

MFN= 010181  
01 SID/SCD  
02 9260  
03 INPE-9260-PRE/4929  
04 ETES  
05 MC  
06 am  
10 Orlando, Valcir  
10 Kuga, Hélio Koiti  
12 Effect analysis of the maximal allowable maneuver application rate  
for an autonomous orbit control procedure using GPS  
18 Proceedings  
40 En  
41 En  
42 <E>  
52 CNES  
53 International Symposium Space Dynamics  
54 26-30 June <2000>  
56 Bearritz  
57 FR  
58 DMC  
61 <CI>  
64 <2000>  
68 PRE  
76 ENGENHARIA E TECNOLOGIA ESPACIAL  
83 Informer studies the performance of a procedure for autonomous  
control of the Equator longitude phase drift of low-Earth phased  
orbits, considering the use of the GPS to provide the needed  
autonomous orbit estimates was analyzed The GPS system is wide-world  
spread and its use is increasingly being considered for many future  
Earth missions as an on-board navigation system. The preliminary  
results, obtained when the direct feeding of the coarse GPS  
navigation solution (standard deviations of the order of 100m and 1  
m/s for the position and velocity components, respectively) is  
considered in the autonomous control system, where very promising.  
This investigation, however, considered a very high sampling rate of  
the orbit estimates via GPS: one estimate set every 10 seconds. As  
far as the maximal allowable maneuver application rate to correct the  
evolution of is concerned, a rate of a single semi-major axis  
correction per orbit period has been adopted The current work  
presents an analysis of the influence, on the autonomous control  
procedure performance, of the maximal allowable maneuver application  
rate.



MINISTÉRIO DA CIÊNCIA E TECNOLOGIA

**INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS**

**INPE-9618 – TDI/843**

**DETERMINAÇÃO DE PONTOS FIXOS E ÓRBITAS PERIÓDICAS  
EM SISTEMAS CAÓTICOS**

Bruno Aloís Forlin Roth

Dissertação de Mestrado em Computação Aplicada, orientada pelos Drs. Elbert  
Einstein Nehrer Macau e Dra. Maisa de Oliveira Terra, aprovada em  
18 de Junho de 2002.

INPE  
São José dos Campos  
2003

MFN= 010181  
01 SID/SCD  
02 9260  
03 INPE-9260-PRE/4929  
04 ETES  
05 MC  
06 am  
10 Orlando, Valcir  
10 Kuga, Hélio Koiti  
12 Effect analysis of the maximal allowable maneuver application rate  
for an autonomous orbit control procedure using GPS  
18 Proceedings  
40 En  
41 En  
42 <E>  
52 CNES  
53 International Symposium Space Dynamics  
54 26-30 June <2000>  
56 Bearritz  
57 FR  
58 DMC  
61 <CI>  
64 <2000>  
68 PRE  
76 ENGENHARIA E TECNOLOGIA ESPACIAL

# EFFECT ANALYSIS OF THE MAXIMAL ALLOWABLE MANEUVER APPLICATION RATE FOR AN AUTONOMOUS ORBIT CONTROL PROCEDURE USING GPS

\*Valcir ORLANDO

\*\*Hélio Koiti KUGA

INPE – Instituto Nacional de Pesquisas Espaciais  
CP 515 -12201-970 - São José dos Campos, SP, Brazil

\*Phone: ++55-12-3456374, Fax: ++55-12-3411873, e-mail: valcir@gama.ccs.inpe.br

\*\*Phone: ++55-12-3456183, e-mail: hkk@dem.inpe.br

**ABSTRACT** - In former studies the performance of a procedure for autonomous control of the Equator longitude phase drift ( $\Delta L_0$ ) of low-Earth phased orbits, considering the use of the GPS to provide the needed autonomous orbit estimates was analyzed. The GPS system is wide-world spread and its use is increasingly being considered for many future Earth missions as an on-board navigation system. The preliminary results, obtained when the direct feeding of the coarse GPS navigation solution (standard deviations of the order of 100m and 1m/s for the position and velocity components, respectively) is considered in the autonomous control system, were very promising. This investigation, however, considered a very high sampling rate of the orbit estimates via GPS: one estimate set every 10 seconds. As far as the maximal allowable maneuver application rate to correct the evolution of  $\Delta L_0$  is concerned, a rate of a single semi-major axis correction per orbit period has been adopted. The current work presents an analysis of the influence, on the autonomous control procedure performance, of the maximal allowable maneuver application rate.

