# CBERS-2 LEOP ORBIT ANALYSIS

**Valcir Orlando, Helio Koiti Kuga, Jun Tominaga**

*INPE - Instituto Nacional de Pesquisas Espaciais Avenida dos Astronautas, 1758 - Jardim da Granja, 12227-010, Sao Jose dos Campos, SP, Brazil, e-mail: valcir@ccs.inpe.br, hkk@dem.inpe.br, jun@ccs.inpe.br*

**ABSTRACT**

This work presents an analysis of CBERS-2 orbit during LEOP (Launching and Early Orbit Phase), including the main aspects related to the INPE´s pass to pass improvement of the initial orbit determination process application. This is the second of four sun-synchronous earth observation satellites foreseen to be developed and manufactured within a cooperation program between Brazil and China. A short overview of the CBERS mission and the main characteristics of its two-country shared operational activities are introductorily presented. The overall orbit determination process, which was performed by INPE flight dynamics (FD) team just after orbit injection are reported and commented. The pass to pass enhancement of the orbit estimates accuracy, since the first orbit until the time when routine estimation procedure could be started is highlighted. The global orbit determination results for the CBERS-2 LEOP are analyzed and discussed. These results are compared with independent estimates of Chinese results. The main deviations between the injected orbit and the target one are commented, emphasizing the needed corrections to be applied during the orbit acquisition phase, in order to position the satellite on its proper working orbit.

## 1. INTRODUCTION

A short overview of the CBERS-2 (China-Brazil Earth Resources Satellite) mission and the main characteristics of its two-country shared operational activities are introductorily presented in section 2.

The section 3 is dedicated to present the nominally planned flight dynamics (FD) activities [1], which were foreseen to be performed by INPE FD team, in order to accomplish a pass to pass enhancement of the orbit estimates accuracy, since orbit injection until routine flight dynamics operations could be started.

The actual FD operations were very close to the planned one. The overall orbit determination process performed during CBERS-2 LEOP, and its relevant results, are reported and commented in section 4.

The performance of the first orbit maneuver executed by INPE is briefly commented in section 5.

Final comments, presented in section 6, close the paper.

## 2. THE CBERS-2

The CBERS-2 (China-Brazil Earth Resources Satellite) was successfully launched on October 21st of 2003, by a Chinese Long March 4B launcher, from Taiyuan Launch Center. Its nominal orbit is at 778km altitude, 98.5 degrees inclination, sun-synchronous, with frozen orbit requirements. This is the second of four sun-synchronous earth observation satellites foreseen to be developed and manufactured within a joint program between Brazil and China. It is three-axis attitude stabilized and shall supply images from three kinds of optical instruments: a high resolution CCD camera, an Infrared Multi-Spectral Scanner (IRMSS), and a Wide Field Imager (WFI). In addition the satellite is also equipped with a data collecting transponder, being able to retransmit the signals received from the INPE´s network of environmental data collecting platforms (DCP) [2]. This network reached nowadays a number of about 600 DCP spread over the entire Brazilian territory, covering a large number of environmental applications.

The CBERS-2 is operated on a time-shared basis by the two countries. After the launch until July 21st of 2004 the China Satellite Tracking and Control General (CLTC) was in charge of the CBERS-2 platform control. During this period INPE only performed telemetry monitoring, tracking, orbit determination, and payload operations for Brazilian applications. From this date on, INPE assumed, after detailed hand-over criteria compliance, the overall satellite control for the next 8 months. This responsibility includes onboard failure recovery and orbit maneuvers execution.

The maximum allowable variation range for longitude Equator phase drift of CBERS-2 orbit ground tracks was originally ±10km, the same as CBERS-1 [3]. However, it has been later reduced up to ±4km, in order to comply with recent requests from the project management and image processing experts. In addition to this constraint, the maneuver design considers also the following specifications: orbit cycle maintenance of 26 days or 373 orbits, minimization of altitude variations, frozen argument of perigee at 90± 5 degrees and maximization of the interval between maneuvers.

