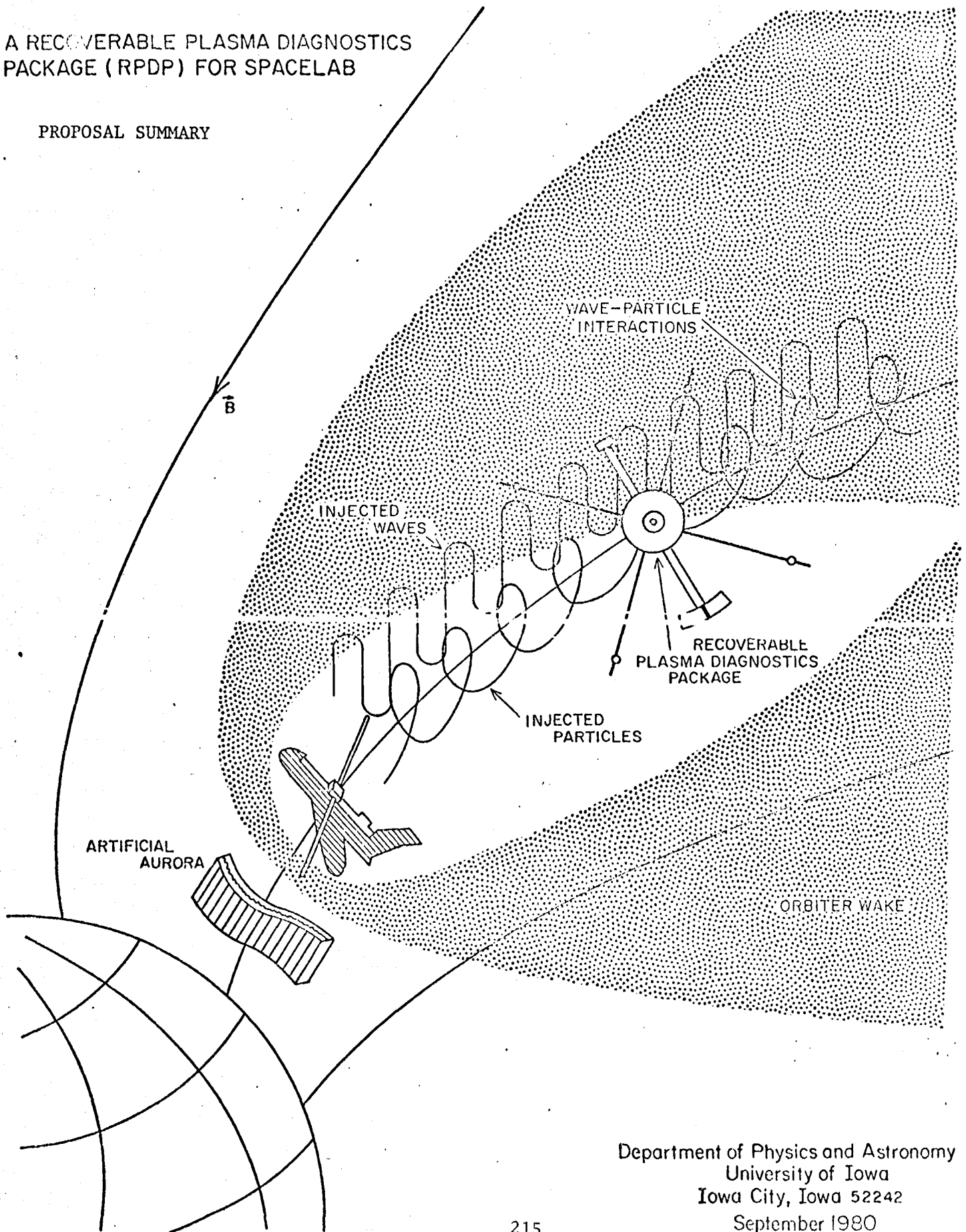# A RECOVERABLE PLASMA DIAGNOSTICS PACKAGE (RPDP) FOR SPACELAB

PROPOSAL SUMMARY

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A RECOVERABLE PLASMA DIAGNOSTICS PACKAGE (RPDP) FOR SPACELAB

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INVESTIGATION SUMMARY
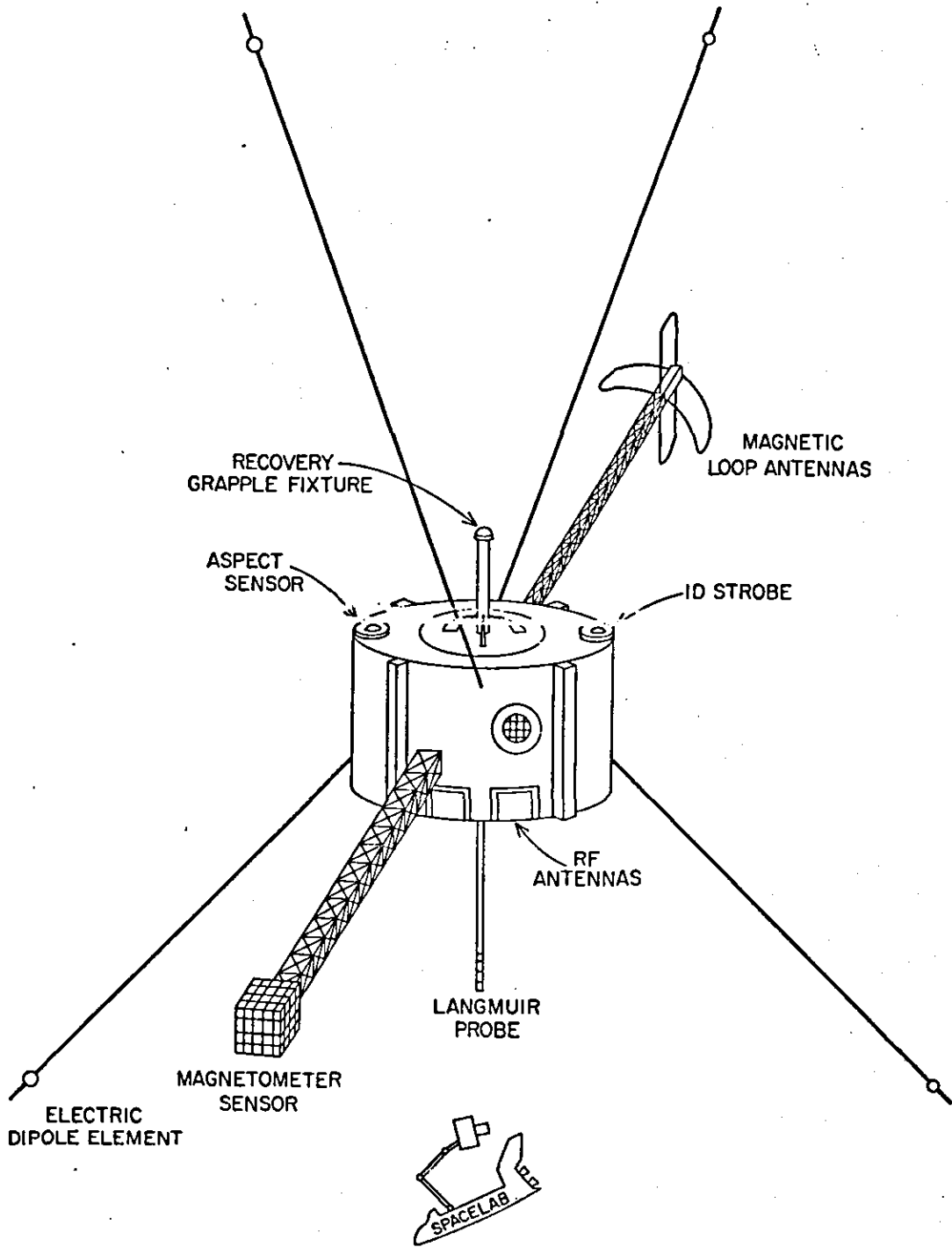## RECOVERABLE PLASMA DIAGNOSTICS PACKAGE

In response to NASA AO-OSS-2-78, the University of Iowa proposed a Recoverable Plasma Diagnostics Package (RPDP) as an essential element for the cost-effective use of the Space Shuttle to conduct research in space plasma physics and related disciplines on the Spacelab Missions. This RPDP program is a continuation of the ejectable Plasma Diagnostics Package investigation under development for the OSS-1 and Spacelab 2 Missions.

