FLIGHT DYNAMICS OPERATIONS DURING LEOP FOR THE INPE'S SECOND ENVIRONMENTAL DATA COLLECTING SATELLITE SCD2

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Abstract

After almost six years of outstanding in-flight performance of the first environmental data collecting Brazilian satellite SCD1, the follow-up second and improved satellite SCD2 was launched on October 22, 1998, by the North-American Pegasus launcher. This paper describes the flight dynamics operations which took place during LEOP. Due to the differences between SCD1 and SCD2 satellites, improvements developed and implemented in the flight dynamics application software of the Satellite Control Center are commented. The main problems are outlined and the adopted solutions together with corresponding results are discussed.

Key words: SCD2, LEOP, Flight dynamics.

Introduction

The second environmental data collecting satellite, SCD2, developed by the Brazilian National Institute for Space Research (INPE), was launched in October 22, 1998, by the North-American Pegasus launcher. As such, this paper aims at describing the flight dynamics operations during LEOP, the planned as well as the actual ones. At first, a brief overview of relevant differences between the SCD2 and SCD1 attitude control subsystems and the main implications on the SCD2 control operations is presented. Improvements which have been developed and implemented in the flight dynamics application software of the Satellite Control Center are commented. Following, the planned flight dynamics operations are focused, describing the orbit determination sequence, attitude determination scheme, and the attitude positioning from the injection to the prescribed orientation. The nominal operations are presented and discussed, including some aspects of the performed launch windows analysis. Actually, besides usual constraints, the launch window considered relative positioning between the two satellites, SCD1 and SCD2, in both right ascension of the ascending node and relative orbit phasing. The designed nominal LEOP flight dynamics operations are then presented in detail. The actual control activities which took place are described, analyzed and compared with the nominal planned ones. The main occurred problems are outlined and the adopted solutions together with corresponding results are discussed. In conclusion, the lessons learnt with this second experience of INPE flight dynamics team in supporting a satellite LEOP phase is highlighted.

Ground System

The INPE's Satellite Tracking and Control Center, is a ground complex composed of: i) Satellite Control Center (SCC) in Sao Jose dos Campos; ii) Cuiaba S-band TM/TC tracking station located in Mato Grosso state near the geographical center of South America; and iii) Alcantara S-band TM/TC tracking station located in northeast of Brazil near the Equator. They are interconnected via a dedicated private data communication network named RECDAS. For LEO satellites, the location of Cuiaba station makes possible the coverage of most of South America. On the other hand, Alcantara station is close to the Brazilian launching center allowing thus the tracking of the satellite orbit injection and sometimes since the lift-off of the launcher. The satellite control operations are planned, coordinated, and executed from the SCC. Through the real time link via RECDAS network, SCC receives TMs, transmits TCs, and collects measurements (such as ranging, Doppler, angular measurements) needed for orbit determination.

The Former SCD1 Satellite

The SCD1 satellite was the first satellite designed, built and in-orbit operated by INPE. It was launched by the American Pegasus rocket, in February 1993, into an orbit of 750km altitude, nearly circular and 25°

inclination, with nominal lifetime of one year. Nowadays, almost six years later, SCD1 still presents an overwhelming performance. Its mission is to relay to a base receiving station (Cuiaba) all (scientific, meteorological, hydrological) data collected by a network of automatic data collection platforms (DCP) distributed along the Brazilian territory[1]. At Cuiaba the data are recorded and forwarded to the Mission Control Center near Sao Jose dos Campos, that process and broadcast them to the user community. Currently Alcantara station also is equipped to record the DCP data as a backup.

The SCD1 satellite is spin stabilized (120 rpm at the beginning of life), with a octagonal prism shape, where the bottom panel is a passive thermal dissipator. Therefore sun light shall not reach such panel, or in other words, the sun aspect angle, θ, shall be kept less than 90°. Right after launch, a thermal analysis showed that an excessive heating of the satellite payload could happen if the sun aspect angle were less than 60°. Consequently this constrained the satellite spin axis to be controlled within the range $60° < \theta < 90°$. Such constraint imposed spin axis maneuvers which were executed through magnetic coils, with a periodicity around 3 months.

