STENTOR PLASMA PROPULSION SYSTEM EXPERIENCE

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Abstract

With lost of STENTOR spacecraft due to launcher failure in December 2002, in-flight results related to plasma propulsion system could unfortunately not be processed and presented.

Nevertheless, successful development of the plasma propulsion system, to be used for north/south station keeping of geostationary spacecraft, provides to industry and CNES a strong experience that will support use of plasma propulsion onto European spacecraft.

This paper describes the main experience and achievements obtained during the program.

INTRODUCTION

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 will not be 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 with an overview of the propulsion system design, equipment and system development and test results achieved during spacecraft Assembly, Integration and Tests.

Figure 1.: STENTOR Spacecraft

PROPULSION SYSTEM DESIGN

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

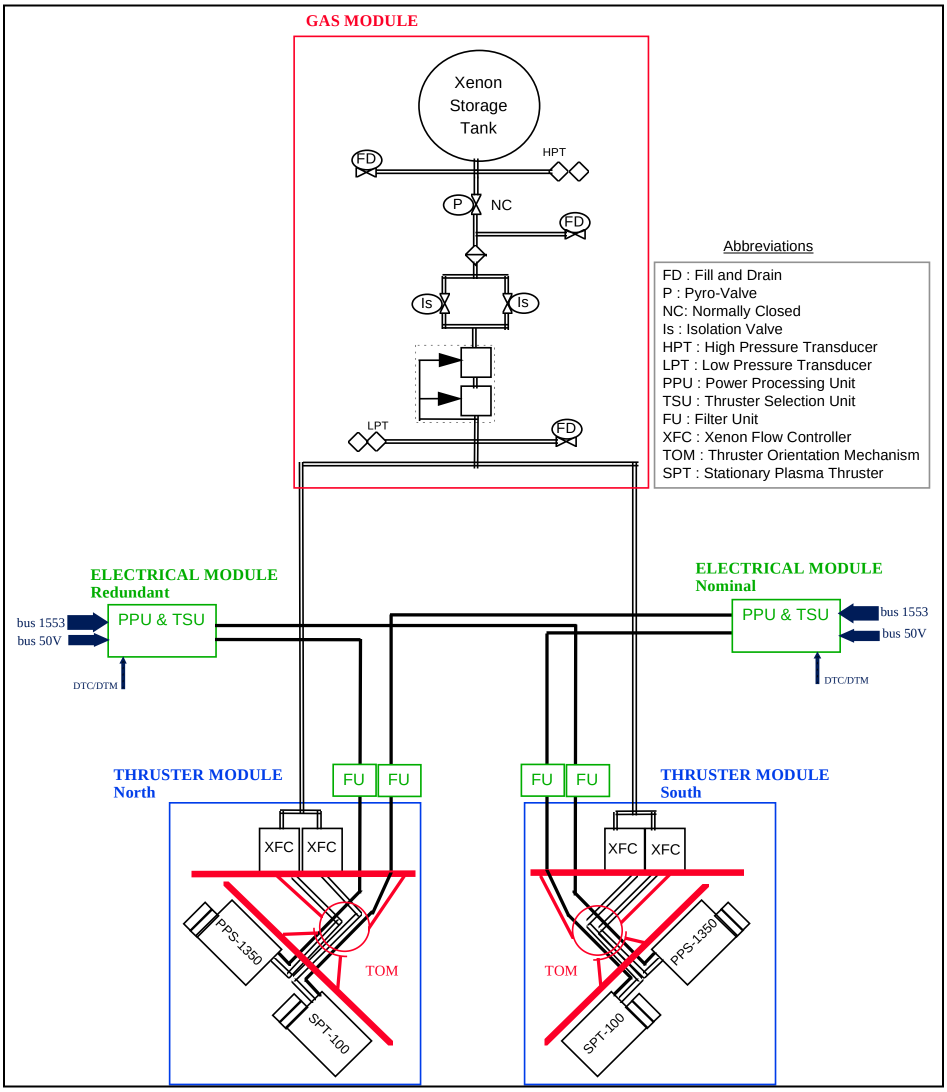


Figure 2.: Plasma Propulsion System architecture

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.

DEVELOPMENT AT EQUIPMENT LEVEL

The following equipment were fully developed and qualified in the frame of the STENTOR program.

