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Orbit Determination and Maneuver Planning for the KOMPSAT Spacecraft in Launch and Early Orbit Phase Operation

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Abstract

KOrea Multi-Purpose SATellite(KOMPSAT) is scheduled to be launched by TAURUS launch vehicle in November, 1999. Tracking, Telemetry and Command(TT&C) operation and the flight dynamics support should be performed for the successful Launch and Early Orbit Phase(LEOP) operation.
After the first contact of the KOMPSAT spacecraft, initial orbit determination using ground based tracking data should be performed for the acquisition of the orbit. Although the KOMPSAT is planned to be directly inserted into the Sun-synchronous orbit of 685 km altitude, the orbit maneuvers are required for the correction of the launch vehicle dispersion.
Flight dynamics support such as orbit determination and maneuver planning will be performed by using KOMPSAT Mission Analysis and Planning Subsystem(MAPS) in KOMPSAT Mission Control Element(MCE). The KOMPSAT MAPS have been jointly developed by Electronics and Telecommunications Research Institute(ETRI) and Hyundai Space & Aircraft Company(HYSA). The KOMPSAT MCE was installed in Korea Aerospace Research Institute(KARI) site for the KOMPSAT operation.
In this paper, the orbit determination and maneuver planning are introduced and simulated for the KOMPSAT spacecraft in LEOP operation. Initial orbit determination using short arc tracking data and definitive orbit determination using multiple passes tracking data are performed. Orbit maneuvers for the altitude correction and inclination correction are planned for achieving the final mission orbit of the KOMPSAT.

1. Introduction

The principal missions of the KOrea Multi-Purpose SATellite(KOMPSAT) are to perform cartography of Korea, to provide large-scale multi-spectral images of oceans, and to provide information about ion layer and particle environment during the design life of three years. The KOMPSAT will be maintained and operated on the Sun-synchronous orbit of 685 ± 1 km altitude and 10:50 AM +10/-15 minutes Local Time of Ascending Node(LTAN)[1]. The KOMPSAT is scheduled to be launched by TAURUS launch vehicle on November 1999, from Vandenberg Air Force Base in California, U.S.A. After separation from the TAURUS, the KOMPSAT will be operated by Mission Control Elements(MCE) and Image Reception and Processing Elements(IRPE) located in Korea Aerospace Research Institute(KARI), Taejon, Korea. The MCE provides tracking, telemetry and command interfaces to the satellite via S-band antenna. The IRPE provides the payload data reception and processing function via X-band antenna. The MCE consists of four subsystem such as Tracking, Telemetry and Command subsystem(TTC), Satellite Operations Subsystem(SOS), Mission Analysis and Planning Subsystem(MAPS), and SIMulator subsystem(SIM). The MCE have been jointly developed by Electronics and Telecommunications Research Institute(ETRI), Hyundai Space & Aircraft Company, and Daewoo Heavy Industry.

Tracking, Telemetry and Command(TT&C) operation and the flight dynamics support should be performed for the successful Launch and Early Orbit Phase(LEOP) operation. Flight dynamics support such as orbit determination and maneuver planning will be performed by using KOMPSAT MAPS in MCE. After the first contact of the KOMPSAT spacecraft, initial orbit determination using ground based tracking data should be performed for the acquisition of the orbit. Although the KOMPSAT is planned to be directly inserted into the Sun-synchronous orbit of 685 km altitude, the orbit maneuvers are required for correcting the launch vehicle dispersion.

In this paper, the orbit determination and maneuver planning are introduced and simulated for the KOMPSAT spacecraft in LEOP operation. Initial orbit determination using short arc tracking data and definitive orbit determination using multiple passes tracking data are performed. Orbit maneuvers for the altitude correction and inclination correction are planned for achieving the final mission orbit of the KOMPSAT.

2. LEOP Tracking

The KOMPSAT will be directly injected into the Sun-synchronous orbit after 827.46 seconds from launch[2]. The initial state vector in Earth-Centered-Earth-Fixed(ECEF) coordinate is transferred from Orbital Sciences Corporation(OSC), the manufacturer of TAURUS launch vehicle. The ECEF state vector is transformed to Earth-Centered-Inertial(ECI) coordinate in True-Of-Date(TOD) system to predict the antenna pointing data in LEOP tracking stations.

Table 1 shows the nominal osculating injection orbital elements and the simulated orbital elements for the LEOP simulation. The simulated injection orbital elements are biased from nominal elements.

