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GROUND TRACK MAINTENANCE MANEUVER SIMULATIONS FOR THE KOMPSAT SPACECRAFT

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ABSTRACT

Ground track maintenance maneuver simulations for the KOMPSAT spacecraft are performed for three and half years. Both longitude targeting and time targeting strategies are applied for in-plane maneuvers. The nominal longitude bands of maneuvers for ±5 km and ±10 km are applied for the longitude targeting and the 21-day maneuver time duration is used for the time targeting. Daily solar flux values for the simulation period are derived from the previous solar cycle values. Atmospheric drag formula for the KOMPSAT orbit altitude is derived from Jacchia model using polynomial and sinusoidal curve fitting. Total required delta velocity and proper time between successive maneuvers are estimated during ground track maintenance maneuver simulations.

1. INTRODUCTION

The ground track of the orbit is defined to be the trace of the points on the Earth's surface directly beneath the spacecraft orbit. The reference ground track for a remote sensing satellite mission is useful for the long-term mission planning purposes. When the remote sensing spacecraft mission for the exact repeat or near repeat orbit pattern are planned, the geopotential perturbation effects such as J2 and J3 terms are normally included. In fact, the atmospheric drag effect causes the drift of the ground track and the orbit raising maneuver is required for the maintenance of the ground track within a certain bandwidth. The mission planning and menevuer analysis for the GEOSAT-ERM exact repeat pattern was performed by Born *et al.* (1988). Comprehensive study for the TOPEX/POSEIDON orbit maintenance maneuver strategy was accomplished by Bhat *et al.* (1989). Lee *et al.* (1997) made an analytical approach for the acquisition and maintenance of the ground track for a low-earth orbit. In this paper, the ground track maintenance maneuver simulations for the KOMPSAT spacecraft are performed for three and half years. The nominal longitude bands of maneuvers for ±5 km and ±10 km are applied for the longitude targeting maneuver and the 21-day maneuver time duration is used for the time targeting maneuver. Daily solar flux values for the 3.5 years simulation time are derived from the previous solar cycle values. Atmospheric drag formula for the KOMPSAT orbit altitude is derived from Jacchia model using polynomial and sinusoidal curve fitting. In order to trace the ground track of the spacecraft, the analytical mean orbit propagator and maneuver planner by Shapiro (1993) are used and modified for the KOMPSAT orbit. The perturbation force models, such as the zonal harmonics of the Earth up to J4, gravitational forces of the Sun and the Moon, and the atmospheric drag are used for the mean orbit propagator. Total required delta velocity and the proper time between successive maneuvers according to the solar flux variations are estimated during the simulations.

2. MODELING OF THE ATMOSPHERIC DRAG

Atmospheric density is modeled as a function of solar activity and several geometric parameters including satellite altitude, latitude, and diurnal variations (Bhat *et al.* 1989). Since the KOMPSAT orbit is near circular, only the orbital average density at the mean altitude of 685.31 km is considered here. In this manner, the atmospheric density becomes a function only of daily solar flux values. In order to derive the daily average atmospheric density, numerical orbit propagator with Jacchia (1970)'s atmospheric model is used. For the first day of the month, the osculating orbital elements of the KOMPSAT are defined such that 10:50 local time of ascending node passing time is maintained. Then numerical orbit propagation for one day is performed with one of twelve solar flux value of 70, 80, 90, 100, 125, 150, 175, 200, 225, 250, 275, and 300. At this time, the geomagnetic index Ap is fixed to 25. The atmospheric densities for every 10 minutes are extracted during the orbit propagation, then the average atmospheric density is obtained. In this manner, total of 144 atmospheric density values are obtained by the numerical orbit propagator. Figure 1 shows the monthly atmospheric density profile for the flux values. There are annual and semi-annual atmospheric density variations in Figure 1. In order to derive the atmospheric density for the arbitrary solar flux values and time, the mixed polynomial and sinusoidal curve fitting is performed using Sigma Plot for 144 points. The Equation (1) shows the atmospheric density as the function of the solar flux values and the day of year.