## 1 - INTRODUCTION

A procedure for autonomous control of the Equator longitude phase drift ( $\Delta L_0$ ) of low-Earth phased orbits, based on the use of the French DIODE navigator [Bert 93, Tour 99] was analyzed in former studies. The obtained results, presented in previous papers [Orla 96 and 97], gave the motivation to direct the study to the investigation on the performance of the autonomous control concept considering the use of the GPS (Global Positioning System) to provide the needed autonomous orbit estimates. The GPS system is wide-world spread and its use is increasingly being considered for many future Earth missions as an on-board navigation system. The preliminary results [Orla 99], obtained when the direct feeding of the coarse GPS navigation solution [Gill 97] (standard deviations of the order of 100m and 1m/s for the position and velocity components, respectively) is considered in the autonomous control system, were very promising. Even under worse case conditions in terms of solar activity, the autonomous control procedure maintained  $\Delta L_0$  within a range between -1000m and 1700m. This result can be considered very satisfactory once the  $\Delta L_0$  excursion range for the CBERS-1 (China-Brazil Earth Resources Satellite, successfully launched on October 14, 1999) is of

This work has been supported by CNPq (Comissão Nacional de Desenvolvimento Científico e Tecnológico)

$\pm 10000\text{m}$ . This investigation, however, considered a very high sampling rate of the GPS orbit estimates: 1 estimate set every 10 seconds, that is the same sampling rate taken in previous studies, when a DIODE-like navigator was used. In addition, a very high maximal allowable application rate of one semi-major axis correction per orbit period was assumed in this former work. The current work presents an analysis of the influence on the autonomous control procedure performance of the maximal allowable maneuver application rate. This analysis has been carried out considering the application of a version of the autonomous orbit control procedure, which considers only the application of semi-major ( $\Delta a$ ) axis corrections with a constant, previously chosen amplitude. Actually, such version was the one that presented the best performance among all the ones analyzed in previous studies [Orla 96]. However, some improvements in this version have been implemented: the constant correction amplitude value and some control parameters are maintained constant only between previously tabulated ranges of solar activity. Therefore, during the control process, the corresponding adequate value and parameters are selected in real time, as a function of the current range of solar activity, which is inferred, in an autonomous way, from estimates of the second time derivative of  $\Delta L_0$ . To assess the procedure, the same worst case conditions, in terms of solar activity assumed in previous investigations, have been considered. The results of a long-term computer simulation are presented, discussed, and compared with former studies.

## 2 - AUTONOMOUS CONTROL

The current work considers an hypothetical satellite, equipped with a GPS navigator receiver, placed in a phased helio-synchronous orbit. The function of the GPS receiver is to provide, on-board the satellite, the orbit observations (estimates) which are needed in order to allow the autonomous monitoring of the  $\Delta L_0$  time evolution. In the study, the orbit estimates corresponding to the coarse GPS navigation solution were sequentially simulated from the output of a realistic orbit simulation process. The GPS coarse orbit estimates are several order of magnitude less accurate than the ones yielded by the French DIODE navigator. Typical root mean square errors of the coarse GPS estimates are of 100m in position and 1m/s in velocity. Added to such random errors these estimates show systematic variations with values of the order of 100m and duration of about 1 to 15 minutes. These variations occur due to the changes of the set of GPS satellites, which are visible to the on-board GPS receiver. Each GPS satellite has its own systematic error and, in this way, whenever a satellite goes out of the GPS receiver antenna coverage region, or a new satellite enters in this region, the systematic error of the global navigation solution is prone to change its value. Both the random and systematic errors are considered in the simulation of GPS coarse navigation solution estimates.

Raw observation of  $\Delta L_0$  and its first time derivative,  $\dot{\Delta L}_0$ , are computed from each simulated set of GPS orbit estimates. The Fig. 1 presents the block diagram of the autonomous control system, depicting how it was simulated for the accomplishment of the current study.