The CBERS-2 orbit determination process is performed by INPE mainly from range measurements, generated by Cuiaba ground station. Two-way Doppler measurements are also generated by this ground station, as backup. Alcantara may too perform range-rate measurements, for support purposes. However, it usually generates them just one-way or three-way, as Cuiaba performs the uplink. The overall orbit determination process performed by INPE´s flight dynamics team, just after CBERS-2 orbit injection, are reported and commented in the next section.

## 3. NOMINAL FD OPERATIONS FOR LEOP

INPE´s Satellite Ground Control System [4] is constituted by the Satellite Control Center (SCC), located in the city of Sao Jose dos Campos, and by the ground stations of Cuiaba (23° 12' S; 45° 51'W), and Alcantara (2°, 20' S; 44°, 24'W). A dedicated communication network connects the three sites.

Cuiaba is located close to the geodetic center of South America, and so it covers almost the whole South-American territory (see Fig.1). Alcantara ground station is located near equator, next to the Alcantara Launching Center. The two ground stations, besides being TT&C stations, are also DCP receiving stations.

Cuiaba is considered as the prime ground station regarding to CBERS-2 control. Therefore, during overlap periods, when the satellite is visible to both ground stations, the telecommunication up-link is established only by Cuiaba, which assumes the responsibility of transmitting, in real time, to the satellite the control data generated by SCC. During these overlaps, Alcantara only acquires satellite telemetry and performs Doppler measurements.

As commented in the previous section, CLTC was responsible for the overall satellite platform control during the first nine months since the launching. The LEOP operations of CBERS-2 has been, in this way, (successfully) performed by XSCC. During this phase INPE should act in a passive way, only performing tracking activities and telemetry monitoring, supplying tracking support to XSCC, if requested. Under this frame, INPE´s FD team had the function of performing orbit determination, by processing the range and range rate data generated by its own ground stations, and to generate the pass predictions data, which are needed to acquire the satellite signal in its successive passes over the ground stations visibility regions [1].

Table 1 shows the nominal orbit elements at injection point of CBERS-2.

*Table 1. Nominal elements at orbit injection point*

| | |
|---|---|
| t (GMT) | 2003/Oct/21 03:28:28 |
| a (m) | 7122304.3 |
| e | 0.001498 |
| i (°) | 98.53 |
| Ω (°) | 4.182612859 |
| ω (°) | 100.129 |
| M (°) | 64.041 |

Fig. 1 presents the trace of the first nine orbits since orbit injection. The first satellite pass over a Brazilian ground station (orbit 5 over Alcantara) was foreseen to happen only about 8 hours 21 minutes and 26 seconds, after orbit injection, that is, at 11:49:34 GMT.

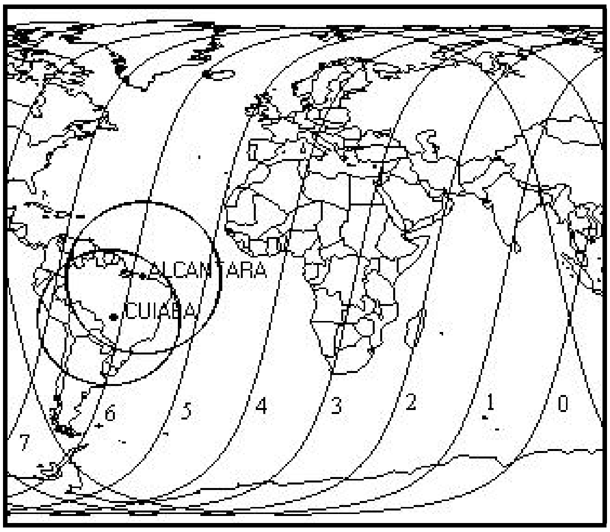


Fig. 1. First Orbit Traces

It was agreed that the Xian Satellite Control Center (XSCC) would send its preliminary orbit estimate to INPE, up to two hours before the first satellite pass over Alcantara ground station. These estimates would be used by INPE to update the existing pass predictions, which were generated from the nominal orbit injection parameters. The updated predictions should be sent to Alcantara, in order to replace the old ones for tracking antenna pointing.

