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KOMPSAT SATELLITE LAUNCH AND DEPLOYMENT OPERATIONS

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ABSTRACT

In this paper, KOMPSAT satellite launch and deployment operations are discussed. The U.S. Taurus launch vehicle delivers KOMPSAT satellite into the mission orbit directly. Launch and deployment operations is monitored and controlled by several international ground stations including Korean Ground Station (KGS). After separation from launch vehicle, KOMPSAT spacecraft deploys solar array by on-board autonomous stored commands without ground intervention and stabilizes the satellite such that solar arrays point to the sun. Autonomous ground communication is designed for KOMPSAT for the early orbit ground contact. KOMPSAT spacecraft has capability of handling contingency situation by on-board fault management design to retry deployment sequence.

1.INTRODUCTION

The KOMPSAT (Korea Multi-Purpose Satellite) System consists of the KOMPSAT satellite including spacecraft bus and multiple payloads that are EOC (Electro-Optical Camera), LRC (Low Resolution Camera) and SPS (Science Physics Sensor), a KOMPSAT Ground Station (KGS), and the Taurus Launch Service to place the satellite into orbit. The KOMPSAT mission is to perform cartography of the Korean Peninsula, to collect large scale multi-spectral images of the ocean and coastal areas to support biological oceanography, and to accommodate scientific instruments to perform space environments measurements. The system undergoes several mission phases during the course of launch, deployment, initial activation and checkout, and mission operations. Among them, launch and deployment operation is one of the most important activities for the KOMPSAT system because hand-over to the normal mission operation can not be done without going through successful launch and deployment operation process.

The system performance during early orbit phase may deviate from what designers have expected as done by ground test. Those deviations must be monitored by nearby ground station as quickly as possible and must be corrected or calibrated before jeopardizing the system into more fatal situation. Through space program history, failure occurred during launch and deployment operation has been more fatal than that occurred during normal operation period and many of cases had not been recovered due to failure of appropriate ground station intervention. In this paper, KOMPSAT launch and deployment operations are discussed.

2. LAUNCH OPERATION

KOMPSAT is scheduled for launch in December of 1999 at the Vandenberg Air Force Base (VAFB) located in California, United State (Baek, 1999a). KOMPSAT satellite will be mated with the Taurus launch vehicle that will be launched into a sun-synchronous, low earth orbit. The launch vehicle will deliver the satellite directly into a 685-km altitude mission orbit with a 98.13-degree orbit inclination. The satellite is configured in the launch and ascent state during this phase. KOMPSAT on-board computers, sensors, and other on-board equipment are powered-on and some allowed to be operated, while the actuators are inhibited from operation during the phase.

The satellite will be controlled by VAFB ground launch control facility until lift-off. About 14 minutes after lift-off there will be a KOMPSAT satellite separation from Taurus Vehicle. U.S. McMurdo Ground Station in the first contact monitors the launch vehicle and the satellite 15 minutes after the separation from launch vehicle. During this time, launch vehicle separation state vector and basic KOMPSAT state of health telemetry data is downlinked and relayed to KGS for future orbit propagation determination and mission planning for the upcoming contact.

About 58 minutes after separation, German GSOC Ground Station controls KOMPSAT satellite. During this contact, major checkout is whether solar array deployment is successful and solar array is pointing the sun with stable margin. Battery state of charge and other key hardware and software function also are verified. About 2 hours and 35 minutes, there is a second GSOC Ground Station contact. During this time, spacecraft sun pointing stability trend analysis is performed and major spacecraft subsystem's state of health is checked. About 6 hours and 19 minutes, there is a first KGS contact. Since the contact is being done during the eclipse time, there will be a telemetry reception and trend analysis unless satellite is in the contingency situation. Also, there will be NASA ground stations support as required by KGS so that KGS can access KOMPSAT as frequently as possible and prepare for the possible system performance deviation or contingency situation as quickly as possible. During launch and deployment phase, GSOC and KGS will control KOMPSAT as full time basis with the NASA ground stations support as required. Table 1 shows KOMPSAT satellite nominal Taurus launch timeline from lift-off to separation of KOMPSAT satellite extracted from Taurus launch manual for KOMPSAT.

Figure 1 shows KOMPSAT ground tracks of Day 1 with the location of McMurdo, GSOC and KGS. McMurdo ground station covers the Southland area, GSOC is located in the Germany and KGS is located in the Republic of Korea.

