MPS CONSTELLATION: Flight EXPERIENCES

M. Battistel, PP. Baubias, P. Garcon
Thales Alenia Space, Cannes, France
marc.battistel@thalesaleniaspace.com

ABSTRACT

Since 2007, the Propulsion Products Line department of Thales Alenia Space has been involved in the design, development, production and delivery of the propulsion sub-system of 3 constellations: Globalstar-2 (GB2), Other 3 Billion (O3b) and Iridium Next

The paper will first focus on LEOP activities performed in the frame of Globalstar-2. This will show how, at Propulsion level, the activities done in the frame of a constellation imply adaptations with respect to what is usually made on Telecom satellites. In a second part, the paper will show how the lessons learnt from Globalstar-2 have been applied to O3b and how different LEOP strategies have been applied on those programs.

1. RECALL OF GB2 AND O3B PROPULSION S/S

These two subsystems are monopropellant hydrazine ones used in blow down mode. Fig 1 presents the GB2 synoptic. O3b design is similar except the addition of 4 thrusters for redundancy purpose.

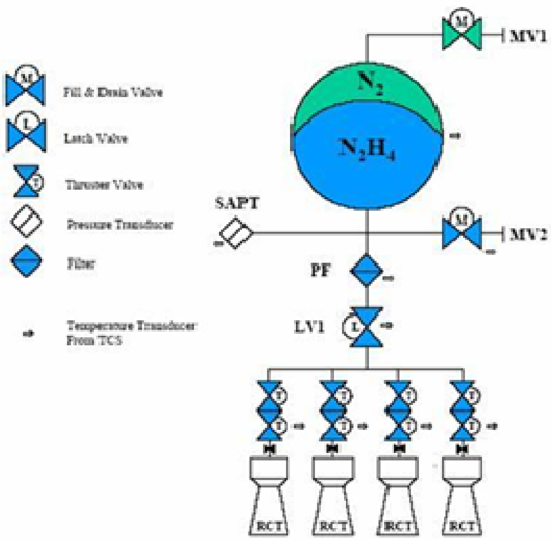

Figure 1: GB2 fluidic synoptic

Particularity on the two constellations is the nature of the thrusters used for the LEOP. They are 1N monopropellant thrusters usually used only for station keeping manoeuvre.

2. LEOP GB2 OVERVIEW

LEOP operations for GB2 program have been realized between November 2011 and August 2013, in order to put 24 satellites into orbit by 4 batches of 6 satellites.

N°	Launch site	Launcher	Date
L1	Baikonour	Souyouz	19/10/2010
L2	Baikonour	Souyouz	13/07/2011
L3	Baikonour	Souyouz	28/12/2011
L4	Baikonour	Souyouz	06/02/2013

Table 2: GB2 launch dates

For these LEOPs, customer facilities located in Milpitas, California were used. Customer team was previously more involved in GB1 constellation maintenance than in LEOP operation and in consequence ask TAS for support.

This support includes definition of the LEOP strategy and TAS staff support between 4 up to 10 people in California during all LEOP duration.

Nominal staffing for propulsion department was one people, with period up to 2 people. A total of 5 different people were involved for these LEOPs during the period from 2011 to 2013.

A dedicated software for LEOP prediction was developed and delivered to Ginc (Globalstar Inc.), including customer training sessions (See §4).

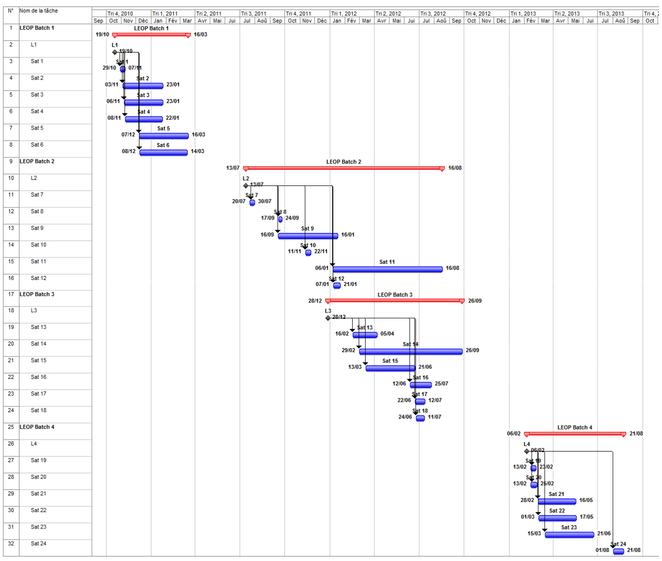

Figure 3: GB2 LEOP Schedule

Due to the 4 launches required to deployed the full GB2 constellation, TAS support to Ginc was less and less important from launch to launch.

Due to the large number of satellites in LEOP at the same time (up to 6), only one manoeuvre per satellite and per day is allowed. The maximum number of manoeuvres per day reached 3 manoeuvres, realized on 3 different satellites.