Equipment	Supplier
Xenon storage tank	EADS
Pressure regulator	STANDFORD MU
Power Processing Unit	ALCATEL ETCA
Filter Unit	EREMS
PPS-1350 and XFC	SNECMA
Thruster Orientation Mechanism	ALCATEL SPACE

It shall be also noted that SPT-100 thruster was delta-qualified to meet higher mechanical environmental requirements.

Development and qualification of the Xenon storage tank and PPS-1350 thruster were directly supported by the CNES Agency.

Photo Alcatel

Figure 3.: PPS-1350 thruster

Photo Alcatel

Figure 4.: Thruster Orientation Mechanism

Photo EADS

Figure 5.: Xenon storage tank

Photo Alcatel ETCA

Figure 6.: Power Processing unit

Photo µSpace

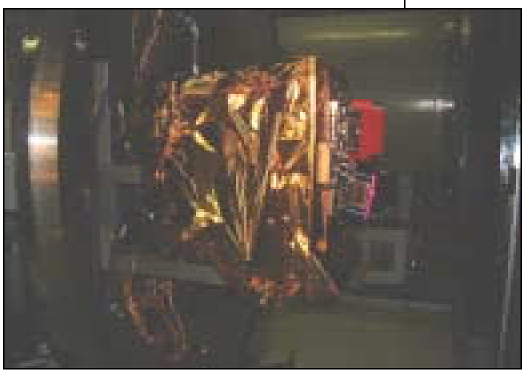
Figure 7.: Pressure Regulator

Detailed information onto those development could be found in dedicated papers.

DEVELOPMENT AT PROPULSION SYSTEM LEVEL

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

Therefore the following main analysis and tests were conducted :

Assembly	Test / analysis
Gas module integrated onto a JIG	. high pressure proof pressure . external leakage . pressure regulation . cleanliness control
Gas module	. thermodynamic analysis of Xenon storage tank fill and drain
Electrical Module	. performance and EMC test with thruster dynamic simulator . performance/EMC test with SPT-100 and PPS-1350 
Thruster Module	. vibration test . thermal test with thruster firings  
Thruster and Electrical Modules	. performance test on each thruster and cathode with electrical module
PPU-XFC- Thruster	. margin analysis of the control loop and sensitivity to perturbations
PPU-FU-Thruster	. Monte Carlo / WCA analysis of the electrical network

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

SYSTEM LEVEL

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 is 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.

