GROUND AND BOARD INTERFACE
OF THE NOSYCA COMMAND CONTROL GONDOLA:
AN ADAPTABLE INTERFACE

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1. ABSTRACT

The NOSYCA system - New Operational System for the Control Of Aerostats - is a set of gondolas that provides a reliable and safe command control system for stratospheric balloons. In such a context, the design of NOSYCA is based on redundant systems: redundancies of functions, equipment and communication flows. Particularly, the main operational gondola is based on two on-board computers that are really similar in terms of functions.

If such a concept increases the reliability of the system, it also increases its complexity. To guarantee an easy-to-operate system, to limit modifications on board and ground sides and also to minimize cost, planning and maintenance conforming with a strict development process, the NOSYCA project has chosen to develop a single piece of embedded software and a single TMTC (TeleMetry – TeleCommand) interface.

Afterwards, a well-defined process adapts and configures the embedded software for each on-board computers and the associated TMTC interfaces with the balloon configuration.

2. CONTEXT

The CNES has been launching several kinds of stratospheric balloons for nearly 40 years for scientists who study the stratosphere and perform astronomical observations. Indeed, this kind of vehicle is a true way to access space and cheaper than satellites. It is well-suited to embed heavy and bulky instruments that do not need to withstand the accelerations and vibrations of a satellite launcher at take-off.

However, new constraints have appeared these last few years: operators have to prove officially that they protect the over flown populations and guarantee the protection of goods, persons and the environment.

In such a context, the CNES – Centre National d'Etudes Spatiales – decided, in 2007, to carry out the development of NOSYCA, the New Operational System for the Control Of Aerostats. This system is based on a set of gondolas and on a control centre. It establishes a reliable and safe command control system for stratospheric balloons and moreover, provides the scientists with a high-performance system in terms of data transmission.

3. NOSYCA ARCHITECTURE

A balloon contains a set of gondolas that is under the control of the command control of the aerostat. On NOSYCA, there are three gondolas dedicated to balloon piloting and another one dedicated to the scientific mission.

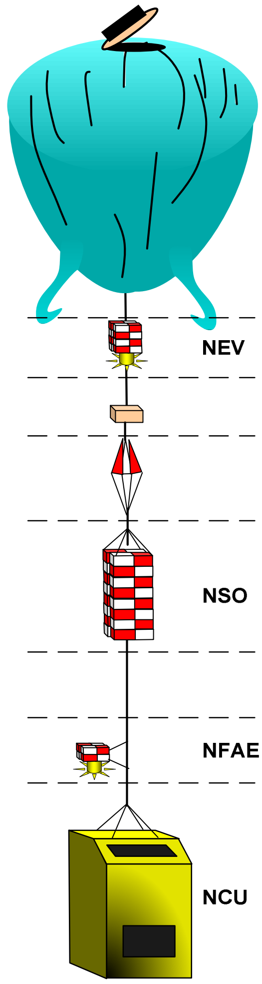

Figure 1 : Nosyca architecture

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3.1. The NSO Operational Gondola

NSO as « Nacelle de Servitude Opérationnelle ».

Overall, balloons of the NOSYCA line have one main gondola. This gondola is linked to a ground control centre and operates onboard actuators to release either gas or ballast. This makes it possible to control the ascent or descent of the balloon from the ground. Moreover, this main gondola contains systems such as GPS or ARGOS in order to give information about its location accurately. It also assures aeronautical safety by radar transponder for navigation in air corridors.

3.2. The NEV Envelope Gondola

NEV as « Nacelle EnVeloppe ».

When the flight has finished, the order is given to the main gondola to separate itself from the envelope. The descents of the two mobile elements (envelope on one hand and gondola with its parachute on the other hand) have to be monitored in real time down to the ground. This means that the envelope has another gondola, able to communicate with the control centre. This envelope gondola also gives information on its position and signals itself to planes with a radar transponder and strobe light.

3.3. The NFAE gondola for the strobe light

NFAE as « Nacelle Feu A Eclat ».

On NOSYCA, there is another little gondola that contains, dues to mechanical constraints, an independent strobe light. It also assures the aeronautical safety for navigation in air corridors.

3.4. The NCU Scientific gondola

NCU as « Nacelle Charge Utile ».

Moreover, there is still another gondola: the scientific gondola. Even if it's independent from the NOSYCA system, this gondola is linked to the NSO. The NSO offers it a communication link with the ground to download its data.

