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VARIATIONS OF THE LOCAL TIME OF ASCENDING NODE FOR THE INITIAL INCLINATIONS OF THE KOMPSAT

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ABSTRACT

The optimal initial inclination for minimizing the variation of the Local Time of Ascending Node(LTAN) during the three year mission of the KOMPSAT is investigated. At first, the analytical equation for the inclination change by the Sun is derived and the optimal initial inclination by analytical method is derived. Then the analytically derived optimal inclination is checked by the numerical orbit propagation with including all major perturbations. Four different cases of the initial orbital elements are used for monitoring the LTAN variations. It is found that the analytically derived optimal inclination is not satisfied for minimizing the variation of the LTAN. Therefore, a new optimal initial inclination by numerical orbit propagation for the KOMPSAT is found. In addition, the variations of the mean and osculating semi-major axis are investigated with the different atmospheric density values. The mean eccentricity vs. argument of perigee diagram for the frozen orbit is obtained.

1. INTRODUCTION

The Sun-synchronous orbit is characterized by the fact that the satellite orbital plane remains fixed with respect to the mean Sun. This is done by matching the secular variation in the right ascension of the ascending node to the Earth's rotation rate around the Sun(Boden 1991). The Local Time of Ascending Node(LTAN) remains fixed in every pass of Sun-synchronous orbit. The Sun-synchronous orbit is used for the various applications in the Earth observations. The KOrea Multi-Purpose SATellite(KOMPSAT) is scheduled to be launched by the TAURUS from Vandenberg Air Force Base in California, U.S.A. in Dec., 1999. The main missions of the KOMPSAT are Korea cartography, ocean color monitoring, ion layer measurement, and high energy particle detection. The KOMPSAT will be operated on a Sun-synchronous orbit of 685 $\pm$ 1 km altitude and 10:50 AM +10/-15 min. LTAN.

The altitude of the KOMPSAT is continuously decreased due to air drag, and the inclination is continuously decreased by the perturbation of the Sun. The change of the inclination affects to the regression rate of the right ascension of the ascending node, and it causes the variation of the LTAN. In order to maintain the orbit of the KOMPSAT, altitude-raising maneuver and inclination control maneuver should be performed. However, the inclination control maneuver requires significantly more fuel than the altitude raising maneuver. Therefore, inclination control maneuver should be avoided for minimizing the fuel expenditure and maximizing the mission lifetime. The passive control of inclination by biasing the initial inclination of the satellite are studied by Folta & Kraft(1992) and Chao & Gist(1995).

In this paper, the optimal initial inclination for minimizing the variation of the LTAN during the 3 year mission life of the KOMPSAT is investigated by the numerical orbit propagation. At first, the analytical equation for the inclination change by the Sun is derived and then the optimal initial inclination is found. The optimal inclination is checked by the numerical orbit propagator with all possible perturbations such as the geo-potential harmonics, Luni-solar gravity, Solar radiation pressure, and the air drag. Four different cases of the initial orbital elements are used for monitoring the LTAN variations. In addition, the variations of the mean and osculating semi-major axis are investigated with the different atmospheric density values. The mean eccentricity vs. argument of perigee diagram for the frozen orbit is obtained for the 3 year mission of the KOMPSAT.

2. VARIATION OF INCLINATION BY ANALYTICAL FORMULA

The Sun-synchronous inclination i_{syn} is derived by (Chobotov 1996)

$$i_{syn} = \cos^{-1}\left(-0.098922(1-e^2)^2(1+\frac{h}{R})^{3.5}\right) \tag{1}$$

where, e is the eccentricity of the orbit, h is the altitude of the orbit, and R is the equatorial radius of the Earth. The Sun-synchronous property causes a deep resonance in the perturbation equations due to the Sun's motion. For a near circular orbit, the deep resonance terms in the variational equation of inclination can be isolated as follows(Chao 1979)

