JPL PUBLICATION 84-56

Report on Final Recommendations for IMPS Engineering/Science Payload

1 September 1984

Prepared for

Air Force Geophysics Laboratory
U.S. Air Force Systems Command

Through an agreement with

National Aeronautics and Space Administration

by

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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REPORT ON FINAL RECOMMENDATIONS FOR IMPS ENGINEERING/SCIENCE PAYLOAD

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The research described in this publication was carried out by the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by Air Force Geophysics Laboratory through an agreement with the National Aeronautics and Space Administration.

ACKNOWLEDGMENTS

The following is a list of those figures previously published and their sources: Fig. 2, Miller, N.J., and Brace, L.H., J. GEOPHYS. RES., 74, 5742, 1969; Fig. 3, Baron, M.J., Repr. DNA 3023F, Stanford Research Institute, Stanford, CA; Fig. 4, Watt, T.M., Incoherent scatter observations of the ionosphere over Chatanika, Alaska, J. GEOPHYS. RES., 78, 3000, 1973; Fig. 5, Hoffman, J.H., and Dodson, W.H., J. GEOPHYS. RES., 85, 629, 1980; Fig. 6, Iijima, T., and Potemra, T.A., Large-scale characteristics of field-aligned currents associated with substorms, J. GEOPHYS. RES., 83, 612, 1978; Fig. 8, Murphy, G.B., Picket, J.S., Raitt, W.T., Shawhan, S.D., Electron and ion density depletions in the STS-3 orbiter wake, PROC. OF THE SPACECRAFT ENVIRONMENTAL INTERACTIONS TECHNOLOGY CONFERENCE, USAF/NASA, Colorado Springs, 1982; Shawhan, S.D., Murphy, G.B., and Picket, J.S., Plasma diagnostics package initial assessment of the shuttle orbiter plasma environment, J. SPACECRAFT AND ROCKETS, in press, 1984, Copyright American Institute of Aeronautics and Astronautics, reprinted by permission; Fig. 11, courtesy of D. Smart and P. Shea, Air Force Geophysics Laboratory; and Fig. 12, Kessler, D.J., and Cour-Palais, B.G., Collision frequency of artificial satellites: Creation of a debris belt, SPACE SYSTEMS AND THEIR INTERACTIONS WITH EARTH'S SPACE ENVIRONMENT, H.B. Garrett and C.P. Pike, eds., AIAA Press, New York, 707-736, 1980.

EXECUTIVE SUMMARY

In support of its activities under the Interactions Measurement Payload for Shuttle (IMPS) project, the Jet Propulsion Laboratory (JPL) established an Engineering/Science Working Group (ESWG) made up of engineering and scientific specialists in the fields of spacecraft interactions and space physics. The ESWG was formed to assist JPL in providing its sponsor, the Air Force Geophysics Laboratory (AFGL), with a mission concept for the IMPS project. IMPS, as originally conceived by AFGL, is intended to be a Shuttle-compatible complement of engineering experiments and environmetal sensors capable of defining spacecraft interactions in the auroral/polar environment. The purpose of this document, as prepared by JPL and the ESWG, is to provide an estimate of the impact of these interactions on materials, equipment, and technologies of future AF systems and, based on their importance, to develop for JPL a generic payload capable of carrying out the IMPS mission so that an accurate mission plan and cost estimate can be prepared. It is also intended that the report will provide a broad base on which future IMPS planning can be conducted.

This document addresses what are perceived as the key scientific and engineering concerns for AF space missions due to the peculiarities of the auroral/polar environment. These concerns have been combined into 6 general categories: (1) dielectric charging; (2) material property changes; (3) electromagnetic interference, plasma interactions, and plasma wake effects associated with high-voltage solar arrays and large space structures; (4) radio frequency distortion and non-linearities due to the enhanced plasma in the Shuttle ram/wake; (5) Shuttle glow and contamination; and (6) plasma interactions with the space-based radar. Other (lesser) areas of concern considered were: interactions associated with EVA; radiation and single-event upset effects peculiar to the auroral/polar cap environment; and space debris. During a series of meetings at which numerous experts in addition to the core ESWG panel were invited to attend and present ideas, a consensus position on the information most critical to an understanding of these categories of effects was developed. The report describes the measurements needed to adequately address the concerns associated with each category and includes a list of generic instrument packages capable of making the required measurements.

Although the ESWG did recommend specific instrument categories to be flown on the first mission, the emphasis in the report is on the spectrum of measurements necessary to quantize the interactions in the auroral/polar environment. The specific evaluation criteria used in selecting the relevant instrumentation were as follows:

(1) Is the interaction effect being studied unique to polar orbits or different in polar orbit than other orbits?

(2) Is the interaction expected to be unique to or enhanced by structure size?

(3) Is the interaction relevant to planned AF systems?

(4) Is the effect being investigated by other programs?

(5) Is it appropriate to carry out the investigation from the Shuttle?

(6) Can useful information be made available by 1990 so as to have a meaningful impact on the next generation of AF spacecraft?

The intent of these criteria is to provide the justification, in terms of AF objectives, for the IMPS mission. Given the potentially broad impact of some of the interactions which meet these criteria on AF missions, the IMPS mission will require a large cross-section of technical expertise ranging from basic research (6.1) to advanced development (6.3).

Given the great complexity and cost of individual AF systems, the report attempts to identify specific components (such as a segment of the space based radar antenna) that should be tested rather than to recommend that the actual systems be flown. The identification of the "weakest link," such as dielectric materials in the case of charging, is a major theme of the report. As the environments encountered in the auroral/polar regions are known to vary on the order of minutes by orders of magnitude, it is unlikely that ground tests will be able to duplicate the actual space conditions affecting these components. It is therefore likely that meaningful component tests will in fact not be capable of being performed on many systems until the IMPS investigations suggested by the report are completed.

This report is written with the intent of making its recommendations available to the widest possible technical community within the AF. The instruments have been presented in a generic sense so that program offices can readily suggest refinements that would specifically benefit their programs. Obvious candidates for material testing would be optical windows for planned AF sensor systems, where contamination, surface chemistry, plasma etching, and ion-induced color centers would be of concern, and dielectric antennas where insulator charging noise could be an issue. Thus the report is intended as a starting point for assisting in the development of actual flight test programs. In support of this, the report includes key contacts (the members of the ESWG) and a detailed appendix of references by topic for each of the interactions discussed in the report.

A suggested ground test plan for the IMPS project has been included as an integral part of the report. The report concludes with a description of proposed follow-on IMPS missions intended to provide a complete, integrated spacecraft interactions program. As time and resources permit, AFGL plans to extend the data base on spacecraft environmental interactions through a series of workshops on specific topics.

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SECTION I

INTRODUCTION

This document contains recommended measurements and instrumentation for the Interactions Measurements Payload for Shuttle (IMPS). The recommendations are defined in terms of the spacecraft interactions relevant to the polar and auroral Shuttle environments. The Jet Propulsion Laboratory (JPL) and its advisory panel, the Engineering/Science Working Group (ESWG), have reviewed the IMPS objectives and have recommended a list of applicable categories for investigation. Investigation categories proposed in this report are as follows: dielectric charging; material property changes; electromagnetic interference, plasma interactions, and plasma wake effects associated with high-voltage solar arrays and large space structures; radio frequency distortion and nonlinearities due to enhanced plasma in the Shuttle ram/wake; Shuttle glow and contamination; and plasma interactions with the space-based radar. Other concerns considered are the interactions associated with EVA; the radiation and single-event-upset effects peculiar to the auroral/polar cap environment; and space debris.

This report first provides a review of the environmental concerns and basic technology issues addressed and the impact of each of these on Air Force (AF) systems. Second, this report lists the measurements required to characterize these interactions and recommends instrument packages capable of obtaining the measurements. Subsequent sections include a suggested ground-test program and possible follow-on missions.

SECTION II

BACKGROUND

A. AF SYSTEM IMPACTS

This section provides the background justification for why the AF should be concerned with the IMPS mission, specifically:

(1) The AF's role in space clearly dictates the need for vehicles in high-inclination orbits in order to achieve mission goals.

(2) Proposed AF missions require that large or high-voltage structures be placed in this environment.

(3) As the military has relied more on sophisticated electronic surveillance, communications, and navigation systems capable of autonomous operation, these systems have become increasingly sensitive to the space environment, a sensitivity that needs to be accurately assessed.

There is a growing urgency to evaluate in detail the effects of the space environment on the long-term operation of military space systems. IMPS is intended to address this problem for the specific case of low-altitude, high-inclination polar Earth orbit (PEO) and for the case of operations in conjunction with large structures such as the Space Shuttle that are capable of locally altering the natural environment.

The objectives of IMPS, as defined by the Air Force Geophysics Laboratory (AFGL), are to determine the effects of the space environment on:

(1) Optical systems as represented by cooled infrared detection systems and laser systems (low power). Such systems are particularly sensitive to surface contamination and to the hazard of "Shuttle glow" at PEO.

(2) Large military structures such as the Space-Based Radar. These systems will be sensitive to a variety of environments, particularly plasma density, turbulence, and radiation unique to the polar/auroral regions.

(3) Large, potentially high-power systems such as the Space Based Laser. High-voltage systems will be affected by the high-density ionospheric plasma at Shuttle altitudes and, possibly, by spacecraft charging during auroral arc passage. Contamination and aging of structural and optical components of such systems are also concerns.

(4) Manned operations requiring EVA during passage through the auroral region. Again, passage through the harsh radiation and charging environments associated with the auroral and polar cap regions poses potentially serious effects.

(5) Communication and radar systems requiring specialized antennas sensitive to polar environments. Antennas with dielectric materials are sensitive to auroral region energetic electrons.

These systems areas are derived from specific mission concepts called out in the AIAA/AFSTC Military Space System Technology Plan (MSSTP). Typical examples of proposed AF space systems that would be impacted are the IR step-stare mosaic surveillance systems, space-based LIDAR, neutral particle-beam weapon systems, medium altitude surveillance radar, intermediate altitude phased-array radar, and the space-based laser. As discussed at length in this report, numerous, potentially destructive interactions with the space environment are possible for these systems. At the least, the proposed effects, many of which are unique to the auroral/polar region, will degrade system performance to the point of failure on long-term (10 or more years) missions. Thus the threat to AF systems must be seriously considered and quantized where possible--again, the purpose of IMPS.

The information gained from the IMPS program is expected to have broad impact across many AF systems in space. The polar space environment and the alteration of the environment by large structures or high-voltage surfaces will cause effects on virtually all space systems. Examples of the effects indicate the generic AF system applicability for IMPS:

(1) Auroral fluxes of keV electrons are capable of surface charging, resulting in electrical breakdown of exposed dielectrics.

(2) Auroral electrons negatively charge spacecraft causing positive ion impacts to occur at high energy (>100 eV) on wake surfaces of large structures. High-energy ions cause sputtering and severe chemical effects on surfaces.

(3) Large spacecraft with charged surfaces or high voltages can "focus" ions or electrons onto sensitive subsystems.

(4) In polar orbit, auroral electron fluxes are encountered four times per orbit throughout the life of the satellite. Severe surface effects (deterioration, discoloration, etc.) are possible due to deep electron penetration with resulting electric fields and enhanced ion sputtering effects.

(5) Charged or high voltage spacecraft surfaces in concert with electromagnetic fields may be able to trap high density plasmas in localized regions near a large spacecraft. Such plasmas can interfere with radiowave propagation or with antenna arrays.

There are many other examples but the point is obvious. The IMPS information is necessary <u>before</u> we design large or polar spacecraft.

B. THE NATURAL ENVIRONMENTS

At altitudes below 1000 km, the Earth's natural environment is dominated by the ionosphere and the upper reaches of the neutral atmosphere. Although this is a dynamic region of high plasma and neutral density, most mission planners tend to ignore it. In Fig. 1, typical profiles for midlatitudes are presented showing how the neutral and charged-particle environments vary with altitude between 100 and 1000 km. The main features of this region are that the densities decrease roughly exponentially with altitude and that the environment changes from one dominated by oxygen to one dominated by hydrogen and hydrogen ions. In addition, this environment is influenced by diurnal and seasonal variations, changes in solar EUV (extreme ultraviolet) and heating due to geomagnetic activity, interactions between the charged particles that make up the ionosphere and the Earth's magnetic field, coupling to the neutral winds, and chemical reactions. Thus, the Shuttle environment is extremely complex and variable, characteristics considerably enhanced over the polar caps and in the auroral zones by the following:

(1) Electron temperatures (Figs. 2-4) can undergo variations on the order of 1000 K over scales of 10° latitude during periods of intense magnetic activity, and on the order of 300-500 K during normal conditions. Temporal variations of 1000 K for Te (100 K for Ti) over 1/2 to 4 hours are typical during active conditions.

(2) O^+ and H^+ densities (Fig. 5) exhibit significant (order of magnitude) spatial/temporal variations at high latitudes in conjunction with such phenomena as the "plasma trough," "ionization hole," "light-ion trough," and "polar wind."

(3) Auroral electrons with fluxes of 10-100 $\mu A\ m^{-2}$ with mean energies in excess of several tens of keV occur in auroral arcs during disturbed periods. Figure 6 indicates typical precipitation regions of electrons and protons as a function of average particle energy.

(4) Magnetic fields are nearly vertical (as opposed to horizontal near the equator) with rapid spatial variations over the geomagnetic poles.

(5) Cosmic ray and solar flare fluxes are within a factor of 2 of those seen in interplanetary space. (Although at lower latitudes the Earth's magnetic field shields these particles, direct entry over the polar caps is possible along the magnetic field lines.)

(6) Significant sudden enhancements in neutral density are produced through joule heating by intensified currents flowing during magnetically disturbed periods.

Whereas the average low-latitude Shuttle environment has been reasonably well modelled, the preceding characteristics have precluded the development of similar models for the auroral and polar cap regimes. Only a few large and extremely complex programs are currently capable of approximating these regimes. Thus the impact of the auroral and polar cap natural environments on space systems represents a unique challenge for the AF mission planner and spacecraft designer.

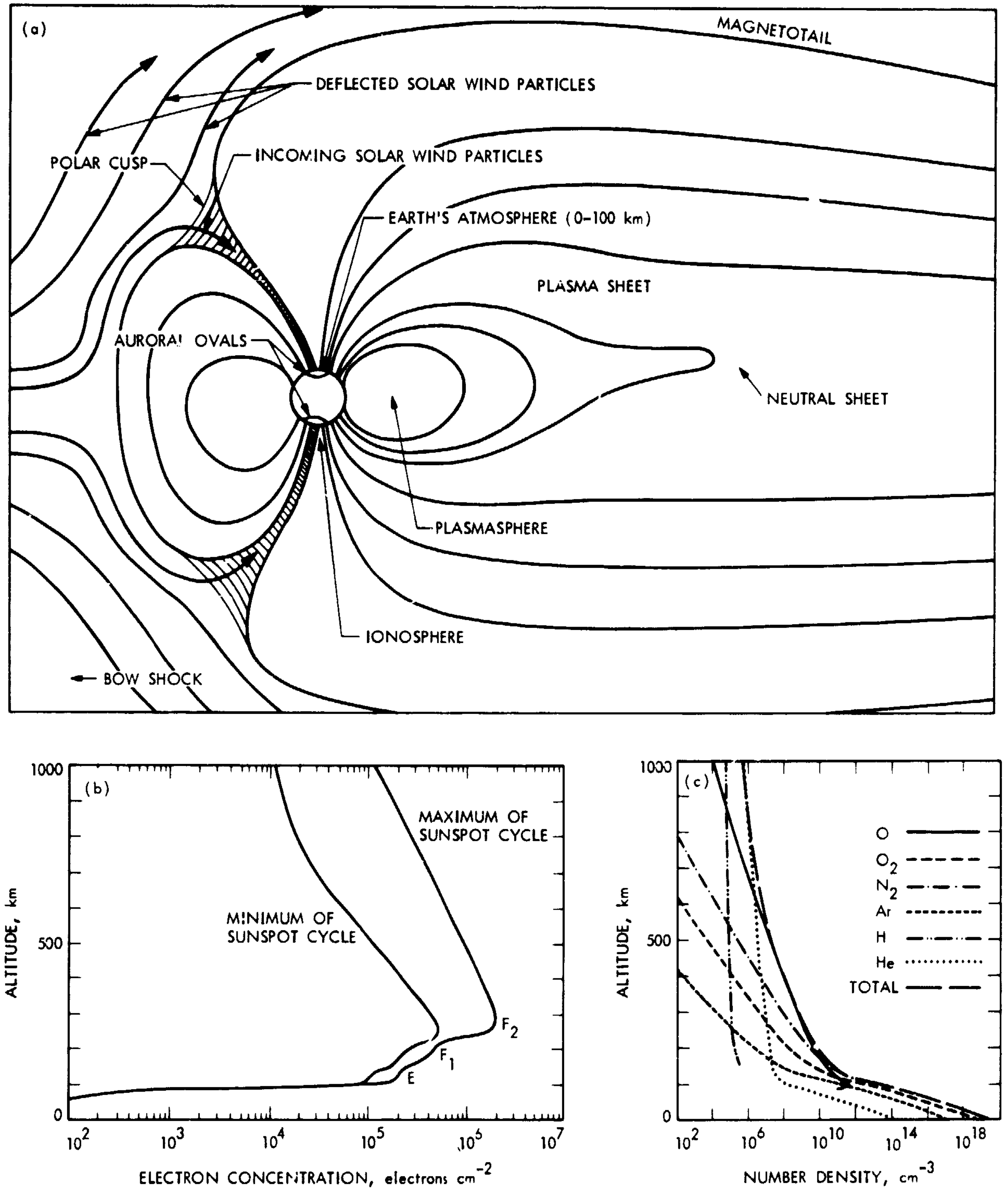

Fig. 1. The Earth's environment: (a) geospace/magnetosphere; (b) ionosphere; and (c) neutral atmosphere

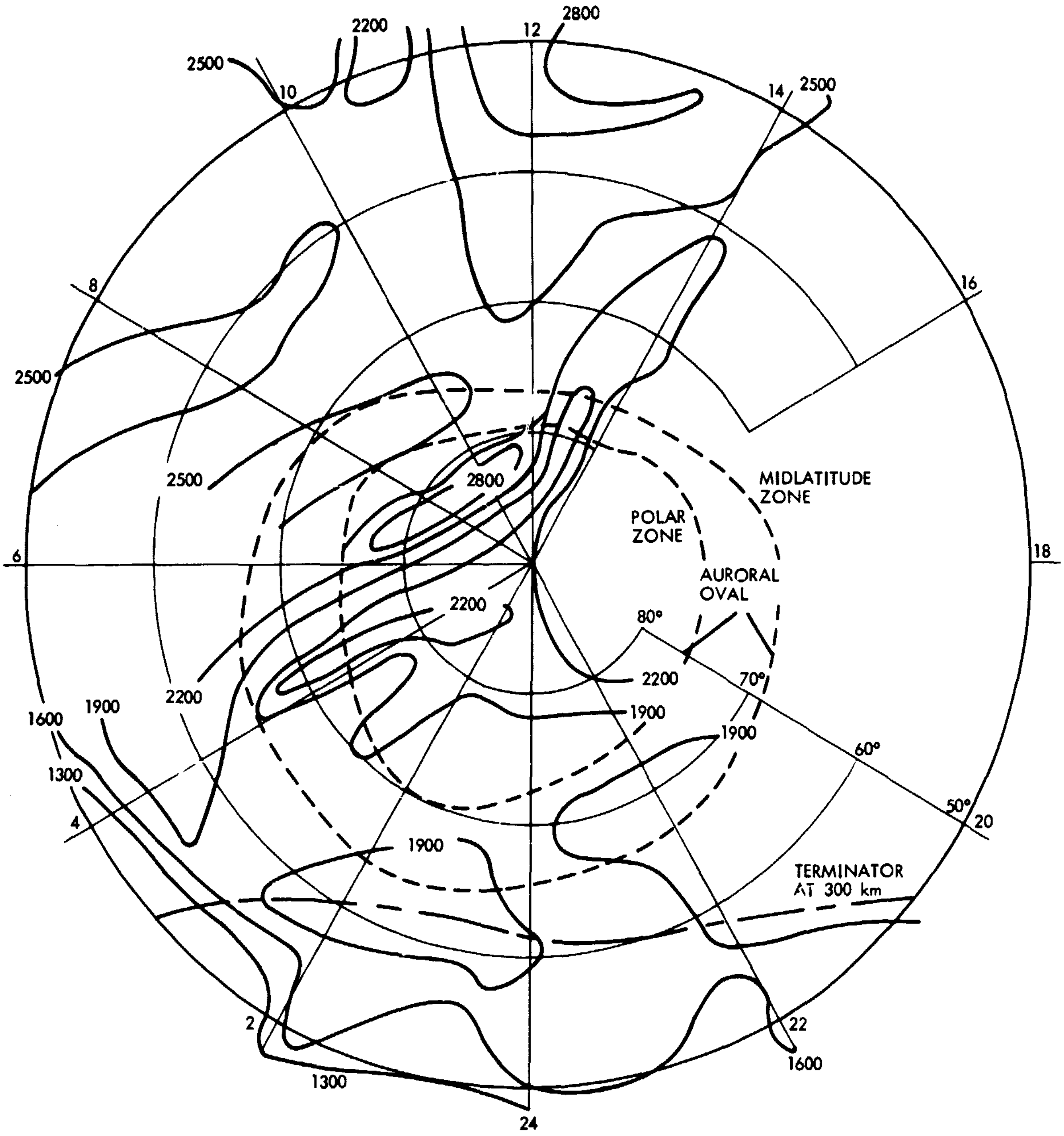

Fig. 2. Electron temperature (K) as a function of geomagnetic latitude and local time at 1000 km over Grand Forks during May-June, 1965

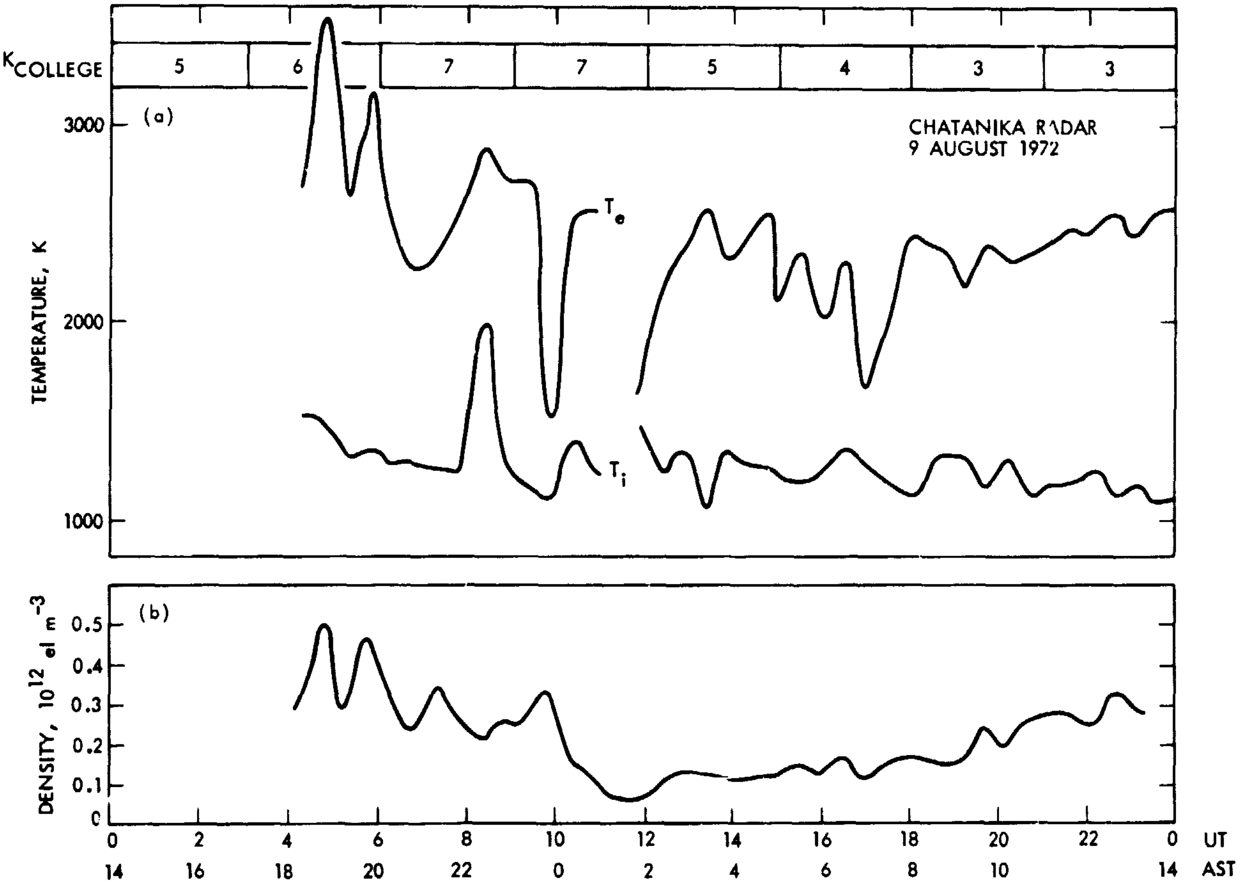

Fig. 3. Temporal variations in (a) electron and ion temperature and (b) density at 300 km for a 24-h period during the very intense storm of August, 1972

