Subsatellite Studies of Wave, Plasma, and Chemical Injections from Spacelab

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Three classes of Orbiter subsatellites have been identified to support Spacelab active plasma investigations: 1) small, throw-away detectors which are not reusable; 2) medium-sized, recoverable subsatellites, and 3) large, maneuverable subsatellites with a significant orbit-adjust capability. A class 1 subsatellite—the Plasma Diagnostics Package (PDP)—was utilized attached to the Remote Manipulator System on the STS-3 flight to diagnose effects of the fast pulse electron generator electron beam and of Orbiter-produced plasma wakes. On the Spacelab-2 mission, the PDP will be released as a subsatellite to examine Orbiter wakes out to 20 km and the ionospheric plasma depletion effects resulting from planned Orbiter engine-burns. Class 1 Magnetospheric Multiprobes and a class 2 Recoverable Plasma Diagnostics Package are under development for the follow-on Spacelab missions. In addition, a study has been completed on a class 3 Solar-Terrestrial Subsatellite. All of these planned subsatellites provide measurements of plasma composition, wave fields, particle spectra, and optical emissions.

Introduction

THE Shuttle/Spacelab system now offers the possibility to provide the platform, the weight and power, and the manned control of space plasma investigations in low Earth orbit.[1] Planned active space plasma physics investigations include the emission of very low frequency (vlf) waves to study propagation and particle interaction effects; the emission of high-frequency (hf) waves to sound the local and remote ionospheric density structure; the injection of energetic electron beams and of hot plasma to examine stability criteria and to remotely measure electric fields along the magnetic field line path; the stimulation of low-frequency waves and the establishment of large-scale current systems by an electrically conducting tether associated with a modulated electron emission source; the release of known materials such as water or H_2 in the vicinity of the Orbiter to emphasize particular chemical reactions and the release of materials such as Ba^+ at high altitudes to trace magnetic field lines and to enhance electric field phenomena; and the diagnostics of wakes of bodies with known shapes and electrical properties.

Diagnostic measurements of the effects stimulated by these active investigations can be carried out with instruments located in the Spacelab payload, manipulated by the 15-m Remote Manipulator System (RMS), carried by other free-flying satellites or stationed along the ground track—such as incoherent scatter radars and optical observatories. Probably the most effective diagnostic element is that of instrumented subsatellites which operate in the vicinity of the Orbiter from the range of the RMS out to several hundred kilometers. Table 1 lists estimates for a few scale lengths that are important for defining the regions to be explored in detail in the active space plasma investigations. These scale lengths range from 10-100 km.

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Heritage of the Spacelab Subsatellite Systems

In the mid-1970s at the conclusion of the successful Skylab program, groups of international scientists began to consider the investigations which might be conducted using the upcoming Shuttle/Spacelab system. These scientists identified scientific objectives for both active and passive measurements, defined instrument complements, and considered mission scenarios in some detail. These studies were coordinated under the Atmosphere, Magnetosphere, and Plasmas-In-Space (AMPS) program.

AMPS scientists defined a set of experiments and the type of major instrument facilities necessary to carry out these experiments.[2] The requirement for subsatellites to make in situ measurements was identified for 8 of these 17 diverse experiments. In the polar region, subsatellites were required for four of the five investigations of natural phenomena. Table 2 gives a list of specific instruments forming model payloads for a subsatellite to make the measurements required for a particular set of investigations.[3,4] These instruments were assumed to be similar to those flown on numerous free-flying satellites.

In 1976 the AMPS Working Group completed its work to suggest a comprehensive and coordinated set of instrumentation and investigations to acquire information on the processes that control the Earth's environment and its susceptibility to modification by human and natural forces.[4] The work and recommendations of the AMPS group were reviewed by an independent panel of scientists.[5] Based on this report, facility definition teams were established to study further the objectives and the implementation of these major Spacelab facilities: LIDAR, spectroscopy, particle beams, chemical releases, subsatellites, and wave injection. An important goal of these teams was to produce specifications and schedules for the evolutionary development and use of the facilities.

The subsatellite facility definition team met between 1977 and 1979. This committee reiterated the need for Spacelab subsatellites as follows[6]:

1) The subsatellites can be equipped with instrumentation to measure/map perturbations generated at or by the Shuttle.

2) The subsatellites can be used in a cooperative mode in

support of active experiments conducted from Spacelab wherein remotely located sensors are required.

3) Subsatellites can be used to make measurements that might otherwise be masked by the Shuttle environment.

4) The subsatellites can be equipped with instrumentation to obtain simultaneous measurements at several points in space.