The RPDP is a fully instrumented, ejectable and recoverable unit with flight and ground support systems so that it can be utilized attached to the Orbiter Remote Manipulator System, tethered from the Orbiter, or as an Orbiter Subsatellite to (200 km range with an operation time up to 200 hours from batteries. Core instruments on the RPDP are flight-proven hardware which provide diagnostics measurements of energetic particles (electrons and ions, 2eV to 50keV), AC electromagnetic and electrostatic waves (5 Hz to 30 MHz), vector magnetic field signatures of current systems ($> 2\gamma$), vector electric field signatures associated with plasma flow and particle acceleration (> 1 mV/m), thermal plasma ion composition and density ($1-64$ AMU $> 1 \text{cm}^{-3}$), thermal plasma electron density and temperature (10^2 to 10^7 cm^{-3}, 1×10^2 to $1 \times 10^{4\circ}$ K) and images of optical emission regions in UV (1100-1700A) or visible (3900-6300A) wavelengths.

Two investigations utilizing the RPDP are the basis for the definition phase: diagnosing the dynamics and consequences of particle beams injected into the magnetosphere from an Orbiter-borne accelerator (SEPAC system by Obayashi et al.) and diagnosing the emission and propagation characteristics of waves injected from an Orbiter-borne transmitter (WISP system by Fredricks et al.) or by means of a conducting tether. Studies, initiated by the PDP on OSS-1 and Spacelab 2, are to be continued for wave, particle and field effects stimulated by the motion of the large-sized Orbiter through the magnetized plasma and for naturally occurring magnetospheric phenomena.

Based on the OSS-1 and Spacelab 2 design, a new PDP unit is to be developed which can accommodate a more flexible complement of instruments and the necessary hardware and electronics subsystems to make the PDP recoverable. Existing PDP flight support and ground support equipment are to be modified to accommodate the RPDP. The major development item is the Special Purpose End Effector which is to effect ejection and recovery of the spinning RPDP (5 to 20 RPM).

Once in existence, the RPDP can provide a cost-effective and comprehensive means of diagnostics for Spacelab experiments such as the Shuttle electrodynamics tether, plasma flow around bodies, magnetospheric multiprobes, chemical release modules, plasma depletion experiments, sheaths around large structures in space, auroral electrodynamics and tethered atmospheric probes. For such follow-on missions several additional instruments can be accommodated.

RECOVERY GRAPPLE FIXTURE

MAGNETIC LOOP ANTENNAS

ASPECT SENSOR

ID STROBE

RF ANTENNAS

LANGMUIR PROBE

MAGNETOMETER SENSOR

ELECTRIC DIPOLE ELEMENT

SPACELAB

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A. GENERAL SCIENTIFIC OBJECTIVES

§ Continue to study the Orbiter-magnetoplasma interactions such as density wakes, energized plasmas, dc electric fields, and wave-particle instabilities.

§ Investigate the dynamics of the primary particle beams ejected from the Orbiter via SEPAC and the characteristics of the secondary and tertiary energetic plasma below 50 keV by measurement of the particle distribution functions with the quadrispherical low energy proton and electron differential energy analyzer (LEPEDEA) within 100km range of the Orbiter. Characterize the induced wave and optical emissions, the current systems and the electric field regions both in the vicinity of the Orbiter and remote to it.

§ Measure the transmitting antenna radiation pattern and the propagation and mode coupling characteristics of electrostatic and electromagnetic waves injected by the Orbiter, via WISP, in the range of 0.3 kHz -30 MHz with a step frequency correlator receiver and antennas. Characterize the ambient plasma and induced modifications such as particle acceleration and precipitation.

§ Within a range of 100 km from the Orbiter, probe the microscale properties of wave-particle interactions induced by joint operations of wave and particle beam injectors and the RPDP.

§ Support investigations which may be carried out with the Magnetospheric Multiprobes, Chemical Release Module and Tether System investigations.

B. RECOVERABLE PLASMA DIAGNOSTICS PACKAGE DESCRIPTION

1. General Description of the Recoverable PDP and Operating Scheme

The major subsystems which make up the RPDP Flight and Operations system are identified in Figure 1. In Table 1 the function of each major subsystem is stated and its performance characteristics are specified.

Taken together the RPDP systems provide for a plasma diagnostics package which can be operated on the RMS, tethered to the Orbiter or released from and recovered by the Orbiter to serve as a reusable subsatellite. Figure 2 depicts the interfaces to Spacelab. The Recoverable Plasma Diagnostics Package (RPDP), shown as an artist's conception as part of the Summary, is latched to the Spacelab pallet structure by the Release Mechanism (REM) which is controlled via the Payload Retention Panel in the aft flight deck (AFD). The Recovery Special Purpose End Effector (RSPEE) provides the mechanical and electrical interface to the Remote Manipulator System which allows the RSPEE to be controlled from the Standard Switch Panel in location L12 in the AFD. Spin-up, deployment on-orbit and retrieval of the RPDP are effected by the RSPEE. Once the RPDP is released from the REM it operates on batteries and commands are transmitted and data received through the 400 MHz RF antenna (RFA) located on the pallet. Commands and data processing are controlled by the Receiver and Data Processing Electronics (RDP) which are mounted under the pallet shelf on a cold plate. This unit contains the command generator
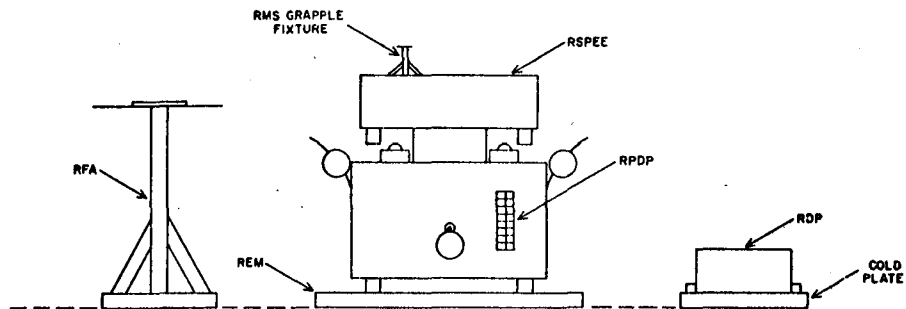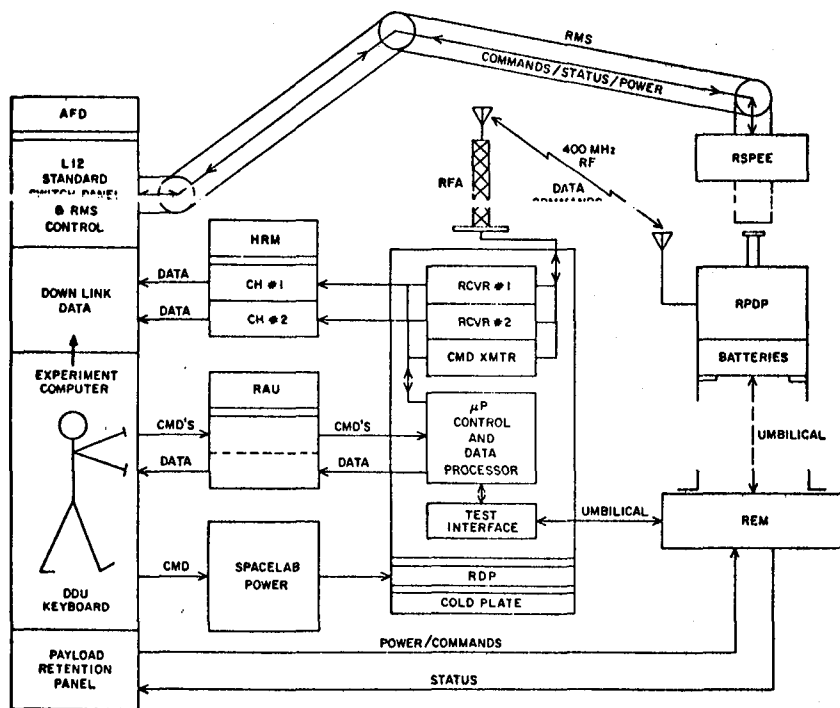
FIGURE I. FLIGHT HARDWARE ITEMS*