Table 1. Nominal and simulated osculating elements at injection time

	Nominal Injection (ECEF)		Nominal Injection (Keplerian)	Simulation (Keplerian)
Epoch	1999/11/03	Epoch	1999/11/03	1999/11/03
UTC	07:29:38.46	UTC	07:29:38.46	07:29:38.40
X(km)	-4560.7727	a (km)	7073.2345	7061.74020
Y(km)	-5396.1359	e (-)	0.00048144	0.00231871
Z(km)	-253.9565	i (deg)	98.1284	98.0235
Vx(km/s)	-1.0322057	Ω (deg)	204.6201	203.6195
Vy(km/s)	1.2230220	ω (deg)	193.4245	185.9493
Vz(km/s)	-7.4300557	M (deg)	348.6549	5.5705
		$\omega + M$	182.0794	191.5198

Currently, six S-band tracking stations are participated in KOMPSAT LEOP operation. Table 2 shows the positions of the tracking stations. McMurdo station covers the southern polar region of the orbit and the northern polar region will be covered by Poker Flat and Svalbard station. GSOC Weilheim station is directly linked with TaeJon station for the telemetry reception and command transmission.

Table 2. Tracking stations for KOMPSAT LEOP

Tracking Station	Longitude(deg)	Latitude(deg)	Altitude(m)
McMurdo	166.6671	-77.8391	153.053
Wallops	284.5250	37.9273	-19.732
Poker Flat	212.5409	65.1172	431.420
Svalbard	15.392840	78.2303	455.010
Weilheim	11.0850	47.8800	662.143
TaeJon	127.3547	36.3748	93.507

Fig. 1 shows the ground track of the KOMPSAT from injection to 1999/11/04 00:00:00. The coverage regions of the tracking stations are also shown in Fig. 1. The pass numbers are tagged based on the descending node passing. The first contact of the KOMPSAT will be occurred at McMurdo tracking station in Antartica within 15 minutes from injection. At that time, the KOMPSAT is in Sun light position. The second contact of the KOMPSAT will be occurred at GSOC Weilheim station after ascending node passing.

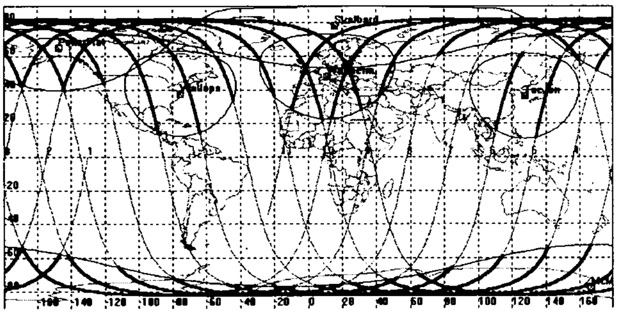

Fig. 1. KOMPSAT ground track and tracking station coverage

Fig. 2 shows the time-ordered contacts of the KOMPSAT at six LEOP tracking stations. The maximum elevation angles are shown for each contact. The tracking data collection, telemetry reception, and command transmission are performed during the contact time.

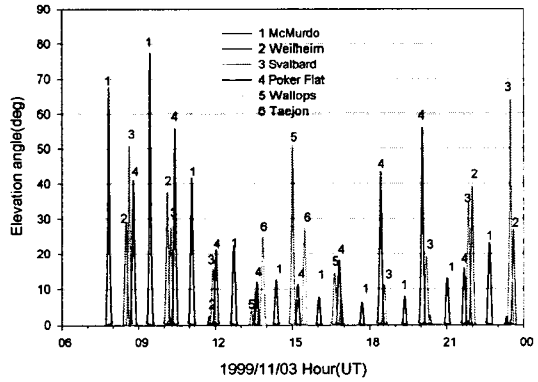

Fig. 2. Ground station contact time for the launch day

3. Orbit Determination

The tracking and orbit determination are crucial activities in LEOP operation. Two types of the orbit determination for the KOMPSAT are available for the normal mission[3]. The one uses the ground-based tracking data such as azimuth, elevation, range, and range rate. The other uses the GPS navigation solutions such as position and velocity vector. The GPS-based orbit determination will provide the better accuracy and this is the primary method for the KOMPSAT operation[4]. However, the GPS receiver on-board the KOMPSAT is off at the beginning of the LEOP. Only ground-based tracking data will be used for the orbit determination before switched on the GPS receiver.

Obit determination using ground-based tracking data

The ground-based orbit determination is performed for the first orbit of the KOMPSAT. Fig. 3 shows the first contacts at the four tracking stations. The tracking data from the four stations are simulated and used for the first ground-based orbit determination. The tracking data are generated every 5-second interval and the Gaussian errors are added to the tracking data for the simulation. Table 3 shows the tracking accuracy used in the simulation and Table 4 shows the number of tracking data points for the stations.