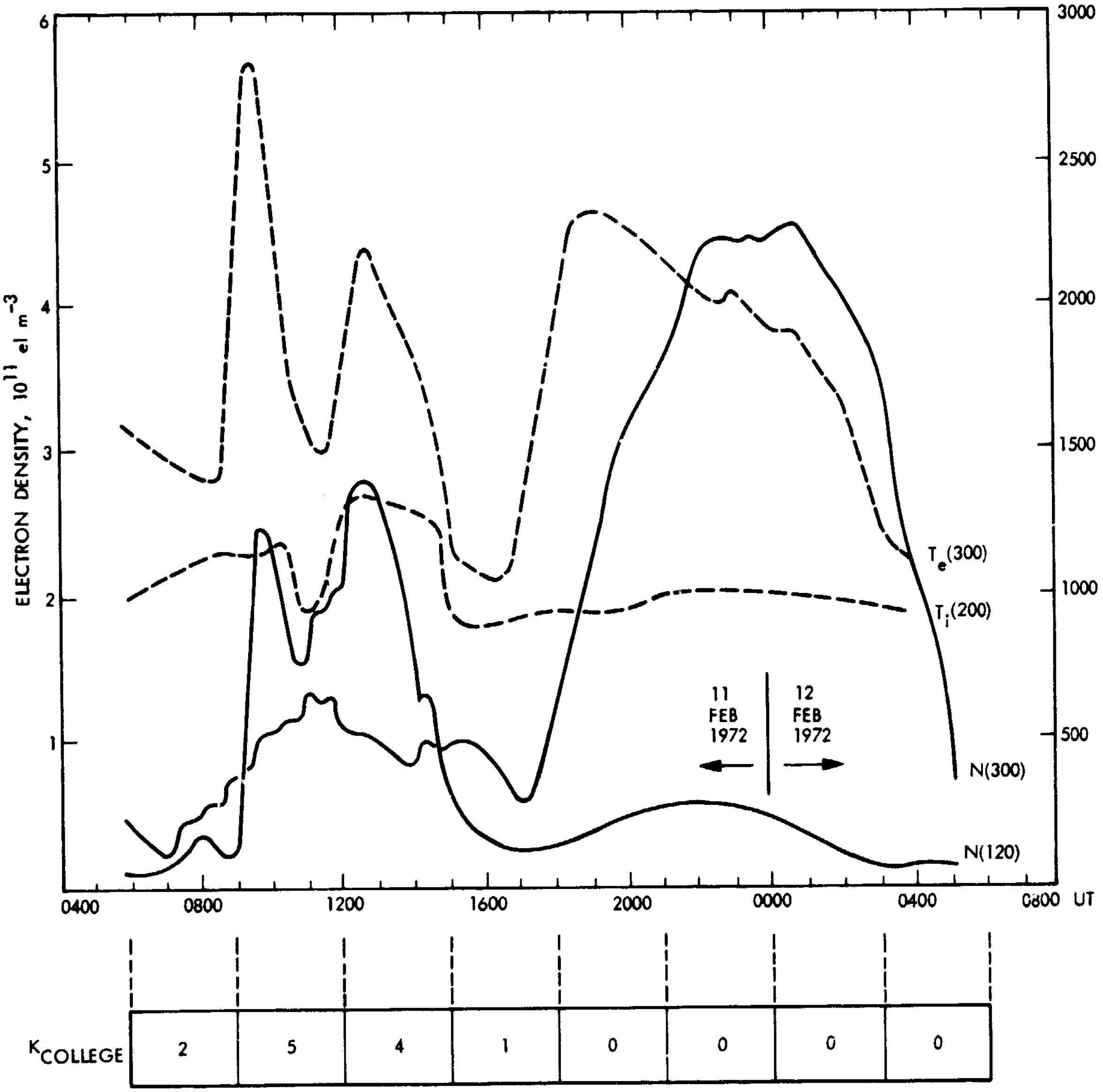

Fig. 4. Temporal variations in electron and ion temperature and electron density for a 24-h period February 11-12, 1972

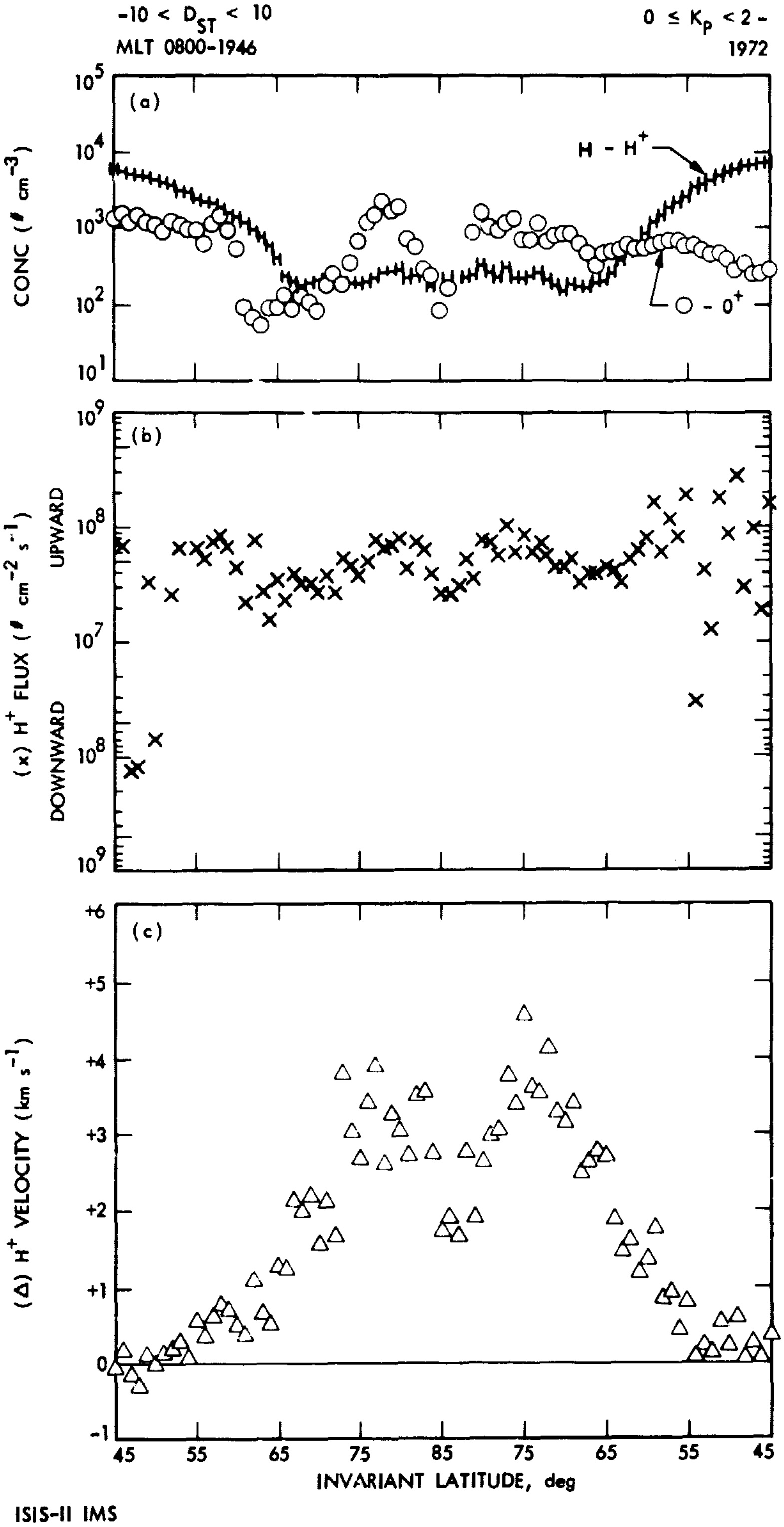

Fig. 5. As a function of invariant latitude, the (a) H^+ and O^+ concentrations, (b) H^+ flux, and (c) H^+ flow velocity. Each point on the graph is an average of data from 5 to 30 satellite passes. Dusk is to the left, and dawn to the right. The time period over which the data were averaged is 4 weeks around winter solstice.

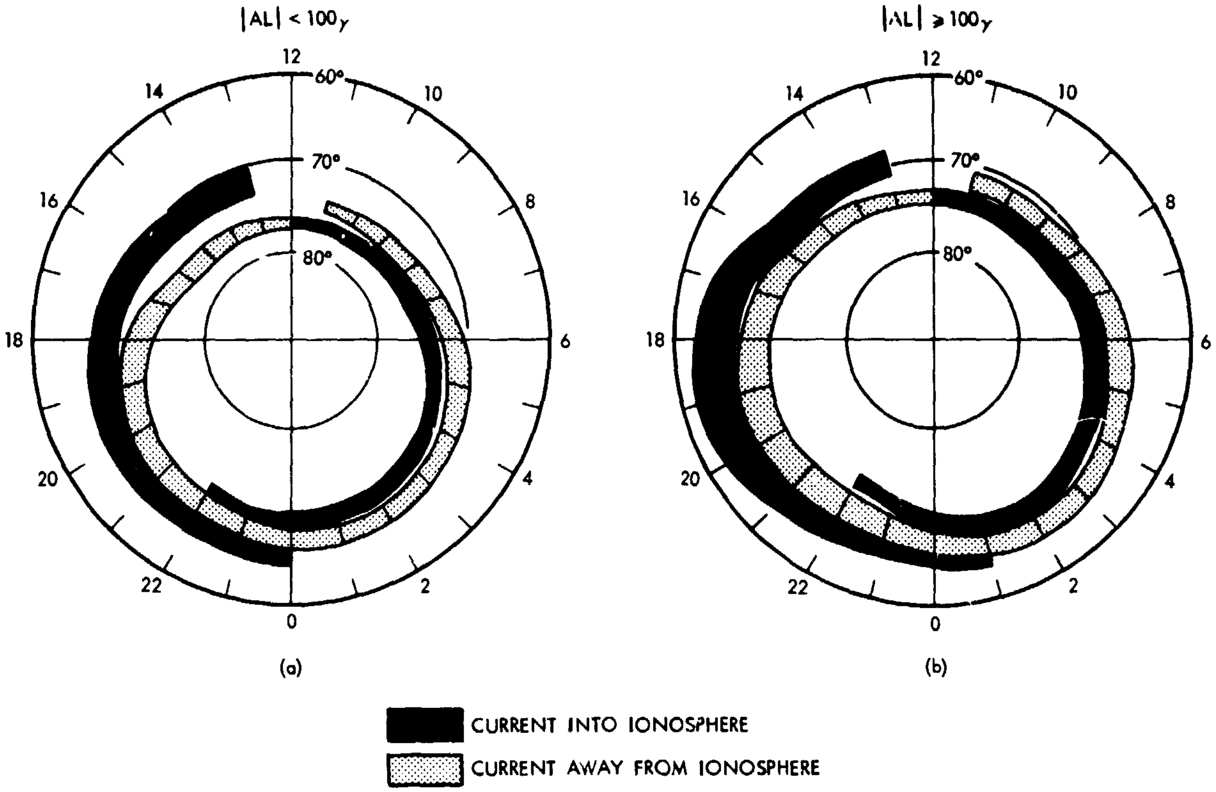

Fig. 6. A summary of the distribution and flow directions of large-scale field-aligned currents determined from (a) data obtained from 439 passes of Triad during weakly disturbed conditions (AL $< 100\ \gamma$) and (b) data obtained from 366 Triad passes during active periods (AL $\geq 100\ \gamma$)

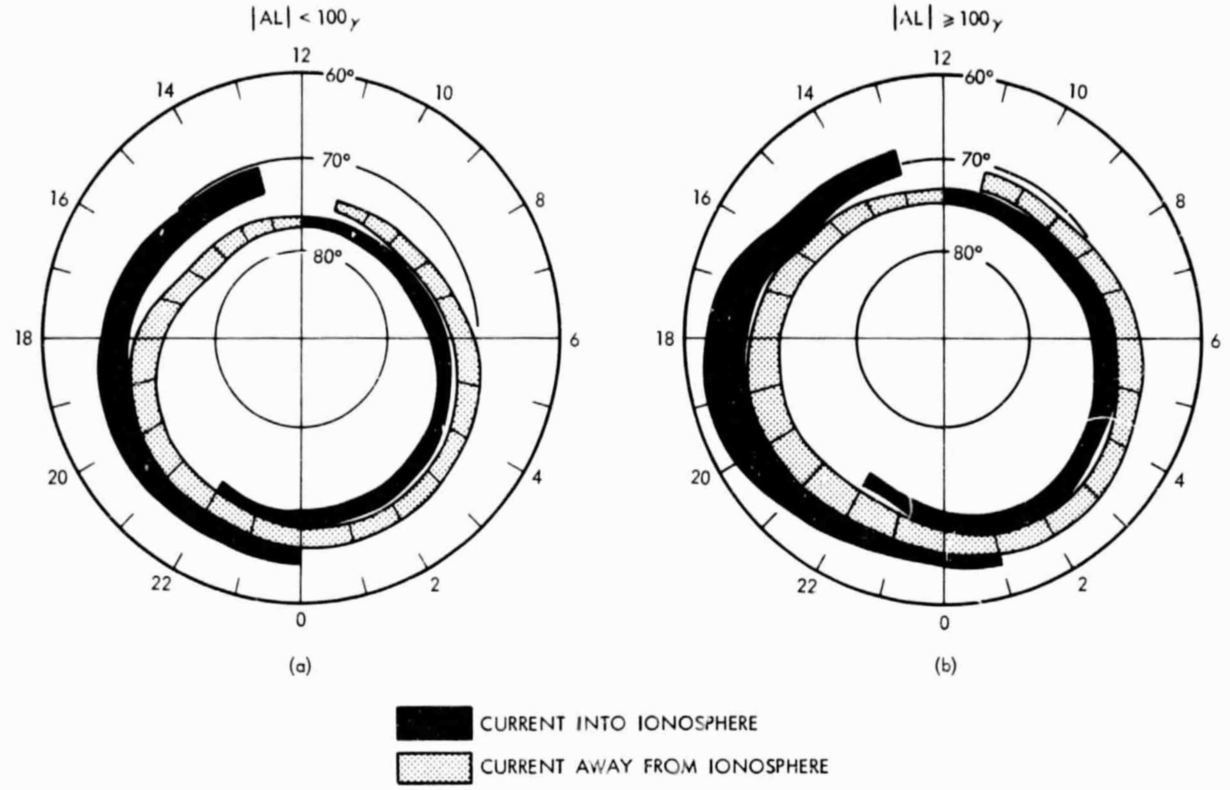

Fig. 6. A summary of the distribution and flow directions of large-scale field-aligned currents determined from (a) data obtained from 439 passes of Triad during weakly disturbed conditions (AL < 100 γ) and (b) data obtained from 366 Triad passes during active periods (AL ≥ 100 γ)

C. THE INDUCED ENVIRONMENTS

In addition to the ambient environment encountered between 100 and 1000 km, spacecraft possess locally induced environments by virtue of their interaction with the ambient environment. The induced environment is often dominant in terms of the effects on spacecraft activities, especially for large structures. Potentially important to the local environment are the outgassing and thruster effluents, near-surface chemical interactions (contamination), generation of plasma waves and turbulence, optical emissions (the "Shuttle glow"), enhanced (depleted) gas and plasma densities in the ram (wake) region, and local generation of electric and magnetic fields. Much useful experimental evidence concerning these interactions is available from a variety of measurements aboard STS-3, results of which are reported by Murphy et al., Shawhan et al., Murphy et al., Raitt et al., and Narcisi et al.[1] The "Shuttle glow" has been observed on STS-3 and STS-4 by Banks et al. and Mende et al.[2], respectively. These observations are briefly summarized below (see also Figs. 7 and 8 and Table 1).

1. Neutral Gaseous Environment

(a) A ram/wake modulation of two orders of magnitude in neutral pressure (10^{-5} T to 10^{-7} T: 10^{-7} T = ambient pressure at 240 km) has been observed within the payload bay on STS-3.

(b) The initial bay pressure on STS-3 was 10^{-5} T. It took nearly twenty-four hours to outgas to the ambient level of 10^{-7} T.

(c) Short-duration (approximately a few seconds) pressure increases of an order of magnitude typically accompanied attitude-control thruster firings on STS-3.

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[1] G.B. Murphy et al., Electron and ion density depletions in the STS-3 orbiter wake, PROC. OF THE SPACECRAFT ENVIRONMENTAL INTERACTIONS TECHNOLOGY CONFERENCE, USAF/NASA, Colorado Springs, 4-6 Oct. 1982; S.D. Shawhan et al., Plasma diagnostics package initial assessment of the Shuttle Orbiter plasma environment, J. SPACECRAFT AND ROCKETS, in press, 1984; G.B. Murphy et al., Interaction of the space shuttle orbiter with the ionospheric plasma, PROC. OF THE 17TH ESLAB SYMPOSIUM ON SPACECRAFT/PLASMA INTERACTIONS AND THEIR INFLUENCE ON FIELD AND PARTICLE MEASUREMENTS (Noordwijk, Netherlands), 13-16 Sept. 1983a; G.B. Murphy et al., Perturbations to the plasma environment induced by the Orbiter's maneuvering thrusts, PROC. SHUTTLE ENVIRONMENT AND OPERATIONS MEETING (AIAA, Washington, D.C.), 1983b; W.J. Raitt et al., Measurements of the thermal plasma environment of the space shuttle, PLANET SPACE SCI., in press, 1984; R. Narcisi et al., The gaseous plasma environment around the space shuttle, PROC. SHUTTLE ENVIRONMENT AND OPERATIONS MEETING (AIAA, Washington, D.C.), 1983.

[2] P.M. Banks et al., Space shuttle glow observation, GEOPHYS. RES. LETT., 10, 118-121, 1983; S.B. Mende et al., Observations of optical emissions on STS-4, GEOPHYS. RES. LETT., 10, 122-125, 1983.

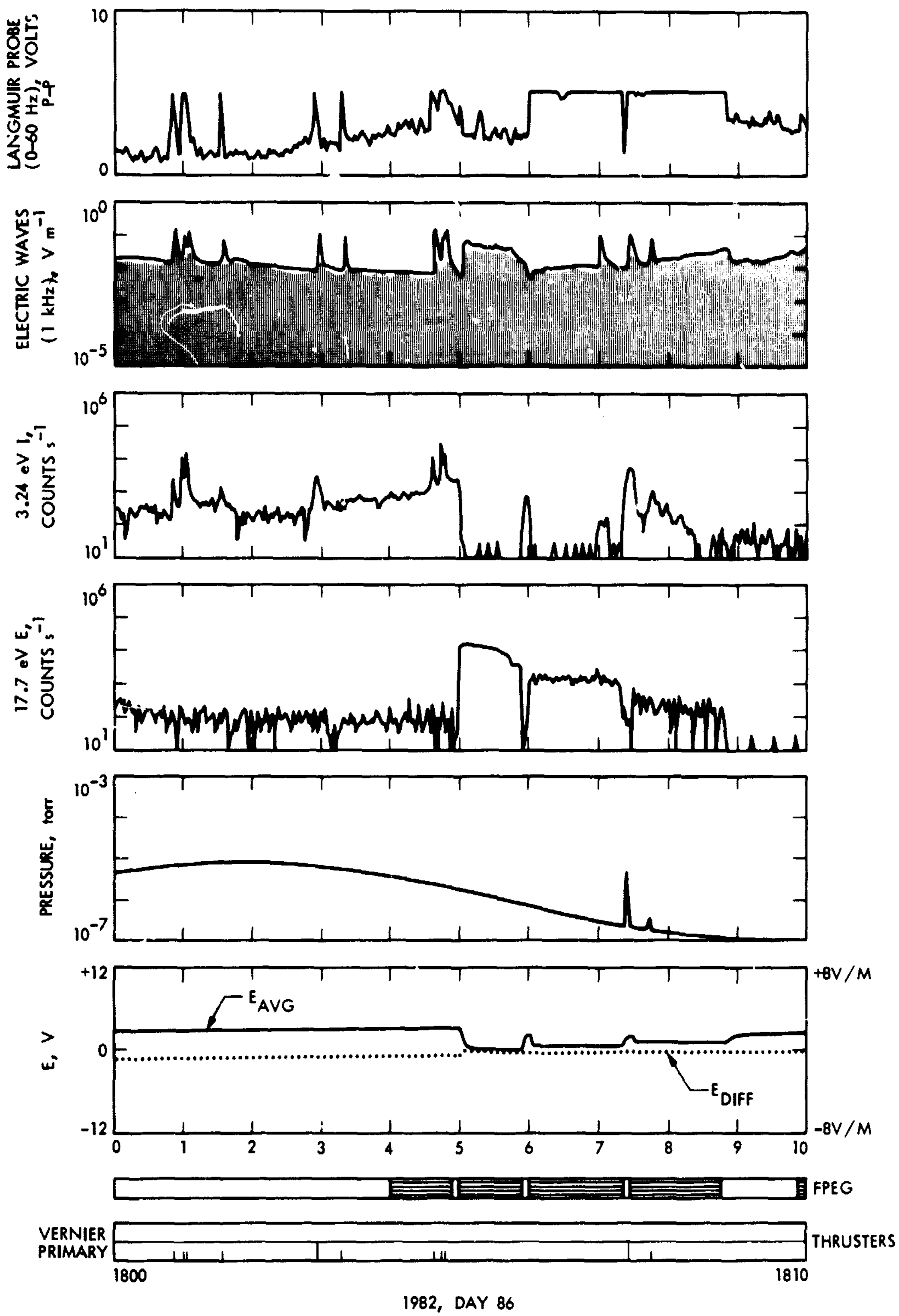
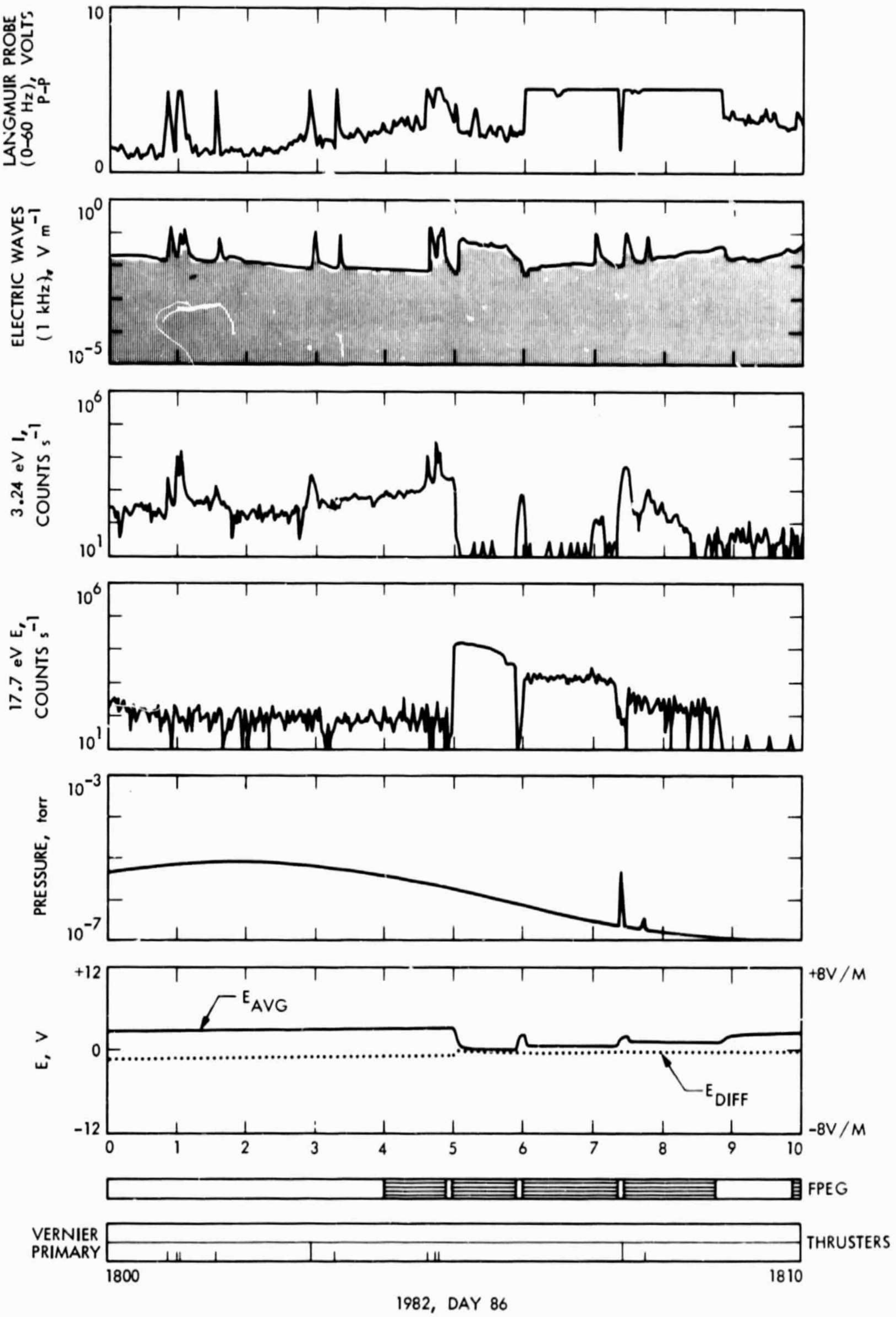


