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STUDY OF SPACECRAFT-GENERATED ENVIRONMENT ON SPACE FLYER UNIT

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Abstract

This paper presents the study of spacecraft-generated environment planned on SFU (Space Flyer Unit) Mission 1. The diagnostic system on SFU to measure the space environment consists of vacuum gauges, a mass analyzer, plasma probes, potential detectors, wave receivers, micro-g meters, a visible spectroscope, magnetometers, and an electron density fluctuation detector. It also carries test materials exposed to the space medium, which will be recovered and analyzed on the ground. The SFU diagnostic system is prepared not merely to measure the natural space environment, rather to study the environment induced by the interaction between spacecraft and natural environment. The results will be applied to plasma physics, gas dynamics and atomic/molecular chemistry. They will be used to predict the environment around larger spacecraft and to evaluate the effects of human activities on the space environment.

Introduction

Space Flyer Unit(SFU)[1)] is a free-flying space platform which has been developed jointly by the Institute of Space and Astronautical Science, the Ministry of International Trading and Industry and the National Space Development Agency. It is the first reusable space system developed in Japan that is retrieved by the U.S. space shuttle. The total weight is about 4000kg including mission peculiar instruments and payloads. The scale is 4.55 m octagonal in diameter by 1.4 m height. The first mission will be launched by the third H-II rocket in 1995 and be retrieved by the STS-72 after 6 months mission operation. The mission orbit will be circular at the height of 500km.

In the first SFU mission, a study of spacecraft-generated environment is planned as one of the science and technology experiments. This study takes aim at a new field of scientific research on the space environment[2)]. Earlier, the study of space environment just means measurement of geophysical parameters in space, avoiding the effects of spacecraft itself as much as possible. But this study is intended for the research of the space environment generated by the interactions between the space medium and spacecraft. The interactions include a lot of important physical processes that we can not study on ground. The gas, plasma and electromagnetic environment generated near the spacecraft is usually quite different from the natural one. In terms of utilization of space environment, the knowledge of spacecraft-generated environment is more important than that of the natural one, because the on-board instruments and crews experience the spacecraft-generated environment rather than the natural space environment.

The study of spacecraft-generated environment was initiated at the early stage of the space shuttle operation in 1980's. The gas environment inside the orbiter cargo bay was measured in the initial test flights, and electromagnetic environments were studied by the Plasma Diagnostic Package(PDP) associated with the electron beam experiments[3)]. In the SEPAC experiment(Space Experiment with Particle Accelerators) performed in 1983, the gas

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and plasma environment modified by the particle beam injection was extensively explored[4]. In these studies, a lot of new findings were obtained on the spacecraft-generated environment. However, the study was recessed after these preliminary researches, leaving many problems unresolved. In 1990's, the research of this field has been resumed associated with the space station program. The large-scale modification of space environment expected surrounding the space station has attracted interests of the space scientists again. Research groups for the spacecraft-generated environment have been organized in the countries taking part in the space station program. They have been trying to establish an international framework to study the space station-induced environment[5].

In Japan, the SFU environment study team was organized in 1987 by the scientists who participated in the SEPAC project. The team has developed the SFU environment diagnostic system based on the experiences obtained in the SEPAC experiment. The team has made proposals for particle and electromagnetic measurements on the JEM of the Space Station.

SFU Environment Diagnostic System

SFU has totally 6 payload unit boxes attached to the main structure, in which the experimental apparatus are contained. The experiments are also installed on the upper platform of the SFU.

