PLASMA PROPULSION SYSTEM FUNCTIONAL CHAIN FIRST THREE YEARS IN ORBIT ON EUROSTAR 3000

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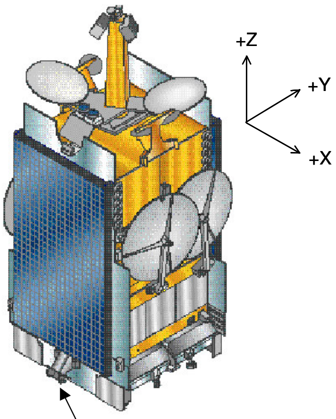
Abstract: This paper presents the first observations derived from one full year of telemetry survey of the Plasma Propulsion System (PPS) fitted on Astrium Satellites Eurostar E3000 Geostationary telecommunication platform. The paper briefly recalls the main features of the PPS before visiting the thruster performances, assessing the thruster to spacecraft interactions in comparison with the predications and finally outlining the first lessons learnt mainly on the operational level.
As the results presented only addresses the first 18 months of a fleet of 3 spacecraft currently in orbit; future work is planned either to confirm the observations presented here below or to enhance them with more accurate observations as described in the last part of the paper.

I. Eurostar E3000 Plasma propulsion system presentation.

The function of the Plasma Propulsion System (PPS) using two pairs of Hall Effect thruster accommodated on a Eurostar E3000 geostationary Telecommunication platform is to provide inclination and eccentricity control for North/South station keeping (NSSK) of the satellite. The PPS, whose thruster accommodation is shown schematically in Figure 1, uses Xenon as propellant and includes all devices to store and supply Xenon to the plasma thrusters (four SPT-100), which are accommodated by pairs on two orientation mechanisms (TOM) and which are power supplied by two electronic units (Power Processing Unit, PPU). The manoeuvre plan with firing configuration, times and duration is uploaded in the SCU from ground. A typical manoeuvre plan includes 4 firings of each operational SPT per week In operation the thrust induced momentum on the spacecraft are controlled by the TOM orientation which is driven by the Mechanical Drive Electronics (MDE) function of the Actuator Drive Equipment (ADE).



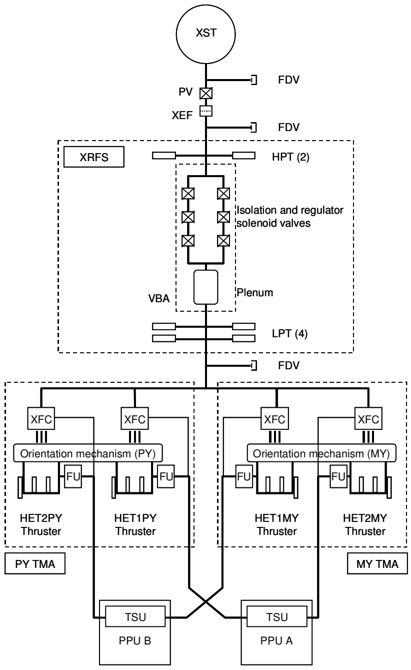
Thruster module (TMA) – MY unit shown

Figure 1: Thruster implementation on Eurostar E3000

The PPS feed system comprises a Xenon storage tank (XST), a pyro valve (PV) with its associated Filter (XEF), an electronic pressure regulation system (XRFS), and three fill and drain valves (FDVs); the PPS is then completed by two thruster module assemblies (TMAs) and two power processing units (PPUs), along with their associated pipework and harnesses. The PPS schematic is shown in Figure 2, and the equipments are listed in Figure 2.

During the on-orbit phase, the XRFS supplies Xenon to the TMAs at the required regulated pressure. .

The validation of the overall flight PPS and interfaces has been achieved by means of rigorous and incremental testing at equipment and spacecraft level, and finally by in-orbit tests prior to flight operations. .



Acronym	Title	Nº Off
PPS	Plasma Propulsion Subsystem	
├ XST	Xenon Storage Tank	1
├ PV	Pyro Valve	1
├ XEF	Xenon Filter	1
├ XRFS	Xenon Regulator and Feed System	1
│ ├ HPT	High Pressure Transducer	2 / XRFS
│ ├ VBA	Valve Block Assembly	1 / XRFS
│ └ LPT	Low Pressure Transducer	4 / XRFS
├ FDV	Fill and Drain Valve	3
├ PPSPIP	Pipework (HP and LP)	1 set
├ TMA	Thruster Module Assembly	2
│ ├ HET	Hall Effect Thruster	2 / TMA
│ ├ XFC	Xenon Flow Controller	2 / TMA
│ ├ TOM	Thruster Orientation Mechanism	1 / TMA
│ ├ FU	Filter Unit	2 / TMA
│ ├ N/A	TMA Thermal Device (MLI)	1 set / TMA
│ ├ BP	Base Plate	1 / TMA
│ ├ N/A	TMA Pipework	1 set / TMA
│ └ N/A	FU - HET Harness (HIB)	1 set / TMA
├ PPU	Power Processing Unit (with TSU)	2
└ EMH	PPU - TMA Harness	1 set

