Small Satellite Missions for Earth Observation

New Developments and Trends

Bearbeitet von
Rainer Sandau, Hans-Peter Roeser, Arnoldo Valenzuela

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Overview on CNES Micro Satellites Missions: In Flight, Under Development and Next

Philippe Landiech and Paul Rodrigues

Abstract This chapter gives a programmatic and technical overview of the MYRIADE micro satellites line of product MYRIADE developed by CNES. The characteristics and mission topics of satellites under CNES responsibility are presented, for in flight, and under development systems. The main drivers of the roadmap for next years are addressed as a Conclusion.

1 Introduction

CNES initiatives. in micro and mini satellites since 1996 have allowed to build, through MYRIADE and PROTEUS, operational two lines of product allowing scientific and operational missions in low earth orbit, for payloads ranging from 50 to 350 kg. From the beginning, these lines of products have been devised so as to offer efficient access to space in terms of schedule and costs. Although significant differences in terms of satellites requirements have appeared along the missions, the benefits of the line of products approach has been constantly highlighted in the 2 mini and micro cases, thanks to a well mastered technical definition and validated associated means. Platform high maturity allows in both cases to start satellite activities at the latest, while schedule is driven by the payload development itself, relying on well known interfaces. In parallel to platforms development, a common ground segment has been settled, which minimizes adaptation effort from a mission to the next one and allows to standardize operations. This chapter focuses on MYRIADE product line.

An overview on missions already in flight will be given, with associated lessons learnt: DEMETER, PARASOL.

Benefit of the approach for missions currently under development will also be highlighted: PICARD, TARANIS, MICROSCOPE.

P. Landiech (✉)
CNES, Toulouse, France
e-mail: philippe.landiech@cnes.fr

This chapter is also written by all CNES mini and micro satellites teams

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2 MYRIADE Genesis

MYRIADE initiative started with the Arcachon scientific seminar held in 1998. It allowed to define a consistent panel of mission objectives, and permitted to offer to scientists the basis of a versatile tool for testing small payload instruments in the range 60 kg–60 W, for low duration missions (typically 2 years), with short development schedule and reduced costs.

The Arcachon scientific seminar held in 1998 allowed to define a panel of missions in this range, which allowed to refine major specifications. DEMETER and PARASOL, the first 2 MYRIADE launched were among them.

Development started in 1999. In an alternate way to PROTEUS, an internal CNES development was followed, with limited engineering support from industry.

Another difference is the search for very low cost equipment units, which lead to select a majority of commercial components which offer lower prices but also allow to take advantage of more integrated functionalities. These components however sustained a ground qualification to space environment radiations.

The OBC (On Board Computer) developed in house, has limited redundancies restricted to critical functions such as TMTC. As it is not fully immune to SEU nor SEL, a specific FDIR function, which combines hardware watchdogs and software functions has been developed to overcome SEL, SEU, corrupted data, interrupted data transfers or dead processes. This FDIR function has been extensively tested and verified on dedicated ground test bench.

The design of the bus structure (Fig. 1) is very simple (quasi cubic – 60 × 60 × 55 cm, aluminium and honey-comb aluminium, . . .) to limit development and recurring costs. The –X panel includes the launcher adapter and the propulsion subsystem with its hydrazine tank.

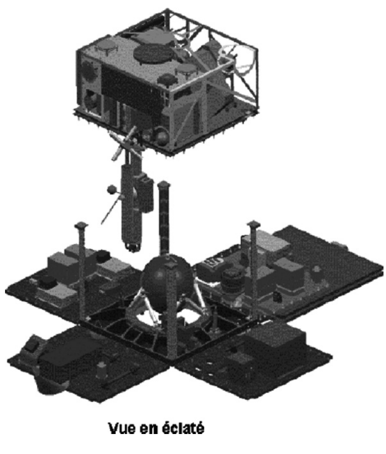


Fig. 1 MYRIADE platform layout

The payload is located on the X+ side of the bus. The power subsystem is based on a single wing solar generator with 2 rigid panels with AsGa cells, rotated by a Solar Array Drive Mechanism controlled by the AOCS through the OBC.

A Power Conditioning and Distribution Unit (PCDU) is in charge of:

– launcher separation detection to connect the main non regulated bar to the battery
– battery regulation
– power distribution to equipment and payload (regulated voltages or voltages 22–37 V)
– thrusters and magnetotorquers commands
– pyro lines distribution

The battery is Li-Ion type.

