Thales Alenia Space Experience on Plasma Propulsion

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Abstract: Thales Alenia Space experience on plasma propulsion has been developed in the frame of Stentor, Astra 1K and GEI programs with plasma propulsion systems using SPT100 thrusters manufactured by Fakel and commercialized by Snecma . The PPS (plasma propulsion system) use in house equipments such as Power Processing Unit (PPU) manufactured by TAS-ETCA in Charleroi and the Thruster Orientation Mechanism (TOM) manufactured by TAS-France in Cannes . The PPS subsystem is used on board our SpaceBus satellite family to perform North-South station keeping. The on going activity on the XPS (Xenon Propulsion System) is devoted to the next European platform Alphabus currently under joint development by Thales Alenia Space and Astrium with CNES and ESA support. The XPS uses also the PPU manufactured by TAS-ETCA , the TOM manufactured by TAS-France and the Xe tank developed by TAS-Italy ; it use also the PPS1350 thruster under qualification by Snecma , a xenon regulator and a latch valve under development at Marotta Ireland.

I. Introduction

THIS document describes the Thales Alenia Space experience gained through Stentor , Astra 1K , GEI, Spacebus and Alphabus programs on plasma Hall effect thrusters propulsion subsystems . For Spacebus application a description of the subsystem is given together with the general achieved performances . For Alphabus application a general status of the on going activities is given .

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II. SpaceBus Plasma Propulsion Subsystem

The function of the Plasma Propulsion Subsystem is to provide inclination and eccentricity control for North/South station keeping and in addition it allows unloading of reaction wheels.

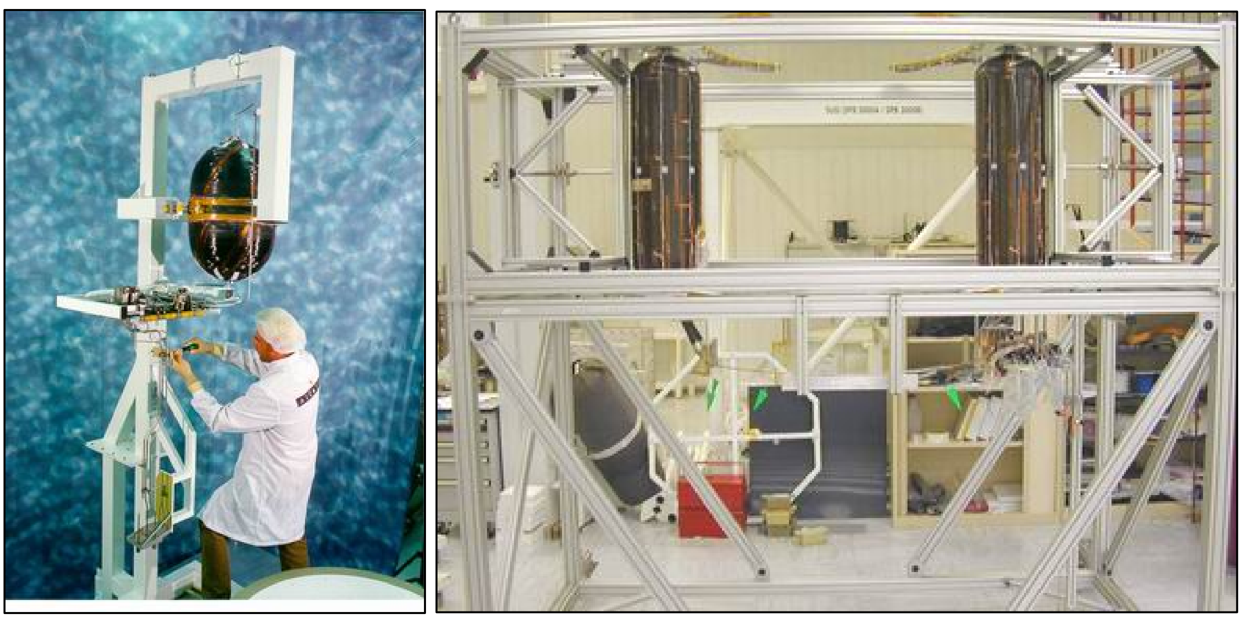
For SPACEBUS platform, the technology retained is based on the use of SPT 100 thrusters which offer an in-orbit great experience as they have been flying since beginning of 1994 on GALS satellites in Russia. They also offer great advantage because of their good compromise between a good specific impulse (1510 s), a high thrust level (80mN) and a decent-sized electrical power needs in comparison with the other electrical thrusters. The Plasma Propulsion Subsystem uses Xenon as propellant.

It includes all devices to store and supply Xenon to the electrical thrusters, four Stationary Plasma Thrusters (SPT100) which are accommodated by pairs on two orientation mechanisms, electronic units required to manage and provide power to the thrusters and the orientation mechanisms.

As shown in the following Figure , the PPS can be divided in three main parts :

- The Gas Module (GM)
- The Power Processing Unit (PPU), which includes one Thruster Selection Unit (TSU). Two PPU are provided, one nominal and one redundant.
- The Thruster Module (TM), with two SPT's and associated Xenon Flow Controller (XFC), an orientation mechanism bearing and canting the SPT's. Two thruster modules are provided, one for the North maneuvers and one for the South maneuvers, each one including a nominal and a redundant thruster.