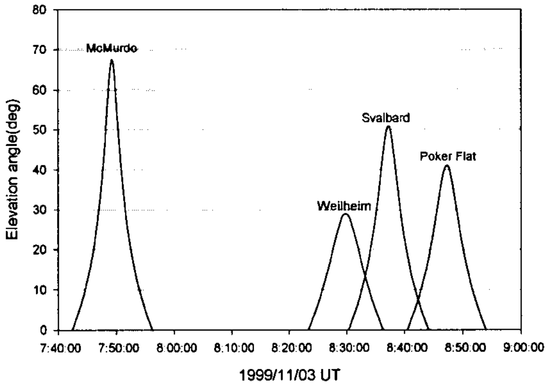

Fig. 3. Ground station contacts for the first orbit

Table 3. Tracking accuracy for the data type

Tracking data type	Accuracy
Azimuth and Elevation(deg)	0.1
Range(m)	30
Range rate(m/s)	0.1

Table 4. Number of data points for tracking stations

	McMurdo(1)	Weilheim(2)	Svalbard(3)	Poker Flat(4)
Az/El	136	124	136	132
Range	136	124	136	132
Range rate	136	124	136	132

The time-ordered orbit determinations are performed using the tracking data from four different stations in Table 4. At first, only the data from McMurdo station is used for orbit determination and then the next orbit determination is performed using the data from McMurdo and GSOC. The tracking data from Svalbard and Poker Flat are added respectively for the next orbit determination.

Table 5 shows the truth orbit and time-ordered orbit determination results for the ground-based tracking data. The more tracking data from different stations are added, the better solutions of orbit determination are obtained.

Table 5. Initial OD results using the ground-based tracking data set(Epoch:1999/11/03 07:42:30.0)

	Truth Orbit	1	1+2	1+2+3	1+2+3+4
Iterations	N/A	4	4	4	4
a (km)	7048.970	7049.008	7048.545	7048.968	7048.973
e (-)	0.001310	0.002154	0.001373	0.001311	0.001311
i (deg)	98.03093	98.02911	98.02317	98.03063	98.03092
Ω (deg)	203.6257	203.5933	203.6119	203.6176	203.6181
ω (deg)	143.8216	155.8870	144.3320	143.8632	143.8036
M (deg)	94.78650	82.62913	94.28758	94.76667	94.82653

$\omega + M$	238.6081	238.5162	238.6196	238.63	238.6302
RMS pos(m)	N/A	277.719	21.479	5.175	4.760
RMS vel(m/s)	N/A	0.612604	0.054748	0.010889	0.006649

Orbit determination using GPS navigation solutions

The GPS receiver is switched off during the launch time and it will be switched on within 4 ~ 5 days after launch. There are initial conditions for the GPS switched on. In order for the GPS to converge, the on-board ephemeris must be within 100 km and 100 m/s, the GPS constellation almanac must be less than 30 days old, and the On-Board Time estimate must be accurate to within 2 seconds of the correct UTC time[5]. After initialization, the GPS will write estimated ECEF position and velocity vector in every 32-second to the Mass Memory for downlink via telemetry. Also the flight software writes estimated ECI position and velocity vector in every 8-second interval to the Mass Memory for telemetry. Then the GPS-based orbit determination in ground is possible.

The GPS-based orbit determination simulation is performed using half-day of ECI position and velocity vector. The position and velocity vectors are propagated every 8-second interval from the known epoch and the Gaussian noises are added. The position errors of 120 m(2-sigma) and the velocity errors of 0.1 m/s(2-sigma) are used for the simulation. Table 6 shows the results of the orbit determination with the different data set.

Table 6. OD results using GPS navigation solutions (Epoch : 1999/11/08 00:00:00.0)

	Truth Orbit	Position & Velocity	Position Only	Velocity Only
Iterations	N/A	3	3	3
a (km)	7050.282	7050.281	7050.281	7050.281
e (-)	0.0030832	0.0030833	0.0030833	0.0030835
i (deg)	98.03288	98.03289	98.03289	98.03287
Ω (deg)	208.19223	208.19223	208.19223	208.19224
ω (deg)	180.03059	180.03075	180.03039	180.03969
M (deg)	234.73671	234.73589	234.73625	234.72684
$\omega + M$	54.7673	54.76664	54.76664	54.76653
RMS pos(m)	N/A	2.328	2.338	21.397
RMS vel(m/s)	N/A	0.002250	0.002261	0.01926

4. Orbit Maneuver

The orbit maneuver should be performed for adjusting the launch dispersions. The TAURUS launch dispersions and its effect on the first ground contact are analyzed by Monte Carlo simulation[6]. Table 7 shows the mean orbital elements that are derived from the osculating orbital elements at injection time in Table 1. The simulated orbital elements are defined such that 10 km lower than nominal altitude, 0.1 degrees smaller inclination, and 1 degree smaller right ascension of ascending node. The differences between the nominal injection and simulation are also shown in Table 7. The Local Time of Ascending Node(LTAN) for the simulated orbital elements are 4 minutes faster than that of nominal elements. The orbit raising maneuvers and inclination change maneuvers should be required for achieving the nominal orbit.