$$\begin{aligned}\rho(F,D) &= a_1 + a_2F + a_3F^2 + a_4F^3 + a_5F^4 + b_1\sin((2\pi D)/365.25 + b_2)\\ &\quad + c_1\sin((4\pi D)/365.25 + c_2) \qquad (1)\end{aligned}$$

where, $a_1 = -5.6737875$, $a_2 = 7.1058801\times 10^{-3}$, $a_3 = 4.90180948\times 10^{-5}$, $a_4 = -2.5004134\times 10^{-7}$, $a_5 = 3.3242079\times 10^{-10}$, $b_1 = 0.07630939$, $b_2 = 7.79731542$, $c_1 = 0.10520567$, $c_2 = -2.32753778$, F is solar flux, and D is day of the year.

The atmospheric drag is a function of the satellite orbital position, atmospheric density, satellite velocity, and the drag reference area. The Equation (2) shows the semi-major axis decay due to the atmospheric drag effect (Escobal 1975)

$$a = -C_d A \rho V^2 / M_s n \qquad (2)$$

where, C_d is drag coefficient, A is area of the satellite, ρ is atmospheric density, V is orbital velocity,

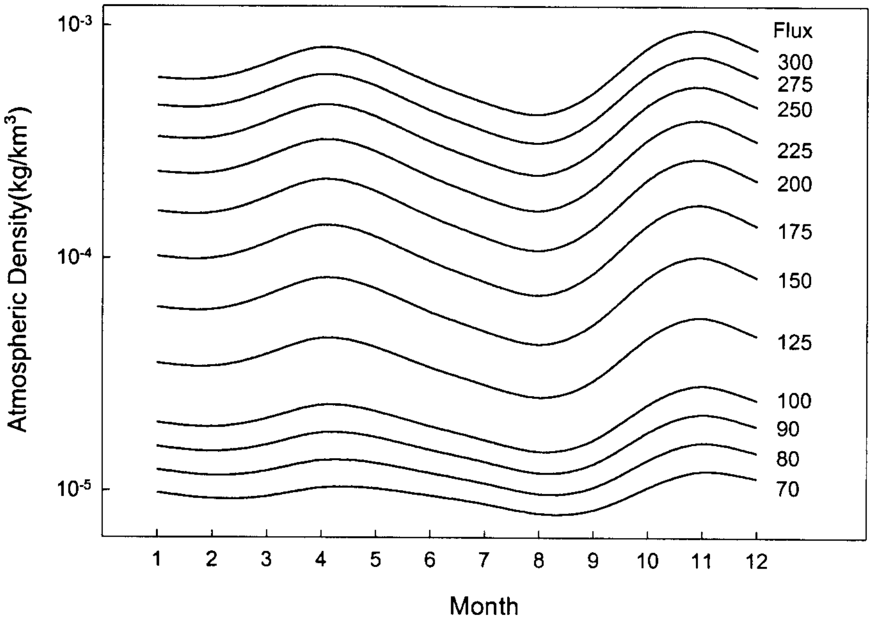

Figure 1. Atmospheric Density Profile for the flux values and the month of year .

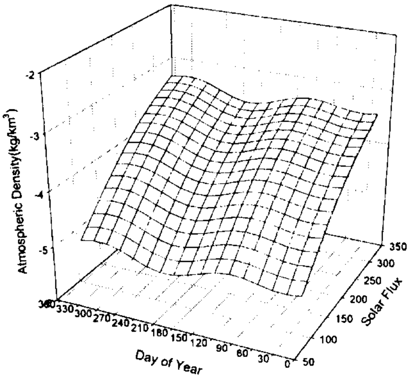

Figure 2. 3-D profile of the atmospheric density with respect to the solar flux and the day of year.

M_s is mass of the satellite, and n is mean motion of the satellite.

Figure 2 shows the 3-dimensional profile of the atmospheric density with respect to the solar flux and the day of year. The Equation (1) is applied for generating Figure 2.