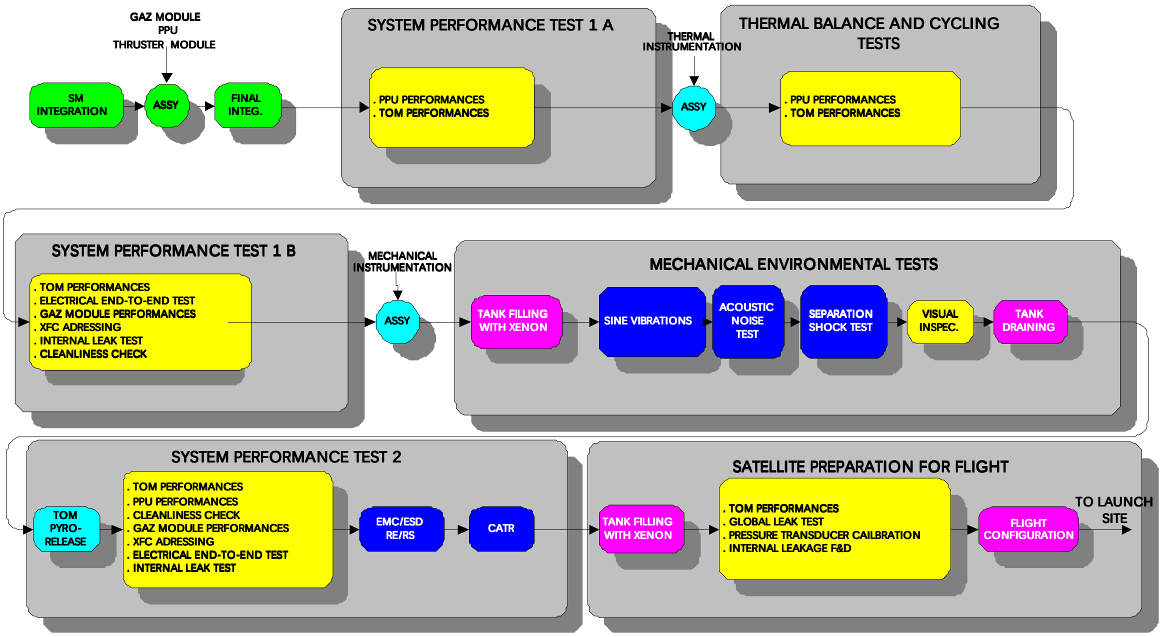


Figure 8.: AIT Flow chart

Specific Ground equipment

Three ground equipment dedicated to plasma propulsion were developed and validated during the spacecraft AIT:

- Xenon Ground Support Equipment (XeGSE) for Xenon filling/draining and test onto the propulsion system,

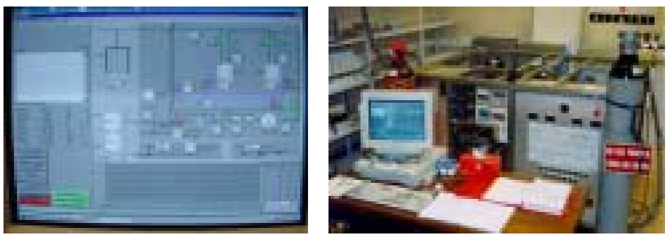


Figure 9.: Xenon ground Support Equipment

- Thruster simulator: representative of the static and dynamic load of a thruster, this equipment is used during PPU performances test and during EMC test,

- Thruster test cap: this cap is connected directly to the thruster electrodes and allows to perform electrical end-to-end test.

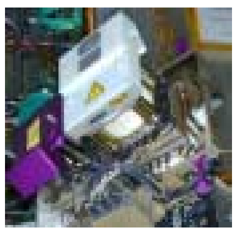


Figure 10.: Test cap mounted onto thruster

Main performances and achievements during AIT:

- Tank filling with Xenon:
  It was for the first time performed into the tank equipped with its thermal insulation and mounted into the spacecraft. Use of thermal compressors has been optimized according to xenon temperatures and pressures in order to reduce tank filling duration down to 5h30 for the 72.5 kg to be loaded. Achieved accuracy onto loaded mass was 0.3 kg for a 0.5 kg expected.

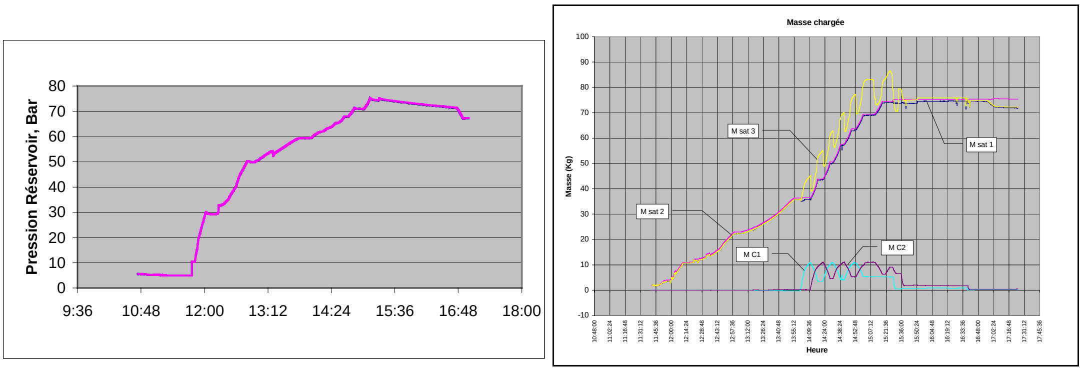


Figure 11.: Pressure and mass evolution during tank filling

- Global leak:
  Such a test is usually performed with Helium. In order to save manipulations (drain Xenon used for vibrations, load Helium and after test, drain Helium to fill with Xenon) and time, we did it directly with the propulsion system in launch configuration i.e. with flight Xenon loaded. Measurement was performed with the procedure used for Helium, except that the spectrometer was calibrated onto Xenon instead of Helium. Such a test demonstrated that we could actually full-load the propulsion system with Xenon only once during the integration and test campaign.

