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FOREWORD

This report documents the primary results from a Workshop on Solar-Terrestrial Studies held October 11-13, 1977, at the Lake Guntersville State Park Convention Center, Alabama, The Workshop centered on three concerns, namely: (1) the intradisciplinary and interdisciplinary ramifications of Joint Observational Programs (JOP's) for solar, magnetospheric, atmospheric, and Sun-weather sciences, (2) the instrumentation requirements, and (3) the utility of the NASA 25 kW Power Module (PM) in conjunction with these advanced Shuttle operational modes.

The Workshop was a sequel to one held at Logan, Utah, February 14-16, 1977, the results of which are summarized in NASA CP-2024, "NASA Workshop on Solar-Terrestrial Studies from a Manned Space Station." The latter Workshop followed the concepts set forth in the NASA document, "The Solar-Terrestrial Observatory as a Major Module of a Space Station: An Advocacy Document," George C. Marshall Space Flight Center, September 1, 1976.

The primary emphasis of the October 1977 Workshop was on the JOP's augmented by the assumption of the availability of the Power Module together with a concerted effort to define the specific types of instrumentation appropriate for the JOP's. The inherent nature of this emphasis engenders an especially dense cybernetic interaction which is heavily inter- and intradisciplinary.

It is the hopeful expectation that this collection of results will help to foster continued development of the ideas, techniques, advanced instrumentation, and space hardware necessary for the acquisition of a full understanding and the capability for the rational management of the solar-terrestrial environment in which and on which man thrives.

The Workshop was organized primarily through the efforts of Dean Jafar Hoomani, University of Alabama in Huntsville; Dr. Peter M. Banks, Utah State University; and Drs. Einar Tandberg-Hanssen and Charles R. Chappell, Space Sciences Laboratory, Marshall Space Flight Center, NASA. The general chairman was Dr. Peter M. Banks, and chairmen of the individual solar, magnetospheric, atmospheric, and Sun-weather sections were Dr. Neil R. Sheeley, Jr., Dr. Paul J. Coleman, Dr. Sydney A. Bowhill, and Dr. Richard L. Blake, respectively.

INTRODUCTION

Since the Workshop held at Logan, Utah, in February 1977, the possibility has developed that NASA will initiate the development of the Power Module (PM). When the Power Module is used with the Shuttle in a sortie support mode, both the instrument capacity and the time in orbit of the Orbiter can be increased several fold. In the free-flyer mode, the Power Module would be capable of providing power, basic attitude control, basic thermal control and housekeeping communications for unmanned, large, independent mission payloads in low Earth orbit for periods of 6 months or longer.

The use of the Power Module, with the resultant increase in sortie mission capability and the potential for extended-duration, large, unmanned payloads in low Earth orbit, is an evolutionary step toward the Solar-Terrestrial Observatory envisioned at the time of the Logan meeting. It now appears unlikely that the full capability of a dedicated manned Solar-Terrestrial Observatory will be available as soon as it, perhaps, was anticipated in those prior discussions; hence, the investigations contemplated in the following paragraphs are primarily those which can be accomplished using the manned Orbiter in an expanded sortie mode or an unmanned Solar-Terrestrial Observatory in an extended-duration mode, powered and supported by the Power Module. (Description summary charts for the Power Module are contained in Appendix C.)

THE SUN

Use of the Power Module

In solar and solar-terrestrial physics the Power Module as an augmentation to the Orbiter will provide improvement in observing capabilities in several ways. It will allow increases in the observing time well beyond 7 days; for example, a 3-month mission would cover more than three solar rotation periods and would allow a number of considerations not otherwise possible. The extended time will permit the permanent monitoring of the Sun necessary for solar-terrestrial studies and will have important applications in much the same way as the current weather-satellite photographs, which must be acquired over more time than the 1- to 2-week interval envisioned for Spacelab 2. It is envisioned that by 1983-84 a number of solar-terrestrial correlations will be fairly well understood. At that point, the appropriate mechanisms can be tested using sophisticated astronaut-operated instrumentation and involving monitors available at that time to optimize the success of the manned mission.

The increased power available from the module will permit supporting nonsolar experiments to be conducted in coordination with the solar experiments. This would permit truly correlated solar-terrestrial studies. For example, the active magnetospheric experiments could be carried out while solar observations are being made. The increased power would also permit increased flexibility in the design of solar experiments, allow more sophisticated experiments such as on-board calibrations involving, for example, arc lamps or lasers, and could be used to maneuver the Power Module to permit more suitable pointing in special cases of solar events when simultaneous terrestrial observations were also needed.

There are certain aspects from the solar physics point of view that should be considered in future development requirements for the Power Module. The solar-pointed end of the Power Module should be accessible for calibrations, film changes, and instrument changes and improvements, including complete instrument changes and replacements. Ultimately, to apply the solar-terrestrial capability of an evolved space station, a high data transmission rate will be required. To evolve in that direction, some consideration of a permanent high data transmission rate is necessary. Generally, at present, any solar instruments that require transmission of solar images to Earth require relatively high data rates. Several docking arrangements would be considered, such as docking perpendicular to the normal to the solar panels. A 360° swivel of the Orbiter around this normal might then be possible and would allow increased solar pointing flexibility of a solar telescope in the Shuttle bay. This increased flexibility would allow more simultaneous solar, terrestrial, and magnetospheric experiments.

There would be advantages attendant with building a solar monitor package into the Power Module from the outset. This package would contain instruments for long-term monitoring such as recording the solar constant and spectral irradiance in certain spectral regions, solar flare patrol telescopes, and coronal hole detectors; that is, those instruments unique to requirements for more or less continuous observations as opposed to observations selective in time and solar disk location.

The idea of two sets of solar-pointed instruments (i.e., one set as a built-in monitor package and others independently or selectively) would require two basic types of pointing. Monitor-type instruments co-aligned with the solar panels would probably be fixed to point to the center of the solar disk. More flexible solar experiments would be mounted in the Shuttle bay and use whatever gimbaled pointing system is available in the Orbiter.

Interdisciplinary Joint Observational Programs (JOP's) and Instrumentation

Of considerable importance to discovering solar-terrestrial cause-and-effect relationships as well as to the separate disciplines of purely solar physics and magnetospheric physics is the ability to separate the effects of flares and of coronal holes on geomagnetic activity. Instrumentation that would give data to allow this separation would be the following complement:

a. Imaging soft X-ray/XUV instruments:
   Mg XII — hot ~ 10 M °K
   Mg IX — cold ~ 1 M °K
   Wideband ~ 2 to 4 M °K

b. Imaging hard X-ray instrument, if practical (to learn about the impulsive phases — Are shocks the important part of 3B flares that are followed by great auroras?); otherwise, hard X-ray flux instrumentation would be satisfactory.

c. An advanced instrument similar to the Spacelab 2 magnetograph experiment would permit observation of the Sun as continuously as possible for approximately 90 days if a suitable optimum polar orbit could be selected.

d. Systematic patrol magnetograms and Hα photography from magnetograph and Hα telescopes.

e. Ground-based radio observations for types II, III, and IV bursts would be useful correlative support for the Power Module/Orbiter (PM/O) observations.

f. PM/O-based and ground-based coronagraph observations to determine the way in which the boundary of a coronal hole extends into interplanetary space.

Evidence points toward the solar magnetic cycle as being closely related to the solar-terrestrial relationships. Continued development of high-resolution photospheric magnetographs would allow the emergence and diffusion of flux to be observed in detail in order to test physical mechanisms that would aid in understanding the solar magnetic cycle.

The combination of magnetic field data and data from instruments operating in the ultraviolet would allow comparison of the magnetic evolution with the evolution of the ultraviolet flux. The ultraviolet flux is, in turn, related to the spectral irradiance which is of importance to atmospheric physics problems, so that a chain of effects might be revealed by the combined use of these instruments.

Intradisciplinary JOP's and Instrumentation

Two important general areas of solar physics that are well suited for investigation using the JOP approach are: (1) solar magnetism (especially the emergence and diffusion of magnetic flux) and (2) solar mass ejections.

With respect to solar magnetism, the following problems could be addressed most appropriately using the JOP approach: With spatial resolution comparable to the photospheric scale height, what is the spatial distribution of photospheric magnetic field strengths? Are there weak fields and strong fields? How do the fields emerge and evolve with time? How much flux emerges as a function of spatial scale size? How is flux transported and how does it disappear? After a flux loop emerges through the photosphere, does it ever resubmerge below the photosphere? How is flux transported from its origin in mesoscale bipolar magnetic regions to the large-scale unipolar magnetic cells such as the polar fields? There has been considerable controversy as to the strength of the magnetic field in different areas of the photosphere. In sunspots, where the field strength can be measured directly by the Zeeman splitting of appropriate spectral lines, field strengths of 3000 to 5000 G are found. However, in active regions without spots and in the quiet solar atmosphere it is not the strength but the flux (strength $\times$ area) that is measured. Because we do not know what fraction of a given area is covered with the magnetic field, we cannot directly measure the strength. Estimates range from several gauss (10 to 20 G) covering most of a given area to roughly 1500 G occurring in small flux tubes that make up only a small fraction of the area observed.

The instrumentation appropriate for investigations designed to answer these questions comprises the following:

a. Photospheric magnetograph with sub-arc-sec spatial resolution, 10 G sensitivity at this resolution, and with wavelength discrimination within the Zeeman spectrum line.

b. A coronal polarimeter with arc-sec to sub-arc-sec spatial resolution and $\sim$100 G sensitivity at this resolution.

c. A high-quality Hα telescope with sub-arc-sec resolution.

d. An extreme ultraviolet and soft X-ray spectroheliograph with sub-arc-sec spatial resolution to observe a variety of emission lines originating in the chromosphere/transition region/lower coronal regions (for diagnosing the plasma associated with the magnetic field lines).

With respect to solar mass ejection, the following problems would yield better to the JOP approach: Where on the Sun does the solar wind originate? What is the role of coronal holes? How and at what height is the solar wind accelerated? How is the evolution of a high-speed stream related to the evolution of a coronal hole? What are the composition and plasma properties of the mass flow near the Sun and how are they determined? Where does the mass associated with prominences originate? What is the mechanism by which the mass is ejected — magnetic forces or thermodynamic forces? What are the composition and plasma properties of the ejected mass?

Mass seems to be ejected from the Sun in basically two ways, viz., (1) as a more or less continuous stream (i.e., the solar wind) and (2) as discrete mass ejections (e.g., ascending prominences of different kinds and flare ejecta). The Skylab Coronal Hole Workshop has documented the importance of coronal holes for the former ejections, while the Skylab Workshop on Solar Flares has brought into focus the importance of acceleration associated with active region magnetic fields in the case of the discrete mass ejections.

The instrumentation appropriate for investigations to explore these problems comprises the following:

a. A coronagraph that is multispectral to distinguish Hα emission from electron-scattered radiation, with polarizers to distinguish electron-scattered radiation from particle-scattered radiation and with a few arc seconds spatial resolution.

b. An ultraviolet coronagraph operable at various wavelengths to determine plasma properties, such as temperature and density, and flow parameters, such as speed.

c. An EUV and a soft X-ray imaging instrument for plasma diagnostics and morphology with arc-sec spatial resolution to observe a variety of emission lines from hot as well as cold plasmas (i.e., from the chromosphere through the transition regions to the middle corona); one would match the inner boundary of the coronagraph instrument.

d. A velocity spectrometer with arc-sec spatial resolution and a few kilometer/sec spectral resolution for determining velocities of either solar wind mass or transient mass ejecta, including both turbulent and Doppler velocities, and operable at various wavelengths to include a wide range of heights in the solar atmosphere (chromosphere to corona).

e. A multispectral photoheliograph with arc-sec spatial resolution to observe both high temperatures in prominences and ejecta.