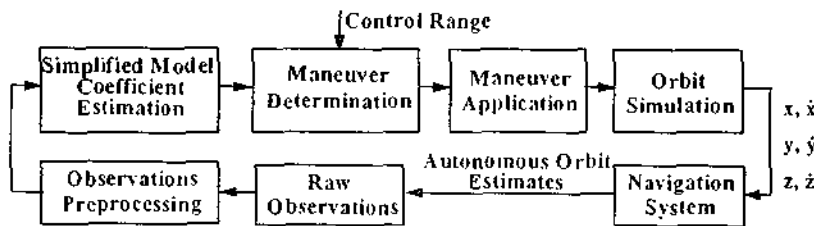


Fig. 1: Block Diagram of the Simulation Process

The next step is to preprocess, in real time, the computed raw observations in order to achieve data smoothing by curve fitting, validation and redundancy reduction. The above mentioned raw observations of  $\Delta L_0$  and  $\dot{\Delta L}_0$ , are computed with help of the following equations [Orla 99]:

$$\Delta L_0 = a_e \cdot \left[ \Delta \Omega + \frac{\Delta \alpha}{(N + P/Q)} \right] \quad (1)$$

$$\dot{\Delta L}_0 = -\frac{3\pi}{T_{te}} \left( \frac{a_e}{a_R} \right) (1 - \varepsilon) \left[ \Delta a - \left( \frac{da}{dt} \right)_p \Delta i \right], \quad (2)$$

where  $T_{te}$  is the mean solar day (86400 s);  $a_e$  is the Equator Earth radius,  $a_R$  is the reference orbit semi major axis;

$$\varepsilon = \frac{7}{3} \frac{T_{te}}{T_{so}} + \frac{7}{2} \left( \frac{a_e}{a} \right)^2 [4 \cos^2(i) - 1]; \quad (3)$$

$$\left( \frac{da}{dt} \right)_p = -\frac{2}{3} a \tan(i) \frac{T_{te}}{T_{so}} \frac{(1 + \eta)}{(1 + \varepsilon)}; \quad (4)$$

with  $T_{so} = 1$  year and

$$\eta = 12 I_2 (T_{so} / T_{te}) (a_e / a)^2 \cos^2(i)$$

Constant solar flux is assumed during the time interval between the application of two successive orbit correction maneuvers. This implies in having constant  $da/dt$  (where  $a$  is the orbit semi-major axis) during this interval. This assumption implies in having an almost parabolic time evolution of  $\Delta L_0$ . In this way, the simplified model of  $\Delta L_0$  (Equation 5) given bellow can be used in order to foresee the future evolution of the Equator longitude phase drift, that is:

$$\Delta L_0(t) = \Delta L_0(t_0) + \dot{\Delta L}_0(t_0) \Delta t + \ddot{\Delta L}_0(t_0) \Delta t^2 / 2. \quad (5)$$

From this equation, the first time derivative of  $\Delta L_0(t)$ ,  $\dot{\Delta L}_0(t)$ , is immediately given by:

$$\dot{\Delta L}_0(t) = \dot{\Delta L}_0(t_0) + \ddot{\Delta L}_0(t_0) \Delta t \quad (6)$$

The preprocessed values of  $\dot{\Delta L}_0(t_k)$  and  $\ddot{\Delta L}_0(t_k)$ , where  $t_k$  is the time tag of the  $k^{th}$  compressed observation issued by the preprocessor, are used as observation, by a Kalman filtering process which provides, in real time, the estimates of the coefficients of Equation 5:  $\hat{\dot{\Delta L}}_0(t_k)$  and  $\hat{\ddot{\Delta L}}_0(t_k)$ . It can be observed that the coefficients of Equation 6 are the same last two coefficients of Equation 5. In this way, in order to have estimates of the complete set of coefficients of both

equations (that is, equations 5 and 6) only one coefficient,  $\Delta L_0(t_k)$ , remains to be estimated. This remaining estimate is directly computed from the following equation:

$$\hat{\Delta L}_0(t_k) = \left[ \sum_{i=0}^{k-1} p_i \overline{\Delta L}_0(t_i) + p_k \overline{\Delta L}_0(t_k) \right] / \left( \sum_{i=0}^{k-1} p_i + p_k \right) \quad (7)$$

where  $p_0, p_1, \dots, p_k$  are weighting factors.

