Determining the Accuracy of the On Board Propagation Software for Optical Intersatellite Link

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***Abstract-* In this paper, the accuracy of the satellite on board orbit calculation is compared with a ground based system calculation. The objective is to determine whether the on board satellite orbit propagator software is sufficient enough for Optical Intersatellite Link communication between a Low Earth Orbit and Geosynchronous Earth Orbit satellites and figuring out the possible reasons of any inaccuracy if any. The study is done by using TURKSAT 3A Geostationary satellites' data. Even the software on board the TURKSAT 3A does not intend to provide fine orbital position for intersatellite communication, this study is done in order to conclude the convergences and open points on the onboard orbit propagator. First, a quick summary is given for TURKSAT 3A satellite and its' station keeping philosophy. In the following sections, comparisons are done between on board and on ground orbit calculations with different time intervals of the year 2010. The possible root causes of the differences between these two calculations are discussed at the end.**

Keywords – Turksat; Optical Intersatellite Link; On Board Propagation Software.

I. INTRODUCTION

After the invention of lasers, lots of studies have been done for laser communications because of its theoretical advantages of higher data rates, lower power, smaller size, and lower mass. The studies for free-space laser communications have been in development in the United States since 1960s and in Japan and Europe since 1970s [1]. The advantage of small wavelength and low beam divergence make lasers attractive for optical communication [2], especially for intersatellite link communication between an observation satellite and a Geostationary Earth Orbit (GEO) satellite. It usually takes long time to send the image taken by a Low Earth Orbit (LEO) observation satellite to Earth. Therefore, one of the advantages of the intersatellite link is that it dramatically reduces the access time of a requested image of a land without a need of a polar station [3], [4], [5].

On the other hand, having a narrow laser beam came with the problem of tracking and finding the target spacecraft (SC). Since the access time between LEO and GEO satellite is limited due to different orbits, it is a time critical operation to find and lock the target SC as soon as both satellites see each other to begin the communication. That's why, finding the target SC on time give more chance to exchange more data between LEO and GEO satellites. And the GEO satellite can send the required information to ground station almost real time.

Successful laser communications between LEO and GEO satellites have been achieved after lots of studies. Two of the main steps of optical intersatellite links (OISL) are; the successful communication between French SPOT-4 (LEO) and ARTEMIS (GEO) on November 2001 and bidirectional laser communication ARTEMIS - Japanese OICETS (LEO) on December 2005. These tests showed that the GEO satellites can be very useful for relay purpose for OISL.

In order to compensate the movement of the satellites, known Ephemerides data and the signals from the electro optics tracking systems are used [6]. The concept of optical intersatellite links in communication satellite networks is discussed in [7] and [8]. The related studies are focused on: satellites optical communication network [9], analyzing the impact of random pointing and tracking errors in coherent and incoherent optical intersatellite communication [10], proposals for adapting the control system to reduce the vibration effect on the satellite[11]. Taking into account the classification of Pointing Errors in intersatellite link [12] ephemeris errors are one of the point-ahead errors which have to be minimized.

In this paper, a series of studies were done on a flying satellite (TURKSAT 3A) in order to calculate whether on board ephemeris propagation is sufficient enough for OISL. Firstly, a quick summary is given for TURKSAT 3A satellite and its' station keeping philosophy. Then, comparisons are done between on board and on ground orbit calculations with different time intervals of the year 2010 in the following sections. At the end, the possible root causes of the differences between these two calculations are discussed.

II. TURKSAT 3A AND ITS' STATION KEEPING PRINCIPLE

TURKSAT 3A, which was built on a Thales Alenia Spaces' SB4000 satellite platform, launched into space on 12 June 2008. It was placed into orbit at 42 degree East longitude where it is collocated with TURKSAT 2A and it has been working properly at that position since then.

Like most of the GEO satellite operators, Türksat AS. choose to make North and East maneuvers in 14 days cycle basis. Fig. 1 shows the Orbit Determinations (OD), North Maneuver (NS), On Orbit Propagator (OOP) initial orbital parameters update and East Maneuver (EW) plan in one cycle [13].

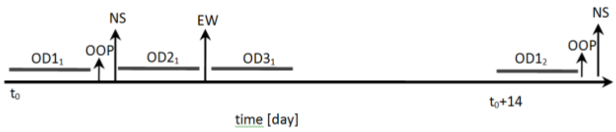

Figure 1. Station Keeping Principle of TURKSAT 3A

The ODs are performed by using an antenna which has tracking capability. During the year 2010, three different antennas, all of which are located in Ankara, Turkey, were used for this purpose. The orbit determination process uses the distance between the station to satellite and the ground station antenna's azimuth and elevation angles during the measurements. During one cycle, three orbit determination campaigns are performed:

1st, before the North maneuver to be used for both calculation of North maneuver and initial Keplerian parameters of OOP on satellite board.