Fig. 7. A sample of PDP measurements indicating the pressure and plasma effects of thruster firings



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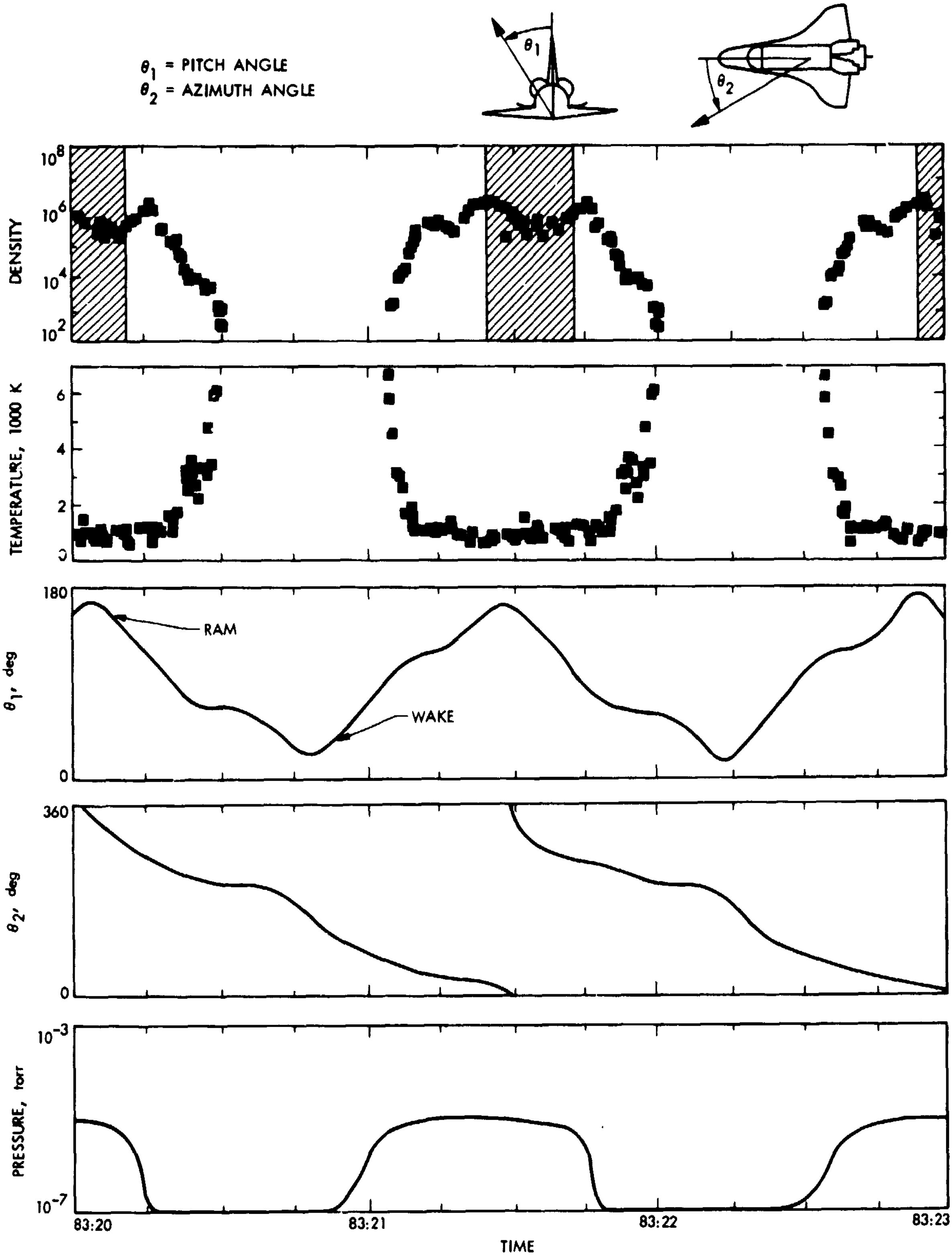

Fig. 8. Summary of PDP Langmuir Probe electron density and temperature as function of vehicle attitude. Neutral pressure measurements are included for reference. The cross-hatched areas are where the probe sweep saturates and the routine used to calculate N_e underestimates density by as much as an order of magnitude

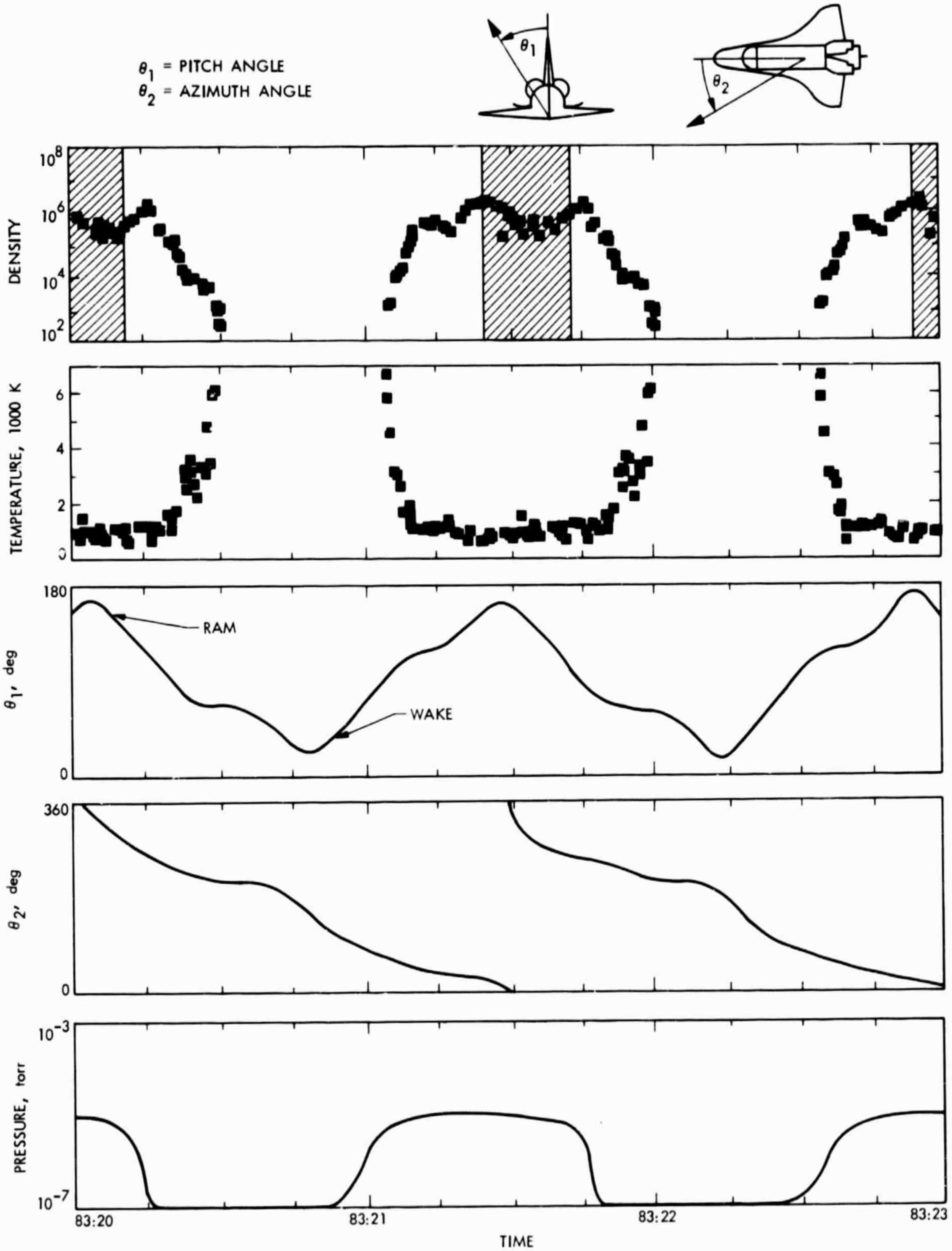

Fig. 8. Summary of PDP Langmuir Probe electron density and temperature as function of vehicle attitude. Neutral pressure measurements are included for reference. The cross-hatched areas are where the probe sweep saturates and the routine used to calculate N_e underestimates density by as much as an order of magnitude

Table 1. IMPS Environment near large surfaces[a]

Parameters	Ram	Wake	Comment
Neutral density, torr	10^{-5}	10^{-7}	Measured
Plasma density, cm^{-3}	As high as 5×10^6	As low as 10	Measured
Plasma waves	∿20 Hz -∿300 kHz $(22V/m)^2$/MHz at peak	Low	Measured electrostatic waves
Energetic particles	Mean energy of electrons: 10-100 eV Flux: ∿$10^8/cm^2$ sec ster eV Mean Energy of ions: 10-30 eV	Low	Higher fluxes predicted; little numerical data published
Glow, photons $(cm^3s)^{-1}$	$10^7 - 10^8$	Low	Glowing layer in Ram 10-20 cm thick

[a] Reference: H. A. Anderson, Induced shuttle environments, in Minutes of the IMPS ESWG, Feb. 14-15, 1984.

(d) The major neutral contaminants around the Shuttle are H_2O and He. The major engine exhausts are N_2, H_2O, and H_2.

(e) Apart from thruster firings and water dumps, the quantity of water vapor detected versus time correlates directly with the temporal variation of spacecraft temperature.

Note: Shawhan et al.[3] do not believe that the measured high pressures represent the ambient bay pressure (which they say is likely to be considerably lower) but that the measurements are more likely connected with a surface near the instrument. Therefore, all of the higher-than-ambient pressures quoted above may be upper-limit values except close to the spacecraft surfaces normal to the ram direction. Even so, the neutral gas density enhancements should be studied because they are beyond current expectations.

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[3] S.D. Shawhan et al., Plasma diagnostics package initial assessment of the shuttle orbiter plasma environment, J. SPACECRAFT AND ROCKETS, in press, 1984.

2. Plasma Environment

(a) Plasma densities of order 2×10^6 to 2×10^7 cm^{-3} are observed in the ram direction of STS-3, whereas ambient values are believed to be less then 10^6 cm^{-3}.

(b) A very significant plasma wake (4-6 orders of magnitude depletion) existed behind the STS-3 orbiter.

(c) Orbiter-produced H_2O^+ ions are observed with densities comparable to the ambient ions, produced from the rapid charge transfer reaction $O^+ + H_2O \rightarrow H_2O^+ + O$. H_3O^+ ions are also produced from the $H_2O^+ + H_2O \rightarrow H_3O^+ + OH$ fast reaction.

(d) Plasma depletions of about an order of magnitude have been observed during VCS firings with enhancements of N_2^+, NO^+, and OH^+ densities created by ion-molecule reactions between O^+ and the exhaust gases.

(e) Electrostatic background noise dominates the electric field spectrum from 30 Hz to 170 kHz with a peak in the spectrum between 300 to 500 Hz. The noise variability exhibits a marked orbital periodicity indicating its origin to be Orbiter-induced. No theory for the source of the noise has been confirmed, but it may be associated with plasma instabilities.

3. Shuttle Glow

Characteristics of the shuttle glow phenonmenon as inferred from currently available data are as follows[4]:

(a) The glow emanates from a layer 5-10 cm thick just beyond spacecraft surfaces facing in the direction of the velocity vector.

(b) The glow brightness on AE-C decreased exponentially with altitude, with a scale height of roughly 35 km, consistent with that of atomic oxygen at a temperature of about 600 K.

(c) The brightness of the glow was about 10-100 kR on STS-3 and 100-300 R on STS-4, the discrepancy being due to the higher altitude and larger angle with respect to the velocity vector on STS-4.

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[4] Origin: see T.G. Slanger, Conjectures on the origin of the surface glow of space vehicles, GEOPHYS. RES. LETT., 10, 130-132, 1983; for glow brightness on AE-C, see M.R. Torr, Optical emissions induced by spacecraft-atmosphere interactions, GEOPHYS. RES. LETT., 10, 114-117, 1983, and J.H. Yee and V.J. Abreu, Visible glow induced by spacecraft-environment interaction, GEOPHYS. RES. LETT., 10, 126-129, 1983.

(d) The dimensions of the glowing layer are consistent with an effective radiative lifetime of the emitting molecule(s) of about 5 ms.

(e) The radiation is believed to be emitted over a continuum (not in discrete visible lines) extending throughout the visible and reaching peak intensities between 6000 and 8000 A.

(f) The glow is enhanced after firing the Shuttle's attitude thrusters, whose effluents primarily consist of H_2O.

(g) There is evidence from AE-C data that a significant brightness enhancement of unknown origin might occur in the vehicle wake.

In addition, recently analyzed data from STS-8 (Aug.-Sept. 1983; S.B. Mende, private communication) showed that the glow brightness and thickness viewed on the ram side of the manipulator hand varied depending on the type of material held up. A somewhat contradictory observation, though, was that oxidation of the surface materials did not lead to perceptible changes in glow characteristics for a particular material. A more complete analysis of these data will be forthcoming (S.B. Mende, private communication).

The above sections represent a brief compilation of natural and induced environment characteristics. In the following, the interactions and their effects on potential AF systems are examined, and where appropriate, specific experiments and instruments are recommended for investigating the interactions of greatest importance.

SECTION III

THE INTERACTIONS OF SPACECRAFT WITH POLAR AND INDUCED ENVIRONMENTS

A. MAJOR INTERACTIONS

1. Dielectric Charging

Ground experiments and in-flight experience such as on SCATHA have indicated that the buildup of potential on exterior surfaces of a spacecraft may not be the only source of spacecraft charging. The buildup of charge in dielectrics and on interior isolated conducting surfaces may also be a potential source. Energetic electrons (typically greater than a few 100 eV) can penetrate a finite distance into a material before stopping. In the case of a dielectric, the charge can become trapped. Eventually, the electric field in the dielectric will build up until the field either repels all incoming electrons or exceeds the breakdown potential of the material and an arc occurs. With high auroral fluxes, the breakdown strength of common dielectrics (typically 10^6 V cm^{-1}) can be reached after only one orbit. In the case of conductive materials, the penetrating electrons can reach interior surfaces and cause charging within shielded areas. Internal charging, as it is called, can cause serious problems for spacecraft systems when, as an illustration, the dielectric insulation in a cable breaks down due to the gradual buildup of charge in it. With the increasing size of AF satellites, huge dielectric areas will be exposed to the space environment and can build up charge--potentially greatly enhancing the threat from this interaction.

The principal surfaces of concern are those that employ large areas of dielectric or have conducting electrodes at potential differences of >100 V mounted near the dielectric surface. The fact that such dielectrics will typically be organic, not ceramic, insulators may make them especially sensitive to bombardment by low-energy particles. In low-Earth orbit such surfaces are immersed in a plasma of 10^4 to 10^6 electrons cm^{-3} density and with a temperature of a few thousand degrees (a fraction of an eV). The plasma in the frame of the Shuttle is doubly anisotropic due to both the magnetic field and the velocity of the plasma past the vehicle, a process which produces ram/wake effects. Thermal electron currents to a surface area are several thousand $\mu A\ m^{-2}$ while ram ion currents are an order of magnitude less. In addition, photoelectron currents are produced in sunlight. Although such low-energy particles will typically not cause dielectric charging, particles with energies of hundreds of eV or more can. There exist at least three different situations in which significant numbers of electrons with energies of several hundred eV can be generated:

(a) The auroral zone is crossed four times per pass for a polar orbit. The flux of electrons from hundreds of eV to a few tens of keV regularly reaches 10 - 100 $\mu A\ m^{-2}$ (ions have a somewhat lower flux) in this orbit. This high-energy flux is downcoming while the flux of electrons backscattered from the atmosphere is of nearly equal magnitude but of lower average energy.

(b) The plasma is accelerated by biased electrodes so that some of the particles strike conductive surfaces while others strike dielectric surfaces.

(c) Acceleration due to electric fields can be created by transmitting antennas or complex spacecraft/plasma interactions.

Dielectric charging begets further charging. Electrostatic fields produced by one surface segment cause spaceborne charged particle trajectories to change, thus inducing further charging on adjacent surfaces. A negatively charged surface prevents solar induced photoelectron currents from escaping adjacent surfaces. These effects, interacting with the space plasma and polar magnetic field, produce complex interactions that cause the dielectric charging process to be very difficult to predict for large structures in polar orbit. Without knowledge of these effects, it is possible to have enhanced charging in a location on the spacecraft where charging is not normally a cause of failure.

2. Material Property Changes

An important concern for the AF is the effect of the auroral/polar environments on the properties of materials to be used on future large or high-powered spacecraft in polar Earth orbit. It is expected that the energetic, precipitating auroral particle fluxes associated with polar orbit will result in significant degradation of surface and bulk mechanical and electrical properties. These changes must be taken into account in the design of spacecraft structures and thermal control systems. Ionic sputtering and surface contamination are processes that can cause these effects. The differential charging of dielectric surfaces relative to the structure may also enhance them. In addition, arc discharges, resulting from charge stored in dielectric/metal configurations, may degrade surfaces. The sputtering or arc discharge by-products may then redeposit on other surfaces causing contamination and thermal problems. Cooled surfaces and biased surfaces are believed to be especially susceptible and should be studied.

Typical spacecraft coatings that might be altered by these effects are metal coatings such as indium tin oxide (ITO) and gold or dielectric coatings such as silicon dioxide. These surfaces are used for electrostatic charge control and thermal control. Other types of surfaces that should be considered, because of pitting, discoloration, and discharging, are aluminum, kapton, and various paints. Second surface mirror properties and solar cell surfaces, especially when biased, may be particularly susceptible to degradation. It is clear that the study of the effects of the environment on all of these surfaces under different AC and DC voltage biases (on the order of ±500 V) should be an important IMPS objective. In addition, as indicated, contamination of these surfaces under biased conditions is also a critical concern. However, as the IMPS mission is of relatively short duration (9 days or less), active measures, such as the use of electron and ion beams, may be needed to enhance the effects of the natural environment and to simulate more hazardous environments. Such hazardous environments are not likely to be encountered during the short IMPS mission but may be encountered on long-duration AF missions.

3. HV Solar Array/Large Structure Interactions

A major characteristic of future AF space systems is likely to be increased power and, by implication, size. Several such missions are called out in the MSSTP and similar long-range plans. These missions are projected for low- or mid-altitude, near-polar orbits requiring power in the range of 5 kW to 30 kW continuous with peaks up to 10 times the continuous requirements on the vehicle bus. To accomplish these missions, the AF needs to understand the interaction of large, high-voltage arrays with the space environment. It appears that the low-altitude polar orbit presents a worst case environment for large, high-voltage solar arrays with its varying gravitational and magnetic fields, high-density ionospheric plasma, high-energy auroral particle fluxes, and the need for the solar array orientation to be maintained normal to the Sun's rays. Even missions projected for midaltitudes and higher will have a higher reliability if they are designed for the low-polar-orbit case. New solar array configurations are under investigation for hardening to nuclear and laser weapon effects that employ materials and designs markedly different from present systems. Examples include concentrator and thin, hardened GaAs solar cell arrays. The concentration systems primarily expose metallic reflecting surfaces not part of the electrical circuit. The thin, hardened arrays represent a very low thermal mass and employ thin substrates and structures. Both of these, as well as rigid arrays, are expected to operate at voltages in the range of 200 to 500 V so as to support an internal voltage in the range of 150 V. These concepts need to be evaluated in the auroral/polar environments. Early testing (FY 86 or 87) would be desirable since it would allow data early in the array development cycle currently planned by the AF and would assist in developing lightweight, high-voltage, high-power systems.

It is clear from these considerations that solar arrays with potentials of 200 or more volts will be required for future spacecraft. Such arrays will have exposed interconnects that can attract current from the space plasma. As electrons, for roughly the same mean energy, have 40 or more times the mobility of the ambient ions, the negatively charged collection area (for positive ions) must be proportionately larger than the positively charged collection area (for electrons) to assure current balance. For spacecraft without onboard plasma sources, this will result in the array floating predominately negative with respect to plasma ground. Thus, exposed array interconnections will collect ions. Since the solar cell coverglass is an insulator, it will remain at a potential near plasma ground, creating a substantial differential voltage with respect to the solar array conductors. This differential has been observed to cause arcing both in laboratory experiments and in space experiments[5]. However, the susceptibility of modern AF

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[5] For laboratory experiments - K.L. Kennerud, High voltage solar array experiments, REP. NASA CR-121280 (Boeing Co., Seattle), March, 1974; N.J. Stevens et al., Investigation of high voltage spacecraft system interactions with plasma environments (Lewis Research Center), NASA Tech. Memo. 78831, 1978; for space experiment - N.T. Grier and N.J. Stevens, Plasma interaction experiment (PIX) flight results, PROC. OF THE SPACECRAFT CHARGING TECHNOLOGY CONFERENCE, AF Academy, Colorado Springs, Oct., 1978 (NASA CP-2071, AFGL-TR-79-0082 295-314), 1979.

systems to such phenomena is, as discussed above, unknown, and the relative sensitivities of two different array designs to the same environment have never been studied. In particular, the variation of arcing threshold with ram/wake conditions, solar illumination, and high-energy auroral electrons has not been determined. Since recent studies indicate surface effects of conductors may be important in initiating arcs, it is necessary to examine discharge rates as a function of exposure to atomic oxygen. An IMPS high-voltage solar array (HVA) experiment would provide information that will lead to improved solar array performance. Experiments are also necessary to help determine safe operating voltages for AF systems.

