Conditioning and Distribution Unit) development
- Solar Array development.
- System test bench .

Under the terms of this partnership, ASTRIUM an ALCATEL SPACE are then authorised to use MYRIADE design and products for their proper applications.

LATECOERE was contracted for spacecraft integration and testing. This company shall eventually be responsible for the satellite adaptation and therefore it shall tailor the original definition of the functional chains to the specifics of each new mission.

CNES is responsible for the operations during launch, orbit positioning , satellite monitoring and control and data collection.

6. Other applications of MYRIADE.

6.1 Missions under development

6.1.1 The ESSAIM constellation.

Fig. 11: The ESSAIM constellation.

6.1.1.1 Presentation.

MYRIADE product line has been developed with a particular attention to flexibility. As presented in the previous part, the CNES mission applications are essentially targeting scientific applications such as DEMETER.
However, MYRIADE application can cover a wider variety of missions, from technological experiments to earth observation missions and, why not, telecommunication applications, using the formation flying principle. Thus, the product line is a valid candidate for commercial or military missions.
Indeed, concurrently with DEMETER, scientific-aimed application, Astrium has been awarded a contract, by the French Defence Agency (DGA), in early 2000, for an Earth Observation Microsatellite program.
This Microsatellite development was conducted as close as possible to DEMETER development. It took into account the specific needs due to this non-scientific mission.
As for the mission requirements, this mission is less demanding in terms of pointing performances than DEMETER: the constraints are relaxed to a few degrees, compared to one tenth of a degree for DEMETER. This less demanding performance has been exploited to reduce the microsatellite set of modes and equipment, as far as allowed by the mission feasibility.

This resulted in a cost reduction, particularly efficient in case of a constellation.

6.1.1.2 *Adaptation of MYRIADE design.*

Thanks to the low pointing performance requirement, MYRIADE generic concept was simplified:

- the SADM (Solar Array Drive Mechanism) was suppressed, leaving a fixed solar array: the power loss is partly compensated by mean of satellite tilts, around North and South Earth poles. They induce a gain of solar illumination ,
- the MNO, was removed from the conceptual design, the normal operational mode becoming MGT, which is compatible with the pointing performances demanded.

These modifications permitted to suppress the star sensor (SST), only used for MNO measurements purposes and the X-axis and Z-axis reaction wheels. The two remaining Y-axis wheels were tilted around the Z-axis (by 20 °, symmetrically about Y-axis), to permit either X or Y kinetic momentum generation.

Except for the suppression of these equipment the structural architecture is not changed. The on board software needed to be adapted to the dynamics of the satellite, and a specific algorithm implemented for controlling the maneuver of the satellite for sun pointing in the regions of North and South pole.

6.1.1.3 *Status.*

The ESSAIM micro satellites are actually in integration at ASTRIUM premises. Launch is scheduled for late 2004, aboard ARIANE V ASAP.

This application demonstrated the ability of the MYRIAD concept to be customised to a different application with minimum modifications, while being fully compliant with the mission requirements. It also demonstrated the efficiency of the partnership between CNES and the companies and the ability to transfer the control of the design.

6.1.2 Parasol application.

Fig. 12: The PARASOL microsatellite

6.1.2.1 *Presentation.*

PARASOL is the second micro satellite developed by CNES in the frame of MYRIAD.

It will be part of a swarm (the AQUA train) also composed by AQUA, OCO, CENA, AURA and CLOUDSAT with a launch scheduled at the end of 2004.

PARASOL addresses climatology and in particular the influence of aerosols and clouds on the evolution of climate. The scientific mission is to improve the knowledge of the cloud and aerosol properties and to assess the aerosol effects and the cloud and radiative budget interaction (contribution to the global warming)

IT will carry an instrument derived from POLDER, instrument already flown aboard the Japanese ADEOS-I and ADEOS-II satellites.

6.1.2.2 *Adaptation of MYRIADE design.*

Adaptation of the MYRIADE design to Parasol was really minimal.

The modifications concern:

- The cant angle of the solar generator : the cant angle of 17° used on DEMETER generates pointing disturbances not compliant with the high pointing requirements of the mission, while the SG is in rotation. It was then decided to set the cant angle to 0. The reduction of available power is compliant with the mission.
- The power distribution is adapted to the payload interfaces.

The payload mass memory capacity is carried to 16 Gbits.

A yaw steering capacity will be implanted in order to compensate for the earth rotation when the payload is taking images.

6.1.2.3 Status.

Integration of PARASOL was initiated in June, 2003.
Launch is scheduled for late 2004, aboard ARIANE V ASAP (together with ESSAIM).

