CNES miniaturization policy: an answer to Nanosatellites challenges

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ABSTRACT

The reduction of mass and size with improvement of the performance of a device is a permanent challenge for the space industry. The French National Space Agency has funded hundreds of R&D activities in the past, in all dedicated technical areas to facilitate these kind of technological evolution. Miniaturization efforts have, more recently, encountered a growing field of application, the one of Nanosatellites. For these applications, performance/cost trade-off is largely dominated by full cost, that is to say the cost including the entire satellite system development, from the initial idea to the end of life, including operations, data processing and its distribution. The carried out trade-offs are therefore based on a different constraints environment, in which the risk variable is systematically re-evaluated considering the cost/performance couple; the methods, the development process and the planning of delivery being directly impacted by this challenge.

In this logic, and while continuing its efforts to miniaturize and improve performance for conventional markets (Earth observation, science, telecommunications, ...), CNES has adapted its working environment around the Nanosats domain to accelerate the development of adapted solutions. This adaptation being made both in terms of new development processes and of use of new COTS technology for equipment themselves. Moreover, projects in New Space are changing the historical relationship between CNES and its industrial partners and are encouraging a transition from a client/provider approach to a more co-partners approach. The objective of success for both parties implies active collaboration. Together, CNES and industrials manage to anticipate difficulties and accelerate project schedule.

The article presents the state of the current activities around the Nanosat environment by specifying the origin of these activities and the trends that are pursued for the future.

MINITURIZATION POLICY: TOWARDS THE NANOSATELLITES NEEDS

As a technical driver for space activities in France, CNES has always stimulated the industrial ecosystem to reach new levels of performances. For a long time, CNES strategy for its missions consisted in offering more miniaturized equipment and instruments, but always with a high degree of priority regarding performance improvement. For example, Spot-like Earth observation missions (Figure 1) have been optimized according to the performance/cost trade-off, while guaranteeing a drastic improvement in resolution.

As soon as 1998, CNES developed a new product approach showing a clear desire of facilitating access to space for missions with a smaller scale of performance than A-class missions. This is similar to the approach originally developed for the nanosatellites. It has led to the definition of a generic multi-mission platform called Myriade. The development of the platform has been driven to allow carrying 25 to 50 kg instruments fitting into an almost standardized pattern in order to reduce the recurring cost of production.

The platform is composed of a set of functional items that can be upgraded independently to be adapted to institutional missions for CNES or other French administrations and to commercial or foreign institutional missions. The Myriade platform was declined by CNES and its industrial partners through a tens of missions. DEMETER in 2004 (study of Earth electromagnetic environment) was the first microsatellite of the series, soon followed by PARASOL (characterization of the radiative property of clouds and aerosols) the same year illustrating the flexibility of this new approach and the benefits for projects.

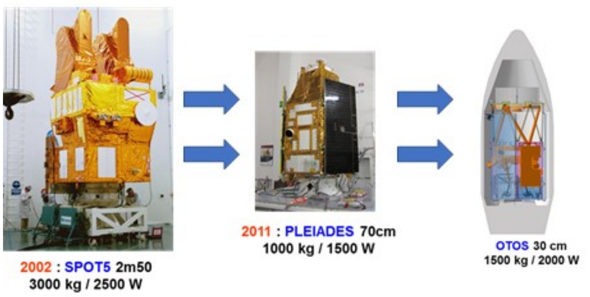

Figure 1: Example of payload miniaturization for Earth Observation missions

The Myriade satellites were the first step towards the nanosatellites philosophy: generic platform with flexibility for the subsystems and the payloads.

Figure 2: Myriade satellite in an open configuration

At the same moment, another level toward nanosatellites was being reached with development of activities requiring extreme miniaturization like for instance, proximity links for space exploration missions, typically InterSatellite Link (ISL) between an orbiter and a small lander.

In that type of mission, the lander presents the same very strong constraints than a nanosatellite such as minimum allowed consumption, very limited mass and volume while providing reliable performances. These constraints were applied to the first S-band antenna and ISL equipment for Rosetta mission [1]. This equipment was then adapted to be reused for the Myriade satellite family as a TT&C subsystem.

This miniaturization and generic platform approach were initiated without specifically anticipating the nanosatellite market expansion but they were two essential steps towards it.