Joselyn *et al.* (1996) empirically find that odd-numbered cycles are larger than their preceding

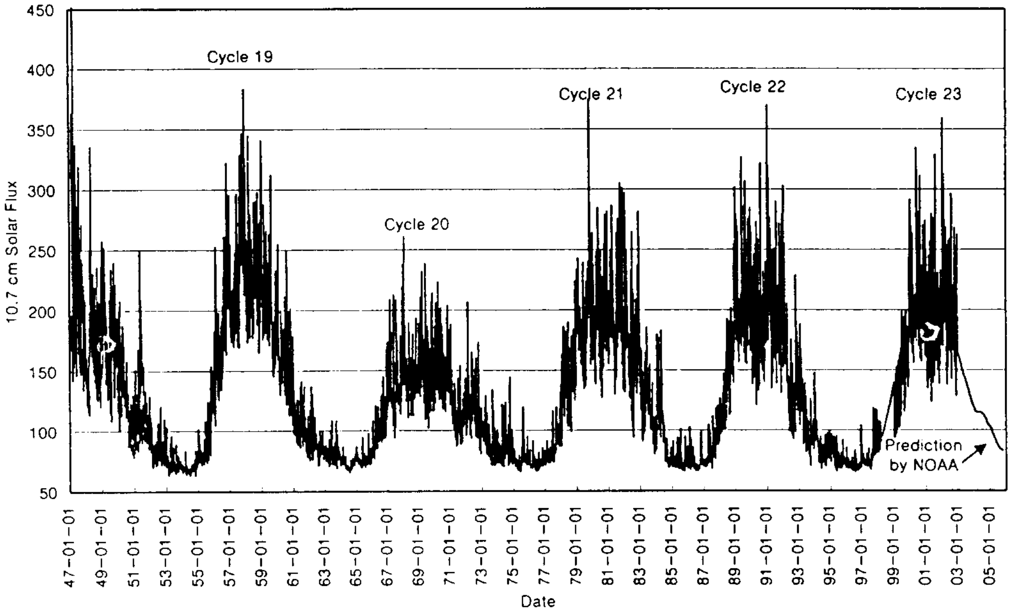

Figure 3. Solar flux variations in the year between 1947 to 2005.

cycle, and it suggests that the next cycle 23 will exceed cycle 22 and could be larger than cycle 19. In this paper, the predicted solar flux values between the year 1999 and 2002 are based on the observed flux values between the year 1988 and 1991 for the simplicity. The KOMPSAT spacecraft will be launched in the year 1999 and the mission will be operated during the maximum solar flux period of solar cycle 23. Figure 3 shows the solar flux variations in the year between 1947 to 2005. The observed solar flux values are obtained from NOAA (1998)'s ftp site. The 81-day average flux values predicted by NOAA (1998) are also shown in Figure 3.

3. GROUND TRACK MAINTENANCE MANEUVER SIMULATION

A 28-day repeat ground track is assumed for the KOMPSAT simulations. A total of 409 reference ground track longitudes is defined, and the Earth-fixed reference node are at East longitudes of 144.009°+0.880°n , where, n = 0, 1, 2,... ,408. The equatorial distance between the adjacent longitude crossing is about 97.96 km, and the equatorial longitude spacing between successive ground tracks is 24.645°/orbit. Figure 4 shows the nominal ground track spacing in the area of the Korean peninsula.

Table 1. Mean orbital elements and spacecraft parameters (1999/07/01 00:00:00).

Semi-major Axis(km)	7063. 270	R.A. of Asc. Node(deg)	81.108
Eccentricity	0.001151884	Arg. of Perigee(deg)	90.000
Inclination(deg)	98.127	Mean Anomaly(deg)	0.000
Spacecraft Mass(kg)	400.0	Spacecraft Area(km^2)	8.25×10^{-6}