The North (resp. South) module is implemented on the anti-earth face on the north (resp. south) face of the satellite and is used for South (resp. North) Station keeping maneuvers.



Figures 1 : STENTOR AND ASTRA 1K GAS MODULE INTEGRATED ON JIG

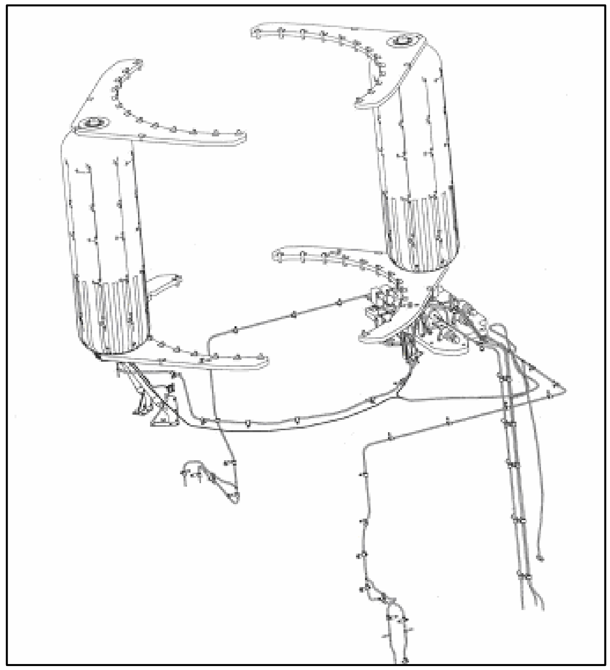


Figure 2 : ASTRA1K PPS GAS MODULE ON THE SATELLITE

III. PPS DESCRIPTION

A. GAS MODULE

The Gas Module is required to store Xenon and isolate the Xenon storage from the Plasma thrusters during prelaunch, launch and orbit raising phases in safe conditions. During on-orbit phase, it will then supply Xenon to the Thruster Modules at the required regulated pressure and cleanliness level.

The Plasma Gas Module includes the following equipments :

- two Xenon tank to store Xenon up to 150 bar,
- a high pressure fill and drain valve to pressurize the tanks,
- a normally closed pyro valve isolating the storage volume during ground integration activities and launch,
- two high pressure transducers for Xenon gauging,
- associated titanium feed lines (1/4" diameter).
- Three fill and drain valves located upstream and downstream the pressure regulator. These valves are used for ground tests,
- two valves in parallel in order to provide isolation of the distribution assembly in case of abnormal external leakage,
- a filter in order to protect all the downstream components of any abnormal particulate cleanliness,
- a mechanical pressure regulator which is fully series redundant. Each stage is capable of delivering Xenon at a regulated pressure to the thruster module over the complete range of temperature, inlet pressure and flow rate during thruster operation and it provides leak tightness between two thruster operations.
- two low pressure transducers used to tightly monitored the level of the regulated pressure at the outlet of the pressure regulator.
- titanium feed lines up to the thruster modules and titanium-stainless steel connection which ensure leak-tightness of the subsystem as a whole and minimizes mass.

The arrangement of the high pressure transducers (upstream) and of the low pressure transducers (downstream) provide a full redundancy and allows to measure:

· the pressures in the tanks and in the feed lines for general monitoring.
· the pressure delivered by the pressure regulator for general monitoring.
· the pressure accumulated downstream of the pressure regulator in worst case of leakage (if any) to prevent over pressure.
· the pressure conditions at the XFC inlet for general monitoring.
· the needed measured pressures for propellant gauging purposes.

The PGM is kept clear of any liquid Xenon. The Thermal Control Subsystem (TCS) provides thermistors and heaters to control accurately the Xenon temperatures and state inside the tank and at the puppet level of the pressure regulator.

B. PLASMA THRUSTER MODULES

Each Thruster Module consists of the following elements:
· Two SPT-100 plasma thrusters, one nominal and one redundant,
· Two Xenon Flow Controllers (XFC) associated to each thruster. Each XFC are feeding each the cathode and the anode and providing by the way redundancy. The XFC includes a thermo throttle which allows to control the Xenon mass flow-rate.
· Two Filter Unit (FU). The filter unit is located upstream each SPT in order to limit electromagnetic conduction from the thruster towards the PPU.
· A Thruster Orientation Mechanism (TOM) used to steer the plasma thrusters around two axes in order to orient the thrust wrt COG and to unload momentum wheels of the Attitude and Orbit Control System.
· One set of Xenon feeding pipes and electrical harness to SPTs and XFCs, including a flexible part accommodated through TOM gimbals assembly. They are routed as close as possible from the rotation center of the TOM to minimize resisting torques.
· One set of thermal control devices (thermistors, thermo switches, heaters, OSR and MLI).
· Two harness brackets (Hot Interconnection Brackets) located on the TOM mobile plate side. They are used for connection between thruster harness and the flexible harness accommodated through the TOM gimbals assembly.

The SPTs are mounted on the mobile part of the orientation mechanism, which also constitutes a radiative plate. The XFCs are accommodated on the back of the fixed part. Interface connectors are located on a lateral face of the fixed part of the Assembly.

In the reference position, the mobile plate is canted to 44° relatively to the interface plane. Shims are used for thruster individual alignment in order to provide alignment of the thrust vectors towards the average position of the center of mass over the mission.