Should INPE, due to any contingency, fail to receive the orbit estimates from XSCC by fifteen minutes before the beginning of the first Alcantara pass, then the planned action was to update the pass predictions by using NORAD, CELESTRAK or NASA two-lines elements, if available. If not, then the only possibility would be to use the nominal prediction.

The first pass over Alcantara would not meet the minimum elevation requirement criterion for ranging sessions. In this way, the ground station should perform, during this pass, only range-rate measurements. The acquisition of signal (AOS) for the second pass over Alcantara should occur at 13:25:14 GMT, and the loss of signal (LOS) was foreseen by 13:39:02. However, the first pass over Cuiaba ground station would start at 13:30:12 GMT, that is, within visibility interval of Alcantara. As Cuiaba is the prime station, Alcantara should interrupt up-link at that time, so that Cuiaba could establish it. In this way, Alcantara should perform ranging and ranging rate only prior to the Cuiaba AOS. Cuiaba, by its time, should perform ranging and ranging rate throughout the entire duration of its pass.

The first orbit determination was foreseen to be performed only after the first pass over Cuiaba, by using all the range and range-rate data generated before by both stations. After that, the plan was to perform one orbit determination following each one of the next passes over Cuiaba, using only the range and Doppler measurements generated by this station.

Twenty-four hours after orbit injection the routine phase for the flight dynamics activities was foreseen to start. In this phase the orbit determination is performed three times every week.

## 4. ACTUAL FD OPERATIONS LEOP

The actual LEOP FD operations were very close to the nominally planned situation. XSCC readily sent to INPE its orbit parameters estimates at injection point. By using these estimates the existing pass prediction data was updated and sent to the ground stations. These data was to be used to track the satellite in the first passes over Alcantara (orbits 5 and 6) and Cuiaba (orbit 6) ground stations. Both stations had no problem in acquiring the satellite signal during the corresponding passes. All planned ranging and ranging rate measurements sessions were nominally performed, which allowed the FD team to start the execution of the scheduled orbit determination processes.

### 4.1 Tracking Schedule

For the flight dynamics activities from the Brazilian side, the tracking stations of Cuiaba and Alcantara were utilized. Tables 2-4 give an account of the tracking schedule planned for the LEOP phase of CBERS-2. Effective data collected (data duration column) as well as the type of measurements performed are presented, where RA (range) stands for 2-way range measurements and RR (range-rate) for 2-way Doppler measurements. Tracking data up to orbit 20 were used in the successive Orbit Determinations (OD). One can notice that Alcantara collects only Doppler data, and starts tracking the satellite for the first time in Brazilian territory in orbit 5. On the other hand, Cuiaba is the prime station and collects ranging and Doppler data, although Doppler data were unavailable at orbit 6. With Cuiaba playing the main role, Alcantara had some passes shortened due to overlapped passes with Cuiaba, for instance, in orbits 6 and 13. The last tracking data used for OD was that of orbit 20, since in orbit 21 a rising maneuver was carried out.

*Table 2. Summary of Alcantara passes*

| Orbit | Start Day and Time (UTC) | Pass Duration (min.) | Data Duration (min.) | Types |
|---|---|---|---|---|
| 5 | 21 11:49:05 | 8 | 5 | RR |
| 6 | 21 13:24:35 | 14 | 4 | RR |
| 12 | 22 00:13:38 | 11 | 3 | RR |
| 13 | 22 01:51:05 | 12 | 3 | RR |

*Table 3. Summary of Cuiaba Ranging passes*

| Orbit | Start Day and Time (UTC) | Pass Duration (min.) | Data Duration (min.) | Types |
|---|---|---|---|---|
| 6 | 21 13:29:35 | 12 | 6 | RA |
| 7 | 21 15:10:35 | 7 | 7 | RA |
| 13 | 22 01:48:37 | 12 | 9 | RA |
| 14 | 22 03:29:05 | 7 | 4 | RA |
| 20 | 22 12:47:18 | 9 | 8 | RA |