AOCS design is rather classic. It uses solar sensor, 3 axis magnetometer, high accuracy star sensor, gyros and GPS (option) as sensors, and magnetotorquers, reaction wheels as actuators. Hydrazine propulsion (4 × 1 N thrusters) (option) is only used for orbit control.

Four AOCS modes are used: acquisition/safe mode, transition mode, normal mode and orbit control mode.

On board data management and control/command perform the following main functions:

– satellite configuration management
– mission plan management
– storage of house keeping and payload data, and transmission to S band station
– implementation of AOCS

The architecture is centralized: processing is achieved by one single OBC with direct links with PCDU, Solar generator rotating system, AOCS equipment, RX and TX, payload.

Thermal control is based on use of passive systems (paints, MLI, SSM coatings, . . .) and SW controlled heaters.

Table 1 gathers MYRIADE main characteristics.

Table 1 MYRIADE characteristics synthesis

MYRIADE characteristics/Basic performances		
Structure	Alu structure, honeycomb panels	600 × 600 × 800 mm, 130 kg (with payload) payload 600 × 600 × 350 mm, 60 kg max.

Table 1 (continued)

MYRIADE characteristics/Basic performances		
Power	Solar panels (*ThalesAlenia Space*) AsGa cells (*Spectrolab*) Battery Li-ion 14 Ah (*AEA*) PCDU (*ETCA*) Solar Array Drive (*OERLIKON*)	2 panels, 0.9 m^2 total, rotating (200 W peak) more than 90 W total permanent in SSO (60 W permanent – even during eclipse – for payload)
AOCS	Sun sensors (*Astrium*) Magnetometer (*IAI/Tamam –Israël*) Star sensor (*TUD Denmark*) Gyros < 6°/h (*Litef – D*) Magnetoactuators (IAI/Tamam – Israël) Reaction wheels 0.12 Nms (Teldix – D) Propulsion: 4 × 1 N thrusters, hydrazine system Isp 210 s (EADS Gmbh)	*Demonstrated Performances nominal mode*: 1 axis, 3 axis, . . . pointing capability A priori pointing: <0.02° (1σ) each axis Pointing stability: <0.02°/s DeltaV available: 80 m/s for 120 kg satellite
Localization/Orbit determination	Performed by Control Center Option: GPS TOPSTAR 3000 (*Alcatel A. S.*)	By Doppler measurements: Position restitution/prevision at 3 σ: ±350/±575 m along the track and less than ±10 m ⊥ to the track or in altitude (idem for prevision) Localisation by GPS: <±1 m
On board data management and Command/Control	OBC with μprocessor T 805 CNES design (STEEL manufacturing) Flight software: (CSSI)	5 Mips, 1 Gb memory (EDAC) In-orbit reprogrammable OS-link between OBC and payload 5 Mb/s Payload has its own computer Datation: ±15 ms/UT (at 700 km altitude)
Communications S band	TX link: CCSDS and coding RX link: CCSDS and coding Emitter (QPSK modulation) THALES Receiver (QPSK demodulation) 2 antennas (SHELTON)	Error Bit Rate: 10^{-10} Error Bit Rate: 10^{-10} 10 or 400–600 kb/s – cold redundant 20 kb/s – hot redundant opposite sides, omnidirectional coverage
Payload data downlink with X band	Option: X band emitter for payload (*Thales Alenia Space*)	18 Mb/s–80 Mb/ more than 100 Mb/s in development
Payload management and data storage	Performed by dedicated payload electronic computer with microprocessor, solid state memory (*STEEL*)	8, 16, 32 Gbits mass memory included in payload electronics

3 In Flight Missions Highlights

Up to now:

- 2 MYRIADE CNES missions (DEMETER and PARASOL) are operating in flight.
- 4 other MYRIADE satellites part of the ESSAIM French Defence mission are also operating in flight.

DEMETER was the first MYRIADE in flight. Launch occurred on DNIEPR on June 29th 2004 (see Fig. 2).

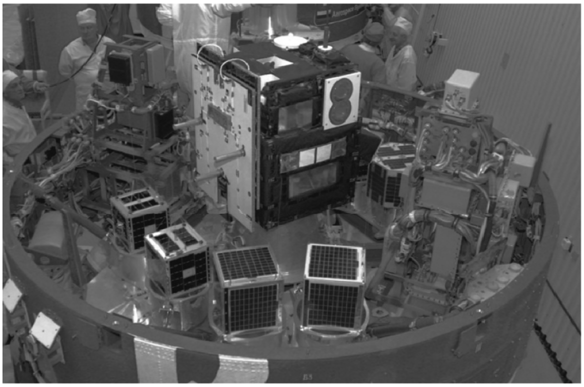


Fig. 2 DEMETER accommodation on DNIEPR with various nanosats

DEMETER (Fig. 3) is a scientific mission proposed by CNRS agency (LPCE laboratory was the orderer). It is dedicated to the detection and the characterisation of electro magnetic waves signals associated with telluric activities (earthquakes, volcanic) or issued from human activities (Power lines, VLF, HF broadcasting).