Release is performed using pyrotechnics bolts and when released, a capability of rotation up to 8.5° around two axes is provided.

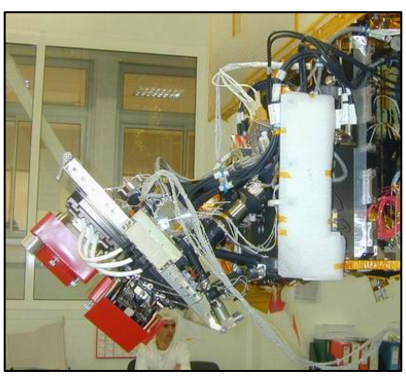
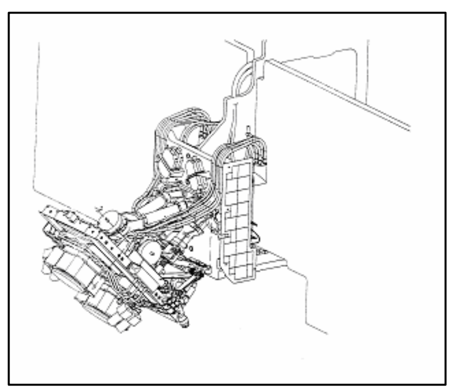



Figure 3: Thruster Module Overview

C. POWER PROCESSING UNIT

The PPU manage and deliver to SPTs the required power for operation. Each PPU (prime and redundant) is connected to two SPTs but operates only one thruster at one time.

PPU controls the selected SPT and its associated XFC on the basis of programmed procedures and commands received from the on-board computer. In particular the PPU manages an automatic sequence for the thruster start-up and control the discharge current closed loop as described on the following Figure.

PPU also includes a remote control mode in order to provide tools for step by step control / diagnostics purposes.

PPU is connected to the OBDH Bus and to the 100 Volts power bus.

D. LAYOUT

The arrangement of the Plasma Propulsion is characterized by its modular design, which facilitates the pre-integration of subassemblies. The Xenon tanks are accommodated on the central tube, face East and West. A system of boomerang supports the tanks, that are fastened on their pole ends with one free polar displacement fitting each, allowing for mechanical and thermal expansion.

The Pressure Regulator, the Pressure Transducers, the Xenon Filter, the Latch Valves and the NC Pyro Valve are placed on a mounting plate that is accommodated in the Internal Deck.

The Fill and Drain Valves are accommodated on a support plate on the anti-earth face on the satellite.

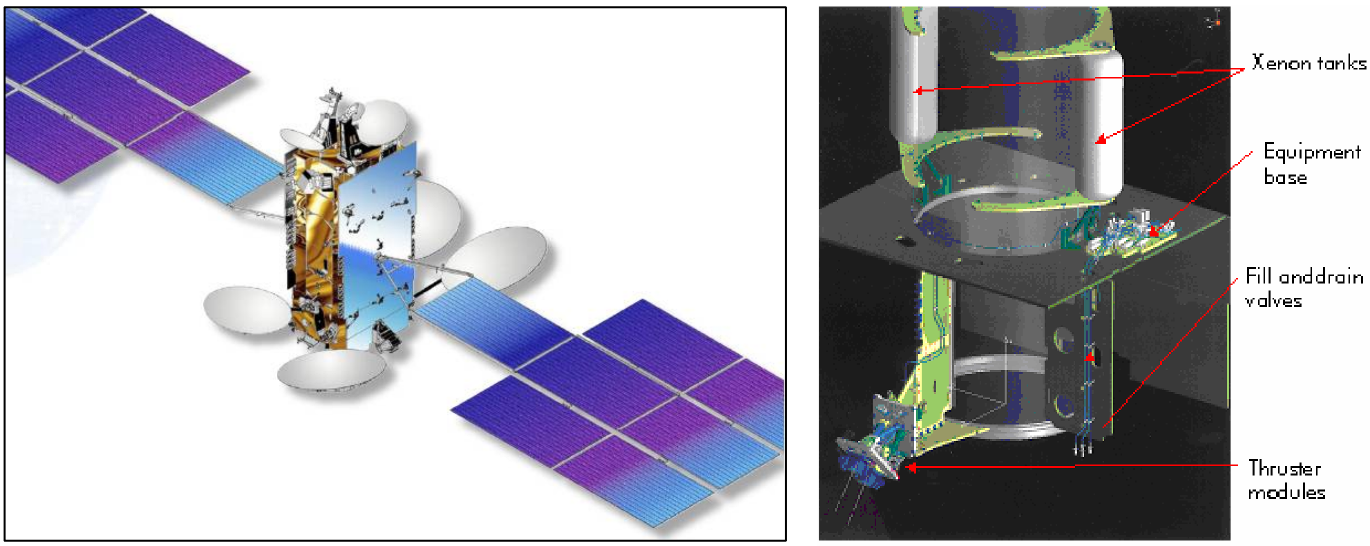


Figure 4 : SpaceBus Propulsion Subsystem Layout

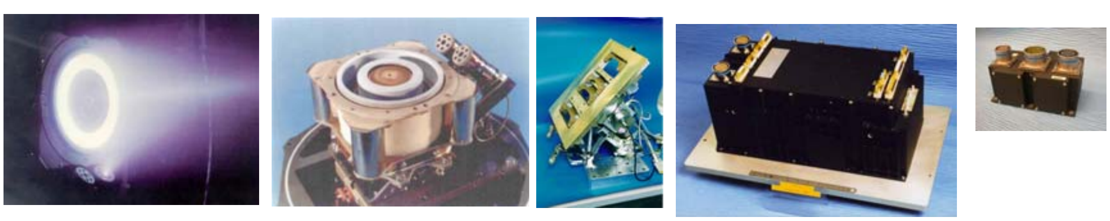


Figure 5 : SPT100 Fakel/Snecma ; TOM Thales Alenia Space Cannes ; PPU-FU Thales Alenia Space ETCA ,

The Gas Module has the capability of being integrated as subassemblies on a structural panel and has the capability to support pressure tests of the complete high pressure module.