The instants of application of longitude phase drift maneuvers are determined from the estimates

$\hat{\Delta L}_0(t_k)$ ,  $\hat{\dot{\Delta L}}_0(t_k)$  and  $\hat{\ddot{\Delta L}}_0(t_k)$ . The autonomous orbit control procedure which will be analyzed is described just below. To test the autonomous control procedure, the control loop is closed by a realistic orbit simulator, from whose outputs the navigator orbit estimates are simulated.

### 3 - ADAPTIVE DISCRETE CORRECTIONS AMPLITUDE

In previous works the analysis of an autonomous orbit control procedure, which considers only a positive constant amplitude for all orbit semi major axis corrections, was presented. The amplitude of corrections has always the same pre-determined value, independent of the current conditions in terms of navigation error magnitude and solar activity. It was verified that, when the satellite is under intense solar activity periods the upper limit of the  $\Delta L_0$  control range is attained in a faster way and, as a consequence, the maneuver rate is automatically increased. This procedure proved to be more robust than another version, in which the amplitudes of the semi major axis corrections are computed so as to consider the current level of solar activity. The maneuvers amplitude is computed so that, under the current conditions of solar activity, the minimum value to be attained by  $\Delta L_0$  is equal to the control range lower limit. The main problem of this version is that, if the solar activity conditions decrease after the application of a given maneuver then, the lower limit of the considered  $\Delta L_0$  control range can be surpassed. Since the first procedure considers the application of only smaller constant amplitude orbit corrections then, even under weak levels of solar activity, the lower limit of the control range has less probability of being attained. However, as confirmed by previous results [Orla 96], this kind of procedure can, in some cases, present some performance problems. Considering a maximal allowable value of the maneuver application rate (1 per orbit period, in the referred previous analyzed case) it was seen that, when under strong solar activity periods, the fixed maneuver magnitude can not be enough to cause an average increasing of the  $\Delta L_0$  time evolution. To avoid this situation one improved version of this procedure type was proposed. In this new version a given amplitude of correction is maintained constant only when the solar activity remains within pre-established variation range, which is associated to this amplitude. If the solar activity crosses one of the limits of the current range, then another correction amplitude, associated to another adjacent solar activity variation range, is taken into account. The problem is that the instantaneous values of the solar flux are not available on-board of the satellite. Fortunately, its magnitude can, however, be inferred, in an autonomous way, from the estimates of the second time derivative ( $\ddot{\Delta L}_0(t)$ ) of  $\Delta L_0$ . Since  $\ddot{\Delta L}_0$  is a parameter of the adopted simplified (parabolic) model of  $\Delta L_0(t)$ , it is naturally computed by the autonomous control procedure, with help of the before mentioned Kalman filtering procedure. Actually, only three discrete values of semi major axis corrections were considered in the current analysis, that is:

$$\Delta a = \Delta a_1 \text{ m if } \hat{\ddot{\Delta L}}_0(t_{k-1}/t_{k-1}) < L_1 \text{ m/s}^2, \quad (8)$$

$$\Delta a = A2 \text{ m if } L1 \text{ m/s}^2 \leq \frac{\hat{\Delta L}}{\Delta t} (t_{k-1}/t_{k-1}) \leq L2 \text{ m/s}^2, \quad (9)$$

$$\Delta a = A3 \text{ m if } \frac{\hat{\Delta L}}{\Delta t} (t_{k-1}/t_{k-1}) > L2 \text{ m/s}^2, \quad (10)$$

where: A1, A2 and A3 are the chosen correction amplitudes, and L1 and L2 are limit values of  $\frac{\hat{\Delta L}}{\Delta t}$ , which determines, according to the above conditions, the autonomous change of the orbit correction amplitudes.

This improved version is the one considered in the current investigation, which consists of an analysis of the behavior of the autonomous control procedure when the maximal allowable maneuver rate is decreased

#### 4. PROCEDURE ANALYSIS

As mentioned before the autonomous orbit control procedure analysis was performed with help of numerical simulation. A SPOT like orbit (mean altitude of 837 km) was considered. The simulation runs always were performed over a simulation period of about one year, under unrealistically worst conditions in terms of solar activity variation. In the same way as in the referred previous works, the solar flux 11-year cycle has been shortened to one-year simulation, with a very high maximum (360 in flux units), and kept the 27-day cycle oscillations due to solar rotation.