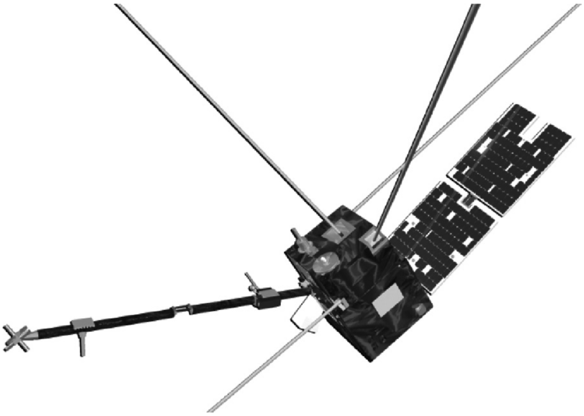


Fig. 3 DEMETER satellite layout

These signals disturb the ionosphere and high atmosphere. These perturbations should occur between a few tens of minutes and a few hours prior to the seism. The scientific payload is made of very sensitive magnetic and electric sensors. To limit bus perturbations, the magnetic sensors are set at the end of a 2 m length deployable boom, while the 4 electric sensors are set at the extremity of 4 m length expendable booms.

The main challenge of DEMETER bus was the necessity to procure to payload the lowest possible electric and magnetic perturbation levels (1,000 Hz range).

The magnetic satellite mission is limited to –24 dBpT from 1 to 7 kHz (some streaks are over but there are few). This has been done by specific wirings, active filtering, magnetic shields on wheels, connectors, ITO on solar generator . . .

In flight operations confirmed the good platform design. Just a sensitivity of reaction wheels electronics to SEU requested some SW modifications so as to reinitialize autonomously communications on these events. An other concern was high sensitivity of the star tracker to moon in the field of view which required operational modifications.

After almost 4 years in flight, more than 1,500 seisms have been registered and some maps as depicted on Fig. 4 show some correlations in electrical field near the geographical location a few hours before.

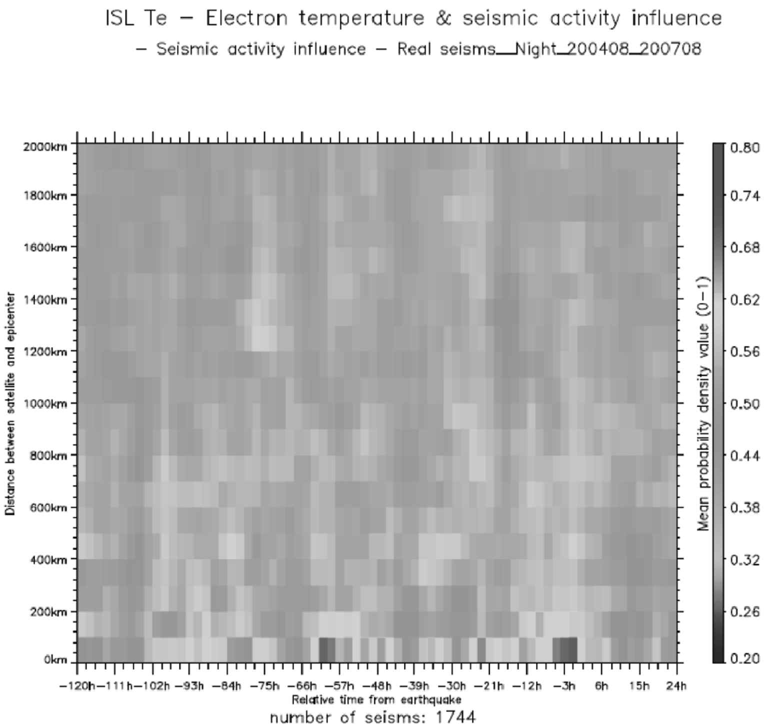


Fig. 4 DEMETER science Results

Besides the primary mission, an autonomous orbit control was implemented inside the satellite SW as a technological demonstrator. This demo closes the loop between on line orbit restitution on board through GPS and thrusters burns to fulfil ground programmed criteria: position on orbit, ground track,

Figure 5 highlights the good behaviour evidenced in flight on more than 150 manoeuvers.

