Study of Spacecraft Environment on SFU

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Summary: A study of spacecraft environment is planned on Space Flyer Unit (SFU) Mission-1 in 1994. The environmental parameters are measured by two diagnostic packages attached to the SFU platform and by four small packages inside the payload unit boxes. The diagnostic instruments are two high-sensitivity vacuum gauges, four low sensitivity-vacuum gauges, a mass analyzer, three plasma probes, two wave receivers, an electron density fluctuation detector, a visible spectrometer, a magnetometer, and five micro-g meters. The two packages carry totally 11 pieces of test material which are exposed to the space medium and recovered for analysis after the mission. The major objectives of the diagnostic instruments are to study the body/plasma interaction, gas/plasma interaction, and particle/solid interaction from a scientific point of view, as well as to support the onboard experiments and SFU system operation. This report describes the performance of the SFU-1 diagnostic instruments and the achievements expected in the study of the spacecraft environment on SFU.

1. INTRODUCTION

A free-flying space platform, Space Flyer Unit (SFU), is now under development jointly by the Institute of Space and Astronautical Science, the Ministry of International Trading and Industry, and the National Space Development Agency. SFU is an unmanned, multipurpose reusable platform for science and technology experiments, space observation, and flight tests of space technologies and industrial technologies. The weight is about 4,000 kg including the payloads. The scale is 4.55 m octagonal in diameter by 1.4 m height. The SFU Mission-1 will be launched by H-2 rocket early in 1994 and will be retrieved by the Space Shuttle after 6 months mission operation. The mission orbit will be circular at the height of 500 km.

For the first mission, two dimensional array deployment experiment, high voltage solar array experiment, plasma environment study, material experiment, and biology experiment are planned as science and technology experiments. An infrared telescope is carried for astronomical observation. Three types of furnace and material cartridge samples are installed in the payload unit boxes for the flight tests of advanced industrial technologies. An engineering verification of partial model of the exposed facility in JEM attached to the Space Station is also planned in the first mission.

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The SFU moving in the ionosphere generates a plasma wake, collisionless shock structure, plasma turbulence surrounding the SFU, and particle/solid interactions at the surface. The spacecraft-generated effects are similar to the phenomena excited around the space bodies such as planets and comets in the solar wind and satellites moving in the planetary magnetosphere. From this point of view, the spacecraft is regarded as an experimental apparatus to study the body/plasma interaction in space plasma physics.

On the other hand, the study of the spacecraft environment is required from a standpoint of space utilization. The environment surrounding the spacecraft is considerably different from the natural space environment due to the disturbances generated by the spacecraft itself. The spacecraft-generated disturbances are stronger and wider for the larger spacecrafts planned in the coming space utilization era. The knowledge of the spacecraft environment is indispensable for planning and designing the space utilization experiments.

2. SFU Environment Diagnostic System

The SFU environment diagnostic system is designed not only as a standard diagnostic system for the space utilization era, but also to study the spacecraft environment from a standpoint of space science. The system consists of a mission-independent diagnostic subsystem (Environment Monitoring System; EMS) and a mission-dependent diagnostic package (Space Plasma Diagnostic Package; SPDP). The EMS measures standard environmental parameters independently on the mission, while the SPDP measures the environmental parameters depending on each mission. The combination of the mission-independent and mission-dependent instruments makes it possible to constitute an optimum diagnostic system flexibly for each SFU mission. The EMS is composed of a diagnostic package on the SFU platform (Space Environment Monitoring System; SEM) and four smaller packages (Payload Unit Environment Monitoring System; PEM) distributed in each payload unit box. The SEM has two vacuum gauges, a mass analyzer, a Langmuir probe, a floating probe, an impedance probe, two wave receivers, a 3-axes micro-g meter, and 8 pieces of test material attached to the platform of the package (Fig. 1). The PEM has a 3-axes micro-g meter and a Pirani pressure gauge (Fig. 2). On the other hand, the SPDP, also installed on the SFU platform, has a visible spectrometer, an electron density fluctuation detector, a 3-axes magnetometer, and three pieces of test material combined with laser diodes (Fig. 3). The performance of the SFU diagnostic instruments are summarized in Table 1. These instruments are designed based on the instruments onboard the scientific satellites and sounding rockets, but are modified to satisfy the requirements to measure the spacecraft environment. The two diagnostic packages configured on the SFU platform are shown in Fig. 4.

2.1 Multi-point Measurement

Since the spacecraft environment is generated by complicated processes, measurements at one location are not sufficient to identify the physical mechanism. This is one of the

Table 1. SFU Diagnostic Instruments

Instrument	Characteristics
Mission-Independent (EMS)	
Exposed (EMS-SEM)	
Pressure Gauge	Two Ionization Gauges $5x10^{-4}$~10^{-8} Torr
Mas 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 ±10 mg 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