$$di/dt = (3/8)(n_s^2/n)(a_s/r_s)^3 \sin i \cdot (1+\cos\epsilon - 0.5\sin^2\epsilon)\sin 2(\Omega - \alpha_s) \tag{2}$$

where, n_s and n are the mean motion of the Sun and the satellite, a_s and r_s are semi-major axis and radius of the Sun's orbit around the Earth, i and Ω are the inclination and right ascension of the ascending node of the satellite, ϵ and α_s are the obliquity of the ecliptic and right ascension of the mean Sun, respectively. The Equation (2) indicates that the change rate of the inclination is dependent on the LTAN. For the KOMPSAT mission orbit with 685.13 km altitude and 98.127 deg nominal inclination, the above equation can be reduced to the following simple form

$$di/dt = 0.046 \sin 2(\Omega - \alpha_s) \quad (\text{deg/year}) \tag{3}$$

For the LTAN of 10:50 and the 3 year mission of the KOMPSAT, the inclination variation is estimated as -0.0792 degrees.

A proper biasing of the initial inclination can significantly reduce the maximum deviations in LTAN. The time of the maximum deviation is the positive root of the quadratic equation and is a function of the mission duration T in year alone as derived by Chao & Gist(1995)

$$t_{mvd} - t_0 = T/(1+\sqrt{2}) = 0.4142T \quad (4)$$

where, t_0 is the initial time, and t_{mvd} is the time of maximum node deviation. By using the Equation (4), the optimized inclination for the KOMPSAT case is

$$\begin{aligned} i_{opt} &= i_{syn} - 0.046 \sin 2(\Omega - \alpha_s)(t_{mvd} - t_0) \\ &= i_{syn} - 0.01905T \sin 2(\Omega - \alpha_s) \end{aligned} \quad (5)$$

where, T denotes the mission duration in year. The optimized inclination for the KOMPSAT is calculated as i_{opt} = 98.1604 deg.

3. VARIATION OF INCLINATION BY NUMERICAL ORBIT PROPAGATION

The numerical orbit propagation is performed to check out the validity of the optimized inclination by analytical method. Two types of orbit propagation are performed to estimate the inclination change during the mission duration. The one is standard Cowell type numerical orbit propagation with the osculating elements and the other is the variation of parameter type numerical orbit propagation with the mean orbital elements.

The perturbation modeling of the Cowell type orbit propagator consists of geopotential harmonics upto 70×70, luni-solar attraction by DE403 ephemeris, Solar radiation pressure, and air drag by Jachhia 71(Choi et al. 1998). Whereas, the perturbation modeling of the variation of parameter type orbit propagator consists of geopotential harmonics upto 21×21, luni-solar perturbation by analytical ephemeris, Solar radiation pressure, and air drag by simple exponential model(Kwok 1986). Table 1 shows the osculating and the mean orbital elements used for the KOMPSAT orbit propagation. The KOMPSAT mass of 470 kg and area of 8.25 m2 are used for orbit propagation. Table 2 shows the atmospheric density table for exponential modeling(Cappelari et al, 1976).

Figure 1 shows the inclination change for the 3-year mission life of the KOMPSAT. The dark line shows the osculating inclination by Cowell method and the light line shows the mean inclination by variation of parameter method. The results of the two independent propagators are consistent

Table 1. Nominal Keplerian orbital elements(Epoch : 1999/12/01 00:00:00).