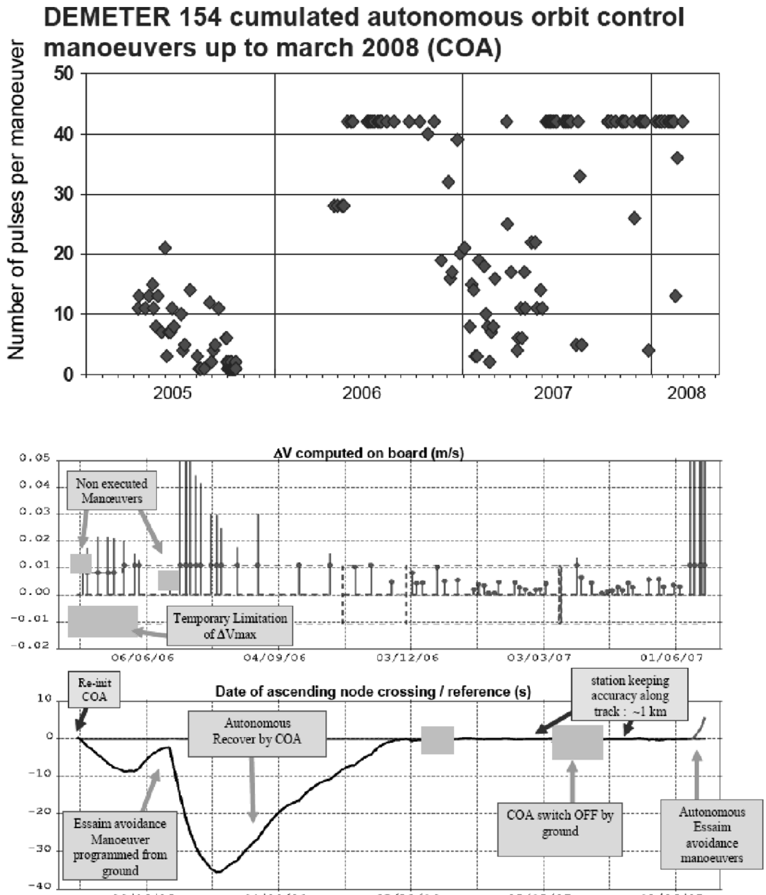


Fig. 5 DEMETER autonomous orbit control

Overall experiment availability is close to 90%. Mission has been extended until end 2009.

An in flight experimentation session is foreseen during first semester 2010, in order to enrich the knowledge of equipment performances after 4.5 years of in flight operation, before deorbitation and passivation operations.

PARASOL is the second mission developed by CNES within the frame of MYRIADE. It has been proposed by CNRS agency (LOA laboratory was the orderer), as being a part of the AQUA train composed by CALIPSO, AQUA, OCO, AURA and CLOUDSAT.

PARASOL addresses climatology topics, in particular measurements of clouds and aerosols properties, and radiative budget interaction (contribution to the global warming).

PARASOL bus design (Fig. 6) is almost similar to DEMETER/MYRIADE one.

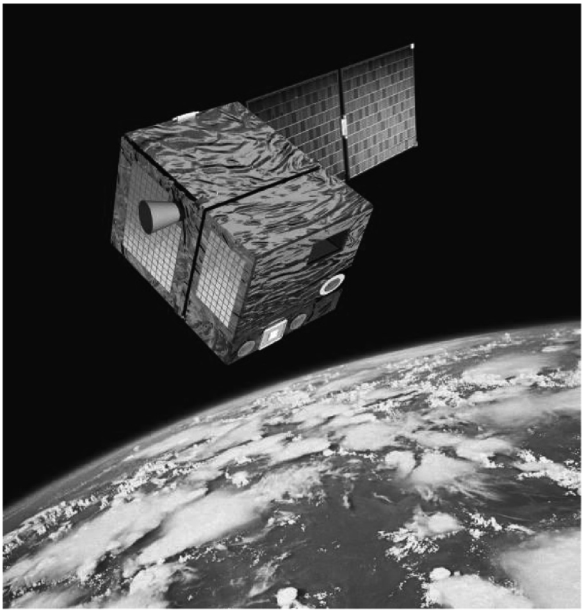


Fig. 6 PARASOL satellite layout

Minor modifications concern:

- The solar generator cant angle has been set to 0° to avoid disturbances not compliant with the pointing stability requirements of the mission (< 0.01°/s over 5 s) while the solar generator is in rotation.
- A yaw steering capacity has been implemented in order to compensate for the earth rotation when the payload is taking images.
- Concerning the payload, mass memory capacity was extended from 8 to\break 16 Gbits.