The North (respectively South) Plasma Thruster Modules (PTM) are implemented on the anti-Earth face on the North (respectively South) edge of the satellite and is used for South (respectively North) Station Keeping Maneuvers (NSSK).

The 4 SPT 100 are accommodated on the Anti-Earth panel, one above the other, oriented toward the On-Station Satellite Center of Gravity (CoG):

- on the edge of the North panel, the North Nominal (NO-NO) and the North Redundant (NO-RE)
- on the edge of the South panel, the South Nominal (SO-NO) and the South Redundant (SO-RE).

Each set of two thrusters (North and South) is fixed on a thermal radiating plate, connected to the Thruster Orientation Mechanism (TOM). The layout of the thrusters is done, taking into account :

- the overall satellite layout
- the plume effects
- the AOCS needs
- the optimization of the Xenon budget
- the thermal control of the feed lines
- the fluid needs.

Mechanical design of thrusters fitting brackets allows, before and after welding of the feed lines, displacements and rotations in order to:

- take into account the measured positions of the Center Of Gravity and inertial axis in order to compensate prevision errors, mechanical dispersions
- adjust the alignment according to each flight configuration. The alignments are verified after vibration test and after transportation on the launch pad.

E. KEY FEATURES

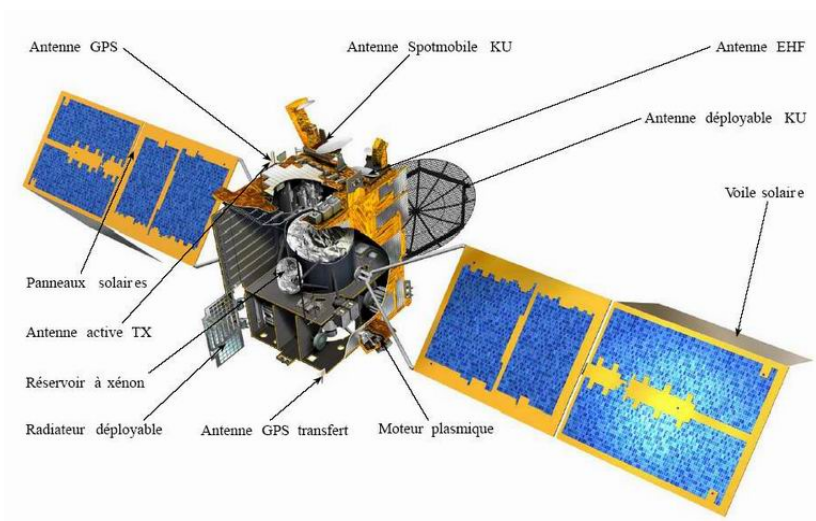
The selected SPT 100 thruster data are based on test results of several Flight Russian thrusters and several Recurring Russian S/S. The SPT100 is used since 1994 on EXPRESS and GALS platform. There are more than 80 thrusters in orbit, and SPT100 are baselined for use on several western programs such as Sesat, Stentor, Astra1K, Inmarsat (3 satellites), IntelsatX (1 satellite), Mbsat (2 satellites) , Americas8, TerreStar (2 satellites) , XM5, IPStar

IV. Stentor application

Purpose of the STENTOR Spacecraft was in particular to provide on-ground qualification and in-flight demonstration of plasma propulsion onto European spacecraft.

In-flight return of experience was not possible due to launcher failure on December 2002.

However, on-ground qualification was achieved and experience accumulated during this program is rich up to the level of the technical challenge and complexity of industrial organization. The main achievements are presented in reference[2] with an overview of the propulsion system design, equipment and system development and test results achieved during spacecraft Assembly, Integration and Tests.



F. PROPULSION SYSTEM DESIGN

The propulsion system was designed by THALES ALENIA SPACE with a main requirement of compatibility with the SPACEBUS Family platform.

Function of the Plasma Propulsion System is to provide inclination and eccentricity control for north/south station keeping.

The system is a plasma propulsion system using Xenon as propellant. It includes a Gas Module in order to store and supply Xenon to two Thruster Modules, one for the north maneuvers and one for the south maneuvers.

Each Thruster Module is composed of two stationary plasma thrusters (one nominal and one redundant) mounted onto an orientation mechanism and of Xenon Flow Controllers (XFC) associated to each thruster. Thruster and XFC are powered and controlled by Electrical Modules.

Each Electrical Module includes one Power Processing Unit (PPU) including Thruster Selection Unit, a filter unit (FU) upstream each Thruster. One Electrical module is dedicated to the two nominal thrusters, the other one is redundant, associated to redundant thrusters.