Table 1 Scale lengths for active space plasma investigations

Wavelength for 300 Hz whistler mode wave, km	10-100
Far field of Orbiter antenna at 30 MHz, km	9
Gyrodiameter for 7.5 keV electron, m	8
Orbiter motion during energetic electron transit to opposite hemisphere and back, km	5-20
Size of plasma depletion regions from Orbiter burns, km	100
Extension of Orbiter-induced plasma wake, km	3

Further consideration of specific requirements for subsatellites and the resources that might be available to develop them lead to three classes of subsatellite systems.[7] Table 3 identifies these classes, some performance characteristics, and approximate cost estimates. Both the single mission/class 1 and the recoverable/class 2 subsatellites seem to be within the capabilities of a principal investigator's institution whereas the maneuverable-recoverable/class 3 subsatellite would be a facility to be developed and managed by a NASA Center or by industry. In 1979, industry was invited to submit proposals on the adaptation of existing qualified spacecraft to the class 3 subsatellite requirements; this satellite program was named the Solar-Terrestrial Subsatellite (S-TSS).[8] More details on the development of all three classes are given in the following sections.

Current Plasma Diagnostics Package Flight Program

A throw-away subsatellite falling within the class 1 category has been developed for flight on two Shuttle missions. On the

TABLE 2. INSTRUMENT COMPLEMENT FOR ATMOSPHERE, MAGNETOSPHERE AND PLASMAS-IN-SPACE MODEL PAYLOADS[3]

MODEL PAYLOADS / EXPERIMENTS	LANGMUIR PROBE	ELECTRON DETECTOR 0.1 - 20 keV	ELECTRON DETECTOR 15 keV - 3 MeV	NEUTR. TEMP. & WIND EXPERIMENT	NEUTRAL MASS SPECTROMETER	ION MASS SPECTROMETER	ION DRIFT DETECTOR (RPA)	PROTON DETECTOR 0.5 - 20 keV	ION ENERGY & MASS ANALYSIS 10 keV < E/Q < 30 keV	ION ENERGY & MASS ANALYSIS 25 keV < E/Q < 10 MeV	TRIAXIAL MICRO ACCELEROMETER	AC/DC ELECTRIC FIELD	DC MAGNETIC FIELD (FLUXGATE)	AC MAGNETIC FIELD (SEARCH COIL)	RESONANCE CONE EXPERIMENT	QUADRUPOLE PROBE	GRID ANTENNA	NEAR IR - TELESCOPE	UV - TELESCOPE
1. AERONOMY	X	X		X	X	X	X	X			X								
2. MAGNETOSPHERIC (PLASMA & FIELDS)	X	X					X	X	X			X	X	X					
3. MAGNETOSPHERIC (PARTICLES)	X	X	X				X	X	X	X				X					
4. PLASMA ACCEL. MONITORING	X	X	X			X	X	X	X			X	X	X					
5. DEVELOPMENT PAYLOAD	X						X					X	X	X	X	X	X		
6. CONTAMINATION (EMI, CHEMICAL)	X				X	X	X					X	X	X					
7. OPTICAL	X				X	X	X											X	X

TABLE 3. COMPARISON OF SUBSATELLITE CLASSES(A)

SUBSATELLITE PERFORMANCE	PRINCIPAL INVESTIGATOR CLASS: SINGLE MISSION (CLASS 1)	PRINCIPAL INVESTIGATOR CLASS: RECOVERABLE (CLASS 2)	FACILITY CLASS: MANEUVERABLE (CLASS 3)
NUMBER PER MISSION	1 TO 6	1 TO 4	1 TO 2
MAXIMUM SIZE	42" DIA, 27" H	60" DIA, 42" H	> 60" DIA, > 42" H
WEIGHT	25 TO 250 KG	250 TO 500 KG	> 500 KG
POWER B = BATTERIES, S = SOLAR CELLS, F = FUEL CELL	20-40 WATTS (B)	50-150 WATTS (B & S)	100-1000 WATTS (B & S OR F)
DATA: TELEMETRY	10-100 KBPS + 50 KHZ	16-512 KBPS + 250 KHZ	256 KBPS + 250 KHZ + TV
TAPE RECORDER	NONE	512 KBPS + 250 KHZ	MBPS + 250 KHZ + TV
COMMANDS	NONE-6 (DISCRETE)	16-64 (SERIAL)	> 256 (SERIAL)
ANTENNAS AND BOOMS	< 10M, ONE SHOT	< 10M, RETRACTABLE	< 100M, RETRACTABLE
ALTITUDE/ORBIT ADJUST	NONE SPIN STABILIZED	CRUDE ACS FOR SPIN AXIS	3 AXIS STABILIZED, ΔV ~ 2500-FT/SEC
LIFETIME ON-ORBIT	DAYS	MONTHS	MONTH UP TO YEARS
NUMBER OF INSTRUMENTS	3-8	6-12	10-16
DEVELOPMENT COST	$3-5M	$10-20M	$50-100M
REFLIGHT COST	~ $2M	~ $2M	~ $5M

(A) ADOPTED FROM REFERENCE #7.

first flight—STS-3, which was flown in March 1982 as part of the Office of Space Science-1 pallet—this Plasma Diagnostics Package (PDP) was not released into orbit but was manipulated by the systems RMS out to distances of 15 m from the Orbiter. On the second flight—the Spacelab-2 mission scheduled for November 1984—the PDP is spun up and released by a special end effector on the RMS. The Orbiter will keep the PDP within telemetry range (~ 100 km) for several days.

