This work presents the adaptation of MYRIADE satellite to the mission TARANIS. The particularity of this mission is the 8 instruments embedded, in various area of science: electro-magnetic detection instrument, optical detection and radiation detector. This heterogeneity has strong impact on satellite design, and moreover on an existing platform. First adaptation was made on mechanical structure to accept a 200kg satellite, instead of 130 kg previously, in perimeter of launcher constraint, which was a small allocated volume and stronger random vibration level. Second adaptation was the power budget design. Maximum capacity of MYRIADE satellite was around 100W for all satellite, and payload was expected 70W of consumption. This high consumption required to reduce severely all margin historically taken (on system, on thermal control) and to have a strong payload consumption follow up with the scientific instrument’s designers. Thirdly, the compactness and sensibility of payload require a specific design of harness payload and also a stronger test campaign on EM model for testing the payload auto-compatibility. Finally, 8 instruments require a synchronization of 1ms with the ground. This level of performance forced to adapt MYRIADE dating performance from 15ms to 1ms in adding new counter and new oscillator compensation algorithm.

INTRODUCTION

In Celtic mythology Taranis is the god of thunder. Thousands of thunderstorms are every day active across the surface of the Earth. Mysterious and spectacular phenomena have been observed above the thunderstorm clouds. Since their first discovery in the 90's they have been many observations of impressive Transient Luminous Events (TLEs) and energetic Terrestrial Gamma-ray Flashes (TGFs) above thunderstorm clouds. This relatively late discovery illustrates our lack of understanding of thunderstorms. It also indicates that the thunderstorms affect not only the lower layer of the atmosphere but also the upper layers up to the near space environment. What we need to do now is discover and understand the hidden side of thunderstorms. The TARANIS (Tool for the Analysis of RAdiation from lightNIng and Sprites) satellite located on a quasi-polar sun-synchronous orbit at an altitude of 700 km is able to acquire data in the near space environment. The TARANIS mission has four main objectives:

1. Estimate the rate of occurrence of TLEs, TGFs and their associated emissions, highlight trigger factors
2. Characterize TGFs and runaway electrons that accelerate upwards in the atmosphere to the magnetosphere
3. Identify the effects of TLEs and TGFs on coupling between the ionosphere and the magnetosphere

NCES is the prime contractor of the TARANIS mission. It oversees the integration of the payload, the platform and the satellite. The LPC2E supervises the development of the scientific payload and part of the TARANIS Scientific Mission Centre. The scientific responsibilities related to the mission are undertaken by the LPC2E from Orléans seconded by CEA. Other French scientific laboratories are collaborating in the TARANIS mission. They are: IRAP from Toulouse, LATMOS from Paris/Guyancourt, and APC from Paris. Electronic modules are supplied by Stanford University (USA), the Goddard Space Flight Centre (USA), the Institute of Atmospheric Physics and Charles University (Czech Republic) and Warsaw Space Research Center (Poland).

The general objective of the TARANIS mission is to study magnetosphere-ionosphere-atmosphere coupling via transient processes. At the beginning of the project proposal, the transient processes considered were essentially sprites and their associated phenomena, hence the name TARANIS (Tool for the Analysis of RAdiation from lightNIng and Sprites). Today, all transient optical phenomena observed at an altitude of between 20 and 100 km (blue jets, red sprites, halos, elves, etc.) are covered by the term TLEs (Transient Luminous Events).

Furthermore, the study's reach has been extended to incorporate the transient precipitations and accelerations of energy electrons, regardless of whether they are directly linked to TLEs. The detection and the study of the gamma-ray and X-ray flashes probably associated to the TLEs, called TGFs (Terrestrial Gamma Flashes), are part of the mission objectives. In view of the satellite's orbit, emphasis is placed on medium and low latitudes, which, by definition, have been the focus of very few studies in the past.

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- Specify the role of precipitated electrons in coupling between the magnetosphere and the atmosphere.

