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SGDC1 Technical Note

UPS and Mission Analysis health status

15 MARCH 2019 to 15 MARCH 2020

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THALES ALENIA SPACE INTERNAL

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ACRONYMS AND SYMBOLS

AOCS	: Attitude and Orbit Control Subsystem
BOL	: Beginning Of Life
DV	: Delta-V
EOL	: End Of Life
E/W	: East/West
Fu	: Fuel
IOAR	: In Orbit Acceptance Review
Isp	: Specific Impulse
MMH	: Mono Methyl Hydrazine
MON	: Mixed Oxides of Nitrogen
NM	: Normal Mode
N/S	: North/South
Ox	: Oxidizer
PC	: Pulse Counting
PVT	: Pressure Volume Temperature
S/C	: Spacecraft
SKM	: Station Keeping Mode
SOH	: Satellite Operational Handbook
SPB	: Satellite Parameter Book.
UPS	: Unified Propulsion Subsystem

THALES ALENIA SPACE INTERNAL

1. INTRODUCTION

The SGDC1 spacecraft is based on a SPACEBUS 4000C4 platform.
SGDC1 has been launched on 04/05/2017 and is positioned at 74.85°W.

1.1 General Aim

This technical note is part of the SGDC1 Health status report that gives a yearly survey of activities and performance evaluation.

This document deals with the Mission Analysis part and covers the period 15 March 2019 to 15 March 2020, corresponding to the third year in orbit.

The main parameters submitted to analysis are:

- the consumption of orbit control and AOCS maneuvers
- the remaining SGDC1 lifetime

1.2 Applicable Documents

None

1.3 Reference Documents

- [RD1] SOH Part 1: Unified Propulsion Subsystem, SB4-ASPI-MA-0112
- [RD2] SGDC - Propellant Budget Analysis, 200769140B, Issue 07

2. MISSION ANALYSIS

The inputs are based on the information sent by SGDC1 station keeping orbit reports from 15/03/2019 to 15/03/2020.

SGDC1 is positioned at 74.85°W.

Basically, inclination control is done every 14 days by one North or South maneuver. Longitude drift control is realized in a “single-burn” strategy by West maneuvers every 7 days, except two double burns at the end of the period (January and February 2020).

Typically, longitude drift control was realized by West maneuvers occurring on the third and tenth days after the North or South correction.

The drift caused by the in-plane cross-coupling is integrated during 2 or 3 days.

All the maneuvers have been performed in NM.

2.1 Propellant budget analysis

SGDC1 mass at the beginning of the analyzed period was:	3446.20 kg	:	- Dry + He:	2459.89 kg
(15/03/19)			- Oxidizer:	617.92kg
			- Fuel:	368.39 kg

At the end of the analyzed period, the mass was:	3384.63 kg	:	- Dry + He:	2459.89 kg
(15/03/20)			- Oxidizer:	579.76 kg
			- Fuel:	344.98 kg

Then for these twelve months of SGDC1 lifetime, the corresponding consumption was **61.57 kg**.

Sections below present:

- the consumption of orbit control and AOCS maneuvers over the period from 15/03/2019 to 15/03/2020.
- an estimation of remaining SGDC1 lifetime

2.1.1 Estimation of Isp during each N/S and E/W maneuver

The formula used for the computation of the Isp of each maneuver is the following one:

$$Isp.eff = \frac{DV}{g_0 \cdot \ln \left[\frac{M_i}{M_f} \right]}$$

where:

- "Isp" [s] is the specific impulse.
- "eff" [-] is the maneuver efficiency. This value was computed before S/C launch by Thales Alenia Space, it takes into account the cant angles of the thrusters, the predicted plume impingement effects, and the finite burn loss effect.
- "DV" [m/s] is the normal Delta-V for N/S maneuvers and tangential Delta-V for E/W maneuvers.

Three types of Delta-V are considered:

- DV commanded,
- DV estimated by Thrusters History method,
- DV estimated by Ranging method,

- "M_i" [kg] is the S/C mass before the maneuver.
- "M_f" [kg] is the S/C mass after the maneuver.

with the following statement:

The consumption (M_i - M_f) of each maneuver includes the effect of attitude control thrusters that occurs during each orbit control boost.

- "g₀" is the reference earth gravity acceleration: 9.80665 m/s².

Isp values are function of the AOCS mode used for maneuver, NM or DPM.

The Isp values estimated in yearly report are hardly comparable to the Isp used in the S/C propellant budget made by Thales Alenia Space before S/C launch. Indeed, the Isp computed in the yearly report take into account the attitude control contribution during orbit control maneuvers, whereas the Isp used in the pre-launch budget correspond to a mean pressure

value (MOL), mean theoretical duty cycle and the specific thrusters characteristics, and do not include attitude control contribution.