As seen in Figure 1, in most of time, there will be nominal 2 contacts during daytime and 2 contacts during nighttime. Table 2 and Table 3 describe Day 1 GSOC and KGS contact timeline.

3. DEPLOYMENT OPERATION

After separation from launch vehicle, KOMPSAT performs the following sequences for deployment operation. Deployment sequences are performed with the autonomous on-board stored

Table 1. Nominal launch timeline (OSC 1996).

Event #	Event Description	Time (Sec)	Interval (Sec)	Altitude (Km)	Latitude (Deg)	Longitude (Deg)	Range (Km)
1	Stage 0 Ignition	0.0	82.3	0.0	34.74	-120.62	0
2	Stage 0 Burnout: Stage 1 Ignition	82.3	76.1	43.1	34.25	-120.87	73.3
3	Stage 1 Burnout	158.4	10.0	133.9	32.30	-121.63	319.1
4	Stage 1 Separation	168.4	2.1	147.8	31.92	-121.75	365.0
5	Stage 2 Ignition	170.5	3.3	150.6	31.84	-121.78	374.5
6	Fairing Separation	173.8	74.7	154.9	31.72	-121.82	389.4
7	Stage 2 Burnout	248.5	329.6	260.1	28.29	-122.80	803.9
8	VAFB Loss of Signal (LOS)	578.1	176.8	616.4	11.14	-126.96	2865.0
9	Stage 2 Separation	754.9	10.0	681.9	2.45	-128.95	
10	Stage 3 Ignition	764.9	69.0	683.0	1.96	-129.06	
11	Stage 3 Burnout	833.9	65.0	685.2	-1.81	-129.88	
12	Separate KOMPSAT	898.9	60.0	685.2	-5.75	-130.72	

commands without ground station intervention.

- Spacecraft starts deployment sequences with on-board computers, configures the subsystems appropriately for the deployment activities. If the separation timer times out, the on-board computer halts itself, causing the spacecraft power control unit to apply power to the redundant computers, which subsequently repeat the solar array deployment sequence.
- Spacecraft automatically deploys the solar arrays while the spacecraft attitude is uncontrolled.
- Spacecraft automatically performs the gyro selection logic test. If the test fails, the on-board computer halts itself, causing the spacecraft power control unit to apply power to the redundant computers that subsequently repeat the solar array deployment sequence. If the test fails in

Table 2. Day 1 GSOC contact timeline.

Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)	Pass
1	99-12-20 8:27:30	99-12-20 8:37:51	621	1
2	99-12-20 10:04:32	99-12-20 10:15:32	659	2
3	99-12-20 21:58:11	99-12-20 22:09:12	662	9
4	99-12-20 23:35:54	99-12-20 23:46:09	615	10

Note: Contact time based on Dec. 20, 1999. The data may vary for the actual launch date and window.

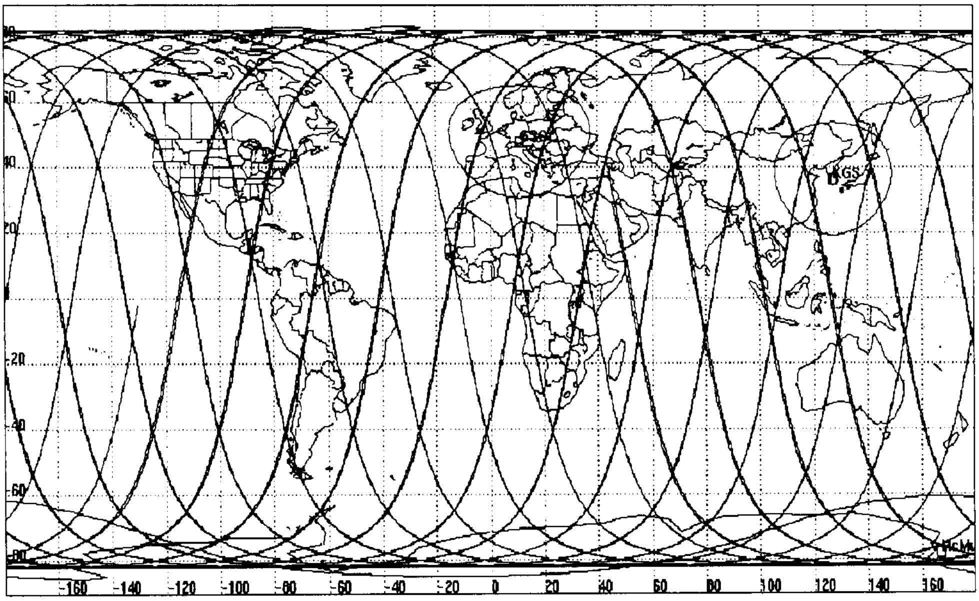


Figure 1. KOMPSAT ground track and McMurdo, GSOC and KGS.