*Table 4. Summary of Cuiaba Doppler passes*

| Orbit | Start Day and Time (UTC) | Pass Duration (min.) | Data Duration (min.) | Types |
|---|---|---|---|---|
| 7 | 21 15:10:35 | 7 | 6 | RR |
| 13 | 22 01:48:37 | 12 | 10 | RR |
| 14 | 22 03:29:05 | 7 | 6 | RR |
| 20 | 22 12:47:18 | 9 | 9 | RR |

### 4.2 Orbit Determination Assessment

The strategy of assessing the results consisted on performing successive ODs to determine the orbit at the injection time. Each OD was then compared to its subsequent OD by computing the overlap of the corresponding orbit predictions during the first 6 hours from the injection time. Therefore, along time, the errors should decrease as more and more tracking data is added to the OD system [5]. At the end, a reference OD prediction was adopted (using data up to orbit 20) for estimating the accuracy of the successive ODs.

Table 5 shows the mean deviation in the overlap interval (6 hours) from reference when the ODs using Alcantara Doppler data were processed. The deviations seem to be decreasing steadily up to orbit 13.

*Table 5. Overlap mean deviation for Alcantara with Doppler measurements*

| Orbit | Radial (m) | Normal (m) | Tangential (m) | 3D error (m) |
|---|---|---|---|---|
| 5 | 71.74 | 337.06 | 1748.15 | 1781.80 |
| 6 | 17.36 | 18.67 | 1196.16 | 1196.43 |
| 12 | 30.10 | 14.45 | 1025.24 | 1025.78 |
| 13 | 37.77 | 52.42 | -563.30 | 566.99 |

Actually Alcantara was less favored due to cut-offs of tracking data. Fig. 2 shows the Doppler residuals and the elevation for the 4 passes over Alcantara. Looking at the elevation path, it is clearly seen that only the first pass (orbit 5) had a complete Doppler pass, and the other 3 passes were incomplete. Due to this fact, convergence of the Alcantara ODs is somewhat slow.

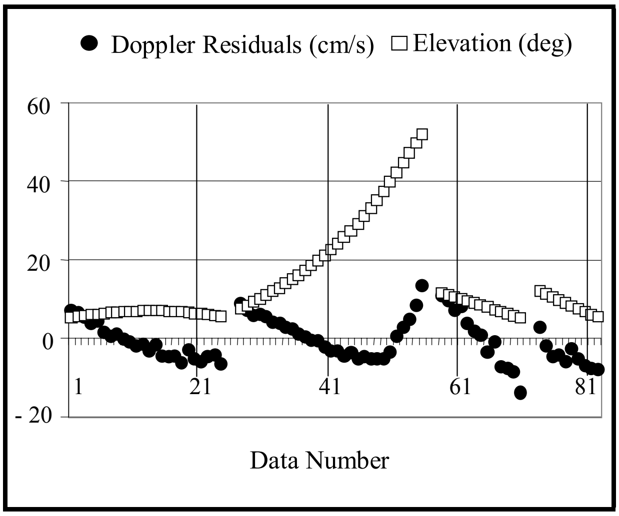


Fig. 2 – Doppler residuals and elevation for the 4 passes over Alcantara station

Table 6 shows the overlap deviation using ranging measurements from Cuiaba solely. The orbit 7 misled the OD due to being a very low elevation pass, with maximum elevation of 9°. As well, orbit 14 was another low elevation pass, also of 9° maximum elevation. However OD accuracy was enough to allow tracking of CBERS-2 without problems.

*Table 6. Overlap mean deviation for Cuiaba with ranging measurements*

| Orbit | Radial (m) | Normal (m) | Tangential (m) | 3D error (m) |
|---|---|---|---|---|
| 6 | 14.93 | -1.25 | 335.33 | 335.66 |
| 7 | 299.10 | -380.24 | 7451.35 | 7467.04 |
| 13 | -0.35 | 4.14 | 168.78 | 168.83 |
| 14 | -2.73 | -1.40 | 718.24 | 718.25 |

Table 7 shows the overlap deviation for Cuiaba station when using Doppler measurements. It forwarded quite good performance in terms of accuracy. However we wonder if this was not just lucky OD, happened by chance.