FIGURE 2. SPACELAB/RPDP INTERFACES*

*KEY   RPDP : RECOVERABLE PLASMA DIAGNOSTICS PACKAGE
         RFA : RADIO FREQUENCY ANTENNA
         REM : RELEASE MECHANISM
        RSPEE : RECOVERY SPECIAL PURPOSE END EFFECTOR FOR RMS
         RMS : REMOTE MANIPULATOR SYSTEM
         RDP : RECEIVER, COMMAND TRANSMITTER AND DATA PROCESSING ELECTRONICS

TABLE 1. SPECIFICATIONS FOR RPDP SUBSYSTEMS

SUBSYSTEM: FUNCTION	PARAMETER: SPECIFICATION

Recoverable Plasma Diagnostics Package (RPDP): Houses scientific instruments and subsystems on RMS and as subsatellite	Size . . . . 107 cm dia x 66 cm high
	Weight . . . . 250 kg
	Energy . . . . 9 KWH from batteries
	Power. . . . . 45-90 watts
	Operating Life . . . . 100-200 hours
	Accommodations . . . . 6-10 scientific instruments
	Telemetry. . . . . . . 400-402 MHz UHF band, 1 watt
	  Downlink #1 . . . . . 32 kbps PCM data
	  Downlink #2 . . . . . 50 kHz analog data
	  Uplink. . . . . Commands, sync signal, tone ranging
	Telemetry Range. . . . 100-200 km
	Commands . . . . 32 for S/C functions & data mode
	Data System. . . . . . RCA 1802 µP based
	Antennas . . . . 4 of 15 m - tubular type/retractable
	Booms. . . . . 2 of 3 m - telescoping/retractable
	Aspect . . . . Star sensor, sun sensor, triaxial
	    magnetometer for ±0.1° accuracy
	ID Strobe. . . . . . . 1 or 2 - 40 flashes/minute

Recovery Special Purpose End Effector (RSPEE): Provides mechanical and electrical interface to the RMS and spin-up, release and recovery of the RPDP	Size . . . . 91 cm x 91 cm x 45 cm Weight . . . . 100 kg Power. . . . . 50 W average, 150 W peak DC RMS Interface. . . . . Electrical grapple fixture Control & Status . . . Standard switch panel L12/AFD Spin-up Range. . . . . 5-20 RPM ± 10% in < 1 minute
Release Mechanism Assembly (REM): Mechanically latches RPDP to Spacelab pallet and provides electrical umbilical connection to test RPDP (Developed by MSFC for JSC)	Size . . . . 120 cm x 142 cm x 16 cm Weight . . . . 53 kg Power. . . . . 118 W peak DC; 450 W peak AC Technique. . . . . . . Guide rails for x, y location; secured by motor-driven screws Control & Status . . . Payload retention panel in AFD

Receiver and Data Processing Electronics (RDP): Houses RF data receivers and command transmitter; interfaces to RAU and HRM; processes data and commands	Size . . . . 33 cm x 50 cm x 30 cm
	Weight . . . . 20 kg
	Power. . . . . 50 W DC
	Thermal Control. . . . Cold plate mounted
	RAU Interface. . . . . Analog Inputs - 32
	    Discrete Outputs - 40
	    Discrete Inputs - 40
	    Serial Commands - 1
	    Serial Inputs - 1
	    All data available to DDU & POCC
	HRM Interface. . . . . Channel 1 - 1.2 Mbps
	    Channel 2 - 32 kbps
	Data/Control System. . Intel 8085 µP based

RF Antenna Assembly (RFA): Receives 400 MHz telemetry data from RPDP and transmits 400 MHz uplink commands & sync signals	Size . . . . 40 cm x 40 cm x 2 cm plate on top of ~ 150 cm mast Weight . . . . 15 kg Power. . . . . None Technique. . . . . . . Dual polarized microstrip Pattern. . . . . +8 dBI along +Z, -30 dBI along -Z

Experiment Ground Support Equipment (EGSE): Processes RPDP data from HRM, RAU and OI stream in POCC	Complement . . . . . . 2 Chromemco Z-80 microcomputers
	    with periferials for controlling
	    RPDP, displaying, listing and
	    tape recording data.

and transmitter and the data receivers for the RF links to the RPDP. Included also are a microprocessor and interface electronics for command and data processing to provide two data streams to the High Rate Multiplexer (HRM) and to exchange data and commands with the Remote Acquisition Unit (RAU). Commands to the RPDP can be issued either by the POCC or by the crew through the keyboard and experiment computer. Data and housekeeping parameters from the RDP are available for display on the DDU via the RAU and experiment computer.

The Definition Phase study will include tasks to verify the following proposal assumptions: The REM will exist as part of both the MSFC IECM program and the U of Iowa PDP on OSS-1 and Spacelab 2 programs. It can be used without modification. On Spacelab 2 the PDP is to be released and not recovered so that the RPDP must be fabricated based on the PDP structural and electrical subsystem designs with modifications to accommodate the recovery mechanism, several more scientific instruments and more complex, but more flexible, subsystems such as the command/sync signal uplink and the microprocessor-based data system. A SPEE for spin-up and deployment of the Spacelab 2 PDP will exist, however, because of cost constraints, it will not be capable of effecting recovery. The added capability of recovery requires careful design and consideration because of the safety aspects; this design and fabrication is to be subcontracted. The RF Antenna can probably be used without modification. It provides hemispherical coverage about the Orbiter +Z axis with good suppression of Orbiter EMI in the -Z hemisphere. Data receivers, the microprocessor data processing elements, and RAU and HRM interface circuits from the Spacelab 2 RDP can be utilized. Additions to the RDP include the command generator and command transmitter as well as expansion of the RAU interface and the microprocessor ROM and RAM.

