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# ANGELS, Opening the Door of the French NewSpace

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## ABSTRACT

In December 2019, ANGELS, the first nanosatellite designed and developed by French industry, supported by the French Space Agency, CNES, was launched from Kourou. Development and qualification of the satellite were achieved in two and a half years: quite a challenge!

The ANGELS demonstration mission was set up as a co-funded partnership between CNES and Hemeria in order both to validate new technologies and to promote the "new space" approach. Thales Alenia Space & Syrlinks led the team in charge of the Argos Néo instrument payload. The data collected for two years now show that the chosen compromise was the right one. The satellite provides operational class performance at a fraction of the cost of previous versions of the Argos system.

The first technical challenge has been met: the size of the satellite is 22 cm x 22 cm x 35 cm, the weight is less than 20 kg although housing the Argos-Néo instrument. The latter is a demonstrator much smaller than its predecessors; it is also ten times lighter (1.5 kg) and requires three times less energy. Thanks to breakthrough technologies developed by Hemeria, Thales Alenia Space, Syrlinks and seven other industrial partners, ANGELS proved in orbit its new miniaturization design and its high capabilities.

Much beyond the original demonstration target, ANGELS with its Argos Néo instrument ensures an operational service to the Argos user community. It is now part of the existing Argos operational constellation whose Mission Center is operated by Kinéis. It collects Argos beacon messages used for environmental monitoring and wildlife tracking.

Management, design, development and validation, use of miniaturized commercial components, smart risk strategy to reduce costs and lead times, operational concept... almost everything was revisited through ANGELS. To carry out this mission, CNES and Hemeria jointly worked as a single team collocated at Hemeria Toulouse facilities. Twenty-five engineers were involved in the project, including five CNES engineers who brought their expertise and knowledge to achieve the platform hardware and software development, the satellite assembly, the development of the control center and the simulator for operations.

ANGELS has now completed two years in orbit, meeting the initial lifetime requirement. It has proven its reliability, service lifetime and operability. Considering this success, CNES decided to extend the satellite lifetime by two and a half years, thus leading to 4.5 years total!

The paper addresses the ANGELS mission and presents the system and the satellite design. It gives an up-to-date status of the satellite and provides in-orbit feedback. It focuses on the different elements that contributed to the success of this challenging program, while having a development approach driven by cost and schedule on one hand and by risk control on the other. Thus, the paper elaborates on lessons learned concerning product assurance strategy, innovative development approach and new working methods that were set up in line with the specific constraints of a nanosatellite combining low cost, quick development, in-orbit technology demonstration, high performance and users' operational expectations.

## GENERAL CONTEXT

In 2016, CNES decided to qualify a new nanosatellite platform concept to support French industry and to encourage the emergence of the French NewSpace ecosystem with a nanosatellite platform at low cost, in record time and with satisfactory performance.

The project was initiated in 2017. CNES selected HEMERIA to develop an in-orbit demonstrator called ANGELS (Argos Néo on a Generic Economical and Light Satellite) because it houses an Argos miniaturized instrument on a nanosatellite platform for a low-cost program with a challenging schedule.

After two and a half years of development and ground validation and qualification, ANGELS was launched on December 18$^{th}$, 2019 from the French space base in Kourou.

## ARGOS SYSTEM

The Argos system is a global system for data collection and beacon location by satellite. The Argos system makes it possible to independently locate beacons anywhere on the surface of the Earth. An Argos beacon can be installed on a sailboat, a lifeboat, buoys, a drifting automatic weather station, a skier, an animal, etc.

Initiated in 1978 by CNES with the U.S. National Oceanic & Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA), Argos was historically operated by CLS (Collecte Localisation Satellites) and is now operated by Kinéis. Currently, there are also other government institutions actively involved like EUMETSAT (EUropean organization for the exploitation of METeorological SATellites) and ISRO (Indian Space Research Organization).

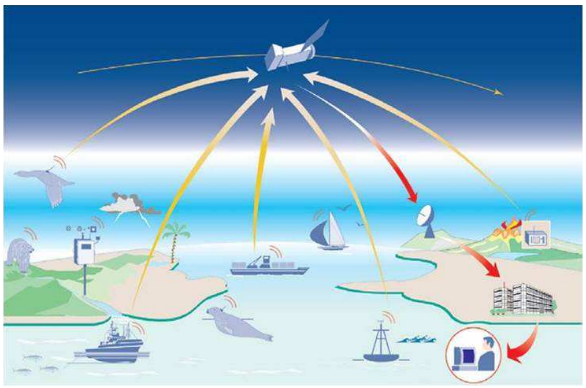

**Figure 1: Argos system principle**

The reference Argos constellation is based on three orbital planes with a minimum of one satellite per plane following sun-synchronous polar orbits. The local time for the ascending node of each orbital plane is: 13:30, 17:30 and 21:30 respectively. The local time at ascending node of the ANGELS orbit is 5:30.