2nd, after the North maneuver in order to calculate the efficiency of the applied maneuver and its cross coupling effect in tangential direction. This determination also used for East Maneuver calculation.

3rd, after the East maneuver to determine the efficiency of the maneuver and the last orbit after the maneuver sequence.

As it can be seen in the Figure 1, there are two maneuvers between two OOP update operations and three orbit determinations. That's why, the On Ground Orbit Calculation (OGOC) considered as more reliable depending on the antenna tracking performance. This calculation take into account all perturbation effects, SC mass, effective cross-section area opposed to sun and tracking antennas angles and distance when calculating the new orbit. Similarly, the OOP also take into account the perturbations, thruster activities on satellite and all other parameters special to Spacecraft.

Since the cumulative errors and on board unexpected activities may disturb the orbit, there should be a gap between OGOC and OOP. This gap may remain or change as long as new initial OOP parameters loaded. This means that Ephemeris data, which can be used for rough pointing to target SC [14], may be different than expected.

III. CALCULATION OOP AND OGOC DIFFERENCES

A. *Philosophy of the Calculations*

The analysis is done by dumping the on board orbital telemetries at specific time interval and propagating the freshest orbit on ground for the same time. Since the on board orbit propagator does not give semimajor axis value, it has been calculated by using longitude drift parameter [16]. After that, the Keplerian parameters were transferred to position and velocity [15]. The Euclidean distance has been calculated from rms of the position errors.

The following figures are representing the differences between Keplerain parameters, position and velocity differences and Euclidean differences between these two calculations.

B. *Comparison of OOP and OGOC for the year 2010*

First, one year analysis was performed for the year 2010; everyday, two points were taken into account for calculation. The on board OOP telemetries were dumped each day at around 5:00:00 GMT and 17:00:00 GMT and transferred to position and velocity. On ground side the up-to-the-minute orbit was calculated by OGOC. Table 1 shows the rms values of the difference between OOP and OGOC, where μ is the mean and the σ is the standard deviation of the corresponding data. In table, 'a' is the semimajor-axis, 'i' is inclination, 'e' is the eccentricity of the orbit, 'RAAN' is the Right Ascension of Ascending Node, 'AoP' is the Argument of Perigee and MeanAnom represents Mean Anomaly of the orbit. x, y, z and V_x, V_y and V_z are position and velocity of the satellite with respect to Earth Center J2000 reference frame.

TABLE 1. OOP-OGOC PARAMETER DIFFERENCES FOR THE YEAR 2010

Δ OOP - OGOC	*max*	*Min*	*μ*	*σ*	*unit*
Δ a	1.714	0.00144	0.6415	0.399	km
Δ i	0.00862	1.59e-07	0.002	0.00192	degree
Δ e	3.294e-5	5.55e-09	4.77e-06	5.3e-6	-
Δ RAAN	11.546	9.18e-05	2.0263	2.2452	degree
Δ MeanAnom	4.1619	7.74e-06	0.6219	0.5921	degree
Δ AoP	11.669	1.207e-04	2.18	2.1702	degree
Δ x	16.283	5.47e-03	3.1232	2.9645	km
Δ y	27.38	1.13e-03	2.888	2.6346	km
Δ z	6.2129	6.75e-03	1.5243	1.22	km
Δ Vx	1.5617	5.80e-05	0.21327	0.195	m/s
Δ Vy	1.1834	2.258e-04	0.2172	0.2165	m/s
Δ Vz	0.6775	3.284e-05	0.125	0.141	m/s
Δ Euclidean	**21.756**	**1.43e-01**	**5.166**	**3.307**	**km**

As can be seen in this table, the maximum Euclidean distance between on ground and on board parameters is 21.7564 km.