PARASOL is the first demonstration of recurring mission developed within less of 3 years with a low recurring cost and with a very reduced time gap with previous DEMETER mission: 6 months: launch occurred on December 2004, aboard the ARIANE 5 ASAP together with the 4 other MYRIADE used for French Defence ESSAIM mission: see Fig. 7.

Overall mission availability is close to 90%. The star tracker concerns found on DEMETER were exacerbated because of higher mean temperature levels. SW

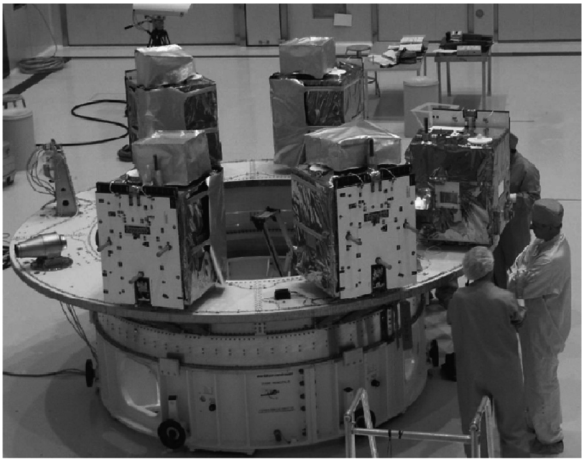


Fig. 7 PARASOL on Ariane 5 ASAP with companions

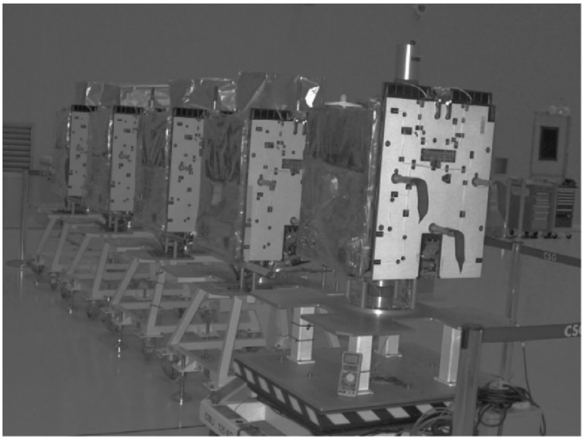


Fig. 8 PARASOL and ESSAIM satellites

modifications have allowed to retrieve correct tracking mode statistics. Mission has been extended till mid 2010.

In addition of these CNES missions, the MYRIADE standard has been selected by ASTRIUM to provide French Defence with 4 ESSAIM satellites (Figs. 7, 8, and 9) in orbit at time being.

4 CNES Missions Under Development

Regarding CNES missions, 3 MYRIADE satellites are under development (PICARD, TARANIS, MICRO-SCOPE), planned to be launched respectively in 2009, 2011 and 2013. Eight others satellites have been ordered to prime contractors by other customers.

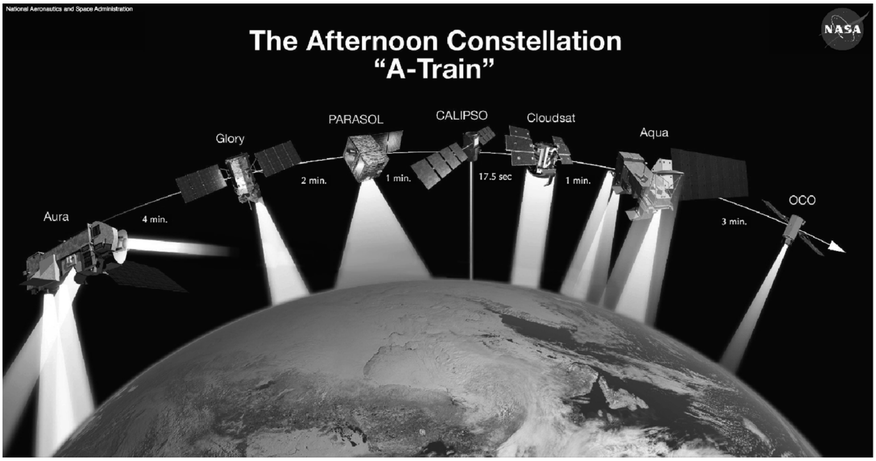


Fig. 9 PARASOL in the AQUA train constellation

PICARD is the next CNES MYRIADE mission scheduled for a November 2009 launch together with Swedish PRISMA mission on DNIEPR. Launch date is constrained by the beginning of the next solar cycle (Fig. 10).

