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BRIEF REPORTS ON KAISTSAT-4 MISSION ANALYSIS

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ABSTRACT

Five scientific instruments are planned on KAISTSAT-4 that is scheduled to be launched in 2002. A far ultra-violet imaging spectrograph and a set of space plasma instruments are currently being designed. The imaging spectrograph will make observations of astronomical objects and Earth's upper atmosphere. The plasma instrumentation is capable of fast measuring the thermal magnetospheric plasmas, cold ionospheric plasmas and the Earth's magnetic fields. Major system drivers and constraints on the payloads as well as the spacecraft are identified. A preliminary analysis of the K-4 mission has been undertaken with the system requirements that are derived from the system drivers. Detailed investigation shows that Sun-synchronous orbits with approximate altitudes of 800 km are optimal to satisfy the identified requirements. Comparisons with other orbits of different inclinations are also shown. Four operation modes and a daily schedule of spacecraft maneuver are found from the Sun-synchronous orbital model. It is shown that the scientific objectives of K-4 can be achieved with moderate levels of design and operation risks

Key words: satellite, mission analysis

1. INTRODUCTION

The KAISTSAT-4 (K-4) is the fourth experimental satellite developed by the Satellite Technology Research Center (SaTReC) of Korea Advanced Institute of Science and Technology (KAIST). SaTReC has successfully developed and operated three micro-satellites (Park et al. 1996). K-4 is a continuing effort by SaTReC to develop and operate small, cost-effective experimental satellites within moderately short development period. The launch of K-4 is scheduled in 2002. The orbit of the satellite will be near circular polar orbits with altitudes of about 800km. The primary objective

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Table 1. KAISTSAT-4 and other missions.

Mission	Freja	Akebono	Fast	DMSP†	KAISTSAT-4
Inclination, deg.	63	75	83	$\sim$92	$\sim$92
Apogee, km	1756	10,500	4175	$\sim$ 820	800-1200
Perigee, km	601	275	350	$\sim$ 820	800-1200
Size, m^3	$2.2(\phi) \times 1.7$			$1.2(\phi) \times 3.4$	$\sim$ 0.6 x 0.6 x 0.8
Weight, kg	225.9	295	191	750-830	$\sim$120
Attitude Control	Spin	Spin	Spin	3-Axis	3-Axis

† The Defense Meteorological Satellite Program (DMSP) consists of several satellites. The values shown here represent the nominal values.

of K-4 is to provide spectral diagnostics of galactic plasmas in the Far-Ultraviolet ranges with the Far-ultraviolet Imaging Spectrograph (FIMS) (Edelstein 1998, Min et al. 1999). FIMS is sensitive to emission line fluxes in 900-1175 Å and 1335-1750 Å. The instrument will allow the detailed mapping of the spatial distribution of the hot galactic plasmas and the determination of the physical states of hot interstellar matters as well as the detection of the various emission lines from the Earth's upper atmosphere. Four additional instruments are being designed to acquire the in-situ measurements of Earth's magnetic fields and populations of charged particles flowing toward and away from the Earth's upper atmosphere. Sampled in-situ measurements from the four instruments are expected to provide a significant contribution to the existing understanding on the Earth's polar region. The contribution is expected to be greater if the satellite is maneuvered to align with the viewing directions of the FIMS instrument to monitor the Earth's Aurora over the polar region. The present paper is to provide a summary of initial mission analysis on K-4 . Section 2 briefly reviews the previous missions that cover the low-altitude polar regions. Section 3 explains scientific objectives of K-4 missions. Descriptions of mission analysis that has been performed for K-4 are found in section 4.

2. PREVIOUS MISSIONS

The expected altitude and inclination of KAISTSAT-4 are 800-1200 km and 92°, respectively. The orbits of the Defense Meteorological Satellite Program (DMSP) closely approximate the anticipated orbits of KAISTSAT-4, but several other space missions transited the KAISTSAT-4 orbits with highly eccentric elliptical orbits. Previous missions such as DMSP (http://www.ngdc.noaa.gov/dmsp/), Akebono (Tsuruda & Oya 1993), FAST (Carlson et al. 1998), and Freja (Lundin et al. 1994) are summarized in the table below.

