ASTRIUM EXPERIENCE ON SPACECRAFTS DEORBITATIONS

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Abstract

In the last 10 years Astrium has acquired a significant experience on end of life operations for several satellites which had been developed under the company leadership. Such end of life operations have been performed either under CNES or ESA responsibility or in some other cases under Astrium direct responsibility.

INTRODUCTION

In the context of increasing orbit debris in space, international and national regulations are progressively compelling spacecraft operators to remove their spacecrafts at the end of life from restricted zones (see references [1] to [4]). As a consequence, space agencies (CNES, ESA) try to show they comply to legislation with their own satellites.

In the case of Low Earth Orbit (LEO) satellites, there is a constraint to obtain either a controlled re-entry or an uncontrolled re-entry into Earth atmosphere in less than 25 years. The different regulations also ask operators to passivate the satellites once the deorbiting operations have been conducted.

This paper describes the activities performed in the past 10 years by Astrium relative to end of life operations, either in support to agencies or as a spacecraft operator. The concerned spacecrafts, some of which were launched more than 15 years ago, were not initially designed to fulfil the new regulations so it was necessary to put in place specific solutions in order to fulfil as far as possible the new directives.

The main activities performed by Astrium are the following:

a) Definition of leading procedures associated to the different deorbitation and passivation strategies including Failure Detection Isolation and Recovery (FDIR) issues

b) Definition of procedures for final thrusts and electrical passivation

c) Related Attitude and Orbit Control System (AOCS) analyses

d) Related on-board software (SW) activities

e) Support to CNES/ESA for procedures validation and flight operations

f) Deorbitation operations from Astrium Toulouse premises

1. ORBIT STRATEGIES

There are different orbit strategies for spacecraft deorbitation. The selected strategy will depend on the following non-exhaustive elements:

- Initial orbit characteristics (altitude, eccentricity, inclination),
- Remaining on board propellant on starting deorbitation operations,
- Spacecraft (S/C) capacity to withstand non-nominal orbits (e.g. compatibility of sensors field of view with lower altitudes; compatibility of on-board actuators with increased disturbing torques),
- On-board equipment health status at the start of the deorbitation

Current Astrium experience has led to consider the following orbit strategies, which can be organised into two large categories:

- Low Earth Orbits (initially circular)
- Geostationary Transfer Orbits (highly elliptical)

For LEO satellites three main strategies have been considered:

- The elliptical orbit strategy consisting in lowering the orbit perigee as much as possible so that air drag will naturally erode the orbit and induce a natural orbit decay and subsequent re-entry (see Fig. 1). This will be obtained by applying repeated orbit control manoeuvres at the orbit apogee,

- The circular orbit strategy consisting in a series of Hohmann transfers (see Fig. 2), that

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will reduce the orbit semi-major axis while keeping a circular orbit,

- The continuous thrust strategy consisting in a single continuous manoeuvre. This strategy has been considered for emergency cases and has never been applied so far. The final orbit will be elliptical in a general case.

In the case of the elliptical orbit, the initial phase of the deorbitation will consist in a clearance manoeuvre aiming to extract the S/C from the operational orbit by lowering its altitude.

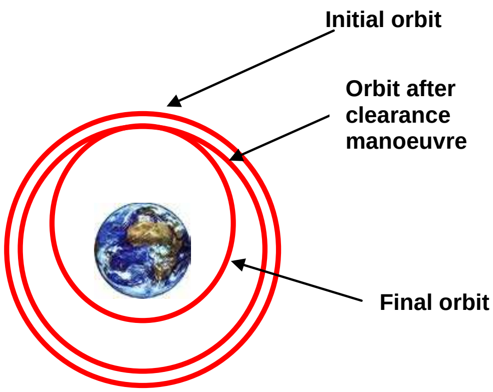

Figure 1: Elliptical orbit strategy

The elliptical orbit strategy has been applied for SPOT1 and SPOT 2 deorbitation and it will probably be used again for SPOT5.

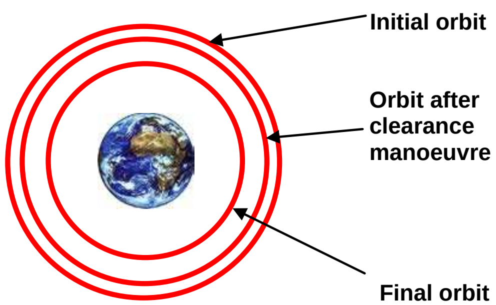

Figure 2: Circular orbit strategy

The circular orbit strategy has been applied for ERS-2, HELIOS 1A and will be used again for SPOT4 by mid-2013.