Figure 2: PPS Schematic and Hardware list

II. Eurostar E300 Plasma propulsion system flight record.

On the current Eurostar E3000 fleet operated in orbit since 2003 3 spacecraft are using PPS for their NNSK manoeuvres: Intelsat 10-02 launched from Baikanour Cosmodrome on June 16th, 2004 aboard Proton/Breeze M was the first one. It was followed by Inmarsat 4 F1 from Cape Canaveral on March 11th, 2005 aboard Atlas 5 and Inmarsat 4 F2 on 5 November 5th, 2005 from Sea Launch aboard Zenith. Following PPS venting and in orbit tests of all thrusters and cathodes, the operational life was started. Along this the redundant cathode and SPT were regularly activated to ensure their operational capability as redundant units.

In June 2007 the cumulated lifetime was 4300 hours over the three spacecraft. One single HET has accumulated 1150 hours of firing. No change in behaviour had been seen at that stage on the thrusters.

III. Thruster performances

Among the three ground life test there has been a consistent observation in the drop of the Isp over the first thousand hours of firing as shown on Figure 3. Each of these has shown an initial decrease of performances before a stabilisation and a slow recovery.

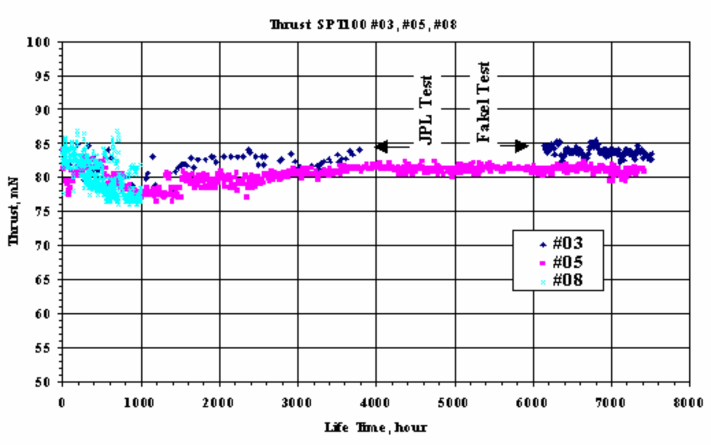


Figure 3: SPT-100 Thrust evolution along firing time for three life test

The first systematic analysis of the ageing trends in flight was conducted at the end of 2006 under a CNES contract and did not show any discrepancy with the life test results. Thrust and flowrate had been reconstructed through the discharge and thermothrottle currents telemered by the PPU. The evolution of thrust for two thrusters is shown on Figure 4. The slight discontinuities are due to the periodic switch to redundant elements. Accounting for the inaccuracy introduced by the telemetry chain which is above 6%, the trends confirm the ground observation.

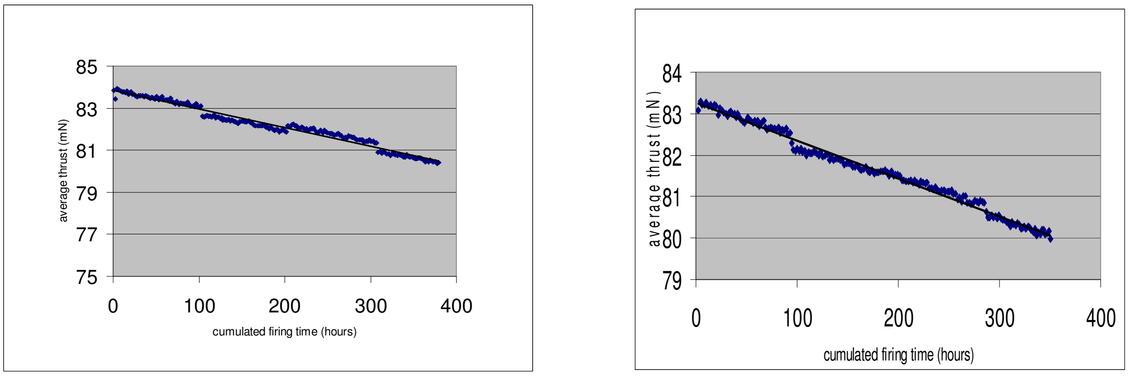


Figure 4: Thrust evolution as deduced from electrical parameters on two HET

Because this calls for better precision, thrusts have been deduced from ranging measurements and compared to the predictions on an important number of manoeuvres. With this method when comparing the resulting thrust of one manoeuvre to the one expected through the performance life model, the analysis of the residual tracking errors revealed that for pair of manoeuvres and over a set of plan manoeuvres the propagator was accurate to better than 1%.