3. SCIENTIFIC OBJECTIVES

The main scientific objective of K-4 is to study the diffuse hot interstellar matter, for which Far-ultraviolet Imaging Spectrograph (FIMS) is currently under development. The instrument employs a dual bandpass (900-1175 Å and 1335-1750 Å), high resolution (1.5 Å and 2.5 Å, respectively) imaging spectrograph with a $8^\circ \times 5'$ field of view and $5'$ spatial resolution. FIMS is sensitive to emission line fluxes that are fainter than any previous detection by an order of magnitude. The instrument also allows us to determine the thermal and ionization equilibrium state in hot Galactic plasmas. Scientific goals of FIMS are 1) to map the spatial distribution of hot Galactic plasmas through a one-year sky survey, 2) to determine physical states of hot interstellar matter such as superbubbles and supernova remnants with pointed observations, and 3) to test the models presently available for the Galactic evolution. The scientific objectives of the space plasma instrumentation can be summarized as 1) detection of directly penetrating solar wind plasmas and up-flowing, cold ionospheric electrons, 2) investigation of sub-kilometric scale structures of the Earth's polar regions, and 3) comparisons of the in-situ measurements with the spectrographic images ($\Delta\lambda/\lambda \sim 500$) of the Earth's Aurora in the far-ultraviolet ranges.

4. RESULTS OF MISSION ANALYSIS

4.1 SYSTEM DRIVERS AND CONSTRAINTS

For design of the payloads and spacecraft following system drivers and constraints are taken into account. It should be noted that most of the system drivers and their corresponding requirements are generated for the FIMS instrument. This is because the instrument is to observe faint astronomical objects at inertially fixed locations, whereas the plasma instruments are designed to mesaure the velocity distributions of plasmas over large solid angles at the location of the spacecraft. Therefore, the requirements on plasma instruments are easily satisfied with those derived for FIMS instrument.

System Drivers

1. Important FUV emission lines such as C IV at 1550 Å, He II at 1640 Å, O VI at 1034 Å are to be detected.
2. Important emission lines such as Ly α at 1027Å and O VI at 1034 Å are to be separated.
3. The FOV of FIMS is to cover extended features of astronomical and geophysical objects.
4. The sensitivity of FIMS is to allow detection of about 100 astronomical objects in a year.
5. The sampling rate of plasma instruments is to allow investigation of sub-kilometer auroral physics.

Constraints

1. The total mass of the entire spacecraft system, *i.e.* bus plus payload, is to be near 120 kg.
2. The total budget for development of the system is to be less than US$ 8M. This includes the launch cost and expenses for initial operations.
3. The spacecraft is to be launched in 2002.
4. The expected life time is to be greater than 3 years.
5. The expected attitude control capability from the spacecraft is about accuracy 0.5°, knowledge $5'$, and stability $5'/s$.

4.2 SYSTEM REQUIREMENTS

With a consideration of above system drivers and constraints following requirements on the payload and the bus system are generated.

Payload requirements

1. The spectral range of FIMS is to cover 850-1800 Å for most of the important FUV lines.

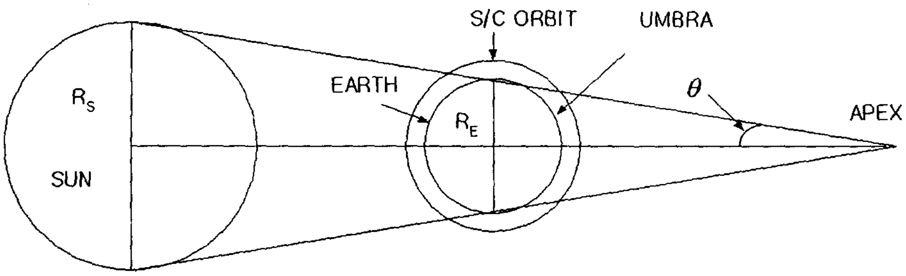

Figure 1. Definition of total eclipse.