The SFU environment diagnostic system consists of two main diagnostic packages, SEM(Space Environment Monitor) and SPDP(Space Plasma Diagnostic Package), on the platform, and four smaller packages, PEM(Payload unit Environment Monitor), inside the payload unit boxes. SEM(Fig.1) contains two vacuum gauges, a mass analyzer, a Langmuir probe, a floating probe, an impedance probe, two wave receivers, a 3 axes

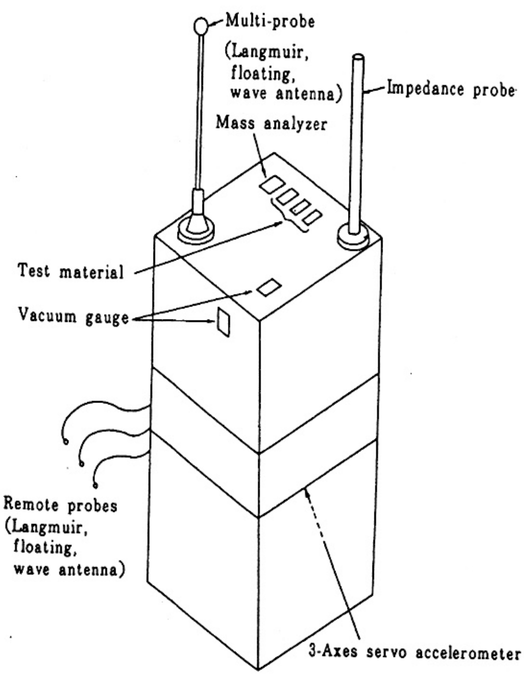

Fig.1 SEM package.

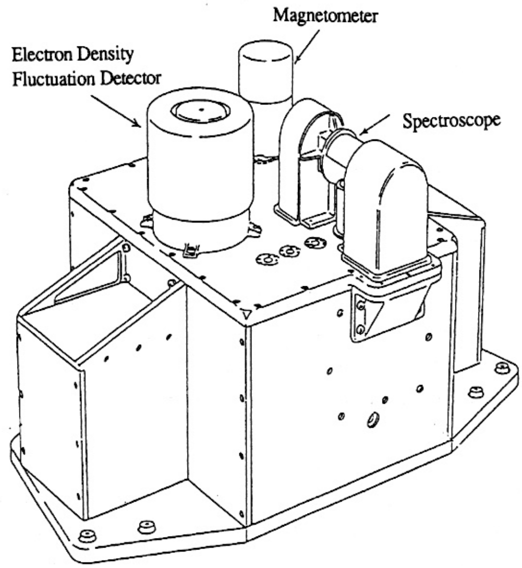

Fig.2 SPDP package.

micro-g meter and 8 pieces of test material attached to the platform of package. SPDP(Fig.2) has a visible spectroscope, an electron density fluctuation detector, a 3-axes magnetometer, and three pieces of test material. The smaller package PEM has a 3 axes micro-g meter and a Pirani gauge. The performance of each diagnostic instrument is summarized in Table 1. The location of SEM and SPDP on the SFU is depicted in Fig.3.

Although each sensor itself is conventional, the total system has been designed as an advanced diagnostic system to study the spacecraft-generated environment. It integrates various kind of sensors as many as possible to clarify the complicated physical processes. The sensors are distributed over the SFU as many as possible. For the test materials to study the surface reaction, in-situ measurements are performed by the visible spectroscope and the mass analyzer.

(1) Multi-point Measurement

Since the spacecraft-induced environment is generated by complicated physical processes, measurements only at one point are not sufficient to identify the physical mechanism. This is one of the reasons why the past studies have not been well successful to identify the physical processes involved in the generation of the spacecraft environment. The SEM has three remote probes besides a main probe on the diagnostic package to measure the

Table 1 SFU Diagnostic Instruments.