This scientific mission has been proposed by CNRS agency, Belgium and Switzerland laboratories. Service Aéronomie /CNRS is the prime for the main payload. It is dedicated to the sun observation (diameter, irradiation, differential rotation, UV) in relation with the earth climatology, together with solar physics measurements (oscillations, UV).

The payload is composed of three instruments (total 60 kg, 60 W):

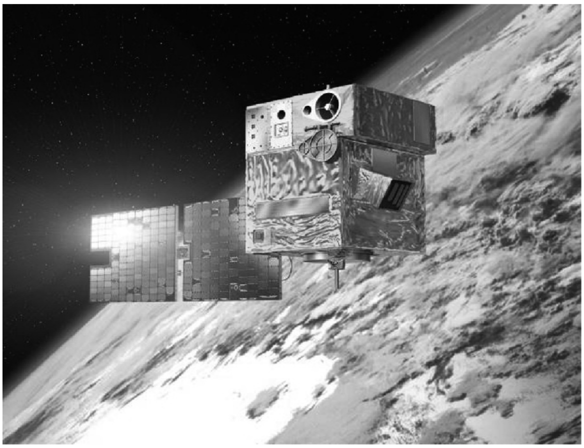


Fig. 10 The PICARD satellite

- a high resolution and high thermomechanical stability telescope SODISM (SA/CNRS) with CCD detector, for sun diameter measurement at high precision: a few milliarcseconds
- a radiometer SOVAP (IRMB) for total irradiation measurement
- a UV radiometer PREMOS (WRC/PMOD)

Platform has already been integrated and Payload mating is scheduled for July 2008.

The payload main sizing requirement is linked to bus pointing: the need is absolute sun pointing precision of less than $\pm$ 0.01° and pointing stability less than 0.01°/s. For that purpose, symmetrically from COROT, a fine sun sensor included in the payload telescope has been put in the AOCS loop through a specific mode.

Notice that this mission does not require the propulsion module nor the X band emitter (2 Gbits/day). On the opposite, AOCS mixes Payload sensor for sun 2 axes precise pointing. Third axis is provided by one of the 2 star trackers fitted in different directions.

The *TARANIS* mission is dedicated to study the magnetosphere-ionosphere-atmosphere coupling via transient processes. The mission will address unanswered questions relating to the recently discovered discharges in the stratosphere and mesosphere above thunderstorms, the so-called "Transient Luminous Events" (TLEs), and their relationship with the Terrestrial Gamma-ray Flashes (TGFs) of radiation from relativistic electrons accelerated in the atmosphere above thunderstorms.

The study of these phenomena is extended to the transient LEP (Lightning Induced Electron Precipitation) and accelerations of energetic electrons.

According to the mission objectives, the necessary instruments to fulfill the mission are:

- optical sensors,
- X and γ detectors,
- electron detectors,
- electric antennas,
- magnetic antennas.

This leads to an overall satellite mass close to 160 kg, which requires structural stiffening, but as a side effect, allows to set a new standard above the original MYRIADE 130 kg one, particularly fitted to the 200 kg ASAP capacities developed in the frame of SOYUZ.

Figures 11 and 12 depict satellite and mission.

Deployed antennae are close to the ones used on DEMETER. As well, stringent EMC requirements apply to the satellite, for which similar methods than DEMETER will be applied: filters at the output of the SA and SADM, between OBC and SST, reaction wheels covered by magnetic shielding . . .

Satellite is currently in B phase and launch is scheduled for beginning of 2012.