4. NOSYCA RELIABILITY

The reliability of the NOSYCA system has been ensured to guarantee that the balloon can always be controlled, even in case of failure. It shall not present any single failure that could generate any catastrophic consequence. Therefore, if a single failure appears, the NOSYCA system has been designed to reach a landing zone, free from dwellings or people, un any event.

To do this, the NOSYCA team has first identified a set of functions that could cause a catastrophic event in case of failure: separation, navigation, positioning and piloting functions. Then, NOSYCA team has studied a reliable design to reduce the associated risks and make a failure acceptable on these elements. This design relies on:

- Redundancy to avoid the loss of a function: redundancy of functions, equipment and communication links.

- Double barriers to avoid untimely commands.

- A qualified and truly strict development process for electronic components and software.

4.1. Redundancy of communication links

After the separation of the balloon, the envelope gondola must be localized accurately by the control centre. Therefore, it has its own communication link based on Iridium satellite technology and uses it to transmit its GPS position. If there is a failure either on GPS or Iridium modem, the envelope gondola contains another independent beacon based on Argos: it's able to communicate directly with the control centre.

The same concept is used for the operational gondola. This gondola controls all the actuators of the balloon. Therefore, it is based on a computer with software able to command and control all the equipment. To limit the risks associated to a failure of this computer, there is another computer with nearly the same functions. Each computer is equiped with certain equipments to assume its functions: GPS, ARGOS, modem etc. This set of computers and equipment is called a module.

Both modules assume the same safeguard functions: ITAC (Interface de TéléAcquisition et de Commande) is the nominal module and ULIS (Unité Légère d'Interface Satellitaire) the redundant one.

The ITAC module has several communication links:

- S-band radiofrequency: enables a high bit rate of 1.75Mb/s. It provides on one hand the download of servitude telemetry and on the other hand the download of scientific telemetry through a standard IP link provided that the balloon is in the S-Band station coverage (about 500km).

- Inmarsat satellite communication: when the balloon is out of S-Band station coverage, the ITAC module switches its communication onto an Inmarsat modem (about 2.4Kbps) and downloads its servitude telemetry.

- As for the envelope gondola, if a failure occurs on the location (GPS or telecommunication problem), the ITAC module has its own ARGOS beacon, independent in terms of communication flows.

If any failure occurs on ITAC module, there is still the redundant module ULIS with its own communication link:

- Iridium satellite communication to download its servitude telemetry.

Therefore, Nosyca architecture relies on redundant communication flows but also flows of different types as shown in the figure below:

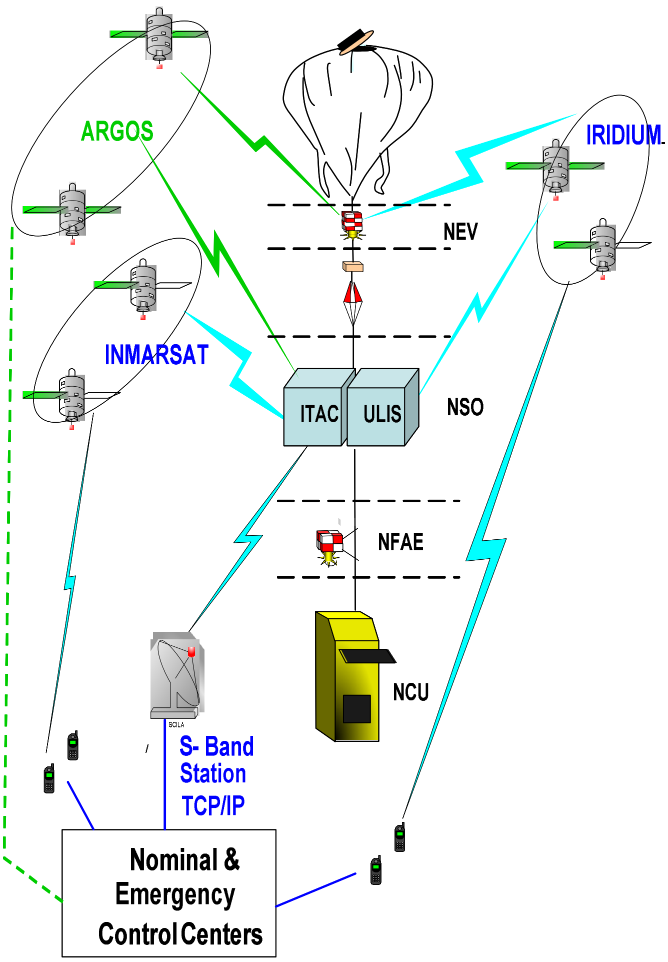

Figure 2: NOSYCA Communication flows

4.2. Types of Redundancy

To ensure the safeguard constraints, the NOSYCA design relies on several kinds of redundancies of equipment. This has various impacts on the computer and software in charge of their command control.