Differences between SCD2 and SCD1

SCD2 satellite presents some differences with respect to SCD1, which impacts mainly the attitude stabilization and control. Some meaningful differences are listed:

a. SCD2 has only the lateral faces covered with solar cells for on-board power supply, contrasting to SCD1 which has also the upper panel with solar cells. The absence of cells on the upper and bottom panels makes undesirable the direct incidence of sun rays, which can cause thermal problems.

b. SCD2 possesses only one DCP payload receiving antenna (UHF) on the upper panel whereas SCD1 had two located on the upper and bottom panel.

c. SCD2 antennas transmit and receive preferably on the transversal to the spin direction whereas for SCD1 the direction is longitudinal.

d. SCD2 bottom antennas have RHC (Right Hand Circular) polarization and the upper antennas have LHC (Left Hand Circular) polarization). For SCD1 all antennas have RHC polarization.

e. SCD2 has an autonomous spin rate control to keep the rate between 32 to 36 rpm. SCD1 has no control, its initial rate (120 rpm) decayed naturally to around 50rpm nowadays.

The differences listed on items a, b, c, lead to tighter than SCD1 constraints for the orientation of the spin axis of SCD2. For SCD2 the sun aspect angle shall range between 80° to 100° and, additionally, the spin axis shall be kept perpendicular to the ecliptic plane. The constraints impose to SCD2, the execution of more sophisticated attitude maneuvers. The main improvement of the SCD2 Flight Dynamics software, in relation to the SCD1 one, is that for SCD2 a different software to compute attitude maneuvers was developed. Such software uses a modified version[2] of the QOMAC (Quarter of Orbit Magnetic Attitude Control) algorithm[3], which minimizes the quadratic error between the actual and the estimated attitude imposing a quarter of orbit commutation of coil polarities. This implies coil commutation outside the range of the ground stations and makes use of programmed TCs. Such TCs are stored in the on-board computer which execute them automatically at the programmed times.

On the other hand, item d, makes necessary the polarity commutation of the ground station antenna when the station antenna to spin-axis angle is crossing 90°, in order to avoid losing the downlink signal of SCD2. Nevertheless the uplink in lost and therefore an interval of around 30s is need to reestablish the uplink.

Flight Dynamics System

Fig. 1 depicts the basic functions and the operation of the Flight Dynamics (FD) System[5,6] developed to SCC.

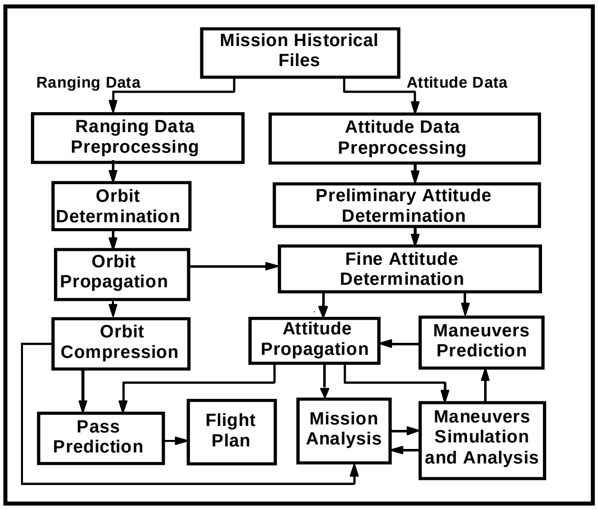

Fig. 1 - Flight Dynamics System

The FD system operates on non-real time basis from the attitude sensors measurements (sun sensors and magnetometers sampled at 2Hz) and ranging measurements (using ESA SDID protocol) retrieved from the historical archiving system. There are two basic processes executed by FD: orbit determination and attitude determination executed in weekly basis.