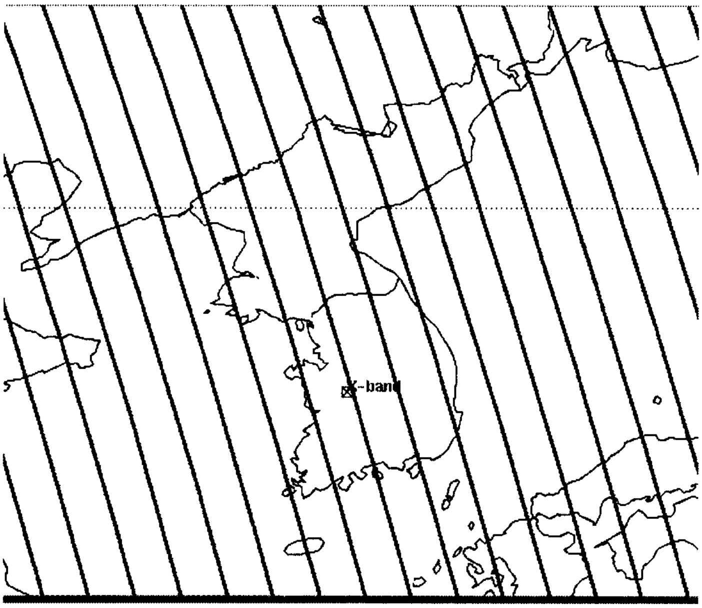

Figure 4. Nominal ground track spacing in the area of Korean peninsula.

Table 1 shows the initial mean orbital elements for the 3.5 years' ground track maintenance maneuver simulation.

Two classes of the maneuver strategies are applied for the simulations. One is the longitude targeting strategy and the other is time targeting strategy. In longitude targeting strategy, the control band for ground track offset is defined and the maneuver strategy utilizes the full control band to maximize the time between maneuvers. When the initial semi-major axis of the orbit is greater than that of the reference orbit, the ground track offset in the eastern boundary of the control band drifts westward and the drift continues until the ground track matches the western boundary of the control band. And then, the ground track offset turns around and begin to move eastward. When the ground track offset matches the eastern boundary of the control band, the orbit raising maneuver should be

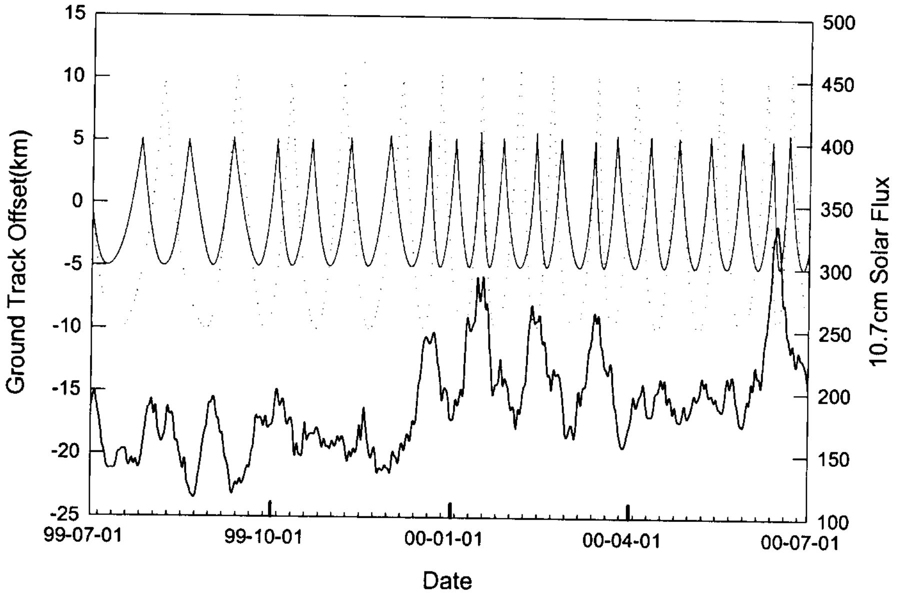

Figure 5. Ground track offset for longitude targeting.

executed. In time targeting strategy, the time duration between the maneuvers is defined.

A orbit raising maneuver is applied at the eastern boundary of the control band such that the ground track offset firstly drifts westward up to the certain point and moves back eastward up to the eastern boundary within a predefined maneuver time interval.