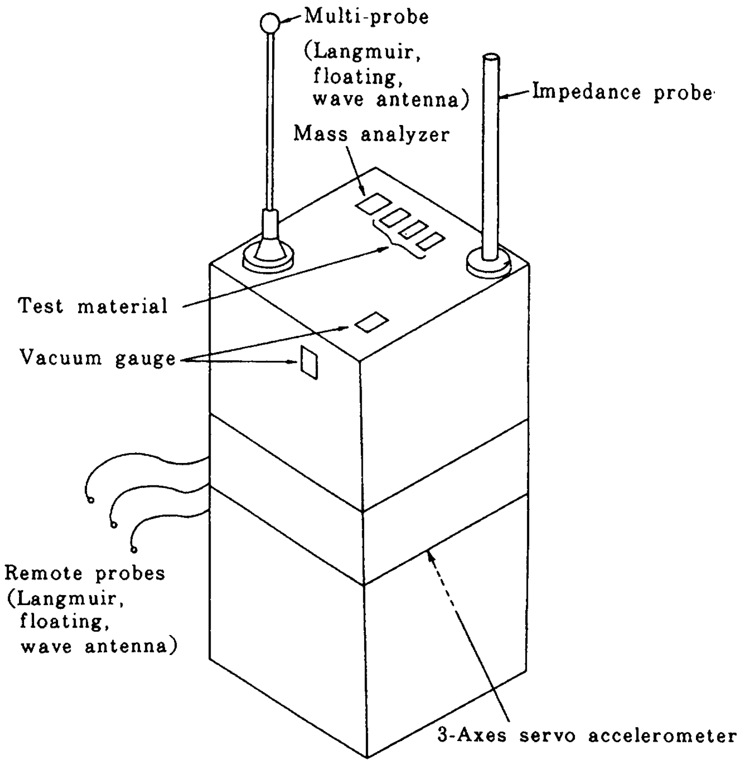

Fig. 1. EMS-SEM Diagnostic Package on SFU Platform

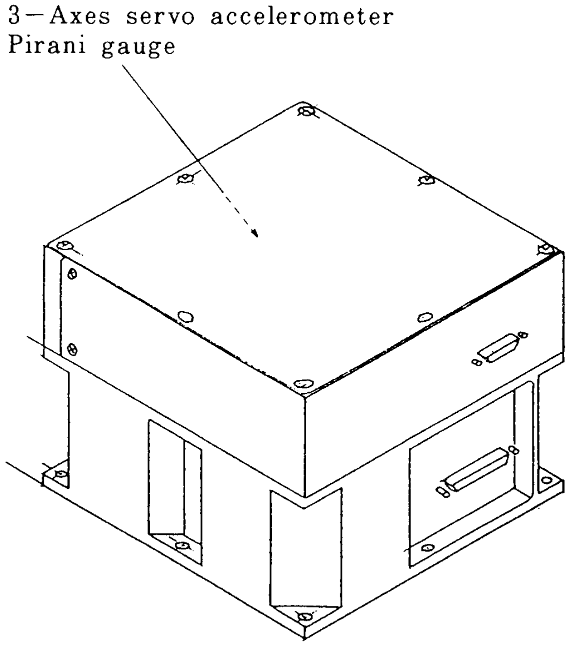

Fig. 2. EMS-PEM Diagnostic Package in Payload Unit Box

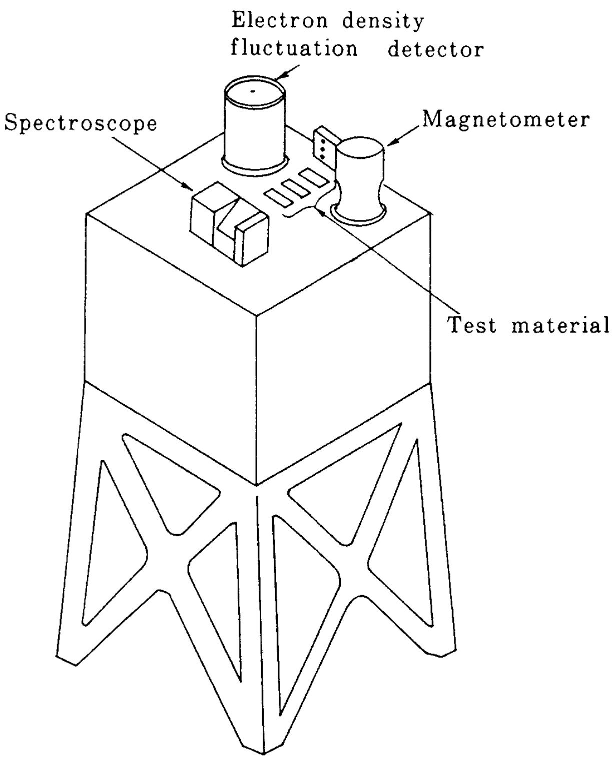

Fig. 3. SPDP Diagnostic Package on SFU Platform

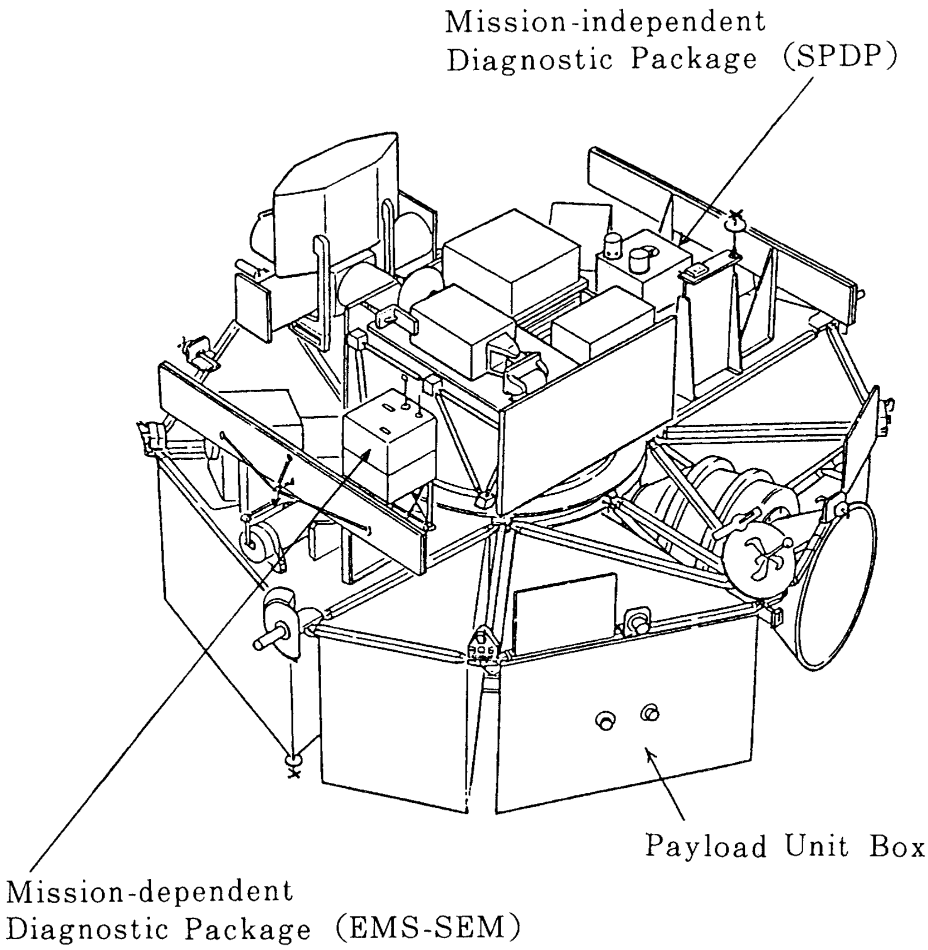

Fig. 4. Configuration of SFU Diagnostic Packages for Mission-1

reasons why the past studies have not been well successful to reveal the physical processes involved in the generation of the spacecraft environment. The SEM has three sensors (Fig. 5) besides one sensor on the diagnostic package to measure the plasma density, floating potential and plasma waves, and are distributed over the SFU platform. Two of them are attached to the SFU platform and the other is attached to the rear side. The plasma environments both in the ram and wake sides are simultaneously measured. There are two vacuum gauges installed in the SEM. One of the 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 and the others in the payload unit boxes.