Universities support and JANUS project

The actual first CNES steps into the nanosatellite domain were the implication in academic projects in order to provide space expertise and arouse vocations. As soon as 2006, CNES worked with some universities (Montpellier, Paris Diderot, …) to develop and build the first French students nanosatellites.

Facing a growing enthusiasm in the educational community with respect to this new satellite format, the initiative of a national support structuration was taken leading to the JANUS program in 2012. The latter proposes to transmit knowledge and space enthusiasm to students of universities and engineering schools to manufacture their own nanosatellites [2].

CNES provides a multi-layer support beginning with a supervisory staff including three engineers: a project manager, a system manager and an expert in space technics. It provides also an engineering support in various fields of space activities depending on the project's needs (RF, ADCS, thermal studies, energy, …), conferences and courses, presentation of CNES activities, presentation of French Space Law regulations, teachers and students training about methods and tools used by CNES to design space systems (satellite and ground segment). Until today more than 500 students and teachers have been trained and the number of initiatives in French universities and schools is increasing. Three nanosatellites have already been launched (Robusta 1B, Xcubesat, SPaceCube), and 6 others are in C/D development phase or ready to launch.

STARTING OF NANOSATELLITE ACTIVITIES

From external support to internal developments

In the framework of JANUS project, the support to specific satellite components like antennae or TT&C (Telemetry, Tracking & Command) transceivers has led CNES to start internal technical activities with Research and Development (R&D) budgets. Industrial partnerships were initiated with small firms mostly, to develop new range of products adapted to nanosatellite format at reduced cost.

Year after year, the development of nano products has reached many of the CNES technical departments (antennae, onboard electronics, power management, …). For instance, CNES started developments on miniaturized antennae for small platforms in the 2010's (spectrum survey, MASCOT, a lander collecting scientific data at the surface of Ryugu asteroid which successfully landed on 3rd October 2018 [3]). More recently, compact and wideband antennae for TT&C were designed, manufactured and tested for cubesats needs. Some efforts were made also on the TT&C transceivers and HDRT transmitter in collaboration with industrial partners [4][5].

In order to provide a good environment of development, CNES started also internal activities to provide a support to multiple partners such as quality analysis of new components and emission of recommendations in various fields (e.g. electromagnetic compatibility, space radiations).

Nano subsystems to improve nanosatellite design

The process of subsystem functions miniaturization gradually led to an integrated and centralized architecture in which the On-Board Computer (OBC) is the central piece.

The avionics architecture of satellites, including nanosatellites, is one of the most critical subsystems to be designed.

In the framework of JANUS program, for the need of a student nanosatellite, EYESAT programmed to be launched by the end of 2019, a first development of integrated avionics in the OBC was achieved. The Ninano board was born. A previous study for avionics optimization on small platform has shown that the Attitude and Orbital Control Systems (AOCS) processing could be integrated in the OBC. On the other hand, some components like the star tracker optical head are mounted on suitable part of the satellite but all the data are routed to the OBC where the computation is done.

The Ninano board benefited from the inheritance of several CNES R&D activities allowing the validation of innovative concepts and the use of new COTS technologies (Commercial Off-The-Shelf). Systems on Chip (SoC) coming from automotive industry associated to modular FPGA (Field-Programmable Gate Array) conception and a software architecture strategy allowed optimizing the resources distribution and the software sequencing for the different integrated functions in the OBC. Thanks to this modular approach, students could work independently on different functions which were then integrated in the OBC.

The step forward was to continue the functional integration and to do so, to continue the work of miniaturization for servitude functions. The feedback on Ninano board development was essential for the optimization, adaptation and integration of the GNSS (Global Navigation Satellite System) receiver in the OBC.

Nano payload to address nanosatellites mission needs

The arrival of Software Defined Radio (SDR) technologies at the beginning of the 2010's allowed the growing of new perspectives for miniaturized payloads or integrated subsystem functions. The example of a radiofrequency payload is given below illustrating the general philosophy promoted by CNES.

Electronic architecture of radiofrequency payloads lies on the expertise on radiofrequency stacks and on embarked Digital Signal Processing (DSP) implementation. Their miniaturization goes hand to hand with optimization of the overall RF architecture and of the digital system in charge of the signal processing in order to guarantee high performances while addressing the constraints of mass, volume and power consumption.

A development in several steps was needed to reach the best final product.