Bhat *et al.* (1989) provide the Equation (3) and Equation (4) with respect that the maximum maneuver magnitude $\Delta V_{\max}$ provides maximum maneuver time interval $\Delta T_{\max}$, while maintaining the ground track just inside the control bandwidth $\Delta\lambda_{\max}$.

$$\Delta V_{max} = \sqrt{\frac{C_d A}{M_s}\frac{\rho V}{3}\frac{\Delta\lambda_{max}}{\omega_e}} \tag{3}$$

$$T_{max} = \frac{4M_s \Delta V_{max}}{C_d A \rho V} \tag{4}$$

Using the longitude targeting strategy and the time targeting strategy, total of 3.5 years periods ground track maintenance maneuver simulations are performed. The control bands of the longitude targeting simulation are defined as ±5 km and ±10 km. The control time between the maneuvers for time targeting simulation is defined as 21 days.

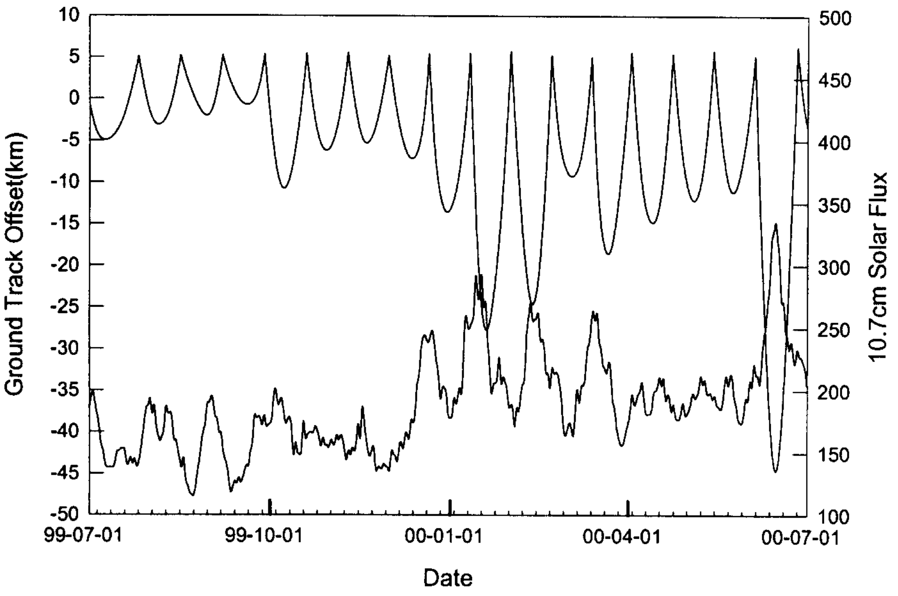

Figure 6. Ground track offset for time targeting.

The ground track offset for the longitude targeting strategy during the first year of the KOMPSAT simulation is shown in Figure 5. Both maneuvers for ±5 km and ±10 km control bands are shown above and the solar flux values during the same period are shown below in Figure 5. The number of maneuvers is increased during the high solar activity periods.

The ground track offset for the time targeting strategy during the first year of the KOMPSAT simulation is shown in Figure 6. Maneuvers by 21-day time targeting strategy are shown above and the solar flux values during the same period are shown below in Figure 6. The ground track offsets show more westerly biases during the high solar activity periods.

Figure 7 and Figure 8 show the required delta velocity for the ground track maintenance maneuver using ±5 km and ±10 km longitude targeting bands. More frequent maneuvers are required for the ±5 km longitude band case and the bigger maneuvers are required for the ±10 km longitude band. The first maneuver in Figure 7 and Figure 8 is the smallest maneuver because of no ground track bias at the epoch.

Figure 9 and Figure 10 show the time of the next maneuver for the ground track maintenance maneuver using ±5 km and ±10 km longitude targeting bands. For the ±5 km longitude band, the maximum time between maneuvers is 26 days and the minimum time between maneuvers is 7 days. For the ±10 km longitude band, the maximum time between maneuvers is 37 days and the minimum time between maneuvers is 13 days.