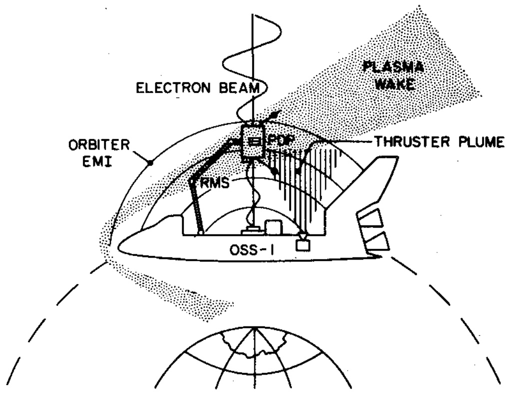

Fig. 1 OSS-1/PDP science objectives.

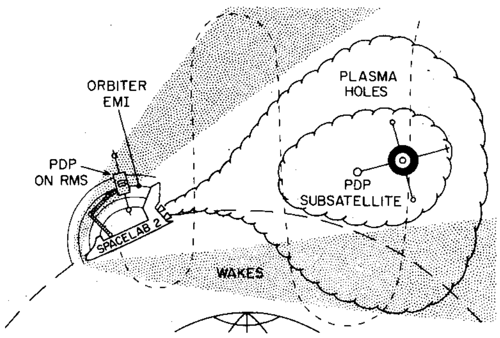

Fig. 2 Spacelab-2/PDP science objectives.

In Fig. 1 the PDP on the RMS is depicted making measurements in and about the Orbiter. The specific objectives for the PDP on the STS-3 flight included:

1) Study the Orbiter-magnetoplasma interactions within 15 m of the Orbiter through the measurement of electric and magnetic fields, ionized particle wakes, and generated waves.

2) Determine the characteristics of the electron beam emitted from the fast pulse electron generator (FPEG) experiment out to a range of 15 m from the Orbiter and measure the results of beam-plasma interactions in terms of fields, waves, and particle distribution functions.

3) Measure and locate the sources of fields, electromagnetic interference (EMI), and plasma contamination in the environment of the Orbiter out to 15 m.

4) Flight-test the systems and procedures associated with the Spacelab-2 Plasma Diagnostics Package experiment with particular emphasis on operations with the Remote Manipulator System (RMS), on unlatching and relatching the PDP unit, and on evaluating the radio frequency (rf) telemetry link.

The PDP is cylindrical in shape with a 107 cm diam by 69 cm height with electric field, magnetic search coil, and Langmuir probe sensors extending ~30 cm beyond the cylinder. On top of the PDP is the special electrical grapple fixture for mating to the RMS standard end effector. For STS-3 the PDP weighed 159 kg and used 45 W of Orbiter power. Other flight systems included the release/engagement mechanism (REM), a 400 MHz rf receiving antenna, and an electronics assembly with rf receivers and logic for processing commands and for generating onboard displays.[9]

Within the PDP housing are instruments for measuring characteristics of the plasma environments in the vicinity of the Orbiter and of the phenomena induced by operation of the fast pulse electron generator (FPEG), which is part of the vehicle charging and potential (VCAP) investigation.[9,10] The measurements made by the PDP include magnetic and electric fields, plasma waves, plasma composition, temperature and directed velocity, and energetic particle flux and pitch angle distributions.

For Spacelab-2, the PDP is equipped with batteries (adding 91 kg in weight) for ~7 days of energy and with folding booms to extend the sensors about 1.5 m from the spacecraft body. The PDP is to be released into orbit with the

TABLE 4. PHASED DEVELOPMENT OF SPACELAB FACILITIES(A)

	CY 82	CY 83	CY 84	CY 85	CY 86	CY 87	CY 88
PHASE I (UNDER DEVELOPMENT)							
A. OSS-1 MISSION ----------------------------	▽						
1. PLASMA DIAGNOSTICS PACKAGE ON RMS							
2. VCAP FAST PULSE ELECTRON GENERATOR							
B. SPACELAB-1 MISSION ------------------------------------		▽					
1. SEPAC							
C. SPACELAB-2 MISSION ---			▽				
1. EJECTABLE PLASMA DIAGNOSTICS PACKAGE							
2. PLASMA DEPLETION EXPERIMENTS							
PHASE II (SELECTED FOR DEFINITION)--					-AVAILABLE--		
1. RECOVERABLE PDP							
2. MULTIPROBES							
3. AUGMENTED SEPAC							
4. WISP							
5. CHEMICAL RELEASE MODULE							
6. TETHER							
7. LIDAR							
PHASE III (PROPOSAL STAGE) ---							?
1. S-TSS							
2. OPEN FREE-FLYERS (4)							
3. UARS FREE-FLYERS (2)							

