Flight Dynamics Operation for KOMPSAT-5 LEOP

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The KOMPSAT-5 is the first synthetic aperture radar satellite in South Korea, equipped with a single frequency GPS receiver and a dual frequency GPS receiver. The KOMPSAT-5 will be launched in the middle of 2012 by DNEPR launcher, and its mission orbit is 550km sun-synchronous dawn-dusk orbit with a 28 day ground repeat cycle. The main mission of KOMPSAT-5 supports geographic information system, ocean and land management, and disaster and environmental monitoring. The SAR payload has three operation modes including high-resolution, standard, and wide-swath, and its image resolutions in dedicated swaths are 1 m, 3 m, and 20 m, respectively. This paper was initially intended to describe the whole operational results from KOMPSAT-5 LEOP. However, the preparations for LEOP activities are mainly dealt with due to the unexpected launch delay. In this paper, pre-launch activities are summarized including the system functional review and the operational validation test for flight dynamics system of KOMPSAT-5. And, the sequence of events with nominal operational timeline for flight dynamics activities is defined for initial orbit acquisition and initial orbit determination. In addition, the results of operational validation test, which is intended to check and validate the readiness of flight dynamics system and operational procedure, are summarized.

I. Introduction

KOMPSAT-5(Korea Multi-purpose Satellite-5) is the first Korean SAR mission satellite, which will be launched by Dnepr launcher from Yasny in 2012. The KOMPSAT-5 satellite will be delivered to low Earth orbit for all-weather day-night monitoring of Korean peninsula. Figure 1 represents the flying image of KOMPSAT-5. The primary mission of KOMPSAT-5 system is to provide high resolution mode SAR image of 1 m (5 km swath-width) resolution, standard mode SAR image of 3 m resolution (30 km swath-width), and wide swath mode SAR image of 20 m resolution (100 km swath-width) with viewing condition of the incidence angle of 45 degrees, using COSI (COrea SAR Instrument) payload, for meeting its mission objectives[1]. For this, there are 50 beams including 31 beams for high resolution mode and 19 beams for Standard mode. And, the wide swath mode uses the combination of 19 beams of standard mode. The nominal attitude mode of KOMPSAT-5 is right looking mode, and it can be changed to left looking mode, if necessary. Figure 2 depicts the basic concept of multiple imaging modes of

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KOMPSAT-5 operations. The main mission objectives of KOMPSAT-5 system are to provide the following applications (GOLDEN mission):

- Geographic Information System
- Ocean Management
- Land Management
- Disaster Monitoring
- ENvironment Monitoring

The secondary mission of KOMPSAT-5 is to generate the atmospheric sounding profile and support radio occultation science using AOPOD (Atmospheric Occultation and Precision Orbit Determination) secondary payload which is composed of dual frequency GPS receiver and Laser Retro Reflector Array (LRRA).

Figure 1. Flying Image of KOMPSAT-5 (Artist View)