2. The spectral resolution of FIMS is to be better than 5 Å for the separation of important emission lines.
3. The angular resolution of FIMS is to be better than 5′.
4. The FOV of FIMS is greater than 5° for coverage of extended features.
5. The effective grasp of FIMS angular resolution is to be greater than $5.0 \times 10^{-5}\text{cm}^2\text{sr}$ for the detection of an astronomical object in 100s.
6. The sampling rate of space science instrument is better than 20 samples per second for the investigation of sub-kilometer auroral physics.

Orbital requirements

1. Minimum observation time during the eclipse is to be greater than 10 minutes for statistically significant observations.
2. The altitude of satellite is to be greater than 500 km for the reduction of background air-glow intensities and less than 1300 km for reduction of energetic particle precipitation.
3. The inclination of satellite is greater than 80°and less than 110°for the observation of Earth's Aurora.

4.3 RESULTS OF MISSION ANALYSIS

During the mission analysis a particular attention has been given to orbit analysis because of the minimum observation time of 10 minutes in the eclipse as described in the previous section. Results of orbit analysis for several inclinations and altitudes will be presented in this section. It should be noted that our investigation includes comprensive analyses such as link budget analysis, power budget analysis and thermal analysis. It was found that the results of orbit analysis provide stringent restrictions on this mission analysis.

In the eclipse analysis, characteristics of the eclipse times based on the above requirements are investigated. The eclipse is defined as the occultation of the Sun due to the transition of the Earth in front of the satellite as illustrated in the following figure. The half apex angle θ can be calculated as

$$\theta = \tan^{-1}\frac{R_S - R_E}{D} = 0.26411$$

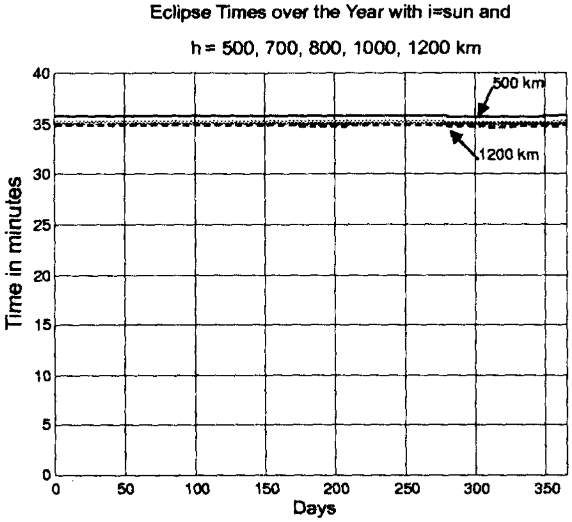

Figure 2. Eclipse times of sun-synchronous orbits.

where R_S, R_E and D are 6.9599×10^5 km, 6378.14 km and 1.496×10^8 km, respectively.

The inclination and the altitude selected for the present investigation are 80° to Sun-synchronous and between 500 km and 1200 km, respectively. These parameters are two of the most decisive parameters that will determine the orbital behaviour of the satellite. There are five different inclinations, 80°, 85°, 90°, 95°and Sun-synchronous, that are selected for investigation in this study. Each of these inclinations has been examined with five different altitudes, 500km, 700km, 800km, 1000km and 1200km. For these inclinations and altitudes, following orbit parameters are assumed.

1. local time of ascending node: 10:30 hrs
2. Right Ascention of Ascending Node (RAAN): 335.58220 and Longitude of Ascending Node: 157.50
3. Orbit Epoch: 21 Mar 1999 at 00:00 hrs
4. One year: 010199 to 311299

Figures 2 to 4 summarizes our orbit analysis. Figure 2 shows characteristics of Sun-synchornous orbits with altitudes from 500 km to 1200km. The results show that the eclipse times are constant throughout the year for Sun-synchronous orbits. Further, the eclipse time does not deviate much even its altitudes varies from 500 km to 1200 km. Shorter eclipse time is found for higher altitudes among the 5 orbits.