*Table 7. Overlap mean deviation for Cuiaba with Doppler measurements*

| Orbit | Radial (m) | Normal (m) | Tangential (m) | 3D error (m) |
|---|---|---|---|---|
| 7 | 20.55 | 1.35 | 77.34 | 80.04 |
| 13 | -0.40 | -3.05 | -156.14 | 156.17 |
| 14 | -0.65 | -4.57 | -107.17 | 107.27 |

The residuals statistics were as expected. Cuiaba ranging presented at last around 20m of standard deviation. Cuiaba Doppler measurements were at the level of 1cm/s. Alcantara Doppler residuals presented higher standard deviation of 5cm/s owing to broken Doppler passes as shown in Fig. 2.

### 4.3 Injection Orbit Estimates

Table 8 shows the aimed (target) injection point, the XSCC (Chinese Xian Satellite Control Center) estimate and the successive injection estimates from our control center. The longitude and latitude of injection point were well estimated from the beginning (orbit 5) but altitude could only be ratified using all tracking data up to orbit 20.

*Table 8. Injection point estimates*

| Orbit | Long. (°) | Lat. (°) | Alt. (km) |
|---|---|---|---|
| 5 | 105.08 | 14.88 | 751.48 |
| 6 | 105.10 | 14.89 | 752.18 |
| 7 | 105.11 | 14.79 | 751.87 |
| 13 | 105.10 | 14.89 | 752.23 |
| 14 | 105.10 | 14.89 | 752.29 |
| 20 | 105.11 | 14.90 | 746.66 |
| Target | 105.27 | 15.58 | 741.03 |
| XSCC | 105.07 | 14.90 | 746.32 |

Table 9 shows the orbit estimates of the injection point of CBERS-2, in terms of mean elements. The columns show the nominal (target) injection point, the XSCC estimates and INPE estimates, based either on ranging or Doppler measurements. In terms of the aimed target orbit, there was an under-performance of 7km on the semi-major axis. XSCC and INPE results differed in the eccentricity and inclination. Nevertheless it is clear that XSCC used very few tracking passes in their OD, and the estimates were not definitive at that time. In the end 6 passes were used (orbits 5, 6, 7, 13, 14, 20) to the final estimate of the injection orbit elements.

*Table 9. Injection point orbit estimates*

| Orbit Elements | Target | XSCC estimates | Range solution | Doppler solution |
|---|---|---|---|---|
| $a$ (km) | 7122.304 | 7115.584 | 7115.798 | 7115.797 |
| $e$ | 0.001498 | 0.001370 | 0.001604 | 0.001603 |
| $i$ (°) | 98.53 | 98.50 | 98.54 | 98.54 |
| $\Omega$ (°) | 4.18 | 4.19 | 4.21 | 4.21 |
| $\omega$+$M$ (°) | 164.17 | 164.91 | 164.88 | 164.87 |

## 5. ORBIT MANEUVER

The first longitude phasing orbit maneuver executed with CBERS-2 under INPE´s responsibility was applied on August 11$^{th}$ of 2004. The objective was to maintain the longitudinal phase drift of the orbit between a reduced range of about ±5km around the nominal ground track. Fig. 3 shows the time evolution curve of the phase drift, covering the period when the maneuver was applied. The curve segment before August 30th is based on real data and shows, in this way, the actual behavior of the orbit phase drift just after maneuver application. The complementary curve segment shows the predicted evolution, based on the data available at that time. One observes that the longitude phase drift will attain a minimal value of about 2.7km, which is far from the lower limit of the reduced variation range considered (–5km). This very conservative result is justified by the fact that, being this maneuver the first one executed under responsibility of INPE, the adopted margins where overestimated. The applied semi-major axis increment was of 27.0m.