## ANGELS MISSION

ANGELS is a demonstrator which, in addition to its in-orbit technological & concept validation role, was originally foreseen to ensure a Gap-Filler to the SARAL satellite on the same orbit.

### *System architecture*

The ANGELS system is composed of:

- The Flight Segment. In the form of a 12U nanosatellite (226 mm x 226 mm x 340 mm) of less than 20 kg, it consists of
    - The platform: developed by HEMERIA
    - The payload: developed by Thales Alenia Space and Syrlinks, Argos-Néo

is a new generation miniaturized Argos instrument.

- The Ground Segment including
    - The Command and Control Center, in charge of uploading commands and monitoring the satellite
    - The Satellite Simulator
    - The CNES S-Band Stations and related mission services
    - The Payload Mission Center (CTA, Centre de Traitement Argos) located at Kinéis
- Launcher and deployer device

The ANGELS system architecture is summarized in the figure below:

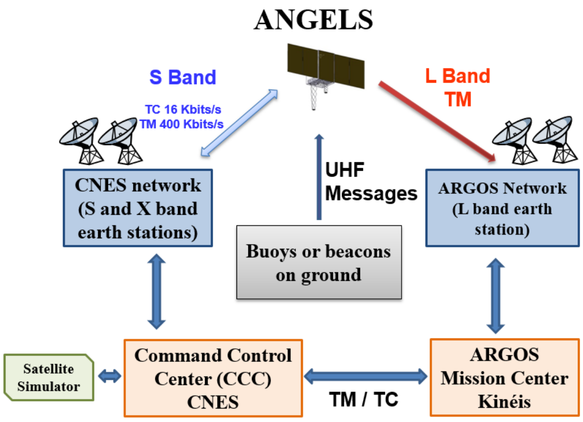


**Figure 2: ANGELS system architecture**

### *Platform architecture*

Despite its small size, the ANGELS platform is composed of subsystems similar to those of traditional satellites:

- The Data Handling Subsystem (DHS) consisting of a Main On-Board Computer (MOBC) and the Main Flight Software (MFSW)
- The Electrical Power Subsystem (EPS) consisting of solar arrays, battery modules and a Power Conditioning and Distribution Unit (PCDU)
- An Attitude Determination and Control System (ADCS) consisting of a reaction wheel, a sun sensor, magnetorquer bars and a magnetometer. A star tracker is implemented on ANGELS as a technological demonstration passenger. It is not used in the Attitude and Orbit Control System (AOCS) loop but it provides feedback for future missions that will use the same sensor
- The positioning Subsystem consisting of a GNSS (Global Navigation Satellite System) Receiver and its antenna
- The Radio Frequency Control Subsystem (RFCS) consisting of a transceiver and two S-band antennas
- The Thermal Control Subsystem (TCS) consisting of thermal sensors and heaters to regulate the satellite temperatures

It is to be noted that ANGELS does not host any propulsion system.

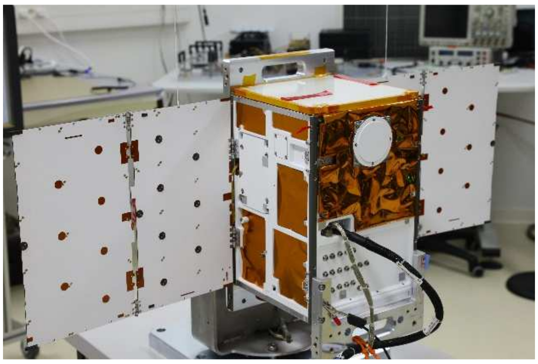

**Figure 3: ANGELS nanosatellite**

### *Payload architecture*

The Argos Néo payload is composed of:

- The ARGOS reception subsystem that captures and processes beacon messages received from Earth in UHF bands. It is composed of an antenna and an electronic module.
- An L-band telemetry subsystem to download mission and housekeeping payload data.

For the purpose of miniaturization, the electronics boards of the two subsystems are commonly integrated in the same electronics module.

The Electronics module, based on a custom Software Design Radio (SDR) approach, integrates in a 200 mm x

100 mm x 45 mm volume the software beacon processing and telemetry generation on low-cost miniaturized commercial components (RF transceiver, system on chip). Such an approach naturally required several mitigation techniques to guarantee a final high level of availability.