2.2 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. In addition to this, the electron density oscillation up to 30 kHz is detected by a new measurement technique, a combination of a Langmuir plate probe and an electron detector. The electrons entering a hole at the

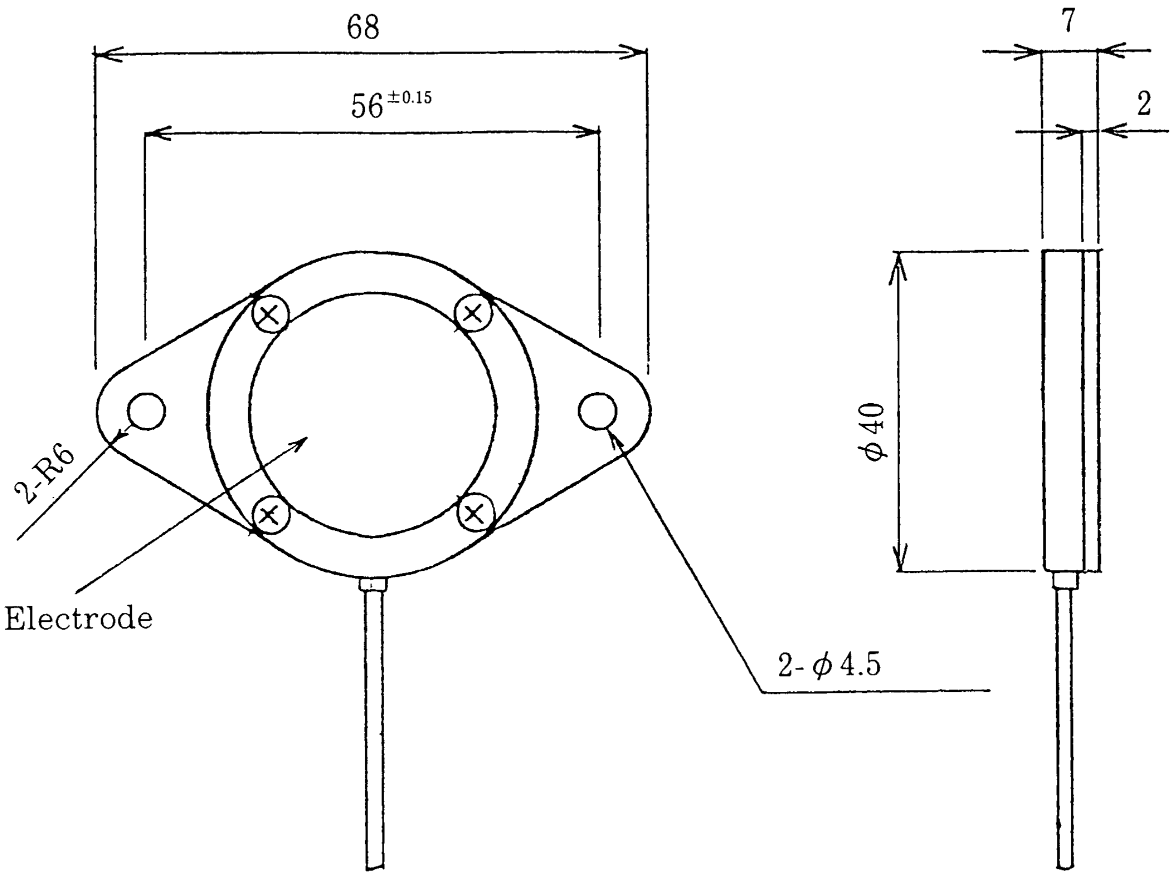

Fig. 5. Remote sensors distributed on SFU. They are used as Langmuir probes, floating probes, and wave antennas.

center of the electrode which is biased positively to the electron saturation region are detected by a channeltron. The oscillation of the electron current reflects 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. This scheme will be a great help to identify the mode of the waves.

2.3 Spectroscopy Combined with Test Material

The visible spectroscope will be used to study the surface degradation of the test material, as well as to observe the optical environment surrounding the SFU. A thin transparent film is coated with a test material under which a laser diode is installed. The change of laser light transmission which is in inverse proportion to the thickness of the material layer is measured by the spectroscope (Fig. 6). Three sets of test material and laser diode are attached on the top panel of the SPDP. The spectrums of the reflected sunlight from the surface of the test material are also analyzed by the spectroscope to study the surface change.