The first step was the unitary modelling of elementary functions. For that, evaluation boards from mass market were used allowing the validation of architecture choices. Then, an SDR prototype platform was developed called Serpentine. It integrates all the RF and digital interfaces and thanks to its powerful SoC, several digital signal processing applications could be evaluated. In order to allow payload functions validation and fine adjustments, the Serpentine board is representative of the payload architecture (PCB technology, key component choice, interfaces, …). This test-oriented approach has allowed very soon in the development making design choices and contributing to risks mitigation.

The second step consisted for the payload in moving to the nanosatellite format based on an SDR approach. Directly benefiting from Serpentine inheritance, Spectrolite project aimed at providing RF payloads fitted to nanosatellite format.

Reprogrammable components flexibility used in SDR architecture allows versatile design and final application definition during the programmation. Thus, the same SDR platform can be used for different applications. RF or electronic functions needs to be defined earlier in the project than DSP or software but the use of programmable transceivers gives flexibility to RF-DSP interfaces.

Beyond the innovative technological aspect using SDR, the innovation lies also on the development method used for the payload which was wanted to be flexible within a time-constraint schedule. A SCRUM agile method, usually employed for software development, was adopted for Spectrolite for the whole RF, DSP, electronic and software developments which was a first for CNES payload development projects. With this type of method, the relationship between providers and customers is different. They are both implicated within an integrated team and work together, with pragmatism, for a good project development. As the project progresses, some specifications can be reevaluated to redefine the fair needed margins. The method implementation was achieved with the support of a coach. As the project started, he has trained the provider-customer team in order to bring them the elementary notions and rules. This training has contributed to a team building and stimulated the communication within the team during the project.

The Spectrolite project purpose was the provision of flight models for a spectrum survey payload without identified flight opportunity.

This opportunity finally came with the NESS project beginning before the end of Spectrolite project. NESS is presented in a further chapter of the article. The overlapping of both projects has induced new specifications towards the Spectrolite payload. They could be simply taken into account thanks to the Agile method used for the project and the segmentation of the activities in methodical and elementary concise tasks (Sprint).

This easy integration of new specifications during the project development has revealed the benefits of using such a method to develop nanosatellite payload.

Nanosatellite missions study

In parallel to all these activities, CNES has mobilized its internal prospective structure to study complex missions based on nanosatellites. The purpose was to identify the existing and non-existing parts of the mission to then, confront the results to the on-going equipment roadmaps. If there was a hole in the racket, strategies could be updated.

The results of these studies have shown concept feasibility for LEO or lunar missions implying numerous nanosatellites working together to reach the mission target. If these concepts are first of all seen as technological demonstrators, the foreseen onboard scientific payloads have a true added value and can bring a new way of doing science in space, for instance interferometric measurements.

Two examples of fulfillment of these studies are presented below.

CNES STRUCTURAL EVOLUTION

After years of academic initiatives support, elementary equipment developments and upstream studies, CNES decided in 2016 to start R&D projects to support the emergence of nanosatellite applicative programs both at payload and satellite levels. This evolution marks the CNES will of materializing all the work of the last years.

ANGELS

ANGELS (Argos Neo on a Generic Economical and Light Satellite) is the first nanosatellite project decided by CNES and going out of the scope of JANUS program. In 2016, after several months necessary to define the project requirements and to handle a call for tender, NEXEYA has been selected as prime contractor to develop the 12U nanosatellite demonstrator and its associated ground control center. ANGELS is currently under development since mid-March 2017 and will carry the ARGOS Neo instrument developed by Thales Alenia Space and Syrlinks [6].

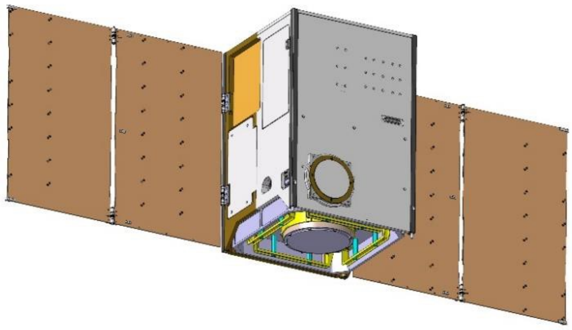

Figure 3: ANGELS nanosatellite

This project has brought multiple challenges to the implicated teams for the nanosatellite platform along with the embarked payload and the way the overall project was managed.