Instrument	Characteristics
Mission-Independent (EMS)	
Exposed (EMS-SEM)	
Pressure Gauge	Two Ionization Gauges $5 \times 10^{-4} \sim 10^{-8}$ Torr
Mass Analyzer	QP Sensor with CEM 2~100 AMU
Plasma Probe	4 Sensors Langmuir & Floating Modes
Impedance Probe	0-10 MHz
Wave Receiver	Two Receivers 0.1 kHz~10 MHz
Micro-g Meter	3-axes Servo Accelerometer ±10mg with 10 μg resolution
In Payload Unit (EMS-PEM)	
Micro-g Meter	3-axes Servo Accelerometer ±1 mg with 10 μg resolution
Pressure Monitor	Pirani Gauge 10 m Torr~1 Torr
Mission-Dependent (SPDP)	
Exposed	
Spectroscope	2000~8000Å with 25Å resolution Movable Object Mirror Test Material with Laser Diodes
Magnetometer	3-axes Fluxgate Type ±0.5 Gauss with 0.1% accuracy
Electron Density Fluctuation Detector	Langmuir Probe with CEM 1 Hz~30 kHz

plasma density, floating potential and plasma waves. Two remote probes are attached at the upper platform of the SFU, and the other is at the rear side. The plasma environment both in the ram and wake sides can be simultaneously measured. There are two vacuum gauges installed in the SEM. One of the two apertures directs straight upward with respect to the SFU platform and another directs perpendicularly. The micro-g environment is measured by totally 5 different sensors, one on the platform inside the SEM and the other four in the payload unit boxes.

(2) Plasma Oscillation Measurement

Both the plasma density oscillation and potential oscillation are measured by the two wave receivers up to 10 MHz with 4 mono-pole antennas, one on the SEM platform and three distributed over the SFU platform. In addition to these, the electron density oscillation up to 30kHz is detected by a new measurement technique, a combination of a Langmuir plate probe and an electron

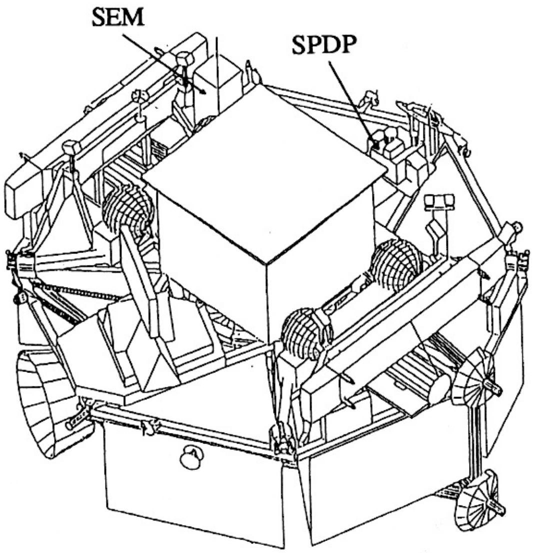

Fig.3 Configuration of SEM and SPDP on SFU.

counter. The electrons entering a hole at the center of the electrode which is biased positively to the electron saturation current region are detected by a channeltron. The oscillation of the electron current reflects only the component of the density oscillation(the component of the potential oscillation is vanished at the electrode). The electron current oscillation is analyzed by an FFT in the instrument. Using the two types of oscillation detector, we can discriminate the components of the density and potential oscillations. The scheme will be a great help to identify the mode of the plasma waves.

(3)Visible Spectroscopy Combined with Test Material

The visible spectroscope is used to study the surface degradation of the test material, as well as to observe the optical environment surrounding the SFU. Three sets of thin transparent test material are installed on the top panel of the SPDP under which a laser diode is installed each(Fig.4). The change of laser light transmission indicates a change of material property and surface contamination. Polyimide, aluminized polyimide and gold-plated polyimide are used for the exposure test. The spectrums of the reflected sunlight from the surface of the test materials are also analyzed by the spectroscope to detect the surface change.

(4) Mass Spectroscopy Combined with Test Material

8 pieces of test material are installed near the aperture of the mass spectrometer. They are Teflon, polyimide,

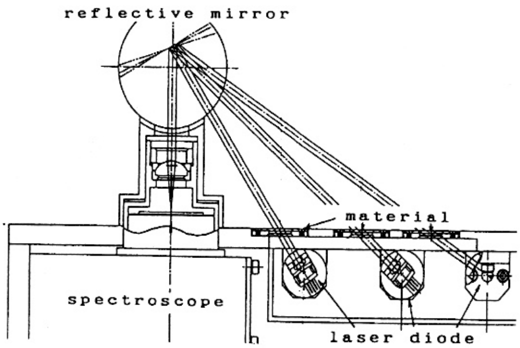

Fig.4 Study of material surface by the spectroscope.