Once on-orbit, the Payload Specialist will be required to carry out a functional check of the RPDP by issuing commands through the keyboard and monitoring housekeeping and scientific parameters on the DDU. To deploy the RPDP, the RMS operation grapples the electrical grapple fixture on the RSPEE using the CCTV; the REM is then operated to release the combined RPDP and RSPEE units; Orbiter attitude is adjusted and the RMS articulates the RPDP so that it will be deployed in the cartwheel mode--the RPDP spin plane is parallel to the Orbiter's orbital plane. The RSPEE in controlled and monitored via the L12 Standard Switch Panel; functions include heater, spin-up to preset rate in the 5-20 RPM range and separation. Commands sent to the RPDP prior to spin-up are used to partially extend the booms and antennas to establish a stable dynamic configuration for the RPDP. Once spin-up and separation are effected, the Orbiter is flown away from the RPDP to a prescribed position in order to carry out experiments. The Payload Specialist will be required to carry out predefined experimental programs by operating the particle beam and/or wave injectors and by monitoring the results from the RPDP. The Payload Specialist will then make adjustments in parameters such as RPDP location, transmitter frequency, etc., to optimize the results. After completion of the mission objectives, the Orbiter is to rendezvous with the RPDP. Commands are sent to retract the booms and antennas and the RSPEE spin rate is matched to that of the RPDP. Recovery is monitored through use of the CCTV, the RPDP is restowed on the REM and the RMS is ungrappled and stowed.

2. Orbiter Resource Requirements

Orbiter resource requirements in terms of size, weight, power, command, and data handling and operating modes are given in Table 1.

3. PDP Launch/Recovery System Concept

The launch/recovery system for the RPDP represents a somewhat new development item which may represent a safety hazard especially during recovery operations. A Special Purpose End Effector (SPEE) for the RMS is being developed by Ball Aerospace Systems Division for launch of the Spacelab 2 PDP which provides a design base and relevant experience with qualification tests and safety aspects.

Two feasible launch/recovery concepts developed by Ball Aerospace and Spar Aerospace were included in the original proposal. Highlights of the concepts are as follows:

§ *Ball--The Spacelab 2 SPEE is modified to handle multiple satellites. The SPEE latches to a cone and probe device on the RPDP that is similar to the standard grapple fixture. This SPEE provides spin-up and launch. For recovery the RPDP is yo-yo despun to 5 RPM or less and grasped by the standard end effector.*

§ *Spar--A spin joint is to be inserted between the standard end effector and the wrist roll joint of the Remote Manipulator System. This approach is possible because the SEE is a "Line Replaceable Unit". This spin joint provides the spin-up and spin down function while the SEE provides the release and recapture functions. Only a standard grapple fixture is required on the RPDP.*

Iowa proposes to issue three design contracts for this SPEE during the definition phase and one development and testing contract to a selected aerospace vendor during the development phase.

In order to recover the PDP, the deployed booms and antennas must be retracted or severed. Of concern is the possibility that the RPDP batteries would be depleted of energy before recovery is possible. To avoid this situation, it is proposed to provide a separate battery pack with sufficient energy to continually operate a command receiver and to operate motors and/or pyrotechnics as required to ready the RPDP for recovery. Since there is a possibility that the RPDP might have to be stored on-orbit between Spacelab flights due to a contingency situation, consideration will be given to using a small solar cell array to keep this recovery battery pack charged.

4. Objectives For Possible RPDP Follow-on Missions

With minor refurbishment and the addition or change of instrumentation the RPDP can be used on many different sorts of investigations. Some of thse are depicted in Figure 3. Note that the RPDP might be combined with the teleoperator or IUS to attain an orbit significantly different from the Orbiter.

Three possible follow-on investigations are described as follows:

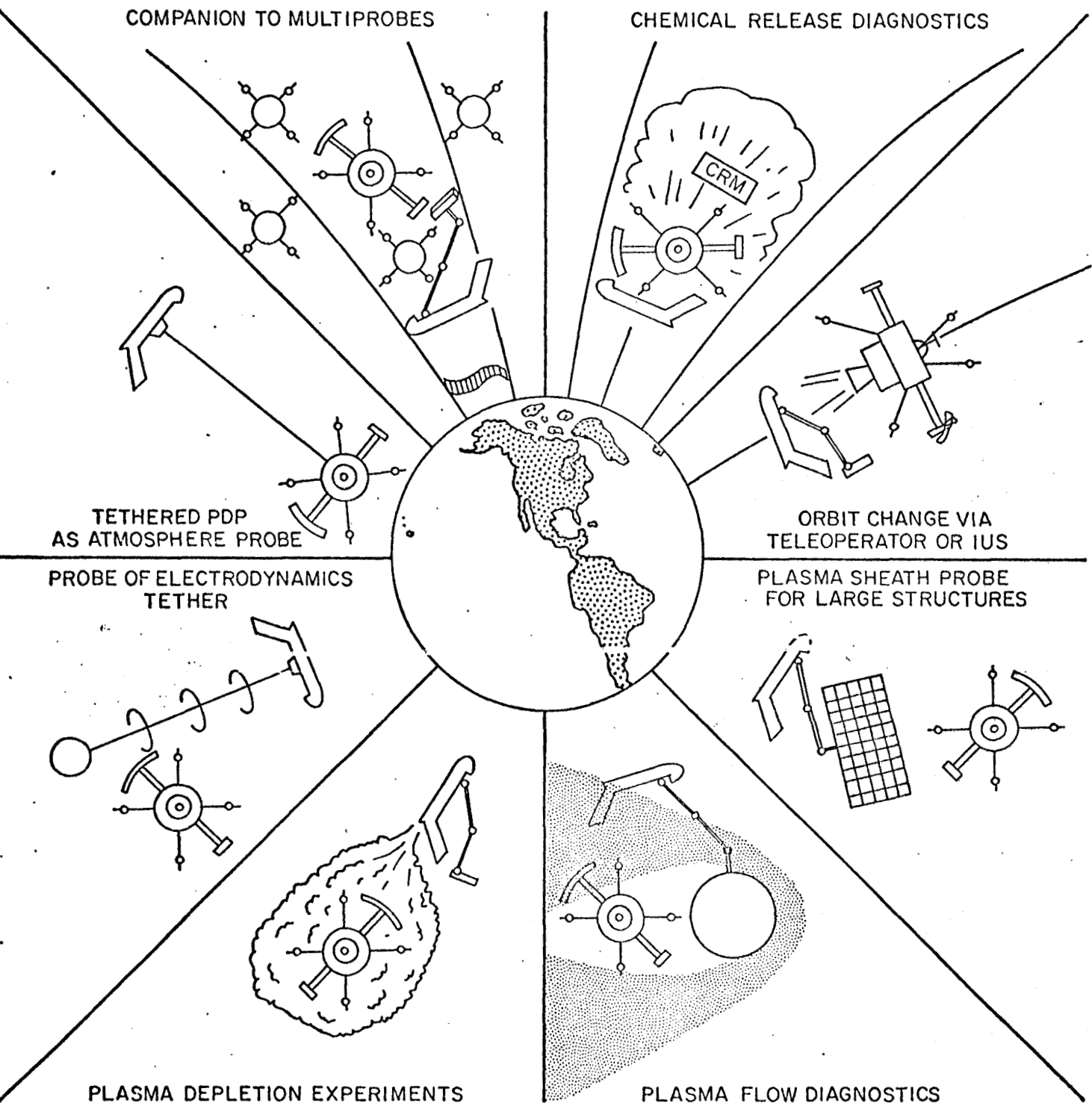# RECOVERABLE PLASMA DIAGNOSTICS PACKAGE FOLLOW-ON MISSIONS

COMPANION TO MULTIPROBES

CHEMICAL RELEASE DIAGNOSTICS

CRM

TETHERED PDP
AS ATMOSPHERE PROBE

ORBIT CHANGE VIA
TELEOPERATOR OR IUS

PROBE OF ELECTRODYNAMICS
TETHER

PLASMA SHEATH PROBE
FOR LARGE STRUCTURES

PLASMA DEPLETION EXPERIMENTS

PLASMA FLOW DIAGNOSTICS

FIGURE 3

(a) **Plasma Flow Investigation and Required Instrumentation** (N. H. Stone/MSFC)

The Space Shuttle and its payload are capable of serving as a near-earth plasma laboratory which uses the ionospheric plasma as a natural collisionless and unbounded working medium. The use of the methods of laboratory plasma physics in earth-orbit will provide a great stride forward in experimental capabilities: Opening up a new range of parameter space, previously unattainable, and alleviating a number of problems inherent in earth-bound laboratories.