The orbit determination is two stepwise: data pre-processing and orbit estimation. The pre-processing consists of preparing data through application of procedures of validation, compression, calibration, and unit conversion. The orbit estimation applies to the pre-processed data a batch least squares method to fit the orbit according to the optimality criteria. The force model considers the effects of geopotential up to any order and degree of the harmonic coefficients, atmospheric drag, radiation pressure, third-body effects (Sun and Moon), precession, nutation, polar motion, atmospheric refraction (troposphere and ionosphere), and propagation delay.

The attitude determination comprises: sensors data pre-processing, preliminary attitude determination, and fine attitude determination[4]. The pre-processing is applied to each set of raw data of the attitude sensors collected every satellite pass over a ground station. A single satellite pass yields **n** magnetic aspect angles (angle between the spin axis and local geomagnetic vector), **1** (one) sun aspect angle (angle between the spin axis and the sun vector), and **1** (one) spin velocity. Afterwards, from the whole preprocessed data, the preliminary attitude determination produces estimates of the angular velocity vector to every satellite pass over a given ground station. The fine attitude determination takes a (one week) set of angular velocity vectors and, besides the angular velocity vector, estimates dynamical parameters which fit the attitude motion of the spin axis. Those parameters are further used in the attitude propagation to predict the need of maneuvers and monitor the sun aspect angle.

The orbit and the attitude propagation procedures archive the whole past ephemeris as well as a period of 3 months ahead.

The Launching of SCD2 Satellite

SCD2, the second satellite developed by INPE was also successfully launched by the American Pegasus launcher in October 22, 1998. The rocket was transported on a wing of an ordinary airplane up to a given altitude and location when was then released. After 5 seconds of free fall the first stage booster was burn-out. Then followed the second, third stage burn and finally separation 11 minutes later. Fig. 2 presents the very first orbit of SCD2 from the injection point.

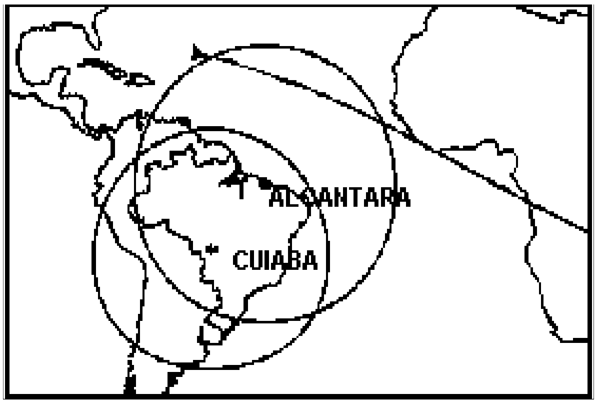

Fig. 2 – Orbit injection of SCD2

12 seconds after separation, the SCD2 signal was acquired by Alcantara station where the real time TM indicated no mal-function and sun sensor were switched on. The SCD2 launching was very nominal and the satellite was injected into an 760 km orbit as seen in Table 1.

Table 1 – Nominal and actual orbit of SCD2

Orbit parameter	Nominal	Actual
Semi-major axis (m)	7133893	7128550
Eccentricity	0.000756	0.000023
Inclination (°)	24.987	25.001
Right asc. of ascending node (°)	219.912	219.774
Argument of perigee (°)	348.543	291.050
Mean anomaly (°)	124.478	183.595
Injection time (Brazil's time)	23/10/1998 22:12:1.12	23/10/1998 22:12:57

The data on the injection orbit, which should be provided by the launcher manufacturer (Orbital Science Corp.) within 30 minutes after separation, were actually received by INPE's SCC only 5 minutes post separation. Such information revealed good consistency with the nominally expected orbit state and was used to generate acquisition look angles to Cuiaba and Alcantara ground stations for the next satellite passes. Meanwhile this injection orbit was checked against the available ranging data of Alcantara showing good agreement and giving no further worries. After the second pass over Alcantara, Cuiaba also started tracking the satellite and the accumulated ranging data were processed in successive orbit determinations. After the first sequence of passes of SCD2 over the ground stations the orbit was considered well determined and the application of flight dynamics procedures went to operation routine although monitored closely by the flight dynamics team during a week.