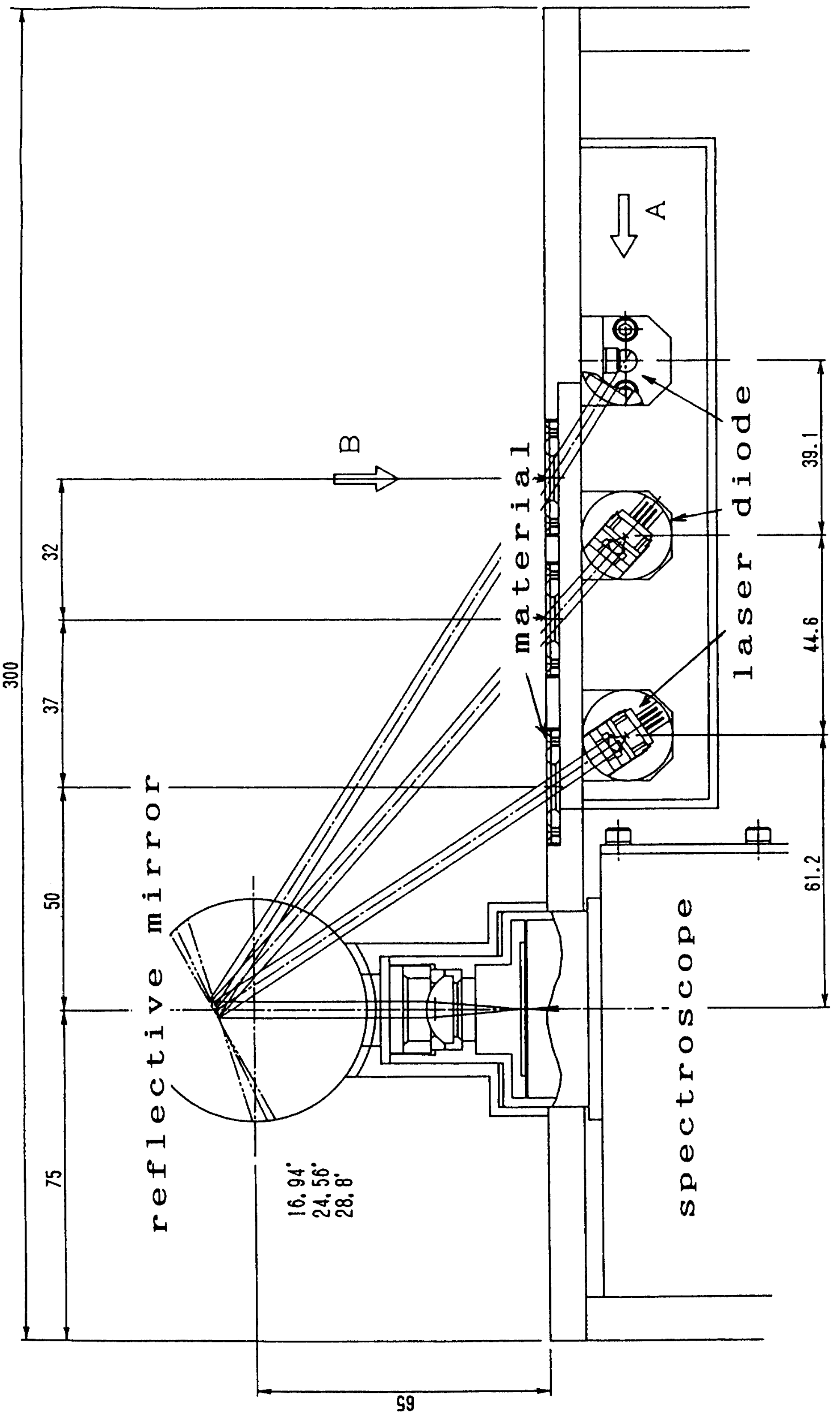

Fig. 6. Combination of thin material, laser diodes, and a spectroscope to study degradation of material.

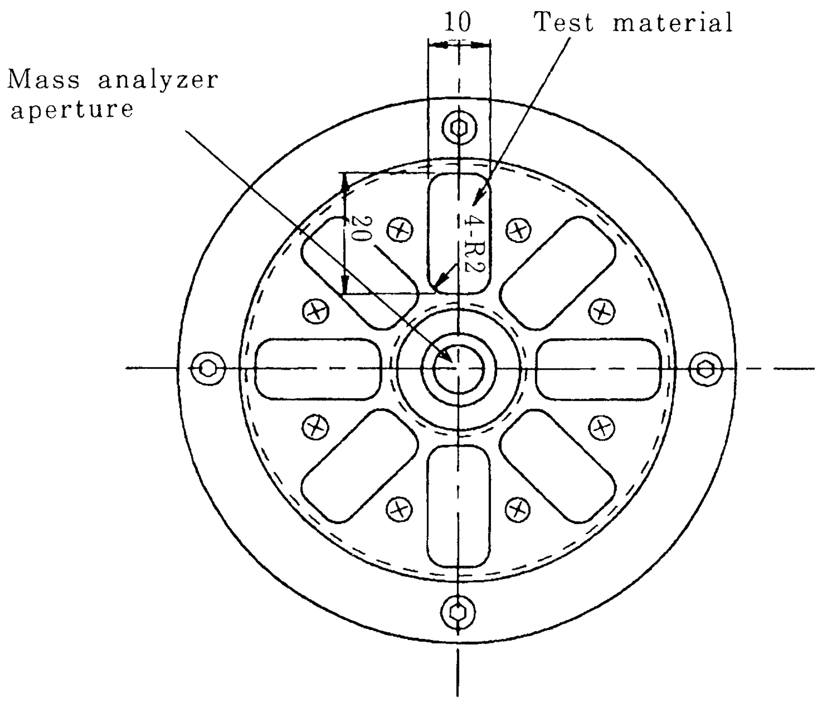

Fig. 7. Combination of test material and a mass analyzer to detect surface atomic/molecular reaction.

2.4 Mass Spectroscopy Combined with Test Material

8 pieces of test material are installed near the aperture of the mass spectrometer (Fig. 7). The molecules produced by atomic/molecular reactions such as oxidization and nitrification at the material surface will be detected by the mass spectrometer. The surfaces of these material are also analyzed by an electron microscope and a spectroscope after recovery. Some of them will be subject to a mechanical test to measure the change of structural characteristics.

3. Scientific Objectives

3.1 Plasma Environment Surrounding SFU

A spacecraft moving with a supersonic velocity in the ionosphere will produce a strong plasma disturbance in the surroundings (Fig. 8). In the front, the ions reflected by the spacecraft will excite low-frequency ion mode waves. A void-region where the space plasma and gas are excluded will be generated in the rear side. The scale of the plasma void-region (plasma wake) will extend about ten meters behind the SFU as shown in Fig. 9. Plasma diffusion toward the void-region will cause plasma cooling and ion acceleration (Gurevich et al., 1966). Fig. 10 shows the profile of plasma density, ion temperature and ion drift velocity in case of the SFU. The accelerated plasma streams will collide at the far wake region, resulting in the two stream instabilities.

The plasma effects generated near the SFU are directly related to the phenomena excited near the natural space body moving in the space plasma. In the wake-side of the Venus, the wake effects such as a plasma reduction and a high-level density fluctuation have actually been observed by the Venus probes. One possible explanation for the generation of the plasma clouds in the night-side Venus observed by the Pioneer-Venus (Brace et al., 1982) has been given by the ion acceleration of the wake model.