	Mean	Osculating
(km)	7063.270	7054.136
(-)	0.001151884	0.000562334
(deg)	98.12761	98.131256
(deg)	231.91238	231.91467
(deg)	90.0	268.93399
(deg)	0.0	181.064079

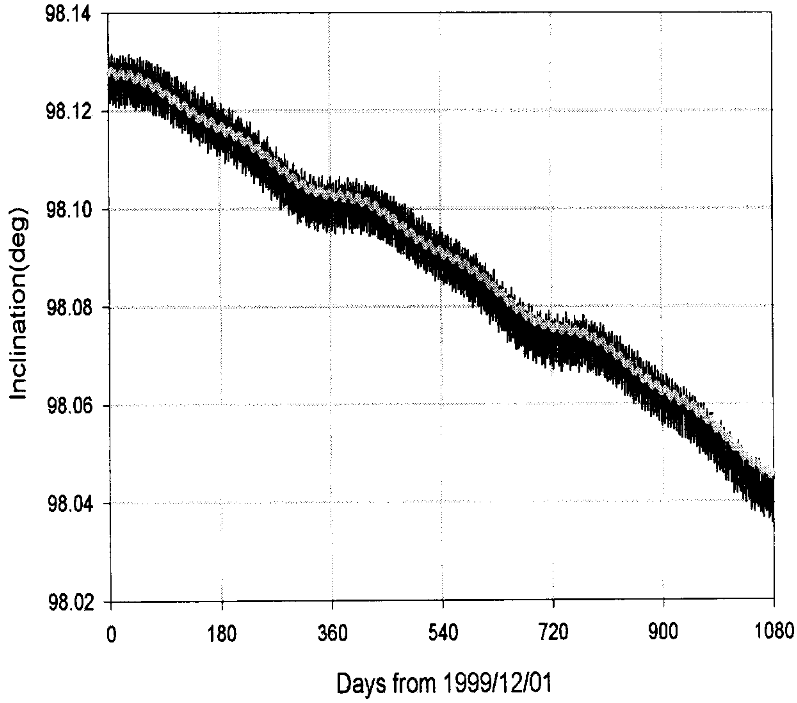

Figure 1. Inclination change for 3 years

in decreasing pattern and magnitude. The mean inclination change for the 3-year mission life of the KOMPSAT is estimated about -0.0821 degrees. The magnitude of the inclination change by numerical propagation is 0.0029 degrees bigger than that by analytical method in the Equation (3).

Figure 2 shows the osculating semi-major axis change for the 3-year time. Jacchia 71 atmospheric model is used for the air drag perturbation. The predicted Solar flux and geomagnetic index between the year 1999 and 2002 are derived based on the observed values between the year 1988 and 1991 as in Lee & Lee(1998). About 20 km of semi-major axis decreasing is predicted during the 3 year mission life. The KOMPSAT mission will be operated during the maximum Solar flux period of Solar cycle 23.

Figure 3 shows that the change of the mean semi-major axis for the 3 years by using three different fixed atmospheric density in Table 2. The change of the osculating semi-major axis in Figure 2 indicates that the applicable atmospheric density is somewhat smaller than that of the maximum density in Figure 3.

Table 2. Atmospheric density table for orbit propagation.

Altitude(km)	Min. Density(gm/km3)	Mid. Density(gm/km3)	Max. Density(gm/km3)
680	0.02632	0.14771	0.2691
780	0.008496	0.053128	0.09776

4. OPTIMAL INITIAL INCLINATION FOR MINIMIZING LTAN VARIATION

Four different cases are used for the mean orbit propagation to check out the change of the inclination and LTAN during the 3-year mission lifetime of the KOMPSAT. Table 3 shows the four different cases of initial inclination and LTAN. Case 1 starts from the nominal inclination and LTAN of the KOMPSAT. Case 2 starts from the nominal inclination but the maximum time limit of the LTAN 11:00 is used. Case 3 starts from the optimal inclination value by analytical method in Equation (5). The initial inclination in Case 4 starts from the somewhat bigger value than that of Case 3. The inclination in Case 4 is found by a few trials of numerical propagation.

The mean semi-major axis of the KOMPSAT is maintained within the 685.13 ± 1 km range during the simulation. Figure 4 shows the change of the mean semi-major axis during the 3-year simulation. The maximum density in Table 2 is used for the air drag modeling.