Two types of thrusters are be used: SPT-100 thrusters, manufactured by Fakel in Russia and PPS-1350 thruster manufactured by SNECMA in France.

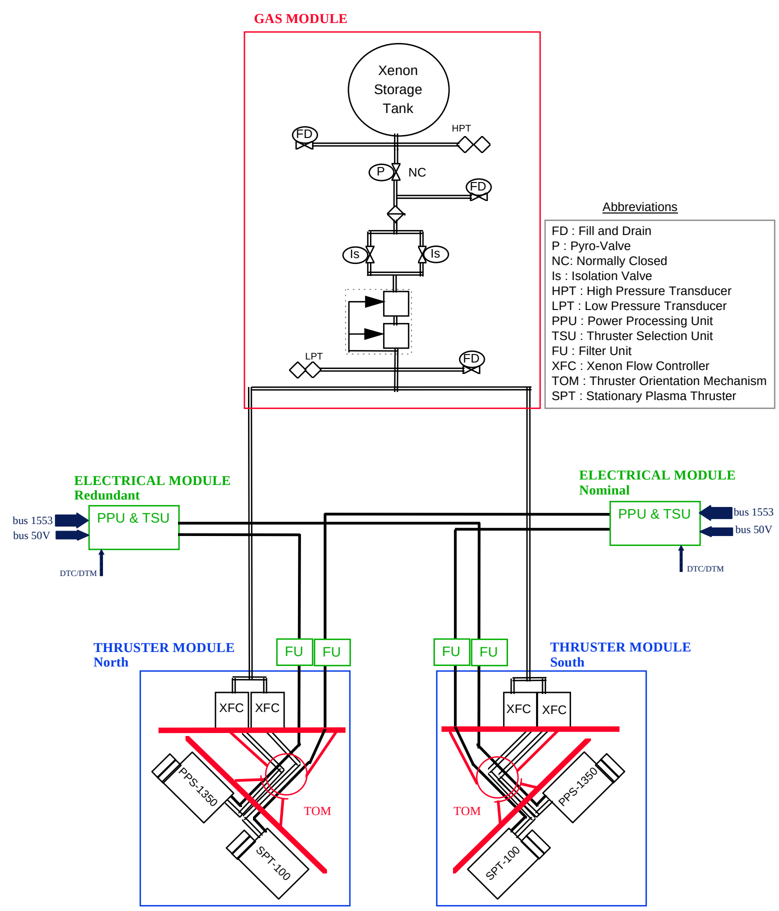


Figure 6 : Stentor Plasma Propulsion System architecture

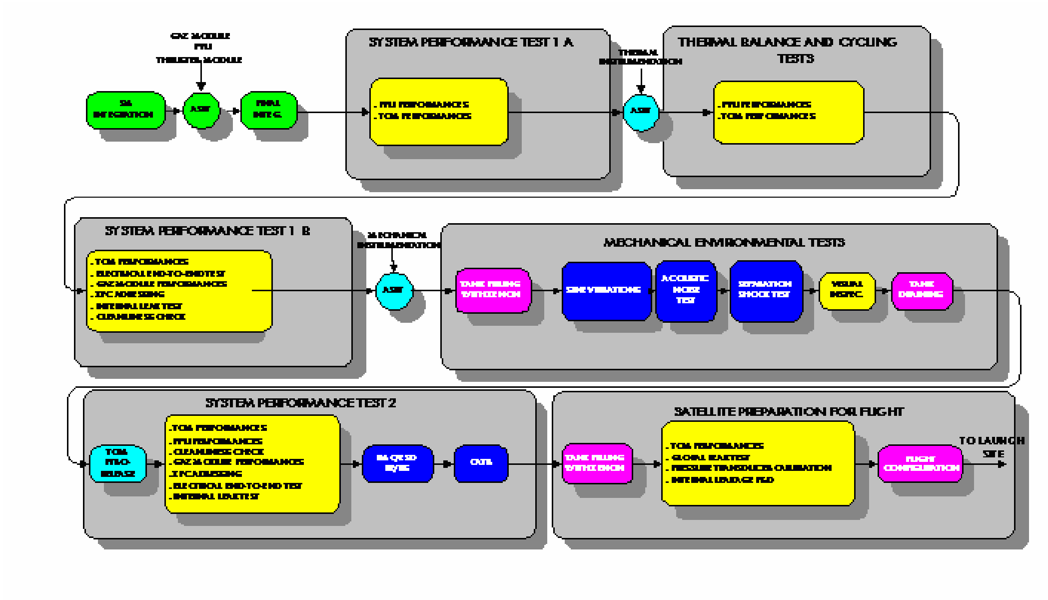
During the development at propulsion system level , a strong effort was dedicated to interactions between equipment and coupled tests in order to guarantee performances .

All analysis and test results provided strong experience and confidence in overall performances of the propulsion system.