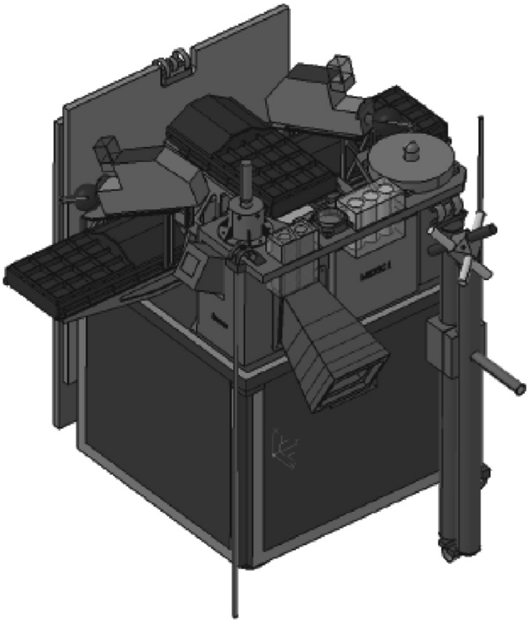


Fig. 11 The TARANIS satellite

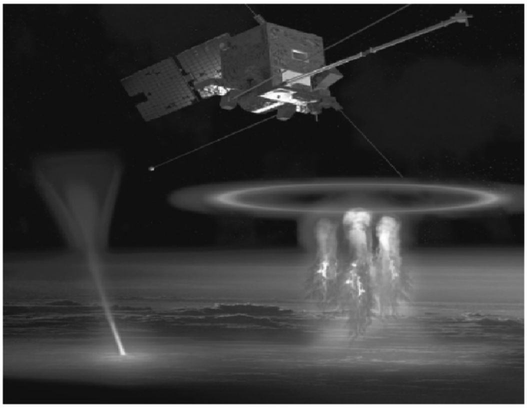


Fig. 12 TARANIS mission artist view

MICROSCOPE is a scientific mission proposed by ONERA who is also payload prime. MICROSCOPE is dedicated to the demonstration of the EP (Equivalence Principle). This principle states that the gravitational mass and the inertial masses should be equal (see Fig. 13).

The payload is based on two high performance (10^{-12} m.s^{-2} precision) differential accelerometers developed by ONERA. Detection of an acceleration on the second accelerometer, using a proof mass with a different density, will bring evidence of a violation or not of the equivalence principle at a 10^{-15} precision level.

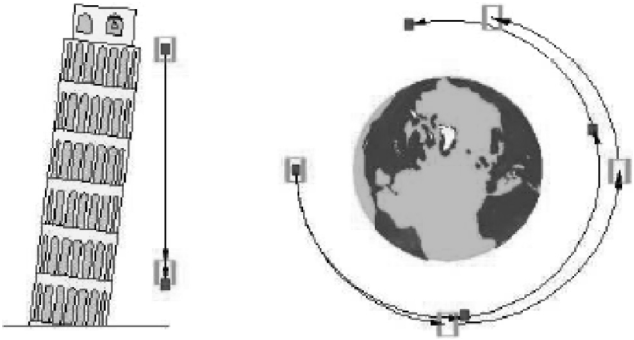
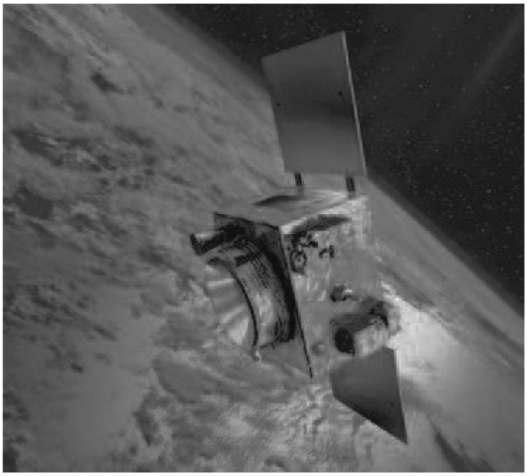


Fig. 13 The equivalence principle

Fig. 14 The MICROSCOPE satellite



In order to measure such differential accelerations, the accelerometers have to operate in proper conditions:

– the satellite (Fig. 14) has to be controlled drag free with residual linear acceleration less than 3.10^{-10} $m.s^{-2}.Hz^{-1/2}$.
– the satellite has to be spinned at 10^{-3} Hz.
– MICROSCOPE requires important adaptations of the basic MYRIADE design.
– payload accelerometers have to be located precisely at the satellite CoG, with very high thermal decoupling from spacecraft structure.
– dedicated AOCS modes have to be developed, using low thrust electric thrusters (Field Emission Electric Propulsion thrusters) as actuators. These thrusters are developed under ESA responsibility. A trade off is currently performed to also evaluate less complex cold gas proportional thrusters.
– bus architecture is specific; a new solar generator (symmetric) has been designed.

Main mission characteristics are:

Orbit	700 km, SSO 6 am/18 pm
Pointing	spin axis $\perp$ to orbit plane
AOCS	new modes for drag free at 3.10^{-10}
Power	2 deployable then fix solar panels
Propulsion	12 FEEP thrusters on 4 pods 150 μ N thrust each
Weight	Total: 190 kg

The program is in phase B. Launch is scheduled in 2013. This mission is an example of the high flexibility of MYRIADE design.