Two additional constraints were imposed to the SCD2 orbit so as to maximize the number of passes of both satellites (SCD1 and SCD2) tracked by Cuiaba (prime station). In fact, out of 14 daily orbits, around 8 are tracked by Cuiaba. Therefore the launch window was chosen such that the nominal orbit parameters could provide complementary passes over Cuiaba of SCD2 with respect to SCD1 satellite. Besides, SCD2 was phased so that the pass of one satellite would occur only some time after the other satellite pass.

As for the SCD2 attitude, it was also very close to the nominal. The constraint here was that the sun rays should not hit the upper and bottom panels with incidence angle greater than 10°. This means that the sun aspect angle should remain within the 80° to 100° range. Additionally, another constraint, a little more stringent, has been imposed on the SCD2 attitude: the spin-axis should remain into a half cone angle of 10° around the north pole of the ecliptic plan orthogonal vector. The read-outs of the sun sensors, right after injection, indicated a mean value of 87.7°, closely to nominal angle of 90°. Also the spin rate was 37.8rpm very close to the 38rpm nominally expected.

After the lessons learnt from the SCD1 launching and the corrective procedures adopted since then[4], the attitude computation procedure for SCD2 was actually carried out very smoothly

Performance of SCD2

During the acceptance phase, one month after launching, all the SCD2 sub-systems were performing nicely.

The power supply sub-system was performing rigorously nominal.

The on-board monitoring system also presents suitable behavior. The procedure of uploading the operational on-board computer program via TCs was successfully realized from the second set of passes over Cuiaba. In November 17, 1998, the computer was turned off due to the announced cloud of meteor debris. In the day after, the upload was again executed and up to now no problems were reported.

The service telecommunications system behaves satisfactorily. No power drop on the transmission was reported. The satellite primary transmitter and the redundant receivers are flawless. No TCs presented any failure and TMs show that all sub-systems are performing within the allowable ranges.

As for the Attitude Control System (ACS), sun sensors and magnetometer are providing very reliable data for attitude determination. The first attitude maneuver was performed in middle of December, 1998, and is described later in this paper. In middle of November, 1998, the spin rate control circuit has been tested through its the activation by telecommand. It showed a satisfactory performance, causing the increase of the spin rate from 35 to 36rpm. Once attained this last value, the spin rate control circuit was, as expected, automatically deactivated by the on-board computer.

The DCP (Data Collecting Platform) payload performance of SCD2 resulted in an increased reliability of DCP network. The capability of the system more than doubled and SCD2 is over-performing at least 30% better than SCD1 with respect to amount of collected data. Also due to the different attitude maintenance approach (perpendicular to ecliptic plane), which provides a better geometry regarding the ground station antennas, a 12% higher quantity of different DCP data are collected.

First Attitude Maneuver

Figure 3 presents the curve of the SCD2 sun aspect angle as a function of time, since the launching until April 1998. The final part of the curve (three months) corresponds to numerically predicted attitude data.