Redundancy and diversity of equipment

Several functions have a redundancy. For instance, the NSO operational gondola contains two GPS, one on each module. To assume a variety of technologies, a trimble GPS is embedded on ITAC and a U-blox GPS is embedded on ULIS.

Figure 3: Redundant and various GPS

Independent redundancy of equipments

Redundant equipment can be controlled by each module independently. For instance, the separation actuator is controlled by both the ITAC and ULIS modules: one pyrotechnic system is available on each module (two commands at system level) and two straps, which show the separation are available on each module (4 straps at system level).

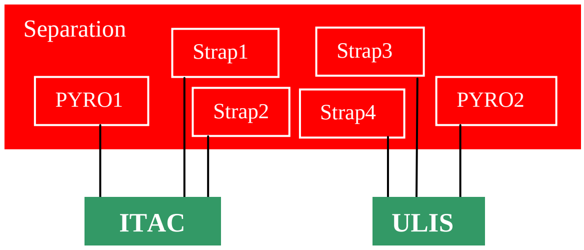

Figure 4: Redundant and independent equipment

Shared redundancy of equipment

It is not always possible to define fully redundant equipment. For instance, the ballast system is too heavy to be duplicated. So, the internal electronic design of such equipment guarantees fail-safe constraints. But, in terms of command-control, such equipment is controlled by both computers (ITAC, ULIS) and, therefore, can be shared between both computers. For instance, the valve system is composed of:

- Two nominal valves, each one controlled independently by both modules.
- One redundant valve, whose control is shared by both computers.

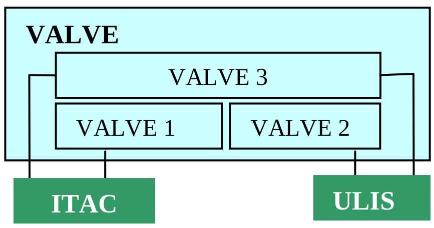

Figure 5: shared actuators

Therefore, with such a concept, if a failure occurs on the ITAC computer, the valve could still be controlled by the ULIS computer to finish the flight.

4.3. Double barriers for critical functions

A set of critical functions had been identified on NOSYCA: inside one computer (ITAC or ULIS), these functions will be performed by two independent commands, each one executed by two independent microcontrollers and software.

This design guarantees the absence of untimely and unwanted commands.

4.4. Strict quality process for critical software

The embedded software is defined as critical software; it means that it participates in a critical function.

Therefore, embedded software is developed with a strict quality process. For instance, it imposes the application of the European Standards ECSS-Q-80C and ECSS-E-40C with a test coverage of 100% of decisions, no dead code, scheduling analysis …

5. NOSYCA EMBEDDED SOFTWARE

Both computers ITAC and ULIS assume the redundancy of critical functions. These two computers are really similar in terms of functions and equipment.

In addition, NOSYCA embedded software is critical software: it has to be developed with a really strict quality process and so, it is an expensive process.

One of the project development choices is to define and develop one single generic piece of embedded software. First, to minimize its cost, planning and maintenance. And then, to increase its control in conformity with development constraints of critical software. This single piece of embedded software will then be configured and deployed in both ITAC and ULIS computers.

5.1. Embedded Software Specifications

Well-known configurations

To keep a high level of control on this generic piece of embedded software, the deployed configurations (ITAC and ULIS) have been well-defined. They contain the details of the equipment and their specific characteristics.

As described in the §Kinds of redundancy, here below is an extract of a balloon configuration with the equipment controlled by each on-board computer ITAC or ULIS.