As a result a variety of physical processes, some of which are qualitatively similar to processes important to solar system plasma physics, can be studied over a wide range of scale sizes and plasma conditions. For example, supersonic sub-Alfvenic plasma flow can be studied in a collisionless regime; the range of scale sizes will enable a direct comparison of the continuum-MHD and kinetic theories, thereby establishing the range of applicability of single fluid MHD models, possibly determined quantitatively by the ratio of the body sizes to the ion Larmor Radius ($R_0/L+$); and the interaction of the satellite, Io, with the Jovian mangetosphere can be qualitatively simulated in order to study the nature of the plasma sheath in the presence of a substantial voltage drop, the possibility of an associated charged particle acceleration mechanism, and the resulting field aligned circuit system--all of which are thought to be characteristic of the Io interaction. Such an extrapolation from experiments conducted in the ionosphere to the plasma physics of the solar system is analogous to the extrapolation from heliospheric plasma processes to astrophysical phenomena advocated by the Space Science Board.

This application of the Shuttle as a near-earth plasma laboratory will be the subject of a proposal to be submitted next year by N. H. Stone, U. Samir, and others. It should be emphasized here that the PDP will be a necessary component of these studies.

To conduct these experiments, it will be necessary to have a test body to generate the plasma disturbance and a set of diagnostic instruments to measure the characteristics of the disturbed plasma flow. Control of the relative position of the instrument package with respect to the test body is required to effect a mapping of the flow field. It is also desirable to simultaneously monitor certain characteristics fo the ambient atmostphere.

The required diagnostic instrumentation can be carried on the PDP. This would include instruments to measure the ion and electron temperatures and densities, the ion drift velocity (magnitude and direction), the ion mass, and the local space potential. The space potential should be measured with sufficient temporal resolution to detect oscillations in the range of the ion plasma and ion cyclotron frequencies. With the exception of the vector flow velocity, all of these measurements can be made by standard plasma diagnostic instruments. The vector velocity measurements can be made with the Differential Ion Flux Probe (DIFP) which has recently been developed at MSFC and will fly as part of the Spacelab 2 PDP experiment. It may be decided that this instrument should be included on the RPDP proposed here.

A small (one-meter diameter) spherical conducting body mounted on the Shuttle RMS is being proposed by P. M. Banks, et al. This body would be available for these experiments and would provide the lower-end of the range of scale size needed for the comparison of the continuum and kinetic theories (i.e., $R_0/L+\ll1$). In addition, Banks' proposal will include diagnostics which can measure ion and electron densities and temperatures out to two meters from the body surface. This would combine ideally with the PDP instrumentation

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which would be used to measure the disturbed flow field at larger distances (out to ~100 m) while the insturmentation from the Banks' experiment would be used to monitor the ambient conditions. A mapping of the flow field would be effected by a combination of varying the stand-off distance fo the free-flying PDP, downstream from the test body, by maneuvering the Shuttle and manipulation of the test body position normal to the flow direction with the RMS.

In later expeiments, bodies with diameters of ~10 m (R_0/L+≈1) and ~100 m (R_0/L+>>1) would be used to complete the desired range of scale sizes. The 10 m diameter body can be manipulated by the RMS in conjunction with a free-flying PDP as described above for the 1 m body. However, the 100 m body will require a tether system and some capability to manuever the PDP-- possibly with the MSFC teleoperator.

In summary, the PDP is a necessary component for experimental investigations of plasma flow interactions with obstacles in earth-orbit which are applicable to space plasma physics, and in particular to solar system plasma physics. The PDP can be used directly in initial small-body studies, and possibly with some modification to allow manueverability in later large-body studies. A reusable PDP is particularly cost effective in this class of experiments, since the complete investigation will involve an evolutionary series of experiments carried out over a number of different Shuttle missions.

(b) Neutral Atmosphere Wind, Composition and Temperature (W. R. Hoegy and N. W. Spencer/GSFC)

In the recent past, measurement of neutral gravity wave properties have provided only a few of the parameters necessary to determine the wave characteristics. Some of the neutral wave parameters have been indirectly inferred from the observations of traveling ionospheric disturbances (TID's). A unique specification of the neutral waves (period, wavelengths and direction of propagation) is possible only with simultaneous in situ measurements of neutral wind, temperature, and composition data (Hoegy et al., 1978). A spectral analysis of the data gives wave amplitudes and phases for one component of the wind, temperature and composition. Linear gravity wave theory is ued to convert the amplitudes and phases into the wave parameters ω and $\vec{K}$, which are needed to compute the velocity of wave energy propagation and eventually the wave source. Flights of an instrument which provides wind, temperature, and composition data are needed for a complete and accurate determination of gravity wave characteristics, and for comparison with simultaneous TID observations.

Instruments meeting these requirements will be employed on the Dynamics Explorer B and San Marco D1 spacecraft. Three components of the winds (vertical, orbit plane normal, and horizontal in-plane) will be measured in situ on these spacecraft using an advanced design based on first generation instruments providing similar data on AE. In situ kinetic temperature (N_2 and 0) as well as composition are time sequenced measurements. The temperature measurement technique involves determination of the velocity distribution among the particles of a particular gas, usually N_2, from which the kinetic temperature is calculated. The wind velocity components are determined through the use of a baffle which modulates the stream of gas entering the mass spectrometer allowing determination of the angle of entry with respect to the spacecraft velocity vector. The vertical and orbit normal components are measured in this way, but the in-plane component is determined in an "rpa"

manner by decelerating the ionized component of the incoming gas stream and computing the resulting velocity effect. Composition is determined using the instrument in the usual mass spectrometer mode.

References:

Hoegy, W. R., P. L. Dyson, L. E. Wharton, and N. W. Spencer, Neutral atmosphere waves determined from Atmosphere Explorer measurements, NASA TM #79670, November 1978.

Spencer et al., Geophys. Res. Ltrs., Vol. 3, #6, 1976.

Spencer et al., The midnight neutral (N_2) temperature maximum, (in preparation).

(c) The Cornell DELTA N Experiment (M. Kelley/Cornell)

The Cornell University DELTA N experiment is designed to detect the fluctuating density component of electrostatic waves generated both naturally in the near space region of the Earth and artificially by active experiments conducted from the Space Shutttle. The detector is sensitive to waves with frequencies from dc to 10 kHz which corresponds to wavelengths from zero order background scale lengths to a few Debye lengths. Such waves are very important in a low temperature plasma such as the ionosphere and low altitude magnetosphere since their phase velocities are comparable to either the thermal velocity of the constituents or to the drift velocity of species due to applied forces such as electric fields, pressure gradients and gravitational fields. Their role is equally important in active experiments since they can be directly produced by beams, antennas, and chemical releases or be generated in a multi-step process by instabilities or parametric decay of large amplitude electromagnetic or electrostatic waves. In addition to the direct production of electrostatic waves in active experiments, there are important processes in the background plasma which can feed back on the primary beam or wave. An example is the self-focusing effect on electromagnetic waves near the electron plasma frequency observed in the ground based HF heating experiments. This is caused by plasma heating which reduces the density locally and which in turn causes a focusing effect on the waves and creates more heating. The DELTA N experiment is ideally suited for detection of such induced structures with wave number perpendicular to the magnetic field. Effects of naturally occurring plasma gradients and irregularities will also be measurable with the detector.