(A) ADAPTED FROM REFERENCE 8

TABLE 5. ACTIVE SPACE PLASMA LAB INVESTIGATIONS

ACTIVE INVESTIGATION/TECHNIQUE	PRIMARY OBJECTIVES	SUBSATELLITE OBJECTIVES
WISP-WAVES IN SPACE PLASMA[13] • 1 KW VLF TRANSMITTER, 1 TO 30 KHZ • 100 METER TIP-TO-TIP ELECTRIC ANTENNA • VLF RECEIVERS ON SUBSATELLITE • HF SOUNDER TRANSMITTER ON ORBITER 0.3 TO 30 MHZ • HF SOUNDER RECEIVERS ON ORBITER AND ON SUBSATELLITE	• EMIT ELECTROMAGNETIC AND ELECTROSTATIC PLASMA WAVES • EFFECT MODE COUPLING AT CRITICAL PLASMA REGIONS FOR CRITICAL PLASMA FREQUENCIES • STIMULATE WAVE-PARTICLE INTERACTIONS LEADING TO WAVE GROWTH AND PARTICLE MODIFICATION • SOUND THE PLASMA VOLUME FOR DENSITY IRREGULARITY STRUCTURES	• MEASURE VLF AND HF WAVE AMPLITUDE AND SPECTRA FOR ELECTROMAGNETIC AND ELECTROSTATIC MODES OUT TO RANGES OF 100'S KM • OBSERVE WAVE GROWTH STIMULATED BY VLF WAVES • OBSERVE RETURNING HF WAVES FROM REMOTE DENSITY IRREGULARITIES
SEPAC-SPACE EXPERIMENTS WITH PARTICLE ACCELERATORS[13] • ELECTRON ACCELERATOR, 7.5 KV, 1.5A, 10 MS - 1 SEC PULSE • MPD ARCJET, 2 KJ/PULSE, 10^9 IONS/PULSE, 250 V ENERGY, 1 MS PULSE, ARGON GAS • DIAGNOSTIC INSTRUMENTS IN ORBITER BAY	• EMIT ENERGETIC ELECTRON AND PLASMA BEAMS TO INVESTIGATE BEAM STABILITY AND BEAM PROPAGATION • UTILIZE ELECTRON BEAM TO STIMULATE ARTIFICIAL AURORAL SPOTS • DIRECT ELECTRON BEAM TO EXAMINE ELECTRIC FIELDS IN THE MAGNETOSPHERE	• MEASURE THE ELECTRON AND PLASMA BEAM EVOLUTION IN SPACE OUT TO RANGES OF 200 KM • REMOTELY SENSE THE PLASMA PARAMETERS ASSOCIATED WITH THE ARTIFICIAL AURORA MAGNETIC FLUX TUBE • TRAIL THE ORBITER TO INTERCEPT ELECTRON BEAMS MODIFIED BY MAGNETOSPHERIC ELECTRIC FIELDS
ELECTRODYNAMICS TETHER SYSTEM[14] • CONDUCTING WIRE EXTENDED UPWARD FROM ORBITER BY 1-30 KM • CONDUCTING BALLOON OF 20-100 METER DIAMETER TETHERED TO END OF WIRE • ELECTRON GUN ON ORBITER	• EXCITE ALFVEN WAVE STRUCTURES BY THE MOTION OF THE TETHER THROUGH THE GEOMAGNETIC FIELD • CREATE A FIELD-ALIGNED CURRENT SYSTEM WITH CLOSURE IN THE IONOSPHERE • SERVE AS AN EFFICIENT VLF WAVE TRANSMITTING ANTENNA	• MEASURE WAVE AMPLITUDES AND SPECTRA FROM ULF THROUGH VLF IN THE NEAR AND FAR FIELD OF THE TETHER • LOCATE FLUX TUBES WITH TETHER INDUCED CURRENT SYSTEMS • DIAGNOSE PLASMA ENERGIZED BY THE POTENTIAL SYSTEM ASSOCIATED WITH THE TETHER
SPACELAB-2 PLASMA DEPLETION EXPERIMENTS[11] • ORBITER OMS ENGINES EMITTING 200-2000 KG OF PROPELLANT COMBUSTION PRODUCTS • SUBSATELLITE, GROUND RADAR, GROUND OPTICAL DIAGNOSTICS OF IONOSPHERIC DEPLETION EFFECTS	• INTRODUCE COMBUSTION PRODUCTS INTO IONOSPHERE TO STUDY CHEMICAL REACTIONS LEADING TO DEPLETION AND REPLENISHMENT OF THE IONSPHERIC PLASMA • STUDY ASSOCIATED OPTICAL EMISSIONS AND RADIO PROPAGATION PERTURBATIONS	• CHARACTERIZE THE PLASMA PROPERTIES BEFORE, DURING AND AFTER RELEASE OF THE COMBUSTION PRODUCTS • MEASURE ASSOCIATED EFFECTS SUCH AS THE STIMULATION OF PLASMA WAVES AND THE ESTABLISHMENT OF PLASMA FLOWS
CHEMICAL RELEASE EXPERIMENTS[13] • TRACE CHEMICALS SUCH AS BA^+ ARE RELEASED FROM ORBITER-BORNE CANISTERS OR FROM A FREE-FLYING SATELLITE ~ 10'S KG PER CANISTER	• CREATE CHEMICAL REACTIONS AT LOW ALTITUDE TO STUDY ATMOSPHERIC PROCESSES • TRACE MAGNETIC FIELDLINES EXTENDING INTO THE MAGNETOSPHERE TO DETECT ELECTRIC FIELD REGIONS	• MAKE IN SITU MEASUREMENTS OF PLASMA CHANGES AS CHEMICAL IS INTRODUCED • DETECT FIELDS, WAVES AND PARTICLE CHARACTERISTICS ASSOCIATED WITH MAGNETOSPHERIC FIELD LINES WITH TRACES