The current analysis consists, at first, of checking the autonomous control procedure performance when the autonomous orbit estimates are issued by the navigator at a rate of one set each 60 seconds. In previous works the navigator sampling rate was taken always as 1 estimates set each 10 seconds, the same as the french DIODE navigator [Bert 93]. This rate can be considered high, faced to the rate of variation of  $\Delta L_0$ . At this sampling rate, the generated raw observations of  $\Delta L_0$  presents a high degree of redundancy, which was reduced by a data compression process applied in the observations preprocessing phase.

The performance of the autonomous control procedure which considers the application of adaptive corrections amplitude was analyzed in a previous study, where the use of DIODE like orbit estimates was considered (1 orbit state vector estimate each 10 seconds, with rms errors of 10m and 0.001m/s in the position and velocity components, respectively). The maximal allowable rate of maneuver application was of one maneuver per orbital period. The Equator longitude phase drift remained, in this case, in a very narrow range of about  $\pm 200\text{m}$ , during, practically, all the simulated period of almost one year.

The Fig. 2 presents the obtained  $\Delta L_0 \times \text{time}$  curve, for the case where a GPS like coarse navigation solution is used to generate the raw  $\Delta L_0$  observations for the feedback loop of the autonomous control system. The same maximal allowable maneuver rate of the case above was considered. As far as the generation rate of orbit estimates issued by the navigator is concerned, it was considered the value of 1 orbital state vector estimate each minute. The three values considered for  $\Delta a$ , and the conditions to drive the choice of values to be applied in each maneuver are the following:

$$\Delta a = 10\text{m if } \frac{\hat{\Delta L}}{\Delta t} (t_{k-1}/t_{k-1}) < 5 \cdot 10^{-09} \text{ m/s}^2, \quad (11)$$

$$\Delta a = 25\text{m if } 5 \cdot 10^{-09} \text{ m/s}^2 \leq \frac{\hat{\Delta L}}{\Delta t} (t_{k-1}/t_{k-1}) \leq 2 \cdot 10^{-08} \text{ m/s}^2, \quad (12)$$

$$\Delta a = 40\text{m if } \frac{\hat{\Delta L}}{\Delta t} (t_{k-1}/t_{k-1}) > 2 \cdot 10^{-08} \text{ m/s}^2 \quad (13)$$

One can see that, as expected, the results show a sensible degradation in the autonomous control performance. After the convergence period, the controlled values of  $\Delta L_0$  remained, during almost all the simulated period, inside the range of  $\pm 2$  km, which is one order of magnitude worse than of the former case. The cause of this lower performance basically is, in this case, only due to the use of less accurate orbit estimates to monitor the values assumed by the longitude phase drift. The results can, however, be considered very satisfactory, since the values of  $\Delta L_0$  remained inside a range which is, in the worst case, less than half of the allowable  $\Delta L_0$  variation range considered for the orbit control of the CBERS1 satellite (China Brazil Earth Resources Satellites).

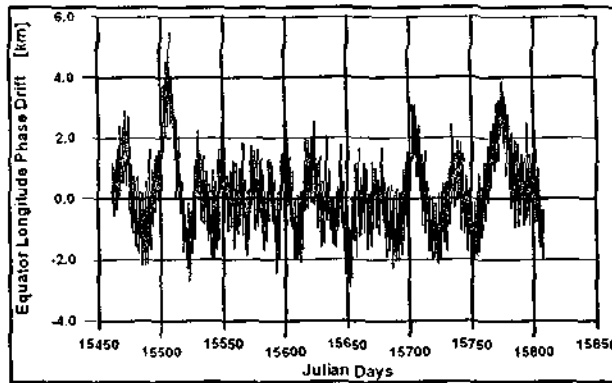


Fig. 2:  $\Delta L_0$  x time - GPS Navigation Solution

In the new simulation cases performed, whose results will be presented and commented in what follows, the sampling rate of the autonomous orbit estimates issued by the navigator are maintained always constant (one samplings each 60 seconds). The observations compression rates, however, are