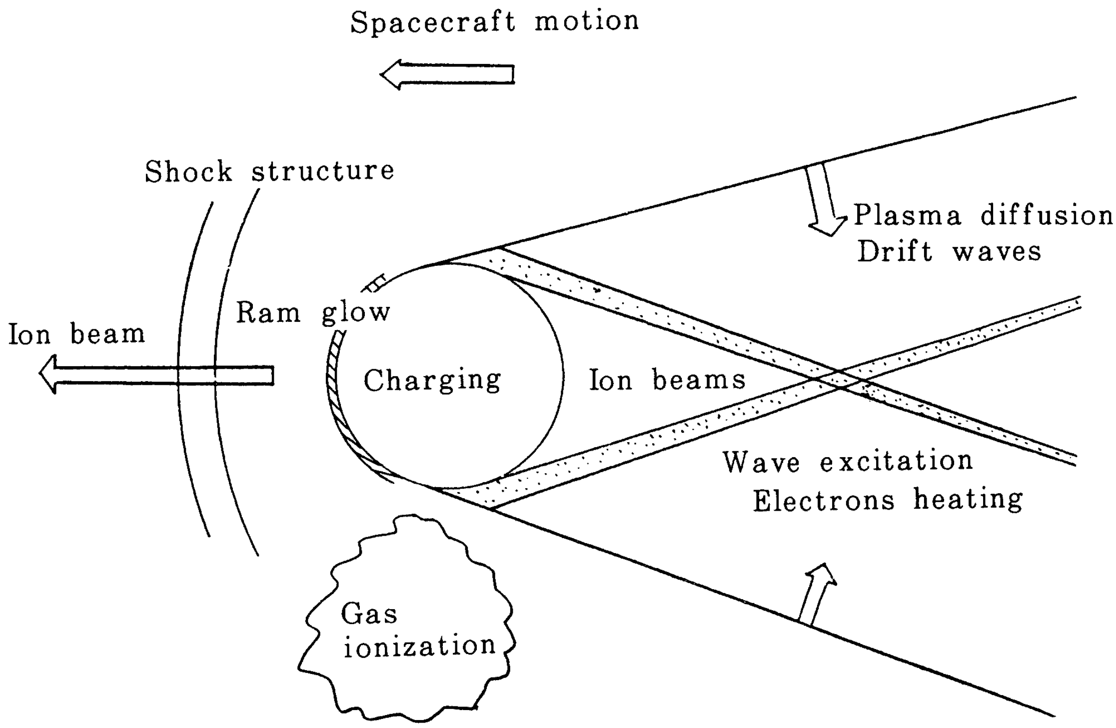

Fig. 8. Plasma environment surrounding a spacecraft moving in the ionosphere

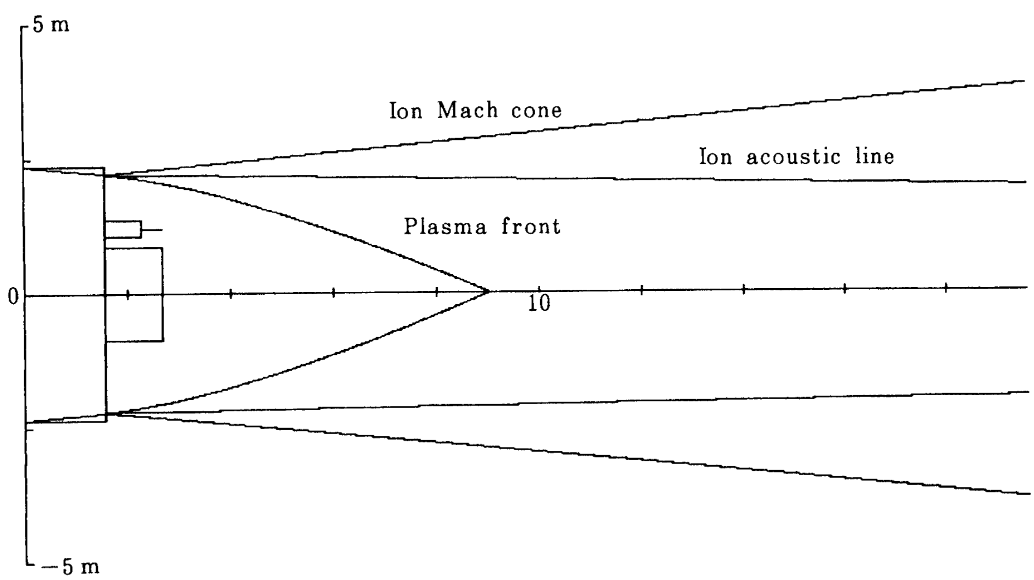

Fig. 9. Plasma environment structure behind the SFU calculated by a one-dimensional model for plasma diffusion.

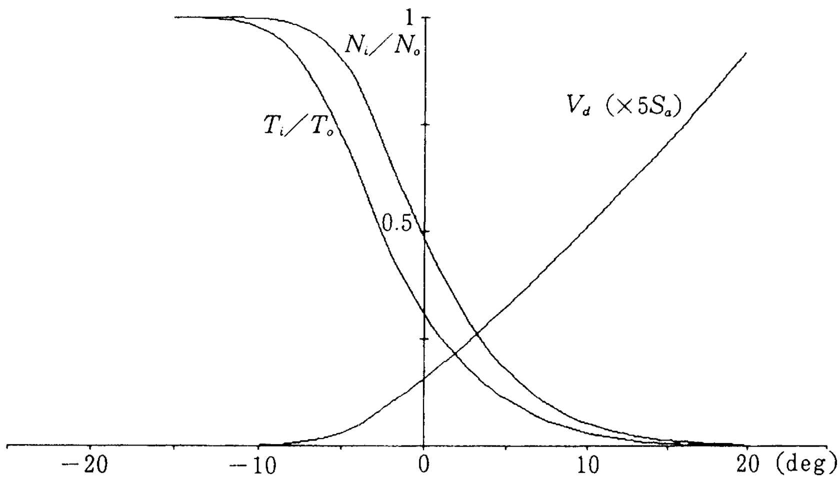

Fig. 10. Distribution of plasma density, ion temperature, and ion drift velocity in the SFU wake. Angle (−20~+20°) is measured from a straight backward line at the edge of the spacecraft. Sa is the ion acoustic velocity.

The study of the spacecraft plasma environment has been carried out repeatedly by the Space Shuttle, but still remains in a preliminary stage. The plasma-void region in the wake (Siskind et al., 1984), low frequency plasma waves in the ram side (Pickett et al., 1985), density fluctuation in the wake side (Murphy et al., 1986), and temperature change both in the wake and ram sides have been detected. But the structure of the plasma wake, change of the ion distribution function in the wake have not been studied and the physical processes for the density fluctuation and the wave generation have not been identified yet. Furthermore, there are many mysterious problems still left unsolved; the ion beams observed in the ram direction in STS-3 experiment (Stone et al., 1983), the wake glow observed by the AE-C satellite (Torr, 1983) suggesting a strong plasma process in the wake side, and inconsistent results on the electron temperature in the ram and wake sides (Siskind et al., 1984; Murphy et al., 1986). The major scientific objective of the SFU environment study is to reveal the physical processes of the plasma phenomena excited by the body-plasma interaction and to apply the results to the space plasma physics.

3.2 Gas/Plasma Interaction

The gas/plasma interaction takes 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. 11 shows possible physical processes involved in the gas/plasma interaction (Sasaki, 1988). 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. The gas/plasma interaction possibly play an important role for the generation of the Io plasma torus and moon plasma. The gas/plasma interaction processes are believed much more complicated than previously expected. The SFU diagnostic system will reveal the physical processes involved in the gas/plasma interaction in space.