THE MAGNETOSPHERE

Use of the Power Module

The primary use of the Power Module in magnetospheric physics would be to extend Orbiter mission lifetimes. A secondary use would be to provide power for experiment elements with relatively high demands. Because of the importance of these two functions in the overall program of magnetospheric research, the Power Module development should be accelerated.

In addition, the module should have a number of special capabilities. It should be able to provide specified Orbiter orientations. Further, it would be desirable to consider the incorporation of various platforms as follows: (1) platforms for instrument packages that would be used to monitor certain variables on a more or less continuous basis, (2) platforms for equipment packages such as high-power transmitters which could be operated while the Orbiter would be used simultaneously for remote observations of the effects of the Power Module-mounted instrument package, (3) platforms for storing instrument packages, with environmental control as needed, when such on-orbit storage is preferable to multiple trips to and from orbit, (4) a platform for a rechargeable power unit that would be stored on the Power Module for transfer to the Orbiter for use as desired in extending the Orbiter operation remote from the Power Module, (5) a platform for a tether unit for use with tethered subsatellites, and (6) capability for operation in orbits with different inclinations as well as different altitudes. (The latter may require different orientation.)

Initially, the primary use of the Power Module would be to supply power to the Orbiter. Continuous operation or storage of instrument packages and operation of high-powered equipment off-loaded from the Orbiter would be anticipated in follow-on operations. The other functions mentioned previously would occur later in the operational sequence.

Instrument Requirements

The early Spacelab flights will begin to develop new instrument techniques for magnetospheric measurements, including active perturbation systems as well as passive imaging systems. These early, short-duration (~ 7 days) missions will help to develop the methods of operating these new instruments and will give interesting new information on specific magnetospheric processes. However, the acquisition of data on magnetospheric responses to varying solar conditions will be quite limited due to the short mission duration and limitation on variety and quality of instruments because of the low amount of power.

The applications of these Spacelab techniques to a long-duration observation program such as the PM/O will significantly broaden the scope of magnetospheric science that can be accomplished and will, in effect, release the mission duration constraints imposed by the Shuttle Orbiter in early flights. These lengthened missions will permit the type of global coverage during varying solar activity which is necessary to uncover the links between solar changes and terrestrial responses. In addition, greater power levels could be used to increase the instrument operating time as well as the variety and quantity of instruments, and hence the total of its scientific return.

1. First-Generation Instruments

a. Particle Beams and Diagnostics. The measurement of electric fields perpendicular and parallel to the magnetic field can be accomplished with electron and ion accelerators in low Earth orbit. These investigations may use diagnostic measurements to be made by subsatellites and by low-light-level imagers. Instruments of this type are being developed for the early Spacelab missions. In these missions the required techniques for measuring the patterns of electric and magnetic fields in the Earth's vicinity will be developed. However, the short-duration missions that will be possible in Spacelab missions will not allow determination of the development of these phenomena in response to varying solar conditions. Long-duration missions would allow the necessary investigations to be made. Additionally, since accelerator output powers of 50 kW or more will be required, the availability of increased power will certainly increase their achievable duty cycles over those obtainable on Spacelab itself.

b. Wave Injectors. A broad-band wave injection facility (in the kilohertz to several megahertz range) will be used to stimulate artificially the various wave particle interactions believed to be responsible for the precipitation of energetic electrons and ions into the atmosphere. Experiments of this type have been performed with ground-based transmitters, but only a small fraction of the radiated power is transmitted through the ionosphere and into the magnetosphere where the interactions with particles can occur. Also, a given ground station can illuminate only a single field line (or L-shell) with waves. These problems are eliminated with a Shuttle-mounted facility, and first-generation instruments of this type may be developed for Spacelab missions in the 1982-1983 time interval. The development of these techniques on shorter-duration Shuttle flights will lead naturally into the required investigation of determining the efficiency of particle precipitation by wave-particle interactions under varying solar conditions. As in the case of the accelerator, high powers of several kilowatts will be required in the VLF range, and increased power capability will allow more extensive operation of the transmitter over various latitudes and L-shells. Long antennas, with lengths from several hundred meters to several kilometers, will be required for transmission at the lower frequencies.

c. Chemical Release Modules. The release of certain solar-ionizable gases along the Shuttle orbit will produce an ion cloud that can be tracked optically through the detection of solar resonance lines. The motion of these clouds will be determined by the electric and magnetic fields they encounter. The stability of the geomagnetic field at Shuttle altitudes will then allow the component of electric field perpendicular to the magnetic field to be determined. This technique has been well developed using releases from sounding rockets combined with ground-based optical tracking. Techniques for making global measurements of ionospheric electric fields will likely be developed by the use of a chemical release module developed for early Spacelab flights. The use of these techniques in long-duration flights will make possible the determination of the development of global electric field distributions in response to various solar phenomena.

The ejection of the gases by a rocket-borne, shaped-charge explosive device has been used to trace magnetic field lines and to measure field-aligned potential drops. A shaped-charge release module, likely to be developed for early Spacelab flights, will allow the development of techniques for observing these phenomena which play a crucial role in the transfer of energy from the magnetosphere to the atmosphere. Long-duration missions will, however, be required to determine their evolution in time in response to various phenomena on the Sun, thereby establishing their role in the solar-magnetosphere-atmosphere chain of interactions.

The instruments listed previously represent the cadre of first-generation facilities that would make up the core of a long-duration PM/O. These facilities are being considered for early Spacelab flights.

2. Advanced Instruments

The categories of instruments, some of which are in a relatively undeveloped state but which should be considered for further definition because they will have direct applicability to a long-duration observing platform, are:

a. Tethered Current Generator and Deployable Antenna. One of the most interesting and challenging concepts for the extension of Shuttle capabilities involves the deployment of a subsatellite on the end of a tether. This type of deployment makes possible a number of different types of experiments. The tether itself can be used as a current generator. Moving the long tether across magnetic field lines as the Shuttle orbits the Earth will result in the generation of electric currents. These currents can be used for an additional power source for the on-board experiments. The tether system can also be used to deploy instruments from the 200 km Shuttle orbit down to the upper atmosphere at approximately 100 km, making possible direct measurement of atmospheric constituents and electric currents that cannot otherwise be measured globally. This long, deployed tether can also be used as an antenna for injecting ULF and ELF waves into the ionosphere for studying wave propagation effects.

b. Subsatellite Cluster. It has become increasingly apparent that the detailed understanding of many magnetospheric phenomena requires simultaneous multipoint measurements made by a cluster of satellites. An example of this is the determination of magnetospheric current systems for which four-point measurements of the magnetic perturbations caused by the spatially and temporally varying currents must be made with satellite separations of the order of 10 km or greater. Early Spacelab flights will utilize short-lived clusters of throw-away detectors (TAD's), but long-duration "formation" flying when combined with the requirement of station keeping is as yet an undeveloped capability. It would be most valuable to have such a cluster orbiting near the observatory making the detailed magnetospheric and ionospheric measurements necessary to support the active experiments.

c. Coherent Scatter Radar System. The orbiting of a phased-array coherent scatter radar system transmitting at 30 to 40 MHz makes possible the measurement of plasma turbulence conditions at high altitudes along auroral field lines. The view from orbit is required to allow the measurements to be made perpendicular to the magnetic field lines at high latitudes where the magnetic field lines are almost vertical. The observation of plasma turbulence may hold the key to understanding the mechanisms for auroral particle acceleration.

d. High-Sensitivity Imaging of the Aurora. Because the aurora represents a major energy input to the atmosphere, its morphology and dynamics are of fundamental importance. A high-sensitivity imaging system with the capability to view the aurora in the visible and ultraviolet range (including 1216 Å) will give new information on the global dynamics of energetic particle precipitation, including both particle fluxes along auroral field lines and the location and separation of ion and electron precipitation. These instruments are representative of the types of measurement techniques that will be needed on a long-duration PM/O. It is expected that many will be developed for early Spacelab flights. The development of the ultimate instrument complement for the observatory should be planned and this planning used as guidance for the acquisition of experiments and facilities during the formative years of Shuttle/ Spacelab.

Joint Observational Programs

There are several tasks in magnetospheric research that should serve as examples that would contribute to significant JOP's. For each of these tasks there are multidisciplinary objectives; i.e., to establish the causal solar phenomena; to provide quantitative remote measurements of phenomena in the magnetosphere/ionosphere/atmosphere interaction region with a coverage that is essentially global; to provide systematic information on the state of the magnetosphere using both active and passive Orbiter systems and subsatellites; to use all these tools in an effort to define the physics of the processes involved in this interaction; and to establish cause-and-effect relationships in the solar, magnetospheric, and ionospheric processes and ultimately relate these to weather.

With these objectives in mind, the following tasks are examples of those that should be considered for JOP's:

a. Auroral precipitation

b. Overall charged-particle precipitation

c. Sources and processes of transport for hot plasma in the magnetosphere (material exchange)

d. Large-scale currents in the magnetosphere and the associated transport and deposition of material, momentum, and energy

e. Magnetospheric dynamics, changes in the distribution and state of plasma, and the topography of the distant regions of the magnetosphere

f. Ionospheric irregularities at high latitudes.

For complete effectiveness, these measurement programs would require coordination with:

a. Ground-based measurements of field emissions

b. Ground-based solar monitors

c. Spacecraft-borne monitors of near-Earth interplanetary space

d. Other spacecraft measurements in the magnetosphere

e. Synoptic measurements in space (perhaps on the Power Module) to provide baselines.

The solar-magnetospheric coupling is now understood to be accomplished via the solar wind. The panoply of electromagnetic radiation is, of course, the major driving function of terrestrial climatic variations. Yet the ill-understood, but statistically correlated, association of short time-scale (several days) solar-related atmospheric phenomena discussed elsewhere in this report and in the literature must be attacked by a wide range and variety of observations which should be made in association with those made by the Power Module observatory. Simply stated, the solar observations (flares, coronal hole observations, transients) should be followed immediately in an operational sense by, first, ground-based solar radio observations (types II, III, IV) and interplanetary scintillations of discrete radio sources and then by in situ solar wind probes in front of (ISEE-C type spacecraft) or near the Earth (IMP, VELA, OGO, HEOS, Prognoz, Solrad, and $E \parallel B$ type probes). Synergistic "tracking" to Earth of coronal hole-type solar wind streams, with their associated sector boundary changes (including latitudinal magnetic field excursions), and flare-generated disturbances will provide direct physical evidence of energy, momentum, and mass transmission from the Sun.

Continuous tracking of the kinetic energy flux modulations, for example, from the visual 0.1 erg cm^{-2} sec^{-1} to pathological values (during August 1972-type storm) of 36 to 100 erg cm^{-2} sec^{-1} could provide an important link in the Sun-Earth transmission line. Prediction of shock arrivals at Earth from flares and extremely large holes as well as more moderate stream modulations from normal holes could precipitate correlative, dynamic magnetospheric responses following geomagnetic storm onset as well as during substorm activity. Computer MHD simulations (solar global circulation models) could be used as supportive tools for the purpose of investigating basic physical processes of this transmission chain.

Many of the ground-based facilities exist but require committed support to the PM/O's goal of unambiguous association of solar-magnetospheric coupling to the final goal of low atmospheric responses described in the Sun-Weather Relationships and Atmosphere sections of this report. Associated interplanetary spacecraft are essential in modes which provide near-real-time plasma, magnetic field, and energetic particle observations with presently available and well-developed instruments.