Other health indicators of the thrusters are being monitored regularly. The oscillation of the discharge current and the number of pulses necessary before ignition of the discharge have not varied since the first uses on any of the units in flights. Oscillations are contained to a few hundreds of milliamps and ignitions always take place on the first pulse sent on the cathode igniter.

IV. Thruster Interactions

HETs produce both highly energetic and charged particles, with a non-negligible ion flux at high angles from the thrust axis. This raises several potential interactions with the surrounding surfaces of the spacecraft: .

- Dynamic effects.
- Spacecraft charging modifications.
- Radio-Frequency perturbations .
- Erosion and contamination of sensitive surfaces.

Some of those interactions may have non-negligible impacts at system level (dynamic effects must be managed by ADCS, erosion and contamination may lead to thermo-optical properties degradation over life, etc.). Astrium has developed a set of modelling tools to assess the main effects of PPS at system level. These tools have been developed in the frame of the generic Eurostar E3000 platform programme, and used to perform PPS / spacecraft interaction analyses for the specific configurations.

Among the above effects the Electromagnetic Interference has not been observed as predicted after the thorough characterization campaign.

The erosion and contamination aspects are not leading to visible effects (according to the models) in the first years and limited. Indeed to date no effect could be noticed on the PPS fitted fleet.

Plume effects have to be tightly controlled as expected and predicted. As the residual torque on the spacecraft is constantly left to a minimum the thruster orientation mechanism has to compensate for the plume. Two phenomenoms contribute to the plume effects. The first one is an average thrust direction shift over the first minutes of firings and on the long term. The second one is the interaction of the plume with the spacecraft surfaces.

The thrust direction shift has been observed to be larger and takes longer than predicted through the ground measurements. However the effects remain well within the control capability of the spacecraft Attitude and Control Determination System. The second effect has revealed that the plume model needed to be updated to reflect the inhomogeneity of the plume. This leads indeed to spacecraft surfaces to be impacted slightly differently by ion or electrons according to their potential. Such observations have been fed back in the interaction models. Erosion effects have been revisited on this occasion and initial predictions have been found to stay valid. On the long term (steady state conditions of firings) The thrust remains in the cone predicted through the ground tests as shown in . Figure 5.

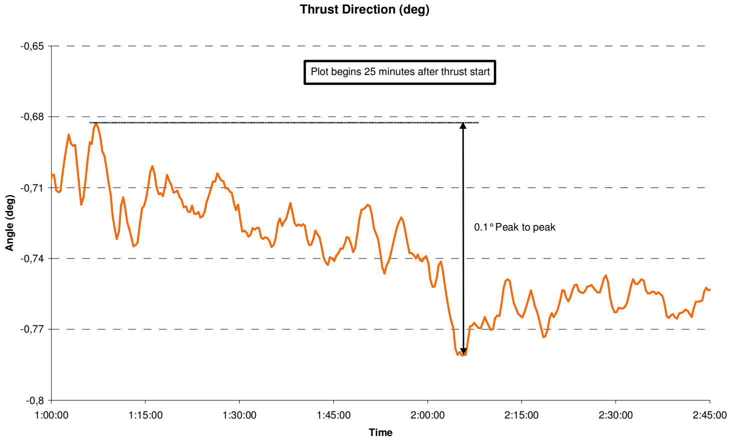


Figure 5: Thrust vector depointing vs time

The Cathode Reference Potential Telemetry shows that the cathode potential stabilises at a lower positive potential (typically a few volts) than originally predicted, this stabilised potential depending on solar array position. This could be due to one or both of the following: .

Ion current collected by the solar array interconnects has been over-estimated in the above analysis.

Current collection by the thruster casing itself (grounded by a low impedance). This collection happens in the thruster vicinity and is thus subjected to high uncertainties. .

Comparison of the CRP theoretical predictions with in-flight measurements will be subject of further future study. .