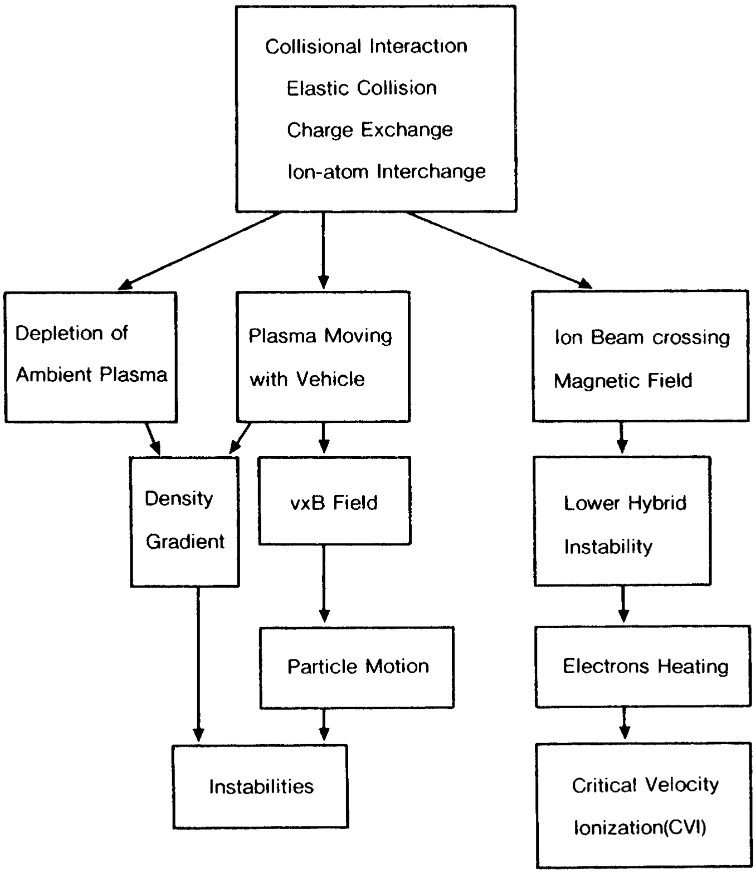

Fig. 11. Possible physical processes involved in gas/plasma interaction in space.

3.3 Gas/Solid, Plasma/Solid Interaction

The problem of particle/solid interaction is directly related to the degradation of the space material and structure, and is now a big concern in the space development technology. One of the important issues is the degradation of exposed material by the active atomic oxygen which was first found by the space shuttle. These 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 (Torr, 1983; Swenson et al., 1985; Slanger, 1983; Green, 1984; Prince, 1985), but the reaction process has not been identified yet. The collision 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 diagnostic instruments, especially the spectroscope and the neutral mass analyzer combined with the test material, will reveal the processes in the solid/gas and solid/plasma interaction which have not been well studied by the past spacecrafts.

4. Diagnostics For Science And Technology Experiments

4.1 Electric Propulsion Experiment

In the SFU Mission-1, a magneto-plasma dynamic arcjet (MPD-AJ) is tested as a thruster. In the experiment, they will try to change the SFU orbit by operating the MPD-AJ at 1 kW level. The MPD-AJ is operated at 1.4 Hz with hydrazine gas. About 625 Joules of energy is released at a shot, generating a thruster more than 30 mN. Besides the orbit change test, the modification of plasma environment during MPD-AJ operation will be studied.

In the SEPAC experiment by Spacelab-1 in 1983, a variety of electromagnetic phenomena were observed during the MPD-AJ operation. The most prominent effect was an excitation of discharge-like phenomena surrounding the orbiter which lasted for several tens of milliseconds even after the termination of MPD-AJ discharge (Fig. 12; Sasaki et al., 1986). One possible explanation for the discharge is the critical velocity ionization triggered by the MPD-AJ plasma, but no definite conclusion on the mechanism has been obtained because the data were too scanty. In the SFU experiment, the repetition rate of the MPD-AJ operation is higher by more than 10 times and the experiment time is longer by more than 100 times than the SEPAC experiment. The plasma detectors, wave receivers and spectroscope will be used to clarify the plasma phenomena excited by the MPD-AJ operation.

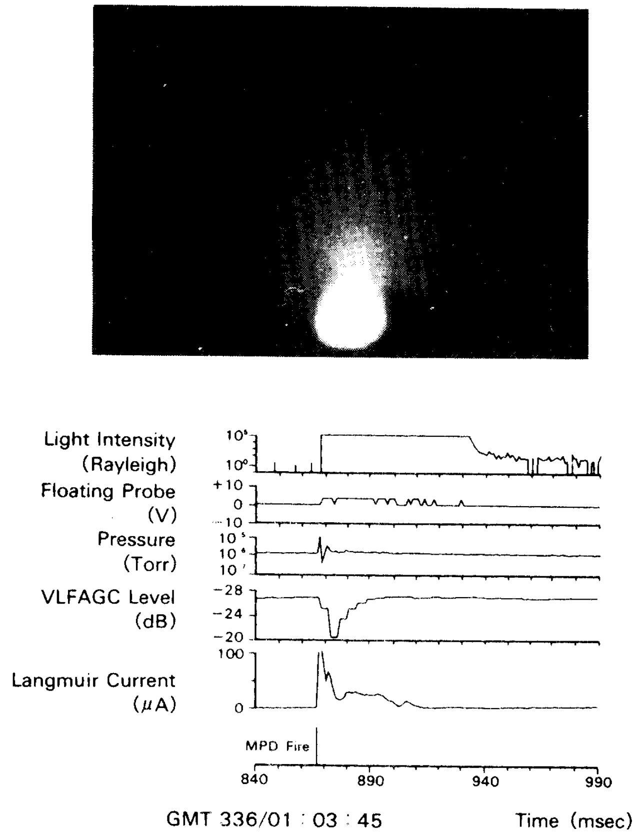

Fig. 12. Discharge-like phenomena triggered by MPD-AJ operation observed in Spacelab-1 SEPAC experiment in 1983.

4.2 High Voltage Solar Array Experiment

A high voltage power generation has been proposed for the space facilities consuming a high power. A power generation at 100–200 V is now under consideration for the Space Station. From the requirement to reduce the power loss, power generation at a higher voltage is profitable, but a high voltage may interact with the ambient plasma, resulting in a current leak, arc discharge, and associated damage to the solar cells and the power system in the worst case.

In the high voltage solar array experiment on SFU-1, the interaction of a high voltage up to 500V with the ambient plasma will be studied and an optimum voltage will be found for the high voltage power generation at the same altitude as the Space Station. In the experiment, an electrodynamic drag generated by the high voltage solar arrays is also studied by detecting the change of the SFU attitude.

The problems of the high voltage/plasma interaction are closely related to the phenomena surrounding the high voltage space bodies, such as the Jupiter Io. They are also related to the study of the satellite charging in the magnetosphere.