**Figure 1: Artist view of Taranis satellite**

**MISSION OBJECTIVES**

**Phenomena associated with atmospheric storms**

Atmospheric storms constitute one of the most significant disturbance phenomena in the Earth’s environment. Two thousand storms are every day active throughout the world, producing 50 to 100 lighting bolts per second. Recent observations of light emissions in the medium and upper atmosphere and of gamma emissions from atmospheric origins demonstrate that there is impulsive coupling of the Earth’s atmosphere with the ionosphere and the magnetosphere above active storm cells. With regards to space plasma and the chemistry and dynamics of the medium atmosphere, this direct coupling and the considerable energy involved leads to the intervention of processes that had not been envisaged until now. It can be triggered by cosmic radiation, solar winds and the meteorological and volcanic processes that affect the lower layers in the atmosphere.

Since the discovery of these phenomena is very recent, current knowledge is limited to light emissions observed in the spectrum visible from the ground or using optical detectors embedded on satellites and directed towards the horizon. Theoretical studies demonstrate that these emissions are just a small part of a much more complex phenomenon that also involves X and gamma rays, electromagnetic rays that extend over a large range (0.1 Hz to several tens of MHz) and atmospheric/ionospheric coupling that results in the generation of intense electronic fields and electron acceleration that can reach very high energy levels (up to 30 MeV).

**TLEs Detection and characterization**

The objective is to measure lightning and Transient Luminous Events (TLEs), which occur above storm systems at between 20 and 10 km of altitude. These TLEs were observed by focusing on the horizon from the ground or by satellite like ISUAL [1] or FORMOSAT [2]. The figure 2 is a diagram of different TLEs.

The number of TLEs is not currently known. It is possible to estimate their number from global lightning frequency figures calculated by the LIS and OTD experiments onboard the TRRM satellite [3]. Global lightning frequency stands at 45 flashes per second. This leads to between 5 and 27 sprites per minute, if we assume that there is 1 sprite (1.5 Mb) for 100 to 500 lightning flashes. The number of elves, which occur more frequently than sprites, could reach between 500 and 600 per minute.

These phenomena have different spatial and temporal characteristics. They are all systematically produced after a lightning flash but some last for varying lengths of time. Their characteristics are summarized in the table below:

**Table 1: TLEs characteristics**

<table>
<thead>
<tr>
<th>TLEs Type</th>
<th>Horizontal Extent</th>
<th>Vertical Extent</th>
<th>Altitude Range</th>
<th>Duration</th>
<th>Delay between Lightning/TLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column sprites</td>
<td>~1 km</td>
<td>10-40 km</td>
<td>30-70 km</td>
<td>1-5 ms</td>
<td>&lt; 2 ms</td>
</tr>
<tr>
<td>Carrot sprites</td>
<td>5-30 km</td>
<td>20-60 km</td>
<td>30-90 km</td>
<td>1-5 ms</td>
<td>2-400 ms*</td>
</tr>
<tr>
<td>Grouped sprites</td>
<td>50-80 km</td>
<td>few km</td>
<td>85-95 km</td>
<td>1 ms</td>
<td>&lt; 1 ms</td>
</tr>
<tr>
<td>Elves</td>
<td>200-500 km</td>
<td>~20 km</td>
<td>70-90 km</td>
<td>1-5 ms</td>
<td>&lt; 1 ms</td>
</tr>
<tr>
<td>Halos</td>
<td>~75 km</td>
<td>~20 km</td>
<td>70-90 km</td>
<td>1-5 ms</td>
<td>&lt; 1 ms</td>
</tr>
<tr>
<td>Jets</td>
<td>1-10 km</td>
<td>20 km</td>
<td>18-45 km</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gigantic jets</td>
<td>1-50 km</td>
<td>60 km</td>
<td>18-75 km</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lightning (cloud illumination)</td>
<td>5-20 km</td>
<td>3-10 km</td>
<td>3-15 km</td>
<td>1-100 ms (for direct current)</td>
<td></td>
</tr>
</tbody>
</table>

*: the average delay between a sprite and a lightning flash is 30 ms, but its distribution presents large standard deviation. This delay cannot be estimated as yet.