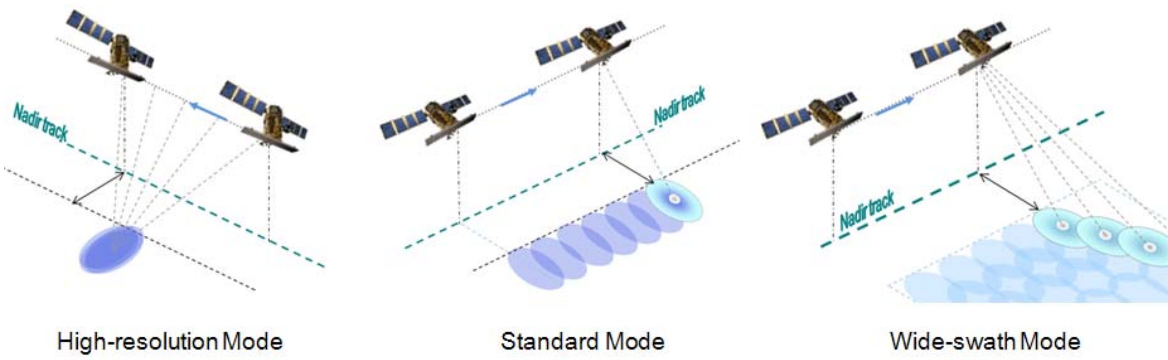

Figure 2. Multiple Imaging Modes of KOMPSAT-5 SAR Operation

The KOMPSAT-5 system consists of space segment, ground segment, launch segment, and various external interfaces including additional external ground stations to support launch and early orbit phase and normal operation phase. Figure 3 depicts the KOMPSAT-5 system overall architecture. The ground segment consists of a ground facility for transmitting commands for the satellite operation, receiving and processing both telemetry and payload observation data to provide level products to the user. The ground segment in the KOMPSAT-5 system, which is referred as KGS(KOMPSAT-5 Ground Segment), is designed to consist of 3 elements of the MCE (Mission Control Element), the IRPE (Image Reception and Processing Element), and the CVE (Calibration and Validation Element). The mission control element provides the mission planning, satellite command, and control functions that allow the operators to perform the mission and maintain the health of the satellite. The mission control element provides the S-band command and telemetry communications interface to the satellite and the necessary functions to operate the satellite. The flight dynamics functions in mission control element provide orbit data which is essential for mission operations and image processing. The image reception and processing element provides the capability to receive and store KOMPSAT-5 SAR collected data, interface with the mission control element in order to support image collection planning, generate standard and value added SAR imagery products, and distribute imagery products to users. The calibration and validation element provides the capability to reduce to the maximum extent of any deviation from the nominal conditions of any parameter which affect the SAR performance and to know and reduce any deviation to a residual value inside the accuracy limits defined in the design phase of the instrument and consequently to allow a reassessment of performance.

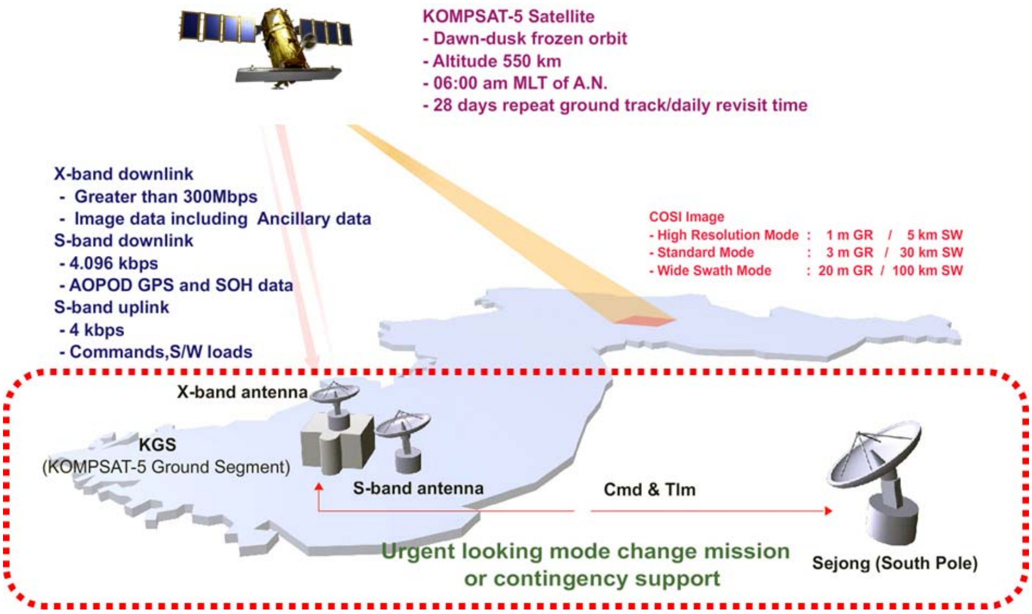

Figure 3. System Architecture of KOMPSAT-5

The designed mission orbit for the KOMPSAT-5 is a repeat ground track frozen dawn-dusk orbit with 28 days repeat ground track period at normal altitude 550 km. The Mean Local Time of Ascending is 06:00 A.M. The orbital characteristics of KOMPSAT-5 mission orbit are summarized in Table 1.