THE ATMOSPHERE

Use of the Power Module

In considering the appropriate science and the instrument evolution for the PM/O, its specific capabilities and operational modes were assumed to be as follows:

a. Support of the Spacelab during longer duration (60 to 90 days) missions

b. Free-flying support of a Spacelab pallet for a 1-year mission

c. Availability of much higher power

d. An environment that has low contamination (no thrusters).

In the succeeding sections, the science objectives for which the preceding capabilities would be used are first reviewed; then the existing Spacelab 1 and Spacelab 2 instruments are reviewed; and, finally, the new instruments requiring further development are described.

Science Objectives

1. Troposphere. Atmospheric processes occur on all time and size scales from the microphysical processes with time scales on the order of seconds that result in the formation and growth of clouds to global scale waves with time scales on the order of days to weeks. While the short time interval of the microphysical processes precludes their observation remotely from an orbiting vehicle, the low-gravity environment in which these vehicles orbit could be used advantageously to study these same processes in laboratories carried aboard the vehicle. In this case, the longer the mission, the more experiments could be accomplished. Observational programs planned for the current orbital cloud physics laboratory are restricted by the power available for thermally controlling the laboratory equipment to be used in the experiments.

Mesoscale systems with dimensions on the order of tens of kilometers and time scales of several hours to days could be monitored by the 7-day and 60- to 90-day sorties as well as the free flyers; however, the smaller scale severe storms such as tornadoes and thunderstorms could not be adequately monitored due to their shorter lifetimes. These smaller scale systems require the continuous observations obtainable only by a geosynchronous Earth orbit satellite with observational resolution capabilities exceeding those of the current meteorological satellites.

Areas of active cyclogenesis can be adequately monitored on all lengths of missions if the orbital parameters are such that the areas can be viewed at least once per day. These areas must be identified early in their lifetimes if they are to be useful in short-term forecasting activities.

Stratospheric warmings and hurricanes are phenomena with lifetimes on the order of days, possibly extending to a week to 10 days. Since predictions of either the time or location of their occurrence are not very accurate, monitoring either of them on a 7-day sortie would be difficult unless the mission was initiated immediately upon their detection or unless by unlikely chance their formation happened to occur and be detected during the short mission; therefore, it would be preferable and more probabilistically favorable to attempt to monitor these phenomena on the 60- to 90-day or free-flyer missions.

The gas-to-particle conversion of SO_2 by ultraviolet in the presence of water vapor is being considered by cloud physicists as a possible source for cloud nuclei. The process is also important in pollution studies; therefore, monitoring of the SO_2 budget is an important task that could be accomplished on all three types of missions.

The distribution of the aerosols in the troposphere and stratosphere plays an important role in the radiation budget of the Earth. Monitoring how this distribution varies on a global basis, how new aerosols are injected into the atmosphere and how they disperse, and how these aerosols in the troposphere and stratosphere are interchanged and mixed are tasks that require long-duration missions rather than the repetition of 7-day sorties at discrete intervals.

2. Changes in Ultraviolet Solar Radiation and Energetic Particles in Relation to Stratospheric Chemistry Effects. The photochemistry of the minor constituents in the middle atmosphere is strongly controlled by ultraviolet radiation in the wavelength region of approximately 1700 to 3200 Å. Both the solar radiation and the species absorption cross sections exhibit line structure of less than 50 mÅ in certain portions of this spectral region, thus requiring very careful measurement of these parameters. The limited data base on ultraviolet solar irradiance suggests that, contrary to initial expectations, significant temporal variations may also be present. Such variations can result in significant composition changes which, in turn, can lead to changes in the energetics and dynamics of this altitude region. Therefore, a meaningful

understanding of the chemistry and physics of the middle atmosphere requires careful and accurate (~ 5 percent) measurements of the spectral characteristics and temporal variability of the solar radiation in this wavelength region.

Observations of rapid changes in high altitude and high latitude ozone concentrations following strong PCA and magnetic storm events have demonstrated the influence of particle precipitation on the mesospheric chemistry. The actual steps in this interaction are believed to be via the creation of NO_x compounds by the precipitation particles, which is followed by catalytic destruction of ozone and other accompanying chemical changes. At present very little is known about the details of the physical and/or chemical processes coupling the middle atmosphere to the upper atmosphere and magnetosphere, and the mechanisms involved will be a high-priority area for study during the next 10 years.

The successful detection of middle atmosphere response to changes in either particle or radiation influx will require extended observing periods. Processes with time constants in excess of a few days can be studied from a high-inclination orbiter but require missions lasting much more than a week. Periodic sampling will be acceptable in some cases, but for impulsive solar events, such as PCA's, long observing times are required.

Relationship to Existing or Already Designed Instruments

All of the atmospheric instruments previously proposed will provide better science from more extended observations. In particular, a 3-month sortie mission during northern-hemisphere winter will permit extensive study of changes in the middle atmosphere in the adaptive (or learning) mode that only manned operation can accomplish.

During the last decade a long series of studies was carried out to establish optional payload complements for atmospheric science studies from the Space Shuttle-borne platforms. The recent selection of three atmospheric science instruments for flight on Spacelab 1 is the first step in the evolution of facility instruments envisioned for the Shuttle era. A brief summary of these instruments together with their scientific objective follows.

The continuous scanning Fourier spectrometer is designed to operate in the 2 to 16 μ wavelength region with a spectral resolution of 0.02 cm^{-1}. Spectra obtained by this instrument during periods just prior to entry and shortly after emerging from solar occultation will provide the information necessary to establish the vertical composition profile of many important minor constituents in the stratosphere.

The cluster of imaging spectrometers will measure the airglow spectrum from the EUV to the IR (200 to 12,000 Å) with a wavelength resolution between 3 to 6 Å. The instrument package is composed of five spectrometers, with each module using a 9 × 256 element matrix detector. Thus, a single measurement by each of these five units produces nine spectrograms from specifically adjacent observational fields. The resulting airglow data will provide information on a large range of minor constituents, metastable species of both atomic and molecular ions, and neutrals in the middle and upper atmosphere.

The photometric imaging experiment is a dual-channel video system mounted on a stabilized two-axis platform. One detector will consist of a SEC vidicon with a microchannel plate-type intensifier for high-sensitivity, high-resolution operation. The other detection channel utilizes a 10 × 10 element microchannel detector array in a photon counting mode. Observations of the auroral emissions by this instrument can be used to study particle fluxes into the high-latitude atmosphere.

A solar-flux monitoring package is an essential part of the PM/O atmospheric experiments, covering the 500 to 7000 Å region with high accuracy.

New Instruments Requiring Further Development

The Logan document addresses the problems that could be fruitfully investigated on a space station located in both low and geostationary orbits. However, the realization of proper instrumentation for a space station will require the judicious choice of instruments, experiments, and hardware for inclusion in Shuttle-based missions. These instruments should be chosen with full awareness of the possibilities that would be inherent in the PM/O and later the Solar-Terrestrial Observatory.

Both existing and undeveloped instrumentation will be important in the realization of this goal. Also, the development of a Power Module to operate in conjunction with and separate from the Shuttle Orbiter is the next logical step beyond the normal Spacelab missions. It can provide a base for important solar-terrestrial observations and instrumentation development by taking advantage of vastly expanded power capabilities for operating instruments and for extending the length of Shuttle observations from 7 days to several months.

The need for the Power Module capability is very clear in the context of active experiments. Electron fluorescence and scattering experiments designed to determine excitation cross sections of highly reactive or metastable species require the use of an electron gun with high current capabilities and precise energy control. In this regard, the important excitation cross section of $O(^1S)$ can be measured relative to the permitted states.

If gas release techniques are used, a host of other chemical reactions involving ions and excited states could be undertaken. For example, the state of excitation and the kinetic energy of the oxygen atoms in dissociative recombination in a plasma generated by the electron accelerator could be investigated.

Other chemical reactions in an open gas release experiment, or in the photochemical reaction chamber, could be probed with selective laser fluorescence techniques which, again, require increased power and the use of man on board.

For the data from a PM/O to be most beneficial, the basic atomic and molecular processes occurring within the atmosphere need to be better defined. There is a need to expand our knowledge of many basic physical and chemical processes — many of which cannot be studied in conventional laboratories but which are well suited for studies on a space vehicle where both men and power are available.

As shown in previous studies, the space environment provides a laboratory for observing the interaction of unattenuated solar flux on atmospheric constituents in the absence of walls or complicating molecular collisions prevalent in Earth-bound laboratories, although some studies are needed that could be carried out in a photochemical reaction chamber where the solar radiation is admitted through both windowed and windowless ports in a more or less controlled manner.

One of the most useful methods of remotely sensing atmospheric composition and conditions is the measurement of atmospheric thermal emissions. This emission is always present and requires only passive observation; it can be used to deduce abundances and distributions of various constituents as well as conditions of temperature and pressure. Two instruments using this method will be available for long-duration flights in the mid-1980's.

The first is an interferometric spectrometer observing emission in the mid-infrared (4 to 25 μm). To achieve maximum sensitivity, it will be necessary to cool the entire instrument to $\sim 60^\circ$K to reduce noise from fluctuations in the emission of the instrument itself. Combining the high sensitivity of photon noise-limited detection with the spectral discrimination and high operating speed of Fouier transform spectroscopy results in an instrument capable of accurate measurements of substances with concentrations much less than one part per billion. From a high inclination orbit in the limb-viewing mode, daily global coverage is possible with ~ 2 km vertical resolution for many species above the tropopause. The instrument can also be used in a downward-viewing mode but at much reduced sensitivity. The same instrument in a nonspectral scanning mode can be used as a very sensitive conventional radiometer for measurements of temperature and distribution of more abundant species.

The second instrument uses microwave radiometry, in either the limb-viewing or nadir-viewing mode. A large antenna, not feasible before Shuttle, is necessary for good vertical resolution at the limb. The microwave spectrometer has less sensitivity than the infrared spectrometer, but the spectral resolution is so high that it can measure detailed line profiles sufficiently well to yield temperature, pressure, line-of-sight velocities, and magnetic fields. The two instruments provide much complementary information.

While these instruments will fly first in sortie missions, longer duration observations are important for studying the temporal evolution of systems in the middle atmosphere and for observing the response of the atmosphere to unusual external inputs such as proton flares. The larger power capability of the Power Module may allow replacement of stored cryogens with cryostats, which may be important for long-duration observations. The low contamination environment using the Power Module is particularly important for the cryogenic instrument.

Additional Scientific Considerations

There are at least two main areas of climatic relevant observations of surface and tropospheric conditions in which enhanced capabilities in infrared and in microwaves could have a substantial impact. One concerns water vapor and liquid water distributions in tropical weather systems, and the other concerns the observation of sea surface temperature and various aspects of sea-state in the presence of cloud cover.

Convective and radiative processes, both significantly influenced by inhomogeneities in the water vapor distribution, appear to play a major role in the dynamics of the tropical troposphere. Transient heat storage as well as transport of heat by currents in the underlying ocean are of global climatic significance, yet their interaction with tropical weather is as yet poorly understood. The possibility, in principle, to establish joint distributions of temperature and water vapor mixing ratio as a function of air pressure on the basis of infrared and microwave emission spectra is well established and serves as the basis for the satellite sounding system on Nimbus as developed for synoptic meteorological use. The system performance has, in practice, been marginal in the tropics, leading to a substantial need for radiosonde launching from ships during the First Garp Global Experiment. Higher spatial as well as spectral resolution in the microwave observations appears to offer significant improvements, at least in a process research mode. It is of particular interest that achievement of 1 km resolution would allow mapping of liquid water content in individual storms.