spin axis perpendicular to the orbital plane with a spin rate of 6 rpm.[11] By using the Orbiter propulsion system, the Orbiter maneuvers about the PDP and also releases combustion products to create local depletion of the ionosphere.[12] As depicted in Fig. 2 the Spacelab-2 PDP is to meet the following objectives:

1) Provide in situ measurements of the ionospheric plasma "holes" induced by the Orbiter engine burns in support of ground radar observations of the plasma depletion experiment.

2) Observe natural waves, fields, and plasmas in the unperturbed magnetosphere.

3) Assess the Spacelab system for performance of active and passive magnetospheric experiments.

Evolution of Space Plasma Lab Investigations

Instrumentation has been developed for the conduct of investigations in the space plasma physics disciplines. These investigations are listed in Table 4 under phase I for the OSS-1, Spacelab-1, and Spacelab-2 missions[9,11,13] by the calendar year of the Shuttle launch. At the same time there is another set of Spacelab facilities and principal investigator class instruments which have been selected for possible follow-on Spacelab missions, phase II. Some of these phase II items are being defined and others are in an early definition phase for development starting in 1984 pointing toward a Spacelab-6 flight opportunity in mid-1987, the Space Plasma Lab-1.

Orbiter subsatellites are to be developed under phase II. The recoverable PDP (RPDP) is a class 2 system that follows from the Spacelab-2 PDP. Magnetospheric Multiprobes (MMP) is a system of up to six class 1 subsatellites to make the first set of simultaneous but spatially separated measurements. These subsatellite systems are to be joined by the Solar-Terrestrial Subsatellite toward the end of the decade and with other free-flyer satellite systems, such as the Origin of Plasmas in the Earth's Neighborhood (OPEN) and the Upper Atmosphere Research Satellites (UARS).

Table 5 gives the features of several active Space Plasma Lab perturbation sources—waves, particles, currents, and chemical tracers—that may be available as part of phase II. This table gives a summary of the investigation technique, the primary objectives, and the objectives to be met by the subsatellites and free-flyers (if available). As the Spacelab instrumentation and investigation experience evolves, these space plasma active experiments can be conducted and diagnosed by any and all of the subsatellite systems—MMP, RPDP, of S-TSS. These systems are described in more detail in the following sections.

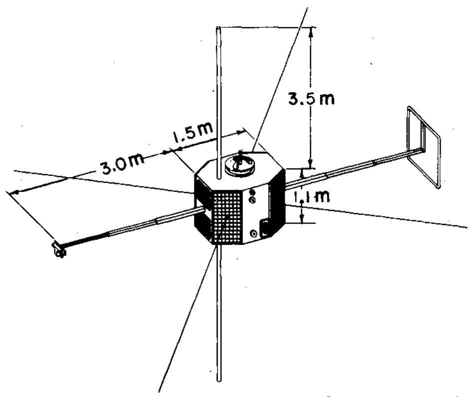

Fig. 3 Recoverable plasma diagnostics concept.

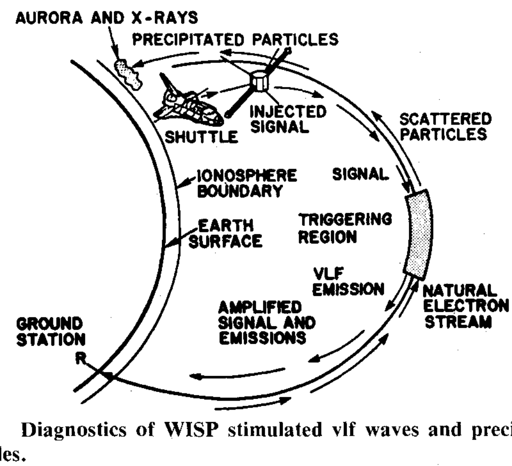

Fig. 4 Diagnostics of WISP stimulated vlf waves and precipitated particles.