Table 1. Mission Orbit of KOMPSAT-5

Orbital Elements	Value
Altitude	550 km
Inclination	97.6 deg.
Eccentricity	0.001 (Nearly Circular)
Orbital Period	95.78 min.
Local Time of Ascending Node	06:00 A.M.
Orbital Characteristics	Dawn-dusk frozen orbit
Ground-track Revisit	28 days (with 421 revolutions)
Ground-track Maintenance	+/- 2 km w.r.t the reference longitude

II. Flight Dynamics System for KOMPSAT-5 Operations

Flight dynamics operations is one of the core activities in the satellite mission operations for comprehensive orbital analysis and mission planning support as well as orbit data provision for image processing enhancement. For this, flight dynamics system provides the capability to analyze the satellite orbit and attitude in order to support mission operations. Flight dynamics team determines the satellite orbit by using satellite on-board GPS navigation solutions data as well as ground-based antenna tracking and ranging data. And, precise orbit determination using GPS raw data, i.e. pseudo-range and carrier phase measurement, is also carried out on a routine basis. The precise orbit ephemeris is distributed to the users for image processing. In addition, flight dynamics team generates orbit maneuver plan to maintain the satellite orbit within the pre-defined boundaries. Onboard fuel estimation is one of the tasks by flight dynamics team. Figure 4 represents the functional architecture and internal/external interface of KOMPSAT-5 flight dynamics subsystem in mission control element.

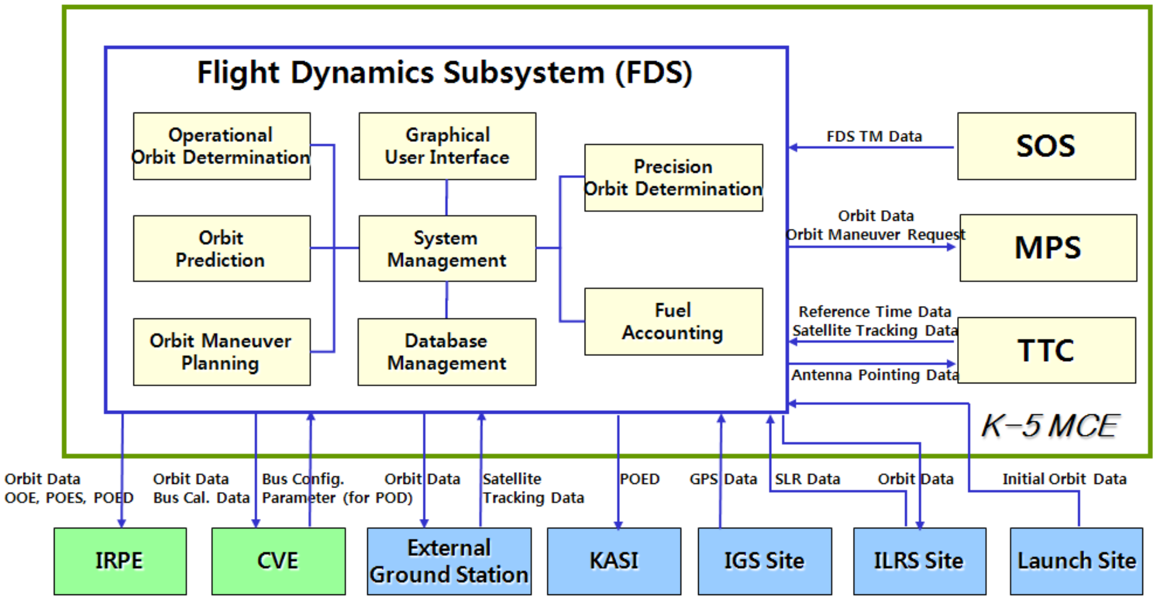

Figure 4. Functional Architecture and Internal/External Interface of FDS

The key functions supported by flight dynamics system are summarized as follows:

<u>Operational Orbit Determination</u>

- Orbit determination using ground based tracking(azimuth/elevation) and ranging data
- Orbit determination using GPS navigation solution data
- Estimation scheme : batch weighted least square method
- Dynamic model: earth gravity, luni-solar gravity, air drag, solar radiation pressure

<u>Orbit Prediction</u>

- Numerical integration : Adams-Cowell predictor-corrector
- Dynamic model: earth gravity, luni-solar gravity, air drag, solar radiation pressure
- Orbit ephemeris generation (TOD, J2000, ECEF, Keplerian)
- Ground track data generation
- Osculating orbit to mean orbit conversion and mean orbit propagation

<u>Orbit Maneuver Planning and Ground Track Maintenance Maneuver Planning</u>

- Targeting mode : in-plane, out-of-plane, combined

- Targeting method : coarse, fine, thruster calibration
- Calculation of the desired delta v for the user specified maneuver goal
- Support the post orbit maneuver evaluations
- Ground track maintenance to keep within +/- 2 km of reference longitude

Precise Orbit Determination

- Provide GPS raw data pre-processing: clock error, cycle slip and bad point data detection
- Double differential data generation
- Estimation scheme: least square batch filter
- Dynamic model: earth gravity, luni-solar gravity, air drag, solar radiation pressure, solid earth and ocean tide, dynamic polar motion, relativity effect & general empirical acceleration
- Precise orbit ephemeris generation for imaging processing

Validation of Precise Orbit Determination using SLR data

- Generate precise orbit ephemeris by using SLR data[2]
- Provide SLR data pre-processing
- Extract range data from SLR NP data acquired by ILRS site
- Using same BLSE algorithm in precise orbit determination

Fuel Accounting

- Calculate the propellant mass of satellite
- Provide two types of calculation method: book-keeping method and PVT method
- Stores/Updates the propellant mass to spacecraft database file

III. LEOP Support by Flight Dynamics System

The main activities of LEOP include the initial orbit acquisition, initial orbit determination, and maneuver execution for target (mission) orbit acquisition[3]. The KOMPSAT-5 will be launched into the target orbit by Dnepr launch vehicle, which is expected to have an altitude error of +/-10km and inclination error of +/-0.05 degree. The initial ground track of the spacecraft is shown in Figure 5. LEOP S-band ground stations were selected to maximize the visibility between satellite and ground. The pole-to-pole ground network allows the sufficient communication availability. Table 2 represents the position information of the individual station to be utilized.