While sea surface temperature may not be needed with better than 100 km resolution for the purpose of atmospheric modelling, the study of oceanic frontal dynamics demands frontal positioning with 10 to 20 km precision. Oceanic frontal signatures in infrared and microwave emission arise from a combination of temperature and emissivity contrasts (the latter in microwave bands only and associated with roughness as well as with foam coverage). A number of ambitious oceanographic research programs currently in the planning stages could be significantly enhanced by high spatial resolution microwave spectroscopy (9.3°K emission temperature precision minimal requirement for temperature precision of 1°K).

Power Module operation allowing high-power, active-system operation would provide additional opportunities as documented in NASA SP-376, Active Microwave Workshop Report.

Joint Observational Programs

The rationale for JOP's is given in the sections on Magnetosphere and Sun-Weather Relationships. The basic premise is that the Sun, magnetosphere, and Earth atmosphere form a complex interacting system. Understanding of the parts will be enhanced by more general investigations of the system in which attempts are made to trace possible sequences of events through the system with appropriate sets of observations from each discipline. One example is to study the direct effects of solar flare emissions on the upper atmosphere and magnetosphere. Another example is to study indirect modulation of atmospheric processes due to solar activity.

SUN-WEATHER RELATIONSHIPS[1]

Use of the Power Module

The proposed PM/O offers substantial advantages that may provide new and needed information in the study of solar influence on weather. These are:

a. The capability to monitor the various outputs of the Sun in a laboratory environment, with the possibility of in-orbit cross-calibration, instrument replacement, and the use of on-board, controlled secondary standards.

b. The capability of real-time observations of specific solar effects on the terrestrial atmosphere, requiring simultaneous or time-correlated observations of both Sun and Earth.

c. The possibility of testing specific hypotheses of Sun-weather connections, through the availability of high-capability atmospheric, magnetospheric and solar observing equipment, and the ability to concentrate on specific geographic areas of interest.

Of all the aspects of a PM/O, the solar-weather objectives are most interdisciplinary and demand the greatest real-time, innovative reaction by the observers in the Orbiter. The very nature of these objectives asks for recognition of relationships between components of a complex sequence of events stretching from the Sun to the surface of the Earth. The ensemble of instruments and data displays on the PM/O will allow the on-board scientists to focus on specific relationships and to follow them as they unfold and evolve. Complete automation to follow these varied relationships seems virtually impossible. Further, the real-time pattern recognition, cognitive, and correlative capabilities of the human mind may discern significant relations that could easily elude notice during subsequent processing of recorded data at a ground site. On the other hand, the human eye may see nothing related to Sun-weather effects. In this case the answers must be deduced from detailed analysis of the comprehensive data sets that will be provided by instruments on the PM/O and on the ground. Here, the various imaging displays expected to be available will be of fundamental importance.

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[1] This section, unlike the others in this report, is basically a revision, although substantial, of the report, NASA CP-2024, generated at the Logan, Utah, Workshop.

Near-real-time and extended analyses of data by a team of specialists on the ground are also essential. The former will provide information for baseline observation plans that can be transmitted to the PM/O. However, such baseline plans will be most effectively carried out and reinforced through the innovations of the on-board PM/O scientific staff.

Instrument Requirements

Investigations of Sun-weather relations can be carried out only through the methods of the disciplines included in the solar-terrestrial "umbrella." In the absence of specific interaction concepts it would be necessary to carry out very comprehensive studies in the broad categories of atmospheric science; namely, radiative, chemical, photochemical, dynamical, and electrification processes. But, this would be such a broad mandate as to encompass the whole of atmospheric science without direction of effort. Therefore, an attempt has been made to find categories of investigations that are specific to present notions of what causes Sun-weather effects but general enough to permit continual evolution of these interaction ideas.

The solar-terrestrial observational program is envisioned as developing in an evolutionary manner. While realization of development of the Power Module will result in stepwise, multifold increases in the capacity to support instrumentation and in stay time in orbit, it is not currently believed that effective use of the greater capacity will require dramatic, stepwise changes in instrumentation. It is anticipated that the early phases of the program using the greater capacity will involve primarily an expansion of the number and diversity of instruments used simultaneously for a variety of observations. Where improvements in the performance of specific instruments appear to be either required or justified, and possible within the total system capability provided by the Power Module, it is expected that such improvements will be made. Totally new instrumentation probably will be developed only when the anticipated increase in data is sufficient to justify its development. Hence, it will be noted that most of the instruments proposed for use in the programs of Sun-weather observations already exist or are proposed for use in other programs. Desired precision of measurement, spectral resolution, data rates, etc., may be greater than are now being attained, but the basic instruments are largely already available.

Program of Investigations and Related Instrument Considerations

Table 1 presents a program of potential investigations that follow from the current understanding of solar-weather connections. The left-hand column contains a brief description of investigations, the middle column provides a statement of purpose, and the right-hand column lists possible instrumentation and, as appropriate, correlative investigations. In some instances the investigation will draw support from relevant unmanned spacecraft.

The investigations are necessarily general, since at this stage a comprehensive attack is what seems to be most needed. Some suggestions are more specific than others, but pinpointing specific mechanisms for trial is avoided. Moreover, the possible mechanisms and solar-weather effects considered are recognized as being incomplete.

Almost all of the experiments proposed here involve apparatus which will serve other areas of research on board the Space Station: solar physics, magnetospheric physics, and atmospheric physics. The specific equipment is listed in the preceding sections about those areas.

The investigations 3 and 4 in Table 1 involve infrared and microwave instruments of general applicability to atmospheric science. Recent work on HRIR data interpretation for sea surface temperature has demonstrated the value of sufficient geometric resolution to allow distinction of clear image elements in scattered cloud situations. There is, in addition, a substantial interest, in the context of oceanic climatology and transient response studies, in the ability to position frontal features with an accuracy of the order of 10 km. The latter is true for both temperature and sea-state gradients.

Microwave capability designed for adequate resolution in atmospheric limb sounding either in low Earth orbit or geosynchronous Earth orbit would coincidentally provide the critical angular resolution capability to begin to resolve liquid water content effects associated with intensive updrafts relative to the more horizontally coherent sea surface features. As detailed in the SEASAT documentation, active altimeter and scatterometer capability would open up opportunities in several climate-relevant areas of air-sea interface dynamics.

The higher resolution and available power in the PM/O era enhance these opportunities significantly.

TABLE 1. PROGRAM OF SUN-WEATHER INVESTIGATION

Investigation	Purpose	Instrumentation
1. Measure the "solar constant," $s = \int_0^\infty s_\lambda d\lambda$, on continuous basis with a precision of 0.1%.	To determine whether and by how much total solar output changes over time scales of days, years, solar cycles, and longer.	Active cavity radiometer. When used in manned sortie mode, capability for in situ calibration should be provided; continuous measurements over two solar rotations desired. When used in free-flyer mode, calibrate at the beginning and end of mission.
2. Measure spectral irradiance, s_λ, in infrared, ultraviolet to X-rays.	To provide input for tests of Sun-weather interactive mechanisms based on variations in solar spectral irradiance. To provide improved input to atmospheric and ionospheric models.	Instrumentation from SL-2 complement as appropriate. For region "0" to 1200 Å filtered CEMA or filtered pinhole camera; need measurements of both integrated full-disk output and modest resolution active region output.
3. Collect global visible-light and infrared images. Select areas of interest and collect images at rates up to one per minute.	To provide inputs to existing atmospheric models which incorporate effects of the areal extent and depth of clouds, temporal and spatial variations in atmospheric particulate load, ice and snow cover, albedo, etc. To provide for the refinement of existing models to permit application to specific Sun-weather interaction hypotheses.	Instrumentation drawn generally from existing weather satellite complements modified to increase resolution and sensitivity, as appropriate. Complement with measurements in (4) as required.
4. Vertical soundings with high spatial and temporal resolution in selected regions of interest, of winds, temperature, water vapor, liquid water, and (as possible) other selected gaseous and particulate components of the global atmospheric system.	The same as (3) but with emphasis on day-to-day weather systems.	High-resolution infrared telescope system, active microwave sounder, LIDAR, active altimeter and scatterometer — instrumentation selected from preceding Spacelab missions and SEASAT complements as appropriate.
5. Measure atmospheric response to, and characteristics of, cosmic ray flux modulations, atmospheric X-rays, precipitating energetic particles, etc. (Measurement protocol involves simultaneous observations of atmospheric parameters; in situ radiation input; solar, magnetospheric and auroral behavior as appropriate.)	To provide inputs for tests of Sun-weather interaction mechanisms based on solar modulation of energetic particle flux to atmosphere. To examine possible direct responses in specific regions such as the auroral zone.	Instrumentation selected from, for example, electrodynamic explorer mission complement. Low-light-level TV system. Gieger counters, ionization chambers, etc., as appropriate to cosmic ray detection.
6. Measure the temporal and spatial distribution over the Earth of rate of occurrence and intensity of lightning (simultaneously measure at one or more selected points the vertical distribution of the electric field, conductivity, and state of ionization of the atmosphere).	To provide input for tests of Sun-weather interactive mechanism based on solar control of the Earth's atmospheric electric field.	Initially, motion picture camera (Apollo, DAC or other) with films of appropriate sensitivities for daytime and nighttime use. If early results warrant it, continuous recordings system using Hα telescope (for corollary measurements, see text).
Related Experiments		
7. Monitor the magnetosphere and interplanetary space to identify effects of coronal holes, high-speed streams, magnetic sector boundaries, flares, etc., on the magnetosphere and Earth's atmosphere.	To provide input connecting solar activity to an atmospheric effect in the investigations presented in preceding items.	Will involve spacecraft and missions in and outside the magnetosphere. The appropriate measurements and instrumentation are discussed in the sections on the Sun and the magnetosphere.
8. In-orbit measurements of brightness of outer planets (studies of atmospheric processes on other planets could aid understanding of Earth's atmosphere).	To test reported correlation of planetary albedos and solar activity.	Initially, low-resolution spectrograph operating in visible-light spectral range. If effects of interest observed, improvements in resolution and optics might be warranted.

Together with improved liquid water diagnostic capabilities, one would here have a significant advance in capacity to study important aspects of tropical oceanic weather systems as well as the atmosphere-ocean interactions in the oceanic polar front regions.

With regard to orbit selection, it is ultimately desirable to have an inclination of at least 55° to cover the subpolar ocean areas. However, 28° inclination would enhance the coverage and, hence, the experimental opportunities in the tropics.

High-resolution infrared, microwave, and LIDAR systems are under development or available.

Instrumentation for the particles and fields measurements in investigation 5 could be initially selected from the Electrodynamics Explorer Mission or other current or future magnetospheric instruments. For monitoring auroral emissions, the TV system (with some modifications) being developed for Spacelab 1 could be used.

A hydrogen-alpha telescope may have the best signal-to-noise ratio for monitoring lightning in investigation 6. Because of the status of current technology, $H\alpha$ filters would be simple and low-cost.

