Orbital and attitude evolution of SCD-1 and SCD-2 Brazilian satellites

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Abstract. The SCD-1 and SCD-2 satellites were launched in 1993 and 1998, respectively, with use of the Launcher “Pegasus” of the OSC (Orbital Sciences Corporation). 21 and 16 years later, the satellites are still in orbit around the Earth and providing data for users. Mission and Operational data from Satellite Tracking Center Network are stored in mission files in the Satellite Control Center (SCC) and made available to the users. The SCC also stores history files of the satellite orbit and attitude ephemeris, besides the on-board telemetry, temperatures, equipment status, etc. This work will present some analysis of the orbit ephemeris evolution based upon the Two-Line Elements sets (TLE’s) obtained from NORAD (North American Aerospace Defense Command). Attitude evolution along time is also presented for both satellites from SCC data. The orbit decay will be explained as resulting mainly due to the solar activity during the satellite lifetime. This work aims to report the history of more than 20 years of continuous operation of SCD-1 and SCD-2. At the end, an estimation of the orbital decay is forecast with the use of NASA’s DAS software.

1. Introduction
On February 9th, 1993, the first Brazilian Environmental Data Collecting Satellite (SCD-1) was launched by the OSC launcher named “Pegasus” from an airplane. With 110 kg mass, it was placed into an orbit of 760 km altitude, circular, with inclination of 25°. In October 23rd of 1998, the SCD-2 was injected by “Pegasus” again in a similar orbit with altitude of 756 km, inclination of 25° and RAAN (Right Ascension of Ascending Node) of 220° (around 180° far from SCD-1 RAAN at the injection time) [1]. Both satellites were conceived to debut Brazil in space technology, under the Complete Brazilian Space Mission (MECB) program. The SCD satellites collect in real time environmental data from automated remote ground platforms. Collected data such as atmospheric properties, weather conditions, environment sensing, are broadcast to the mission ground station, located in Cuiaba, Brazil and disseminated to the interested community. Both satellites were deployed in a Low Earth Orbit (LEO) and were designed and manufactured by the National Institute for Space Research (INPE) in São José dos Campos, São Paulo, Brazil. More information related with the nominal value of the orbital elements are shown in Table 1. The SCD’s are spin stabilized, with a passive nutation damper to reduce any residual nutation of the satellites. Attitude control of the spin axes is achieved by means of a spin plane magnetic air core coil, which is switched by on-ground commands. Additionally, SCD-2 has a spin axis magnetic coil switched by one on-board electronics to control its angular rate around 34 rpm. These satellites are still operating after more than 20 years and during this time orbit and attitude perturbations as well as attitude maneuvers affected their initial orbit
and attitude. The large amount of orbit and attitude data provides a valuable source of information to study and to analyse the time evolution of orbit and attitude parameters.

The main objective of this work is to present the time history of the SCD satellites orbit and attitude, and to present some discussions about the evolution of these parameters.

### Table 1. Nominal Orbital Elements at Injection times [1] [2].

| Orbit Element      | SCD-1          | SCD-2          |
|--------------------|----------------|----------------|
| Semi-major axis (m)| 7135839        | 7133898        |
| Eccentricity       | 0.004568       | 0.000756       |
| Inclination (°)    | 24.972         | 24.987         |
| RAAN (°)           | 180            | 219.912        |
| Argument of perigee (°)| 347.75       | 348.543        |
| Mean anomaly (°)   | 348.42         | 124.479        |

To analyse the variation in the orbital elements, two types of data were collected: the first are the TLE’s (Two-Line Elements set) from NORAD site (celestrak.com) and the second was the orbital history from Satellite Control Center, SCC, (at INPE, in São José do Campos, Brazil). The data from SCC was compared with the NORAD data to search for differences in orbital elements. Critical points where the values change rapidly in short time intervals were selected, and the perturbations that caused those changes are analysed in the next sections. The attitude of both satellites was obtained from SCC historical records and represents the satellites space orientation, angular speeds and the magnetic coils switching times. The data packages were obtained through the SCC, hourly, from February 10/1993 to October 24/2014, covering more than 21 years of data for SCD-1 satellite and 16 years for SCD-2. TLE packages were collected for the same period, containing daily orbital evolution.