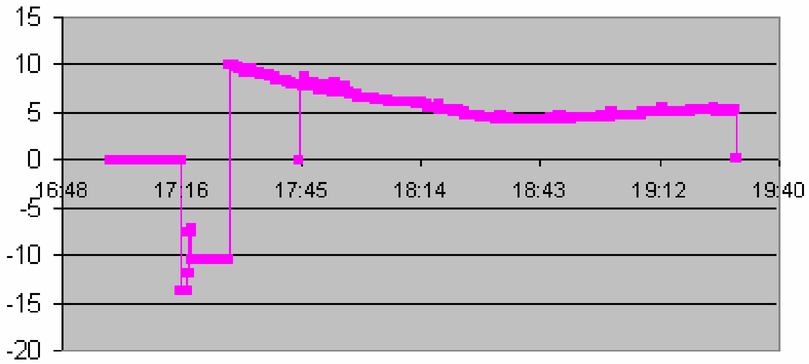


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Figure 6: CRP evolution along a firing

V. Lessons learnt

Xenon Gauging

The Xenon gauging using the XRFS high pressure transducer information is a PVT method relying on the Michel's equation to model the Xenon behaviour inside the tank. Comparisons of pressure and temperature readings over time have been shown that the best accuracy was achieved when the upper tank temperature sensor was used instead of the middle or the bottom one. The variations of pressure and tank top temperature were quite in phase and found consistent with the known mass of Xenon at that time of the mission (initial load). However, the error linked to the PVT method can be as large as 50kg around the Xenon critical point.

Therefore another approach has been to develop a tool estimating the Xenon consumed for each manoeuvre and added. The flowrate was estimated from the following equation: $\dot{m} = m_0 + m_1 I_{tt} + m_2 I_{tt}^2 + \alpha (P - P_{ref})$ (where Itt stands for the thermothrottle current and P for the xenon pressure at the thruster valve inlet). In this "bookkeeping" method the major inaccuracy lies with the sampling of Itt, every 20s. Therefore the rapid increase of Itt at XRFS opening and concurrent Xenon surge could be missed. Attempts to reconstruct the signal considering its recurring character have however shown not great benefit when considering the other sources of error (Itt TM accuracy for instance). The nominal flowrate accuracy is +7.6/-11.0% and the sampling was estimated to add 0.5%. Moreover though there is a significant uncertainty in the instantaneous flowrate computation, averaging the measurements over a firing allow to decrease the error. Hence the analysis was so far processed with raw telemetered data. .

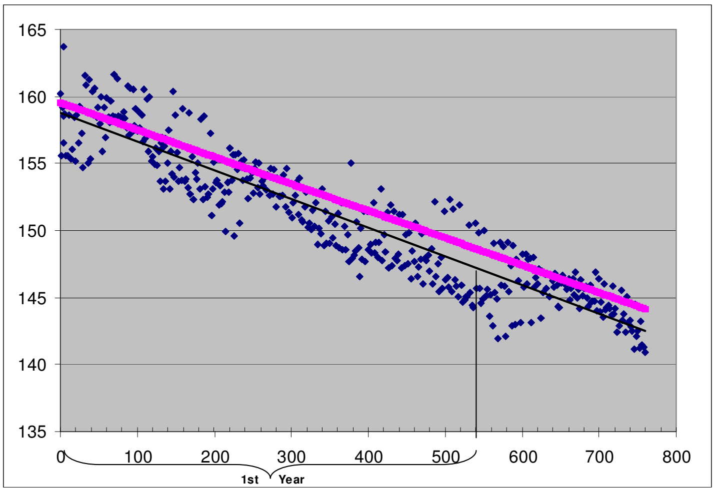

Figure 7: PVT and book-keeping Xenon budget comparison vs firing time

Thruster Events

Thanks to an exhaustive instrumentation and set of telemetries the plasma propulsion good health can be monitored throughout the manoeuvres. Over the first three years no firing interruption has been observed. Only one transient discharge condition trig was observed as it had been during the ground life tests (single event) without any effect on the manoeuvre. This can have been due to external conditions or worn ceramics getting in the plasma as observed during the life tests. As this was expected the robustness built in the system allowed the manoeuvre to continue safely.

VI. Future Work

The first years of PPS operations have been marked by a flawless record. Both operators have acknowledged the smoothness and the predictability of the manoeuvres. Deeper survey of the above results spread over the three years is going to be started to refine the actual thrust measurement by using very accurate ranging tools. In the end this should allow the operators to simplify their operative planning of the PPS fitted fleet. Another work would be to continue the Xenon gauging survey; thoughts along the possible improvements have already allowed to propose a significant improvement of the end of life prediction with the reference architecture. The future work will also be to verify the thruster performances as they should stabilize after 1000hrs.

A new set of observations is also foreseen with the assessment of the first effects of erosion, sputtering on the spacecraft, the actual measurement of Electromagnetic Interference with the radiofrequency signals and the verification of the CRP behaviour.

Further activities will be started also to ease the operators' tasks in the fleet surveillance tasks. As a result of the present survey Astrium has been able to positively contribute to the plasma propulsion suitability for Telecommunication missions.

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