The observational capabilities given in Table 1 provide a typical set of tools to investigate the class of scenarios suggested currently for the solar influence on weather. For example, the fact that any appreciable variation of solar radiation could have a fairly direct influence on the Earth's atmosphere is addressed by items 1 through 4. Similarly, the hypothesis that solar modulation of ionizing particles reaching the atmosphere may influence cloud mechanics, and hence weather, can be investigated by a combination of items 3, 4, and 5. Likewise, the idea that solar-induced changes of electrical conditions in the ionosphere influence meteorology is addressed in items 3, 4, 5, and 6. The concept that solar particle radiation filtered by the Earth's magnetosphere may change ozone concentrations in northwestern North America, resulting in the formation of cold anticyclones that propagate across the continent, can be investigated by items 3, 4, and 5. These are examples drawn from contemporary literature.

Even more important, however, is the encompassing ability of the instrumentation complement, when it is finally selected, to test refined and still-to-be-proposed scenarios that will surely come forward between now and the advent of the PM/O. In actual PM/O operations, a specific observation plan could be tailored to each of the prime candidate mechanisms for solar influence on weather and climate. At present the observations to be made must be discussed in the preceding general terms. Ultimately, the observing campaigns must be quite specific. This is the feature that distinguishes the PM/O from the traditional monitoring observations.

Between now and the time the PM/O becomes operational it is important to encourage development of ideas for mechanisms and processes by which the Sun-weather interaction might occur. Ideas can always be quantitatively evaluated within the context of models to determine which ideas are worth pursuing experimentally. There are existing useful models of the atmosphere, ionosphere, magnetosphere, solar wind, etc., that could be used to evaluate ideas. But, what is most needed is encouragement for cross-disciplinary thinking that could lead to new models for coupling between these physical systems. At present it is unrealistic to attempt a super-model that includes all solar-terrestrial processes, but it is realistic to look for new models based on concrete ideas for coupling processes. This type of analytical research should be encouraged with financial support.

Preliminary Ideas for Interdisciplinary Investigations (JOP's)

1. The Solar Constant. Variations in the solar radiative output would have a near-proportional effect on tropospheric heating. This effect would result partly from changes in direct heating and partly from changes in the ground temperature and oceans, which largely control the convective heating of the troposphere. The measurement must be made from an extraterrestrial platform in order to include the full spectrum and eliminate variations due to terrestrial factors. An active cavity radiometer is an appropriate instrument (there will be one on the Solar Maximum Mission and two on Spacelab 1). Complementary measurements will be needed on the global state of the troposphere and the biosphere. Since only long-term variations in the solar constant are likely to be sufficiently large to be significant to tropospheric processes, there is a need for climatologists and ecologists to define the types of atmospheric, oceanic, and biospheric data that should be assembled over periods of years to decades in order to evaluate this possible cause of terrestrial change.

2. The Solar Spectral Irradiance. The solar flux measured as a function of wavelength is important to solar physics and to the state of Earth's upper atmosphere. Solar physics needs include the following:

a. A calibration cross reference for solar physics Spacelab prime experiments that observe in the XUV.

b. A broad range coverage of the solar spectral irradiance to provide adequate boundary value data for models of the processes responsible for heating the outer solar atmosphere and for the solar activity cycle.

c. The same boundary value data for solar flares in order to establish the energy content of flares and to provide rough criteria for specifying the relative contributions of competing processes in the buildup and release of flare energy.

d. Provide real-time information on solar activity for possible control of prime solar experiments.

e. Provide correlative data to other solar physics investigations in space or on the ground, to experiments pertinent to solar-terrestrial phenomena, and to statistical studies.

Some needs for a solar spectral irradiance monitor in atmospheric sciences, aeronomy, and climatology include the following:

a. An accurate monitor of the 200 to 300 nm portion of the solar flux, which makes a significant contribution to the solar constant.

b. High-resolution (0.002 nm) occasional monitoring of the O_2 absorption band region (175 to 204 nm) for atmospheric modeling.

c. Moderate resolution (0.1 nm) monitoring of the XUV region of 0.1 to 300 nm for atmospheric modeling.

d. High time resolution (~ 1 sec) XUV monitoring (0.1 to 300 nm) for ionospheric modeling.

e. Long-term monitoring to permit evaluation of the relative roles of XUV, solar wind, solar flare protons, and galactic cosmic rays to atmospheric processes, especially processes with long time constants such as the NO_x cycle and ozone variability.

Performance requirements as a function of wavelength interval are given in Table 2.

Simultaneous measurements of the atmospheric structure and composition from the lower stratosphere to the thermosphere are needed. Planetary wave monitoring is important because changes in the thermosphere due to XUV can influence reflection coefficients of these waves.

TABLE 2. PERFORMANCE REQUIREMENTS FOR XUV MONITOR[a]

Performance Category and Wavelength Interval (nm)	Scientific Discipline				
	Aeronomy		Solar Physics		
	Normal	Flares	Solar Constant	Solar Atmosphere	Flares
Wavelength Resolution					
0.1 - 175	0.1	0.2-20	-	0.2-20	0.2-20
175 - 204 occasional	0.002	-	-	-	-
175 - 204 monitor	0.1	20	-	0.1-20	20
204 - 300	0.1	20	2	0.1-20	20
Time Resolution					
0.1 - 120	hours	<1 sec	-	hours	$\lesssim$ 1 sec
120 - 400	hours	-	hours	hours	?
Absolute Accuracy					
0.1 - 120	10-20%	10-20%	-	20%	20%
120 - 300	10%	10%	10-1%	20-2%	20%
Sensitivity[b]					
0.1 - 2	-	<0.1%FS	-	<0.1%FS	<0.1%FS
2 - 30	3%	0.1%	-	<10%	0.1%
30 - 120	3%	0.1%	-	<10%	0.1%
120 - 160	2%	<0.1%	-	<5%	<0.1%
160 - 200	2%	?	-	1%	?
200 - 300	1%	?	$\lesssim$ 1%	<1%	?

[a] Estimated in part from "The Solar Output and Its Variations," edited by O. R. White

[b] Fraction of full scale (FS) for 0.1 - 2 nm because of large dynamic range; otherwise, fraction of average level

XUV monitor instruments are being developed for Spacelab 2, and others have been conceived as low-cost, simple Shuttle experiments. The PM/O makes them more effective by the longer observation time.

3. Variations of Atmospheric Aerosols and Gaseous Materials. This investigation overlaps the roles of natural and man-made influences on weather and climate.

The radiative characteristics of the Earth-atmosphere system can be changed in response to the input of aerosol and gaseous materials into the troposphere and stratosphere. Sources of these materials include volcanic emissions, wind-blown dust, and man-made pollutants. Changes in the integrated albedo of the Earth, its spatial variation, and the radiative heating of the atmospheric column will feed back into the dynamics and thermodynamics of atmospheric circulation. An example of this process would be the effect of a dust layer in the lower atmosphere. A thick dust layer in mid-latitudes would radiate heat more effectively to space than in the tropics, thereby reducing the horizontal temperature gradient at that level and causing a reduction in strength of the subtropical jet.

Aerosols influence the weather through the concentration of cloud condensation nuclei and ice nuclei. An aerosol increase can act to increase drop and ice condensation, causing reduced fall velocities and increased competition for water vapor with subsequent decrease in rainfall, but an increase in nonprecipitating cloud cover. Aerosols can also act to decrease the tropospheric electrical conductivity which may cause changes in the upper atmosphere and in thunderstorm development. A PM/O using an appropriate monitoring device could permit selective sampling of materials localized in the atmosphere and diagnosis of changes in atmospheric processes due to their presence. Monitoring of wind, temperature, and moisture distributions over the globe would permit evaluation of changes caused by input of these materials, including man-made inputs.

Some instruments already exist, and others are included among the needs of atmospheric sciences.

4. Atmospheric Electrical Sun-Weather Mechanism. This investigation has the most explicit scenario developed for a Sun-weather interaction mechanism. The idea is that solar activity will modulate the conductivity of the Earth's upper atmosphere, which is coupled to the troposphere via thunderstorms. An explicit model for the electrical circuit has been proposed. There are two main objectives of the investigation. One is to evaluate the electrical

circuit model quantitatively. The other is to determine what physical processes in the atmosphere are most sensitive to the changes in electrical conductivity and how these processes couple to other processes to affect weather. It should be noted that this mechanism of variable electrification is applicable to both short-term (weather) and long-term (climate) Sun-weather relations.

Measurements to be made from a space station include:

a. Global Distribution of Lightning. The spatial and temporal variations of lightning can serve as an index of cloud electrification. A wide-field Hα telescope with CCD detector could be developed from standard components.

b. Global Distribution of Water Vapor and Liquid Water. The spatial and temporal variations can serve as an index of atmospheric energy variations. Microwave systems developed for atmospheric sciences would serve this purpose.

c. Global Distribution of Clouds. The distribution of cloud tops and shapes (especially deep cumulus) can serve as an index of convection. Visible and infrared imaging systems for atmospheric sciences will suffice.

d. Global Distribution of Ionizing Radiation. This will permit calculation of atmospheric conductivity once a procedure is set up to adjust such calculations to agree with direct measurements of conductivity. Measurements of XUV radiation require only a solar XUV monitor. However, the ionizing particle radiation has a complicated spatial and temporal variation that requires in situ measurements. Some thought will be needed on how best to obtain these measurements in an affordable way. Instruments from magnetospheric physics, aeronomy, and geomagnetism will be needed together with ground-based instruments.

Correlative measurements needed from balloons include:

a. Vertical electric field from surface to apogee — the integration of this field and the addition of a small estimator term provide the ionospheric electric potential.

b. Stratospheric conductivity — measured with a Gerdien tube.

c. Stratospheric ion production rate — direct measurements of the degree of ionization and ionizing radiation itself are needed in conjunction with the preceding item (d) on the global distribution of ionizing radiation.

These three measurements should be made during the same flight (sounding). Soundings should be made at least once a day for a relatively long time (approximately 1 year) at the same time of day. After solar flares or across the time span of solar sector crossings, soundings should be made more often to relate observed variations to specific solar (protons) or atmospheric (X-rays) radiation. For this purpose the sounding data would be correlated with solar optical measurements (possibly from the same space station) and radiation measurements from unmanned free flyers. The purpose of the balloon measurements would be (1) to determine whether the ionospheric potential (a measure of integrated global thunderstorm activity) changes as a function of solar activity and (2) to observe conductivity variations caused by solar-modulated changes in stratospheric ionization.

With the preceding measurements, it would be possible to answer the following questions central to the proposed atmospheric electrical mechanism:

a. Do significant conductivity variations occur in the lower stratosphere in thunderstorm regions?

b. Which particles cause these conductivity changes — modulation of galactic cosmic rays, solar protons, magnetospheric dumping, or auroral X-rays?

c. Does the ionospheric potential change in relation to solar flares or solar sector crossings (solar variability)?

d. Does lightning activity change in relation to solar variability?

e. Does cloud convection change in relation to solar variability?

f. Is there a variation in water vapor/liquid water distribution(s) related to solar variability?

g. Does ionospheric potential change in direct correlation with worldwide thunderstorm activity (this would be the first direct test of the "global circuit" hypothesis)? This circuit is fundamental to the proposed mechanisms.

h. Which convective clouds are electrified and when? For example, are equatorial towering cumulus electrified? Are North Atlantic and North Pacific convective clouds electrified? Are the latter more electrified in winter than in summer?

The ability of on-board observers to pick clouds of interest and focus their instrumentation on the same clouds would be of great value. The initial measurements might be a pilot program to develop instrumentation and observing procedures (e.g., define the best way to measure lightning and most appropriate spatial resolution) for later, more extended measurements.