G. Satellite Assembly Integration and Tests Flow chart

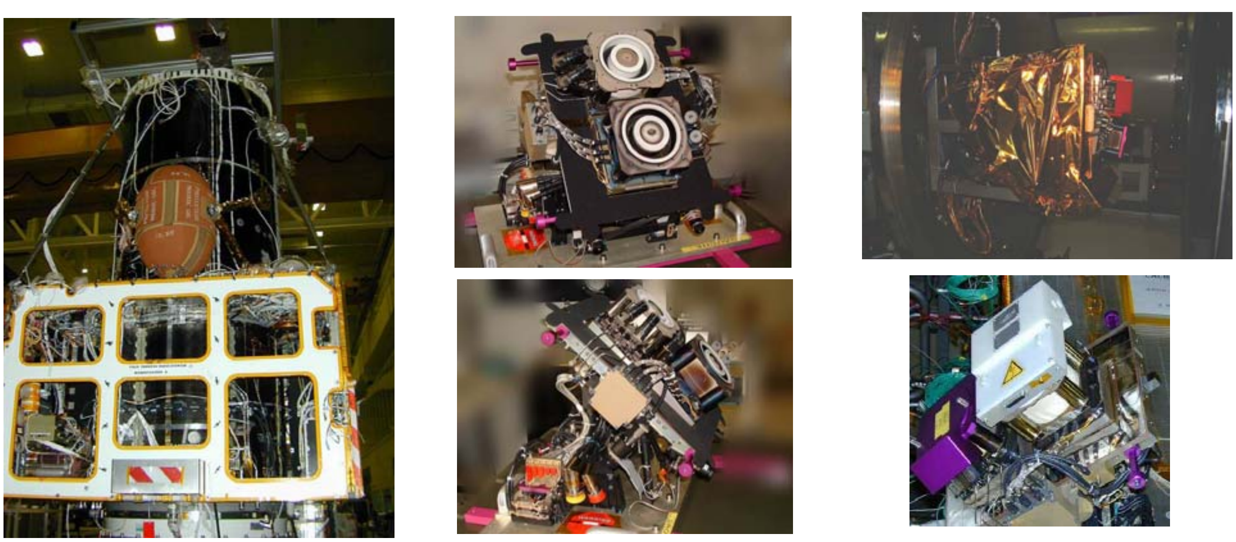
The following flow chart provides the test sequence performed onto the plasma propulsion system during the spacecraft Assembly Integration and Test (AIT) campaign.

It was the first plasma propulsion system to be tested at spacecraft level in Europe. Therefore it allowed to validate all the new procedures and innovative ground equipment



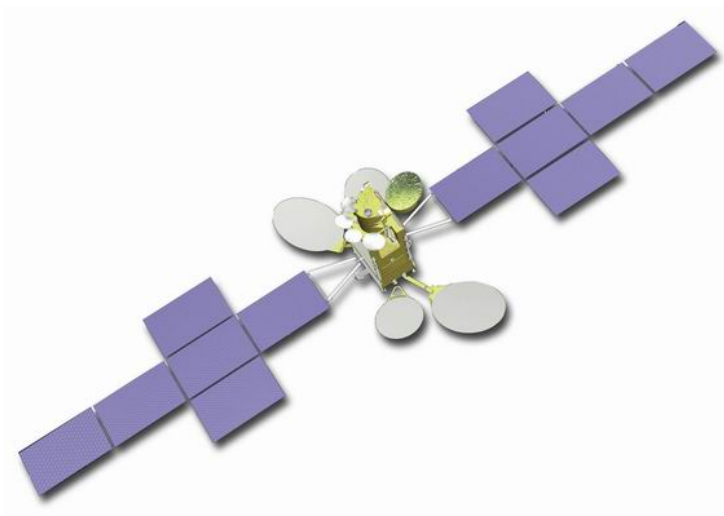
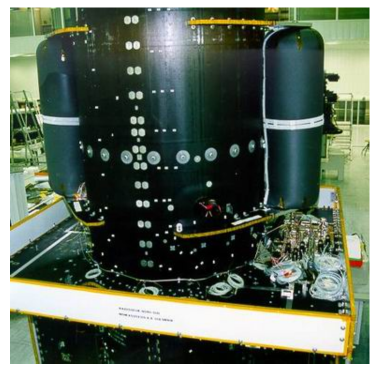
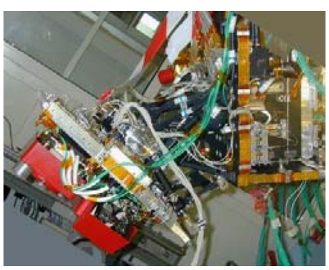
H. Synthesis of Stentor ground qualification experience

Development of the plasma propulsion system in the frame of the STENTOR program was a great challenge for all the partners involved. Six completely new equipment were developed and we succeeded in making them working together as a system integrated onto the spacecraft. Moreover, the in-orbit operational procedures of the subsystem have been validated successfully with the satellite simulator



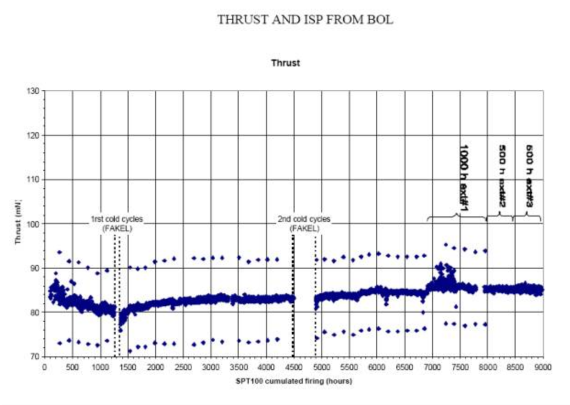
V. ASTRA 1K application




The Société Européenne de Satellites (SES) awarded THALES ALENIA SPACE the prime contractorship for Astra-1K, one of the largest telecommunication satellite[2]. This spacecraft, launched by Proton end of 2002, was designed to use the Plasma Propulsion Subsystem manufactured by THALES ALENIA SPACE