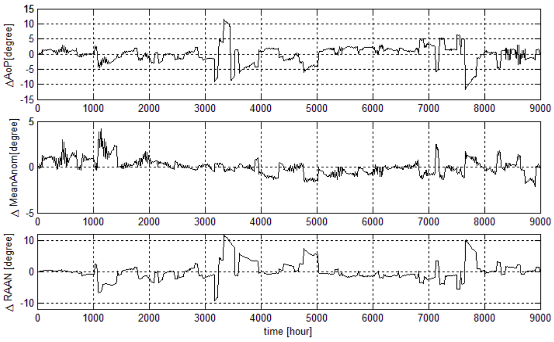

Figure 2. Differences in AoP, M and RAAN

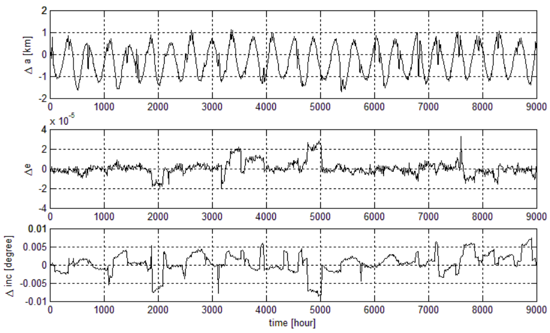

Figure 3. Differences in semimajor axis, eccentricity and inclination

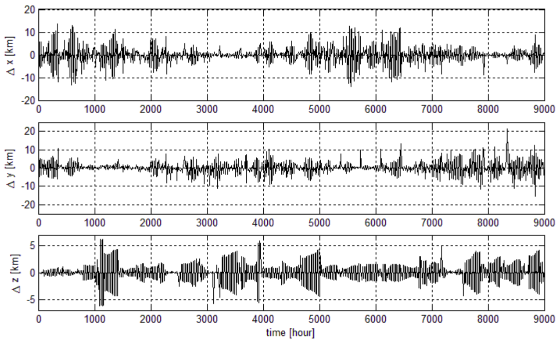

Figure 4. Variations in positions, x, y and z

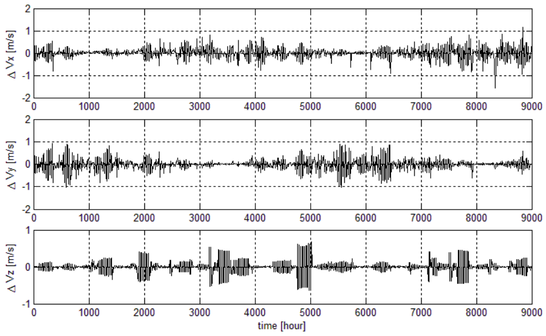

Figure 5. Variations in velocities Vx, Vy and Vz

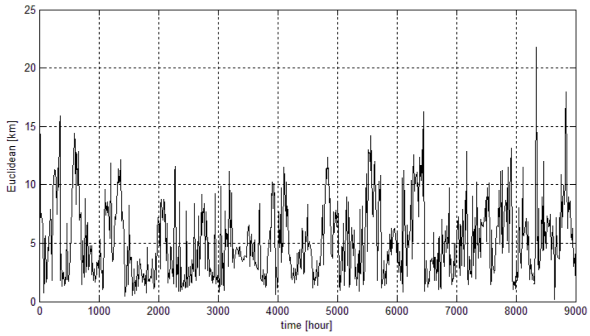

Figure 6. Differences in Euclidean distance for 2010

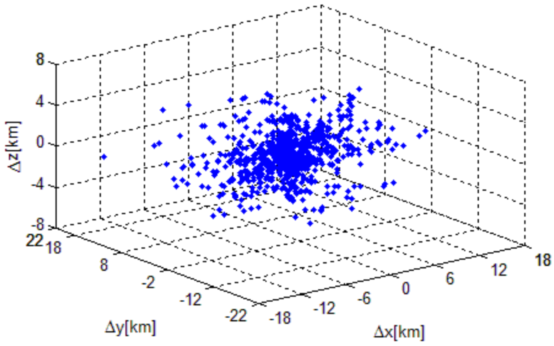

Figure 7. Differences in Euclidean in space for 2010

As shown in figures above and detailed in Table 1, for the year 2010 the mean Euclidean error between satellite calculation and on ground calculation is 5.116 km and the standard deviation is 3.307 km. Only 0.266% of the values are bigger than 20 km, 0.532% of the values are between 15 km to 20 km. 9.587% of the values are between 10 km to 15 km and finally 89.61% of the values are less than 10km.

C. Two-Week Analysis (between 18.10.2010 – 02.11.2010)

Further analysis was done between two OOP initialization operations, starting the calculation from 18.10.2010 to 02.11.2010 by comparing the orbital parameters every three hours. The following figures show the variations of position and velocity. It is observed from the orbital parameters, whenever the new OOP parameters are loaded on the board the differences are getting closer to zero. The following figures give the variations of position and velocity errors.