Electromagnetic and electrostatic interferences of various types are anticipated that could increase with the size of the structure and that may seriously impact sensitive sensor systems. Electrostatic noise has been observed on the Shuttle between 30 and 180 Hz (Fig. 9). Amplitudes measured

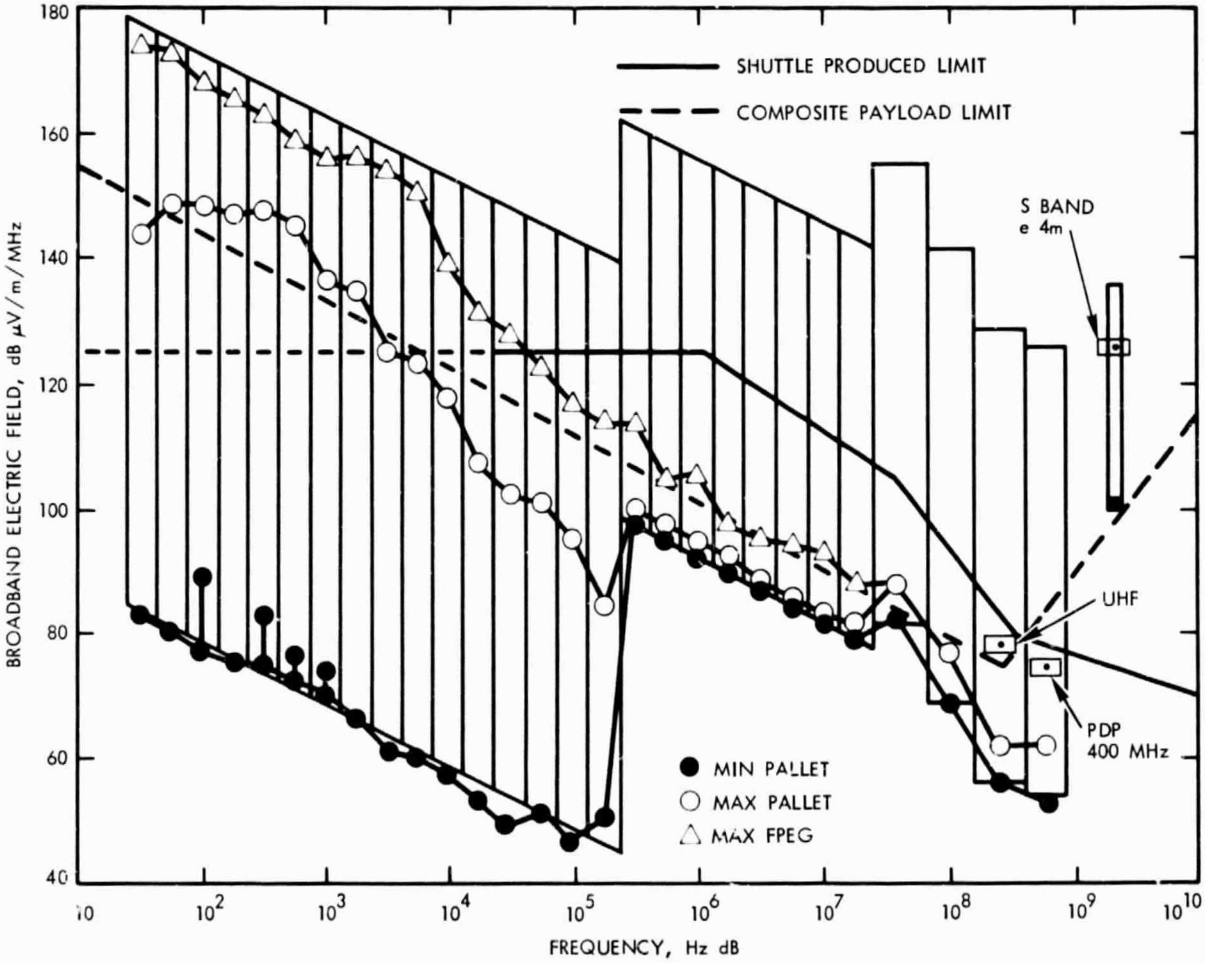

Fig. 9. PDP measurements of Orbiter transmitter and subsystem electromagnetic interference on the STS-3/OSS-1 mission (reproduced with permission)

were a maximum of $(22.4)^2$ V m^{-1} MHz^{-1} at 300 Hz (for a receiver passband of 100 Hz, which represents a field strength of 0.22 V m^{-1}). This noise, observed both within and outside of the Shuttle bay when the detectors were on the ram side of the Shuttle, decreased to near zero on the wake side, implying that the phenomenon is associated with the ram/wake orientation. Recent theories imply that the field strength of this noise would increase with the size of the generating structure.

Data on the phenomenology of the EMI sources in the auroral/polar environments, their location, amplitude, waveshape, modes, and spectrum, are all important in designing effective countermeasures to electromagnetic interference (EMI). (By phenomenology is meant the environmental conditions such as plasma density [ram-wake], temperature, and ionic composition as well as the physical configurations and materials involved in the EMI generation process.)

4. RF Distortions

The Shuttle and similar large spacecraft will produce large ram/wake effects. In addition, ram particles can sometimes be ionized by auroral electrons producing transient "dense" plasmas. For antenna arrays on large space structures, the unusual RF beam scattering properties of this extended, nonuniform plasma may be a problem. Several specific concerns have been identified that relate to these RF effects in the auroral/polar region. Three such concerns are beam pattern distortion, EMI (discussed earlier), and harmonic distortion. These concerns apply to communications links between the space system and space- or ground-terminal points, to space-based radar systems, and to systems with large reflectors and sensitive receivers such as radioastronomy or RF surveillance of the Earth. Each is described below.

The first of the RF concerns is beam pattern distortion. Electron density irregularities in the vicinity of an antenna and antenna feed system can distort the far-field antenna patterns, reducing the main beam efficiency and increasing the sidelobe levels. This effect is undesirable for either receiving or transmitting antennas. Severe destruction of the beam pattern occurs if the plasma density leads to a plasma frequency comparable to the wave frequency:

$$f_{plasma}(\mathrm{Hz}) = 9 \times 10^3 N^{1/2}$$

where N is electron number density in cm^{-3}. Densities of 10^8-10^{12} cm^{-3} are necessary to severely affect the 100 MHz to 10 GHz range. Although natural polar electron densities range only up to 10^6 cm^{-3}, local ionization in the vicinity of a large space structure may be significantly higher due to auroral particle bombardment and other effects.

For densities expected in polar orbit the near-field phase pattern can be modified so that the far-field pattern is distorted. If the density is irregular in either space or time, the far-field pattern will change with time. Ram/wake densities were observed to vary by a factor of 10^5 near the Orbiter on STS-3 and STS-4. Such ram/wake variations would modulate the far-field beam of any antenna-feed system to some extent. Even without the large structure ram/wake, a spectrum of density irregularites exists in the polar ionosphere due to auroral particle precipitation and auroral current systems. These density irregularities have scale sizes of centimeters to meters.

The second RF concern, already discussed in some detail, is EMI. EMI is a low-frequency RF problem that needs to be quantified so that the threat can be avoided.

The third RF concern is that due to harmonic distortion. The presence of plasma and plasma irregularities in the vicinity of high-power transmitters could cause nonlinear effects on the signals. If the plasma tends to rectify, as at the surface of the spacecraft, then harmonic distortions will occur. Also, irregularities can cause wave energy to become trapped in a localized volume leading to nonlinear effects. Such effects cause spectrum spreading and beam envelope spreading, which lead to interference and reduced privacy.

5. Shuttle Glow and Contamination

Three facets of spacecraft contamination for IMPS to evaluate in the auroral/polar environment are (1) contaminant modification of the electrostatic charging and discharging of vehicle and payload surfaces; (2) electrostatic charging and discharging effects on contamination; and (3) optical contamination by the so-called "Shuttle glow" phenomenon. Common contaminants can decrease the photoyield and can change the secondary electron yield of surface materials. These changes will affect the response of the vehicle and payload to the transient charging environments found at auroral/polar latitudes. Further, since many contaminants are dielectrics, they may serve as sites for discharges and cause extensive differential charging.

Work by Clark and Hall[6] and others has indicated that charged spacecraft surfaces may buildup contamination at a faster rate than uncharged sufaces (Fig. 10). Dielectrics tend to have the largest differential potentials relative to the spacecraft ground. Since many optical and thermal surfaces consist of dielectrics, the implication is that these surfaces would be rendered even more sensitive to contamination as a result of their ability to charge and attract contaminant ions. This phenomenon is not well characterized and requires study by IMPS at Shuttle altitudes in polar orbit.

As discussed in Section II.C, a major source of background optical contamination may be the glow that has been detected on Shuttle surfaces exposed to the ram environment. One apparent source of this "Shuttle glow" is the interaction between the neutral oxygen environment and the leading surfaces of the Shuttle (a plasma interaction may also be involved). It is currently postulated that an actual chemical reaction takes place that leads to the degradation and ablation of surfaces (particularly organic compounds such as kapton). Aside from the obvious surface changes thus introduced, the

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[6] D.M. Clark and D.F. Hall, Flight evidence of spacecraft surface contamination rate enhancement by spacecraft charging obtained with a quartz crystal microbalance, SPACECRAFT CHARGING TECHNOLOGY, 1980, NASA CP-2182, 1981.

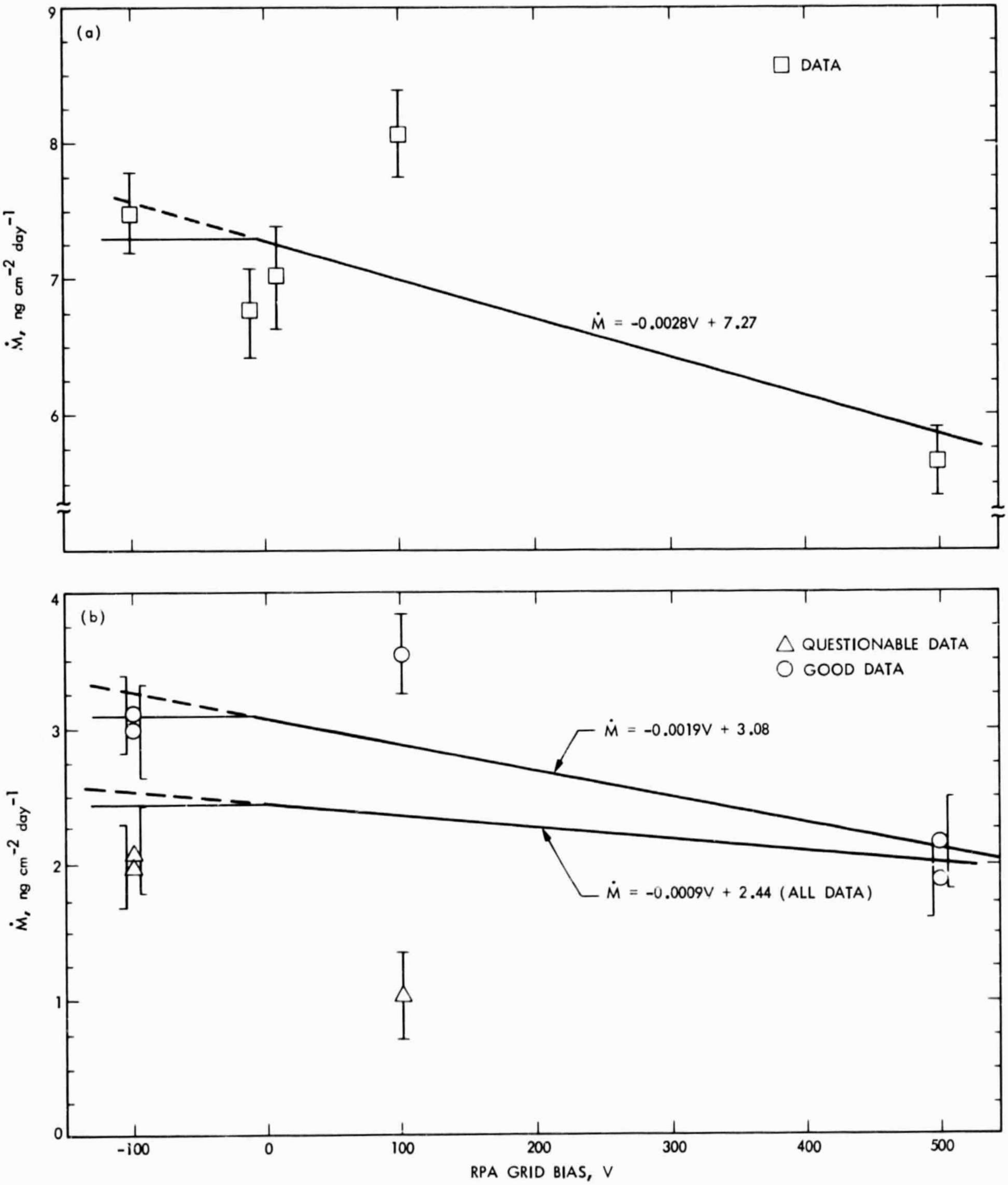

Fig. 10. SCATHA P78-2 measurements of contamination rates as a function of surface bias potential (from Clark and Hall, 1981). ML12-6 TQCM mass accumulation rates at various RPA grid bias potentials during: (a) winter experiment and (b) during summer experiment.

glow apparently associated with the process is quite bright (upwards of 100 kR, as mentioned earlier). This glow potentially threatens optical systems operating in this environment. As the effect may be related to size and neutral and plasma density, it will be necessary to carefully study trade-offs between orbital altitude (at higher altitudes, because of the exponential decrease of oxygen, it is assumed that the problem will disappear) and size. Further, it is unknown how variations in the environment found at high latitudes will affect the phenomenon. A key to understanding this effect would be spectroscopic measurement of the glow during flight operations.

6. Plasma Interactions

One candidate system for future AF missions is the space-based radar. This system and its large antenna will employ dielectric surfaces and high-voltage AC fields that can induce adverse interactions. Several interactions have been proposed that are unique to this type of system. For example, EMI due to dielectric discharge pulse noise initiated by high-energy ($E > 1$ keV) electrons encountered in the polar orbit and RF noise at the operating frequencies such as observed on the Shuttle, would likely be enhanced for large antenna surfaces and could cause serious interference with sensitive RF detectors. Likewise, as discussed in previous sections, dielectric breakdown on large surfaces, initiated by the high-energy polar electron fluxes and powered to completion (full breakdown) by a high antenna voltage, could damage the antenna structure itself and other supporting subsystems.

Solar panels, powered antennas, and large space structures will have exposed potential surfaces that can cause interactions with the space plasma. Such interactions can accelerate the plasma particles to energies greater than 100 eV. The process is not simple and the resulting current flows are difficult to calculate. Theoretical predictors need to be developed and compared with experiment. For example, a 1000 volt dipole 10 cm long will collect a few milliamperes of current (magnitude very uncertain). Some of this current will be collected by other materials adjacent to the dipole causing damage to these materials. Codes to predict resulting plasma particle energies/currents/trajectories need to be validated before biased elements can safely be designed for large space structures.

B. OTHER INTERACTIONS OF CONCERN

1. EVA Interactions

Although no adverse interactions between astronauts and the space environment have been observed, it is expected that as the EVA life-support systems become more complex and astronaut activities more involved, a potential hazard may exist. Specifically, as life-support control systems change from those controlled by analog electronics to electronically complex and active real-time processor systems, the potential failure and the effects of that failure increase dramatically. It has been postulated that an astronaut on EVA in the depleted plasma wake of the Shuttle could experience severe spacecraft charging. The reasons for this are twofold. First, a passive body in orbit at Shuttle altitudes normally charges (at most) to a few volts relative to the ambient plasma. This is due to the low energy of the ambient plasma. The high density of the plasma tends to "short" any differential potentials that might be generated by shadowing or anisotropics in the flux. As structures become larger, however, a large plasma void is created in the antivelocity vector direction (wake). An isolated body such as an astronaut on EVA in this void region may charge to a potential independent of the ambient cold plasma. As only relatively high-energy (keV and higher) particles can easily penetrate this void, under some conditions kV potentials might be expected. At low latitudes, the flux of such particles is diminishingly small. At high latitudes, the auroral fluxes in this energy range can be quite high. Further, these fluxes are along the magnetic field direction (roughly perpendicular to the velocity vector at these latitudes) so that indeed a high-energy-charging source may exist.

It is believed that an actual example of low-altitude charging in the auroral zone was observed on the Defense Meteorlogical Satellite Project (DMSP) satellite. Voltages on the order of 100-200 V were observed. Although no such events have been observed during EVA, it is also true that manned missions have yet to encounter a significant auroral flux. Further, the simplicity of current EVA systems has rendered them virtually immune to such effects. Plans for new, digitally controlled life-support systems and the requirement for frequent EVAs in the auroral and polar cap environments may change this, however.

2. Radiation and SEU Effects

Recently, much attention has been focused on the phenomenon of the single-event upset (SEU). SEUs are the result of the sudden generation of sufficient free carriers in an IC to cause an electronic upset. The increase in free carriers is produced by the passage of a proton or heavier fast particle. The upsets can be divided into two categories:

(1) OFF to ON (Memory Reset) caused by particles in the energy range E > 100 MeV/nucleon

(2) Latch-up caused by particles with E greater than a few hundred MeV/nucleon

Characteristic of these interactions, the effects are at a maximum near the stopping point energy of the nucleon (typically a few 100 MeV). With the increasing sophistication and the movement toward spacecraft autonomy of AF space systems, it is clear that multitudes of ICs with potential sensitivity to SEUs will be employed. Thus SEUs, which could disrupt or confuse sophisticated sensors and autonomous control systems, are a serious threat for AF space systems.

In low-Earth orbit, high-Z galactic cosmic rays cause the first type of interaction, while any cosmic rays of over a few tens of MeV energy, as well as cosmic ray secondaries produced in massive parts of a spacecraft and in the atmosphere below, will cause nuclear collisions. Secondaries are both charged and neutral particles including neutrons (cosmic ray albedo neutrons). These effects occur in any orbit, but the cosmic ray fluxes will be greater in polar orbit because of the so-called Stormer cutoff variation with latitude (the magnetic field of the Earth causes asymmetries in the incoming cosmic ray flux; see Fig. 11):

$$R_{min} = 15 \cos^4 (\mathrm{LAT}) \text{ (in GV)}$$

with

LAT = latitude
R = magnetic rigidity, momentum/Z

Above about 60° latitude, the cutoff goes to approximately zero because the polar cap magnetic flux is into the magnetotail. Further, even though a great many measurements of cosmic rays have been made in the past 25 years, it will be worthwhile to make an accurate calculation of the fluxes expected in polar orbit on IMPS. As an example, theoretical calculations[7] imply flip rates of 10^{-8} upsets per bit-day at low inclinations while at high inclinations, flip rates as high as 10^{-2} may be possible. Thus, SEUs in the auroral/polar regions represent an important concern for IMPS.

3. Space Debris

Kessler, Cour-Palais, and others[8] have systematically analyzed the rate of buildup of man-made debris in low-Earth orbit. Their results (Fig. 12) indicate that there is an increasing likelihood of collisions between the debris itself and active satellites. Such collisions will be at hypervelocity so that the resultant damage will lead to further fragmentation. Under some scenarios, once a few collisions a year become commonplace, the growth rate could become exponential so that within a decade space operations in the affected orbital regimes (typically in and near the Shuttle orbit) could become exceptionally difficult. Given the additional factor that the cross sectional area of space structures may also increase by orders of magnitude in the same time frame, the problem of space debris--its size distribution, its orbital distribution, and its growth/decay rate--will be a major concern by the early 1990's. IMPS, with its emphasis on environmental impacts, makes an excellent platform for studying such space debris. As the SPAS-mounted IMPS will be physically separated from the Shuttle, IMPS will allow measurement of microscopic debris as a function of position relative to the Shuttle as the Shuttle is maneuvered around it. This will make possible a classification of the microscopic debris encountered into Shuttle-induced and "environmental" debris.

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[7] P.A. Robinson, SEU rates for IMPS, Minutes of the IMPS ESWG, Feb. 14-15, 1984.

[8] D.J. Kessler and B.G. Cour-Palais, Collision frequency of artificial satellites: Creation of a debris belt, SPACE SYSTEMS AND THEIR INTERACTIONS WITH EARTH'S SPACE ENVIRONMENT, H.B. Garrett and C.P. Pike eds. (AIAA Press, New York), 707-736, 1980.