Recoverable Plasma Diagnostics Package Scheme

Presently, the Recoverable Plasma Diagnostics Package (RPDP)—derived from the Spacelab-2 PDP—is being designed for a flight as part of the Space Plasma Lab-1 (tentatively, Spacelab-6) complement of hardware.

In Fig. 3, the RPDP is shown in its subsatellite configuration with deployed sensors on booms and with electric long-wire antennas. Energy is supplied by primary batteries and supplemented by solar cells with a secondary battery system to meet the ~100-W operational demand. The 500-kg

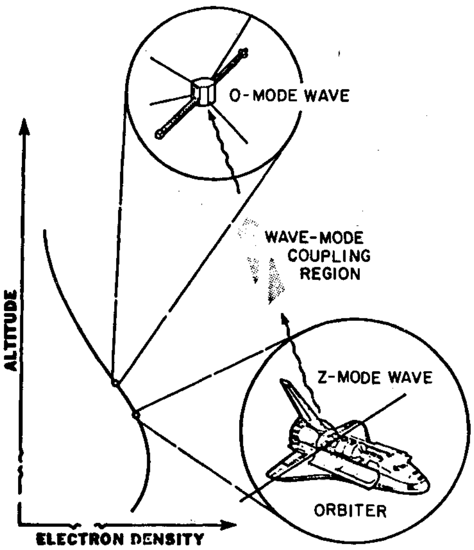

Fig. 5 Diagnostics of WISP emitted hf waves.

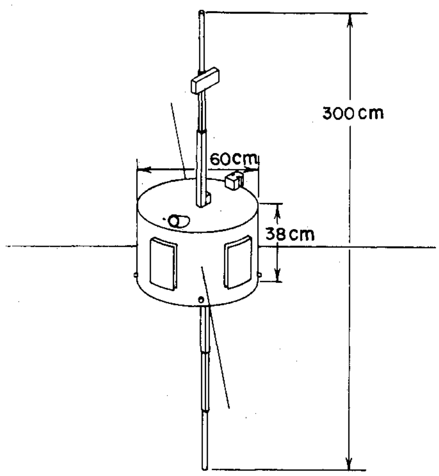

Fig. 6 Magnetospheric multiprobes concept.

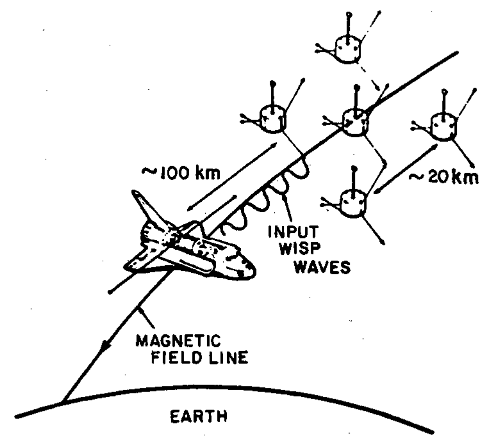

Fig. 7 MMP diagnostics of wave and wave-particle interactions.

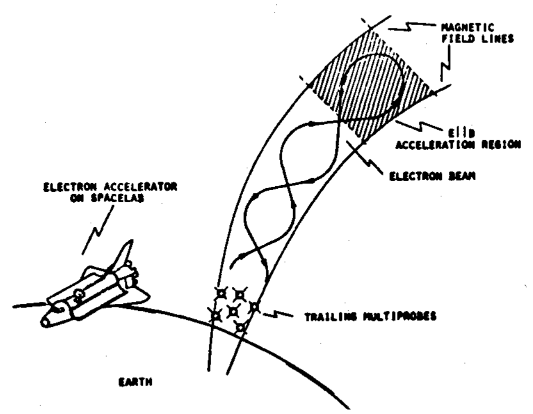

Fig. 8 MMP diagnostics of electron beam returned by parallel electric field region.

unit is spun up to 6 rpm and despun by the combination of a reaction wheel and a cold gas thruster system. The cylindrical dimensions are 152 cm diam by 107 cm height to house up to 12 instrument systems and the supporting spacecraft subsystems. Data are downlinked to the Orbiter over two 400 MHz links and commands are uplinked at S-band. Overall the RPDP satisfies the general specifications of the class 2 recoverable subsatellite in Table 3.