Figure 3 displays the results of the eclipse times for fixed altitude of 800 km and different inclinations, Sun-synchronous, 90°and 95°. The figure shows that orbits with inclinations 90°and 95°have periods for which eclipse times greater than 10 minutes do not exist. For example, the orbits with inclination=95°provide consecutive 132 days of non-eclipse times during the year. No astrophysical observations can take place during the 132 days because the far-ultraviolet instrument should be operated in the eclipse due to intense air-glow emissions in the sun-lit side. If the entire

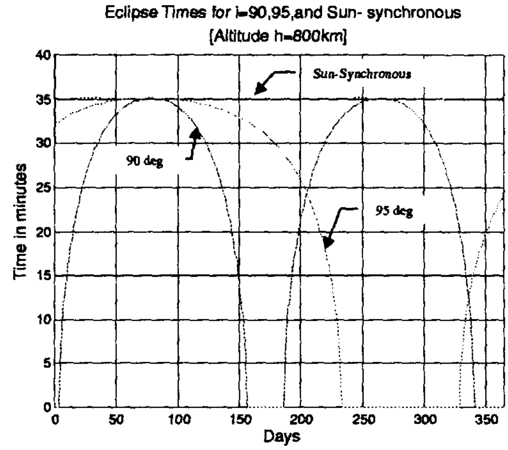

Figure 3. Eclipse times for different inclinations.

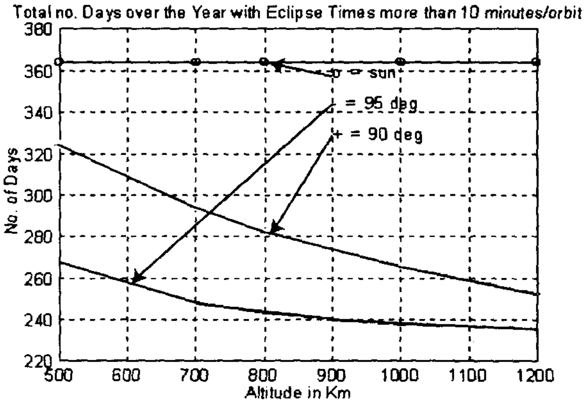

Figure 4. Total eclipse time for different inclinations and altitudes.

sky-survey, as proposed in the scientific objectives, is to be completed for orbits with inclinations 90°or 95°, intensive spacecraft maneuver has to be made during the remaining days of the year. The absence of eclipse times for these orbits makes it significantly complicated to prepare daily schedule of observations. Further, the life time of the spacecraft attitude control system may shorten due to the intensive spacecraft maneuver.

Figure 4 shows total number of days in a year for which the eclipse time exceeds 10 minutes. Orbits with inclinations, 90°, 95°, and Sun-synchronous and altitudes, 500, 700, 800, 1000, and 1200 km, are chosen for study. The figure demonstrates lesser eclipse time is found for higher altitudes. In the figure orbits with inclination 90° provides more eclipse time than 95°.

Table 2 summarises the characteristics of three different types of orbits. The inclination of 95° at 1200 km will have a non-eclipse period of 132 days. This is about 1/3 of a year. Furthermore, it has lesser number of orbits with eclipse time more than 10 minutes as compared to the 90°inclination orbit. On the other hand, Sun-synchronous orbit does not have non-eclipse periods and has constant eclipse time throughout the year. Therefore, a Sun-synchronous orbit with altitude of about 800 km

Table 2. Characteristics of orbits.

