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EFFECT OF VISIBILITY CONSTRAINTS IN ARTIFICIAL SATELLITES MANEUVER

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EFFECT OF VISIBILITY CONSTRAINTS IN ARTIFICIAL SATELLITES MANEUVERS / *EFEITO DE VÍNCULOS DE VISIBILIDADE EM MANOBRAS DE SATÉLITES ARTIFICIAIS*

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Abstract

In this work, the effect of visibility constraints due to the use of only one ground station control of a spacecraft during a bi-impulsive transfer between two given non coplanar elliptical orbits is analyzed from the point of view of fuel consumption. This kind of constraint requires special orbital places to apply impulsive maneuvers, where the ground station is able to track the satellite. The increment of the fuel consumption imposed by this kind of constraint is evaluated by subdividing of the true anomalies' intervals at the initial and final orbits. This research takes part on the orbital maneuvers program for the *China-Brazil Earth Resources Satellite* (CBERS) and should be extended for any kind of bi-impulsive orbital transfer.

Keywords

Astrodynamics, artificial satellites, numerical method, orbital maneuver / Astrodinâmica, satélites artificiais, método numérico, manobra orbital.

1. INTRODUCTION

The *China-Brazil Earth Resources Satellite* (CBERS) is a remote sensing satellite under development by China and Brazil planned to stay in a polar frozen orbit (approximate 98° of inclination). According to the mission objectives of CBERS, the satellite orbit to be selected should meet global coverage, similar conditions of viewing and illumination when the satellite passes through the same latitude to take pictures and periodic observations of the same sampled areas to guarantee the mission success. In order to meet and maintain these requirements several orbital maneuvers has to be planned.

To do so, it was developed a new algorithm and a software that obtain the optimum fuel orbital transfer taking into account the visibility constraint of the ground station. As the propulsion model, it was adopted the bi-impulsive transfer (instantaneous velocity variation on the initial and final points of the transfer). It was assumed a dynamics that contains the keplerian term and the usual perturbations: atmospheric drag and non punctual gravity for the Earth. This problem was transformed in the well-known *Two Point Boundary Value Problem.*

This research is an extension to the study of bi-impulsive transfers between two given coplanar orbits with minimum expenditure of fuel that was developed in *Prado (1993)*.

2. THE TWO POINT BOUNDARY VALUE PROBLEM

When ordinary differential equations are required to satisfy boundary conditions at more than one value of the independent variable, the resulting problem is called a two point boundary value problem. It was implemented the most common case of two point boundary value problem, where boundary conditions are supposed to be satisfied at two points - the starting and ending values of the integration - to solve the problem of bi-impulsive non coplanar orbital maneuvers with fuel optimization.

Given an initial guess, that was found by a method that used the keplerian dynamics (the unique forces involved on the system are the propulsion and the Earth's gravitational attraction, considered a point of mass) it was used the two point boundary value problem to solve the problem assuming that the system dynamics include perturbations, as atmospheric drag and oblateness of the Earth's gravitational field.

The two point boundary value problem has the following form: it's desired to find the solution of a set of N coupled first-order ordinary differential equations (the 6 equations that governs the spacecraft motion), satisfying n_1 boundary conditions (the 3 components of the first impulse position) at the starting point t_1 (the first impulse date), and a remaining set of $n_2 = N - n_1$ boundary conditions (the 3 components of the second impulse position) at the final point t_2 (the last impulse date).

2.1 The Shooting Method

There are distinct classes of numerical methods for solving two point boundary value problems. For this kind of problem the shooting method works very well.

In the shooting method values for all of the dependent variables at one boundary are chose. These values must be consistent with any boundary conditions for that boundary, but otherwise are arranged to depend on arbitrary free parameters whose values are initially guessed. Then the ordinary differential equations are integrated to the final time using the fifth-order Cash-Karp Runge-Kutta method with adaptive stepsize control. Then the discrepancies from the desired boundary values are found there. Now it is a multidimensional root-finding problem: Find the adjustment of the free parameters at the starting point that vanishes the discrepancies at the other boundary point. The shooting method provides a systematic approach to taking a set of ranging shots that allow the user to improve his aim systematically.

3. VISIBILITY TESTS

Several simulations were performed to observe the variations on the fuel consumption due to constraints imposed by possible visibility problems on a specific ground station.