An example of a WISP vlf investigation (see Table 5) utilizing the RPDP is given in Fig. 4. The WISP vlf transmitter illuminates a magnetic flux tube that contains energetic electrons near the equator. These emitted vlf waves can partially organize the particles to stimulate wave growth leading to amplified waves and to particles precipitating into the atmosphere creating an artificial aurora. Very low-frequency sensors on the RPDP can measure both the injected wave characteristics and those of the stimulated waves; other RPDP sensors can detect precipitated electrons in the flux tube and can remotely sense the light of the artificial auroral spot.

For WISP high-frequency (hf) transmissions, the RPDP provides a receiving point which is remote from the Orbiter-borne sounder transmitter/receiver itself. Consequently, these bistatic sounding measurements enhance the information on the dimensionality of the detected density irregularity features. The RPDP can also be used to examine hf wave propagation and mode coupling phenomena as depicted in Fig. 5. A Z-mode wave emitted at the Orbiter may be coupled to an O-mode wave in the presence of a strong gradient in electron density. Such experiments require careful positioning of the Orbiter with respect to the RPDP.

As part of the Space Plasma Lab-1, the RPDP can also be utilized with other phase II instruments to diagnose the SEPAC electron and plasma beams[10] and to characterize reactions to chemical releases.[12]

Magnetospheric Multiprobes Scheme

Multiple throw-away detectors are particularly important for providing a spatial sample of natural and induced phenomena. A system of up to six Magnetospheric Multiprobes (MMPs) is being defined under phase II of the Space Plasma Lab facility.[13]

A possible configuration for the MMP is shown in Fig. 6. Each unit is 60 cm in diameter by about 30 cm high with a telescoping antenna/boom system along the spin axis and four wire antennas perpendicular to the spin axis. These units are battery powered with an uplink command/link and a data downlink in the 400-MHz band at data rates up to 128 kilobit/s. For some missions the units are to be instrumented to measure dc electric fields, particle spectra and pitch angles, magnetic perturbations due to currents, and possibly the vlf plasma wave spectrum. For other missions an ion drift meter and ion mass spectrometer might be substituted for or added to the instrument complement.

Spin up to ~ 20 rpm and ejection of each unit with an Δv up to 10 m/s is accomplished by a special ejection mechanism. The mechanism operates with cold gas to effect the Δv and with an electric motor to provide the spin up. Positioning of the MMPs is accomplished by selecting the correct Orbiter attitude to direct the Δv; 10 m/s yields a peak separation of approximately 10 km from the Orbiter (although the separation varies sinusoidally to ± 10 km peak). With time the

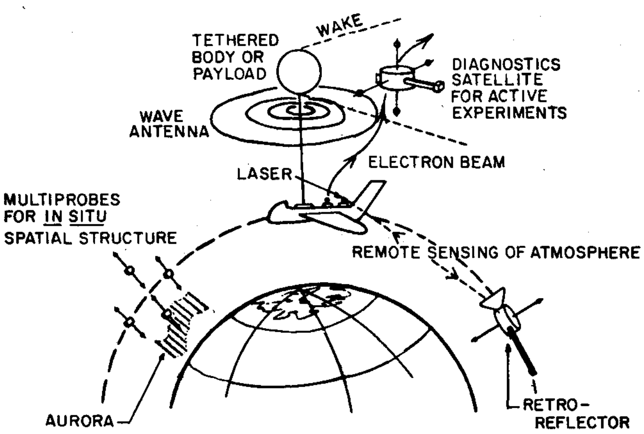

Fig. 9 Summary S-TSS science opportunities.

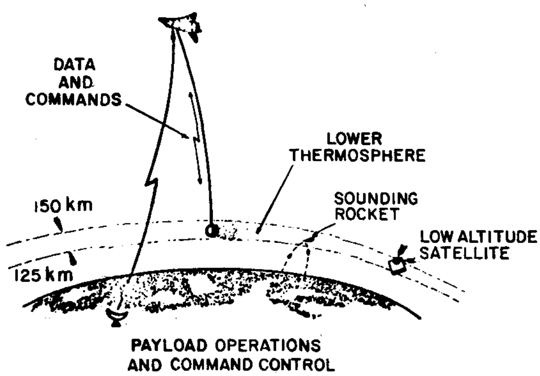

Fig. 10 Tethered atmospheric satellite.

MMP cluster deforms into a string along the orbital track due to atmospheric drag.