The ECSS provides guidelines for Product Assurance down to class 3 projects or instruments. Below the class 3 there is no specifications. A dedicated Product Assurance approach was defined for the ANGELS demonstrator, to be the baseline of future CNES nanosatellite missions within a demonstrator approach (trade off reliability vs risks). It is based on a short mission duration (2 years), a challenging development time (30 months), a reasonable performance mission (availability) and a medium authorized risk level. It allowed the sought reduction of size, weight, power and cost as well as the processes simplification.

The nanosatellite platform design privileged the use of COTS equipment but some specific developments also based on COTS components were necessary, in particular for critical equipment such as PCDU (Power Conditioning and Distribution Unit) with alleviated process for the equipment qualification status review.

The embarked payload is a miniaturized Argos equipment. The Argos system consists of radio transmitters called PTT (Platform Terminal Transmitter) fitted on anything that needs to be tracked, from a boat or buoy to an animal (bird, cetacean, turtle) or even a mountain peak. These radio transmitters provide signals received by Argos instruments orbiting Earth on several sun-synchronous polar satellites. The signals are recorded and then downlinked to the Argos processing center through a ground station network deployed all around the world. Then the sensor data and location of each Argos PPT are distributed to the final users.

The miniaturization was a big challenge and made use of very compact COTS components offering data processing, memory and RF capacity. Some of them were already integrated in prototypes funded by CNES R&D and some feedback was available. A priority was given to the reuse of existing functions such as Argos signal processing core from Argos 4 instrument developed by TAS-F, COTS software drivers or FPGA IPs.

The choice of the industrial partners was also crucial to benefit from their experience in the domain of miniaturization and having tests facilities at their disposal. Meanwhile, CNES provided its expertise from a wide range of technical domains: analog and digital electronics, radiofrequency, mechanics, thermal science, space environment and component quality, Argos laboratory, software & command/control, …

The continuous implication of CNES human resources, from hardware and software conception to integration, validation and qualification, allowed a delay reduction needed to fit into the foreseen schedule.

In-orbit validation of the ANGELS satellite in early 2020 is part of the program objectives. Lessons learned will be extremely beneficial before adapting or generalizing this strategy for other CNES project types.

NεSS

This project is one step further in the direction of adapting the way projects and payloads for nanosatellites are managed and comes as the final step after Serpentine and Spectrolite projects previously mentioned.

NεSS or N3SS stands for Nanosatellite 3U de Surveillance du Spectre or Spectrum Survey 3U Nanosatellite. It started at the beginning of 2019 with a small project team (4 people). Like ANGELS, this project is the fulfillment of a CNES internal study.

The platform and the payload must be distinguished in the way they are developed.

The NεSS satellite platform directly inherits from ANGELS approach. The Product Assurance (PA) is nevertheless not used as is, but confronted to the constraints of the selected industrial to provide an optimized PA the closest to the project needs in terms of costs, schedule and available human resources.

The payload was already being developed within the framework of Spectrolite project when NεSS started, as explained previously.

The payload is managed according to an agile method which is new compared to ANGELS payload. The typical Preliminary Design Review (PDR), Critical Design Review (CDR) or Test Readiness Review (TRR) meetings are replaced with key point meetings possibly dealing with different levels of maturity for the project aspects. There is no need to wait on the same level of maturity for all the aspects to keep moving on the project schedule. This way of proceeding implies some difficulties while providing a high flexibility. Indeed, the specifications are gradually validated with the incremental project progress after non-regression validation. An example of the flexibility is given by the way the documentation is managed. In the ECSS, some documents are compulsory and implies review with RIDS and experts. With the agile method, several documents are initiated, some of them still being compulsory (Interface Control Document, User Manual, …). The reviews with experts are replaced by Sprint meetings with dedicated objectives to be dealt with which allows answering questions and providing expertise more rapidly.

THE PERSPECTIVES

In line with current nanosatellite developments that have already made possible ambitious demonstration missions, CNES is continuing its efforts to accelerate the maturation of next-generation technologies by relying on target demonstration mission objectives which contours remain pretty open. Two types of mission are under consideration.

The first type uses a single-satellite solution, the second puts forward the capabilities of a distributed multi-satellites instrument for scientific mission needs.