Table 1: Extract of a balloon configuration

Generic equipments	**Configuration**	
	ITAC	**ULIS**
MAIN VALVE	1	2
BACK-UP VALVE	3	3
PYRO	1	2
Separation Straps	1,2	3, 4
S-Band Modem	PRESENT	ABSENT
Satellite modem	Inmarsat	Iridium
GPS	Trimble	U-Blox
Temperature sensor	PRESENT	ABSENT

The embedded software may adapt its treatment to this configuration. For instance:

- For embedded software (ITAC or ULIS), there are only a main valve and a back-up valve. From the system’s point of view, there are two main valves (numbers 1 and 2), each one connected to one computer and only one single back-up valve, shared between both computers. The system’s point of view appears in the control centre, when decoding the telemetries: measures coming from ITAC concern the main valve 1 and back-up valve 3, whereas measures coming from ULIS concern the main valve 2 and back-up valve 3.
- This is quite different for the S-Band modem. On the ITAC module, the embedded software establishes the communication with the S-Band modem; on the ULIS one, this communication doesn’t exist. This difference must have no impact on the real-time behaviour of the software.
- For the GPS and satellite modem, each piece of embedded software (ITAC or ULIS) must control them but the protocol is quite different from one module to the other one. Therefore, each piece of embedded software has to be configured with the right protocol (today: GPS Trimble protocol on ITAC and GPS U-Blox protocol on ULIS; but, why not the contrary?). Moreover, these different codes must have no impact on the real-time behaviour of the software.

A generic TCTM interface

The embedded software transmits the information concerning the on-board equipment by telemetries (TM). These telemetries are then analyzed by the control centre. The embedded software must also execute telecommands (TC). TC and TM will depend on the board configuration.

Therefore, to minimize the impact of the different configurations on the embedded software and the control centre, the TCTM interface is generic. It is defined to contain the maximal configuration (all equipment and functions are present).

- TM: It contains all the measures provided by all the equipment. In other words, the structure of TM frames is always the same. If equipment is present, the embedded software will provide the right acquisitions. If not, it will fill the telemetry frame with spare bits.

- TC: the embedded software is still able to execute all the TC.

5.2. Embedded Software Design

The embedded software runs at a frequency of 1Hz. This frequency is divided into temporal slots, each slot dedicated to an acquisition or a function. This kind of software design guarantees a deterministic behaviour.

The impact of the board configuration is of various types:

- If passive equipment (like a temperature sensor) is not installed on board, it is replaced by a hard cap. The embedded software maintains the acquisitions of the equipment and then gets predefined values provided by the hard cap.

- If active equipment (like the S-Band modem which implies a specific communication protocol) is absent, the embedded software adapts its functions: it will not perform any communication with this modem. However, in order to avoid a modification of the real-time behaviour of the embedded software, the slot which is dedicated to the modem shall not be re-used for other functions.

- For equipment that imply specific protocol like the GPS, the embedded software shall use the right protocol. The communication with the GPS (Trimble or U-Blox) will be established in the slot dedicated to the GPS. Therefore, this slot shall be sized for the protocol that takes the longer duration.

Table 2: Example of slots repartition

Slot	Duration (ms)	Linked function
1	5	Temperature sensor acquisition
2	15	GPS communication
3	30	S-Band modem communication

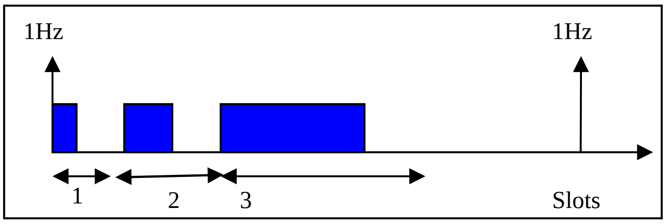

Figure 6-a: Real-time behaviour of ITAC Software

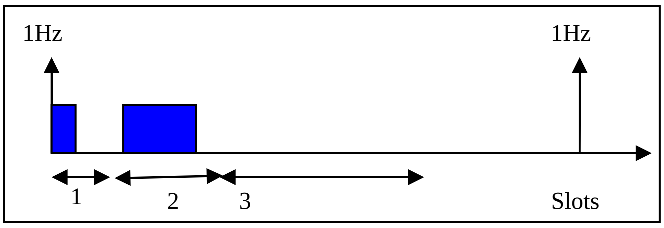

Figure 6-b: Real-time behaviour of ULIS Software

In addition, the embedded software shall always execute any TC, even in case of absent equipment. Indeed, the TC will be directly suppressed from the control centre. If the embedded software ever sends a TC to an absent equipment, the NOSYCA electronic design guarantees that it will have no effect on the on-board electronics.

6. THE CONTROL CENTRE

The NOSYCA control centre is based on the OCTAVE tool, developed by CNES. The TMTC interface is described with BEST tool, also developed by CNES.