Two of these simulations are showed here. The first one is a transfer between a low inclined and eccentric orbit and a geostationary one. The second is an orbital correction where the final orbital is nominal CBERS orbit.

The visibility problems require special orbital places to perform the maneuvers, and the variation of the fuel consumption imposed by this requirement is studied by the subdivision of the true anomalies' intervals of the initial and/or final orbits. The reason why it is better to perform the maneuvers under visibility is to assure more security on the determination of the orbit after the impulse.

3.1 First Simulation

This is an example of transfer between a low orbit and a geostationary one. The orbital elements of the initial orbit are: semi-major axis 7500,0 km; eccentricity 0,02000; inclination 0,03491 rad (2°); perigee argument 0,87266 rad (50°); right ascension of the ascending node 0,52359 rad (30°). The orbital elements of the final orbit are: semi-major axis 42164,2 km; eccentricity 0,0; inclination 0,0 rad (0°); perigee argument 0,87266 rad (50°); right ascension of the ascending node 0,52359 rad (30°).

As a first step, the true anomalies were varied from 0° to 360° on both orbits. The result for the minimum velocity variation was:

ΔV = 3,649 km/s

As a second step, the true anomalies' intervals were subdivided, on such a way that was possible compare the fuel consumption variations by the velocity variations for different cases of ground station visibility. First, it was maintained the variation interval of 0° to 360° for the true anomaly of the initial orbit (ϕ_1) and subdivided the variation interval for the true anomaly of the final orbit (ϕ_2) in subintervals of 30°. Then, it was time of maintain the variation interval of 0° to 360° for the true anomaly of the final orbit and subdivide the variation interval for the true anomaly of the initial orbit in the same way. In the last part, the variations intervals for the true anomalies of the both orbits were subdivided in equals intervals of 30°.

The results could be seen on tables 1, 2 and 3.

Table 1: Visibility Test 1

ϕ_1	ϕ_2	ΔV (km/sec)
0° - 360°	0° - 30°	3,963
	30° - 60°	4,035
	60° - 90°	3,964
	90° - 120°	3,882
	120° - 150°	3,708
	150° - 180°	3,759
	180° - 210°	3,891
	210° - 240°	4,290
	240° - 270°	3,965
	270° - 300°	3,910
	300° - 330°	**3,649**
	330° - 360°	3,675

Table 2: Visibility Test 2

ϕ_1	ϕ_2	ΔV (km/sec)
0° - 30°	0° - 360°	4,072
30° - 60°		4,307
60° - 90°		4,185
90° - 120°		3,773
120° - 150°		**3,649**
150° - 180°		3,714
180° - 210°		3,846
210° - 240°		4,103
240° - 270°		4,035
270° - 300°		3,915
300° - 330°		3,921
330° - 360°		3,716

Table 3: Visibility Test 3

ϕ_1	ϕ_2	ΔV (km/sec)
0° - 30°	0° - 30°	12,689
30° - 60°	30° - 60°	12,606
60° - 90°	60° - 90°	12,504
90° - 120°	90° - 120°	12,408
120° - 150°	120° - 150°	12,341
150° - 180°	150° - 180°	12,320
180° - 210°	180° - 210°	12,329
210° - 240°	210° - 240°	12,333
240° - 270°	240° - 270°	12,390
270° - 300°	270° - 300°	12,489
300° - 330°	300° - 330°	12,599
330° - 360°	330° - 360°	12,691

These results show that the effects of a ground station visibility exist and can be very strong. The results on table 3 clearly demonstrate that this kind of constraint can improve the fuel expenditure up to 4 times. Moreover, the results on the restrictions on only one true anomaly show that this expenditure can get 10% over the cost of a maneuver without visibility restriction.

The reason for the table 3 construction is explained now. Suppose that a mission is groundtracked by only one ground station, and that the impulsive maneuvers could be applied only when the satellite is visible by this station. This means that the orbital region where the impulse can be applied is really strict. The exact size depends on certain parameters, such as, orbital altitude and antenna parameters. Only as an example, the orbits were divided in 30° intervals. To the maneuvers simulated on this example the perigee argument is not changed, so the same region that is allowed to impulse application on initial orbital is valid to the final orbit. For this reason the combinations on table 3 use the same intervals to the true anomalies ϕ_1 and ϕ_2.