The leak current through the ambient plasma is measured by a current detector inside their experiment controller. The diagnostic package will measure the plasma environment modified by the high voltage solar arrays. According to the past sounding rocket experiment, a potential difference between the rocket and surrounding plasma generates wave emissions in the low frequency around several kHz (Fig. 13; Sasaki et al., 1988). When an arc discharge is ignited, high frequency emission beyond MHz will be excited. These emissions are detected by the wave receivers. The SFU potential during the high voltage solar array experiment is measured by the floating probes. The spectroscope sweeping its line of sight will detect the location of the arc discharge on the solar panel. The plasma detectors will measure the scale and characteristics of the plasma sheath generated by the high voltage solar arrays. These diagnostic instruments will detect the precursor effect for the discharge, which is very important for actual application.

5. Support Operation For SFU-1 Experiments And Core System

The diagnostic packages will support the experiments and SFU system operation by measuring the environmental parameters.

5.1 Micro-g Measurement

Since the SFU is an unmanned free-flying platform, the g-environment is expected to be superior to the Space Shuttle and the Space Station. On the SFU Mission 1, material experiment, biology experiment, three furnaces experiments, and gas dynamics experiment are requiring a high quality micro-g environment. The g-environment is measured by 4 sensors in the payload unit boxes containing the micro-g experiments and by a sensor installed in the SEM on the SFU platform. The SEM sensor can measure the g-environment with a high frequency response more than 30 Hz typically for 30 min. The PEM sensors measure the g-environment inside the payload unit box typically every 4 sec continuously during the mission period. Combining the data from the SEM and PEM micro-g sensors, the baseline of SFU g-environment is obtained. During the micro-g experiments are operating, the PEM will monitor unexpected g-disturbances at a lower sampling rate, typically every 64 sec.

5.2 Gas Leak Monitor

There are a plenty of sealed containers, pressure vessels and lines onboard the SFU. The leakage from these components will be identified by the mass analyzer because the gas species contained in these components are quite different from the ambient space constituents. The ionization gauges on the platform which have a high sensitivity of 1×10^{-8} Torr are also used to detect the gas leakage. The leakage of the heat pipes or sealed containers inside the payload unit will possibly be detected by the Pirani gauge with low sensitivity (10 mTorr). Once these gas sensors detect any abnormal gas leakage, a warning will be given to the experiments and SFU operators.

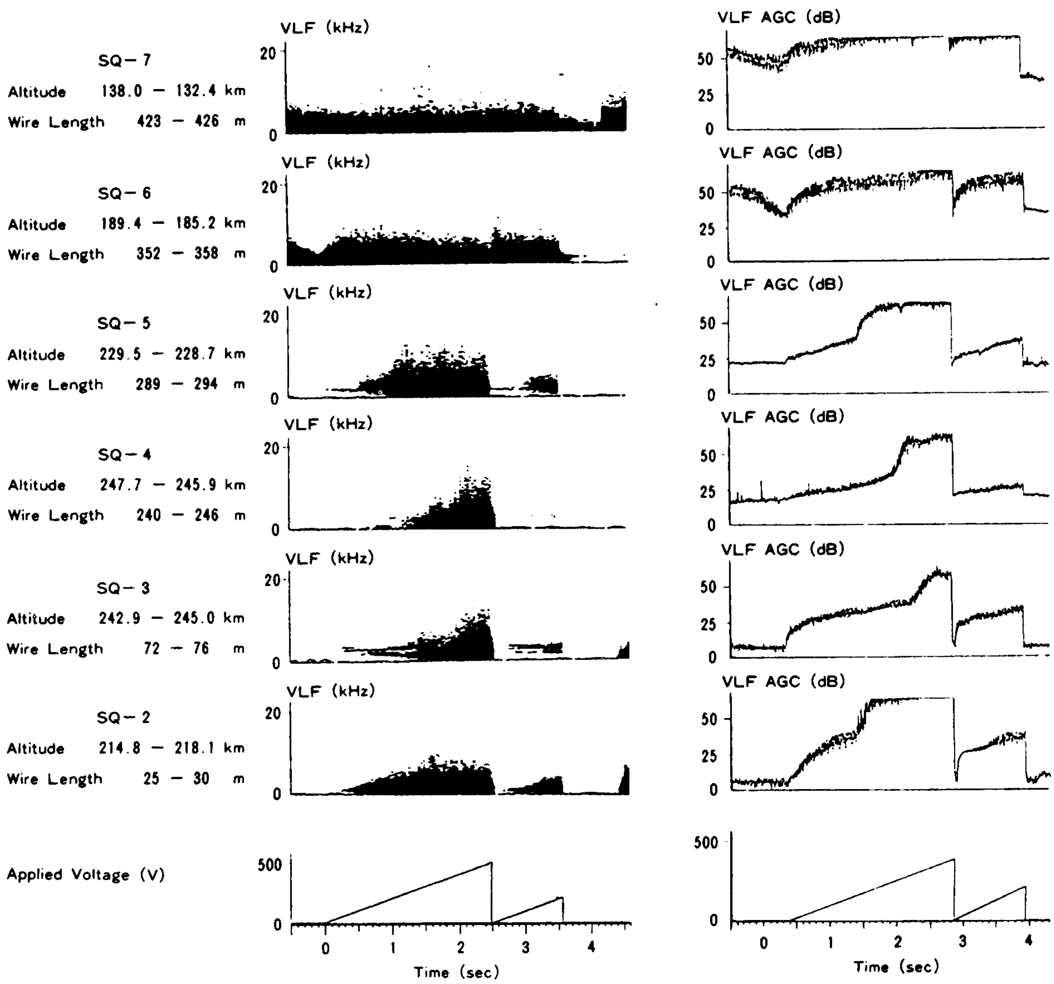

Fig. 13. VLF emissions excited by a potential difference between a spacecraft and ambient plasma, observed in tethered rocket experiment (CHARGE-2) in 1985.

5.3 Contamination Monitor

The gas sensors, a mass analyzer and two ionization gauges, can monitor the contamination for contamination-sensitive instruments, such as infrared telescope and the solar panels. The measurement of the material thickness by laser transmission described in 2.3 can detect even a mere contamination on the material layer.

5.4 Electrical Failure Detection

Electrical failure, such as discharge, short circuit and over-current, usually generates an intense electromagnetic radiation. The radiation will be detected by the two wave receivers. If the electrical failure is associated with the ambient plasma, the plasma disturbance excited by the electrical failure will be detected by the plasma probes distributed over the SFU. These information will be used to locate the problems.