Unlike previous experiments, TARANIS will observe these phenomena as it passes directly below them to study the different effects on the medium (ionosphere) and couplings with neighboring mediums (atmosphere and magnetosphere). To this end, it will have an embedded optical detection and observation system for TLEs that is designed to:

- Detect TLEs and lightning on board the satellite to send out a warning signal to all equipment.
- Differentiate between the lightning signal and that of TLEs.
- Locate and characterize lightning and TLEs and their occurrence frequency.
- Study any correlations between these characteristics and those of other associated phenomena (TGFs, waves, etc.).

**Figure 2: TLEs**

**TGFs detection**

TGFs (Terrestrial Gamma ray Flashes) were discovered during the BATSE experiment [4]. They originate in the upper atmosphere and would appear to be related to storm activity.

The mechanisms behind the creation of TLEs and TGFs have been the subject of numerous, often contradictory, studies. According to certain studies, they could be related to quasi-static electric fields that result in air breakdown; according to others they could be the result of an avalanche of relativistic electrons that are triggered by cosmic radiation and develop as far as the ionosphere and the magnetosphere. This avalanche could produce secondary X and gamma ray through deceleration radiation.

**Runaway electrons detection**

Observations of ray have demonstrated the existence of energetic runaway electrons travelling upwards as TLEs occur. Several theoretical studies indicate that these runaway electrons cross the ionosphere and spread across into the magnetosphere. If this hypothesis were confirmed we would have a process that contributes to both:

- populating radiation belts through the acceleration towards the magnetosphere of high-energy electrons generated by cosmic radiation at low altitudes,
- variations in ionization rates in the atmosphere.

**Coupling effects between ionosphere, magnetosphere and atmosphere**

Electron acceleration and precipitation are generally accompanied by electromagnetic and electrostatic waves, which either contribute to the process or were generated by it. In both cases, it is essential to research the electromagnetic and/or electrostatic signature to identify the mechanisms at work, or even to detect runaway electrons that are too narrow to be observed directly. A significant example of signatures of this kind is currently provided by the "second peaks" observed from the ground on ELF whistles. They are currently interpreted as the signature of currents produced in sprite cores.

**EYES Experiment**

EYES is a CNES R&T experiment based on nanocameras available on the market. It is composed of three nanocameras and an electronic module in charge of the communication with the satellite platform. This set, placed upon the satellite, provides low resolution images or videos in order to control satellite’s elements (platform’s coating, deployment of instruments’ booms...) or for public communication (views of the satellite and the earth).

**HFPE Experiment**

Apart from the study of TLEs and TGFs, the mission will also test the possibility to communicate with the spacecraft even when it is out of visibility from ground antenna. The instrument IME-HF is well suited to validate the technique envisioned. In case of success this technique would allow to keep the contact with low altitude satellites whatever their position along the orbit.

**SYSTEM DESCRIPTION**

**Mission**

The TARANIS mission was designed to detect and study different phenomena associated with atmospheric storms using a micro satellite placed in a quasi-polar orbit. The system will make maximum use of the elements and resources from CNES MYRIADE micro satellite program [6].

The scientific observation area of TARANIS is between -60° and +60° of geographical latitude (mission area, see fig 5), on the dayside and on the nightside of the orbit. The system is designed to observe stormy regions with a view to detecting TLEs and TGFs as the satellite travels above the phenomena at around 700 km of altitude. A warning is then sent to each of the payload instruments so they can acquire the maximum amount of data during the event.

The satellite memory's massive capacities in telemetry, onboard storage and management will make it possible to accumulate a large amount of data for each event and for a large number of events per day. This is all with a view to satisfying the statistical analysis requirements and being able to correlate the different parameters.