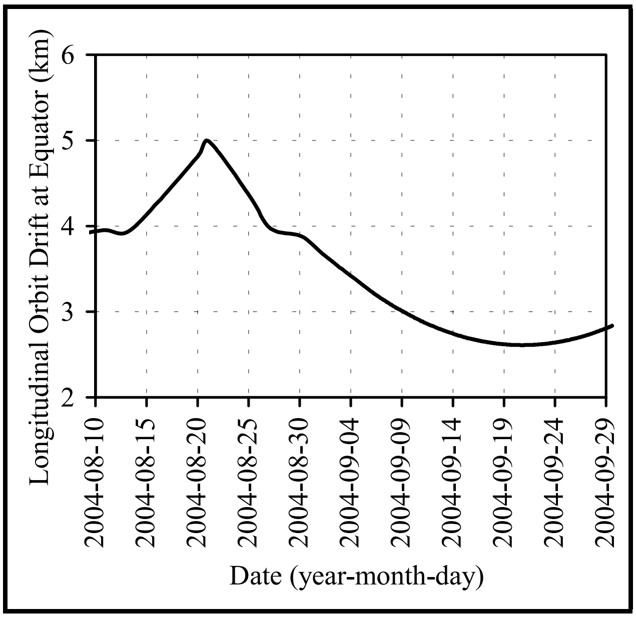


Fig. 3 – CBERS-2 orbit longitudinal phase drift at equator

## 6. FINAL COMMENTS

The LEOP of CBERS-2 happened very close to the nominally foreseen situation. It is common that LEOP presents varied degrees of difficulties [6-9]. However, thanks to the good quality of the initial orbit parameters estimates at injection point, received by INPE from XSCC, both INPE ground stations had no problem in acquiring the satellite signal in the first passes over its visibility regions. By using the ranging and ranging rate measurements performed by the ground stations during the successive passes the FD team could readily generate, and gradually assess, its own orbit parameters estimates. From these estimates new updated pass prediction data could be generated and sent to the ground stations. As a result, the routine phase for the flight dynamics activities started in a rigorously nominal way.

**References**


1. Kuga, H. K., et al. *Flight Dynamics Analysis and Operational Support for CBERS,* Journal of the Brazilian Society of Mechanical Sciences, Vol. XXI-Special Issue, 506 - 513, 1999.

2. Rozenfeld, P., et al. *Orbit Analysis for an Environmental Data Collecting Constellation*, 17th International Symposium on Space Flight Dynamics, vol. 2, 97 – 104, Moscow, Russia, 2003

3. Kuga, H. K. and Orlando, V., *Orbit Control of CBERS-1 Satellite at INPE,* 16th International Symposium on Space Flight Dynamics, Pasadena, California, USA, 2001.

4. Rozenfeld, P., et al. *Applying the 21st Century Technology to the 20th Century Mission Control,* SPACEOPS 2002-Fourth International Symposium on Space Mission Operations and Ground Data Systems, NASA, Houston, 2002.

5. Kuga, H. K., Gill, E. ODEM orbit determination user manual, Oberpfaffenhofen, Germany, 1995, DLR-GSOC IB 94-07.

6. Kuga, H.K. and Kondapalli, R.R., Satellite orbit determination: a first-hand experience with the first Brazilian satellite SCD1. 44th Congress of the *International Astronautical Federation*, Graz, Austria, October 16-22, 1993 (Paper IAF-93-A.5.43).

7. Kuga, H.K. and Kondapalli, R.R., SCD1 orbit determination system: pre-launch preparation, LEOP performance and routine operations, *RBCM Journal of the Brazilian Society of Mechanical Sciences*, Vol. XVI, p. 472-477, 1994.

8. Orlando, V., Kuga, H.K., Guedes, U.T.V., Flight Dynamics LEOP and routine operations for SCD2, the INPE's second environmental data collecting satellite, *Advances in the Astronautical Sciences*, Vol. 100, p. 1003-1013, 1998.

9. Vighnesam, N.V., Soney, A., Narasimha Murty, S., IRS-P4 orbit determination system performance (initial phase), *Proceedings* of International Symposium on Space Dynamics, Biarritz, France, June 26-30, 2000 (Paper MS00/P18).