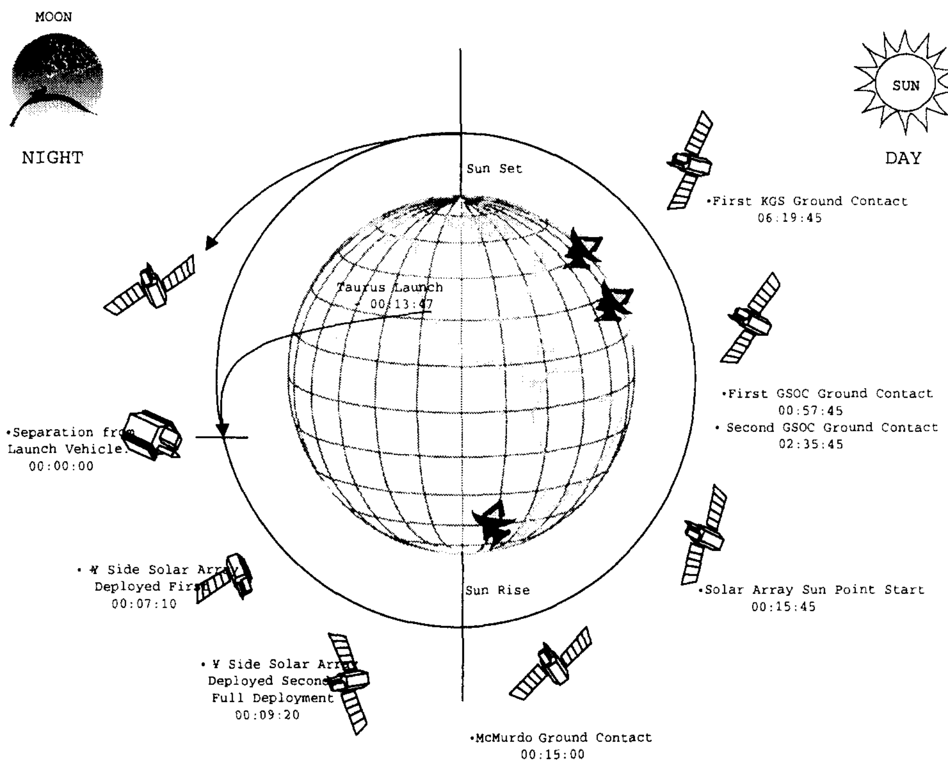
the redundant deployment sequences, spacecraft disables attitude control and waits for ground control.

- Spacecraft automatically nulls all existing spacecraft separation rates.
- Spacecraft automatically performs a check to verify solar array deployment. If the test passes, the solar array deployment relay and the launch memory relay are closed. If the test fails, the relays are left open and the on-board computer halts itself, causing the spacecraft power control unit to apply power to the redundant computers, which subsequently repeat the solar array deployment sequence. If the test fails in the redundant deployment sequences, spacecraft disables attitude control and waits for ground control.
- Spacecraft automatically enables attitude control law outputs, allowing the spacecraft to perform a sun acquisition maneuver.

Table 3. Day 1 KGS contact timeline.

Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)	Pass
1	99-12-20 13:50:09	99-12-20 13:57:54	465	4
2	99-12-20 15:27:25	99-12-20 15:35:26	482	5

Note: Contact time based on Nov. 03, 1999. The data may vary for the actual launch date and window.



Deployment Phase Timeline

Figure 2. KOMPSAT deployment major activity.

- After performing a sun acquisition the spacecraft maintains sun-pointing attitude.
- After successful solar array deployment, spacecraft performs the first 4 autonomous ground communications with McMurdo, GSOC (2 times) and KGS.

Figure 2 describes major activities conducted after separation from launch vehicle. Note that the timeline in the Figure 2 may vary before launch.