The Scientific Mission Centre has adopted the same plan that was implemented with great success in conjunction with the LPC2E for the DEMETER mission [7]. The minimum requested mission duration is two years after the satellite commissioning. An objective of four years of mission duration will be taken into account in the studies as far as it does not lead to additional requirements or qualifications.
The satellite characteristics are the following ones:

- Mass: 185 kg
- Power Budget: 180W Solar Panel / 80W allocated to Payload / 35W for platform services

**Payload**

The payload includes numerous sensors to observe the TLEs and to perform in-situ measurements of perturbations caused on the local plasma (fields, waves and particles). The upper side, which carries the payload, will be pointed towards Earth. The payload includes the following elements:

- MCP, set of 2 cameras and 4 photometers, → 30 images/s, 512x512 pixels and luminance measurements of the different high-resolution spectral bands;
- XGRE, set of 3 X and Gamma rays detectors → Measurements of high-energy photons between 20 keV and 10 MeV and relativistic electrons between 1 MeV to 10 MeV;
- IDEE, set of 2 electron detectors, → Measurements of high-energy electron spectrums between 70 KeV and 4 MeV;
- IME-BF, LF antenna to measure electric fields, → Measurement of an electric component between 0 and 1 MHz;
- IME-HF, HF antenna to measure electric fields, → Measurement of an electric component between 100 kHz and 30 MHz
- MCP, set of 2 cameras and 4 photometers, → 30 images/s, 512x512 pixels and luminance measurements of the
- IMM, a triaxes search coil magnetometer to measure the alternative magnetic field:
- IMM-BF, 2 mono-band coils to measure the LF field;
- IMM-MF, 1 dual band coil to measure the LF and MF field; → Measure 3 components of between a few Hz to 20 kHz and of a component of 10 kHz up to 1 MHz;
- MEXIC, a set of 2 electronic boxes comprised of the 8 analyzers associated with the instruments, providing electronic power to the instruments, management of the payload modes and the interface with the Mass Storage and the platform computer. MEXIC also ensures the synchronization of the instruments from events detections by the photometers.

**Orbit**

Myriade is a low earth orbit satellite product line. The Taranis altitude is defined in mission studies as the difference between the orbit mean semi major axis and the earth radius. Considering that the observed transient phenomena such as TLEs and TGFs are supposed to be produced between 10km and 100 km altitude, the range of Taranis altitudes compliant with scientific objectives is between 650km and 750km.

This range of Taranis altitudes was studied by the AOCS satellite sub-system and was analyzed through the Mission Analysis to define the following minimum and maximum altitude:

- 650 km is the minimum altitude authorized by the scientific mission and by the satellite AOCS sub system (for all AOCS modes). This altitude is calculated with a mean solar activity.
- 720km is the maximum altitude to be compliant with the end of life requirements: re-entry must be performed within 25 years.

For statistic purpose of TLEs’ detection by the MCP instrument, the orbit eccentricity shall be maintained and monitored so that the geodesic altitude gap all along the mission orbit is less than 30 km. For scientific purposes, there is also a requirement to have the ascending or descending node local time between 22H30 and 02H00. Nevertheless, this range of local time doesn’t suit with thermal satellite constraints around the midnight orbit, it is why the ascending or descending node local time will be in one of the following ranges: [22H30, 23H30] or [0H30, 2H00]. This must be applied from the injection orbit until mission disposal. Besides, there is no requirement to have a phased orbit or to have an ascending or descending node local time drift.
Guidance requirements

The most constraining requirement about the pointing and the attitude of the satellite is the localization accuracy of lightnings imaged by the Micro-Cameras of the MCP instrument. As a consequence, the geocentric pointing accuracy of the satellite in the satellite mission mode must be better than 0.5° at 3σ on each axis when the Star Tracker (SST) is not dazzled by the moon. This requirement does not take into account the SST bias.

The restitution of the satellite attitude is performed with a ground tool called ORAM already used for the PARASOL Myriade mission. When all the SST measures are available, the performance of the restitution of satellite attitude is given by the performance of the SST and the accuracy of the restitution of the satellite attitude must be better than +/−0.05° at 3σ on each axis (without the SST bias). When the SST is dazzled by the Moon and the gyrometer is switch ON, ORAM is able to propagate the SST attitude with the gyrometer telemetry via a specific non real time gyro-stellar Kalman filter “back” and “worth” and to evaluate a quality index associated to the attitude performance degradation.