Multipoint measurements can provide a snapshot of the WISP antenna pattern for a particular geometry and plasma parameters as indicated in Fig. 7. Also wave-particle phenomena at particular, but not entirely predictable, spatial locations (such as the density gradient in Fig. 5) are more likely to be encountered with multiple probes. Likewise experiments with the electron beam sounding of magnetic field lines for electric field regions depicted in Fig. 8 has a higher chance of success if multipoint measurements of the return electrons are made.[10,13] Similarly, measurements in and near flux tubes containing chemical releases can give estimates of spatial gradients as well as of temporal evolution.[12,13]

Solar-Terrestrial Subsatellite Scheme

Four adaptations of the Solar-Terrestrial Subsatellite based on existing technology were proposed: the inertial upper stage (IUS), the Teleoperator Retrieval System, the Detached Experiment Carrier, and the AE/DE technology.[8]

As implied in Table 3, the class 3 S-TSS is bigger and better than the other two classes. Besides providing for nearly twice the number of instruments, for increased data handling capabilities, and for sustained management from a NASA Center, the S-TSS is to provide both an orbit adjust and stabilized attitude capability. This orbit adjust capability is required to: 1) minimize Orbiter resource requirements in terms of propulsion, rendezvous time, and data handling; 2) carry sensitive instruments outside of the Orbiter contamination envelope; 3) provide lower atmosphere (50-200 km) scan capability by carrying a retroreflector or detector for LIDAR or similar optical source; 4) perform diagnostic measurements of plasma flow around bodies tethered to the Orbiter; and 5) provide numerous experiment opportunities that require specific Orbiter/S-TSS alignments such as along B lines.

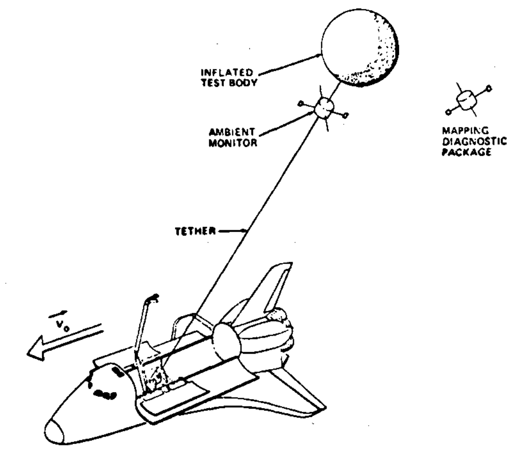

Fig. 11 Electrodynamics tether system with diagnostic satellites.

The stabilized attitude capability is required to: 1) direct mass spectrometers and RPAs into velocity ram direction; 2) point imagers, spectrometers, interferometers, and radiometers toward atmospheric targets such as the limb and auroral regions; 3) position magnetometers, electric field detectors, and energetic particle detectors with respect to the geomagnetic field; 4) establish solar inertial pointing for solar viewing instruments such as imagers and spectrometers; and 5) change attitude according to experiment requirements during the mission.

With the added capabilities of the S-TSS, subsatellite support can be provided to a full range of Spacelab-based facilities as illustrated in Fig. 9.

Electrodynamics Tether System

The Tether Retrieval System provides a means to drag a satellite probe through the atmosphere as in Fig. 10 down to ~100 km altitude without losing the satellite due to atmospheric drag. In this case the tether would provide mechanical support of the atmospheric satellite with a length of ~100 km.[14] This technique provides an important and unique tool for probing the thermospheric region.

For magnetospheric work, a conducting tether wire restraining a large conducting body can produce large motional potentials along the tether of kilovolt magnitudes. An electron accelerator on the Orbiter can emit electrons into the plasma to cause current flow in the tether which may establish electrodynamic effects such as low-frequency wave emissions and field-aligned current systems. Wake, current, and wave effects can be studied by subsatellite probes tethered along the tether wire and by subsatellite probes in the vicinity as depicted in Fig. 11. Combined with the WISP transmitter, the conducting tether can serve as a very efficient vlf transmitting antenna.[14]

On-Orbit Operations

Whatever the subsatellite system in use as part of the Space Plasma Lab Facility, the general operational features are planned as follows:

1) The subsatellites are deployed just after reaching orbit and recovered just before deorbit (if appropriate); the class 2 and class 3 systems may have a capability to stay on orbit between Spacelab missions to serve as a low-altitude spacecraft.

2) The Orbiter or S-TSS must be maneuvered to obtain the appropriate Orbiter-subsatellite geometry along the orbital track or along a magnetic flux tube.

3) Commands are issued simultaneously by the Orbiter crew or the Payload Operations Control Center (POCC) to all of the Spacelab instruments and the subsatellite instruments as to mode and time of the next experiment.

4) Data are transmitted back to the Orbiter and displayed

to the crew so that critical instrument parameters can be changed in order to optimize the experiment conditions.

Summary

Subsatellites are an essential part of the evolving Space Plasma Lab Facility. A simple throw-away subsatellite—the Plasma Diagnostics Package—has flown in 1982 attached to the RMS and will fly as a subsatellite in 1984. A system of Magnetospheric Multiprobes and a Recoverable Plasma Diagnostics Package is undergoing initial design for a 1987 launch opportunity as enhancements to the Space Plasma Lab capability. By 1990 a fully maneuverable Solar-Terrestrial Subsatellite may be available. These subsatellite systems measure fields, waves, particles, and optical emissions associated with natural magnetospheric processes and with active injections of waves, plasma beams, and chemical tracers.

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