RESOLUTION

The following resolution was adopted by the participants in the Workshop:

> The availability of a 25 kW Power Module in low Earth orbit has been found to be of great potential benefit to all disciplines involved in a Solar-Terrestrial Observatory (STO). While some individual experiments can make very good use of the extra power available above the nominal Orbiter capability, the most important advantage to all groups is the opportunity for extended flight durations of manned operation for 2 months, and for longer durations (years) in the free-flying mode. Most STO experiment objectives cannot be accomplished well in brief flight opportunities of only a week or so, and the Power Module would greatly increase flight productivity and success probability. We, therefore, strongly recommend that NASA encourage the early development of this capability with flight scheduled for as early as possible, and no later than early 1983, which would permit its use for the latter half of the middle atmosphere program. The preferred orbit for the Power Module would have an inclination of 55°.

APPENDIX A

AGENDA

GUNTERSVILLE WORKSHOP ON SOLAR-TERRESTRIAL STUDIES

October 11-13, 1977

<u>October 11</u>

9:00 a.m.	Opening of Workshop:
	- Dr. Banks, Utah State University, Workshop Chairman - Dean Hoomani, University of Alabama in Huntsville
	Discussion of Agenda - Dr. Banks
	Remarks from NASA Headquarters
	- Dr. Taylor, Space Sciences Directorate - Dr. Huber, Space Flights Directorate
	The European Connection - ESA Representative, Dr. Durney
10:00 a.m.	Coffee Break
	Plenary Session:
10:15 a.m.	25 kW Power Module - Mr. Huber
11:30 a.m.	OFT Experiments - Dr. R. Smith, OFT-2
11:50 a.m.	Spacelab 1 Experiments - Dr. Chappell
12:10 p.m.	Spacelab 2 Experiments - Dr. Urban
12:30 p.m.	Lunch
2:00 p.m.	Group Meetings:
	Requirements for evolutionary steps to the Solar-Terrestrial Observatory (e.g., Spacelab instruments, Power Module, habitability, etc.)
6:30 p.m.	Social Hour

AGENDA (Concluded)

October 12

9:00 a.m.	Plenary Session
	Joint Observational Programs (JOP's). The Skylab Experience Dr. Sheeley, NRL
10:30 a.m.	Coffee Break
10:50 a.m.	Solar-Terrestrial Problems — Discussion of Scenarios Introduction - Dr. Johnson
12:30 p.m.	Lunch
2:00 p.m.	Group Meetings
	JOP's for Solar-Terrestrial Observatory
6:30 p.m.	Social Hour

October 13

9:00 a.m.	Plenary Session
	Summaries:
	- Requirements for Evolutionary Steps to the Solar-Terrestrial Observatory
	- JOP's for Solar-Terrestrial Observatory
12:00 a.m.	Adjournment

APPENDIX B

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APPENDIX C

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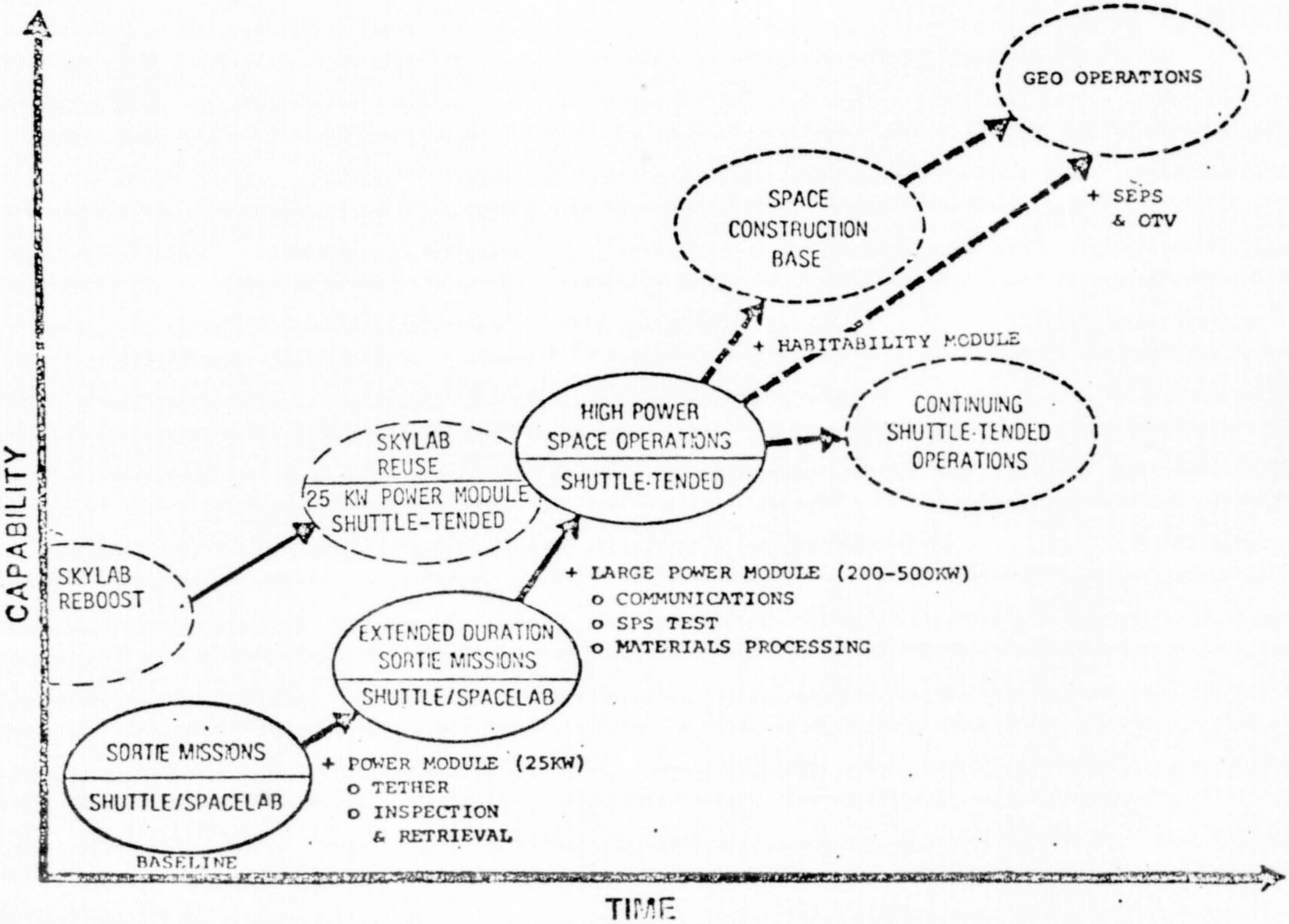
25 kW POWER MODULE

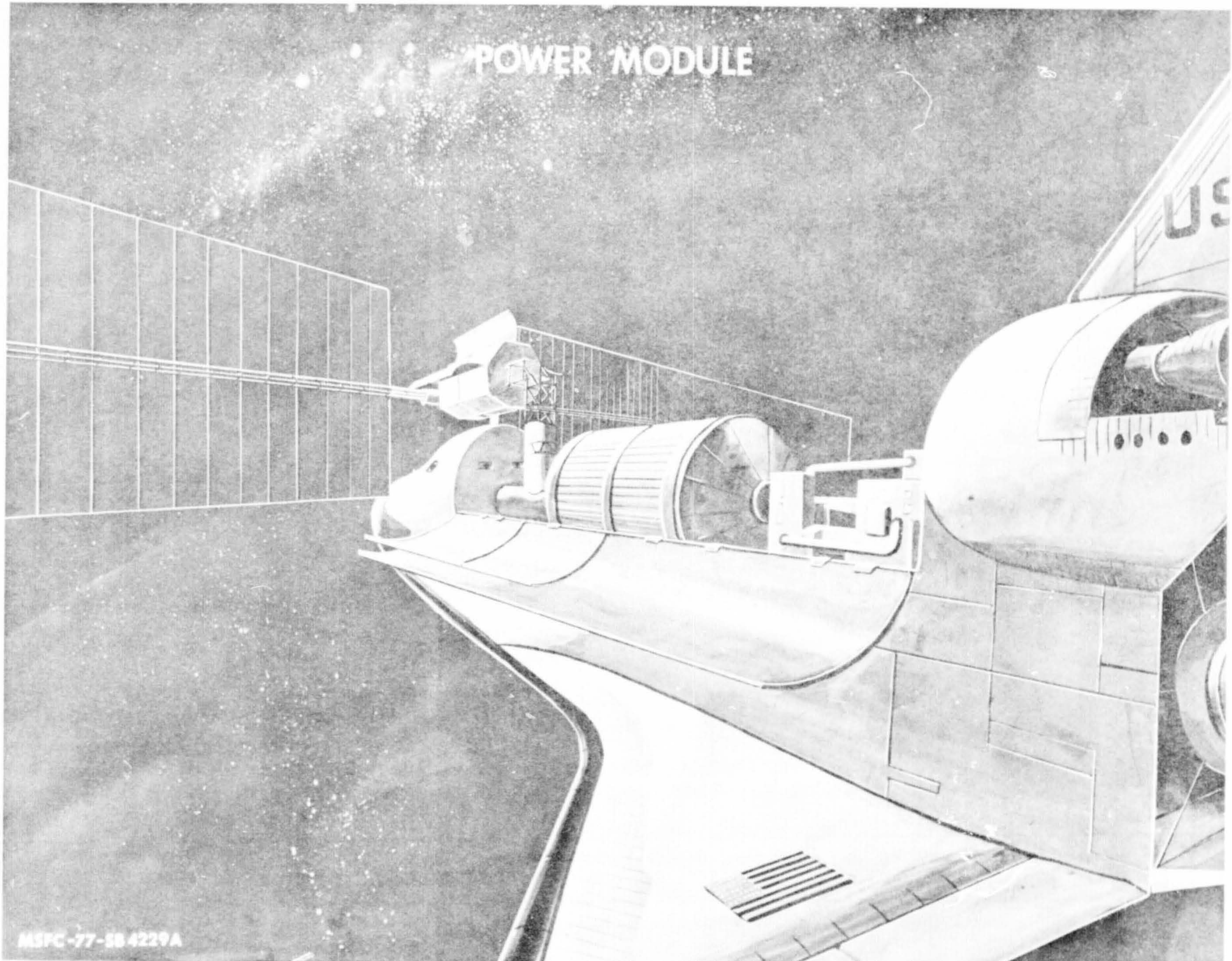
Briefing to
Guntersville Workshop on Solar-Terrestrial Studies