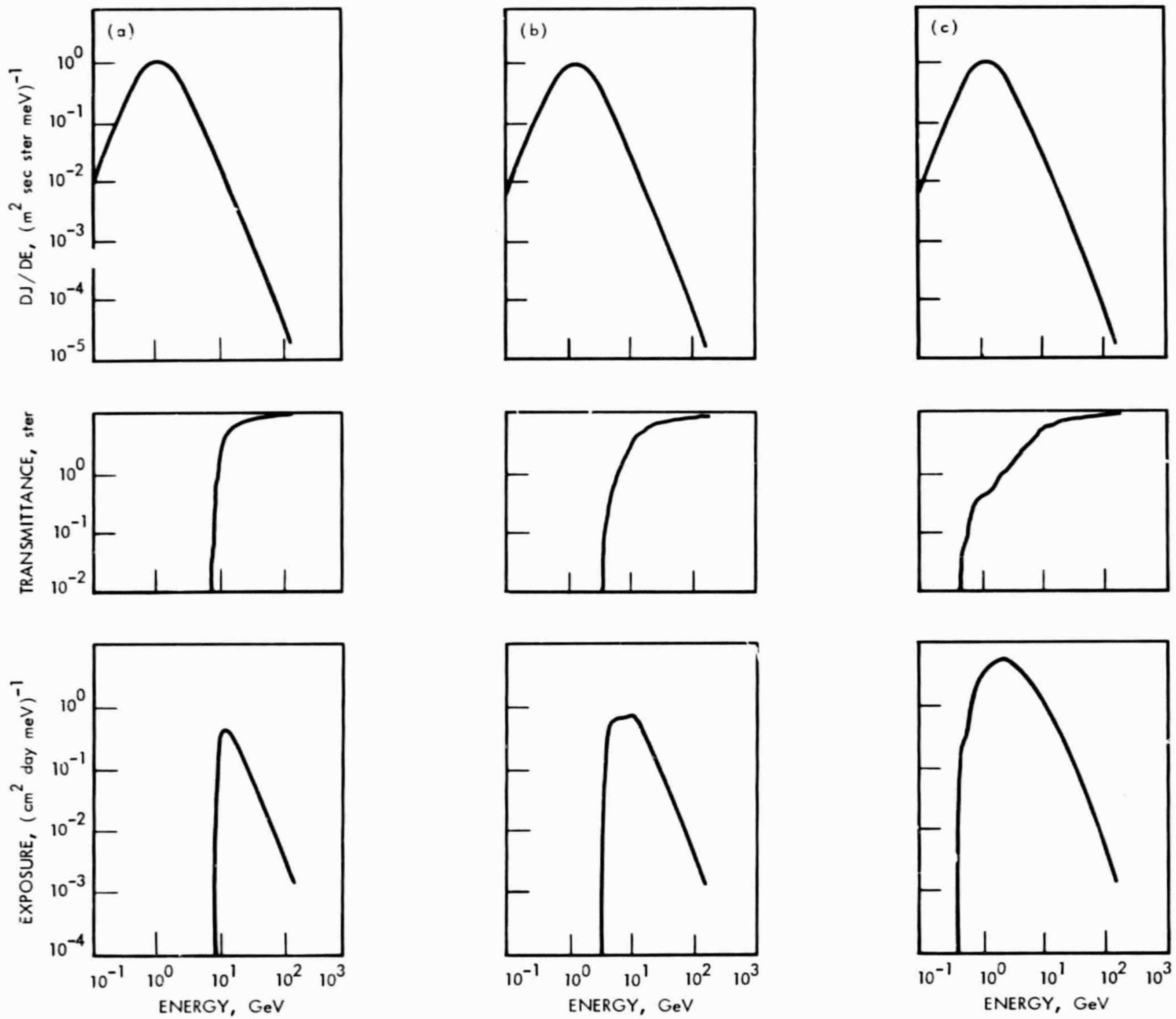

Fig. 11. Integrated high-energy particle fluxes for a 400-km circular orbit as a function of orbital inclination: (a) 0° inclination; (b) 30° inclination; and (c) 50° inclination

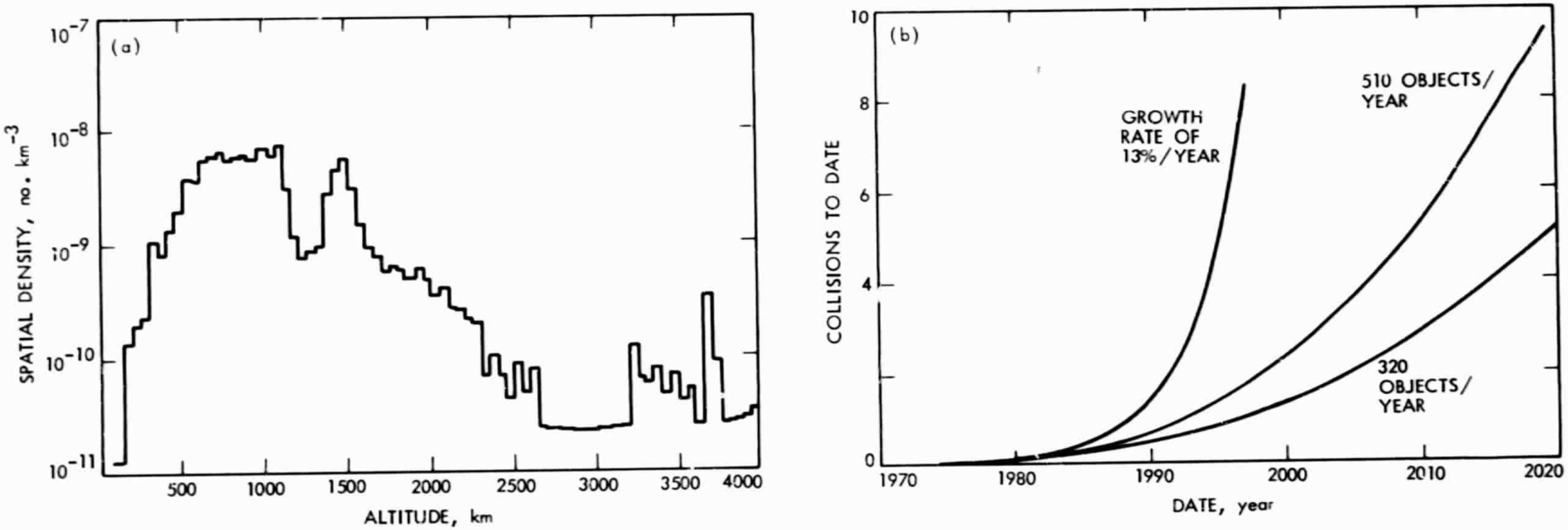

Fig. 12. The man-made debris environment: (a) distribution of 4762 satellites in Earth orbit (NORAD, Oct. 1, 1978); (b) total collisions by year for different growth assumptions; first collision expected 1989-1997

SECTION IV

INVESTIGATIONS SUGGESTED TO QUANTIFY AF SYSTEM DESIGN GOALS FOR POLAR ORBIT

Based on the requirements described in the previous sections, fifteen generic categories of investigations capable of obtaining the required measurements have been defined. In the following, the purpose of each of these investigations is briefly described followed by a suggested list of support instruments (the investigations are listed approximately in order of importance as estimated by the ESWG). At the end of this Section, for reference, the investigations are listed in Table 2 along with the types of measurements supported; Table 3 lists the various types of support instruments. As should be clear from this latter table, the total list of instruments necessary for a comprehensive IMPS mission is not as large and diverse as might have been initially assumed. This finding should be of value to mission planners in defining the IMPS payloads since the number of instruments that must be considered is significantly limited.

A. DIELECTRIC CHARGING, MATERIAL PROPERTY EFFECTS, AND ELECTROSTATIC DISCHARGE (DME)

As discussed earlier, an important investigation for IMPS would be the monitoring of changes in the bulk properties and surfaces of materials. In addition, the package should allow the study of the effects of charge deposition in dielectrics and associated arc discharges. To analyze the effects of spacecraft potentials on charge deposition, surfaces should be capable of bias to ±500 V relative to the SPAS ground. Cryogenic cooling, to simulate effects on IR sensors, would also be desirable. Typical sample surfaces would be dielectrics, optical surfaces, mirrors, and solar cells. A number of dielectric samples should be flown to look for discharge pulses. Since exposure time to the auroral fluxes will be relatively short and since the parameters of interest are numerous, a large number (>100) of samples are required. Auroral electrons are likely to induce discharges in the dielectrics. Although the passage through one auroral arc may be insufficient to initiate a pulse, the effect is cumulative, with subsequent passes producing discharges. It should be noted, however, that leaky dielectrics, produced by sunlight shining on the material, would be less likely to break down by this process.

The purpose of this DME investigation would be to measure several material properties which are expected to be important in polar orbit over a broad class of materials. The experiment will be designed to simultaneously measure a number of effects on many samples. Figure 13 shows how many samples can be exposed to the Shuttle environment simultaneously. Simply exposing materials to polar shuttle orbits will usually not be a sufficient test of the material. Some of the effects, which occur either slowly or rarely but cause a significant effect when they do occur, need to be artificially enhanced during a short duration mission like IMPS so that they can be studied; the experiment described in Figs. 13, 14 and 15 is designed to do this.

Table 2. Instrument (or investigation) categories for IMPS versus measurements parameters

Measurement Parameter	Instrument Category[a]														
	DME	SBR	HVA	CEM	WCE	EIM	EMI	EPD	TVM	RFT	EIS	GLW	SEU	LSS	DDE
Material Properties															
Bulk conductivity	P							S							
Bulk charge	P														
Secondary emission	S							P							
Photoelectron emission	S							P							
Surface ablation	P							S							P
Contamination															
Surface build-up	P			P				S							
Absorptance	P			P											
Emittance	P			P											
Reflectivity	P			P											
Vehicle glow									P			P		S	
Induced contamination	P			P		S					S			S	
RF Contamination															
Arc noise	P	S				S	P			S					
EMI background		S				S	P				S			P	
Propagation effects		P								P				P	
HV Effects															
Power loss			P											P	
Arc breakdown	S		P		P		S				P				
Single Event Upsets															
Event detector						?							P		
Plasma Environment															
Ionospheric plasma						P								S	
Auroral fluxes						P									
Radiation fluxes						P									
Cosmic ray fluxes						?							P		
Atmospheric Environment															
Neutral density					S	P									
Neutral composition					S	P									
Neutral pressure					S	P				S					
Ram/Wake Environment															
Plasma density					S	P				P					
EMI noise					S	S	P								
Charging					P	S	S	S			P				

Table 2 (cont)

Measurement Parameter	Instrument Category[a]														
	DME	SBR	HVA	CEM	WCE	EIM	EMI	EPD	TVM	RFT	EIS	GLW	SEU	LSS	DDE
E&M Environment															
DC magnetic fields						P									
AC magnetic fields						P									
DC electric fields						P									
AC electric fields		S				P	S								
Photon Flux															
Visible						?			S		S				
EUV						?			?		S				
IR						?			?		S				
X-ray						?									
Meteoroid Environment															
Particulates														S	P

[a]P Primary experiment
S Secondary experiment
? Inclusion uncertain

The plasma retarding ring/grid shown in Fig. 14 may be used to accelerate ions and reject electrons from the plasma in order to study the effects of ions on the sample. The ring/grid would be negatively biased to voltages of a kilovolt or more under the restriction that the current drawn by the ring/grid does not exceed a predetermined value and that the Shuttle does not change its potential with respect to the space plasma. If higher energy ions are to be studied, the high voltage can be applied directly to the sample while the ring/grid remains closer to ground potential. In this configuration the number of ions collected will be less but at a higher energy. Ring/grid biases would be adjusted while considering the effect on adjacent samples (a biased ring can affect the plasma particle trajectories near adjacent samples).

1. Pulsing in Insulators Caused by Auroral Electrons

It is estimated that one or a few passes through the auroral zones during electron precipitation events would be sufficient to initiate electrical pulsing noise in highly insulating materials. This needs to be studied in both ram and wake configurations. The ring/grid can be used to simulate the wake condition by biasing out the positive ions while letting the electrons continue to bombard the sample. Ram conditions can not be simulated when in wake. Pulsing would be monitored on the sample using electrodes which are wired to pulsed current detectors such as the IDM detectors being developed by JPL for the AFWL. In addition, radiated electromagnetic noise should be measured by RF sensors placed as much as a few feet away from, and in front

Table 3. IMPS support instrumentation for investigation categories

Supporting Instrument	Investigation Category	Supporting Instrument	Investigation Category
Artificial Arc Source	EMI	Monitor-Albedo	CEM
Beam-Electron	EIS	Neutral Pressure Monitor	EIM
	EPD		RFT
Beam-Ion	EIS	Plasma Diagnostics Package	EIM
	WCE		EIS
Biasing Supply	CEM		LSS
	DME		RFT
	HVA		WCE
	SBR	Samples-Dielectric	DME
Contaminant Release		Samples-IC	SEU
Cannister	CEM	Samples-Optical Surfaces	DME
Current Monitor	EMI	Samples-SBR Antenna Segment	SBR
	EPD	Samples-Solar Cells	HVA
Detector-Arc	DME	Samples-Surfaces	DDE
	HVA		EPD
	WCE		GLW
Detector-EMI	EMI	Spectrometer-EUV	GLW
	LSS	Spectrometer-IR	GLW
	SBR	Spectrometer-Neutral Mass	CEM
	WCE		EIM
Detector-Faraday Cup	EPD	Spectrometer-Visible	GLW
Detector-Particulates	DDE	Sun Sensor	EPD
Free Flyer	WCE		HVA
Imager-IR	DDE	Surface Potential Monitor	EIS
Impact Monitor	DDE		EMI
	LSS	TQCM	CEM
Langmuir Probe	HVA		LSS
	SBR	Telescope-Cosmic Ray	SEU
Low-Light TV	DDE	Transient Pulse Monitor	DME
	EIS	Transponder or Reflector	RFT
	GLW	Variable Frequency	
	LSS	Transceiver	RFT
	TVM		

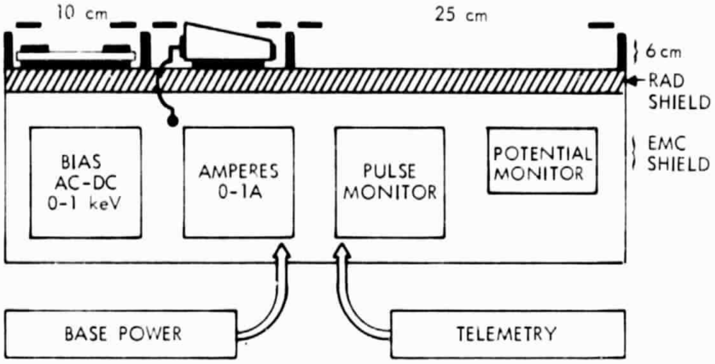

Fig. 13. Standard sample trays to test many samples using common support instruments. Each tray may contain up to 100 bins; each bin contains one sample.

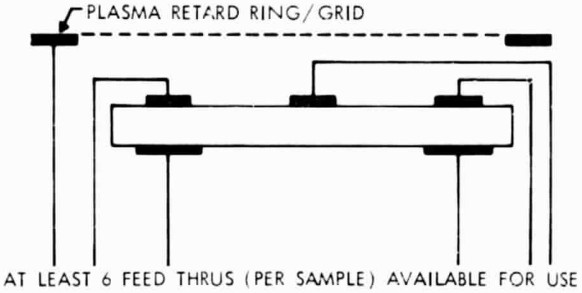

Fig. 14. A typical electrode-dielectric sample. The feed throughs are necessary to pass through the thick plate that protects the electronics from space radiation as well as structurally supports the samples and apparatus.

of, the sample trays shown in Fig. 13. The RF sensors should be looking for rare pulses which last from 10 nanoseconds to 10 microseconds. The RF signal level should be measured and if possible the frequency spectrum should be determined (see the EMI experiment for RF noise measurements).

Several electrode configurations will be necessary for this experiment because large structures will have a large variety of dielectric materials associated with them such as antenna elements mounted on insulators or glasses mounted on metal holders. These configurations should be tested using appropriate electrode configurations, and in some cases bias should be applied to the electrodes. AC bias could be especially interesting because of the unusual fields that could be created within the dielectric. Biased electrodes should be wired with current limiting resistors so that a discharge pulse does not overload the power supply.

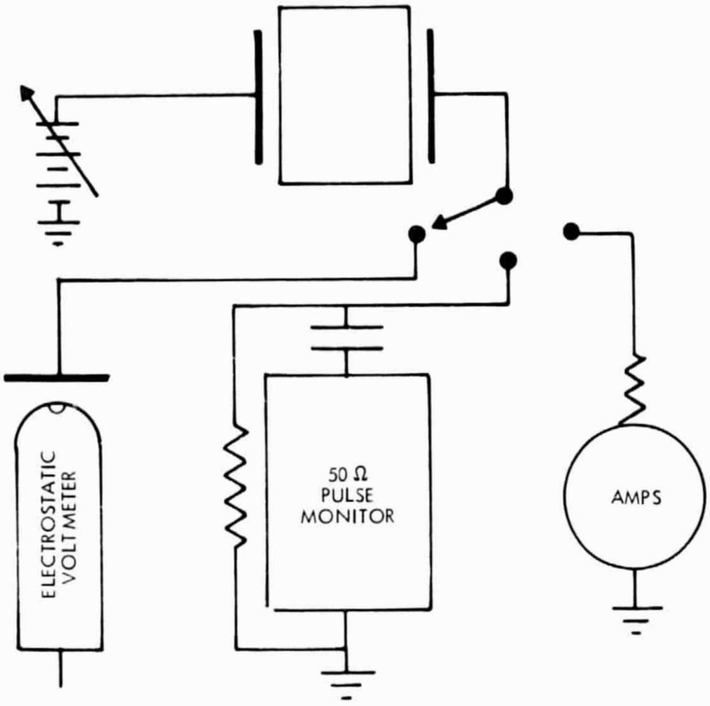

Fig. 15. Typical telemetry controlled switchable connections to sample electrodes

Pulsing should be monitored through several paths, between

(1) An electrode and ground

(2) Two electrodes on the same surface

(3) Two electrodes on differing surfaces of the same sample

(4) An electrode and the ring/grid

The pulsing should be monitored with and without bias applied to one of the electrodes.

2. Surface Charging in Wake and by Auroral Electrons

It will be important to know the extreme potentials achieved by surfaces in wake in the dark. One may do this by measuring the potentials of DME sample electrodes or of conductive DME samples using the potential monitor shown in Figs. 13-15. However, the validity of such data is strongly dependent on experiment designs and on effects such as the "boot strap" which cause the potentials of nearby surfaces to be similar. The whole DME apparatus may have to be electrically floated to do this experiment well. It may turn out that the multisample trays shown in Figs. 13-15 are not appropriate for determining the surface potentials on insulated surfaces of a large structure. In order to properly design such an experiment, one should first decide exactly what information is needed and then use a surface charging computer code such as POLAR or NASCAP to see if an experiment can be designed to get the data. It will often turn out that the surface potential will depend mostly on interactions with other portions of the spacecraft through plasma particle trajectories and depend only weakly on the properties of the sample in question.

It is of interest to measure differential voltages between small adjacent samples on a large structure. Such data are presently lacking and the computer codes are not yet reliable on this case. Thus in Fig. 15 is shown a potential monitor which is basically an electrostatic probe to sense the potential on any chosen electrode. The probe must be of very high input impedance (infinite), and the telemetrically controlled switches must also be highly insulated for this measurement. It is probably only necessary to have one probe in each sample tray, and it will only be necessary to sense a few of the electrodes; these electrodes should be chosen based on analysis of expected surface potentials, and the most extreme cases would be the logical choices.

It should be noted that the surface potential monitors developed for geosynchronous satellites are not appropriate here because the surface potentials are expected to be much smaller. However, such detectors could be used to look for the expected extreme charging levels of a kilovolt in the wake. This information will not be very material specific and will depend greatly on the average over many materials on the wake side of the satellite. Further, geosynchronous potential monitors measure the potential on the back surface of an insulator and assume that the potential drop through the insulator is small relative to the measured potential. Such an assumption is not valid for much of the IMPS investigations.

3. Material Degradation (Surfaces)

Both the chemically reactive and the relatively high-energy species in space are expected to have an adverse effect on sample surfaces. Large structures are expected to alter the nature of this environment by introducing chemical species as well as changing the trajectories of native species. Surfaces charged by auroral electrons will experience bombardment by higher energy positive ions. Some surfaces will experience enhanced ion bombardment not because of charging but because of inadvertent focusing of the space ions by electric fields generated by the structure itself. Thus, a test sample with 0 bias (and with ± grids to keep out ions and electrons) should be flown to be compared with an adjacent series of samples at increasingly more negative bias. This will highlight contamination/damage by ions relative to neutrals. Similarly, one may test for high energy "ram" neutral effects by exposing one surface to the ram while a similar surface, facing down into shuttle bay at all times, is only exposed to slow neutrals, never to energetic neutrals.

A series of experiments using bias and sample covers/position can be used to distinguish effects by various spaceborne species. However, Air Force problems associated with large structures and high voltages should be related to accelerated charged species bombardment effects. These studies should be emphasized for AF studies as NASA and others look at nonaccelerated cases.

The following diagnostics will be used as appropriate for specific samples:

(1) Surface resistivity

(2) Volume resistivity

(3) Surface voltage

(4) Secondary electron emission (see EPD)

(5) Dependence on temperature, comparing hot sample to cold sample

(6) Optical absorptivity, reflectivity (before and after flight)

(7) Mass loss/gain (before and after flight)

(8) Contamination (before and after flight)

(9) Morphology (before and after flight)

The above arguments concerning high- and low-energy ions and neutral particle effects, as controlled by bias and exposure, will also apply to experiments using the above nine diagnostics.

Often, material degradation will depend on sample temperature. At the least, the trays' temperatures will be monitored. If possible, a tray will be designed to heat and/or cool its samples for a long time during the flight.

With the tray configuration shown, it is possible to measure the net electrical current to the entire tray. The tray should be biased relative to the shuttle ground. This provides a method for validating spacecraft charging codes and current collection codes if current versus voltage is measured for the entire tray. Applied bias is not expected to harm individual sample experiments as long as it is applied only for a short time. These trays are of sufficient size to validate the charging codes. Monitoring the (zero bias) current allows a check on the incident space currents (auroral electrons, ions, etc.) during the flight at the tray location. Thus the trays should be grounded through an ammeter.

When devising an experiment scenario, the effect of a biased electrode upon the fluxes to a sample in an adjacent bin should be determined. Because the bin widths are larger than a debye length, the effect is not expected to be large. Measurements should be performed to confirm this, however.

A number of specialized measurements should also be made. Such experiments would be dedicated to a particular AF system component sample requiring detailed testing. For example, reflectivity vs λ or vs accumulated exposure during flight could be measured on mirror materials using a laser reflectometer. Surface chemistry effects could be studied on a SIMS apparatus (Secondary Ion Mass Spectrometry) as well as by measuring sputtered species. Such specialized experiments should be limited to important materials where the effects of the polar environment are expected to be significant.

Exposed electrodes should be biased by capacitors fed by a high impedance ($>10^4$ ohms) source. This prevents a discharge from creating a permanent arc which would drain the power source. The capacitor (≥ 1.0 μF) provides stored charge sufficient to cause larger arcs than occur in dielectrics alone. A monitor can be provided in the 10^4 ohm line to indicate when a pulse has occurred and can correlate with the EMI experiment.

B. EFFECTS ON SPACE-BASED RADAR (SBR)

To investigate the effects of plasma interactions with the Space-Based Radar (SBR) as functions of plasma density and Shuttle orientation, an actual sample of a SBR-antenna segment should be flown on IMPS. To characterize the environment directly in front of the SBR sample, a Langmuir probe or similar low-energy plasma probe is required. To characerize any electrostatic discharges or EMI generated by the operation of the SBR, an ESD-EMI detection system is suggested. Finally, to study the effects of different biases on the operation of the SBR, the sample should be biased relative to the Shuttle using DC and radar RF.

It is recommended that IMPS not only fly but also operate the sample section (1 m^2) of the RADC/OC space radar antenna and expose the antenna during its operation to the ram and wake. The antenna is a structure composed of an aluminum sheet surrounded by an array of dipoles mounted on kapton membranes. When it is operating as a transmitting antenna, it will have roughly 100 W peak radiated power. During the IMPS flight, the segment should be transmitting as much as possible (at least during 1/4 of the flight) using pulses typical of radar. During nontransmission periods, the antenna should be either in a pure receiving mode listening for EMI noise or in a low-frequency to DC mode looking for dielectric discharges within its own structure. It should also have up to 1 kV bias on its elements at times.

Because the de-phasing of SBR beams by the space plasma is so important, the SBR investigations should be correlated with the RFT investigation as discussed in Section I.

C. HIGH-VOLTAGE SOLAR ARRAY EFFECTS (HVA)

Although it would be preferable to fly a large, high-power solar array to investigate the interaction between exposed high-voltage (±500 V) surfaces and space plasmas, this may not be possible during the early IMPS missions. Therefore, it is recommended that on early IMPS missions some small array segments of about 1/2 ft^2 of 2 x 2 cm GaAs solar cells (70 cells) would be flown to generate 70 volts open circuit and about 55 or 60 volts under load. Flying a silicon cell panel of the same 1/2 ft^2 size would generate about 50 volts at open circuit. The latter would also be biased to observe changes in leakage to the plasma as a function of negative and positive bias up to ±1000 volts. Corona effects in current between parts of the array itself would also occur at voltages of 300 to 500 volts. This would be especially true at times of contaminant release when local pressure could approach 10^{-1} Torr and the surrounding vapor/plasma is at least partially ionized. This effect could be measured with a bare conductor held at vehicle ground, instrumented and monitored to measure current vs. array bias voltage. The silicon cell segment should be in two parts: one with interconnects not shielded and one with the interconnects coated with inorganic oxides as accomplished by the Plasma Activated Source (PAS) coating technique under development by the Aero Propulsion Lab of AFWAL. The GaAs solar cell segment could also employ the integral inorganic coating if its development status is sufficient. At present the technique is only suitable with Si segment technology. The current voltage curves should be obtained when the solar cell array segments are illuminated. The cell temperature and sun angle should be measured during testing. The combination of biasing the silicon cell segment(s), measuring EMI, leakage currents, and corona between different solar array parts, and correlating these measurements with the natural and induced environments should provide a first look at high-voltage array interactions with the PEO environment. Other critical parts of solar cell arrays are the materials of which the arrays are made. These include lightweight substrates such as mylar (treated) Kevlar and various laminates for stiffeners and light weight. For the newer hardened concentrator array systems, reflector components should be included and the effects of the Shuttle and space environment on the reflective surfaces should be measured. It is anticipated, however, that a qualified concentrator module could not be prepared in time for the first flight and that achieving orientation of the SPAS ±1° normal to the sun would pose severe constraints on the SPAS housekeeping stores.