This Plasma Propulsion Subsystem was derived from the STENTOR inheritage with evolutions in order to cope with customer/platform requirements, or to improve competitiveness.FAKEL SPT100 thrusters were used as for THALES ALENIA SPACE SPACEBUS 4000 spacecraft family .In this frame, THALES ALENIA SPACE, in coordination with CNES and SNECMA, started a subsystem life test mid 1998 to demonstrate on ground the actual performances of the subsystem over a complete satellite mission (15 years) in ambient temperature conditions.



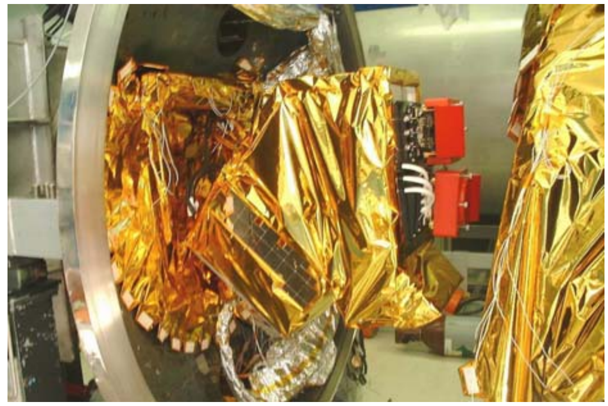


Figure 7 : Astra 1K SPT100 S/N 49 Life test 8976 hours

Figure 8 : Thruster module thermal vaccum test

The status of the SPT100 S/N 49 completed life test is 8976 hours of cumulated firing and 5682 cycles have been performed, that represents +30% beyond the nominal duration for the foreseen satellite mission of ASTRA 1K (13 years), including 1.5 margin factor

I. SPT100 Cold Starts

In order to be more representative of the orbit temperature conditions, THALES ALENIA SPACE decided to perform specific cold starts at Fakel's facilities in the frame of the Plasma Propulsion Subsystem Life Test.
501 cold starts have been performed on the SPT100 S/N49 :
1st cycle : 102 cycles (1167 hours to 1269 hours of total firing duration of the PPS Life Test)
2nd test cycle : 399 cycles (4387 hours to 4786 hours of total firing duration of the PPS Life Test)
This test was carried out on Fakel's facilities from December 1999 to February 2000 and from April to June 2001.

J. Thruster Module / PPU Coupled Test:

The objective was to test the performances of the THALES ALENIA SPACE Thruster Module and the THALES ALENIA SPACE ETCA PPU during one firing sequence on each thruster / each cathode.
One Thruster Module Flight Model (including 2 SPT100, 4 XFC and 2 FUs integrated on one Thruster Orientation Mechanism (TOM)) is placed inside a vacuum chamber and connected to 2 PPUs Flight Models.
The test on each of the two Thruster Modules consisted in performing 4 thruster firings (1 on each cathode) with the dedicated power supply, while performing a TOM actuation on a range of +/- 2°.
One of the two Thruster Modules was a PFM and was submitted to a thermal balance and was fully equipped with thermistors and thermocouples in order to correlate the Thruster Module thermal model.

The three kinds of tests (life test, cold starts, PPU coupled test) performed in the frame of ASTRA 1K application allowed to fully qualify the THALES ALENIA SPACE Plasma Propulsion Subsystem in a space representative environment

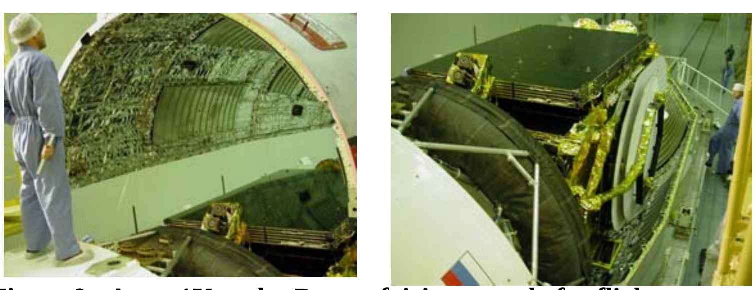


Figure 9 : Astra 1K under Proton fairing – ready for flight

VI. ALPHABUS application

Since several years, a joint team of the two leading European satellite companies is working with the support of ESA (European Space Agency) and CNES (Centre National d'Etudes Spatiales of France) to define a product line able to efficiently address the upper segment of communications satellites. Alphabus is then the vector for Europe to develop new reliable solutions for large satellites and offer them on the world market.
The Alphabus platform is designed for communications satellites with payload power in the range 12-18 kW. This will support the renewal of the fleet for large operators, offering a lower cost per transponder and the ability to accommodate reconfigurable missions, as well as the development of applications such new generation mobile and broadband services, digital audio broadcast and HDTV. Satellites based on Alphabus will have a launch mass in the range 6 to 8 tons, and take full benefit of the capabilities of the new generation of 5 meter fairing commercial launchers. In order to cover the mission range in an optimized way, the platform product line includes several options such as electric propulsion[3] , and features scalable resources (solar array, radiators for thermal dissipation, etc.). The platform[5] will be able to accommodate up to 190 high power transponders and large antenna farms, and will have a significant growth potential.
Astrium and Thales Alenia Space are jointly developing Alphabus and will market it for commercial communications satellites on the worldwide market.