### 2. Orbital elements evolution

The orbit of SCD-1 was specified to be circular, at 750 km altitude and with inclination of 25 degrees with respect to the Equator plane, which favours the mutual contact time of the ground remote platforms in Brazil, the satellite and the Cuiabá Ground Station. The SCD-2 orbit was chosen also to be circular, at 750 km altitude, 25 degrees inclination and with the right ascension of the ascending note (RAAN) 180 degrees apart from SCD-1 (at the time of launching), to increase the daily coverage of both satellites. The initial semi-major axis for SCD-1 just after launch was 7135.8 km. In 21 years the orbit height decreased by almost 12 km, due mainly to the atmospheric drag, as can be seen in figure 1. The orbit decay was increased between years 1999 to 2003, due to the solar maximum activity period, shown in figure 2. SCD-2 was injected at 7134.5 km semi-major axis and decreased some 10km.

It is known that the air density, which causes the decay of the semi-major axis, depends on the solar flux at 10.7 cm of wavelength, and this flux is higher at the solar maximum activity, that occurs in a 10.6 years interval [3] [4]. In 2012 a second solar maximum began, so the altitude decay rate of both SCD-1 and 2 have increased again. During the maximum solar activity, the decay rate was around 2.3 km/year.

The eccentricity of both satellites is shown in figure 3. It can be noted that the orbit eccentricity presents a slight tendency to decrease toward zero, due also to the aerodynamic drag, that causes the apogee to decay faster than the perigee. The SCD-1 orbit eccentricity is very small and nearly circular, around 0.005, or 70 km of difference between the apogee and perigee heights. The eccentricity of SCD-2 orbit is around 0.002.
Due to injection errors, the orbit inclination of the satellites is also slightly different, around 24.970 degrees for SCD-1 and 24.996 degrees for SCD-2, as shown in figure 4. The major perturbations in the inclination are the Sun-Moon gravity forces and the Earth’s non-uniform gravitational field. The inclination deviation of SCD-1 in 2004, as can be seen in figure 4, increased suddenly probably due to some sort of orbit resonance with the geo-gravitational field, but it has yet to be proved.

When the SCD-2 was placed in its orbit, its RAAN was close to 188° offset from the SCD-1 RAAN, with only 8° error from the specified value due to a small delay in the launch time. The non-symmetrical Earth’s mass distribution due to the pole oblateness causes the orbit to precess around the Earth’s rotation axis and so the RAAN changes with time. The rate of change in the right ascension
node depends mainly of the orbit inclination and the semi-major axis, or the orbit height. As can be seen in figure 5, which shows the difference between the SCD-1 and SDC-2 right ascension angles, initially the difference remained constant about 180° since the SCD-2 was inject in orbit with almost the same height of SCD-1 (shown in figure 1). The decay of SCD-1 generates changes in the eccentricity of the orbit and the RAAN. Because of the decay of SCD-1, the difference between RAAN of both satellites has increased, reaching 38° amplitude from 180° at the beginning of 2015 (figure 5).

![Figure 5. Difference between RAAN’s, SCC data.](image)

3. Attitude
The SCD-1 initial spin rate was around 120 rpm, and in less than two years of operations the rotation decayed significantly to 60 rpm. The satellite spin kept on decreasing with the spin rate reaching 20 RPM around 2015.

Unlike SCD-1, the SCD-2 satellite has an autonomous spin control system using magnetic actuator to keep the spin rate between 34 ± 2 rpm. When the spin rate decays to 32 rpm a maneuver is executed to increase the rotation to 36 rpm [5] [6] [7] [8] [9]. Until now, the SCD-2 attitude control system is working according to the requirement (see figure 6).