- Validation of cleanliness procedures:
  Particular and molecular cleanliness control was performed after the mechanical environmental tests directly onto the Xenon that was drained from the spacecraft. Such a control showed no degradation of the Xenon cleanliness validating thus all the cleanliness control plan defined from the equipment integration up to Xenon filling for flight.

- Pressure regulation:
  Choice was made during the design phase to perform Xenon pressure regulation with a mechanical series redundant regulator. This equipment being the heart of the gas module, performance trend analysis was performed during all the equipment life. Pressure regulation accuracy and internal leakage were not degraded after all the operations and tests, in particular after the proto-flight mechanical environmental tests.

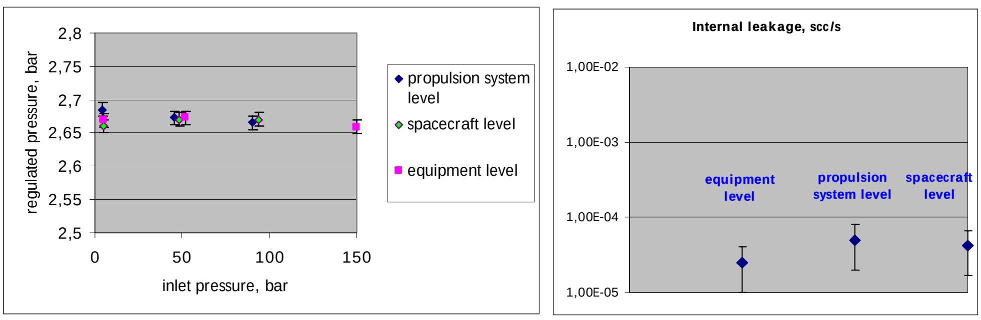


Figure 12.: Regulated pressure and leak rate trend analysis

- Electrical auto-compatibility Test:
  Simulation of a thruster firing was performed with Power Processing Unit loaded onto a representative dynamic simulator in order to check that inrush on the power bus (at switch ON and OFF) are identical

to the inrush measured during qualification and that inrush do not perturb the spacecraft functions (status transitions, FDIR mechanism, susceptibility). Test results demonstrated such a compatibility.

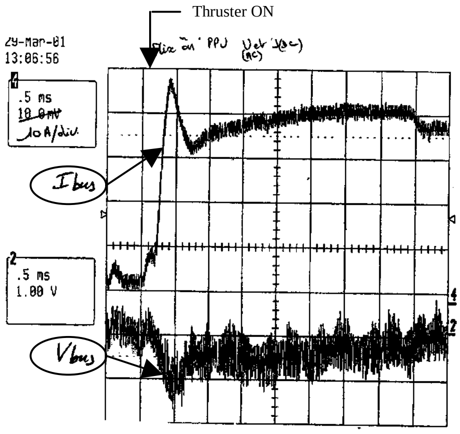


Figure 13.: Bus current and voltage Inrush at thruster start up

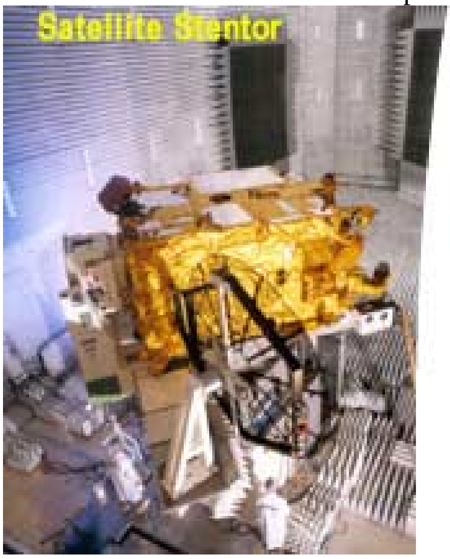
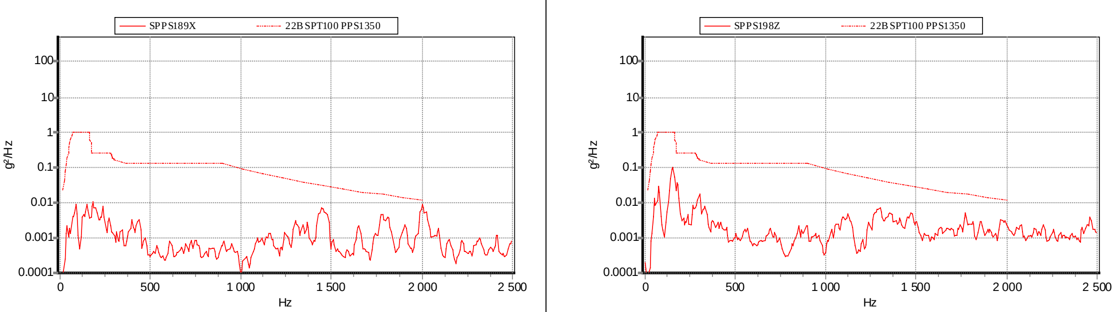