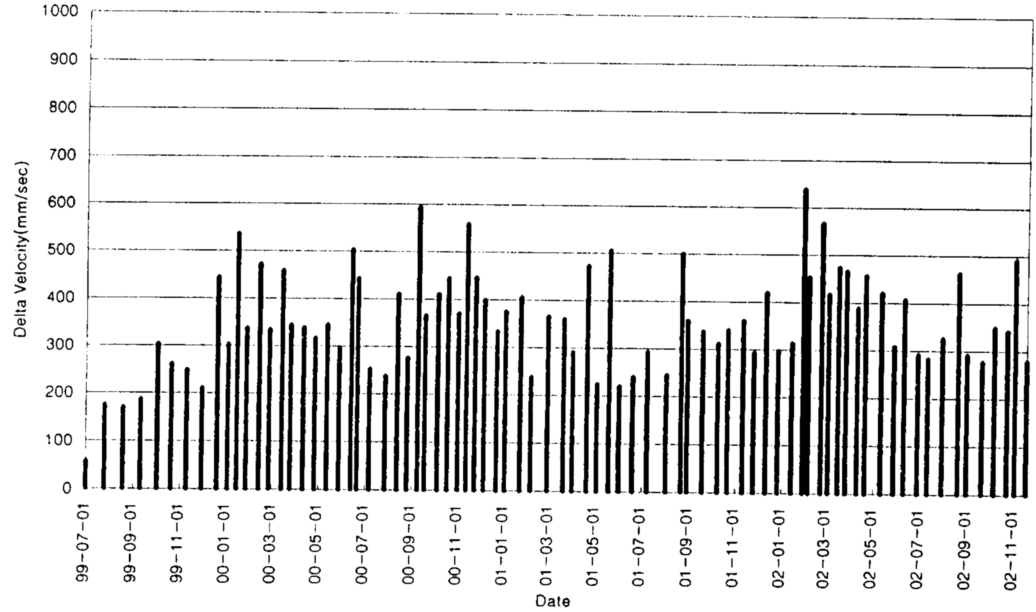

Figure 7. Required delta velocity for the for ±5 km longitude targeting maneuver.

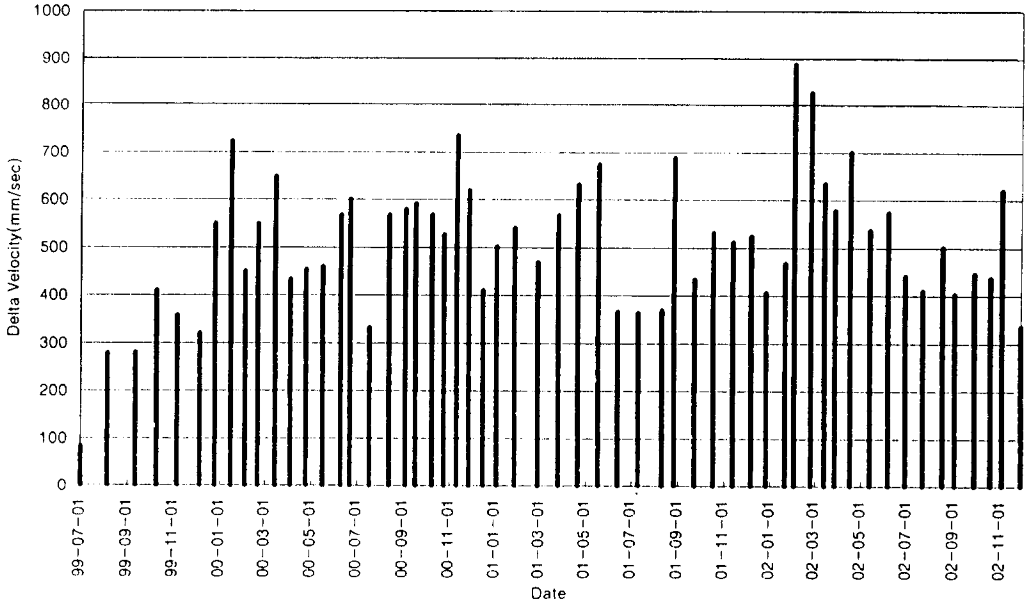

Figure 8. Required delta velocity for the ±10 km longitude targeting maneuver.