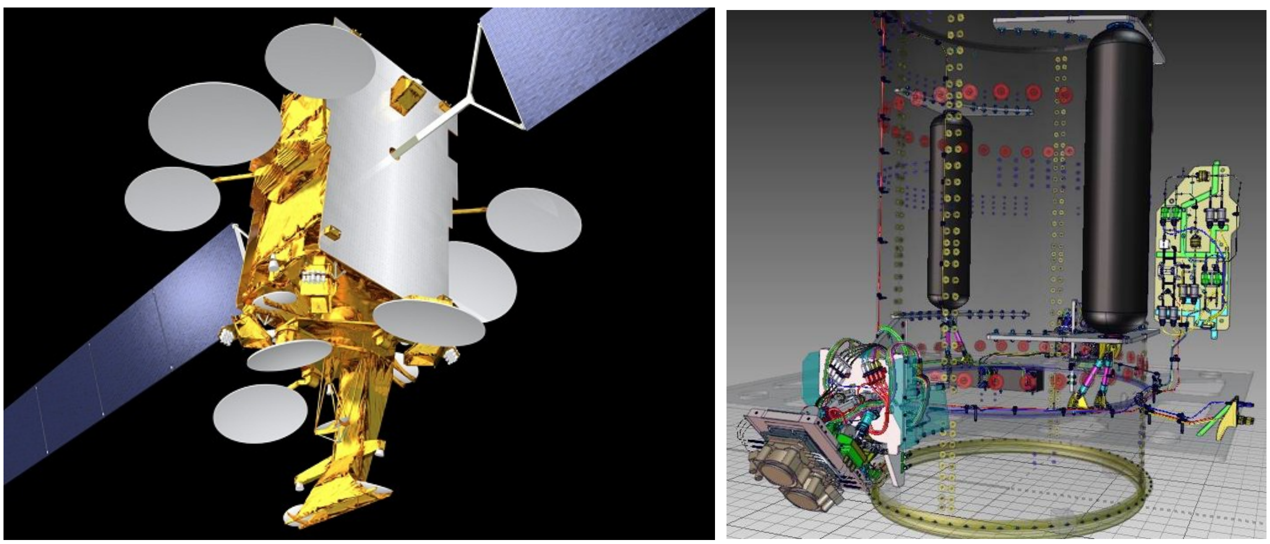


Figure 10 : @Bus Xenon Propulsion System with PPS1350 plasma thrusters

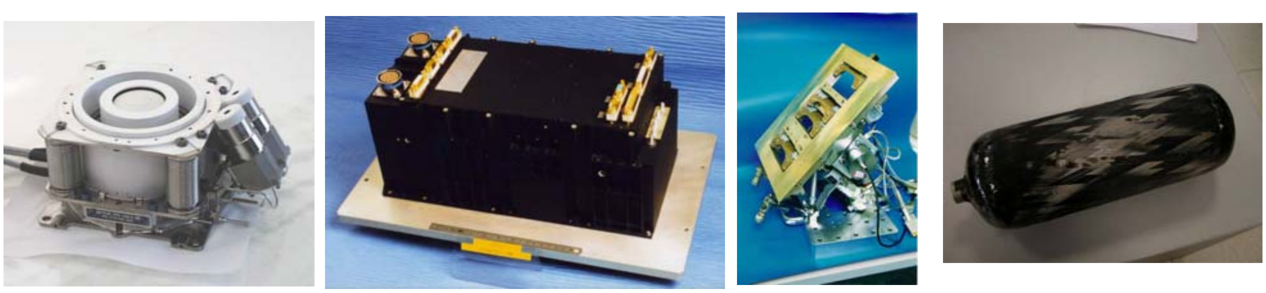


Figure 11 : PPS1350 thruster Snecma ; TOM Thales Alenia Space Cannes ; PPU Thales Alenia Space ETCA , Xe Tank Thales Alenia Space Turin

VII. Conclusion

During STENTOR and ASTRA1K programs system environment tests, THALES ALENIA SPACE successfully performed performances and end-to-end tests of the Plasma Propulsion Subsystem integrated in the spacecraft.

Moreover, the in-orbit operational procedures of the subsystem have been validated successfully with the satellite simulator.

Unfortunately STENTOR and ASTRA-1K will never reach their geostationary orbit due to ARIANE 5 and PROTON failures nevertheless all the satellite qualification plan was achieved and the THALES ALENIA SPACE Plasma Propulsion Subsystems have been formally accepted for flight by two major customers, the CNES with its expertise and SES with its commercial and industrial approach.

Results of all the effort of development has been profitable to the European industry and is now used in flight with THALES ALENIA SPACE major equipments such as TOM and PPU .

THALES ALENIA SPACE has acquired a valuable experience , is in a strong position to offer qualified Plasma Propulsion Subsystem onto its SPACEBUS family , is preparing the XPS propulsion system for ALPHABUS and ALPHASAT and also for other applications like probes.

Acknowledgments

The authors would like to thanks ESA and CNES for their support to the Stentor , Astra 1K and Alphabus program development .

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