Table 7. Nominal and simulated mean elements at injection time

Mean Elements	Nominal (Keplerian)	Simulation (Keplerian)	Differences
Epoch	1999/11/03	1999/11/03	
UTC	07:29:38.46	07:29:38.40	0.06 sec
a (km)	7064.111	7053.2612	10.8498
e (-)	0.0000739	0.0019994	-0.00193
i (deg)	98.1330	98.02755	0.10545
Ω (deg)	204.6185	203.6162	1.0023
ω (deg)	232.7372	179.9952	52.742
M (deg)	309.3404	11.5072	297.8332
$\omega + M$ (deg)	182.0278	191.502	-9.4742
LTAN	10:49:59.2	10:45:58.6	4 min

There are many scenarios of the orbit maneuvers according to the launch dispersions. A straightforward maneuver scenario is planned in this study. Following the initial activation and checkout plan, the first thruster firing for the orbit correction can be performed after the 8 days of initial KOMSPAT bus function checking out[5]. At first, a small calibration burn is performed for checking out the performance of the thrusters. In this study, an orbit-raising maneuver of 300 meters is executed as the first in-plane maneuver when the KOMPSAT is in contact with TaeJon station. Next, an inclination maneuver of 0.1 degrees is performed for achieving the nominal inclination, as the first out-of-plane maneuver. A large in-plane maneuver of 9.7 km orbit-raising is executed for achieving the nominal KOMPSAT altitude. The 4th and 5th maneuvers are performed as two-part maneuver for achieving the frozen orbit[7]. The frozen orbit is not mandatory for the KOMPSAT mission whereas it has its own merits for the satellite mission operation. The correction of the Right Ascension of Ascending Node(RAAN) is not performed since the LTAN is within the required range of 10:50 +10/-15 minutes. The direct change of the RAAN is required large amount of fuel, same as inclination maneuver. Table 8 shows the summary of the maneuvers.

Fig. 3 shows the osculating inclination change in the 2nd maneuver in Table 8. The osculating inclinations with maneuver and without maneuver are shown. Fig. 4 shows the osculating semi-major axis changed in the 3rd maneuver in Table 8.

The final osculating and mean orbital elements achieved after the executions of five maneuvers in this study are shown in Table 9.

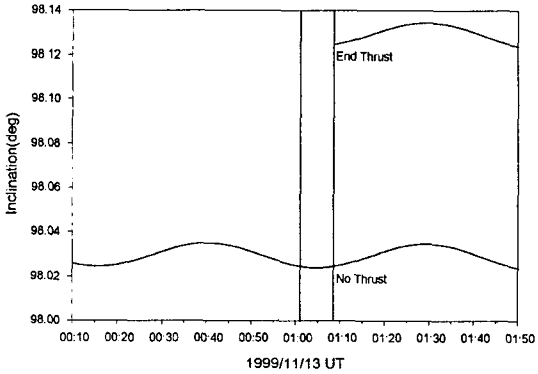

Fig. 3. Inclination change in the 2nd maneuver

Table 8. Orbit maneuver summary

Maneuver Number	1st maneuver	2nd maneuver	3rd maneuver	4th maneuver	5th maneuver
Type	In-plane	Out-of-plane	In-plane	In-plane	In-plane*
Target	Orbit raising 0.3 km	Inclination change 0.1 degrees	Orbit raising 9.7 km	Frozen orbit e and ω	Frozen orbit e and ω
Ignition time option	mean perigee	argument of latitude=0	mean apogee	argument of latitude = 22.572 deg	argument of latitude = 202.572 deg
Burn start time(UTC)	1999/11/12 14:18:02.000	1999/11/13 01:00:57.0	1999/11/14 01:30:47.0	1999/11/15 00:46:06.0	1999/11/15 01:35:19.0
Delta-V(m/s)	0.16126	12.68414	5.1110	2.3310	-2.35454
Burn duration(sec)	5.2	451.4	168.2	74.3	75.0
Effective thrust(N)	14.669	14.669	14.669	14.669	14.669
Isp(sec)	214.414	214.414	214.414	214.414	214.414
Used fuel(Kg)	0.0363	2.97	1.150	0.515	0.5196
Attitude Euler angle (LVLH:R,P,Y)	0, 90, 0	90, 0, 0	0, 90, 0	0, 90, 0	0, -86.6*, 0
TaeJon contact time	14:10:02 ~ 14:20:51	01:09:59 ~ 01:20:39	01:44:46 ~ 01:56:10	00:46:51 ~ 00:56:21	02:23:29 ~ 02:34:18