In subsequent missions, the proposed approach is to deploy a 20-m^2 array (i.e., 2-m x 10-m deployed length), with at least 2 m^2 of active solar cells, extending out of the Shuttle bay (it may be desireable to unfold this array in two different shapes). Figures 16 and 17 show a possible configuration. The segment should also contain a solar concentrator segment as well as provisions for testing candidate materials for solar array components and other spacecraft components. The array experiment should be capable of generating 500 V at about 200 W when oriented normal to the solar radiation. The array segments should include the following experimental technologies:

(1) Two concentrator concepts hardened to laser effects

(2) Hardened, thin GaAs solar array segments

(3) Thin silicon solar array segment (both [2] and [3] would be used in single and series segments to build up the voltage)

(4) Comparison of array segments with and without grounded conductive covers

(5) Provision for biasing the experiment in increments to ±500 V

(6) Conductors arranged such that magnetic torques can be assessed

(7) A current generator so that currents up to 5 A can be imposed

(8) TV monitoring capability

(9) Ability to evaluate in sunlight and eclipse

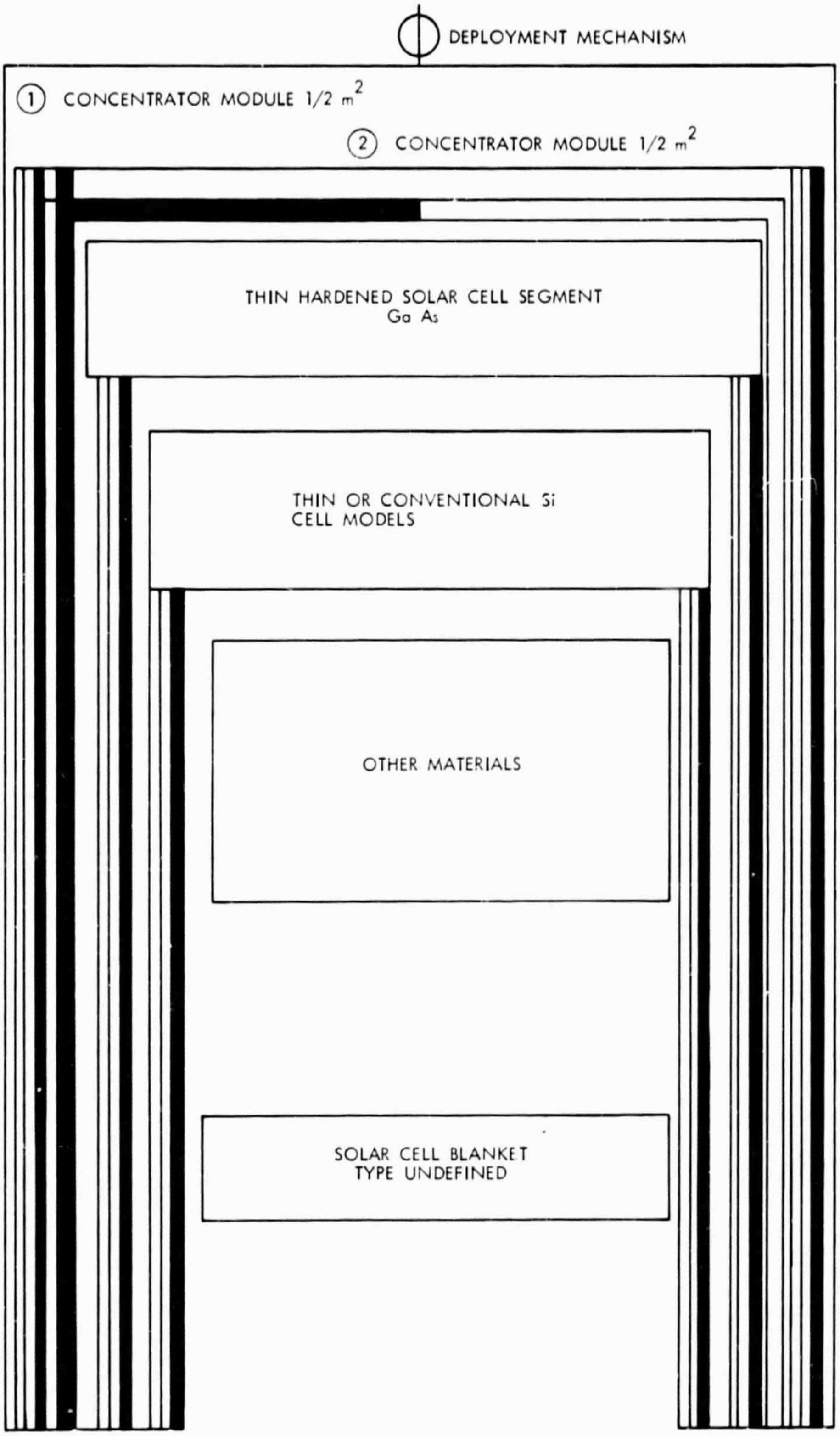

Fig. 16. Possible solar array panel configuration for IMPS

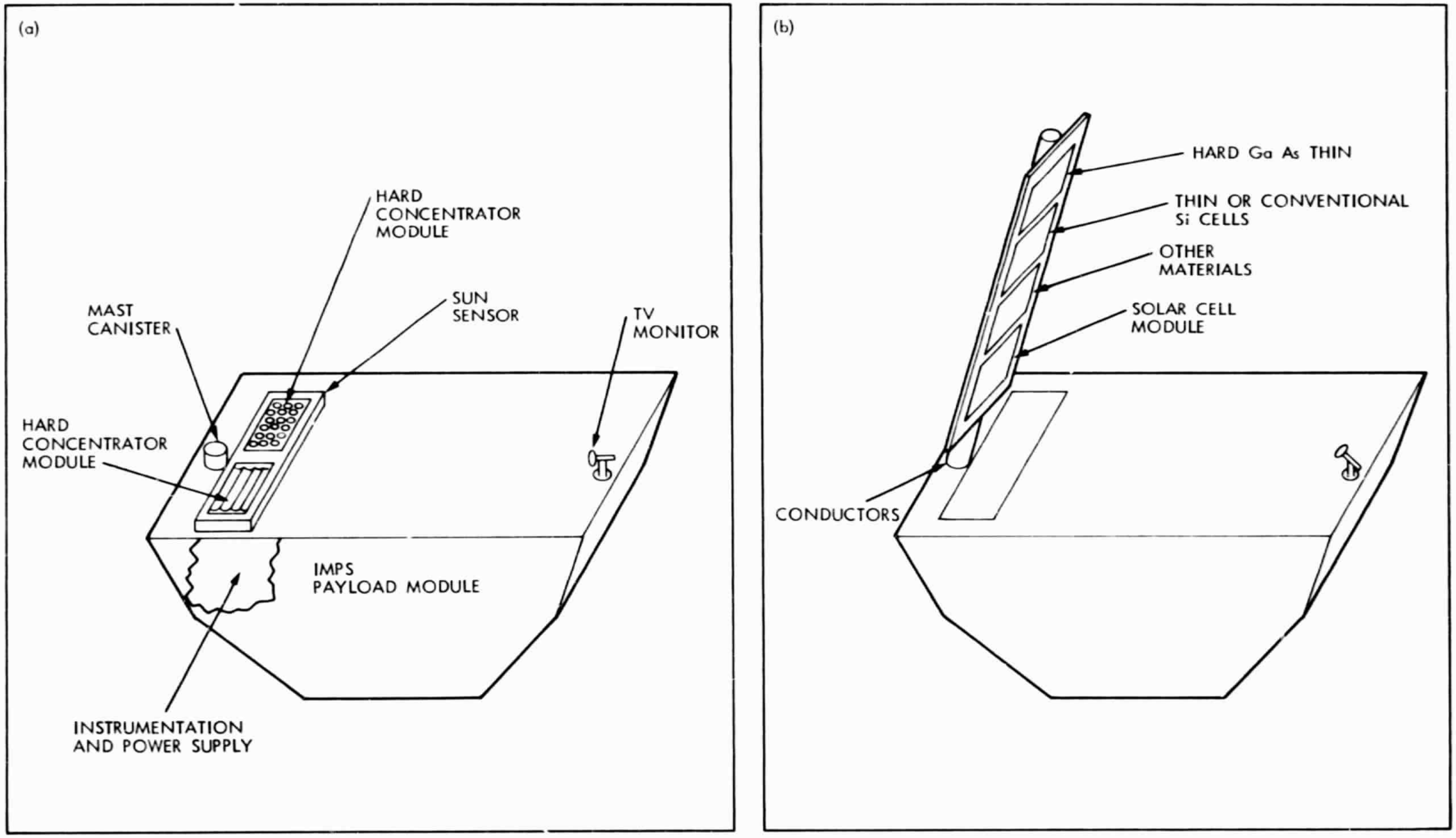

Fig. 17. Layout for IMPS solar array experiment: (a) stowed and (b) deployed

(10) Ability to evaluate in ram and wake and edge on

(11) Orientation and deployment mast structure

(12) Open areas for other material experiments

For studying (and, if necessary, simulating) EMI and related plasma effects on the small or large arrays, electron and ion sources, ±500 V bias supplies, Langmuir probes, differential chargeup monitors, arc discharge detectors, spectrum analyzers, and electric and magnetic field sensors would be required. Electric and magnetic fields should be recorded in the 1 kHz to 1 GHz range, while electric discharge current and voltage wave forms should be measured in the 1-ns to 100-μs range. A search coil magnetometer capable of determining the absolute orientation of the array relative to the magnetic field should also be flown. Sensors should be emplaced near and around the EMI sources and at remote locations to define the applicable coupling or transfer functions (see EMI). Finally, allowance should be made for measurements of flexible body effects and array short circuits.

D. CONTAMINATION EFFECTS (CEM)

The need to characterize contamination in the vicinity of the STS Orbiter in the polar auroral environment arises from the expected complexity of the interactions. Ultimately, of course, any interest in contamination measurements is based on the effects of contamination:

(1) Damage to the sensitive surfaces of certain detectors, optical elements, and special materials

(2) Degradation of the field-of-view of certain instruments

Plasma/contamination interactions will affect the magnitude and nature of these effects.

The rapid changes in material charge states (arcs) that occur in the polar auroral environment will enhance the sources of contaminants. The material itself and its breakdown products will be directly released by arcing. Additionally, pre-existing particulates will be indirectly released. The transport of all contaminants may be profoundly affected by the plasma through ionization (of gases) and charging (of particulates) and their subsequent motion in the induced and ambient electric and magnetic fields. The deposition of contaminants on victim surfaces will be quite complicated by the plasma environment. Plasma collisions will tend to remove contaminants. At the same time, plasma-induced chemical reactions may change the contaminants to forms that tend to persist longer or that have a tendency to more readily collect more contaminants. The chemical changes would also affect the physical (e.g., optical) properties of the contamination on the surface. Finally, the altered physical properties of the surfaces due to contamination, whether changed through further plasma interactions or not, may interact through plasma charging to, in turn, affect sources and transport.

1. Requirements

The desired capability of a contamination monitor instrument for IMPS includes the following:

(1) Measurement of auroral plasma-induced enhanced contamination sources

(2) Characterization of contamination transport in the auroral plasma/STS Orbiter environment

(3) Measurement of contamination deposition as affected by the plasma for a catalog of contaminants

(4) Measurement of the alteration of the physical properties of a catalog of deposited contaminants by the plasma

(5) Determination of the feedback interaction (e.g., dielectric contamination causing arcing that produces more contamination or charging that enhances deposition at other specific sites)

(6) Measurement of the rate of contamination as a function of surface potential.

Several difficult requirements follow from the need to characterize the Orbiter/auroral plasma/contamination interaction so as to permit the use of generic models and predictions for specific unflown arrangements. The data should provide for the separation of plasma-interactive effects from the effects obtained in the absence of the plasma. IMPS specific effects should be separable from generic Orbiter effects. The competing effects that comprise net contamination deposition should also be separable.

Two conclusions may be drawn from the discussion to this point. The contamination monitor package will require a combination of instruments and sensors and will likely not accomplish everything desired. If the additional constraint of a 1987 availability is imposed, the possibilities are even more limited. However, a very useful package is feasible and will be discussed below.

2. Approach

Any approach to contamination measurement may be characterized as either a technique for measuring contaminants in the vicinity of the sensor or a technique for measuring contaminants striking and/or depositing on the sensor. Most approaches are either better for determining molecular (gas) contaminants or for determining particulate contaminants. For the purposes of this discussion, contamination sensors may be categorized as optical imaging sensors, gas mass spectrometers, deposited mass sensors, thermal-optical effects sensors, impact sensors, or inactive collectors.

Optical imaging sensors are the principal means for the measurement of contaminants in the field-of-view. Instruments in this category typically resemble those threatened by such contamination. Examples are television and film cameras, coronagraphs, laser scattering instruments, and telescopes. All of these are especially sensitive to particles. However, direct deposition on the external optical element can confuse the data interpretation. These instruments also have limited sensitivity to small particles (<5 μm). Typically the measurement of contamination threats to an infrared telescope requires the use of an infrared telescope. The measurement of gas species in the field-of-view, in contrast, requires the techniques of absorption spectroscopy (i.e., a stable well-characterized light source at a known distance from the detector), which is extremely difficult.

Gas mass spectrometers exist that can very accurately measure either neutral contaminants or ionized contaminants. Since the source cannot be pumped in vacuo, the measured quantity is by necessity the flux. Without a separate determination of species temperature, however, the density cannot be ascertained. Furthermore, the measured flux may be very specific to the location and orientation of the spectrometer where orders of magnitude effects are common. On the positive side, mass spectrometers provide precise species identification.

Deposited mass sensors are represented by various forms of quartz oscillators whose frequencies change with contaminant (mass) deposition. The prominent types are quartz crystal microbalances (QCM) and tapered element oscillating microbalances (TEOM). The limitations of these sensors are a saturation mass load, temperature effects, no species information, and difficulty in particle collection. The advantages include small sensor size (permitting several measurement locations), very good sensitivity, simplicity, and dependability. QCMs resolve temperature effects by pairing the exposed sensor with an unexposed control crystal; TEOMs, on the other hand, have a respectable dynamic range. A simple existing adaptation of the temperature controlled QCM (TQCM) provides a partial solution to mass saturation and species identification for deposited molecular contaminants by periodic bakeouts which can remove most of the deposition and restore dynamic range. The stepped bakeout after a fixed collection temperature provides information on the activation energy of the deposit which aids in the species identification. Another adaptation of the QCM, its use as the detector element of a retarding potential analyzer, permits species mass identification with an auxiliary species temperature measurement. Furthermore, this technique has been used successfully to quantize the effects of vehicle potential on mass accretion. Finally a soft, sticky coating on either a QCM or TEOM can be used to accomplish particulate collection.

Thermal-optical effects sensors span the range from temperature measurements on thermal control surfaces to narrow-band optical transmission or reflection measurements of targets. The appeal of this approach is the direct determination of the effect of interest. However, except in its most complex form (i.e., full optical spectroscopy), it cannot determine species and quantity. Fortunately, calorimeters exist that can directly measure a/e (absorptivity to emissivity ratio) for a selected thermal control coating at little cost in terms of data requirements, size, and weight. These sensors are an effective compromise.

Impact sensors, such as Y-cut quartz crystals, can provide count rates for the impact of large particles (such as space debris). With the development of a preflight calibration procedure, size distributions may also be possible. Count rate saturation and "ringing" are problems with this approach.

Inactive collectors are designed to return collected contaminants for postflight study. The most common form is the passive sample array. This approach provides the opportunity to use materials of direct interest and special materials chosen for selective contamination collection. Particulates are best retained upon reentry by the use of diaphragms over the collecting surface and traps with doors. To facilitate the separation of auroral environment effects from those of the rest of the orbit, consideration should be given to synchronized shutter mechanisms. This additional feature is very important for the integrating sensors (e.g., deposited mass, thermal-optical effects, and inactive collector types).

Auxiliary measurements, if not available from other packages on the spacecraft, should include solar flux (orientation), ambient pressure, and plasma temperature. An active release and moveable sensor package would also be of value to allow the study of the evolution of artificial contaminant clouds in the vicinity of the Shuttle and in the auroral zone. By the careful timing of releases and placement of the free flyer instrument package, it should be possible to spatially and temporally map the expansion of a contaminant cloud. By careful selection of the contaminants released, the effects of unusual contaminant sources such as laser by-products on representative material surfaces could be studied.

To summarize, the principal recommendation that arises from the preceding is for a package both on the SPAS and in the STS Orbiter bay for the partial separation of Orbiter effects. The SPAS-mounted contamination package should have its active contamination sensors (at least) very near the dielectric charging-material property package (DCM). An active release source should be integrated into the bay package.

Each half of the contamination monitor package should comprise a low temperature (-50°C) TQCM, an "ambient" temperature TQCM (+10°C), and a coated TQCM (for particulates). Each half should also have two identical calorimeters and two identical passive sample arrays. The two calorimeters and the two sample arrays should have a clock-driven shuttering system to expose one at high latitudes (only) and one at low latitudes (only). At least one of each passive sample array's positions should be dedicated to a diaphragm or trapdoor particulate trap.

This recommendation consists of existing designs, the only exception being the synchronized shutter. As discussed, the development of the shutter seems essential to IMPS purpose. The recommended contamination monitor package and active release source for the first flight is a compromise that could only be enhanced by the addition of other sensors as described above. Measurements of contaminants that are ionized by aurora or that are ionized normally when emitted are especially interesting since ionized contaminants may remain with spacecraft for long times.

E. WAKE CHARGING EFFECTS (WCE)

To determine the likelihood and effects of charging of an electrically detached body, such as an astronaut, in the Shuttle wake region during auroral passage or during artificial charging, wake charging should be investigated. Specifically, a recent survey of DMSP data has uncovered several cases where precipitating auroral electron fluxes are both sufficiently intense and energetic to charge the spacecraft materials to high potentials. The usual mechanism that limits the voltage attained by a spacecraft is the increase of collected ambient ion current with increased negative surface potential. In the wake of a large object it has been estimated that the collection of ion current requires a much greater potential than for an isolated satellite (Fig. 18). These high voltages could cause arcing during EVA, docking, or on electrically isolated subsystems on a large space structure. However, the theory of this phenomenon has not been fully developed and calculations are very difficult to perform.

With the IMPS payload on SPAS, there would be the opportunity to measure the ion current voltage characteristic of a large object in the wake which will help greatly in the validation of computational models. The power necessary to maintain high negative voltages on the SPAS should be quite small as the ambient (positive) current is very low in the wake. Assuming an effective collection area of 10 m^2, it is estimated that the <u>maximum</u> positive ambient currents to the SPAS (ion current, secondary current, and photoelectron current) would be of the order of 10 mA and that in the dark wake region (where the ion current and photoelectron current would be minimal) as little as 0.1 mA. Thus the electrical power required is less than 100 watts. The simplest method for biasing the SPAS would be through a conducting wire tether to the Shuttle. This would also allow for direct measurement of the Shuttle-SPAS differential potential and current while using the least electrical power. As currently conceived, however, the IMPS will be a free-floating object, electrically and physically disconnected from the Shuttle. Alternatively, therefore, the SPAS can be bombarded with particles from ion and electron accelerators on the Shuttle. Use of an accelerator allows the free flyer to be at some distance but places constraints on the allowed orientations with respect to the geomagnetic field. In addition, if the current in the particle beam is too large, a beam-plasma interaction may occur which complicates interpretation of the charge neutralization data. Interference with incoming ambient ion measurements could be minimized by using ions in the gun whose atomic mass is very different from oxygen.

The data rate for this experiment would be quite low, consisting of current, voltage, and ambient density and temperature measurements. Since the results are a function of position in the wake, one second resolution seems appropriate. Also required is the SPAS location relative to the shuttle orbiter and the location of the Mach and sun vectors. The experiment should be performed in darkness and in the shadow of the vehicle. To make comparison with analytical models simple, the structure of the SPAS should be covered to a great extent with conducting material tied to a common ground. If need be, much of this material might consist of a transparent mesh. This would provide a collection area that is easily resolvable and geometrically simple enough to be modeled accurately.

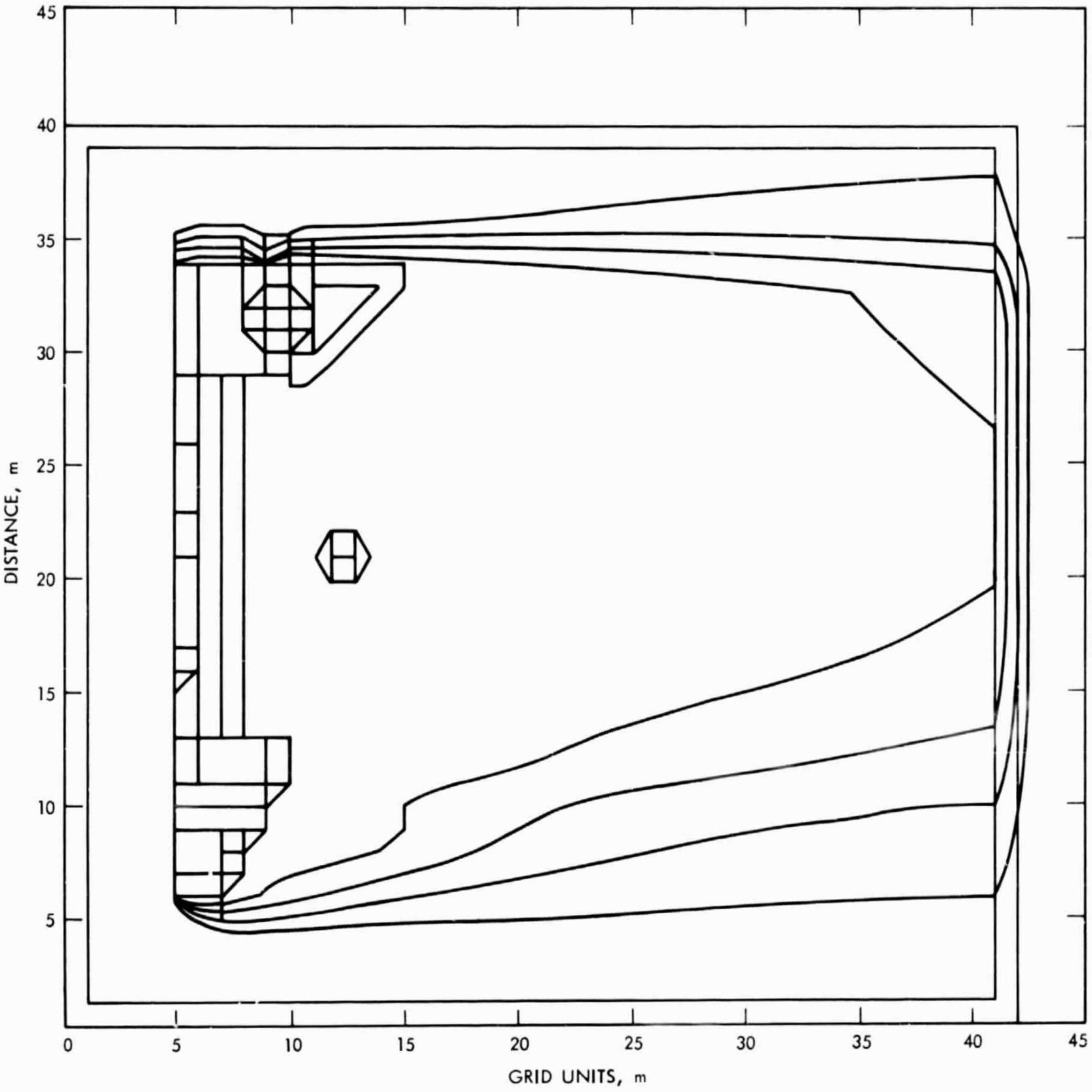

Fig. 18. Ambient ion density in the vicinity of a 2-m satellite flying in the Shuttle orbiter wake. How much ion current such a satellite collects for a given voltage is the issue addressed by the wake-charging experiment.

The total duration of such an experiment would be on the order of a single orbit and during this time, to prevent interference, there should be no other exposed high voltage surfaces on the SPAS.