**Figure 4: Argos Néo electronic module**

The CNES designed dual-band miniaturized antenna offers both UHF band reception and L-band transmission capacity in circular polarization in a volume less than 210 mm x 210 mm x 42 mm.

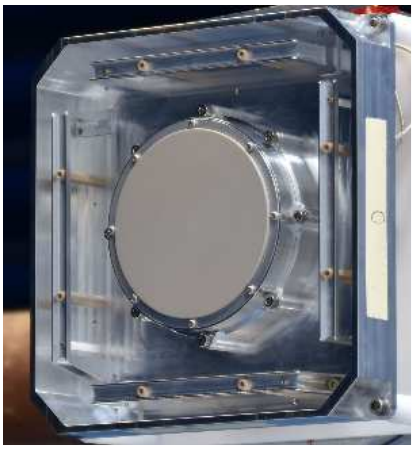

**Figure 5: Argos Néo dual-band antenna**

## ORGANIZATION

CNES was the customer of the ANGELS mission and selected HEMERIA as prime contractor. HEMERIA developed the platform and performed satellite integration and testing while CNES was in charge of mission interface, payload delivery, launch provision and operations. To develop the satellite, HEMERIA relied on partners and subcontractors such as CS-Group, Mecano-ID, EREMS, STEEL, Spacebel and SAFT.

Currently, CNES still operates the satellite in orbit; Kinéis and CNES jointly exploit and monitor the payload and HEMERIA monitors the platform.

## STATUS OF THE SATELLITE

After two years and a half in orbit, ANGELS is healthy and has not experienced any hardware or software anomalies, so far.

### *Platform in-orbit feedback*

The platform availability calculated on the first two years of the mission is 99.39%. Radiative events as well as MOBC resets occasionally occur but do not affect the service that the platform provides to the mission thanks to the mitigation strategy.

All avionics equipment units are operational. Because the PCDU and Central Flight software are uploadable, some functionalities have even been improved since launch.

### *Payload in-orbit feedback*

As for the platform, the payload gives a high level of availability thanks to the mitigation strategy. This level of > 99.9% is very high despite numerous radiative events observed in orbit. The design is able to detect and mitigate these events, by their different nature, while it includes them in the telemetry for ground post-analyses. Validating this functionality is also one of the roles of the demonstrator.

Numerous radiative events occur on embedded commercial electronics without significant impact on Argos service performance (data collection & beacon location) and availability.

The following illustration maps one type of radiative events detected in-orbit by Argos Néo (see triangle symbols mainly located on north and south poles and within the South Atlantic Anomaly):

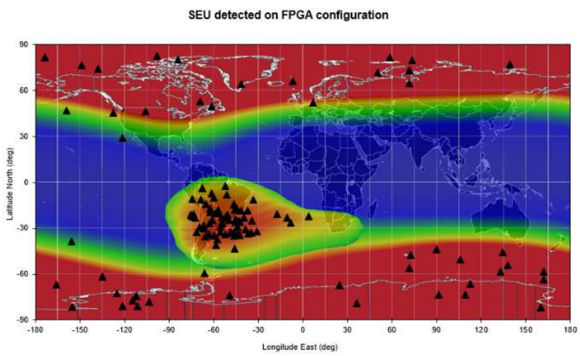


**Figure 6: in-orbit radiative events location detected by Argos Néo**

Performance is not disregarded either – Argos Néo has met or exceeded expectations on all objectives. Very accurate comparisons have been possible thanks to another operational (legacy) Argos payload operated from the SARAL (Indian) satellite; on an orbital plane close to ANGELS'. Thus it has been highlighted that the number of received Argos beacon messages with Argos Néo is quite consistent with SARAL.

### *ANGELS within the Argos satellite fleet*

Given the performance demonstrated during its flight acceptance review, Kinéis decided to integrate ANGELS into the fleet of in-flight operation Argos instruments. So, on top of its demonstrator role, ANGELS is now part of the Argos constellation ensuring operational service to the Argos user community.

### *ANGELS as an in-orbit laboratory*

Thanks to the SDR technology used in the Argos Néo payload on board ANGELS, CNES decided to reconfigure the RF front end in order to assess the radiofrequency activity in different bands. To do that, a new version of the payload software, provided by Thales Alenia Space and Syrlinks, was uploaded in orbit (enabling new RF transceiver configuration, FPGA firmware, CPU software), ensuring the capability to both perform spectral analysis of the frequency bands and process ARGOS beacon messages in a new sub-band.