varied from 1/100 (1 compressed observation set ( $\Delta L_0$  and  $\dot{\Delta L}_0$ ) replacing each 100 raw data (which corresponds to about one compressed observation set per orbital period)) to 1/1440 (one compressed observation set per day). At this point it is important to emphasize that, in this work, the compressed rate defines the minimal time interval between the application of two successive orbit corrections. In this way the increment of the maximal allowable maneuver rate (considering the implementation characteristics of the autonomous control procedure), implies also in increasing, by the same rate, the amount of observations (and consequently increasing the involved compression time interval) from which each compressed observation is computed. That means that increasing the maximal allowable maneuver application rate will imply, on one side in increasing the amount of observations of  $\Delta L_0$  to be replaced by an equivalent compressed one. On the other hand, the variation of  $\Delta L_0$  during the involved increased time interval will be most important. This reduces the validity of the observation compression process, which replaces all observations generated during this interval by only an "equivalent" one. For this reason this work aims to assess the autonomous  $\Delta L_0$  control procedure to work properly, under the above mentioned extreme conditions in terms of solar activity, when the maximal allowable maneuver rate of one  $\Delta a$  increment per 24 hours is imposed.

The Fig 3 shows the results obtained for the case where the minimum allowable maneuver rate is taken as 1 orbit correction each 200 minutes ( $\sim 2$  orbit periods). The same values expressed in the Equations 11 to 13 are considered for the maneuver amplitudes. As one can see, the procedure performance is reduced. The orbit corrections, due to the longer minimum time interval between maneuvers which was imposed in this case, are not enough to maintain the time evolution of curve of

$\Delta L_0$  in an almost symmetrical region around zero. The average time evolution of  $\Delta L_0$ , as can be seen from Fig. 3, begins to continuously increase, after about a half of the simulated period.

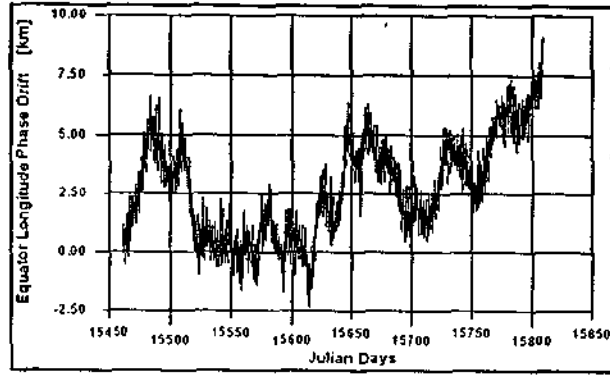


Fig. 3: Minimum Allowable Maneuver Rate of 1 Correction each 200 minutes: First Test

The values of the  $\Delta a$  corrections, taken in the equations 11, 12 and 13, were changed to, respectively, 15m, 30m and 45m. The new results which still consider the minimal interval between maneuvers of 200 minutes, are presented in the Figure 4. As one can observe from this figure the increasing tendency of the  $\Delta L_0$  curve, presented in the last case, disappeared. The curve remains in a region around zero during all simulation period. Both the lower and upper limits of the variation range presented, however, values of the order of 1km greater than the previous case.

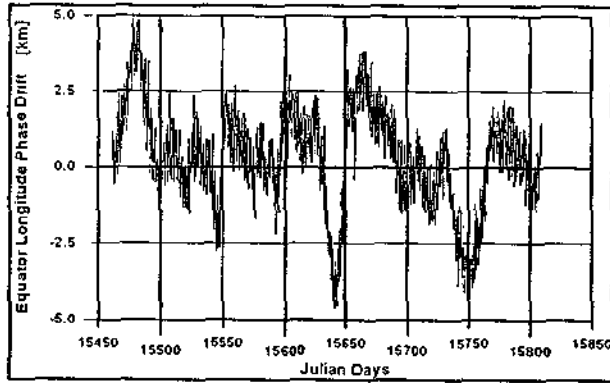


Fig. 4: Minimum Allowable Maneuver Rate of 1 Correction each 200 minutes: Second Test