For Geostationary Transfer Orbits (GTO), the strategy is quite straightforward as it consists in lowering the orbit perigee. Two situations have been experienced by Astrium:

- In the case of end of life operations, the strategy consists in lowering the orbit perigee as much as possible with the remaining propellant as shown in Fig. 3. The orbit will naturally decay until an uncontrolled re-entry takes place,

- In the case of a deorbitation imposed by a launcher injection anomaly. In this case, the amount of propellant is such that it is possible to lower significantly the orbit perigee and obtain a controlled re-entry (see Fig. 4).

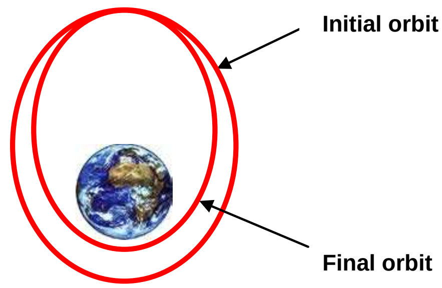

Figure 3: GTO initial orbit

The GTO orbit strategy has been applied to the Myriade class satellites Spirale A and B.

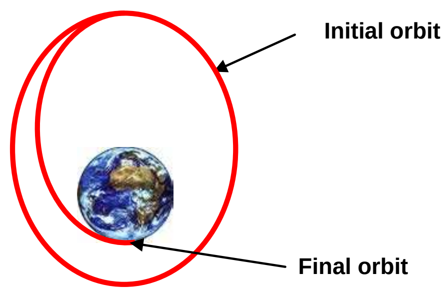

Figure 4: Controlled re-entry

The controlled re-entry has been applied to two telecommunications satellites which were injected on non-exploitable orbits (Arabsat 4A and Express AM4).

2. DEFINITION OF PROCEDURES FOR FINAL THRUSTS AND ELECTRICAL PASSIVATION

Once the deorbitation strategy has been set up, Astrium has defined the associated procedures to perform the deorbitation itself and the satellite final passivation.

In the case of SPOT-like platforms, specific procedures have been defined adapted to three different cases, which correspond actually to different platform generations. The different procedures aim to optimise the sequencing of propellant tanks depletion during the final thrust sequence and the subsequent electrical passivation.

Case 1:
Generation of several thrusts with Ground Station coverage until tanks exhausting criteria are detected by Ground and then sending of passivation commands.
Application case: SPOT1, SPOT2, ERS2 which are based on Spot Mark I platforms.

Figure 5: SPOT1

Case 2:
Generation of one final continuous thrust followed by an autonomous passivation through time-tagged commands.
Application case: Helios1A and foreseen for SPOT4, which are based on Spot Mark II platforms.

Case 3:
Autonomous electrical passivation as soon as batteries under-voltage is detected, which allows for tanks large de-pressurization.
This is foreseen on SPOT5 which is actually based on a SPOT Mark III platform.

Figure 6: SPOT5

The electrical passivation commands cover the transmitter switching OFF and the batteries disconnection.

Fig. 7 hereafter illustrates case 1 application on ERS-2 and how Ground determined tank depletion.

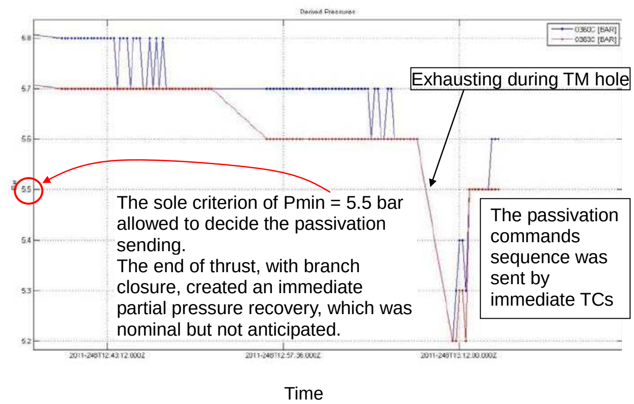

Figure 7: Tank pressure evolution during last thrust

3. RELATED AOCS ANALYSES

A key element in the deorbitation strategy is the AOCS capacity to control the S/C during all the operations.

Actually, it has been necessary to analyse the limits of AOCS sensors and actuators prior to the definition of the deorbitation strategy.