The sensor is a cylinder 15 cm long and 1 cm in diameter deployed parallel to the spin axis on a rigid BeCu boom a distance of 3 m. The collecting surface is coated with a colloidal suspension of carbon with excellent surface properties. Guard rings 1 cm in length are located at each end of the active surface. A 15 cm long cylindrical section of the boom located .5 cm from the sensor is free of the insulating surface and acts as a floating reference potential for the sensor bias. The high data rate channel has automatic gain control to maintain a good signal to noise ratio and is proportional to the relative fluctuations in plasma density, $\delta n/n$, independent of n. This covers the frequency range 1-10,000 Hz. A dc coupled output, proportional to the log of the plasma density, covers the range from 0-50 Hz. The latter yields an accurate relative density measurement in fluctuations due

to long wavelength irregularities or waves and absolute density with an accuracy of 50%.

The basic electronics weighs 2 kg, package occupies a volume of 1500 cm^3 and consumes 2.6 watts of electrical power at 28 volts. The boom system is deployed with a typical pyrotechnic firing pulse of short duration. The stowed outline dimensions of the boom system are a 10 cm diameter cylindrical volume 50 cm in length with long axis parallel to the spin axis. It could be mounted on the outside of the spacecraft. If other than real time wave data is necessary or desirable a spectrum analyzer can be provided with an increase in power of 2 watts and 1 kg in weight.

C. RPDP INSTRUMENT DESCRIPTIONS

A core set of instruments essential to the particle beam and wave injection investigations are to be defined. These instruments are identified and briefly described along with a detailed specification of the measured parameters in Table 2 "Performance Characteristics for RPDP Core Instruments." The heritage and operating principles of each of these instruments are as follows:

1. Correlating Step Frequency Receiver (Gurnett, Shaw, Anderson/Iowa)

For ISEE-1 a four band step frequency receiver was developed. For the Dynamics Explorer-A (DE-A) mission, two of these receivers are being combined with correlating detectors to produce a step frequency correlator covering the range of 100 Hz to 400 kHz.

For the RPDP it is desired to add two bands of 400 kHz to 3.2 MHz and 3.2 MHz to 25.6 MHz to cover the gyrofrequency ((1 MHz) and plasma frequency ((10 MHz) and harmonics in the upper ionosphere. This development is to make the receivers step faster and to extend the dynamic range of each band as well. Also this receiver is to utilize a microprocessor for control of the receiver parameters such as bandwidth, sweep rate, sweep range and antenna selection.

In the present scheme, a master 4 MHz oscillator is divided down to provide the intermediate mixing frequency. The divide-by circuit is controlled by a ROM. Within each band an 8:1 frequency range is covered. A second mixing frequency of 1 MHz is common to all the receivers. These conversion processes are single sideband so that the phase information is preserved and the two receivers for the same band are phase-locked. The output for each band is fed to a log compressor to give amplitude information over (110 dB range and then to a quandrature phase shift network to produce in-phase and quadrature phase components. These components from each band receiver are correlated to produce sine and cosine correlation coefficients from which the relative phase and correlation between signals from two different antennas can be obtained at 192 frequencies from 100 Hz to 25 MHz.

Correlation between the two magnetic antennas can provide the wave normal vector; between two electric antennas the wave polarization and the phase velocity of electrostatic waves; and between electric and magnetic antennas the Poynting vector and the discrimination between electromagnetic and electrostatic waves. Also, the correlation between a single antenna and a reference signal uplinked from the Orbiter can be used for doppler sounding. Measurement of these wave characteristics are necessary to carry out the wave injection investigation and to assess waves generated by beam-plasma interactions. Sample ISEE results are shown in Figure 4A.

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TABLE 2. PERFORMANCE CHARACTERISTICS FOR RPDP CORE INSTRUMENTS

INSTRUMENT: MEASUREMENT	PARAMETER: SPECIFICATION	
Step Frequency Correlator: Measures amplitude and phase between signals from any two sensors; sensors include 4 electric monopoles combined electronically to give triaxial dipoles and crossed magnetic loops to provide 3 magnetic components in 1/4 spin period.	Frequency Range	6 bands: 100-780 Hz, 780-6250 Hz, 6.25-50 kHz, 50-400 kHz, 0.4-3.2 MHz, 3.2-25.6 MHz
	Frequency Step	32 frequencies/band; log spaced
	Frequency Resolution . .	~1%
	Time Resolution	4 spectra/second
	Dynamic Range	110 dB
	Amplitude Resolution . .	0.5 dB
	E-range	10^{-8} to 3×10^{-3} Vm^{-1} $Hz^{-1/2}$
	B-range	10^{-6} to 3γ $Hz^{-1/2}$
	Phase	0-360° ±5°
	Correlation	±1.0, ±5%
Quadrispherical LEPEDEA: Measures distribution function for supra-thermal electrons and ions	Energy Range	2 eV-50 keV in 48 steps
	Field of View	6° x 162°
	Angular Resolution . . .	7 detectors: 9-18°, 18-39°, 39-71°, 71-109°, 109-141°, 141-162°, 162-171°
	Energy Resolution . . .	34%
	Geometric Factors . . .	10^{-3} cm^2-sr electrons, 4×10^{-4} cm^2-sr prot.
	Time Resolution	1 sec for energy-angle scan 1 spin period for distribution function
Ion Mass Spectrometer: Measures ion composition of ambient plasma	Density Range	1 to 10^6 ions cm^{-3}
	Mass Range	1-64 AMU in 3 channels
	Time Resolution	0.2 sec/channel
Triaxial Magnetometer (Fluxgate): Measures vector components of geomagnetic field and perturbations to the field caused by localized current systems	Frequency range	DC to 5 Hz each axis
	Range	±0.6 gauss each axis
	Dynamic Range	15 bits = ± 2γ resolution
	Aspect knowledge	10.1 - 100γ absolute perturbation vector
DC Electric Field/Langmuir Probe: Measures vector components of electric fields in plasma associated with localized space charge regions or plasma convection. Also sweeps sensors to determine characteristics of thermal electron plasma.	Electric Field Range . .	1 mV/m to 1 V/m
	Time Resolution	16 samples/second each axis
	Density	10^3-10^7 electrons cm^{-3}
	Temperature Range . . .	500-10,000°K for electrons
	Sample Resolution . . .	10 probe sweeps/second
Spin-Scan Imaging System: Measures light intensity as a function of position for a selected wavelength range in the UV or visible (but not both) to produce an image of the emitting region.	Pixel Size	0.°25 x 0.°25
	Collimator Field of View	36° x 3°
	Frame Size	36° x 360°
	Visible System Sensitivity (at 20 RPM)	~1.5 counts $(kR\text{-}pixel)^{-1}$, 3914Å (N_2^+), 5577Å (OI), 6300Å (OI)
	Ultra-Violet System* Sensitivity (at 20 RPM) *option	~1.0 counts $(kR\text{-}pixel)^{-1}$ 1170-1240Å (Hα, 1216Å) 1240-1370Å (OI, 1304Å and 1356Å) 1370-1700Å (N_2, LBH Band)
Recoverable Plasma Diagnostics Package (RPDP): Houses scientific instruments and subsystems on RMS and as subsatellite.	Size	107 cm dia x 66 cm high
	Weight	250 kg
	Energy	9 KWH from batteries
	Operating Life	100-200 hours at 90-45 watts
	Telemetry Up & Down . .	400-402 MHz UHF band, ~1 watt
	Telemetry Range	100-200 km
	Commands	32 for S/C functions & data mode
	Data System	RCA 1802 µP based
	Antennas	4 of 15 m-tubular type/retractable
	Booms	2 of 3m-telescoping/retractable
	Aspect	Star sensor, sun sensor, triaxial magnetometer for ±0.1° accuracy
	ID Strobe	1 or 2 @ 40 flashes/minute