As just mentioned before, an objective of the current study was to verify whether it would be possible to have satisfactory control performance of the autonomous control procedure, considering a maximal allowable application rate of orbit corrections of the order of once a day. In this way, several tests were performed, in order to verify the effect of increasing the value of the minimal allowable rate of maneuver application on the control procedure performance. As expected, when the time interval between two successive maneuvers increases, the chosen discrete values of the  $\Delta a$  (Equations 8, 9 and 10) may not be enough to maintain the variation curve of  $\Delta L_0$  inside an adequate variation range around zero. As it is imposed that no maneuver can be applied before a specific time interval after the last one, and since the  $\Delta a$  amplitude is constant (inside the selected range of solar activity, as described) the correction may not be enough to avoid that, in average, the  $\Delta L_0$  curve

increases with time. The minimal allowable maneuver application was in, this way, reduced successively until one  $\Delta a$  correction, at most, over 24 hours. An intermediate result which considers the application of at most one  $\Delta a$  increment per 700 minutes is presented in Fig. 5. The previously selected amplitude of the  $\Delta a$  corrections, taken as the equations 11, 12 and 13, was, respectively, 15m, 45m and 75m. Due to the arguments just described, the two last values needed to be increased, from 30m and 45m to, respectively, 45m and 75m.

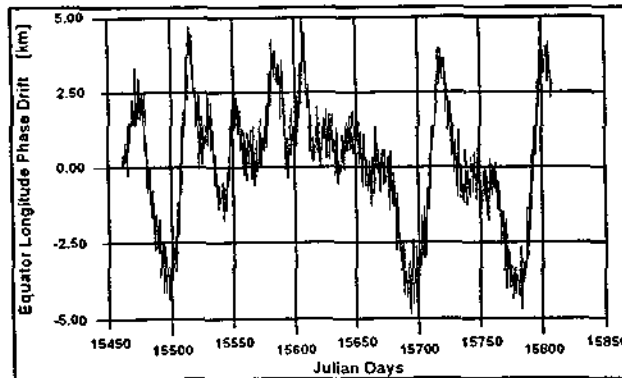


Fig. 5: Minimum Allowable Maneuver Rate of 1 Correction each 700 minutes: Second Test

As one can see from Fig 5 the controlled variation range of  $\Delta L_0$  still remains inside limit values of  $\pm 5\text{km}$ , as in the case of the Fig. 4.

The obtained result when a minimum allowable maneuver rate of one each 24 hours is presented in Fig. 6. It is to be noted that the curve of the longitude phase drift time evolution remains in an acceptable variation range, if compared with the limit values specified for the first China-Brazil remote sensing satellite CBERS1 ( $\pm 10\text{km}$ ). This result was obtained by using for  $\Delta a$  increments A1, A2 and A3 in Equations 11, 12 and 13, respectively, the following values: 15m, 45m and 90m. Besides these ones, other secondary parameters had to be tuned, in order to assess the autonomous control procedure performance as, for instance, some covariance values of the Kalman filtering process used to estimate the parameters of the  $\Delta L_0$  simplified model (Equation 5).

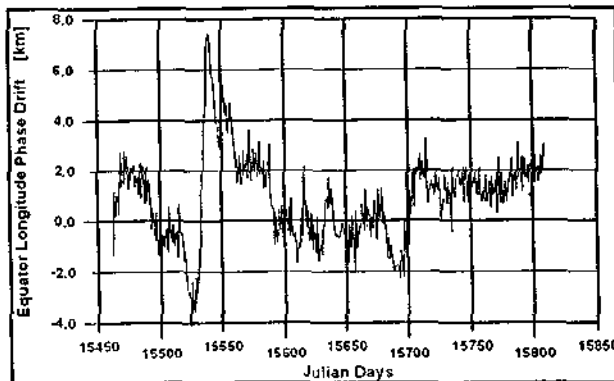


Fig. 6: Minimum Allowable Maneuver Rate of 1 Correction each 24 hours

The Fig. 7 shows superimposed on the same graphics, the curves of the estimated second derivative of  $\Delta L_0$  ( $\ddot{\Delta L}$ ) and of the simulated solar flux as functions of time. The curve of  $\ddot{\Delta L}(t)$ , as one can observe from the figure, follows the shape of the average solar flux time variation, since it directly depends on the solar activity. One can see that the before mentioned inference of the level of the solar activity from the  $\ddot{\Delta L}(t)$  estimates, in which the autonomous control procedure of adaptive discrete corrections amplitude is based, presented a effectively adequate characteristics to perform this task.