*pitch angle is not 90 degrees

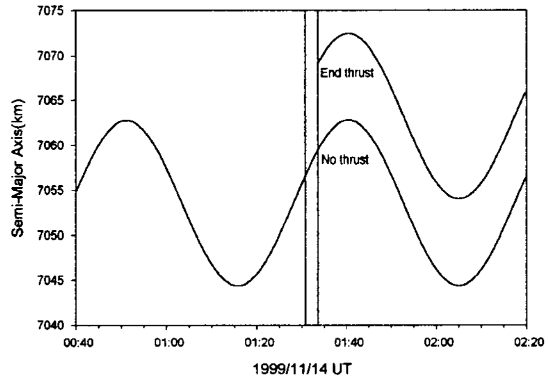

Fig. 4. Semi-major axis change in the 3rd maneuver

Table 9. Final orbit elements(Epoch:1999/11/15 01:36:34)

Orbital Elements	Osculating Orbit	Mean Orbit
a (km)	7069.097	7063.145
e (-)	0.000853615	0.001182119
i (deg)	98.1253	98.1288
Ω (deg)	215.1087	215.1047
ω (deg)	85.9646	90.1506
M (deg)	118.6586	144.4356

The orbit maintenance maneuvers should be performed during the normal mission life of the KOMPSAT. The altitude of the KOMPSAT is continuously decreased due to the air drag and it causes the drift of the ground track[8]. The inclination of the KOMPSAT is decreased due to the perturbation of the Sun and it causes the LTAN earlier and earlier. The biased target inclination is recommended for reducing the variation of the LTAN such that initial inclination is set bigger than that of nominal value[9, 10].

5. Conclusions

The orbit determination and orbit maneuver simulations have been performed for the KOMPSAT spacecraft in launch and early orbit phase operation. The simulations show that the flight dynamics support using MAPS is crucial for the successful KOMPSAT LEOP operations. Many possible scenarios according to the launch dispersions should be prepared for the mission success.

References

[1] ETRI, KOMPSAT MCE System Specification, SAT-TTCR-961008-2554, 1996

[2] OSC, TAURUS T4 Interim Mission Analysis, TD-2734, 1999

[3] B.-S. Lee, J.-S. Lee, Y.-K. Kim, and J. W. Eun, “Orbit Determination Simulations for the KOMPSAT Spacecraft Using On-Board GPS Navigation Solutions and Single Ground Station Tracking Data”, J of KSAS, Vol. 26, No. 1, pp. 99-110, 1998

[4] J.-S. Lee and B.-S. Lee, “Orbit Determination Error Analysis for the KOMPSAT”, J. Astron. Space Sci., Vol. 15, No. 2, pp. 437-447, 1998

[5] KARI, KOMPSAT Initial Activation and Checkout Plan, Rev.06/30/99, 1999

[6] B.-S. Lee and J.-S. Lee, “Monte Carlo Analysis for First Acquisition and Tracking of the KOMPSAT Spacecraft”, J. Astron. Space Sci., Vol. 15, No. 2, pp. 417-425, 1998

[7] B.-S. Lee and J.-S. Lee, “Selection of Initial Frozen Orbit Eccentricity and Evolution of the Orbit Due to Perturbations”, J. of KSAS, Vol. 25, No.1, pp. 126-132, 1997

[8] B.-S. Lee and J.-S. Lee, “Ground Track Maintenance Maneuver Simulations for the KOMPSAT Spacecraft”, J. Astron. Space Sci., Vol. 15, No. 1, pp. 197-208, 1998

[9] C.-C. Chao and R. G. Gist, “The Optimization of Initial Inclination for a Desired Sun-Synchronous Orbit”, AAS/AIAA Astrodynamics Specialist Conference, AAS 95-333, Aug. 14-17, 1995

[10] D. Folta and L. Kraft, “Methodology for the Passive Control of Orbital Inclination and Mean Local Time to Meet Sun-Synchronous Orbit Requirements”, AAS 92-143, 1992