The stability of the satellite corresponds to the satellite attitude variation between two consecutive SST acquisitions, it must be better than 0.03° peak to peak range between two consecutive SST 4Hz acquisitions. The stability of the satellite defined for the Myriade product line fits with the Taranis Mission. It’s one of the contributors concerning the precision of the localization of lightning imaged by the Micro-Cameras of the MCP instrument.

Furthermore, the guidance laws performed by the ground and uploaded to the satellite, should not induce a pointing error of the satellite greater than 0.08 ° in pitch and roll, taking into account errors of the orbit prediction after 5 days

MTB management

On board, the Reaction Wheels used in satellite mission mode to counterbalance the perturbation torque need to be frequently unloaded by the Magneto Torquer Bars (MTB). Indeed, without MTB activation the Reactions Wheels would reach in few orbits there maximum velocity and will not be able to create any torque on the satellite structure.

As payload sensors are strongly polluted by the Magneto Torquer Bars, MTB should not be activated during mission observation areas, that is to say between -60° and +60° of geographical latitude (see Figure 5), especially on the nightside of the orbit when all the scientific instruments are performing measurements.

Solar panel management

To maximize the power available on-board, the solar panel must be orientated as much as possible towards the sun, so rotating at a speed as close as possible to the orbital speed, at least all along the orbit lit by the sun.

Nevertheless, the driving motor of the solar panel can produce slight disturbances on the magnetic antenna data of the IMM instrument. The induced disturbance is considered as acceptable insofar as the expected level is low and it will only occur during the day part part of the orbit when the working scientific payload is reduced (without optical instrument).

In consequence, it is required:

- to stop the rotation of the solar panel during the eclipsed mission area when the entire scientific payload is working.
- to rotate it at the maximum speed in one or two periods at the beginning or/and at the end of the eclipsed mission area in order to be placed in the best position to face the sun again.

As it won’t be possible to keep the solar panel fixed during the complete the night part of the mission area (between -60° and 60° of geographical latitude), we define a restrictive mission area ([+[40°, - 40°]) configurable) where the solar panel will be fixed.
MECHANICAL CONSTRAINT

8 instruments mass budget constraint

Initially the MYRIADE mechanical structure was designed to support a payload of one or two major instruments. The total mass of satellite used to be around 120kg (mass of the first mission DEMETER), on TARANIS mission, the satellite mass will be around 185kg. This difference of 65 kg involved doing major modifications on the structure, and also on the mechanical qualification which was made previously.

Table 2: Payload mass evolution on MYRIADE missions

<table>
<thead>
<tr>
<th></th>
<th>Taranis</th>
<th>Picard</th>
<th>Parasol</th>
<th>Demeter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instruments</td>
<td>8</td>
<td>3</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Mass PL</td>
<td>76.4 kg</td>
<td>60.5 kg</td>
<td>33 kg</td>
<td>36 kg</td>
</tr>
</tbody>
</table>

Launcher compatibility constraint

Another difficulty was the fact that TARANIS mission is the first MYRIADE satellite, which should be compatible with SOYOUZ or VEGA launcher from ESA space port in French Guyane.

The constraint of SOYOUZ launcher was:
- Volume allocated to TARANIS satellite on external ASAP

The allocated volume imposed severe constraints on the design of the mechanical structure, which has to be compact as possible
- Level of vibration (random level)

The random vibration level induces to make again the qualification of previous MYRIADE (propulsion system). Moreover, on the 8 instruments which made the payload some are sensitive to random vibrations, for that reason a specific damper system was developed.
TARANIS payload is the first with 8 instruments. The mechanical layout has to take into account each one of these 9 constraints in the dimension shown in figure 9:

- **Alignment**: 6 instruments or sensors need to be perfectly aligned
- **Field of views**: 6 instruments need to see earth ground during mission, plus the platform services required on earth visibility (S and X Band Antenna)
- **Management of parasitic light**: 4 instruments require not to be directly illuminated by sun
- **Chock constraint**: Optical instrument PH and MC are sensitive to chock. Due to compactness, the deployment mechanism of EMC instrument is near the optical one. After being tested, damper have been added on PH instrument
- **Temperature management**: All instruments are not sensitive in the same way with temperature, it requires to create thermal isolated area between some incompatible instrument
- **EMC constraint**: Due to sensitive instrument on EMC emission (HF, IMM, IME BF MF), specific design of platform has been managed to minimized the emission; All payload harness has been overshielded
- **Electrical potential constraint**: Due to EMC performance reached, the electrical potential of TARANIS has to be homogeneous on all the satellite. It requires to control the grounding point of each part of Thermal MLI and requires also to have a conductive MLI
- **Accommodation of experiment**: More than 8 instruments, one optical experiment has been embedded which requires specific accommodation for the field of view.
- **Ground integration constraint**: for each of the 8 instruments, a specific ground testing structure has to be designed. Some instrument needs optical stimulation, others, radiative sources, or injection of an EMC signal.

### POWER SUPPLY CONSTRAINT

#### Power budget on the limit

The total available power on a MYRIADE satellite is about 180W on solar panel, which induces a maximum of 105W mean power consumption for a sun synchronous orbit at 700km of altitude.

On other MYRIADE programs, the mean consumption was around 70W for all the satellite (i.e. platform consumption of 35W, payload consumption around 30W, and 5W of thermal regulation). The power margin was around 35 to 40W, which was more comfortable.

Due to the 8 instruments architecture on the payload of TARANIS mission, the consumption allocated to payload has increased up to 70W at the beginning of project in 2006 (see table 3 for payload consumption variation).

#### Table 3: Evolution of payload consumption

<table>
<thead>
<tr>
<th>Period</th>
<th>Phase A 2006</th>
<th>Phase B 2010</th>
<th>Phase C 2012</th>
<th>End Of Phase C 2015</th>
<th>Phase D (Actual) 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload consumption</td>
<td>68W</td>
<td>88W</td>
<td>98W</td>
<td>79W</td>
<td>63W</td>
</tr>
<tr>
<td>Margin system</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>OK power budget</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

The maximum of consumption was reached during the C phase of development in October 2012 with a predicted consumption of 98W. At this step, it was impossible to managed the mission on a MYRIADE platform with the mission profile defined. To be compatible with MYRIADE, it was decided to reduce the mission on the night side or to limit the mission between +/- 40° of latitude (instead of +/- 60°, see figure 5). Another action was also to have a strong monitoring of the payload power management (present on next chapter).

With evolution of design and the accompaniment made with all laboratories, the power consumption reached the limit of MYRIADE electrical power system in 2015 with a consumption of 79W. This consumption authorized a margin of 6W for all the system, including thermal control in worst case (see table3 and figure 11). At this...
time the mean consumption of satellite was 105W, which was actually the maximum power available for the platform services. The global margin of 20% is unusual on satellite design. On other satellite designed (government satellite), the margin is around 50% or 40%. The challenge of TARANIS was to keep a low margin for the design.

The impact of a strong consumption also induced constraint on the battery management. The depth of discharge (DoD) cycle induced on battery with a mean consumption of 105W was around 22% during mission time. On other MYRIADE mission, the DoD was around 10%. The impact of having multiply by 2 the DoD is essentially on battery’s lifetime. The figure 10 bellow shows the variation of capacity during lifetime (number of cycle, one cycle = one orbit, 21900 cycles represent 4 years’ mission). The different curves (green, pink, blue and red) present the variation of the capacity with different DoD during mission. Between 20% and 30% of DoD, we can see that the battery is on the edge to reach the lifetime of TARANIS (4 years expected), if we want to keep 70% of nominal capacity.