As the duty cycle of attitude control maneuvers is lower than the duty cycle of orbit control maneuvers, the corresponding Isp are lower than the Isp corresponding to the orbit control maneuvers only.

On the other hand, they are different from the MOL Isp, as Oxidizer and fuel pressures decrease through the S/C lifetime. But the main contribution is the duty cycle; pressure is a second effect.

Moreover, the value of the efficiency used to compute each Isp in the yearly report, from the product $Isp \cdot \text{eff}$, is a mean value for a whole lifetime. This may explain some seasonal discrepancies.

2.1.2 NM_OCC North/South maneuvers

For the studied period the characteristics of North and South maneuvers are:

studied period	15/03/2019 to 15/03/2020
number of North maneuvers	15
number of South maneuvers	11
total commanded normal DV (m/sec)	45.23
total normal DV estimated by thruster history (m/sec)	45.16
total normal DV restituted by ranging (m/sec)	44.83
total consumption (kg)	58.46
Ox consumed (kg)	36.26
Fuel consumed (kg)	22.20

Table 2-1 : Main characteristics of North/South maneuvers

Note: The data presented in the table above include the effect of attitude control thrusters that occurs during the orbit control boost.

The commanded Delta-V of 45.23 m/s is close to the theoretical Delta-V obtained with CNES 1995 model : 43.32 m/sec for the studied period.

Computation of Isp during N/S maneuvers.

The formula used for the computation of the Isp of each maneuver is described in section 2.1.1.

The mean Isp.eff obtained by considering respectively the DV estimated by the thruster history and the ranging are summarized in the table below. This table shows the corresponding Isp obtained by taking a 0.931 efficiency for North/South maneuvers (value computed before SGDC1 launch, taking into account the cant angles of the thrusters, the predicted plume impingement effects and the finite burn loss effect):

N/S	Thruster History	Ranging
Isp.eff (sec)	269.18	267.08
eff	0.931	0.931
Isp (sec)	289.13	286.88

Table 2-2 : Isp characteristics of North/South maneuvers

Note: The data can only provide the restitution of the product Isp.efficiency, with no possibility to compute each term separately. As the estimation of the efficiency of a maneuvers is determinist, the error measured on the term Isp.efficiency is then fully reported on Isp.

Isp evolution is summarized in the table below:

Period	Isp (s) Thruster History	Isp (s) Ranging
1 st year	290.08	286.94
2 nd year	290.43	285.63
3 rd year	289.13	286.88

Table 2-3 : N/S Isp estimation evolution

The estimated Isp over the whole analyzed period in orbit is the mean value of the Isp obtained by thruster history method and obtained by ranging method: 288.0 s.

The Isp mean value of **285.3 s** for N/S station keeping is kept for estimation of remaining SGDC1 lifetime This figure is evaluated taking into account the expected degradation of Isp with the propellant tanks pressure evolution.

2.1.3 NM_OCC West and East maneuvers

For the studied period the characteristics of West and East maneuvers are:

studied period	15/03/2019 to 15/03/2020
number of East maneuvers	2
number of West maneuvers	53
total commanded tangential DV (m/sec)	1.39
total tangential DV estimated by thruster history (m/sec)	1.37
total tangential DV restituted by ranging (m/sec)	1.36
total consumption (kg)	2.73
Ox consumed (kg)	1.67
Fuel consumed (kg)	1.06

Table 2-4 : Main characteristics of East/West maneuvers

Note: As for NS maneuvers, the data presented in the table above include the effect of attitude control thrusters during boost.

The theoretical Delta-V obtained by analyses and used in the post-LEOP propellant budget was 1.6 m/s/y. This value takes into account a single burn strategy (with West maneuvers) from BOL to about 13.5 years and a double burn strategy after, associated to a 7-days control cycle at the longitude of 74.85°W and in a control window of +/- 0.05°.

Today, the applied strategy is a single burn strategy with a West maneuver every 7 days, with two exceptions.

So, the E/W control cost is kept for remaining lifetime computation at the value of 1.6 m/s/y.

Computation of Isp during West and East maneuvers.

The formula used for the computation of the Isp is similar to the one used in section 2.1.2 but instead of the normal Delta-V, we consider the tangential one.

The mean Isp.eff and Isp obtained by considering the DV estimated by the thruster history and the ranging associated to an efficiency of 0.872 are summarized in the table below considering only the West maneuvers.

E/W	thruster history	ranging
Isp.eff (sec)	175.24	175.08
eff	0.872	0.872
Isp (sec)	200.96	200.78

Table 2-5 : Isp characteristics of East/West maneuvers

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Note: The same remarks as for NS maneuvers can be made here.