Deployment operation to activate and configure all necessary equipment, deploy the solar arrays, enter contingency state, and maintain a sun-pointed attitude are accomplished using on-board Relative Time Command Sequences (RTCS). A set of RTCS is stored in the stored command sequence area of the KOMPSAT on-board computer Read Only Memory (ROM). A RTCS consists of a sequence of spacecraft commands with relative time delays between each command. Upon RTCS activation,

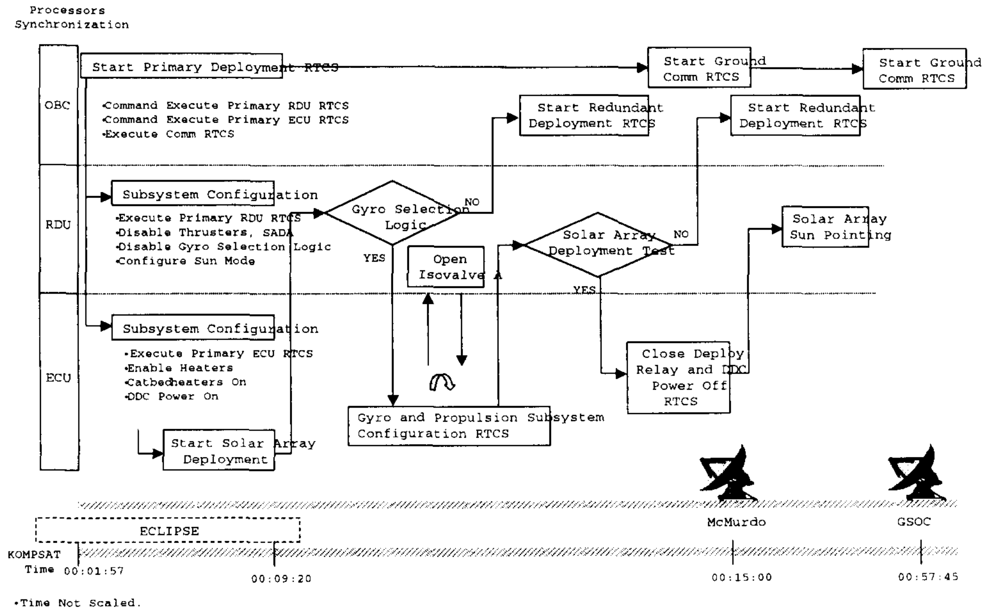


Figure 3. KOMPSAT deployment RTCS execution flow.

the commands are sequentially executed, observing the specified inter-command delays. Figure 3 describes RTCS execution sequence flow between KOMPSAT on-board computers (OBC, RDU, and ECU). It can be seen from the Figure 3 that each computer contains its own RTCSs and can be executed and called by other RTCS or flight software logic such as gyro selection logic and solar array deployment test logic in the sense of end-to-end.

Based on the KOMPSAT deployment operation concept, deployment RTCS has been designed to meet the operation requirement. Table 4 lists key deployment RTCS designed for KOMPSAT deployment operation. They are designed to execute automatically after separation from launch vehicle.

Deployment RTCS design has been tested in different stages of the KOMPSAT program. Each RTCS has been tested during electrical testbed to verify command validation followed by RTCS sequential execution verification. Final RTCS design has been verified during the KOMPSAT fault management end-to-end system level test. With the usage of KOMPSAT flight model satellite, verification of flight hardware and software has been demonstrated for the automated deployment and activation of the KOMPSAT spacecraft following separation from launch vehicle. The test included autonomous ground communication designed for the very first early orbit McMurdo, GSOC and KGS contact. The important test purpose was to verify functions and interfaces that were not completely tested on the electrical testbed.

Table 4. Key deployment RTCS list and design features (Baek & Lee, 1998).

RTCS	Location	Design Feature
Prime OBC Enter Deployment State	OBC (A)	Called on wake-up by the prime OBC after sep from the LV. This RTCS initiates primary solar array deployment sequences and calls RDU and ECU RTCSs and autonomous ground commmuncation RTCS.
Redundant OBC Enter Deployment State	OBC (B)	Called on wake-up by the redundant OBC after sep from the LV. This RTCS initiates redundant solar array deployment sequences and calls RDU and ECU RTCSs.
Deployment Phase Ground Communication	OBC (A)	Called by OBC RTCS. This RTCS enables KOMPSAT to communicate with first McMurdo, first and second GSOC and first KGS automatically.
Prime ECU Enter Deployment State	ECU (A)	Called by OBC RTCS. This RTCS activates primary configuration of the electrical power subsystem for the solar array deployment.
Redundant ECU Enter Deployment State	ECU (B)	Called by OBC RTCS. This RTCS activates redundant hardware and software of the electrical power for the solar array deployment.
Prime RDU Enter Deployment State	RDU (A)	Called by OBC RTCS. This RTCS activates primary configuration of the attutide control and the test for the solar array deployment operation.
Redundant RDU Enter Deployment State	RDU (B)	Called by OBC RTCS. This RTCS activates redundant configuration of the attutide control and the test for the solar array deployment operation.
Configure On Propulsion Subsystem and Unused Gyro Power Off	ECU (B)	Called by RDU KFS after 2 good gyros found. This RTCS activates necessary propulsion hardware for thruster control and power unused gyro off.
Open Isovalve A or B	RDU (A)	Called by ECU RTCS. This RTCS is designed for dedicated purpose of isovalve on.
ECU Disable DDC Power	ECU (A)	Called by RDU KFS after array deployment test passed. This RTCS is designed to configure deployment device disable and solar array deployment pass/fail indation.
Disable Iso-valve A or B Driver	ECU (A)	Called by RDU RTCS. This RTCS is designed for dedicated purpose of isovalve driver disable.