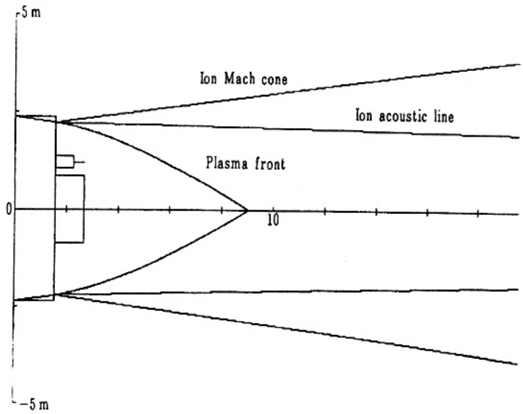

Fig.5 Plasma environment behind the SFU calculated by a one-dimensional model for plasma diffusion.

MgF_2-coated polyimide, SiO_2-coated polyimide, aluminized polyimide, gold-plated polyimide, carbon/carbon and CFRP. The molecules newly produced by atomic or molecular reactions such as oxidization and nitrification at the material surface will be detected during flight by the mass analyzer. The surfaces of the material are also analyzed by an electron microscope and a spectrometer after recovery. Some of them will be subject to a mechanical test to measure the change of structural characteristics.

Scientific Research on SFU Mission 1

(1)Plasma Environment Surrounding SFU

SFU moving at a supersonic velocity in the ionosphere will produce plasma disturbances both in the ram and wake sides. In the front, the ions in the plasma are reflected by the spacecraft surface, interacting with the surrounding plasma and exciting the lower hybrid instabilities in the frequency range of kHz. In the rear side, a void-region is generated where the space plasma and gas are excluded. The scale of the plasma void-region(plasma wake) will extend about ten meters behind the SFU as shown in Fig.5. Plasma diffusion toward the void-region will cause plasma cooling and ion acceleration. Fig.6 shows the profile of plasma density, ion temperature and ion drift velocity inside the wake calculated for the SFU. The accelerated plasma stream will collide at the far wake region, resulting in the two stream instabilities.

In the study of plasma environment surrounding the space shuttle, the plasma-void region in the wake[6], low frequency plasma waves in the ram side[7], density fluctuation in the wake side[8], and temperature change both in the wake and ram sides have been reported. But the structure of the plasma wake, change of the ion distribution function in the wake have not been measured. The physical processes for the density fluctuation and the wave generation have not been identified yet. Furthermore, there are several problems still left unresolved, such as the cause of the mysterious ion beam observed in the ram direction in STS-3 experiment[9] and inconsistent results on the electron temperature in the ram and wake sides[6,8].

The plasma parameters and electromagnetic RF fields simultaneously measured at 4 positions both at the ram and wake sides will clarify the structure of plasma environment surrounding the SFU. In this study, the SFU is planned to be rotated along an axis perpendicular to the orbital motion, which allows us to measure the ram and wake environment continuously.

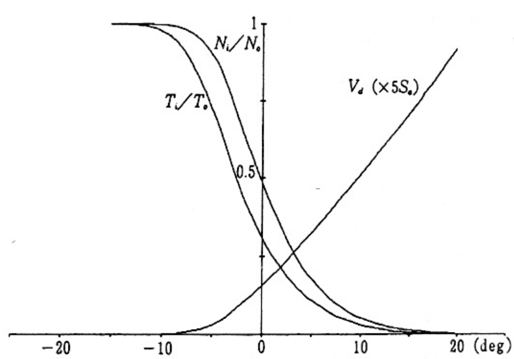

Fig.6 Distribution of plasma density, ion temperature and ion drift velocity in the SFU wake. Sa is the ion acoustic velocity.