Isp evolution is summarized in the table below:

Period	Isp (s) Thruster History	Isp (s) Ranging
1 st year	195.99	203.50
2 nd year	195.28	199.38
3 rd year	200.96	200.78

Table 2-6 : E/W Isp estimation evolution

The estimated Isp over the whole analyzed period in orbit is the mean value of the Isp obtained by thruster history method and obtained by ranging method: 200.9 s for West maneuvers. As explained in section 2.1.1, these values are hardly comparable to the pre-launch analyses.

The Isp mean value of **194.6 s** for E/W station keeping is kept for estimation of remaining SGDC1 lifetime. This figure is evaluated taking into account the expected degradation of Isp with the propellant tanks pressure evolution.

2.1.4 Wheel unloading in NM

From 15th March 2019 to 15th March 2020, consumption of wheel unloading was:

- 0.26 kg just before E/W maneuvers
- 0.13 kg outside maneuvers and contribute to N/S control

A conservative assumption of 1.3 kg/year for AOCS consumption is considered for the propellant budget computation, split in two parts:

- 1.0 kg/year for wheel unloading in NM just before E/W maneuvers
- 0.3 kg/year for wheel unloading in NM between boost (contribute to N/S control).

2.1.5 Inputs and assumptions

- Propellant mass on the 15/03/2020 : 924.74 kg
- Satellite mass on the 15/03/2020 : 3384.63 kg
- Satellite dry mass : 2452.1 kg
- Helium : 7.79 kg

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- N/S control cost : estimated for the S/C remaining lifetime by Thales Alenia Space model
- E/W control cost (derived from sections 2.1.3) : 1.6 m/s/year
- N/S mean thrusters Isp : 285.3 s (derived from section 2.1.2)
- E/W mean thrusters Isp : 194.6 s (derived from section 2.1.3)
- AOCS consumption : conservative value of 1.3 kg/year (see section 2.1.4).
(Isp for wheel unloading participation to N/S control : 80% of N/S Isp)

Additional inputs:

- Residuals in accordance with UPS computation based on PC data:
 - Static residuals : 11.44 kg $\pm$ 0.5 kg
 - Dynamic residuals : 20.21 kg $\pm$ 10.70 kg
 - Gauging accuracy : 9.24 kg Ox ; 5.66 kg Fu
- Provision for longitude repositioning at MOL : 5.68 m/s, corresponding to a longitude shift of 1°/day
- Provision for de-orbiting : 10.94 m/s (300 km)

2.2 Detailed propellant budget and remaining lifetime

The following table presents the propellant budget computation.

The remaining lifetime for SGDC1 starting from 04/05/2019 is : **15.03 years**

This corresponds to a total lifetime from IOAR date (13/06/2017) of : **17.78 years**

End of Life is planned : **March, 2035**

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Satellite mass at 15/03/2020					3384.63 kg
Remaining lifetime					15.03 yr
	DV (m/s)	ISP (s)	eff	Delta mass (kg)	
Attitude: 1st half life				7.51	3377.1
WU participation to N/S	2.78	228.2	0.931	4.51	3372.6
N/S	699.92	285.3	0.931	794.69	2577.9
E/W	24.04	194.6	0.872	36.98	2540.9
Attitude: 2nd half life				7.51	2533.4
Station repositioning	5.68	286.9	0.872	5.86	2527.6
On-orbit raising at EOL	10.94	286.1	0.745	13.19	2514.4
Dispersion corrections	17.42	194.6	1.000	22.84	2491.5
Propellant Static residuals				11.44	2480.1
Propellant Dynamic residuals				20.21	2459.9
Total remaining propellant				924.74	
Pressurant (Helium)				7.79	2452.10
Dry spacecraft					2452.10

Table 2-7 : SGDC1 remaining lifetime

3. ANOMALIES / OBSERVATIONS / RECOMMENDATIONS

No anomaly, observation nor recommendation was recorded during the studied period.

4. CONCLUSION

The following table shows the remaining lifetime evolution from IOAR to the updated estimation.

After the first year on orbit, a decrease of about 1.1 years lifetime with respect to IOAR lifetime has been obtained coming from:

- the raising of propellant residuals estimations at BOL (- 0.7 years)
- lower N/S and particular E/W Isp estimations (- 0.4 years)

Lifetime obtained after this third year in orbit is coherent with the previous yearly report.

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	Current Remaining Lifetime (yr)	Total Lifetime computed from IOAR (Estimated EOL date)
IOAR (13/06/2017)	18.74	18.74 (09/03/2036)
After 1 st year	16.73	17.62 (24/01/2035)
After 2 nd year	15.85	17.74 (09/03/2035)
After 3 rd year	15.03	17.78(March, 2035)

Table 2.8 : SGDC1 remaining lifetime evolution

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