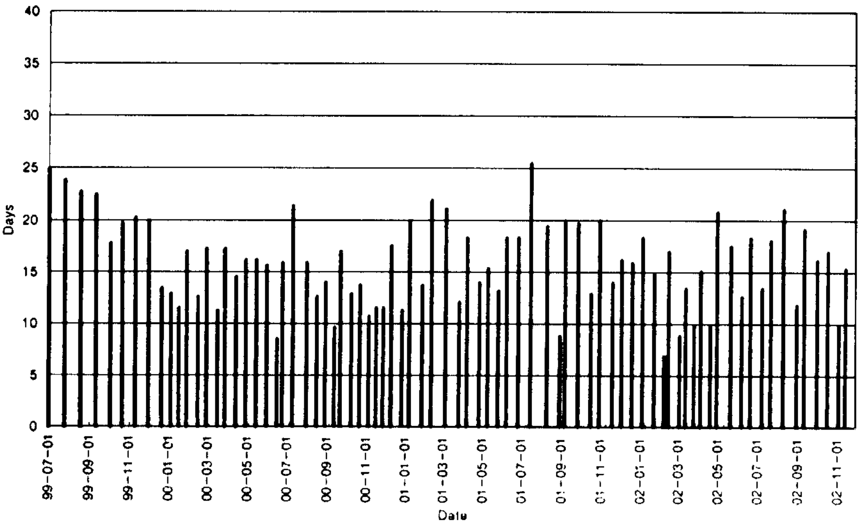

Figure 9. Time of the next maneuvers for ±5 km longitude targeting.

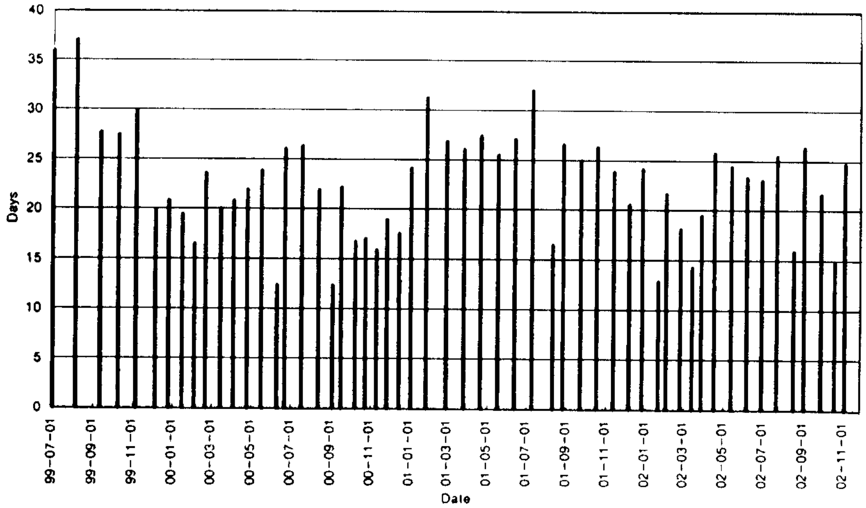

Figure 10. Time of the next maneuvers for ±10 km longitude targeting.

Figure 11 shows the required delta velocity for 21-day time targeting maneuvers. More than 900 mm/sec of delta-velocity maneuvers are required during the solar maximum time. Figure 12 shows the time of the next maneuver for 21-day time targeting strategy. The time variations are ±1 days. The first maneuver in Figure 11 and Figure 12 is the smallest maneuver and the longest time duration because no ground track bias is applied at the epoch time.