October 11-13, 1977

W. Huber
PF10/MSFC

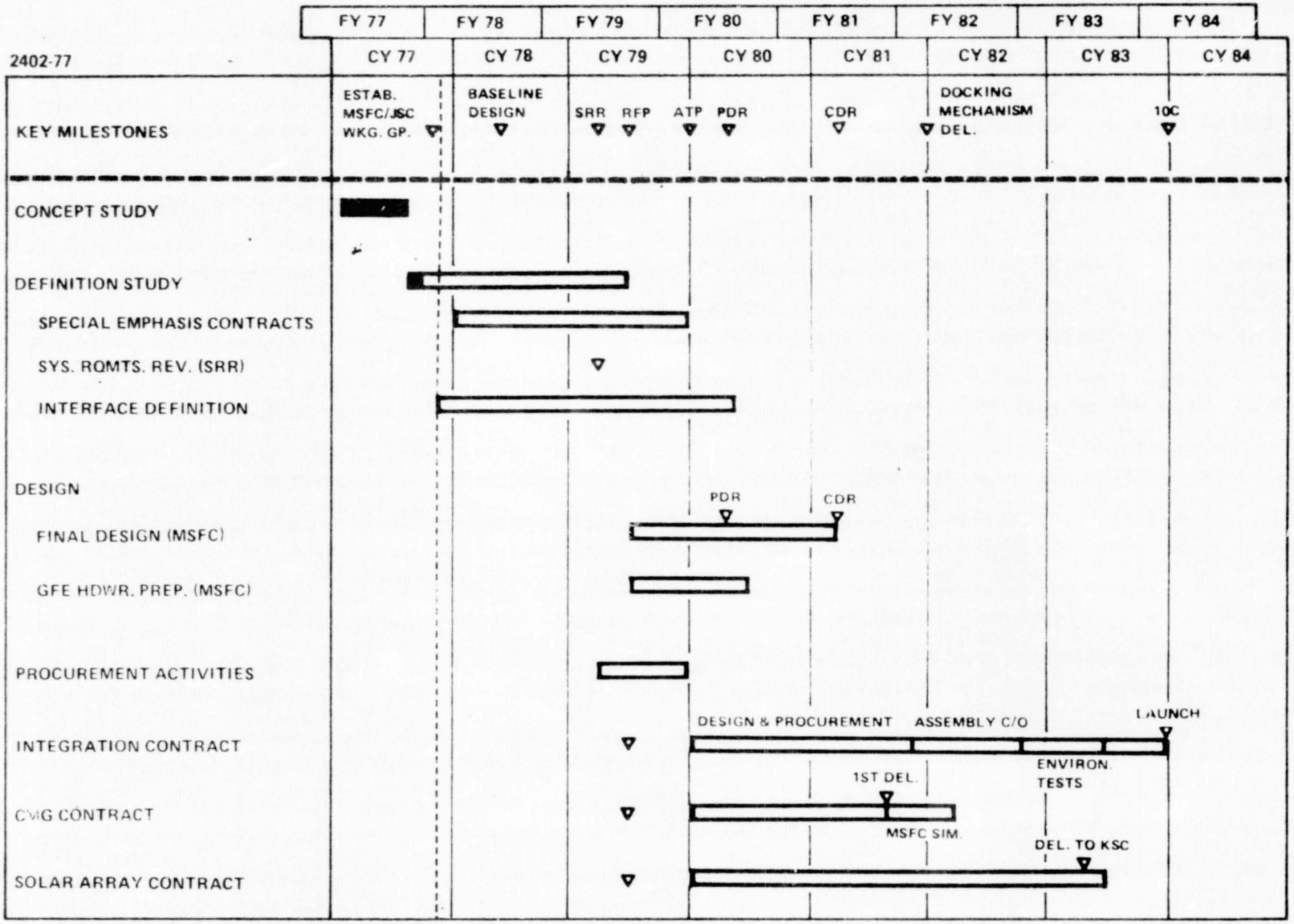
STS EVOLUTION




POWER MODULE
US
MSFC-77-SB 4229A

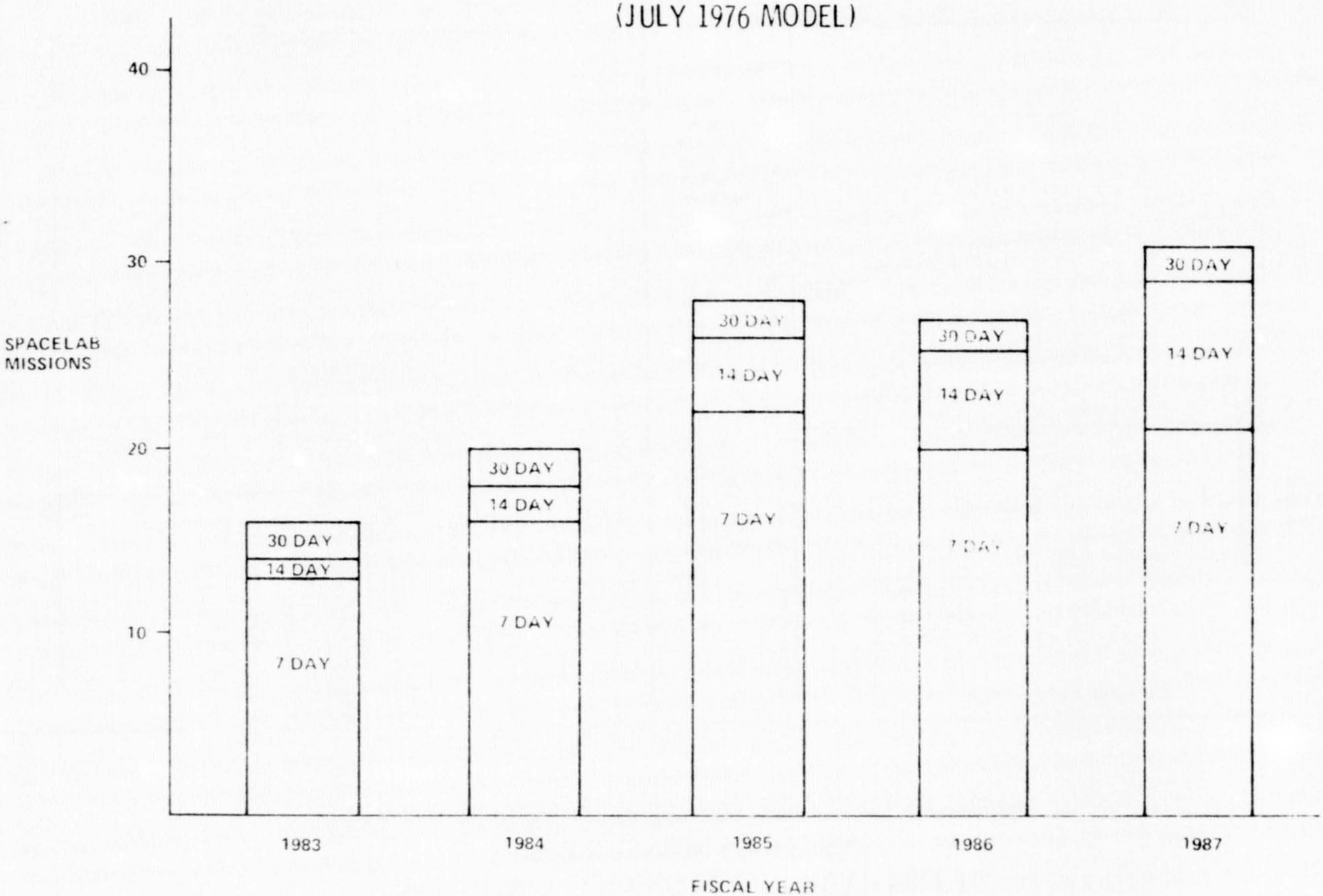
25 kW POWER MODULE PROJECT SCHEDULE

OCT 20, 1977

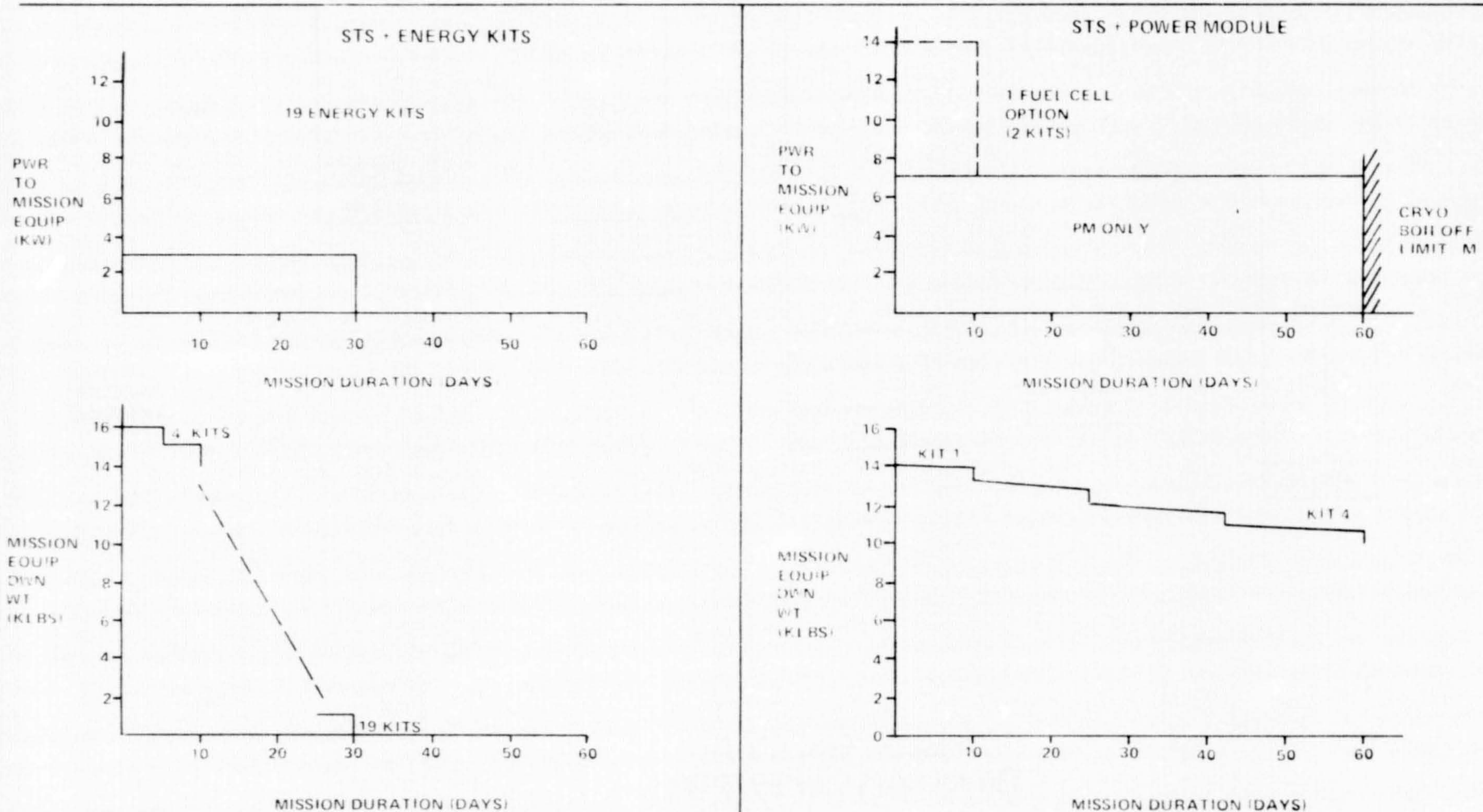


1891–77

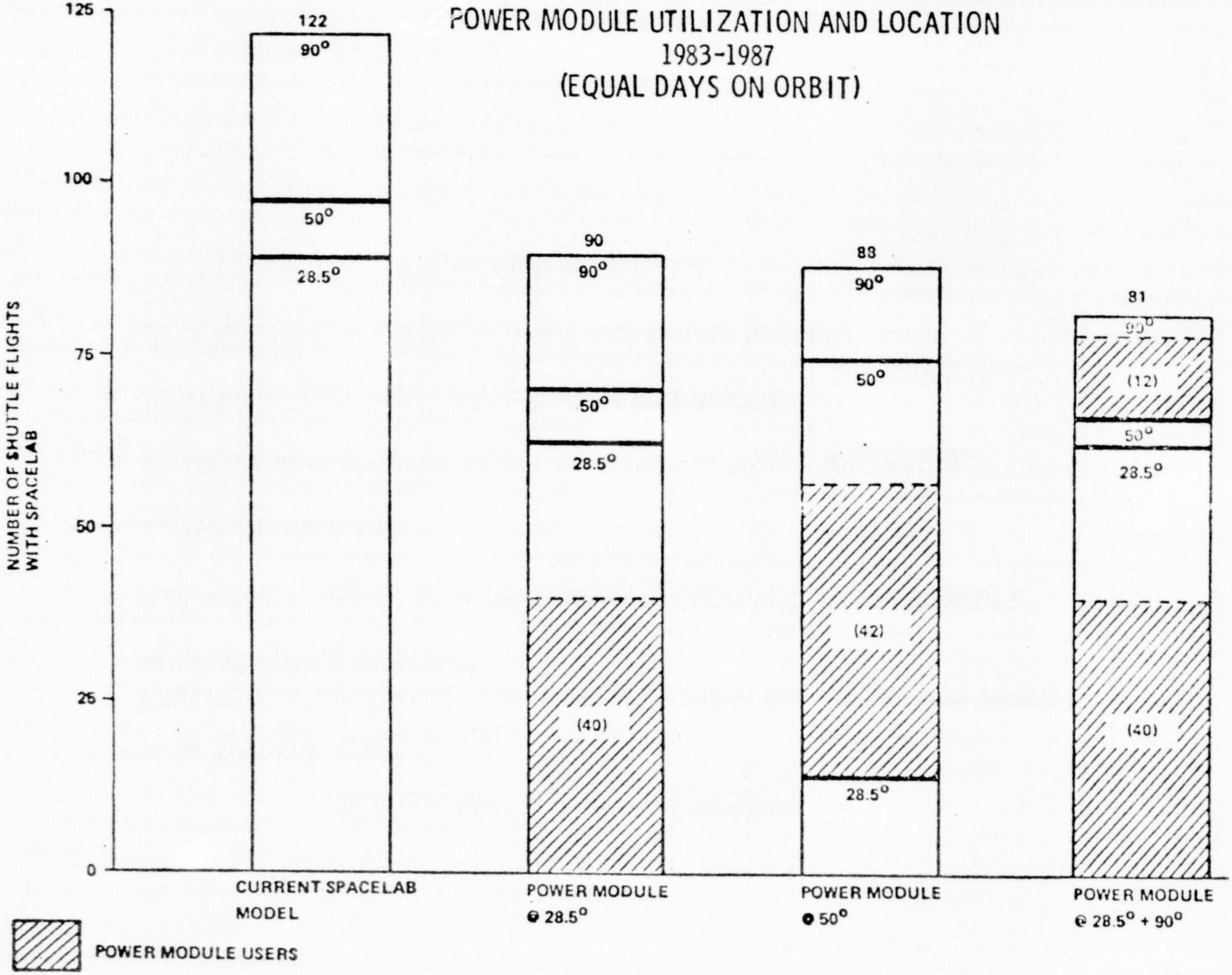
SPACELAB MISSION MODEL
(JULY 1976 MODEL)



STS
POWER AND LANDING WEIGHT AVAILABLE TO USER MISSION EQUIPMENT (4 KW & 16 KLBS ALLOWED FOR SPACELAB SYSTEMS)



1834–77


POWER MODULE UTILIZATION AND LOCATION
1983-1987
(EQUAL DAYS ON ORBIT)
NUMBER OF SHUTTLE FLIGHTS WITH SPACELAB
125
100
75
50
25
0
122
90°
50°
28.5°
90
90°
50°
28.5°
(40)
88
90°
50°
(42)
28.5°
81
90°
(12)
50°
28.5°
(40)
CURRENT SPACELAB MODEL
POWER MODULE @ 28.5°
POWER MODULE @ 50°
POWER MODULE @ 28.5° + 90°
POWER MODULE USERS

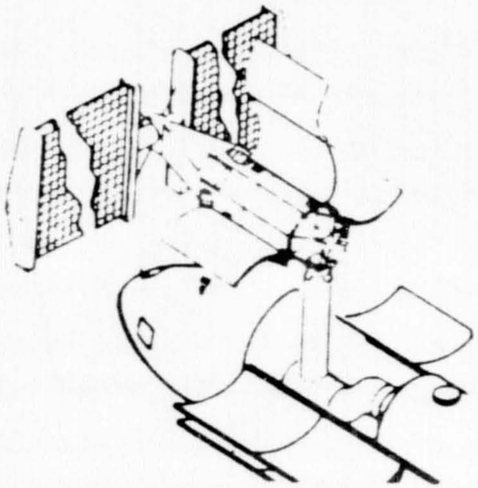
1741-77

POWER MODULE DESIGN REQUIREMENTS

- 25 kW AVERAGE POWER OUTPUT.
- PROVIDE STABILITIZATION AND MANEUVERS FOR POWER MODULE AND POWER MODULE/ORBITER ASSEMBLY.
- ELECTRICAL POWER TO BE COMPATIBLE WITH ORBITER BUS REQUIREMENTS.