![Figure 6. Spin rates of SCD-1 and SCD-2, SCC data.](image)

In the inertial reference system, the satellites longitudinal (spin) axis are oriented based on declination and right ascension angles (figures 7 and 8). Owing to on-orbit acting perturbations, the spin axis is drifting continuously. Due to the SCD-1 ground control system, the spin axis is
maneuvered whenever the sun rays reach the lower surface of the satellite structure (thermal requirement for satellite heat dissipation). The solar aspect angle is therefore maintained in a range between 60° to 90° (figure 9). The SCD-1 maneuvers can be visualized in figure 7 by several jumps on declination angle.

The spin axis of SCD-2 has a different requirement of being perpendicular to the ecliptic plane (Sun plane), and therefore their attitude angles (figure 7 and 8) are kept in a range (declination between 40° and 80°, right ascension between 200° and 300°) corresponding to a solar aspect angle between 80° to 100°, with mean value of 90° (figure 9). The spin axis maneuvers are planned and executed by SCC, which monitors and tracks both satellites [5] [7].

Related to the RAAN and spin evolution, there is the eddy current parameter [7]. Eddy currents flowing inside the satellite coupled with the local geomagnetic field causes perturbations. Such perturbing torque is modelled by the eddy current parameter. Thus, its variation translates to major or minor perturbation on the spin axis mainly on the decay of the spin rate. In SCD-1 the eddy current parameter presented significant changes (from 800 to 0), in the period of 1993 to 1995, and from 0 to 1000 in the years 2013 to 2015 (figure 10). The parameter changes are related to spin rate decays in the same intervals of time (figures 6). In the case of the SCD-2, the eddy current parameter has values from 1300 to -500 reflecting more intense electronics activity onboard (figure 10).

The onboard core magnetic coils generate the magnetic torques to control the spin axis and to assure the compliance of requirements as far as the solar aspect angle is concerned. In figure 11, the switch-on of the magnetic coils are depicted showing the maneuvers executed along time. More than 46 maneuvers were performed for SCD-1 and more than 56 for SCD-2 thanks to the SCC ground attitude control system.

Figure 7. Declination, SCC data.

Figure 8. Right Ascension, SCC data.
4. Orbital decay

One important feature in satellites lifetime is the decay rate and the reentry predictions. The NASA’s Debris Assessment Software (DAS) [10] was used to estimate the satellites semi-major axis decay in the next years. According to the simulations, in a time span superior to 110 years, the apogee altitude will decay only around 200 km (altitude higher than 500 km), and both the satellites will be still in orbit, therefore becoming space debris (if they will be decommissioned before the upcoming 110 years). Such simulations show that, due to the lower area/mass ratio (around 0.01 m²/kg) and the high initial apogee, the reentry epoch (altitude less than 120km) is not foreseeable for the next century. In
figure 1, from the flight data, it is possible to see the relation between the altitude decay and the maximum solar activity. This same behaviour is output by the NASA-DAS software.

5. Conclusions
For more than 20 and 16 years in service, respectively, SCD-1 and SCD-2 satellites have shown reliable operation. The rate of change of their orbital elements is small and the main dissipative orbit perturbations acting on the satellites are the sun radiation pressure and atmospheric drag in a less extent. Estimates obtained by simulations show that the satellites will reach the highest decay around the year 2030. The satellites reentry is estimated to occur well after the year 2120.

In the attitude case, with respect to the solar aspect angle, both satellites still feature spin axis attitude angles within the operational values. In the case of SCD-2, the satellite presents a smoother attitude (less drift) than SCD-1, because of the presence of an onboard spin rate control system. As such, the spin rate of the SCD-2 remains always within operational limits whereas SCD-1 has its spin rate steadily decreasing which weakens the gyroscopic rigidness effect and yields higher drift. In short, spin rate, declination angle, right ascension angle and sun aspect angle have shown fine behaviour during the operational life of SCD-2, because of the presence of an attitude control system which is superior to the SCD-1 system. This constitutes an evidence of the technological improvement of SCD-2 satellite compared to SCD-1.

The maximum operational time was designed, at the launching time, to be around 2 years for each satellite, but the excellent Brazilian manufacturing and engineering made it possible for the satellites to be still operating and collecting data, and to the date there are no signs of any fatal malfunction which could decommission the satellites.

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