Photo Alcatel

Figure 14.: STENTOR Spacecraft

- Electrical end to end tests:
  Use of a test cap directly mounted onto the thruster was decided early during the design phase. This test cap allows to demonstrate during AIT that thruster electrodes are correctly fed when PPU is ON and that the addressing is correct. Such a test cap is necessary as thruster firing once integrated onto spacecraft is not possible onto large commercial spacecraft.

- Vibration tests:
  - Acoustic test: responses at interface but also onto the critical items of the thrusters (cathodes, central and external magnets) were monitored and comparison with qualification results were made. The main result is that actual inputs coming from the acoustic noise test are much lower that levels required into the equipment test specification. This point will be considered for the future programs.



I/F SPT100 (blades HTM3) – SPPS189X | I/F PPS1350 (blades LTM2) – SPPS198Z

Figure 15.: Acoustic noise at thruster interface

  - Sinus test : the input levels were driven by responses measured at thruster interfaces in order not to exceed equipment qualification levels. The thruster module had higher responses than it was foreseen in the mathematical model, due to higher amplification factor (low damping) and more important coupling of the local mode with the first longitudinal mode. Qualification for Ariane 4 and Ariane 5 vibrations environment was achieved. Performances of the thruster module after this test did not reveal any damage.

- Thruster Orientation Mechanism Performances:
  Commandability over the operational domain of about +/-8 °, observability and alignments with regards to the spacecraft have been performed:
  - before, during and after thermal test,
  - before and after vibrations and pyro-release test,
  - during final spacecraft preparation with flight thermal insulation.

  All the results demonstrated that the TOM meet its performances after exposure to thermal and mechanical environmental tests. This test campaign provided a constructive return of experience that is already fruitfull.

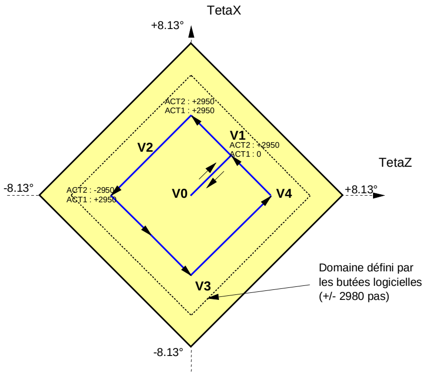


Figure 16.: TOM orientation domain

IN-FLIGHT ACCEPTANCE TEST AND EXPERIMENTATION

The following experiments associated to the plasma propulsion system were foreseen:

- RF impact of ion beam with TTC omni-directional antenna,
- Characterization of thrust magnitude and orientation by successive firings for different solar arrays positions and coupled to a fine satellite localization system,
- Characterization of thruster performances over its working range and during its aging,
- Thruster plasma plume characterization with langmuir probe and retarding potential analyzer,
- Characterization of erosion and deposition effects with micro-balances mounted onto the solar array,
- Characterization of solar cells working point and degradation over lifetime.

Unfortunately, this chapter has to be written some later on…

Figure 17.: Thruster firing

CONCLUSION

Development of the plasma propulsion system in the frame of the STENTOR program was a great challenge for all the partners involved in. 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.

Launch failure and lost of the spacecraft was a great deception as we were not able to conclude by an in-flight demonstration of the plasma propulsion performances.

However, despite this lost, results of all the effort of development already is profitable to the European industry and will be undoubtedly fruitful in the future.

Completion of the on-ground qualification of the plasma propulsion system provides a strong background and allows ALCATEL SPACE to offer benefits of this technology to its customers with use onto its SPACEBUS spacecraft family but also onto other applications.

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