This paragraph presents the main points considered in the case of LEO orbits for the SPOT Mark I and II platforms

For circular or elliptical orbit strategies:

- Analysis of wheels kinetic momentum off-loading capability. As the orbit altitude decreases, the disturbing torque associated to air drag increases and leads to a wheel kinetic momentum build-up which may exceed the off-loading capacity provided by magnetorquers,
- Definition of an optimum elliptical orbit orientation for air drag reduction at perigee: by ensuring a solar array orientation edge-on to the wind at the perigee, the disturbing torques due to air drag observed at such orbit location will be the lowest,
- Analysis of Earth Sensor field of view compatibility with lower altitudes: as the orbit altitude decreases the Earth apparent diameter increases and will ultimately exceed the sensor FOV. Such a situation will lead either to define a target perigee altitude not to be exceeded or to perform part of the deorbitation without optical sensors in the loop.

For unique thrust strategy (emergency case):

- Analysis of optimum AOCS parameters update times during the continuous descent: the significant variation of orbit characteristics during the deorbitation manoeuvre may require adjusting periodically on-board some AOCS parameters (e.g. mean orbital rate).

4. RELATED ON-BOARD SW ACTIVITIES

After the deorbitation itself, it has been necessary to passivate electrically the different spacecrafts. As the considered satellites had not been designed initially to fulfil the stringent passivation rules imposed by the new international directives, it has been necessary to modify on board SW in such a way that electrical passivation of the satellite can be performed in a satisfactory way.

This has required the definition of various patches needed for the procedures application, including FDIR adaptations. Here after we provide some examples of such SW patches:

- Final autonomous electrical passivation upon power bus under-voltage detection: the principle is to determine autonomously on board when to trigger the electrical passivation once the deorbitation has been completed and the propellant has been exhausted. This allows for a significant tank depressurization level,
- Automatic AOCS parameters updates for the continuous thrust option: the objective is to adapt some on-board parameters without ground intervention as the deorbitation progresses (e.g. thruster generated torques, which depend on the remaining propellant mass)
- Disabling of some S/C monitorings or thresholds adjustments and also modified reaction in case of triggering
- Prior to the last orbit control manoeuvre, the Ground just activates, by patching a flag, the sending of the passivation commands upon the triggering of the already-existing main power bus under-voltage surveillance. This commands sending takes place instead of the Power Subsystem reconfiguration.

5. SUPPORT TO CNES/ESA FOR PROCEDURES VALIDATION AND FLIGHT OPERATIONS

In the case of LEO satellites, end of life operations have been performed under CNES and ESA responsibility.

Astrium role in this case was to bring an expertise in terms of S/C design and to support the operations directly conducted by the agencies.

This was the situation for SPOT Mark I and SPOT Mark II satellites: SPOT1&2, ERS-2 and HELIOS 1A.

6. DEORBITATION OPERATIONS DONE FROM ASTRIUM TOULOUSE PREMISES

In the case of Spirale A and B, as well as Arabsat 4A and Express AM4, the end of life operations have been directly conducted by Astrium in their Toulouse premises.

Figure 8: SPIRALE

Figure 9: EXPRESS AM4

7. ACHIEVED ORBITS

Tab. 1 here after provides some figures about the initial orbits, the achieved orbits and S/C mass characteristics and remaining propellant mass at the beginning of the deorbitation.

The table shows the estimated re-entry period which is in all the cases compliant with the 25-year rule.

S/C	Deorbitation date	Remaining propellant	Initial altitude	Altitude drop (variation)	Re-entry period
SPOT Mark I platforms					
SPOT1 (1750 Kg)	November 2003	60 kg	820 km	240 Km (perigee)	< 25 years
SPOT2 (1750 Kg)	July 2009	60 kg	820 km	250 Km (perigee)	< 25 years
ERS2 (2280 Kg)	July-August 2011	160 kg	800 km	210 Km (circular)	15 years
SPOT Mark II platforms					
HELIOS 1A (2360 Kg)	January 2012	40k	Classified	70 Km (circular)	< 25 years
Myriade platforms					
Spirale A (123 kg)	February 2011	2.33 kg	GTO ~650 km (perigee)	465 km (perigee)	< 5 years
Spirale B (123 kg)	March-April 2011	2.3 kg	GTO ~675 km (perigee)	450 km (perigee)	< 25 years

Table 1: Achieved orbits after deorbitation

8. CONCLUSION

Astrium has already acquired a significant experience on end of life operations (deorbitation and passivation) which will be useful:

- For future de-orbitations like SPOT4 (currently scheduled mid-2013), SPOT5 in 2015 and METOP A later on,
- But also for future S/C designs in order to better comply with international regulations on space debris.

9. REFERENCES

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