![Figure 10: Battery capacity variation](image)

The capacity of battery has a major impact on the safe mode transition. In case of too low level of capacity, it will be impossible for satellite to reach the safe mode. The figure 12 present the electrical behavior in case of transition to safe mode at the end of life electrical parameter (ie battery capacity, solar panel capacity). We can see the complete discharge of the battery due to the fact that the initial capacity was too low (10 Ah) with reference to the system consumption.

The figure 13 present a safe transition which is successful, with a maximum discharge of battery of 69%, usually we do not authorize to go more than 80% of DoD.

To have successful transition, and due to strong power consumption hypothesis, we worked on the margin, especially on thermal control margin, to minimize them at the maximum acceptable by all experts. Particularly, we did not take the usual case of “No solar flux in space” into account for thermal consumption.

In 2018, the power budget situation is well better. Actually we have a refined payload consumption of 63W. The system margin has decreased to 10% because of the consumption measurement on Flight Model instrument during satellite integration. It is also important to notice, that the reduction of payload power consumption was possible thanks to the consumption monitoring described in the following part.
Figure 11: Nominal mode consumption profile just on the limit of MYRIADE capacity – 105W mean consumption for 30 orbits

Figure 12: Unsuccessful safe transition mode
Figure 13: Successful transition mode – DoD reach 69%
Realistic monitoring of Payload power budget

At the end of 2012, TARANIS power consumption was too high for a MYRIADE platform services. The reduction of mission profile was a solution on electrical point of view, but not easily acceptable for scientific concern. It was decided to reinforce the accompaniment of all scientific laboratories involved in TARANIS payload design.

This accompaniment was not a direct control of laboratory work, but was more a precise knowledge of consumption hypothesis. The aim of this knowledge was to drive the payload consumption hypothesis in a realistic point of view. Usually on other space program, electrical architect allocates a consumption with margin and do not follow directly the designer. Due to low system margin (sometime negative!), the decision to have not a global value but a realistic consumption value was taken. Realistic consumption means that electrical architect knows all margin taken by the designer and also the worst case covered by designer. With this knowledge, we were able to decide if worst case was too severe or realistic, based on our historic knowledge on MYRIADE satellite behavior in orbit. For example, the real thermal behavior of previous MYRIADE mission (DEMETER, PARASOL, PICARD) authorized us to decrease the worst case temperature range, to be able to have a consumption of electronic component in an IN-FLIGHT situation.

![Figure 14: Consumption monitoring file](image)

This monitoring allows the project to authorize a nominal scientific mission (ie between +/- 60° latitude).

**EMC CONSTRAINT**

**Payload harness management**

On TARANIS payload, 3 of the 8 instruments are EMC measurement instruments (see payload chapter in this article). Due to the compactness of payload accommodation, harness constraint was severe:

- To guarantee no EMC radiative effect from harnesses to EMC instruments
- To guarantee no EMC radiative effect from other instrument to EMC instrument harnesses
- To make possible the integration of harness on payload (see figure bellowed): the overshield of all harness induced severe mechanical constraint (size, routing, ground connection).

![Figure 15: TARANIS Payload harness](image)

It is usual to have overshield on a harness considered as external of satellite structure, but in the case of TARANIS, the compactness of payload due to launcher constraint, has needed a specific work on harness routing and design. Particularly, the shield has to be connected to ground structure every 50cm in order to limit the radiative effect at 100MHz.

**High integration constraint**

A major point on EMC management, was the impact of compactness of payload on auto-compatibility between all the instrument. All the data analyzers are located in two electronic boxes named MEXIC 1 and 2. The various data treatment functions are not always compatible. We have:

- analyzer of optical treatment (compression algorithm mechanism)
- Analyzer of particles (particles detection system)
- Electrical Low frequency analyzer
- Electrical high frequency analyzer (up to 35 MHz)
- Magnetic analyzer (from DC to 3 MHz)

Each one of this treatment has specific working frequency and also a specific sensitivity. TARANIS mission tries to characterize phenomenas that are not well known, it means for designer to reduce at the maximum the global electronic noise to ensure a detection of unknown.