In addition of these CNES missions, the MYRIADE standard has been selected by ASTRIUM and THALES to provide French Defence with 6 new satellites: 2 SPIRALE and 4 ELISA satellites under development. The MYRIADE standard is also the basis for imaging systems in development at ASTRIUM: 3 satellites for 2 export missions.

5 CNES Missions Under Study

The positive experience acquired in previous MYRIADE projects encourages the CNES engineering teams to envisage such hypothesis for the various missions submitted by CNES Program Directorate. Typically, even if preliminary system requirements lead to payload in the class 200–500 kg, an analysis is conducted in order to identify the possibility to support a part of the mission, or reduced performances with a MYRIADE solution. Depending on the programmatic context, this analysis can also highlight the interest for a demonstrator satellite based on MYRIADE. The following missions are under evaluation:

SMAR: Monitoring of maritime traffic. MYRIADE satellites could be involved in reception of AIS messages and transmission to ground processing systems. The need for less than 3 h delays in the operational chain could lead to a constellation of TBD satellites.

Reactive capacity: Imaging system (Pa+4XS), complementary to Pleiades system. The system aims to provide a short delay (3–4 h) to access to any point. Preliminary studies conducted at Astrium and Thales show that with a high resolution (1.5 m) payload can be installed on MYRIADE platform but may difficulties appear with an orbit at 450 km

Mistigri: Evaluation of ground temperature through observation in thermal infrared bands, representative of ground dryness. A MYRIADE satellite could accept a payload providing measurement in 4 bands with a 60 m resolution in TIR and 30 m in VNIR from a 720 km orbit. The system is designed for observation of test sites in South of Europe every 2 days.

6 Return of Experience

Obviously, development of lines of product has allowed CNES to propose for missions an efficient tool on a high variety of satellites configurations. Two of them are already in flight and at least 3 others are scheduled.

Several common determinant factors may be highlighted from the line of product approach:

- after the first mission, the system is well known and it is possible to register a drastic decrease of major anomalies. Of particular interest are all the design documentation, the SW, the validation benches and operation simulators, SDB, AIT GSEs, procedures
- using a generic ground segment with well known interfaces allows to concentrate new developments to the specific mission center; limited adaptations ease the operational teams efficiency and synergies among missions
- well known interfaces between platform and payload allow to specify payload without settling from the beginning the satellite team
- return of experience in flight allows mutual enrichment to continuously increase robustness; moreover, true performances are well known and ease the adequacy check for new missions without considering high margins
- procurement in batch of equipment units guarantees their industrial availability and allows drastic cost decrease, typically more than 30%; moreover, spares are naturally available
- this line of product approach is also of interest for prime contractors: after MYRIADE DEMETER launch, CNES decided to create a partnership with French prime contractors Astrium and THALES, allowing them to benefit from the design, to duplicate benches, to have common LTA with subcontractors. This has proved very efficient since now more than 12 MYRIADE have been or will be used on non CNES missions.

7 2009 A Decisive Year for MYRIADE Product Line

In March 2009, a prospective seminar will be with the same objective as those of Arcachon 1998 and Saint Malo 1994. Decision related to new missions are expected, and in particular MYRIADE implementation will be studies.

The development of a new mechanical structure will allow to take benefits from Soyuz ASAP capabilities: launch mass 200 kg for a payload mass at 95 kg. TARANIS project will be the first user of this structure.

On the other hand, progress are expected on ISIS program (Initiative for Space Innovative Services) aiming to support payloads in the range 100–600 kg. For MYRIADE product line, sharing industrial sources with ISIS program for components or pieces of equipment will allow to take benefits from new technologies, to deal with obsolescence problems and improve cost by common batch in equipment purchase.

8 Conclusion

Evidence of the gains brought by MYRIADE satellites lines of products has been highlighted. Commonalities and synergies are constantly evidenced through the various application missions using them. It is proposed to perpetuate and still strengthen this approach for next generation in the decade to come. This relates to a wide perimeter encompassing all the common services that allow to operate payloads in orbit. Increased flexibility has to be looked for, with respect to the size of the missions to accommodate. Commonality with ISIS new product line will be searched for cost efficiency and perpetuity. The broader the community using these standards will be the larger efficiency should be.

Acknowledgments Acknowledgments to all the CNES and industrial teams, as well as all cooperants who have permitted all the missions using MYRIADE and PROTEUS lines of product to be successful.

Further Reading

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