Figure 5 shows the mean argument of perigee vs. mean eccentricity plot for the 3 years of mission lifetime of the KOMPSAT when the initial orbit is frozen. The period of the phase diagram is about 114 days as found in Lee & Lee(1997).

Figure 6 and Figure 7 show the variation of the mean inclination and the LTAN for the four cases in Table 3. Table 4 summarizes the results of the four cases. The inclination change for the case 1 is the greatest because of the deep resonance effect by the Sun. The LTAN after 3 years in case 1 is estimated about 10:20:51 and it is out of the LTAN range 10:50+10/-15 min. The inclination maneuver should be performed within 2 years in case 1. For the case 2, LTAN starts from the maximum limit range and the LTAN after 3 years slightly exceed the - 15 minutes range. For the case 3, the LTAN after 3 years is 10:39:41 and within the - 15 minutes range. The LTAN in case 4 is controlled within ± 4 minutes range for 3 years. The optimal initial inclination for minimizing the

Table 3. Initial inclinations and LTAN for orbit propagation.

Cases	Inclination (deg)	LTAN(hh:mm)	Remark
Case 1	98.12761	10:50	Nominal parameters
Case 2	98.12761	11:00	Starts at maximum LTAN
Case 3	98.16040	10:50	Optimized by Equation(5)
Case 4	98.17300	10:50	Optimized by propagation