(2) Gas Environment and Interaction with Plasma

According to the studies by the space shuttle orbiter, out-gassing from the payloads has a dominant effect on the gas environment of the wake side, at least during 7-10 days mission. Gas density and composition measurements on the SFU will show the out-gassing effect in a long term of 6 months.

The gas/plasma interaction will take place surrounding the SFU when the thruster system is operated to keep its orbit and attitude. The gas/plasma interaction produces a plasma cloud moving with the SFU, resulting in charge separation, associated plasma instabilities and gas ionization. Fig.7 shows possible physical processes involved in the gas/plasma interaction[10]. All these effects are closely related to the phenomena excited surrounding the space bodies releasing a gas, such as cometary comae and Jupiter Io. The critical velocity ionization is believed to be a possible mechanism for the generation of the cometary plasma. In order to study the gas/plasma interaction under controlled conditions, it is planned to operate the thruster system synchronizing with the diagnostic measurement. The gas plasma interaction will be detected by the ionization gauges, mass analyzer, multiple plasma probes, and wave receivers. The visible spectroscope will be used to identify atomic and molecular reaction process in the interaction region.

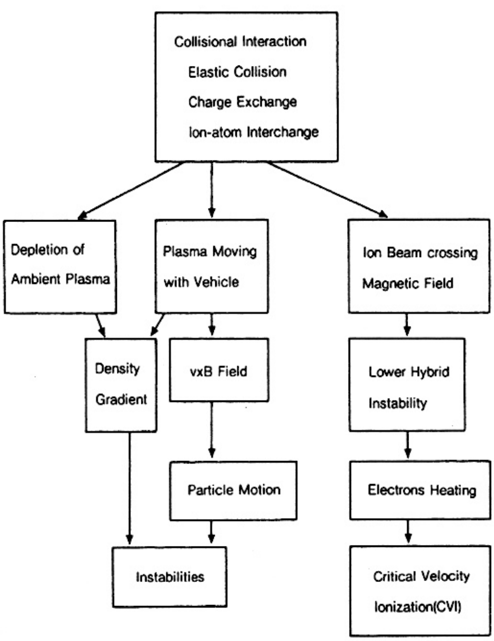

Fig.7 Possible physical processes involved in gas/plasma interaction in space.

(3) Gas/Solid and Plasma/Solid Interaction

The problem of particle/solid interaction is directly related to the degradation of the space material and structure, which is now a big concern for long-life space facilities in the coming space utilization era. One of the important issues is the degradation by the active atomic oxygen which was first found by the space shuttle. The particle/solid interactions are also important subjects in space science. The origin of the ram glow or shuttle glow is believed to be a molecular reaction at the solid surface[11], but the reaction process of the gas molecules and ions of several eVs with a solid is not well understood in the atomic/molecular physics. The measurements of energy loss of the particles at the solid surface and associated surface reaction in space will provide valuable information which are hardly obtained on ground. The change of material surface by particle impingement is related to the study of the surface of the planets and comets without atmosphere which are exposed in the solar wind. Charging of a solid in plasma is another important issue, related to the concentration of the micro particles in the origin of the solar system.

The surface observation of the test material by the spectroscope will provide critical information on the surface reaction accompanying with specific light emission. The products produced in the particle/solid interaction will be analyzed by the mass analyzer, which enable us to identify the physical and chemical processes involved in the interaction.

Conclusion

An environment diagnostic system for the SFU has been developed to study the spacecraft-generated environment from standpoints of space science and space environment utilization. The system consists of a variety of diagnostic sensors distributed over the SFU. It will reveal the plasma, gas, electromagnetic and optical environment surrounding the SFU. The data will be used to clarify the physical processes of plasma reaction, gas/plasma interaction and particle/solid interaction. The output of this research will be applied to predict the space environment surrounding large space structures as the space station, the solar power satellite, and future space factories. The knowledges obtained in this research will also be used to evaluate the effects of the human space activities on the space environment.

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