3.2 Second Simulation

This is an example of orbital correction where the final orbit is the CBERS nominal orbit. The orbital elements of the initial orbit are: semi-major axis 7000,0 km; eccentricity 0,02000; inclination 1,57080 rad (90°); perigee argument 1,72253 rad (98,7°); right ascension of the ascending node 4,93805 rad (-77,1°). The orbital elements of the final orbit are: semi-major axis 7148,9 km; eccentricity 0,00206; inclination 1,71969 rad (98,5°); perigee argument 1,72253 rad (98,7°); right ascension of the ascending node 4,93805 rad (-77,1°).

As a first step, the true anomalies were varied from 0° to 360° on both orbits. The result for the minimum velocity variation was:

ΔV = 1,123 km/s

The following step was subdivide the true anomalies' intervals in the same form as on the previous example to compare the fuel consumption variation by the velocity variation, for different cases of ground station visibility. On the last case the final orbit true anomaly intervals were subdivided not only as the initial orbit ones, but also one subinterval before and one after. The reason to do that is to analyze the cost of a small perigee argument variation on the fuel consumption. The results should be seen on tables 4, 5 and 6.

Table 4: Visibility Test 4

ϕ_1	ϕ_2	ΔV (km/sec)
0° - 360°	0° - 30°	1,227
	30° - 60°	1,241
	60° - 90°	**1,123**
	90° - 120°	1,188
	120° - 150°	1,418
	150° - 180°	1,278
	180° - 210°	1,215
	210° - 240°	1,172
	240° - 270°	1,131
	270° - 300°	1,161
	300° - 330°	1,199
	330° - 360°	1,200

Table 5: Visibility Test 5

ϕ_1	ϕ_2	ΔV (km/s)
0° - 30°	0° - 360°	1,269
30° - 60°		1,410
60° - 90°		1,138
90° - 120°		1,140
120° - 150°		1,172
150° - 180°		1,195
180° - 210°		1,195
210° - 240°		1,216
240° - 270°		1,168
270° - 300°		**1,123**
300° - 330°		1,203
330° - 360°		1,219

Table 6: Visibility Test 6

ϕ_1	ϕ_2	ΔV (km/sec)
0° - 30°	330° - 360°	23,135
	0° - 30°	4,958
	30° - 60°	2,036
30° - 60°	0° - 30°	23,128
	30° - 60°	2,853
	60° - 90°	1,329
60° - 90°	30° - 60°	21,483
	60° - 90°	1,669
	90° - 120°	1,413
90° - 120°	60° - 90°	23,025
	90° - 120°	1,783
	120° - 150°	1,391
120° - 150°	90° - 120°	28,411
	120° - 150°	2,922
	150° - 180°	2,081
150° - 180°	120° - 150°	15,831
	150° - 180°	4,300
	180° - 210°	2,543

180° - 210°	150° - 180°	20,400
	180° - 210°	3,857
	210° - 240°	1,569
210° - 240°	180° - 210°	20,356
	210° - 240°	2,012
	240° - 270°	1,131
240° - 270°	210° - 240°	14,978
	240° - 270°	1,161
	270° - 300°	1,161
270° - 300°	240° - 270°	21,444
	270° - 300°	1,826
	300° - 330°	-
300° - 330°	270° - 300°	27,654
	300° - 330°	3,536
	330° - 360°	2,648
330° - 360°	300° - 330°	27,975
	330° - 360°	4,464
	0° - 30°	2,410

This results show the same behavior of the first example for the cases where the same subintervals for the true anomalies of both orbits are chosen: a restriction due to visibility problem of a ground station should cause an improvement up to 4 times the fuel consumption of a maneuver without this kind of restriction. This result should be observed by comparing the best result for the total velocity variation (1,123 km/sec) with the worst result of table 6 (4,958 km/sec). The simulations also demonstrated that, depending on the true anomalies variation intervals the fuel consumption improvement should be more than 20 times the consumption of a maneuver without visibility restriction, or, on the other hand, don't show significative difference on velocity variation.

4. CONCLUSION

Several simulations were performed to explore the problem of the fuel consumption improvement due to ground station visibility constraints on bi-impulsive transfers between non coplanar elliptical orbits on a non keplerian force field. The results showed that the effects of this restriction could improve the fuel consumption up to 20 times the expenditure of a transfer without this constraint. This tests were performed, due to the CBERS mission requirements.

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