2. Quadrispherical LEPEDEA (Frank and Ackerson/Iowa)

The quadrispherical low energy proton and electron differential energy analyzer (LEPEDEA) is being flown on ISEE-1 and 2. Another unit is being prepared for the OSS-1/Spacelab 2 PDP. Three quadrispherical, concentric plates with radii of curvature 10.8 cm, 11.2 cm, and 11.7 cm form two 90° electrostatic analyzers for proton (positive ion) and electron spectra, separately and simultaneously. The two outer plates are tied to circuit ground and the center plate is supplied with a variable positive potential which ranges from 0.15 V to 3500 V. This geometry of the electostatic analyzers was chosen primarily because of its versatility and mechanical simplicity. Thus, only one curved plate with high voltage is required for two electrostatic analyzers, large energy bandwidths and geometric factors, and ability to provide angular distributions of particle intensities within a fan-shaped solid angle of view, 162° × 6°, via the introduction of multiple detectors. Within this field of view two sets of seven detectors are placed to obtain fluxes simultaneously at seven angles with respect to the satellite spin vector.

A new development is to add microprocessor control to this instrument based on the controller being designed for Galileo. Especially for the RPDP usage this controller would give the flexibility to change sweep rates, energy steps and energy ranges. Also it will be possible to sync the sweep to an external pulse such as a particle beam firing pulse. As an example, the quadrispherical LEPEDEA can be operated in a single comprehensive mode for which the plate voltage is an exponentially decreasing ramp from 3500V to 0.15V. The repetition rate of this ramped voltage is once per second. Thus the differential, directional intensities of protons and electrons are sampled over the energy range 50,000 eV to 2 eV once each second. The responses of each of the fourteen electron multipliers are sampled with a 13-bit to 8-bit digital compressor and fed into the spacecraft telemetry stream. These compressors are sampled 48 times per second and hence 48-passband spectra of electron and proton intensities, each in seven directions, are acquired each second. For a spacecraft spin rate of 5 RPM there are 12 such scans of the spectra per spacecraft revolution. Complete velocity distributions of protons and electrons are gained once each 12 seconds and each comprise 4032 individual intensity samples. The inherent energy resolution of the analyzer $\Delta E/E = 0.17$, and the geometrical factors, 1.0×10^{-3} cm^2-sr for protons and 4.0×10^{-4} cm^2-sr for electrons, are considered generously adequate for measurements of low-altitude plasmas on the basis of previous applications of LEPEDEA instruments on the Injun-5 and Ariel-4 missions. The geometric factors can be adjusted to detect monoenergetic, directional beams of (1 amp(m)$^{-2}$ from an ion or electron gun by adding a collimator with a pinhole at the entrance aperture of an electron multiplier. Sample ISEE results are shown in Figure 4B.

3. Ion Mass Spectrometer (Hoffman/UTD)

As one of the core instruments on the RPDP, an ion mass spectrometer, similar to that to be flown on the Dynamics Explorer-A spacecraft, will be used to determine the composition and density of the plasma in the vicinity of the spacecraft.
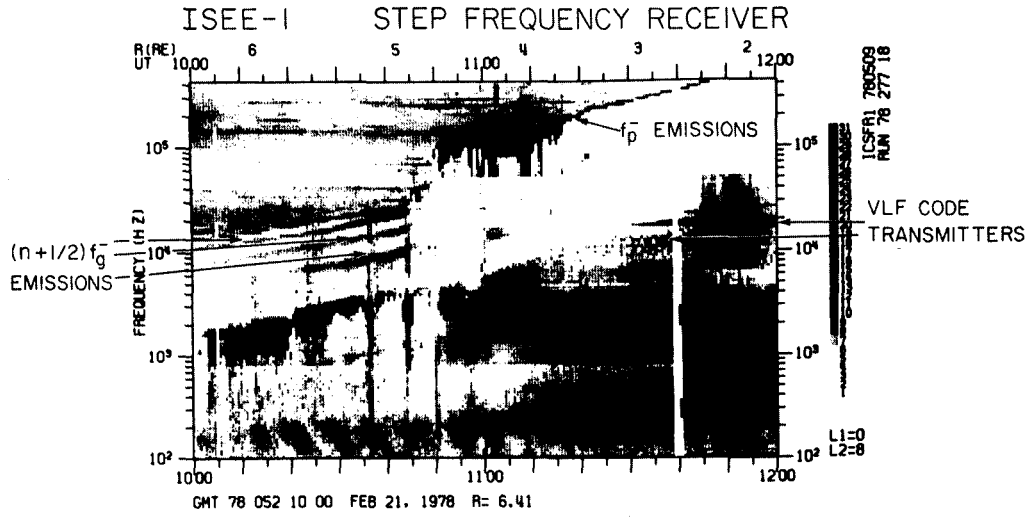
ISEE-1   STEP FREQUENCY RECEIVER

FIGURE 4A
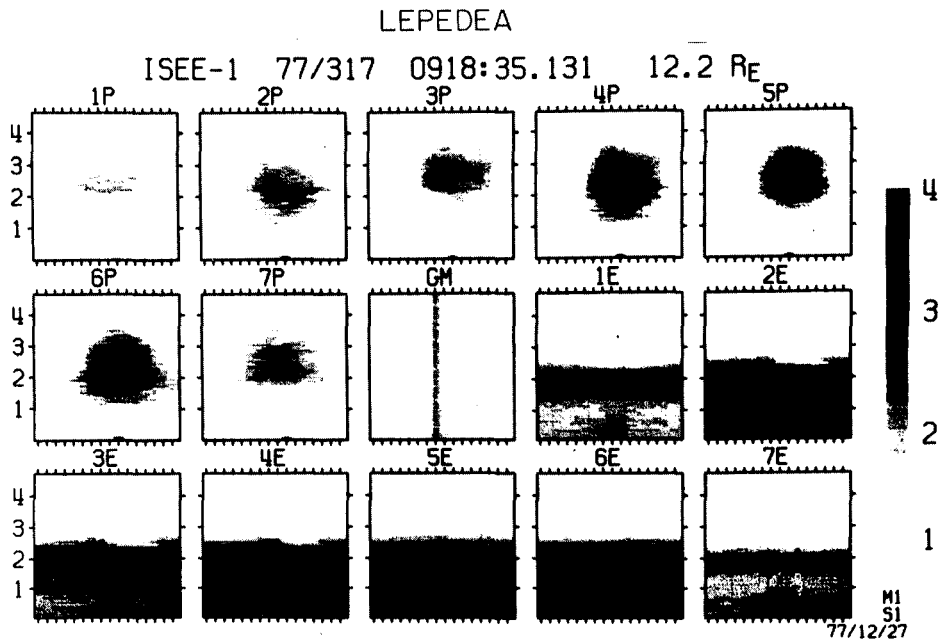
LEPEDEA

ISEE-1   77/317   0918:35.131   12.2 R_E

FIGURE 4B

The principal parts of each sensor are the entrance aperture containing the ion trap, magnetic analyzer, and electron multipliers. The entrance aperture is preceded by a 3-inch diameter screen flush mounted with the spacecraft skin looking out in its equatorial plane. Ambient ions entering the aperture due to the ram velocity of the satellite are collected in part on the ion trap collector which has a small hole in its center. This collector current is proportional to the total ion density. Those ions passing through the hole are post accelerated, collimated and passed through a magnetic analyzer. Three allowed trajectories lead to 3 collector slits which simultaneously collect ions in the mass ratio 1:7:14. Signal detection is by electron multipliers and log electrometer amplifiers. A useful dynamic range of over 7 decades results from a commandable multiplier gain range of 10^3 and a 5 decade log amplifier. The ion post acceleration voltage may be divided into 3 segments which may be repeatedly scanned separately or in any combination. The table below gives the ion species measured by each collector channel during each segment of the scan. Any single range is scanned in 200 ms.