Orbits	No. of obribts (Eclipse time> 10 min.)	Non-ecllipse periods
Sun-synchronous (800km)	5205	None
Inclination=90° (1200km)	3304	59days +57 days
Inclination=95° (1200km)	3082	132 days

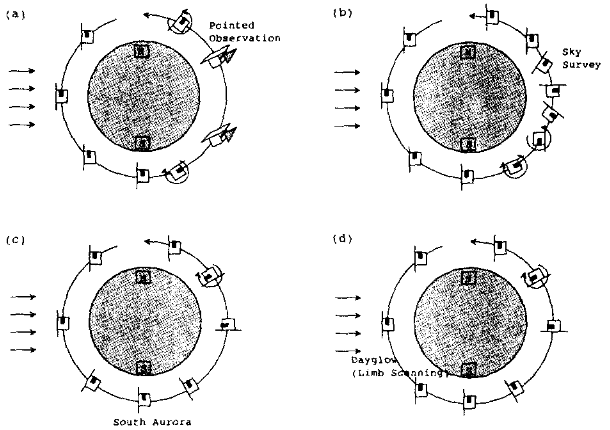

Figure 5. Operation modes for KAISTSAT-4: a) Pointed Observation, b) Sky Survey, c) Aurora, d) Air Glow modes.

is selected as our model candidate. However, it must be noted that proper orbit elements are to be selected in order to ensure acquistion of desired eclipse time. For example, no eclipse time is present at all for local time of ascending node at 06:00 hrs.

A daily schedule of spacecraft operation has been proposed for a Sun-synchronous orbit which is selected as the best model orbit according to the previous discussions. It should be noted that our mission analysis includes a situation for which Sun-synchronous orbit is not available. It is found that considerable complexities in satellite operation arise without Sun-synchronous orbit because the duration of eclipse is a sensitive function of orbital parameters.

The following table demonstrates a possible daily schedule which satisfies the requirements of KAISTSAT-4. The assumed period of spacecraft orbit is near 100 minutes. This daily operation of the spacecraft, as shown in the table, is expected to repeat each day during the designed life time of 3 years unless otherwise required from the ground station. Among available 14 orbits each day, 2 orbits are reserved for ground contacts of the spacecraft. There are 4 orbits for Auroral Obervations (AO), 1 orbit for Day-Glow (DG) and Night-Glow (NG) observations, and 7 orbits for Astophysical Observations (AP) such as pointed observations and sky survey. Schemtaics of spacecraft maneuver in order to perform the above 4 observations are shown in Figure 5. There is only one observation to be undertaken each orbit. Power budget analysis of the spacecraft system shows that performing several observation during a sigle orbit may consume excessive electrical power which causes deeper Depth-Of-Discharge (DOD) for spacecraft battery system. Further, attitude control of the spacecraft system for two or more observations each orbit is considerbaly more complicated that that for single observation. In this study, the daily schedule is prepared with an assumption that signle observation can be performed each orbit.

It is also noted that the Aurora observation is undertaken only for the south polar region. This

Table 3. Daily schedule of observations of KAISTSAT-4.

Orbit No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Sunlit	GC	GC					DG							
North Polar														
Eclipse							NG	AP	AP	AP	AP	AP	AP	AP
South Polar			AO	AO	AO	AO								

is for the sake of reducing risks for attitude maneuvering for descending spacecraft orbits (counterclock wise in the figure) in the sunlit side. Observation of the north polar region for the descending orbits requires complex spacecraft attitude maneuver in the eclipse and sun-lit side.

Final decisions to perform single observation or two or more and to make observations of south (north) polar regions for ascending (descending) nodes in the sunlit side shall be made upon completion of actual spacecraft subsystems.

6. SUMMARY

A mission analysis has been performed for KAISTSAT-4 that is scheduled for launch in 2002. Major system drivers and constraints are identified from the scientific objectives. Quantitative requirements for payloads as well as spacecraft are identified. Preliminary analysis suggests that a Sun-synchronous, 800 km-altitude orbits successfully satisfy the identified requirements. Four operation modes and a daily operation schedule are found from the analysis. The mission objectives of KAISTSAT-4 can be achieved with moderate levels of design and maneuver risks.

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