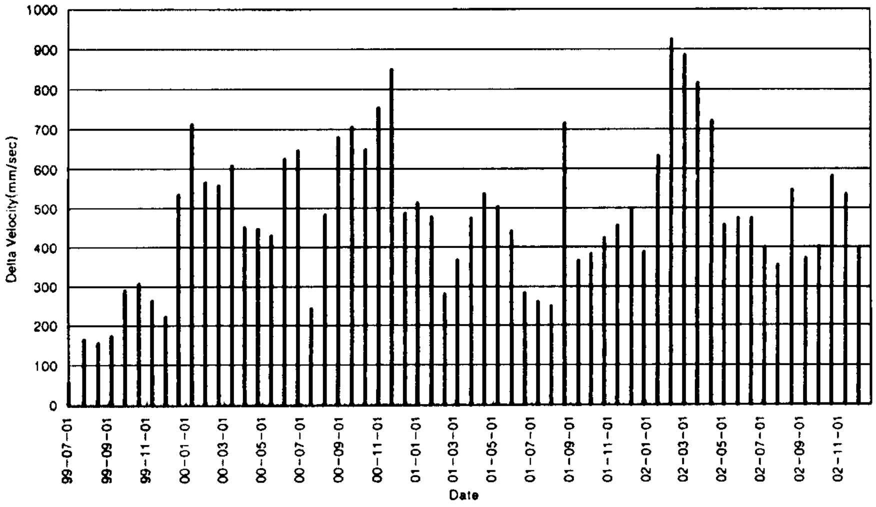

Figure 11. Required delta velocity for 21-day time targeting maneuver.

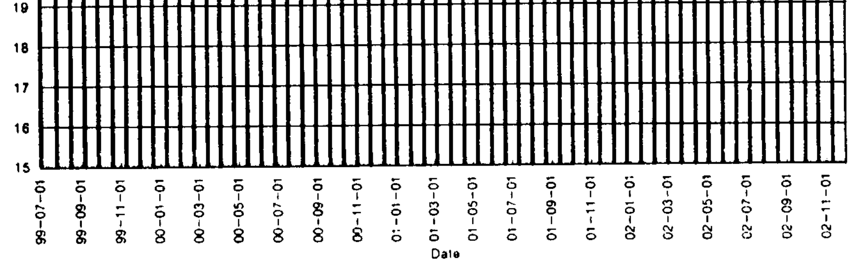

Figure 12. Time of the next maneuver for 21-day time targeting strategy.

Table 2. Summary of Ground Track Maintenance Maneuvers for the KOMPSAT.

Targeting Strategy	±5km longitude	±10km longitude	21 day time
Total Maneuver Duration(days)	1234.415	1245.368	1249.749
Total Required Delta V(mm/sec)	28301.2	28469.6	28620.8
Total Number of Maneuvers	79	56	60
Minimum Delta-V (mm/sec)	169.6	278.2	154.3
Maximum Delta-V (mm/sec)	638.2	888.0	924.1
Average Delta-V (mm/sec)	362.1	516.1	484.1
Minimum Duration (days)	6.8	12.3	20.3
Maximum Duration (days)	25.5	37.0	21.9
Average Duration (days)	15.7	22.4	21.1

Table 2 summarizes the results of three kinds of orbit maintenance maneuvers.

4. CONCLUSIONS

The ground track maintenance maneuver simulations have been performed for the three and half years' orbit of the KOMPSAT spacecraft. Both longitude targeting strategy for the control bandwidth of ±5 km and ±10 km and time targeting strategy for the control duration of 21 days were applied. The polynomial and sinusoidal formula for the atmospheric density of the KOMPSAT altitude was derived as functions of solar flux and day of the year. The atmospheric density formula in this paper can be used as a good approximation for the Jacchia's formula and applied to the operational maneuver planning programs without knowing the exact future solar flux values. The total magnitudes of the required delta velocities are similar to the different strategies and longitude bandwidth. The maneuver cycles for the time targeting were very much dependent on the solar flux values. The KOMPSAT spacecraft will be operated during the solar maximum period of the cycle 23. So frequent orbit maneuvers are required for maintaining the orbital altitude. Currently, there is no tight requirement of the ground track maintenance maneuver for the KOMPSAT mission. Instead, the mean altitude of the KOMPSAT will be maintained within ±1 km band. The altitude band of ±1 km is bigger than the ground track maintenance band of ±10 km. In this case, solar flux variations will the crucial maneuver factor for the maneuver.

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