F. ENVIRONMENT AND INTERACTION MONITORING (EIM)

An important function for the IMPS mission will be to provide in situ measurements of the charged particle, neutral particle, magnetic field, and electric field environments within the Shuttle bay, in the environment perturbed by the Shuttle, and in the undisturbed ambient environment. Measurements of this type are also required for correlation with many of the other instrument packages. Such an instrument package would consist of ambient plasma detectors for low-energy ions and electrons (<10 eV), a magnetometer (AC/DC), an electric field monitor (AC/DC), charged particle detectors capable of measuring fluxes in the energy range of 10 eV to 40 keV, a mass spectrometer capable of measuring ion and neutral composition up to 64 AMU, and a neutral pressure monitor. The package should be placed above or outside the bay. A detailed description of this package is currently being developed by AFGL.

G. ELECTROMAGNETIC INTERFERENCE MEASUREMENTS (EMI)

The purpose of the EMI investigation will be to characterize the signals due to electrostatic discharge and wake-induced electromagnetic interference in the vicinity of the Shuttle. This interference could significantly impact sensitive AF sensor systems. An arc detector and EMI measurement system would form the base of such a system. To characterize the current flow through and from surfaces and the potential changes associated with an arc discharge, a current monitor and surface potential monitor should be included. As envisioned, the system would be used to locate the arc by ranging techniques and multiple sensors. An artificial arc source could be used for calibration.

Low-frequency EMI due to plasma interactions has already been discussed. Large structures with biased or aurora-exposed dielectrics are expected to experience occasional breakdowns producing high frequency EMI pulses. Detectors and pulse counters should register these events. Pulses are expected to be of duration 1 to 100 ns and of amplitude 10^{-3} to 10 amperes over a range from 10 to 5000 volts. The larger currents, voltages, and durations occur in the same pulse, producing 5 X 10^{-3} watt sec pulses of 100 ns duration. Various RF and EMI detectors are currently available for measuring these effects.

These detectors should be placed near the HVA and DME experiments where dielectrics are being tested.

H. ELECTRICAL PROPERTIES DEGRADATION (EPD)

Given the fundamental importance of the electrical properties of materials in the spacecraft charging computer models, it is necessary to accurately characterize these properties in space. To determine the temporal variations in secondary emission, photoelectron emission, and backscatter flux as functions of solar incidence angle, plasma variations, and contamination, an instrument capable of measuring these properties in real time should be flown. Aside from selected sample surfaces, a Sun sensor (to characterize the photoelectron emission rate), a Faraday cup detector (to characterize the secondary fluxes), and a surface current monitor should be included. A low-energy electron beam would also serve as a calibration source relative to the ambient electron flux.

I. RF TRANSMISSION DISTORTION (RFT)

To investigate the distortions in radio-wave propagation through the Shuttle plasma sheath, it is suggested that a variable frequency transceiver be used to measure radio-wave phase delays propagating through the sheath. One possible configuration would place the transponder at one end of the bay and a radio-wave reflector or transponder for returning the signal at the other end. By properly orientating the Shuttle (i.e., bay into the ram), the signal could be transmitted alternately through the ram-plasma enhancement or through the wake-plasma void. As significant phase shifts are expected below 1 GHz, the transmitter should be at this frequency and less. Alternatively, a two-path phase interferometer could be constructed, one path being in the ram plasma.

In support of this instrument, several studies should be attempted prior to the IMPS flight. On Spacelab-2, the PDP is to map the S- and Ku-Band near-field beam patterns. Distortions of these patterns can be detected along with density irregularities in a 50° inclination orbit that will sometimes penetrate into the auroral zone. For EMI, the incidence of ground EMI should be assessed on every Orbiter flight by monitoring the S- and Ku-band receivers. On Spacelab-2, the PDP will have directional S- and Ku-band receivers with the beam looking toward the Earth once per spin period. Any ground-generated EMI could be detected by correlating the PDP and the Orbiter receivers. For harmonic distortion, nonlinear effects in the range of 50 to 600 MHz can be studied in a systematic way with ground radars such as at Jicamarca, Peru, and the EISCAT in Norway. Although the transmitter is not located in the ionospheric plasma, these radars can create V/m fields at the ionosphere level.

Based on the pre-IMPS findings, more definitive measurements could be defined for future IMPS missions. Such instruments would utilize the unique characteristics of the the IMPS mission, namely the changing plasma densities and magnetic fields in polar orbit. A possible suggestion for studying beam-pattern distortions is to map in detail the near-field antenna pattern for different irregularity conditions. To do this, two receivers at Ku- or S-band could be used: One receiver would be placed in the main beam as a phase and amplitude reference while the other would be manipulated through the sidelobe pattern under different density and irregularity conditions. Simultaneously, the electron density and irregularity spectrum should be measured at both receivers. From the phase and amplitude plots, the far-field beam could be constructed. However, a more viable alternative would be a simple phase interferometer. For EMI, IMPS could carry sensitive, wideband receivers to monitor a wide frequency spectrum for large signals of ground origin. Probes to measure both the density and the irregularity spectrum are also necessary. These measurements should be made in the auroral region since the auroral plasma tends to be most unstable. Results from this investigation would be critical to SBR studies.

J. ELECTRON-ION BEAM-INDUCED INTERACTIONS (EIS)

Although a major objective of the IMPS will be to investigate the charging and material properties changes resulting from the natural environment and especially the aurora, it is quite possible that during the short duration of a mission no very intense aurora will be encountered. The energetic auroral particle bombardment of surfaces could be simulated or enhanced by particles from an electron and ion accelerator of modest size. In contrast with the situation achievable in the laboratory, the test surfaces would be bombarded by kilovolt energy particles (whether from the accelerator or the aurora) and the neutral and plasma components of the ionosphere which are impacting the surface at the Shuttle orbital velocity of ~ 7 km/s. In both the natural and simulated cases, the flux reaching the test surfaces should be monitored with suitable detectors. A more detailed assessment of this experiment is required, however.

K. LOW-LIGHT LEVEL TELEVISION MONITOR (TVM)

To observe low-light level visual phenomena such as Shuttle glow, thruster firings, electron-beam operations, arcing, and aurora, the IMPS instrument complement should include a low-light level TV. This would allow identification of the spatial location of the phenomena, estimates of their amplitudes, and, when necessary (as in case of the electron beam), real-time changes in experimental configurations to better observe a given phenomenon.

L. GLOW MEASUREMENTS (GLW)

To determine the variations in Shuttle glow during passage through the auroral zone and polar cap, it is suggested that EUV, IR, and visible spectrometers be flown on IMPS. A low-light TV or similar imaging system should be used to identify "glowing" surfaces in real time. As this implies a very high data rate, it is probably preferable to keep such an assembly in the Shuttle bay during early missions. The glow should be measured as a function of ambient plasma and neutral variations, materials, and Shuttle orientation. This would involve measuring the glow at different locations around the Shuttle during the mission. Induced conditions at a glowing surface should be measured as well. The glow issue is not addressed in detail here since it is being studied by the NASA Shuttle office.

M. LARGE SPACE-STRUCTURE INTERACTIONS (LSS)

Future space missions have requirements which necessitate very large deployable or erectable structures. These new spacecraft will have dimensions ranging up to kilometers and will use light weight materials to achieve the required low density. There are several types of interactions particularly relevant to large structures:

(1) Mechanical interactions: Large structures are subject to a variety of torques including atmospheric drag, solar radiation pressure, gravity gradient forces, and magnetic field-induced forces. The large area-to-mass ratios of large structures will especially require a careful evaluation of their distortion, deformation, and misalignment, and ways in which these effects can be controlled. The movement of large conducting surfaces across magnetic fields will induce electric fields, currents, drag, and surface heating.

(2) Interactions connected with use of on-board high-voltage systems are considered elsewhere in this report and are not discussed here.

(3) The plasma wake leads to asymmetries in the charge distribution around a structure. This asymmetry produces potentials on the surface and differential charging. The wake can also induce plasma waves which may interfere with RF communications.

(4) Contamination of the structure environment originates from at least four sources: (1) exhaust gases or ions emitted by the attitude control system; (2) gas leakage; (3) surface erosion by meteoritic ablation and ion sputtering; and (4) cold photoelectron emission. Some effects of contamination are degradation of solar cell and thermal radiator efficiencies.

On later IMPS missions, it is suggested that a large ($\geq$25-100 m in characteristic length) structure be flown to measure the effects of such a structure on the environment and the effects of the environment on it. The structure should be biased and should include a plasma diagnostics package and EMI and RF pulse detector to monitor plasma interactions. A TQCM, low-light TV, and impact monitor should be included to study enhanced contamination, glow, and debris impact effects. The changes in plasma and neutral densities at various locations caused by erection of the structures should be especially studied.

N. SINGLE-EVENT UPSET (SEU)

To summarize the SEU investigation, the IMPS should

(1) Fly samples of ICs likely to be sensitive to the effects of cosmic-ray-caused SEUs over the polar caps at Shuttle altitudes

(2) Identify the incident cosmic ray fluxes responsible for these upsets by including a cosmic ray telescope or a simple cosmic ray track detector

To compensate for the short duration of the Shuttle mission, it would be sensible to expose a large number of junctions (such as a mass memory) with various amounts of shielding to measure the number of SEUs. It is also possible to measure the charge deposition rate by an array of electronic detectors (proportional and solid-state counters) or using a nuclear emulsion. This might be done with the test memory as part of a coincidence telescope with the counters to identify which cosmic ray caused an SEU. The detectors should cover the relativistic region ($E > 10$ MeV nucleon^{-1}) to provide the necessary correlations between the environment and the experimental results. A dosimeter would be a useful adjunct to this experiment to help separate total radiation exposure effects from short-term SEU effects. This study should be coordinated with existing DoD SEU programs.

O. SPACE-DEBRIS DETECTION (SDD)

Given the increasing concern with space debris at Shuttle altitudes, it has become necessary to measure the size and distribution of such particles in the vicinity of the Shuttle and along the Shuttle orbit. As demonstrated by C. A. Maag (Private Communication, 1984), even microscopic particles can cause significant damage to optical surfaces. It would be valuable therefore to include an impact detector and returnable samples on the IMPS carrier. An IR imager and a low-light level television would provide size and distribution information of larger particles. Samples in the DME, CEM, LSS, SBR, EPD, HVA, and EMI should be inspected after the flight to see if debris impact has occurred. Such impact should cause measurable effects, and the cause should be ascertained.

SECTION V
GROUND TEST PLAN

A. INTRODUCTION

A major consideration missing from the preceding IMPS instrumentation description is that of a ground-test program to be carried out in conjunction with the actual flight(s). Aside from the obvious requirements for preflight calibration and payload integration testing, IMPS can be tested postflight because of the inherent "returnable" nature of Shuttle missions. In conjunction with a well-thought out preflight test plan, such postflight testing will provide a unique opportunity to compare inflight and ground-test techniques. The intent here, therefore, is to describe in general terms a ground test program that would enhance the usefulness and would increase the understanding of the IMPS data.

B. PREFLIGHT TESTING

Several examples in the following illustrate the value of ground testing during preflight planning for the evaluation of the IMPS data return. The major thrust is that the instruments planned for IMPS would be of value in studying space interactions in general--both on the ground and in space. In this concept, the Shuttle flight becomes an extension of the laboratory rather than a separate entity. The laboratory used for this work must be a full-scale space plasma simulation chamber. Currently, large vacuum facilities capable of holding the entire IMPS/SPAS exist at NASA/JSC, NASA/JPL, and AEDC. Both NASA/MSFC and AEDC should have plasma simulation capabilities by the time of IMPS that could be used to test the IMPS components.

As a first example, the EMI and ESD instrument packages could be used for several experiments before the IMPS flys. It would be very useful prior to launch in conjuction with plasma simulation studies to characterize arcs and plasma noise to simplify that classification during the mission. The instrumentation should also be placed in the flight configuration and used to refine the arc-location technique proposed for the flight.

As a second example, the EPD and DME could be employed to catalog Shuttle material properties prior to the first mission. Not only would this significantly enhance the data return from the flight, but it would also be of general value in the understanding of Shuttle materials and how they interact with the environment--currently a topic of very real concern. This is doubly important as, to date, laboratory efforts at characterizing spacecraft charging properties have been minimal.

Development of the EIS electron- and ion-beam systems would complement ongoing AFGL efforts at designing a charge control system for high-voltage arrays. Charging sources similar to the proposed EIS have been utilized in a number of chamber tests such as NASA tests of solar panel charging. These sources are currently used to study the so-called beam plasma discharge phenomenon in vacuum chamber tests. The charging characteristics of the EIS should make it useful in tests with the VOLTS hardware or the IMPS HVA instrumentation. Much still remains to be learned from such chamber tests, and the existence of the HVA prior to the IMPS flight would allow the study of a number of interesting plasma interaction phenomena.

Although there is at present no plan to define specific WCE instrumentation, several interesting experiments could be performed even at this date with existing ground-based equipment. For one, the MMU and suit materials should be characterized electrically, and the ICs being considered for incorporation in future versions should be evaluated for electrostatic sensitivity. This information, aside from influencing the planning of a WCE experiment, would aid in the design of new, safer EVA systems. Likewise, the potential danger that the astronaut might pose to a satellite subsystem due to his own static charge should be investigated on the ground in vacuum chambers prior to launch.

Many experiments require analytical modeling in order to determine the meaning of the results as well as to properly design the investigation/experiment. Wake charging and plasma currents to biased elements are obvious examples. For the RFT, another example, the magnitude of the phase delay and the harmonic distortion need to be estimated to determine the parameters for the apparatus prior to design. Ionization of contaminants and E x B effects on the transport of ions around shuttle need to be estimated in order to develop a successful experiment. Development of such models needs to begin now before poorly designed experiments are generated and meaningless data compiled.

C. POSTFLIGHT GROUND TESTING

In addition to the preflight tests described above, there are unique postflight ground-test opportunities afforded by the IMPS mission. Principal among these are the opportunities to recalibrate the instruments and test assumptions about how an event occurred by conducting chamber simulations with the actual flight hardware. In particular, if an arc were postulated to have occurred at a specific point and to have, as a result, certain electrical characteristics, it would be feasible to test such assumptions by setting up the configuration, synthesizing the arc source, and comparing the results with the original observations. Ideally, such an experiment would permit an unambiguous test of the assumptions.

Material samples can be retested to determine the effects of the space environment on their properties (see Table 2 for a list of properties). If the materials are properly handled, the effects of rentry could be studied systematically. Testing of the material properties such as tensile strength and reflectance of small portions of the Shuttle itself prior to launch and after return would be of additional value. As already noted, several of the IMPS instruments are capable of accomplishing this testing. Additional testing using standard laboratory equipment would complement these studies. This latter type of testing would be valuable in determining the actual sensitivities of the IMPS instruments.

A final type of postflight testing that would be of value is that involved in reconfiguring the system. The initial flight in any series always indicates ways to improve the basic design. With IMPS, as it is intended to be reflown, the recovery of the payload will permit rapid redesign. Testing of the new payload will benefit from the flight data and the postflight ground testing. Given better knowledge of the effects considered critical, the reconfiguration testing can concentrate on those areas.

In Fig. 19, a possible ground-test schedule is presented that incorporates the preceding ideas. The schedule centers on the launch date and indicates prelaunch and postlaunch activities. Prelaunch experiment calibration and systems integration testing have been left out as these will be included in the detailed IMPS mission plan that accompanies this report.

D. GROUND-BASED MEASUREMENTS

Numerous complementary observations in conjunction with IMPS would be of value to the mission. Besides the obvious value of magnetometer, riometer, DMSP auroral photographs and electron precipitation measurements, all-sky auroral photographs, and other measures of the gross features of the magnetosphere during the mission, incoherent scatter radar measurements offer a particularly fruitful source of information on the ambient environment at IMPS. The possibilities implied by such measurements are explored below.

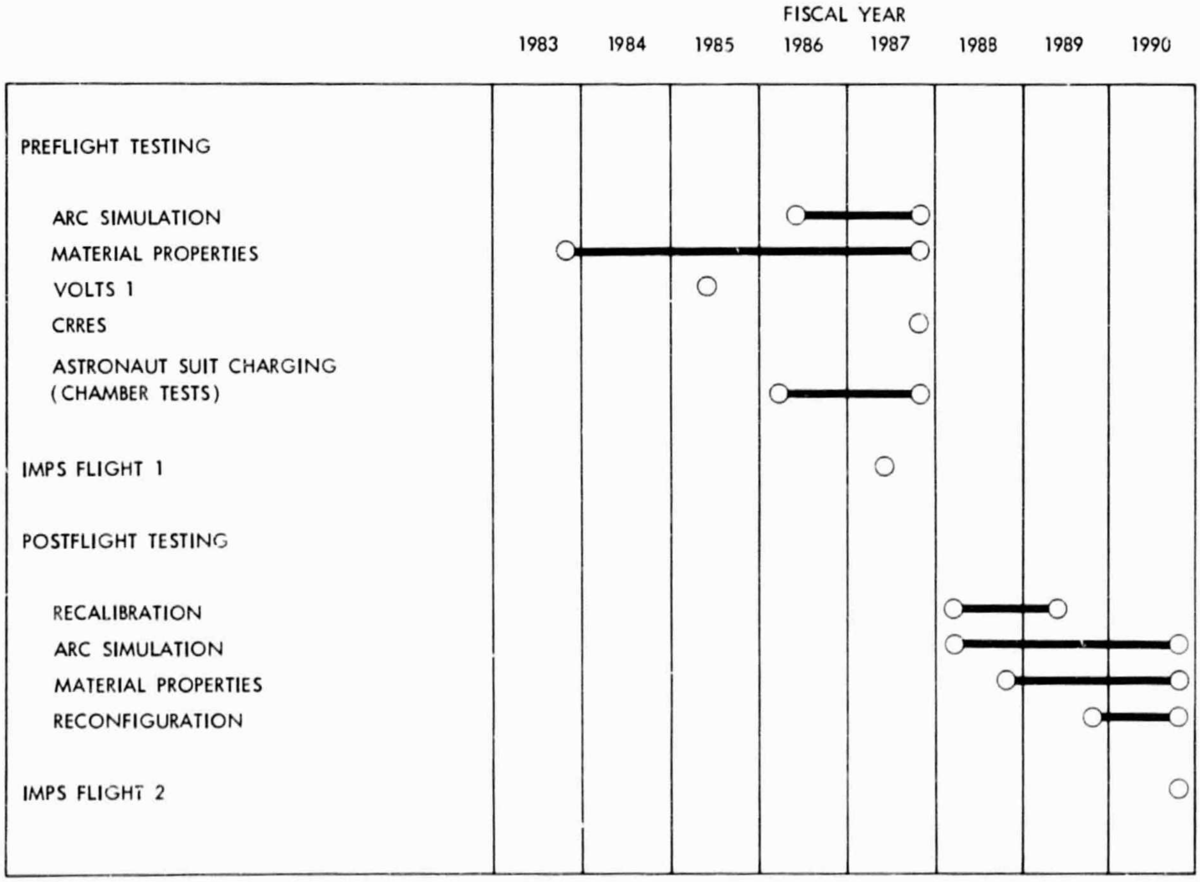

Fig. 19. Ground-test support plan for IMPS

The polar ionospheric plasma is characterized by considerable spatial and temporal variability, as compared with lower latitudes, due to the strong influences of convection electric fields and precipitating particles of magnetospheric origin. Implications for IMPS are that if the spacecraft-environment interaction is to be understood, we must require that

(1) Near simultaneous monitoring of the ambient plasma environment (Te, Ti, Ne, and composition) be provided for

(2) The measurements scenario allows for separating spatial variations in the plasma "disturbance zone" from temporal variations due to movement of the spacecraft through a highly structured and varying medium

A single instrumented subsatellite cannot provide unambiguous separation of the sources of variability of the measured "disturbance zone" plasma characteristics. A preferred approach might be a set of environment sensors strung along the length of a moveable or even a stationary boom or an array of small satellites orbiting in formation. In any case, on the initial and future IMPS missions, both of these options may be precluded by budget considerations. For this reason, the possible contributions of ambient plasma parameters as measured by incoherent scatter radars should be closely examined. Incoherent scatter radars provide measurements of Te, Ti, Ne, and plasma drifts between nominal altitudes of 100 and 1000 km and complement the capabilities of satellites in that they are capable of investigating temporal and sometimes spatial behavior from a fixed geographic location. Resolutions of 40 km and 10 minutes are fairly typical; however, these can be reduced considerably at the expense of spatial coverage and/or accuracy. The latitudinal coverage afforded by the American sector meridian chain of incoherent scatter radars is illustrated in Fig. 20. Basic data relating to currently operational incoherent scatter radars are provided in Tables 4, 5, and 6. A list of key personnel (contacts) at these facilities is included in Table 7.

It is specifically recommended that Thomson Scatter ground support be included as part of the overall IMPS ground support plan to provide information on ambient plasma properties and to provide a context for interpretation of onboard IMPS diagnostics. The meridian chain of radars at Sondrestrom, Millstone Hill, Arecibo, and Jicamarca would provide the capability to monitor Te, Ti, and Ne from low to polar latitudes in the American longitude sector during the mission and to overlap data with IMPS on selected passes. Due to the steerable capability of the Millstone Hill radar, it is anticipated that this facility would play the major role in such a ground support activity.

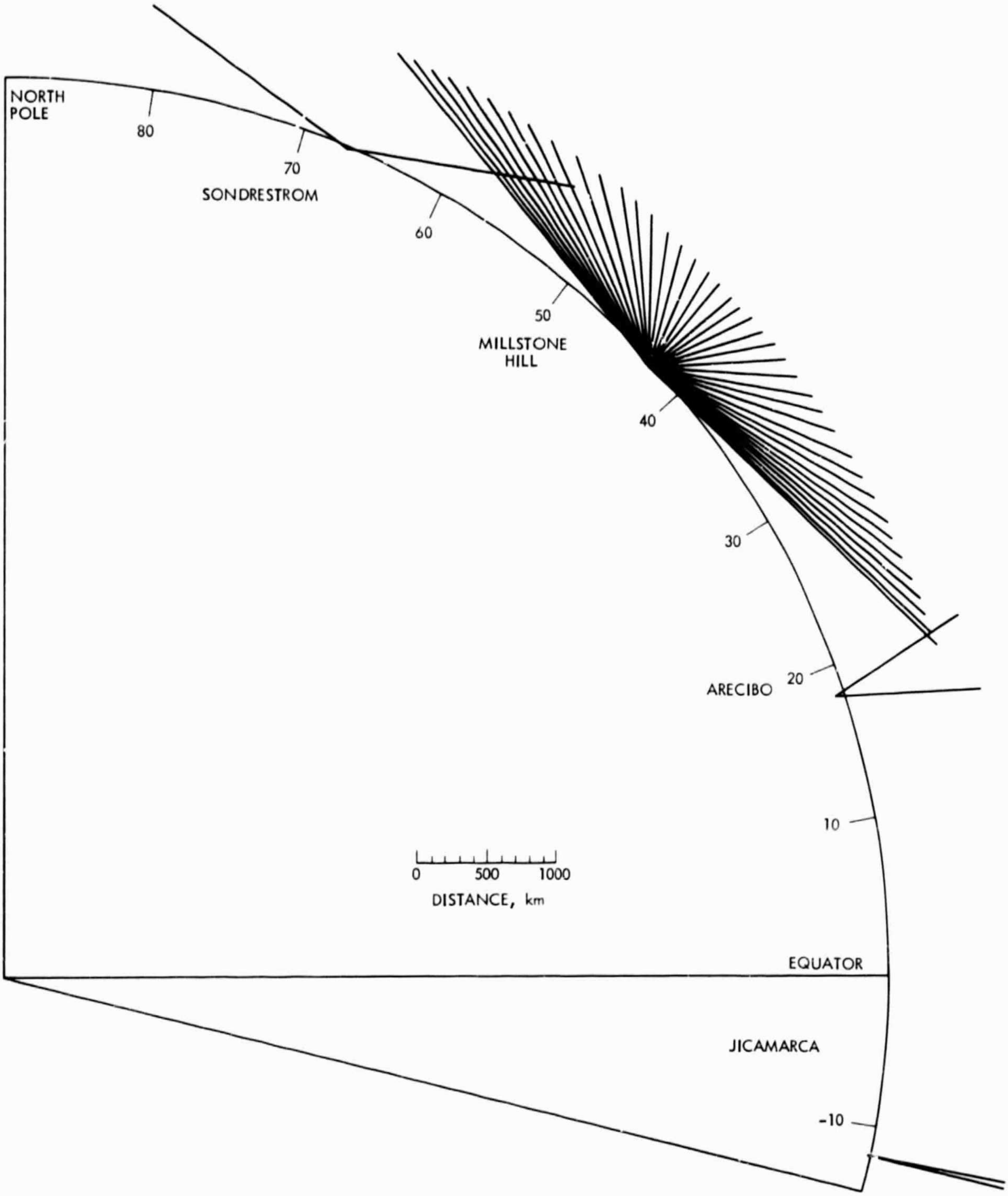

Fig. 20. Meridional chain of radars near 70° West longitude. The radar fields of view in altitude and latitude are shown in relation to the size of the Earth. While these fields of view are typical for most experiments, altitudes above 1 R_E have been obtained at both Arecibo and Jicamarca. Simultaneous measurements can be obtained over an extended region of the atmosphere between the polar cap and the magnetic equator.