In addition to this MEXIC internal constraint, some of the scientific sensors require some specific ground connection, which induce non controlled EMC noise.

For all this reason, EMC team on TARANIS mission has made a lot of measurement since the beginning of design in order to guarantee a “best effort” policy of all actors. The main difficulties of early measurement are to have a realistic accommodation and result. In 2012, we have made a big campaign of measure on EM (Engineering Model) to be as much as possible near of final accommodation. Indeed, the next real measure will be on
Flight Model, integrate on satellite, which mean very late in development time, right before launch.

These measurements allow us to be confident and detect eventual problem on flight model. The test made was:

- Transient and frequency susceptibility
- Conductive and radiative emission
- Conductive and radiative susceptibility

These 3 steps are classical EMC tests for space project. The particularity of TARANIS was to make these test on EM a long time before Flight Model. Figures 16 and 17 show example of results for radiative and conductive emission.

![Figure 16: Conductive emission spectrum of MEXIC 1](image1)

![Figure 17: Radiative emission spectrum of MEXIC 1 & 2](image2)

With these measurements, we have analyzed which instruments generate noise upper than the global EM instruments sensitivity (IMEHF, BF, MF). Thanks to that, we have made some modifications on analyzer design (MC analyzer for example). Another important test was the internal compatibility in MEXIC boxes. In the same sequence of test, using frequency noise injections, we were able to test the internal sensitivity of all MEXIC analyzer. At the output of test we made the figure below:

The table (figure 18) show the instrument sensitivity during test. It allows scientists to better understand their detection algorithm and induce modification in design.

**Figure 18: auto compatibility result on EM test**

**DATING CONSTRAINT**

In nominal, MYRIDE satellites do not use a GPS system for dating purposes. The system uses a TTC synchronous system named “TOPTC”. This mechanism with the ability of On Board Computer to capture the time at 1ms, induces a nominal performance of +/-15ms absolute dating time for event comparison between ground and satellite.

On TARANIS mission, one aim of payload is to compare luminous events in different science area (light, particle, EM) with ground measurements when possible. To achieve this comparison, the precision requires between events detection on ground and on board has to be better than +/-1ms in absolute. A modification of dating has to be done to reach the performance:

First modification was to adapt the On Board Computer. This modification consists to change a size register in FPGA, but with the constraint of maintaining compatibility with other MYRIDE mission (expected for quality management and ground segment system).

Second modification consists in compensating the drift of internal oscillator. To achieve this point, a mathematical model of oscillator behavior has been done in Flight Software (figure 19). This model has also to take into account all bias (static and dynamic) in order to have the best On-Board Time.
Thanks to all mechanism added, we reached to have an absolute dating better than 1ms (we expect 0,1ms)

CONCLUSION

TARANIS mission is based on MYRIADE satellite, which is well known in CNES. Thanks to this knowledge, CNES team have achieved to “push the boundaries” of MYRIADE platform, which was initially design in 2002.

The adaptation of an existing platform on mechanical, electrical, avionic and EMC aspects required a strong knowledge of the platform technical parts.

It was also possible because MYRIADE was the first small satellite based on “On The Shelf” components, and was one of the first “low cost” satellite without redundancies. This “spirit” of MYRIADE allows the engineers to know the margins and the risks they can take, because technical design was made by CNES.

At the beginning, MYRIADE was designed to be used by scientific mission which has low budget. The ultimate objective of Taranis is the scientific characterization of unknown or little-known phenomena, that is why all the teams worked first to serve this objective, which meant having to leave the usual margins and accept to take risks.

REFERENCES


3. Bailey, J.C., and R.J. Blakeslee, Diurnal Lightning Distributions as Observed by the Optical Transient Detector (OTD) and the Lightning Imaging Sensor (LIS), AGU Fall meeting, San Francisco, 2006.


7. T. Cussac, F. Buisson, M. Parrot, The DEMETER program: mission and satellite description – early in flight results, 55th International Astronautical Congress, Vancouver, 2004