 ISBN: 978-1-61208-194-6

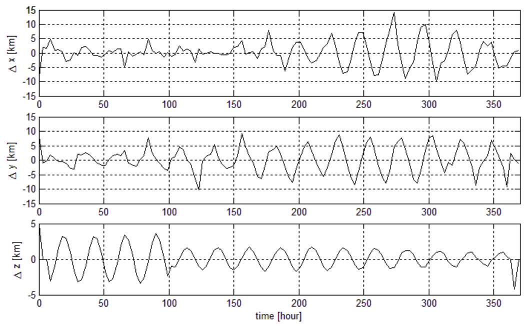

Figure 8. Variations in positions, x, y and z errors

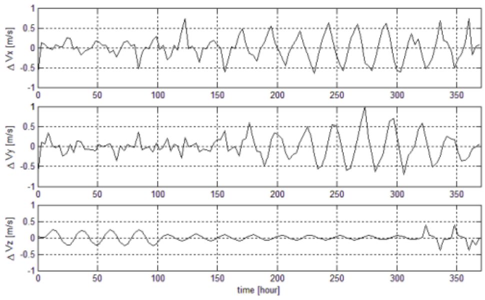

Figure 9. Variations in Vx, Vy and Vz errors

D. 4-Day Analysis (between 24.10.2010 20:00GMT – 29.10.2010 12:00GMT)

In order to analyze the OOP drift, the comparison study was done where there was not any thruster activity (North man, East man or auto wheel unloading) and new OD.

Starting from 24.10.2010 20:00 GMT to 29.10.2010 12:00 GMT, similar analysis was done with 1 hour interval. As can be seen from figures below the most drifting parameters during that time interval are Δx and ΔVy.

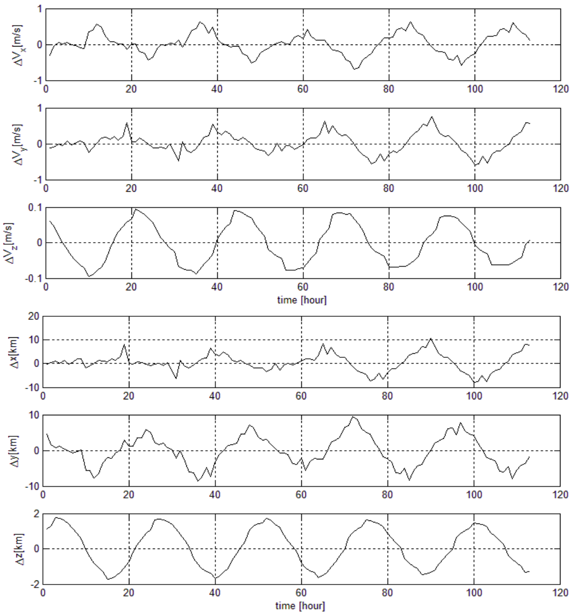

Figure 10. Differences in positions and velocities

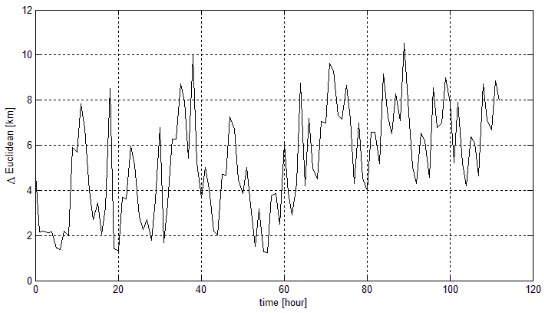

Figure 11. Difference in Euclidean distance

IV. Study on Antenna Angles Used for Orbit Determination

As indicated in previous sections, most of the time the differences in Keplerian Elements are observed between the angle data; RAAN, Argument of Perigee and Mean Anomaly. The differences in semimajor axis, eccentricity and inclination do not have as much affect as other three parameters.

Further analysis was done in order to find the root cause of the differences in OOP and OGOC. Ranging measurements were analyzed for the year 2010. For that purpose, 75 ranging operations in 25 cycles were taken into account.

The software, which is used for orbit computation, calculates the standard deviation of the angle components and distance in normal distribution after calculating the biases. That's why the standard deviations may give some idea whether the qualities of the measurements are good or not.

After the studies on ranging measurements, it has been seen that, whenever the standard deviations of azimuth and elevation are respectively high, it affects all the Keplerian parameters in calculation. The distance measurement seems not as major disturbance as the angular ones.

V. Conclusion

In this paper, we have presented the comparison of orbital calculation using on board satellite computer and on ground orbit propagator. It can be seen that the accuracy of the orbital parameters are crucial and key factors in maintaining a pointing between a GEO and a LEO satellite due to limited time interval. One has to pay attention to load the most accurate initial values to satellites' On Orbit Propagator. The antennas which are used for the orbit determination must have a very accurate angular sensitivity in both azimuth and elevation. Most of the time less than 8 mdeg standard deviation has to be reached for angular resolutions. This issue is as much important as the tracking data that were used as initial parameters calculation for GEO satellite orbit propagator software. The maximization of the quality of the tracking antennas eventually gives better proximity to real position of the satellite in orbit and requires less tracking field of view for LEO satellite beacon and laser beam.

ACKNOWLEDGMENT

We are indebted to our colleague Dr. Lokman Kuzu for his valuable contributions and proofreading this paper.

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