3. GB2 LEOP STRATEGY

Globalstar satellites are placed in 52° (degree) inclined circular orbit at 1414 km. A total of 8 orbital planes with 5 satellites in each plane are used to provide continuous global coverage from 70° North to 70° South latitude.

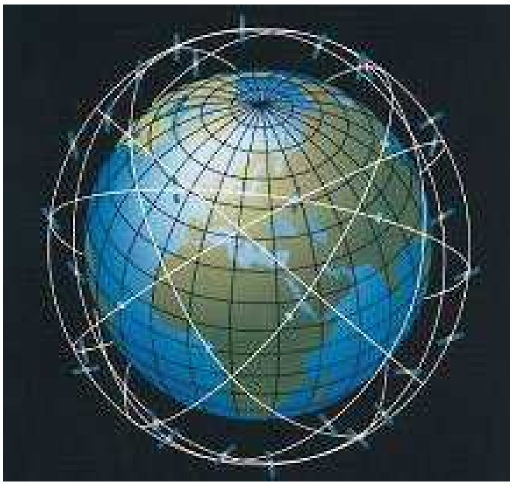

Figure 4: GB2 orbital planes

Starting from a parking orbit at 902 km, the 4 thrusters used at the same time had to provide required delta-V up to 1414 km.

Typical manoeuvres plan include:

- 4 OCM of 2 hours: major delta-V generation
- 2 OCM of 30 min: Correction of previous manoeuvres
- 2 OCM of 3-5 min: final injection
- Total Ton duration for LEOP: 12 Hours

Behind these typical values, significant adaptation of the flight plan was performed for each satellite. For example, the longest manoeuvre duration reached 04H08 and the number of OCMs was adapted from 7 to 10.

Due to the particular orbital planes (see Fig. 4), the satellite uses the natural drift around Earth to reach its target plane. As a consequence, the LEOP duration for one satellite is highly adaptable with range between 7 to 223 calendar days, meaning from 1 to 31 weeks with an average value at 65 days (see Fig 3). For a complete batch of 6 satellites, maximal LEOP duration reached 401 days.

4. GB2 PROPULSION SOFTWARE

As part of TAS support, dedicated propulsion software has been developed and provided to Ginc, after being used internally.

Heart of the software is EcosimPro 4.4.0 and ESPSS Library 1.0 even if Excel is used for human interface.
The software allows classical propulsion calculation (pressure evolution, propellant consumption, thrust for each thruster, …). In order to improve the software's added value, modelling of the degradation of the monopropellant thruster has been introduced allowing a significant improvement of the prediction accuracy. Comparison to qualification lifetime hot firing allows this calculation.

The software allows the prediction of a single manoeuvre or of the full LEOP up to final orbit but limited to a single satellite. The same software is used for manoeuvre restitution.

The validation of the software, in particular its accuracy, has been performed during first launch, when TAS support in Customer premises was at its maximum. Some examples are presented in Fig. 5 and Table 6.
Training of the customer was performed during the LEOP period, allowing immediate application in real time operations.

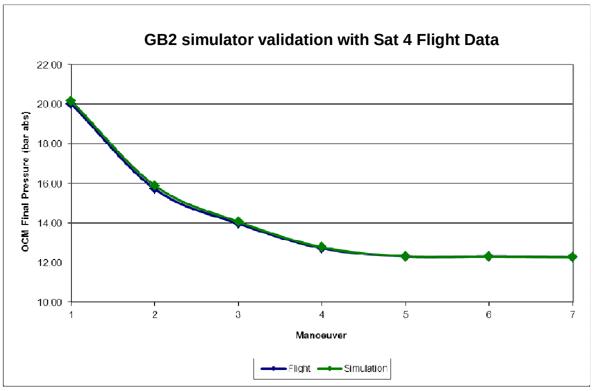

Figure 5: Software validation

Parameter	Sat 4 results	
Pressure (Bar)	-1,09%	Error vs real data
Propellant mass (Kg)	-0,81%	Error vs real data
Thrust degradation (N)	-5,08%	At end of LEOP

Table 6: Software results

Thanks to very good accuracy level reached, some technical design trade-off have been confirmed. For example as full LEOP could be predicted with less than 5% error on the propellant mass consumption without any pressure acquisition, no SAPT redundancy design option has been confirmed.

5. GB2 LEOP: TYPICAL THRUSTER ACTIVITIES

On board AOCS software manages the thrusters thrust by adapting the D/C applicable to each thruster. Fig 7 presents the D/C evolution from 80%-100% to 90%-100% of the 4 thrusters all along the LEOP of one satellite with the demonstration of the system adaptation to the center of gravity displacement.