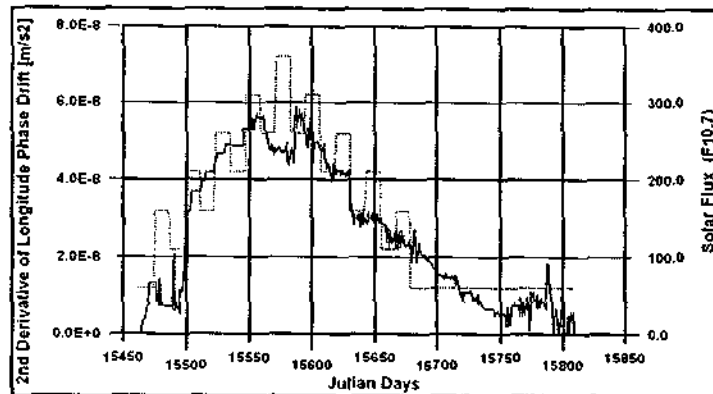


Fig. 7. Estimated Second Derivative of  $\Delta L_0$  and Simulated Solar flux

### Conclusions

The effect of the maximal allowable maneuver application rate for an autonomous orbit control procedure using an GPS like navigator was analyzed. In previous work a minimum interval between maneuvers of only one orbital period was considered. This means that in extreme situations the autonomous control procedure could deal with the very high maneuver application rate of one maneuver per orbit, which could be not compatible with the operation characteristics of the satellite thrusters. The obtained results showed the feasibility of imposing limits to the orbit correction rate to a maximal value of, at least, one per day. It shall be given emphasis on the fact that this result was attained by considering the simulation of the autonomously generated coarse GPS navigation solution, instead of a more accurate system. The rate of generation of these estimates was reduced from 1 estimates set each 10 seconds to one set each minute. The work can, yet, be complemented in future investigation in order to find the lower limit values of both the navigator estimates generation and maneuver application rates.

### References

- [Bert 93] J. P. Berthias, C. Jayles, D. Pradines: D. "DIODE: a DORIS Based Real-time on-board Orbit Determination System for SPOT4", Proceedings of the AAS/GSFC International Symposium on Spacecraft Ground Control and Flight Dynamics, Greenbelt, Maryland, USA, 1993, pp. 125-138.

- [Carr 96] J. P. Carrou, C. Darrigan, J. Foliard, C. Jayles, P. Micheau, M. Tello: "Ground and On-board Autonomous Flight Dynamics Subsystems at CNES", Proceedings of the 11<sup>th</sup> IAS - International Astrodynamics Symposium, Gifu, Japão, May 1996, pp. 137-142.
- [Gill 97] E. Gill: "Orbit Determination of the MIR Space Station from GPS Navigation Data", Proceedings of the 12<sup>th</sup> International Symposium on Space Flight Dynamics, Darmstadt, Germany, June 1997, pp. 79-84.
- [Noue 97] F. Nouel, M. Deleuze, P. Laudet, C. Valorge: "Operational Aspects of Precise Orbit Determination of SPOT and TOPEX/POSEIDON satellites with DORIS", Advances in the Astronautical Sciences, Vol. 84, 1993, pp. 279-290.
- [Orla 99] V. Orlando, H. K. Kuga: "Analysis of an Autonomous Orbit Control Concept Using GPS", Journal of the Brazilian Society of Mechanical Sciences, Vol. XXI, Special Issue, February 1999, pp. 52-59.
- [Orla 97] V. Orlando, H. K. Kuga, R. V. F. Lopes: "Reducing the Geopotential Tesseral Harmonic Effects on Autonomous Longitude Drift Control of Sun-Synchronous Satellites", AAS Advances in the Astronautical Science", AAS Publications Office, USA, Vol. 95, Part I, February 1997, pp. 361-374.
- [Orla 96] V. Orlando, P. Micheau: "Autonomous Orbit Control System for Phased LEO Satellite", Proceedings of the 11th IAS International Astrodynamics Symposium, Gifu, Japan, May, 1996, pp. 143-148.
- [Tour 99] T. Tournier, J. Berthias, C. Jayles, F. Mercier, D. Laurichesse, P. Cauquil: "Orbit and Time On-Board Computation from the Current Spot4 Solution to Gnss2 Needs", Journal of the Brazilian Society of Mechanical Sciences, Vol. XXI, Special Issue, February 1999, pp. 209-219.