Different spectral analysis campaigns were carried out by Kinéis over the period from December 2021 to March 2022, providing very interesting preliminary results, which will be very useful to Kinéis for the opening of future frequency bands and the deployment of future Argos beacons in these new frequency bands.

## LESSONS LEARNED

### *NewSpace approach: an innovative development methodology*

Challenges on the ANGELS program were multiple. The first one was to realize the project with a very tight budget and schedule. Another challenge was to build, through the ANGELS demonstration, the technical bricks for future nanosatellite platform product lines, and future Software Defined Radio product lines, too. To succeed in these challenges, specific working methods and an innovative development methodology have been implemented:

- At the satellite level, the architecture has been simplified to the maximum. The satellite does not implement any redundancy. Functionalities not essential to the ANGELS mission were not implemented. For example, ANGELS does not have a propulsion system.

- Reviews / key-points were reduced to the strictly necessary. During the Preliminary Design Review (PDR) and the Critical Design Review (CDR), only major points were presented to a reduced panel of skilled reviewers.

- Over-specification has been avoided "as much as possible" thanks to co-engineering specification sessions involving the client and the suppliers. This permitted the team to ensure that the needs were well understood by the suppliers and to make choices together leading to the best cost / performance compromise.

- Short decision loops were facilitated by collocating employees from CNES and HEMERIA in the same open space. This private / public partnership allowed an efficient exchange of skills.

- To save time and money, the satellite validation plan was simplified. Finding a good compromise between taking risk and simplifying the validation was a challenging task!

### *Specific product assurance strategy*

The simplified Product Assurance approach was not very new for CNES which had already initialized, for a long time, cost-optimized quality approaches (for example in the Myriad microsatellite program or for the famous Philae scientific exploration mission). Some simplified and reduced quality processes were available; others have been elaborated on a continuous basis.

The main subject here has been the very high level of miniaturization imposed by the nanosatellite approach. In order to meet this challenge, CNES and industrial partners had to select very integrated and state-of-the-art technologies. Thanks to the CNES R&T program, several technologies had fortunately been individually studied and characterized before the start of the ANGELS project. Consequently, project Product Assurance could focus on essential tests and qualifications at board or equipment level, reducing as much as possible the complexity and duration.

### *Command control center and satellite operations*

The overall concept of operations has been adapted to the smallsat approach, in order to increase efficiency and flexibility. Several means were implemented to keep ANGELS in operational conditions:

- the same simulator and the same Command Control Center were used for operations, system qualification, functional validation and satellite assembly, integration and test,

- the same computer language and the same database were used for the flight control plans and the test plans,

- a flight control engineer was integrated in the project team as a direct contact for the design of the flight software and the operational documentation,

- during LEOP (Launch and Early Orbit Phase) and critical operations, satellite experts are located in the same room as flight control engineers,

- the ANGELS system was designed with the objective to operate the satellite with only two satellite passes (TM/TC) per week,

- operations are processed by a very small operational team during working hours, without any on-call duty, except the first hours of LEOP. Routine operations consist of uploading the transmitter switch ON/OFF plan, determining the orbit and monitoring the satellite.

- routine operations can be performed by teleworking, with a lot of automation,

- quality and management processes are streamlined and responsive.

## LIFETIME EXTENSION

ANGELS' reliability, service lifetime and operability have exceeded all expectations. On the back of two successful years in orbit, CNES and Hemeria signed an agreement to extend the satellite's lifetime for a further two and a half years, thus leading to four and a half years in total. This additional time in orbit will allow the team to acquire flight experience feedback and to observe the aging of the platform in orbit while continuing to satisfy users of the Argos service. The last six months will be dedicated to in orbit experiments.

## CONCLUSION

ANGELS is the result of an exemplary workshare between CNES, Hemeria, Thales Alenia Space and Syrlinks. It is a first step in creating a French NewSpace ecosystem and its related innovative working methods.

The success of the ANGELS mission initiates the development of a French sector of nanosatellites in order to address the booming NewSpace market.

The Argos Néo instrument is the precursor of a new generation of low-cost and highly miniaturized instruments.

The ANGELS flight experiments have enabled the consolidation of the design of future Kinéis satellites, inherited from the ANGELS platform and from the Argos Néo payload. This feedback also secures the high reception sensitivity required for the ARGOS system. Argos Néo on board ANGELS provides high level performance, very similar to the other in-flight Argos instruments, and it paves the way to new solutions in the domain of the Internet Of Things.