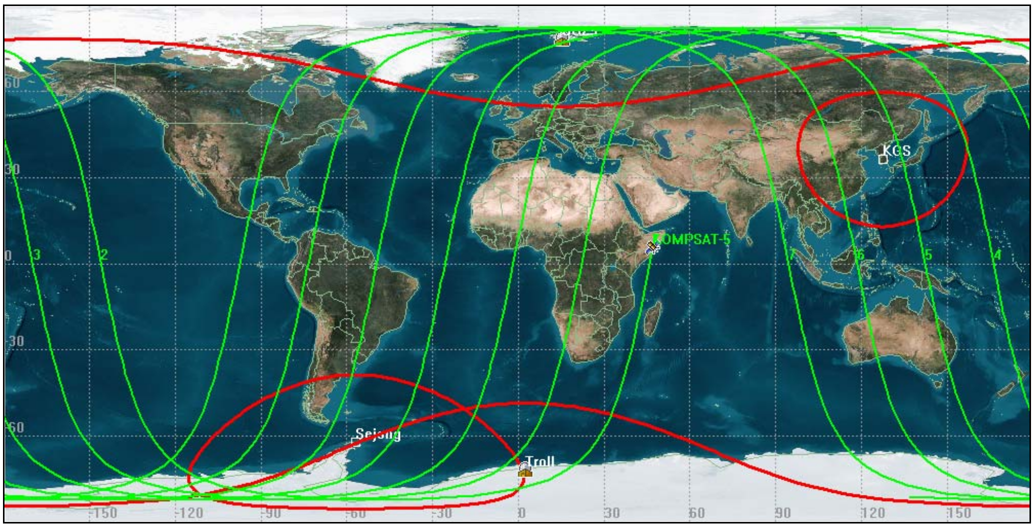

Figure 5. Expected Initial Ground Track of KOMPSAT-5 (Starting from Separation Point)

Table 2. Position Information of Ground Station for KOMPSAT-5 LEOP

TTC Station	Latitude (deg.)	Longitude (deg.)	Remark
SG6 (Svalbard)	+78.2	+15.40	KSAT, Norway
TR1 (Troll)	-72.0	+2.500	KSAT, Antarctica
KGS	+36.4	+127.4	KARI, South Korea
Sejong	-62.2	-56.80	KARI, Antarctica

For initial orbit acquisition, ground based measurements are very essential for initial orbit determination. The first contact has to rely only on pre-defined orbit information. After ground contact with satellite, the angle tracking data and ranging data should be processed to estimate the position of satellite. Table 3 summarizes the sequence of event of flight dynamics activities. The timeline of orbit data processing, validation, and update is very tight. Orbit consistency check will be carried out with separation vector from launcher as well as archived ground tracking data. Flight dynamics team has to decide the correct orbit information based on the analysis results. Additionally, flight dynamics team is going to submit the orbital data request (USSTRATCOM ODR[4]) for launch support of KOMPSAT-5. If it is approved, another source from world-wide space surveillance network can be obtained, which will be helpful initial orbit confirmation.

Table 3. Sequence of Event for Initial Orbit Acquisition

Activities	Relative Time from Launch	Relative Time from Separation	Remark
Launch	L + 00:00:00	N/A	-Launch window variation: 23 sec.
Separation	L + 00:15:22	S + 00:00:00	-Flight Time = 921 sec.
1st Contact	L + 00:31:04	S + 00:15:42	-Troll, Contact Duration: 721 sec.
1st Orbit Determination	L + 01:08:05	S + 00:52:43	-Data Processing Time: 20 min. -Orbit Data Update for Next Contact
2nd Contact	L + 01:26:03	S + 01:10:41	-SGS, Contact Duration: 673 sec.
2nd Orbit Determination	L + 02:02:17	S + 01:46:55	-Data Processing Time: 20 min. -Orbit Data Update for Next Contact
3rd Contact	L + 02:05:34	S + 01:50:12	-SGS, Contact Duration: 734 sec.
3rd Orbit Determination	L + 02:30:34	S + 02:15:12	-Data Processing Time: 20 min. -Orbit Data Update for Next Contact
Separation Vector Reception	L + 02:45:22	S + 02:30:00	-From Launch Vehicle
Orbit Consistency Check	L + 03:15:22	S + 03:00:00	-Input 1: Archived tracking data -Input 2: Separation Vector

After the initial check-out of spacecraft and orbit confirmation, orbit correction maneuver for mission orbit acquisition will be carried out to compensate the deviation of injection orbit from mission orbit. Prior to real maneuver, a test burn should be executed in order to characterize the on-orbit performance and validate the ground procedure and calculations. A test burn consists of three different steps as follows:

- Attitude Maneuver in direction of pitch 90 deg. or -90 deg. (to check the induced orbit change)
- Test burn for 30 seconds with attitude maneuvering in Del-V mode (thruster-based attitude control)
- Test burn for 30 seconds with attitude maneuvering in Fine Del-V mode (wheel-based attitude control)
- Orbit reconstruction and evaluation for maneuver performance

After the completion of a test burn, a large amount of del-V will be applied to achieve the mission of KOMPSAT-5, depending on injection orbit by launch vehicle and calibration imaging purpose[5].