High performances nanosatellite demonstration

A first demonstration mission is to provide additional satellite survey to the French National Frequency Agency (ANFR) ground solutions to assess the state of mobile telephony station networks, including various generations types (From 2G to 4G and potentially to 5G). A preliminary study phase will start in September 2019 to better specify the mission outline and the possible technical solutions. The first results obtained with the support of Airbus Defence and Space France in the framework of several CNES R&D activities, show that a very powerful on-board processing is needed and could lead to SDR components use which are much more efficient than the current solutions. The need for an antenna, in the different desired frequency bands, having enough gain in order to reach the receiver sensitivity may also require a new efficient unfoldable solution. This type of challenging mission demonstration is also foreseen to validate a technology maturity and consider several other mission applications.

Scientific missions

The effect of miniaturization and the fast development of a very efficient dedicated technology like SDR, suggest that a high number of operational or scientific missions are already accessible with satellites of a few tens of kilograms. Current thinking on new scientific missions is now also based, for example, on the use of a nanosatellites swarm to produce a very large distributed instrument like imagined during NOIRE study (Nanosatellites pour un Observatoire Interférométrique Radio dans l'Espace / Nanosatellites for a Radio Interferometer Observatory in Space) [7]. The idea is to analyze the feasibility of an in-orbit low frequency observatory to cope with large signal absorption in the atmosphere encountered by ground-based radio interferometers in the low frequency bands (few kHz to 100 MHz). The distribution principle on several satellites raises new issues such as mission programming, autonomy, inter-satellite links, all kind of subjects already studied within NOIRE study.

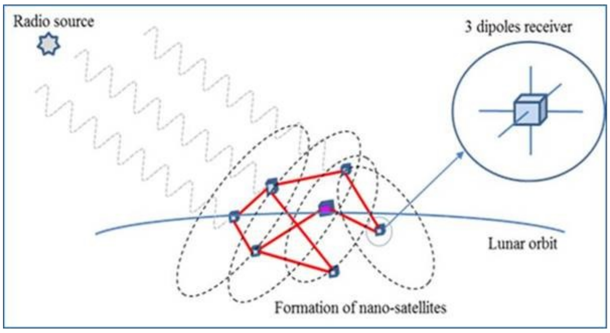

Figure 4: Satellite NOIRE network configuration

Within the swarm each node is a sensor and all sensors must be used together to obtain a measurement (Figure 4). Engineering and instrument development must be jointly studied:

- System principle and concept, number of nodes in the swarm, relative position, mode of communication,
- Space and time management (ranging, clock synchronization)
- Distributed or centralized calculus processing
- Overall and relative flight dynamics between nodes
- Telecommunication between nodes and with ground
- Measurements and processing
- Propulsion
- Electromagnetic compatibility.

Regarding the possible design of the payload, the synoptic of a generic front-end architecture and processing functions is proposed to cope with other possible future missions (Figure 5). A full front-end digitization is associated with a powerful FPGA/SoC in charge of signal processing. The data stream is routed to the Digital Processing Unit (DPU) which manages all further processing.

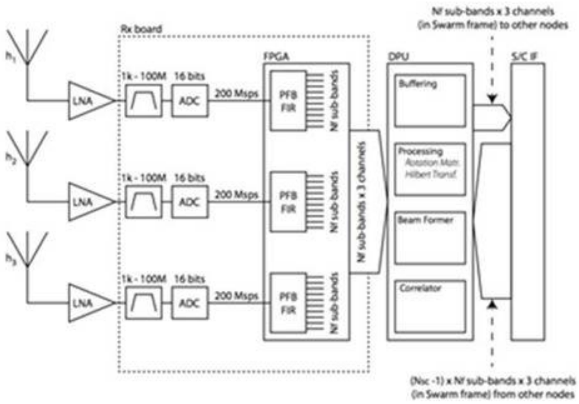

Figure 5: Typical payload architecture

This mission is particularly representative of the challenges to be covered in the medium/long term to open up to the nanosatellite sector, an enormous field of applications on which CNES is already working on.

CONCLUSION

This article retraces the CNES strategy about miniaturized platforms and payloads. It has been seen that constant efforts were put, since twenty years, in providing always smaller payloads or platforms while enhancing the performances. These efforts particularly fit the nanosatellite market that emerged ten years ago. The article detailed the different and evolving strategies over the years, from miniaturization of Earth observation missions to ambitious multi-nanosatellites missions by the way of integrated SDR payloads.

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