Table 4. Incoherent-scatter radar facilities

Facility	Location of Transmitter	Affiliation	Configuration	Geographic		Period of Operation
				Latitude	Longitude	
Jicamarca Radio Observatory	Near Lima, Peru	Geophysical Institute of Peru	Transmitter/receiver	11.9°S	76.00°W	1963-
National Astronomy and Ionosphere Center	Arecibo, Puerto Rico	Cornell University	Transmitter/receiver	18.3°N	66.75°W	1963-
French Incoherent Scatter Radar	St. Santin de Maurs, France	Centre National d'Etudes des Telecommunications	Transmitter	44.6°N	2.2°E	1963-
			Receiver 1	47.4°N	2.2°E	
			Receiver 2	44.7°N	0.8°E	
			Receiver 3	44.5°N	3.45°E	
Millstone Hill	Westford, Mass., USA	Haystack Observatory, MIT	Transmitter/receiver	42.6°N	71.5°W	1964-
Chatanika	Near Fairbanks, Alaska, USA	SRI International	Transmitter/receiver	65.1°N	147.4°W	1971-1982
EISCAT	Tromso, Norway	EISCAT Scientific Association	Transmitter/Receiver 1	69.6°N	19.2°E	1981-
			Receiver 2 (Kiruna)	67.9°N	20.4°E	
			Receiver 3 (Sodankyla)	67.4°N	26.6°E	
Sondrestrom	Sondre Stromfjord Greenland	SRI International	Transmitter/receiver	67.0°N	51.0°E	1983-

Table 5. Technical characteristics of incoherent-scatter radars

Facility	Frequency, MHz	Antenna Size, m	Antenna Steerability	Typical Peak Power, MW
Jicamarca	49.92	290 x 290 dipole array	3 positions near zenith	1.5 (now) 6 (1985)
NAIC	430	300 dia.	Elevation angles greater than 70°	2.0
St. Santin	935	20 x 100	Can intersect from mesophere through the F region	0.150 (continuous)
Millstone Hill	440	69 dia. 46 dia.	Nearly vertical Fully steerable	2.5 (now) 5.0 (1985)
EISCAT	933	32 dia.	Fully steerable	1.5
Sondrestrom	1290	32 dia.	Fully steerable	3.5
Chatanika	1290	27 dia.	Fully steerable	3.5

Table 6. Geomagnetic parameters[a] for incoherent scatter radars

Radar	Dip Angle, deg	Declination, deg	Invariant Latitude, deg	L Value, R_E	B , T
Jicamarca	2.2	2.2	18.2	1.1	0.23
Arecibo	48.4	-10	34.7	1.5	0.35
St. Santin	59.9	-4	42.6	1.8	0.39
Millstone	70.4	-14	55.3	3.1	0.47
Chatanika	77.1	27	65.7	5.9	0.49
EISCAT	77.6	1	66.9	6.5	0.46
Sondrestrom	80.4	-39	74.4	13.9	0.48

[a] Calculated for 350 km altitude from the IGRF (1980) model updated to 1983.0

Table 7. Contacts at incoherent scatter facilities

Facility	Contact
Sondrestrom or Chatanika	Dr. Vincent B. Wickwar Radio Physics Laboratory SRI International Menlo Park, CA 94025 Ph. (415) 859-4782
EISCAT	Dr. Murray J. Baron EISCAT Scientific Foundation Box 705 S-981 27 Kiruna Sweden Ph. 46 980 18740
Millstone Hill	Dr. John Foster Haystack Observation Route 40 Westford, MA 01886 Ph. (617) 692-4761
St. Santin	Dr. Michael Blanc C.R.P.E. 4, avenue de Neptune 94107 Saint-Maur CEDEX France Ph. 33(1) 886 84-66
Arecibo	Dr. Jules Fejer, Director Arecibo Ionospheric Observatory P.O. Box 995 Arecibo, Puerto Rico 00612 Ph. (809) 878-2612
Jicamarca	Bela G. Fejer School of Electrical Engineering Phillips Hall Cornell University Ithaca, N.Y. 14853 Ph. (607) 256-6471

SECTION VI
IMPS ADVANCED CONCEPTS PLAN

A. INTRODUCTION

IMPS does not exist in a vacuum. Several other missions (see Fig. 21) directly related to the IMPS program goals are currently planned for the same time frame. Likewise, the IMPS advanced program concept is not limited to a single flight. It is necessary, in order to obtain the maximum value from IMPS, that IMPS be integrated into other planned efforts and that the IMPS program incorporate the results of these missions into its long-range plan. Such a long range plan is developed below with emphasis on future IMPS payloads and missions into different space environments. Although not intended as a detailed plan, the phased approach presented should provide the skeleton for such a program.

In planning a long-range space program of the scope of IMPS and its companion flights, a phased approach is a necessity. Here, the long-range plan has been divided into four phases: an information-gathering phase, a simulation phase, the actual flight phase, and the analysis phase. Each can exist concurrently with the others (i.e., information will undoubtedly be gathered throughout the program), and the process will be repeated for each flight.

B. INFORMATION COLLECTION AND PLANNING

The purpose of the first phase is to gather data. There are numerous methods of accomplishing this, and indeed, the ESWG has had this as its primary objective. The four principal means that can be employed are

(1) Collecting documentation
(2) Conducting workshops/conferences
(3) Visiting key facilities
(4) Utilizing a panel of experts (i.e., the ESWG)

As an illustration of the first method, numerous literature searches were carried out for AFGL on specific IMPS concerns by the ESWG and JPL. An extensive bibliography of papers on IMPS-related material has been prepared for AFGL under this effort. Several reviews of spacecraft and plasma interactions were prepared. In reference to method two, a workshop was held in December 1981 and a joint AF/NASA conference in October of 1983. Numerous facilities such as NASA headquarters and AFWL were visited with the assistance of the ESWG members, AFGL, and JPL, and data on IMPS issues were collected.

Building on the IMPS data base, future flights should concentrate on specific interaction concerns. If funding permits, workshops on these interactions should become an integral part of the IMPS long-term program. In concert with these topical meetings, every two years a general conference should be held (e.g., such a conference was last held in October 1983). Based on the workshops and the conferences, the data base of references on spacecraft interactions developed by the ESWG can be expanded and made permanent. The

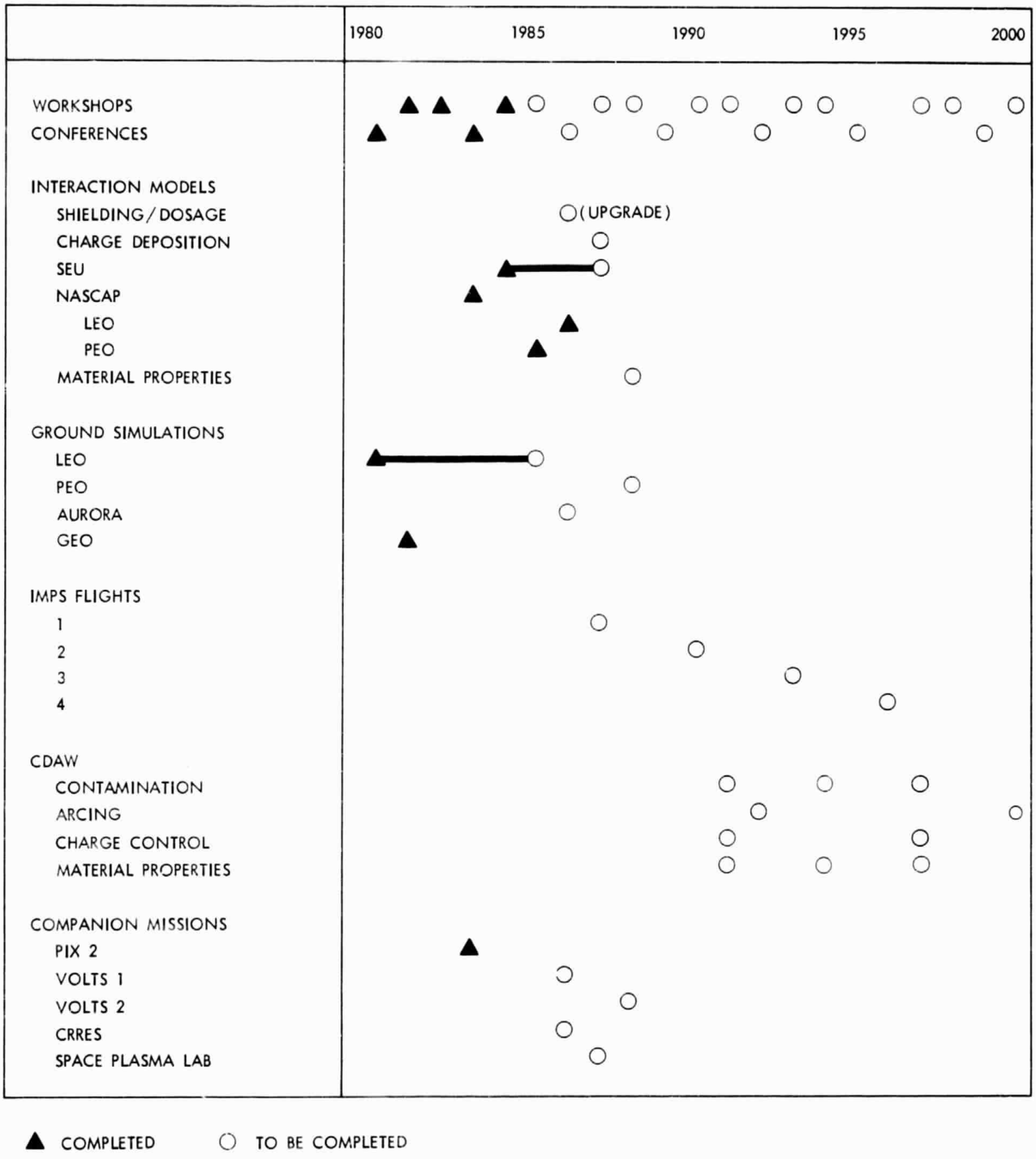

Fig. 21. Master time line for IMPS, 1980-2000

rudiments of such a data base now exist. The material has been divided by interaction effects and is currently being cross-referenced to the specific systems affected.

Blue-ribbon panels, such as represented by the ESWG, should be organized on a permanent basis to advise AFGL on progress in mitigating individual problems and on future research. For example, panels should advise on each of the following:

(1) Space plasmas
(2) Ionosphere/atmosphere
(3) Radiation effects
(4) Charging/plasma interactions
(5) Contamination
(6) Material properties
(7) Astronaut safety

Furthermore, a master technology road map in the area of spacecraft interactions should be developed (the rudiments of such a plan actually exist within the joint AF/NASA technology program) based on the findings of these panels.

C. SIMULATION AND MODELING

For the second phase, the main thrust is to improve the capability to simulate interactions. Given the existence of the data base on spacecraft interactions developed in phase 1, the adequacy of the existing models and experimental data associated with the different interactions can be evaluated. This information can be used to determine where simulation capabilities need to be improved and where more data are required. Again, several approaches are necessary and, as indicated in Fig. 21, this too is a continuing process. Two approaches are considered here:

(1) Theoretical modeling
(2) Ground simulation

As in any scientific activity, the ability to control a given phenomenon depends on the adequacy of the theoretical constructs used to define it. In studies of spacecraft interactions, an adequate understanding of the phenomenon includes an understanding of the source (the environment), of the victim (the space system), and of the interaction (spacecraft charging, radiation damage, etc.). The model then attempts to simulate the effects of the source on the system. Currently, although fairly adequate models of the space environment exist and systems can be modeled to some degree, interaction models are at a very rudimentary level in general (dosage and shielding calculations are an exception). Thus the development of adequate models is a primary concern.

An invaluable adjunct to such models is actual experimentation. Even with the advent of the Shuttle, ground testing remains in most cases the cheapest and easiest way to study many phenomena associated with spacecraft interactions. It is suggested in this report that such ground simulation be given at least as high a priority as the modeling efforts. The primary problems to date with ground testing have been difficulties with scaling plasma phenomena and with simulating the space plasma characteristics. In a departure from previous studies, it is recommended here that specific facilities be developed and dedicated to simulating each of the principal space plasma environments (namely, the plasma associated with low-earth orbit, polar Earth orbit, the aurora, and the energetic particles associated with the radiation environment). Likewise, adequate simulations of particular phenomena are also necessary (launch conditions, rocket-plume effects, arcing, high-voltage surfaces, etc.). Various examples of the required simulations and analytic models in terms of the interactions and flight experiments are presented in Table 8.

D. FOLLOW-ON MISSIONS

Figure 21 shows several possible follow-on flights for IMPS. The intent is to modify the IMPS payload so that the interactions typical of each of the key space regimes (ionosphere, auroral zone, and polar region) discussed in this report are emphasized. It should also be emphasized that the individual IMPS instruments should be viewed as evolutionary so that follow-on versions of the initial engineering experiments would be improved after each mission. In this way, the basic IMPS complement could evolve into an increasingly more complex and sophisticated sensor system capable of characterizing a variety of critical interactions. Those missions in the actual flight phase, in chronological order, are as follows:

(1) IMPS 1--Polar Earth orbit/auroral zone: This is the principal IMPS mission now envisioned and outlined in this report. The SPAS will probably be the carrier for this mission.

(2) IMPS/VOLTS (IMPS 2)--Polar earth orbit/auroral zone: A joint mission with the NASA VOLTS array would mutually benefit both programs. It would afford IMPS the possibility of flying with a large, high-voltage structure. For VOLTS, the IMPS diagnostic capabilities would be of great value in studying interactions with the auroral and polar regions. As IMPS has been designed with such a mission in mind, no modification to the basic IMPS 1 package should be necessary.

(3) IMPS 3--Low-latitude plasmasphere/ionosphere-large structure: Although the primary IMPS mission will pass through the low-latitude regime, the mission is not optimized for this region, nor will it necessarily fly with a large structure (100 m or larger). An actual large structure (as opposed to the samples on IMPS 1), such as the prototype of the space-based radar or the space station, should be available by the time of this launch. Depending on the size and complexity of the structure, multiple EIM packages could be deployed to simultaneously monitor the environment around the structure.

(4) IMPS 4--Polar cusps/magnetosheath: Although currently not really accessible to the Shuttle, improvements in the Shuttle or the free

Table 8. Ground simulation and analytic model requirements compared with interactions and flight experiments

Interaction	Experiment	Ground Simulation	Analysis
Radiation Effects	High time resolution mass spectrometer on IMPS Samples of high density microcircuits on IMPS Charge deposition measurements	Develop "natural" radiation simulation Develop techniques for simulating long-duration exposure	Charge deposition modeling SEU prediction Astronaut EVA dosage models
Spacecraft Charging	Charged beams experiment Sheath and wake measurements Photoelectron, backscatter, and secondary emission properties Arc discharge simulation and monitoring Surface potential monitoring Systems response study	Develop shuttle, geosynchronous, and polar simulation environments Develop arc simulation techniques Sheath and wake simulation	Develop NASCAP and similar models Develop low altitude plasma sheath models Develop material response models
Large, High Voltage Structures	Exposed, high potential surfaces of varying size, construction, and potential Sheath measurements Test shielding methods	Chamber testing Test shielding methods	Compare NASCAP and similar models at geosynchronous orbit Test low altitude plasma sheath models
Contamination	Surface contamination monitors Measure artificially induced contamination	Simulate launch environment Simulate space contamination/degradation Develop thruster simulations	Compute simulation of deposition
Environmental Effects	Launch exhausts measurements Wake-induced wave measurements Meteoroid/debris measurements Chemical release studies Particle depletion measurements Microwave heating/turbulence measurements Measure ambient environment	Rocket plume measurements Radar cross-section studies Chemical reaction studies	Test atmospheric reactions models Compare chemical releases with theory Simulate ionospheric changes Confirm magnetospheric models

flyer should make a flight into this region possible in the indicated time frame. The IMPS package should be modified to allow better detection of high time variations in the ambient electric fields and plasmas in this region as the primary environmental issue is the rapid fluctuation of these parameters. As AF systems will occasionally encounter these rapid variations, it will be important to characterize their engineering effects.

(Note: There will be a continuing need on each successive flight to incorporate updated AF hardware concepts and concerns within the IMPS generic philosophy.)

E. ANALYSIS/DATA WORKSHOPS

The most critical phase for IMPS will be the actual analysis of the data. Although as already indicated, invaluable data can be gained from ground testing, analysis of actual flight data is the ultimate step in gaining a real understanding of interactions. Further, for the IMPS program to be of any lasting value, that understanding has to be documented. As turn-around is a crucial issue in adequately disseminating the IMPS data, a carefully conceived data analysis plan incorporating real-time analysis, data workshops, and quantifiable outputs such as MIL-STDS is a necessity. Each of these issues will be addressed for the IMPS and its companion missions in this section.

Real-time analysis of the IMPS data will be a necessity for some of the instruments. In particular, much of the glow data will have to be returned in real time as the operation of imaging equipment, although perhaps automatic, will require careful monitoring when particle sources (thrusters, etc.) are turned on or the imagers are moved to another position. Further, the status of the aurora will need to be monitored in real time in order to predict the encounter of IMPS with an auroral arc. It is hoped, in fact, that the IMPS package can be configured in specific modes so as to optimize data collection when passing through auroral features, thus making the data available for real-time analysis. It is recommended that at least one such optimized real-time run take place each day. Several candidates for such runs are listed below:

(1) Auroral arc encounter: All instruments capable of recording rapid variations should be in their highest time-resolution modes and, where possible, the data should be broadcast back to Earth in real time.

(2) Thruster firings/beam operations: Specific experiments to observe the results of thruster firings or, if available, charged particle systems should be developed. As was learned from SCATHA, such operations can induce rapid plasma variations.

(3) EMI events: If the ESD/EMI detectors on IMPS report peculiar activity, such intervals would be logical candidates for quick analysis. This analysis requires simultaneous EIM data (see Section IV.F).

(4) Contaminant releases: Past Shuttle flights have indicated that the Shuttle-induced environment can significantly change over short periods.

(5) Major changes in Shuttle orientation: Changes in Shuttle attitude relative to its velocity vector, the Sun, and the Earth's magnetic field can all generate interesting variations.

(6) Movement of the SPAS: Real-time data analysis of the SPAS during its movement would help to indicate locations of interest for further study during the flight and for future flights.

Such real-time analysis will require the principal investigators to commit to a rigorous schedule during flight. Even so, as evidenced by previous Skylab and Shuttle flights, the ability, based on real-time data, to reconfigure the experiments in real time is crucial. An integral part of the program should be a data management system capable of handling real-time needs.

Within the first year following (and, indeed, in the months preceding) launch, a series of data workshops should be held, similar to the NASA Goddard Coordinated Data Analysis Workshops (CDAWs). At these workshops, the IMPS data would be available through the data-management system so that the experimenters could rapidly compare their results. This approach argues for a large central processing unit such as a dedicated VAX and a number of interconnected terminals. By the IMPS launch time (1986-88), such systems should be common, and by the time of the later launches, standard. The key to the workshops, however, is the selection of key topics such as "contamination," "arcing," "charge control," etc. By limiting each workshop to a key topic, it should be possible to generate a report concentrating on that topic as the output of the workshop. These reports should be directed toward improving the relevant MIL-STDs and Guidelines.

A major conference such as held in 1983 should be timed to occur within one to two years of each IMPS mission. These conferences should represent the culmination of each mission and should have several sessions devoted to summarizing the results. In particular, the parallel results from the ground-test programs should be incorporated into the mission reports at this time. The output from these conferences should be comprehensive mission-analysis reports.

Based on the conference reports and the workshop results, the updating of the MIL-STDs and Guidelines should begin in earnest. A time table, spanning the two decades of the IMPS missions, should be established for updating these documents. A tentative time line is presented in Fig. 21. These updates represent the primary goal of the IMPS program and should be given the highest priority of any items considered thus far.

F. SUMMARY

The steps necessary for taking the IMPS and its sister missions from concept to utilization have been documented in this section. The major value of this presentation is that it organizes the IMPS mission into a logical sequence of events. It should be remembered, however, as indicated in Fig. 21, that the steps overlap and repeat. Even so, the progression is clear and valuable for future planning efforts.

SECTION VII
CONCLUSIONS

This report has defined a baseline IMPS program. The description of this program has provided both the justification (in terms of AF mission needs) and the rationale for the proposed IMPS investigations. The environments and the interactions of potential concern to AF missions through the auroral zone/polar caps have been described. Key investigations and the necessary instrumentation for these investigations have been identified. A coherent, long-range plan for multiple IMPS flights has been developed. It is concluded that IMPS offers a significant opportunity to

(1) Improve the reliability of AF missions

(2) Improve the survivability of AF missions

Given the great expense of future systems, the IMPS program outlined in this report is readily justifiable.

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GLOSSARY

AF	Air Force
AFGL	Air Force Geophysics Laboratory
AIAA	American Institute of Aeronautics and Astronautics
AFSTC	Air Force Space Technology Center
AEC	Atomic Energy Commission
CEM	Contamination Effects Monitor
CDAW	Coordinated Data Analysis Workshops
DME	Dielectric charging, material proper effects, and electrostatic discharge
DMSP	Defense Meterological Satellite Project
EIM	Environment and Interactions Monitor
EIS	Electron-ion beam-induced interactions
EMI	Electromagnetic interference
EPD	Electrical properties degradation
ESD	Electrostatic discharge
ESWG	Engineering/Science Working Group
EUV	Extreme ultraviolet
EVA	Extra-vehicular activity
GLW	Glow measurements
HVA	High-voltage array
IMPS	Interactions Measurements Payload for Shuttle
IR	Infrared
ITO	Indium tin oxide
JPL	Jet Propulsion Laboratory
LIDAR	Laser detection and ranging system

LSS	Large space structure
MIL-STDS	Military Standards
MMU	Manned Maneuvering Unit
MSSTP	Military Space System Technology Plan
NASA	National Aeronautics and Space Administration
PDP	Plasma Diagnostic Package
PEO	Polar Earth Orbit
QCM	Quartz crystal microbalance
RADC/OC	Rome Air Development Center, Section OC
RTF	RF transmission distortion
SBR	Space-based radar
SCATHA	The Spacecraft Charging at High Altitudes Program
SDD	Space debris detection
SEU	Single-event upset
TEOM	Tapered element oscillating microbalances
TQCM	Thermally controlled quartz crystal microbalances
TVM	Low-light TV monitor
WCE	Wake charging effects