CHANNEL	RANGE 1	RANGE 2	RANGE 3
A	H^+	D^+	He^+
B	Li^+, N^{++}, O^{++}	N^+, O^+ $\qquad$ Mg^+, Al^+, Si^+, N_2^+, NO^+, O_2^+	
C	N^+, O^+	Mg^+, Al^+, Si^+, N_2^+, NO^+, O_2^+	Fe^+

Comparison between the ion trap collector signal, which is a measure of total ion density, and the summation of all mass spectrometer output current provides an in-flight calibration of the mass spectrometer. If this is done under various conditions of ionospheric composition, calibrations are obtained for the several major ionospheric constituents. This technique has been used successfully between the RPA and IMS on the Atmospheric Explorer satellites, between the topside sounder and IMS on the ISIS-II satellite, and will be used for the RIMS on Dynamics Explorer-A, which is an RPA and IMS in tandem, similar to that proposed for RPDP. Overall accuracy is expected to be approximately 10% for the major ion species.

4. Triaxial Fluxgate Magnetometer (Sugiura/GSFC)

The fluxgate sensor planned for RPDP is a modification of the instrument being flown on Dynamics Explorer (DE). The Dynamics Explorer instrument is a hybrid consisting of a four bit digitally controlled current source and twelve bit internal analog-to-digital converter operating on a ⎬6000 gamma (1 gamma = 1 nT) analog signal. The instrument planned for RPDP will incorporate the same sensor design with the range modified to produce a ⎬64000 gamma analog signal fed into a 14 bit A-D converter to give a resolution of ⎬2 gamma.

Errors include the noise level of the instrument of approximately 0.1 gamma peak to peak, the temperature coefficient of sensitivity which is less than 10 ppm/°C, and the temperature stability of the sensor magnetic axis, which is less than 3 arc seconds/°C. The latter two sources convert to

maximum error sources of .64 gamma/°C and .93 gamma/°C respectively. They are controllable by ground calibration and/or inflight thermal control, and in the case of the sensitivity, by inflight calibration. As is almost always the case with magnetometers, the ultimate accuracy of measurement will be determined by the degree to which spacecraft fields can be eliminated at the sensor, and by the accuracy of attitude determination provided.

5. DC Electric Field/Langmuir Probe (Block and Falthammar/KTH, Gurnett/Iowa)

The electric field instrument developed by the Swedish Royal Institute of Technology (KTH) has been flown on numerous sounding rocket and balloon missions. This unit combines voltages from the four monopole antenna elements with summing and difference amplifiers to produce vector components of the electric field from dc up to 1 kHz. At the end of each antenna element is a 7 cm diameter specially coated spherical probe to minimize the effect of photoemission. This unit is microprocessor controlled so that it is adaptive in case an antenna element fails to open and programmable so that periodically the sensors can be swept with a voltage ramp to produce the Langmuir probe I vs. V characteristics. From this sweep the electron density and temperature can be obtained. This sweep can be initiated up to 10 times/second if desired.

The final design and the fabrication of flight hardware is to be carried out at Iowa based on the KTH design.

6. Spin-Scan Imaging System (Frank and Craven/Iowa)

Two spin-scan imaging systems are being developed for the Dynamics Explorer-A Mission. One of these systems responds in the visible wavelength range at 391.4, 557.7, and 630.0 nm due to the selected interference filters and the other responds in the vacuum ultraviolet region at 117-124, 124-137, and 137-170 nm. It is proposed to fabricate only one of these imagers at this time. The one selected will depend on the specific mission objectives to be accomplished.

Both imaging systems have a similar scheme. Light enters through a collimator which defines the field of view to 36° × 3° and reflects off a mirror which is positioned in angle by a stepping motor. Light from the stepped mirror is focused by a parabolic mirror onto a pinhole aperture. This (4mm diameter light beam passes through a selected interference filter in a filter wheel and is incident on the photocathode of a photomultiplier tube. The PM tube output gives the light intensity. As the RPDP spins, the imager scans a 360° circle producing a line of 1440 pixels. After each scan the stepping mirror changes angle to produce an image field of 144 lines. At a spin rate of 20 RPM it takes 7.2 minutes to form a complete image of 360° × 36°. Scans of smaller fields of view can be obtained in less time by command or by programmed sequence.

7. Additional Instruments for WISP

The RPDP is to be designed so that several additional instruments can be accommodated. For SEPAC, Magnetospheric Multiprobes, CRM, and Tether it

may be that the investigations will provide instruments for RPDP. For WISP there have been two sets of instruments selected for accommodation on RPDP:

+ WISP Plasma Analysis Package (D. L. Reasoner/MSFC). The knowledge of the background plasma composition and density is required to estimate critical parameters in plasma dispersion relations such as ion plasma frequencies and acoustic speeds. In situ plasma measurements will augment sounder observations of F-region plasma bubbles. The RPDP will carry an ion mass spectrometer, a retarding potential analyzer, and a Langmuir probe, all similar to instruments developed for flight on the DOD SCATHA and on satellites or rockets by MSFC. The ion mass spectrometer is a magnetic focussing analyzer which will be able to measure the densities of H^+, He^+, O^+, the N_2^+, NO^+, O_2^+ heavy ion group, and the heavier ions up to mass 56 (Fe^+). The retarding potential analyzer and Langmuir probe feature high frequency responses ($(1$ kHz$)$), important for analyzing transient perturbations caused by wave plasma interactions.

+ WISP HF Sounder (W. W. L. Taylor/TRW). The HF Sounder subsystem is an active, remote radio frequency sensor of considerable flexibility capable of coherent detection and range and Doppler measurements. It will be used to determine ionization structures and motions of TID's. It measures the time delay between transmitted and received pulses and the phase, amplitude and Doppler shift of the received signals. The structure and location of irregularities will be measured, both along the orbit and remote from Spacelab.
The HF Sounder Subsystem will operate in a number of preprogrammed modes, including a survey mode. This is a search operation for natural phenomena of interest which will recognize the local plasma frequency and the condition of the ionosphere (quiescent or disturbed). Subsequent HF Sounder activity will follow to investigate some feature in greater detail by means of another mode of operation, which will usually provide information of interest in a more magnified form. Other modes may change the frequency range of operation, pulse width, pulse repetition frequency and/or the power radiated. Modes may determine Doppler shifts or operate at a single frequency for monitoring the strength and variation of the received signals. Several types of data presentations are possible, including displays of propagation time vs. frequency, Doppler vs. time for selected frequencies, Doppler vs. range at selected frequencies, and range vs. time at selected frequencies.

RPDP QUESTIONS RELATED TO JOINT OPERATIONS

- Other Required/Desired Instruments

- Maximum Range of Operation

- Maximum Spatial/Temporal Resolution (Data Rate)

- Absolute RPDP Attitude Information

  Real Time
  Post Mission

- Absolute RPDP Position Information

  With Respect to Orbiter
  With Respect to Earth/Magnetic Field
  Performance of Ku-Band Radar
  Availability of Global Positioning System
  Real Time
  Post Mission

- Operation On-Orbit Between STS Flights

- Multiple Joint Operations on One Mission

  Total Energy
  Conflicting Requirements