OCTAVE is a data model-driven monitoring and control system. It is able to load a XML file describing the structure of telemetries and telecommands like the ones produced by BEST. Then, OCTAVE can receive, decode and display automatically any telemetry or send any commands without any modification.

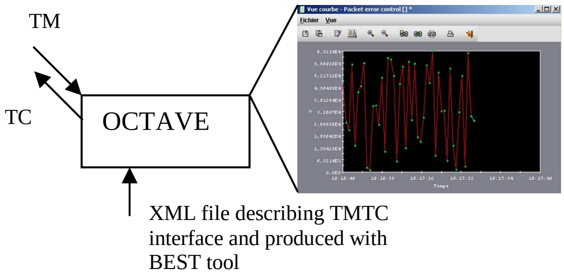

Figure 7: OCTAVE, a monitoring and control system

OCTAVE also lets us define several kinds of displays and define operational procedures based on the TMTC XML file.

7. THE SYSTEM DATABASE: CORE OF THE TMTC INTERFACE ADAPTABILITY

The on-board configuration has to be deployed:
- on one hand on board for the embedded software to let it adapt its functions,
- and on the other hand, on the ground segment for the control centre to adapt either the data decoding or the list of TC of present equipment.

As the system database allows defining the configuration of the balloon in terms of equipment and protocols and manages the generic TMTC interface, it is also in charge of:

- Deploying a board configuration word for the embedded software on each module ITAC, ULIS. The ITAC or ULIS software will use their own on-board configuration word to adapt their functions.

- Generating two specific operational TCTM interfaces (one for ULIS and the other one for ITAC), based on the board configuration. Both these interfaces will then be deployed to the control centre to adapt the decoding.

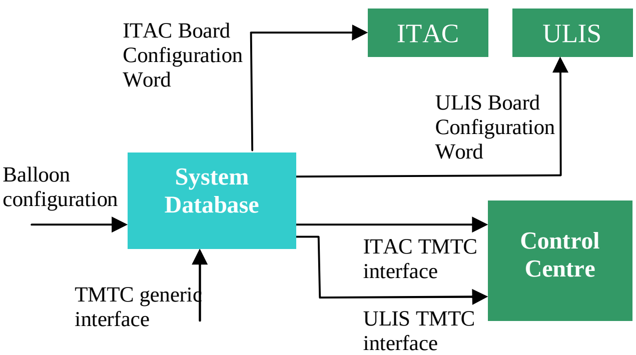

Figure 8: the system database, core of the adaptability of the TMTC interface

The system database links each TM and TC field to its relative equipment. As it contains the operational configuration of a stratospheric balloon (list of present equipment for a configuration, types of equipment), it is able to customize TMTC interfaces that will be used on ground for the ITAC and ULIS module.

For instance, the generic embedded software will download the state of the separation straps: straps 1 and 2 for ITAC, straps 1 and 2 for ULIS. The system database, generating operational TMTC interfaces – dedicated to ULIS and ITAC - will give back the system level to these acquisitions: Straps 1 and 2 for ITAC, 3 and 4 for ULIS.

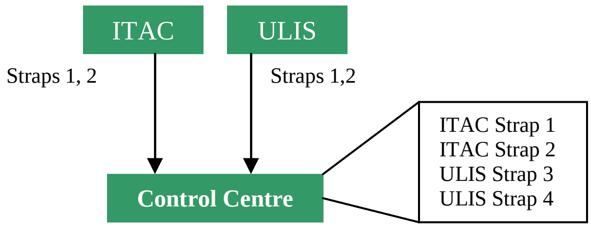

Figure 10: transformation of generic TM interface into Operational TM interface

TC dedicated to absent equipment are suppressed and the associated acquisitions are ignored.

Moreover, the system database will add all the necessary information, functions of the board configuration, to analyse raw telemetries like:
- Physical laws to transform raw data into physical data,
- monitoring
- and derived parameters

linked to the equipment present on the module.

8. CONCLUSION

NOSYCA is still under development. The process that adapts the board and ground interface is nearly operational. For the first flight, it will be used to adapt the embedded software and the control centre to ITAC and ULIS specificities for BSO balloons.

But, in a few years, NOSYCA will certainly be used for other balloon types, increasing again the importance of its adaptability. This process is defined in such a way that it could be able to accept late modifications, even a few hours before the launching.

To conclude, this concept of configurability of ground and board interface is quite innovative in our space developments: never used before with such a level of automation in balloon or satellite developments.