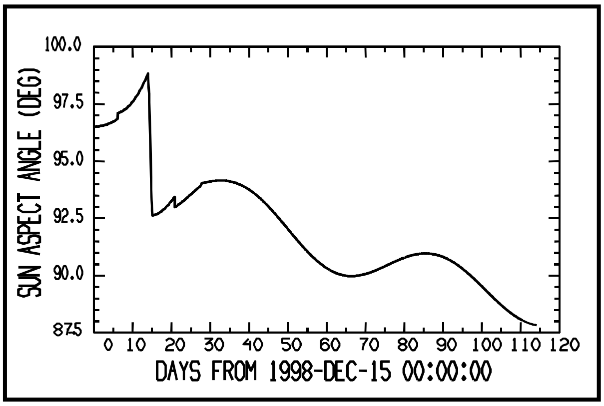

Fig. 3 - Sun Aspect Angle

One sees from Figure 3 that, under the effect of the first spin-axis maneuver execution, the sun aspect angle decreased from about 99°, (very near its allowable upper threshold) to about 92.5°. The foreseen evolution, as can be seen from Figure 3, will remain inside its allowable variation range, at least, during the next three months. This first maneuver has not, however, been performed with help of the newly improved attitude control software, which includes the QOMAC algorithm. The initial instant of the maneuver execution was chosen, in such a way that the satellite was in a satisfactory initial condition, which allowed having an adequate performance even using the former control software of SCD1. It is, however, expected that the improved software can be used to perform the next SCD2 spin axis maneuver.

In Figure 4 one sees the track of the spin-axis intersection with the celestial sphere, whose north pole is defined by the direction orthogonal to the Ecliptic Plan.

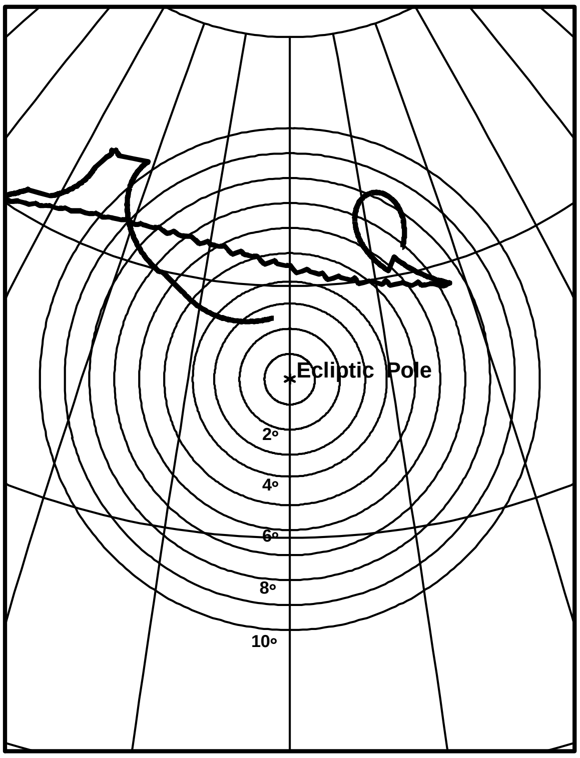

Fig. 4 - Attitude Track on Celestial Sphere

One can observe from Figure 4, that the angle between the spin-axis and the direction of the north pole of the celestial sphere has surpassed the allowable limit circle of 10°. This constraint was imposed in order to have satisfactory geometry between the ground and satellite antennas. It was not considered to present a high degree of criticality. In addition, its limit value has been defined with enough margin to allow waiting for best maneuver conditions, even if it implies in letting the ecliptic angle surpass, by few degrees, the specified limit. The main constraint which shall not be over-passed is the one imposed to the solar aspect angle. As commented, this last constraint has not been violated. The maneuver execution caused the return of the former angle inside the allowable circle. The predicted motion which can be seen in Figure 4, just after the maneuver execution, shows that this angle will remain inside the allowable range, at least, during the next three months.

Final Comments

It was confirmed that SCD2 has in general better performance than its antecessor SCD1 owing to some design improvement as well as a better attitude geometry with respect to the ground tracking stations and DCPs network.

On the other hand the adoption of different polarization of the upper and bottom antennas caused a loss of uplink which makes the ground operator tasks more difficult.

As far as flight dynamics is concerned, there was a significant increase of activities to operate and control both in-orbit satellites.

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