6. Future Plan

6.1 Plasma Interactions Monitoring System for Space Station

Plasma Interactions Monitoring System (PIMS) for Space Station has been proposed by NASA MSFC as an international scientific collaboration program. The PIMS objectives are to provide measurements to verify space station external environment specifications, to provide data to support the development of dynamic space station environment data base, to detect and locate space station problems, and to provide environment data to support attached payloads and their operations. PIMS will consist of a variety of detectors to measure the spacecraft environment. Table 2 summarizes the characteristics of the PIMS. 5 or 6 nearly-equivalent diagnostic packages will be distributed on the space station to measure the environment simultaneously at the different points. Besides the support function for the operation of space station and attached payloads, PIMS will be used to study the spacecraft environment from a scientific point of view. The PIMS program is an advanced concept of the SFU environment monitor.

6.2 Tether Diagnostic Package

Multi-point measurements are carried out on the SFU Mission-1, but all sensors are fixed on the SFU structure. Considering that the spacecraft-generated disturbance will extend more than 100 m for the scale of SFU-class spacecraft, sensors fixed at the spacecraft are not sufficient to obtain the entire picture of the spacecraft environment. A tethered diagnostic package able to reach up to 1,000 m apart from a spacecraft is now proposed as one of the candidates for the SFU Mission-2 experiments. The basic concept of the SFU space tether experiment is illustrated in Fig. 14. The tethered subsatellite will carry plasma detectors, a pressure gauge and wave receivers. This experiment will be combined with a new technology experiment to study the dynamics of a space tether during the deployment, station-keeping and retraction.

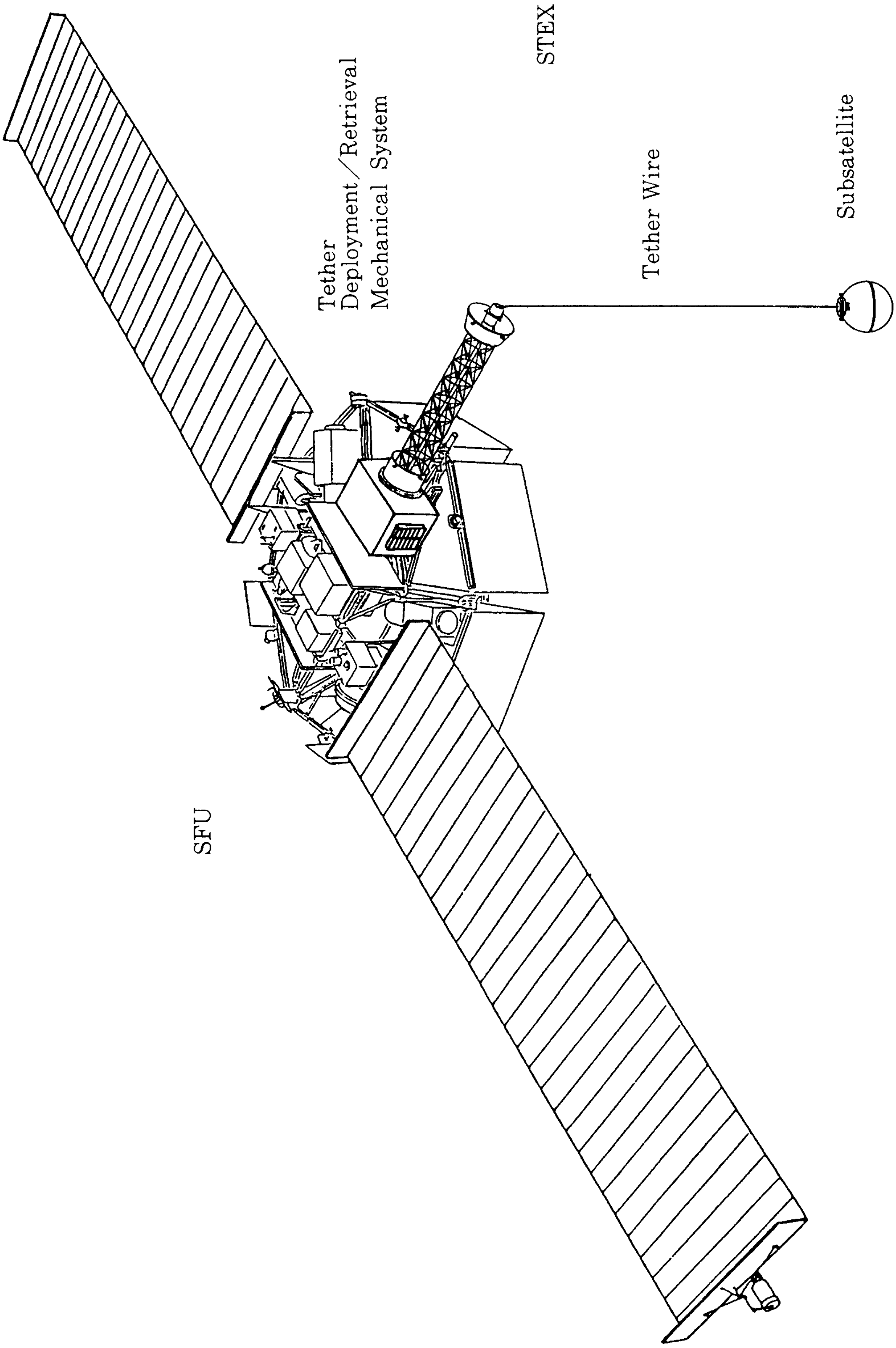

Fig. 14. Space tether experiment proposed for SFU future mission. A tethered subsatellite carries diagnostic instruments to study the spacecraft environment in a wide area.

Table 2. PIMS Characteristics (Proposed)

System Characteristics		
	Weight	100 kg/unit
	Scale	$1 \times 1 \times 1$ m^3
	Power	100 Watt/unit, 208 VAC 20 kHz S/C power
	Data Rate	100 kbps/unit, with low data rate capability
	Command	1 kbps
	Thermal Control	passive with heaters
	Sensor Mounting	flat-plate-mounting
	Platform	rotatable through 320 degrees with tilt rotation 3 degrees/sec
	S/S Attachment	a simple screw adapter and plate
	Operation	minimum crew support
	Unit Number	5 units (6 units desired)
Placement	Installation Phase	3 units in the initial phase
		2 units in the second phase
	Location	4 units on truss nodes
		1 unit on JEM/EF
		1 unit on mobile system (desired)
Diagnostics	Common Instruments	Langmuir probe
		pressure gauge
		QCM
	Unit 1, 5	electric and magnetic field monitors
		ion/neutral mass spectrometer
		ultraviolet and visible spectrometers
	Unit 2, 4	electric and magnetic field monitors
		energetic particle detectors
		laser radar for particulate/debris detection
	Unit 3	near-infrared and election spectrometer
		mass spectrometer for the thermal and medium energy ions

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