4. LAUNCH AND DEPLOYMENT CONTINGENCY OPERATION

Table 5 and Table 6 describes contingency operation during launch and deployment operations. KOMPSAT satellite has on-board autonomous fault management design feature to detect hardware and software fault that can occur during mission operation and to reconfigure the spacecraft to safe the satellite. As shown in Table 5 and Table 6, during launch and deployment operations, there are a number of fault scenarios that can occur. KOMPSAT on-board fault management has design feature for launch and deployment operation in detecting launch and deployment failure using on-board hardware and software fault detection function and performing successful launch and deployment operation with the single fault tolerant capability by reconfiguring the redundant system and by repeating deployment operation. Launch contingency operation is to design the system not to deploy solar array inside the launch vehicle fairing. Deployment contingency operation design has been incorporated into deployment RTCS design for the fault scenarios of the Table 6. The contingency design has been also verified with an electrical testbed and system level KOMPSAT fault management end-to-end test (Baek, 1998, 1999b).

5. SUMMARY

In this paper, KOMPSAT launch and deployment operations have been discussed. The U.S. launch vehicle Taurus will deliver the KOMPSAT satellite directly into a 685-km altitude mission orbit. The KOMPSAT spacecraft has been designed to meet the mission operational requirement during launch and deployment operations. Deployment sequence has been designed to operate with autonomous on-board relative timed command sequence (RTCS) such that the deployment operation can be executed without ground station intervention.

On-board deployment RTCS activates necessary hardware and software to perform deployment operation automatically. During early orbit operations, German GSOC and KGS monitor and control the satellite with the necessary support of NASA ground stations, as required, to access as frequently as possible. In the mean time, even without ground station support, KOMPSAT spacecraft has on-board autonomous fault management design features to detect flight hardware or software fault and to reconfigure the satellite to repeat deployment operation or to transition to safe-hold mode with the single fault tolerant capability.

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Table 5. Launch contingency operation (Lee, 1996).

Item	Fault Scenario	Contingency Operation
During lift-off	Premature wake-up	KOMPSAT on-board computers are powered-on-reset during lift-off. In case of premature wakeup of the computers, on-board computers keep re-booting inside fairing until KOMPSAT satellite indicates the separation from launch vehicle.

Table 6. Deployment contingency operation (Lee, 1996).

Item	Fault Scenario	Contingency Operation
Separation timer times out	Computer hardware or software fault	After separation from launch vehicle, separation timer must be stopped counting timeout. Hard-wired contingency action to select redundant on-board computers and executes redundant deployment sequences.
On-board computer operation	Computer hardware or software fault	Timed task failure, watchdog timer time-out, software heartbeat signal missing, EDAC error fault trigger function enabled. Software contingency action to select redundant on-board computers and executes redundant deployment sequences.
Gyro selection logic failure	Gyro hardware failure or software fault	Gyro selection logic failure fault trigger enabled. Software contingency action to select redundant on-board computers and executes redundant deployment sequences.
Solar array deployment test failure	Failure to deploy solar array or software fault	Solar array deployment test failure fault trigger enabled. Software contingency action to select redundant computers and executes redundant deployment sequences.
Excess attitude rate	Propulsion system failure or software fault	Thruster pulse for sun pointing may cause excessive attitude rate. Excess attitude rate fault trigger enabled. Software contingency action to select redundant on-board computers and executes redundant safing sequences.
Battery charge	Battery cell failure or software fault	A battery cell may fail. Ground station commands to select the operation with a cell failure. Battery depth of discharge, battery charge and battery over-temperature fault trigger enabled. Software contingency action to select redundant on-board computers and executes redundant safing sequences.

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