6.1.3 µ-Scope application.

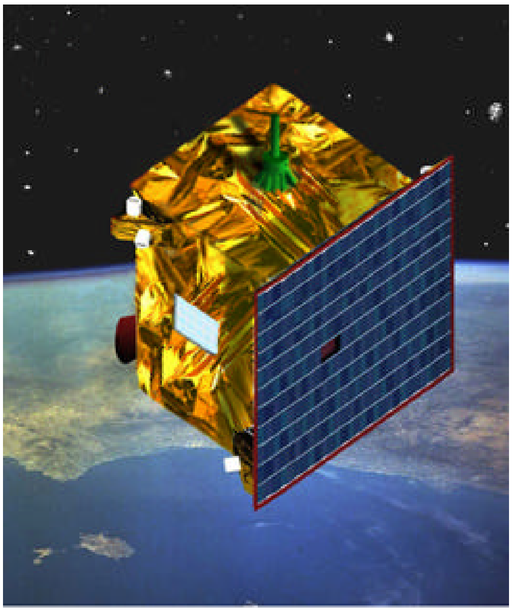


Fig. 13: The µ SCOPE microsatellite

6.1.3.1 Presentation.

µ-SCOPE is dedicated to the demonstration of the Equivalence principle. This principle states that the gravitational mass and the inertial masses should be equal.
The payload will be based on 2 electro static accelerometers developed by ONERA. The satellite will be spinning at a rate of two time the orbital rotation.
The satellite will be drag free. It will be controlled so that to cancel the acceleration on one of the accelerometers. Detection of an acceleration on the second accelerometer, using a proof mass with a different density, will bring evidence of a violation of the equivalence principle.
The drag free will be controlled by FEEP electrical thrusters.

6.1.3.2 Adaptation of MYRIADE design.

Accommodation of µSCOPE requires a high effort of modification of the MYRIADE design.
Power, data handling and telecommunication functional chains should not be too much affected while mechanical, thermal and AOCS architecture as well as software will be deeply reworked.

6.1.3.3 Status.

The program is in phase A.
Launch is scheduled in 2007.

6.1.4 Future missions.

Other missions are presently contemplated, either under CNES responsibility or under contracts with Astrium and Alcatel Space.

Utilization of GTO orbit.

Use of GTO, although one time considered during the project was given up, due to the lack of missions requiring this orbit. With the identification of possible candidate missions on this orbit adaptability of the Myriade concept to GTO will be analyzed.

Earth observations

Utilization of Myriade for the realization of high resolution earth observation satellite is also considered. The on-going feasibility analysis tend to demonstrate that such a mission can be achieved with acceptable performances.

Scientific missions.

Different scientific missions are today considered and could be decided after 2005. Among these are

- PICARD: This mission is dedicated to sun observation and to simultaneous measurements of solar diameter/ differential rotation, solar constant, and variability. It should contribute to the understandibng of the factors of the global warm up.
- TARANIS. This mission is dedicated to the analysis of storms and lightning .
- T2L2: this mission is dedicated to precise synchronization of clocks between ground and space.
- AMPERE. This mission is dedicated to the analysis of the magnetosphere.
- RHEA. This mission is dedicated to biosphere and crops survey.

7. Conclusions.

The field of past, existing or planned micro-satellite through the world is quite diverse in their characteristics: some spacecraft are simplified to the extreme and others are ambitiously sophisticated.
CNES has taken into account the wishes which were expressed by the French Scientific Community to come to a specification set for the micro-satellite MYRIADE leaning on the upper end of the scale.
DEMETER is the first item of the MYRIADE family to be developed and launched.
Its accomplishment is the demonstration that the high level of technical performances set as an objective could be reached.
The resulting product of the MYRIAD program appears very capable, versatile and efficient. In every aspect that has been surveyed so far, the demand of the end-user is satisfied.

In contribution to this result, an industrial organization has been settled and both industrial Spacecraft Primes -ASTRIUM and ALCATEL SPACE- have been associated to the development through engineering partnerships which allow them to use the design for their own applications.

Other missions such as PARASOL and ESSAIM are being implemented concurrently and they demonstrate that the versatility specified for MYRIADE has also become a reality which permits a shorter and cheaper development. Present status of PARASOL permits to verify that a CNES mission can be completely realized in the cost target of 16 M€ .

Additional missions are being proposed, using Myriad; confirming the interest of the space community for this product.

The next expected step is the launch, the commissioning and the operations a decisive key for the success of MYRIADE.

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