IV. Operational Validation for Mission Operations

Although the various tests for flight dynamics system had been successfully completed during the software development phase, the software bugs were found and fixed. In addition, some functions were updated based on the operational needs and design document change. In order to check the current status of flight dynamics system, and to verify the functions in operational point of view, the operational validation test was proposed and carried out. Test items were defined considering the key functions for mission operations. Table 4 summarizes the test items and input/output data. Flight data from KOMPSAT-2 and GRACE satellite[6] were used as many as possible, in order to consider real situation. And, output data were compared with those from other software such as COTS flight dynamics software - STK[7] and MicroCosm[8]. As a result of test, 10 test record sheets were issued during test, and 6 change requests were generated for software modification. After upgrading the software based on the test result, all of test record sheets and change requests were finally closed.

Table 4. Test Items and Input-Output Data for Operational Validation Test

Test ID	Test Title	Input	Output
FDS-OVT-1	Operational orbit determination using GPS navigation solution	- GPS Data(note-1) - Initial Orbit	- OD Report - OOE Data(note-2) - Estimated Orbit - TLE
FDS-OVT-2	Operational orbit determination using ground tracking data	- Tracking Data - Initial Orbit	
FDS-OVT-3	Precise orbit determination using single frequency GPS receiver	- POD Data(note-3) - Initial Orbit - IGS Data(note-4)	- POD Report - POE Data(note-6) - Estimated Orbit - TLE
FDS-OVT-4	Precise orbit determination using double frequency GPS receiver	- POD Data(note-5) - Initial Orbit - IGS Data	
FDS-OVT-5	Orbit prediction with the determined initial condition	- Initial Orbit	- OP Report - Predicted Orbit
FDS-OVT-6	Validation of precise orbit determination with satellite laser range data	- POE Data - SLR Data(note-7)	- Residual
FDS-OVT-7	Consolidated prediction file generation	- Predicted Orbit	- CPF Data
FDS-OVT-8	Orbit maneuver planning and evaluation	- Initial Orbit - Target Orbit	- Del_V - Burn Duration
FDS-OVT-9	Fuel estimation	- Telemetry(note-8)	- Fuel Mass

(note-1) Flight data of KOMPSAT-2 (GPS Navigation solution in ECEF)
(note-2) Operational orbit ephemeris (in ECEF, TOD, J2000 coordinate)
(note-3) Flight data of KOMPSAT-2 (TOPSTAR-3000, Single frequency GPS receiver)
(note-4) International GNSS Data (16 Stations are selected for test purpose)
(note-5) Flight data of GRACE satellite (Double frequency GPS receiver)
(note-6) Precise orbit ephemeris (in ECEF, TOD, J2000 coordinate)
(note-7) Tracking data of GRACE satellite (Satellite Laser Ranging Data)
(note-8) Telemetry of KOMPSAT-2

V. Conclusion

This paper introduces the first synthetic aperture radar satellite of South Korea, KOMPSAT-5. And, the flight dynamics system and its related tasks for LEOP support are described. Flight dynamics operations is one of the core activities in the satellite mission operations for comprehensive orbital analysis and mission planning support as well as orbit data provision for communication between the ground and satellite. The main functions of flight dynamics system for LEOP support include the initial orbit acquisition, initial orbit determination, and maneuver execution for mission orbit acquisition. In this paper, pre-launch activities are summarized including the system functional review and the operational validation test for flight dynamics system of KOMPSAT-5. In order to prepare LEOP activities, the sequence of events to be carried out by flight dynamics team is also presented along with expected timeline. In addition, the results of operational validation test, which is intended to check and validate the readiness of flight dynamics system and operational procedure, are summarized. With these activities included in this paper, flight dynamics team is ready for LEOP of KOMPSAT-5.

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