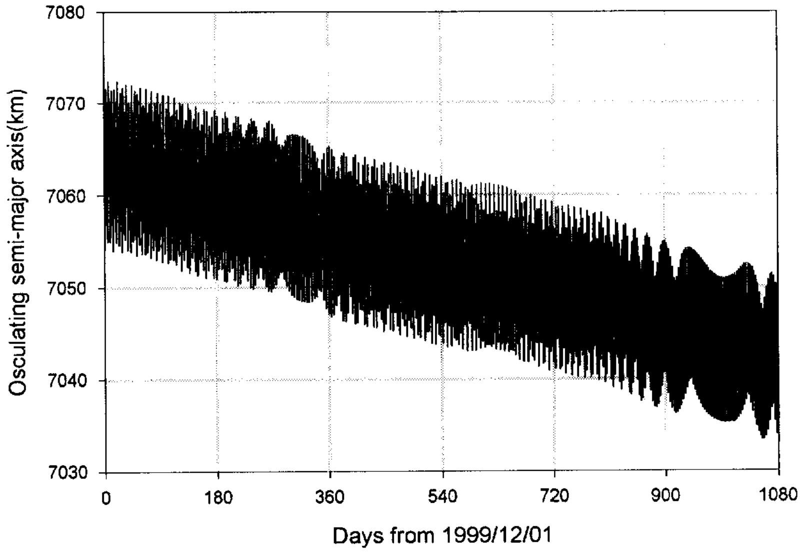

Figure 2. Osculating semi-major axis change

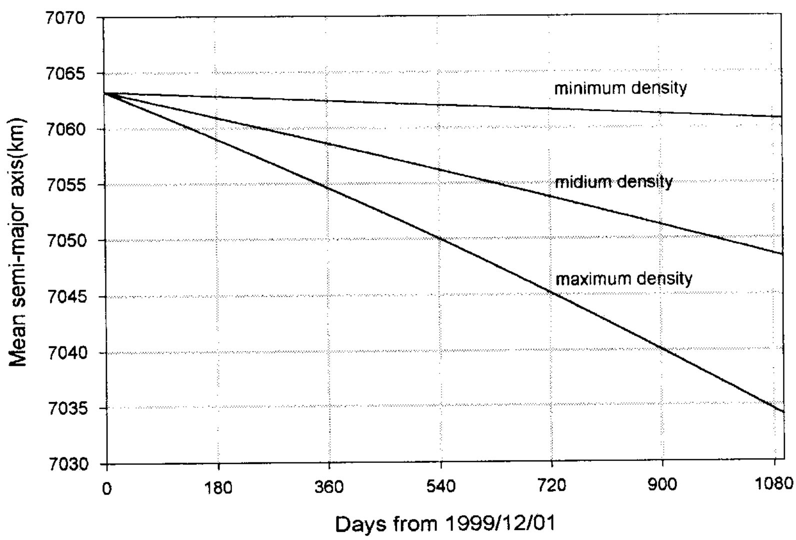

Figure 3. Mean semi-major axis change

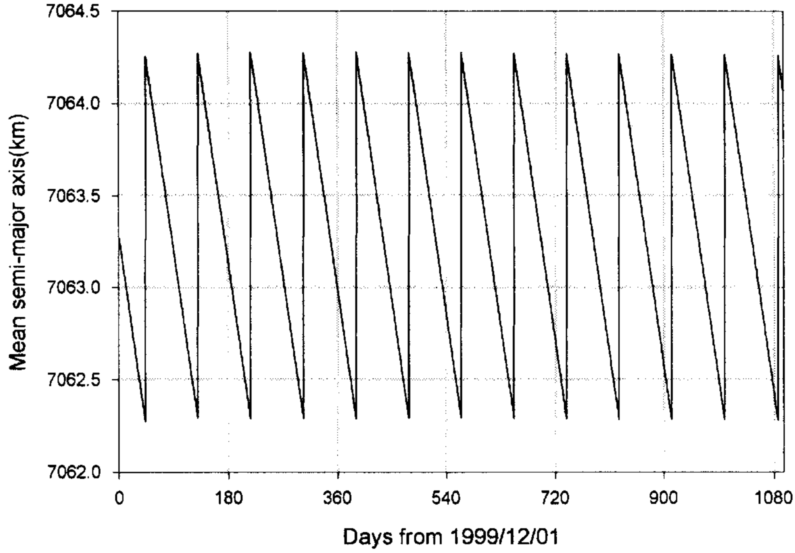

Figure 4. Mean semi-major axis change

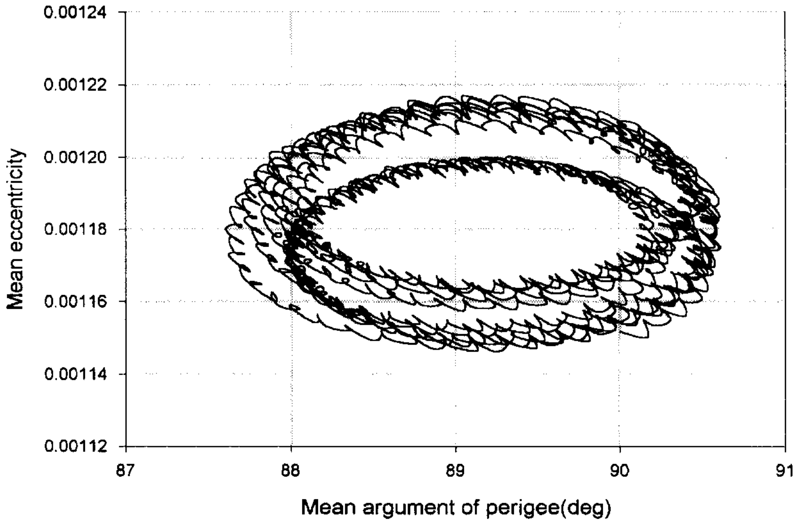

Figure 5. Mean argument of perigee vs. eccentricity

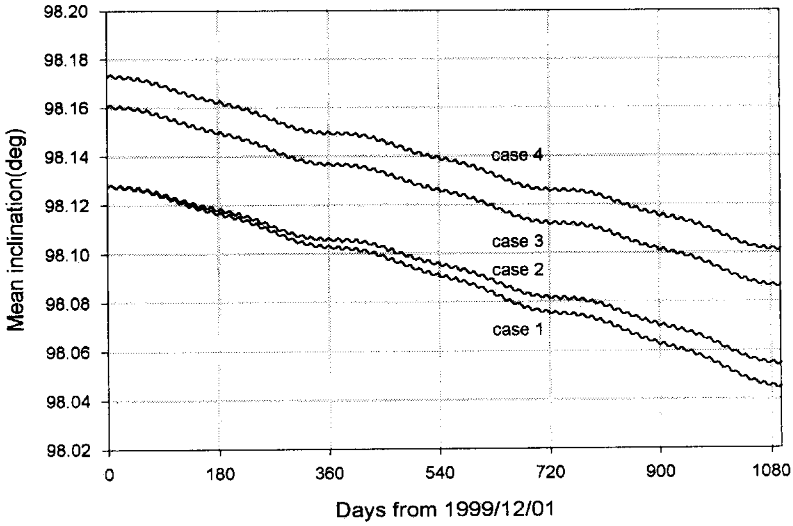

Figure 6. Mean inclination change

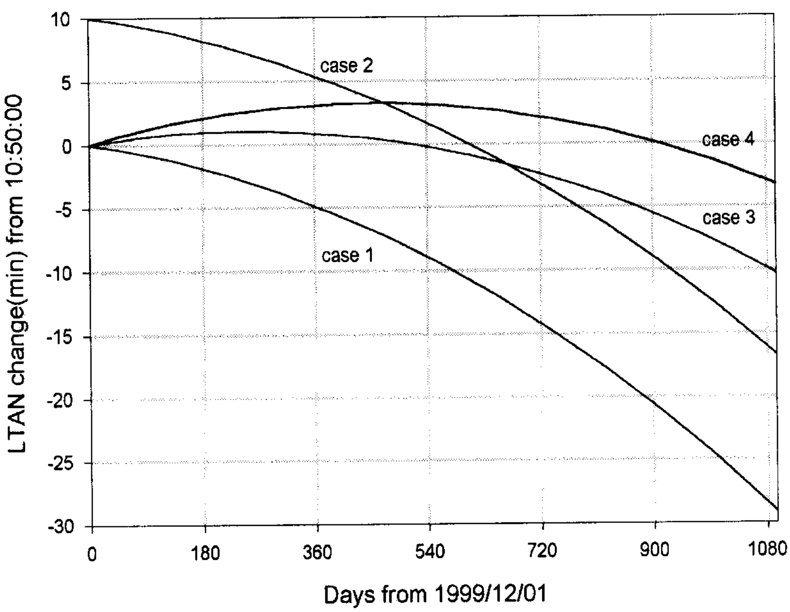

Figure 7. Mean LTAN change

Table 4. Final inclinations and LTAN for the four cases.

	(deg) (deg)	Max. LTAN(hh:mm:ss)	Min. LTAN(hh:mm:ss)	LTAN (mm:ss)
Case 1	98.0455 - 0.0821	10:50:00	10:20:51	29:09
Case 2	98.0549 - 0.0727	11:00:00	10:33:17	26:43
Case 3	98.0870 - 0.0742	10:51:04	10:39:41	11:23
Case 4	98.1019 - 0.0711	10:53:15	10:46:42	06:33

variation of the LTAN of the KOMPSAT is estimated as 98.173 degrees.

5. CONCLUSIONS

The optimal initial inclination for minimizing the variation of the LTAN during the 3-year mission of the KOMPSAT was investigated by the numerical orbit propagation. The analytically derived optimal inclination was found not to satisfy the minimum the variation of the LTAN. Therefore, a new optimal initial inclination by numerical orbit propagation for minimizing the LTAN variation was found.

The initial orbital elements of the KOMPSAT are highly dependent upon the launch dispersions of the TAURUS. A series of orbit maneuvers should be planned and performed for correcting the launch dispersions and initializing the orbital elements. The optimal initial inclination and the corresponding LTAN should be considered for maneuver planning. Bigger than the nominal values of the inclination and LTAN are preferred in consideration of the decreasing properties of the inclination and the LTAN of the KOMPSAT.

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