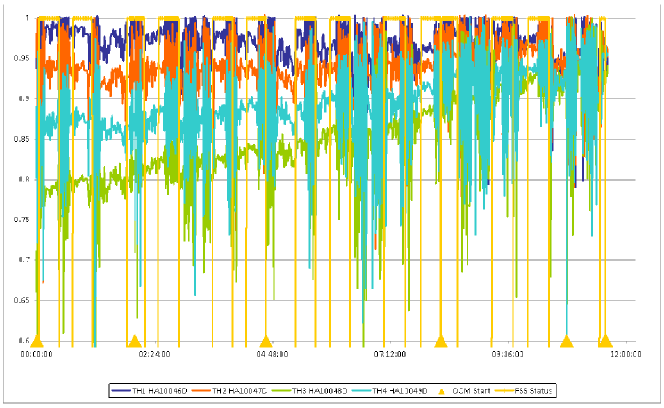

Figure 7: GB2 D/C evolution during all LEOP

This D/C evolution is the main parameter difficult to accurately predict on ground. By consequence, this parameter is recalibrated after each OCM.

As presented in Fig 7, access to the telemetry was not permanent due to the regular earth eclipses. Boost starts were realized with visibility with exception of the boosts for final injection.

6. O3B LEOP OVERVIEW

O3b LEOP was totally performed by TAS, using TAS facilities and team, without software delivery or training of the customer.
The first batch of 4 satellites was launched on 25/06/2013, from KOUROU using a SOYOUZ rocket.

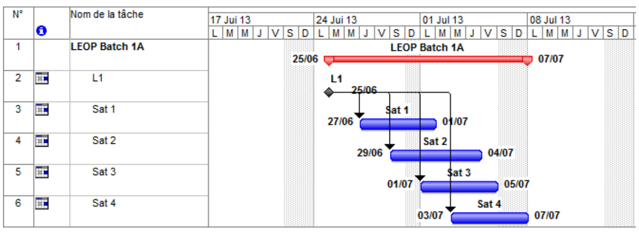

Figure 8: O3b LEOP Schedule

Full deployment of the constellation is not yet finalized with second batch in the next months and third batch in 2015.

7. O3B LEOP STRATEGY

Orbital position is an equatorial circular orbit at 8063 km, with satellites evenly allocated.

Typical manoeuvres plan include:

- 2 OCM of 50 min: major delta-V generation
- 1 OCM of 20 min: Correction of previous manoeuvres
- 2 OCM of 1 to 3 min: final injection

This plan was driven thanks to no need for natural drift and by the low altitude increase required (250 km) compare to GB2 (500 km) with similar satellite mass. By consequence, short schedule was the main driver of the O3b strategy, considering the minimal 7 days already realized for a GB2 satellite LEOP.

This target has been fully achieved. The minimal LEOP duration of an O3b satellite has been only 5 days. The complete LEOP for the first batch of 4 O3b satellites took only 11 days compared to the average 65 days for a single GB2 satellite.

8. O3B PROPULSION SOFTWARE

Due to very similar fluidic synoptic, the same software as GB2 has been used, with limited adaptations:

- Number of thrusters: Additional 4 thrusters are implemented only for redundancy purpose, but a maximum of 4 thrusters are firing at the same time during LEOP as GB2
- Addition of one AOCS mode using only 2 thrusters ON at the same time, not used during LEOP

The accuracy of the prediction of the software was similar to GB2 results, applied in particular to shorter manoeuvres than GB2.

9. O3B LEOP: THRUSTERS ACTIVITY

On board AOCS software manages the thrusters thrust by adapting the D/C applicable to each thruster as GB2. Manoeuvre survey was helped thanks to full visibility always available.

Total duration of firing is low compared to GB2, then the displacement of the center of gravity of the satellite is small and the degradation of the monopropellant thrusters have been reduced. As a consequence, D/C evolution of the thrusters was minor and less significant than Fig 7.

10. SUMMARY

TAS has demonstrated with LEOP's of 28 monopropellant satellites not only its capacity to design and produce satellite for constellation but also to ensure LEOP management of such large amount of satellites, with up to 6 satellites in operation at the same time.

Full range of LEOP activities has been realized including customer support in customer facilities (GB2), dedicated propulsion software development, validation and trainings (GB2), and full TAS responsibility of LEOP using TAS facilities in Cannes (O3b).

This highly adaptable TAS experience will be used to finalize the deployment of the O3b constellation (8 more satellites) and to ensure the deployment of the Iridium NEXT constellation with 72 satellites to be put into orbit + 9 satellites on ground.

11. ACRONYMS

AOCS: Attitude and Orbit Control
D/C: Duty Cycle
LEOP: Launch and Early Orbit Phase
OCM: Orbit Control Manoeuvre
TAS: Thales Alenia Space
Ginc: Globalstar Inc.
GB1: First constellation of Globalstar satellites with structure and propulsion assembly, test and filling operations provided by TAS
GB2: Second constellation of Globalstar satellites provided by TAS
O3b: Other 3 billion satellites constellation provided by TAS

12. REFERENCES

[1] A2365655, Space Propulsion 2012, M. BATTISTEL: Industrial organisation of propulsion subsystems for satellites constellations.

[2] A2980672, Space Propulsion 2014, PP BAUBIAS Offloading and decontamination of a MPS S/S.