- DESIGN TO LOW COST.
- MAXIMUM COST EFFECTIVE USE OF EXISTING HARDWARE AND DESIGN.
- EQUIPT. ACCESSIBILITY FOR ON-ORBIT MAINTENANCE
- DESIGN FOR STS DELIVERY TO ORBIT AND RETURN TO EARTH
- USE STANDARD ORBITER DOCKING MECHANISM

BASELINE POWER MODULE PRIMARY OPERATIONAL MODES

SORTIE SUPPORT MODE
(PM ORBITER PAYLOAD)



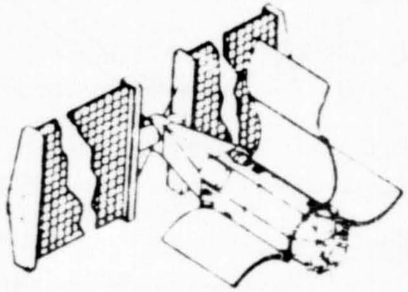
PM PROVIDES

- POWER (25 KW)
- ATTITUDE CONTROL
- PM USER HEAT REJ.

ORBITER PROVIDES

- ORB USER HEAT REJECTION
- RF COMM. TO GND
- ALTITUDE REBOOST
- SUPPLEMENTARY EMERGENCY POWER & ATT. CONTROL IF REQ'D.

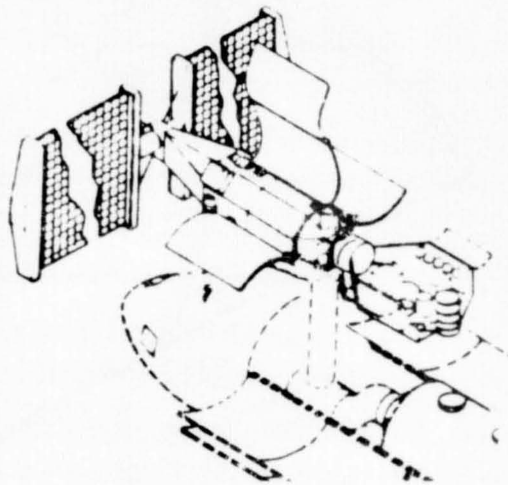
ORBITAL STORAGE MODE
(PM ONLY)



PM PROVIDES

- POWER (ARRAYS RETRACTED TO ~12.5% LENGTH)
- ATTITUDE CONTROL
- RF COMM. TO GND
- HEAT REJECTION

FREE FLYING MODE
(PM FF PAYLOAD)



PM PROVIDES

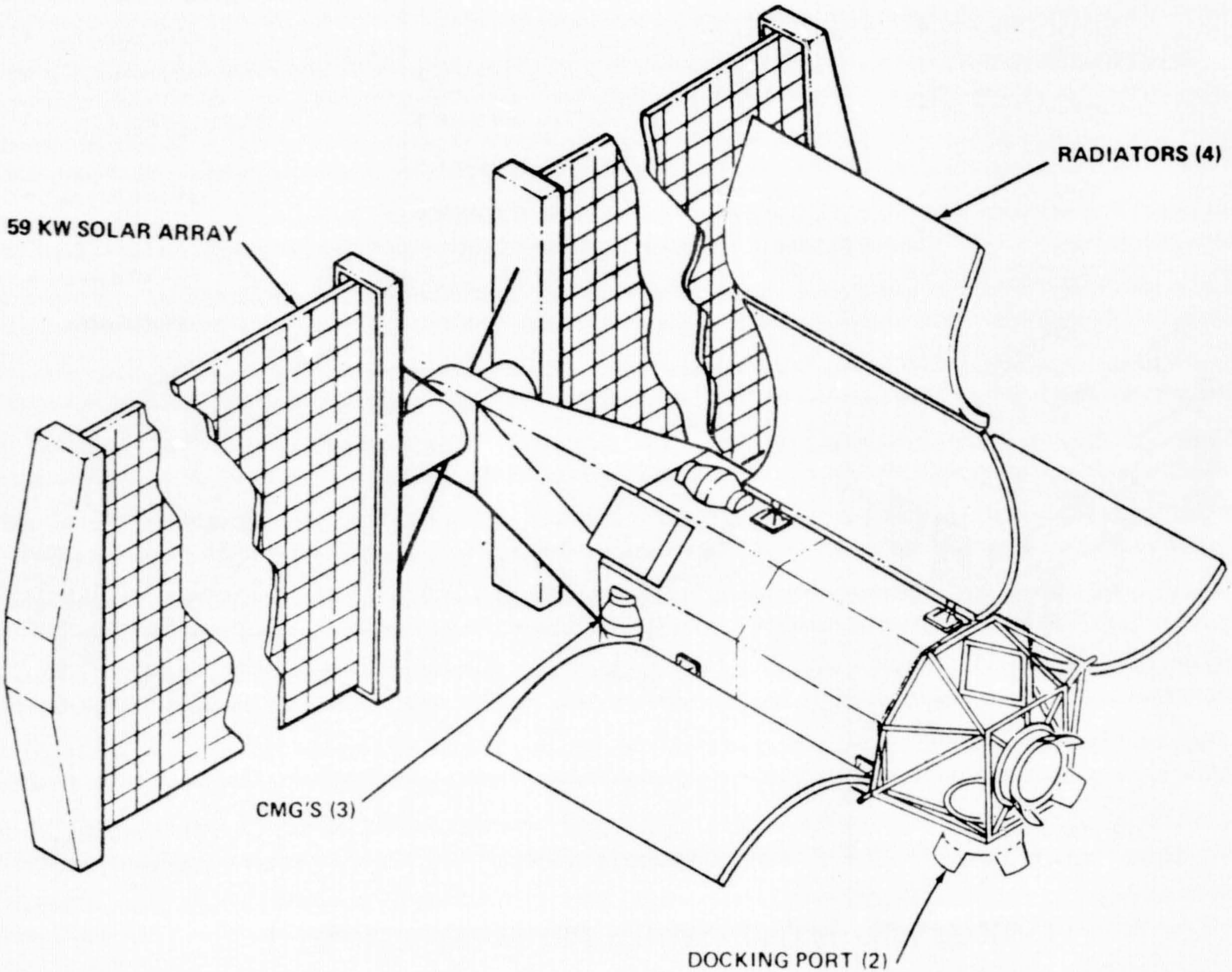
- POWER
- ATTITUDE CONT.
- PM USER HEAT REJ.
- COMM & DATA MGT

FF PAYLOAD PROVIDES

- MISSION CONTROL
- MISSION COMM. & DATA MGT

PD463-77C

BASELINE POWER MODULE



POWER MODULE CONFIGURATION

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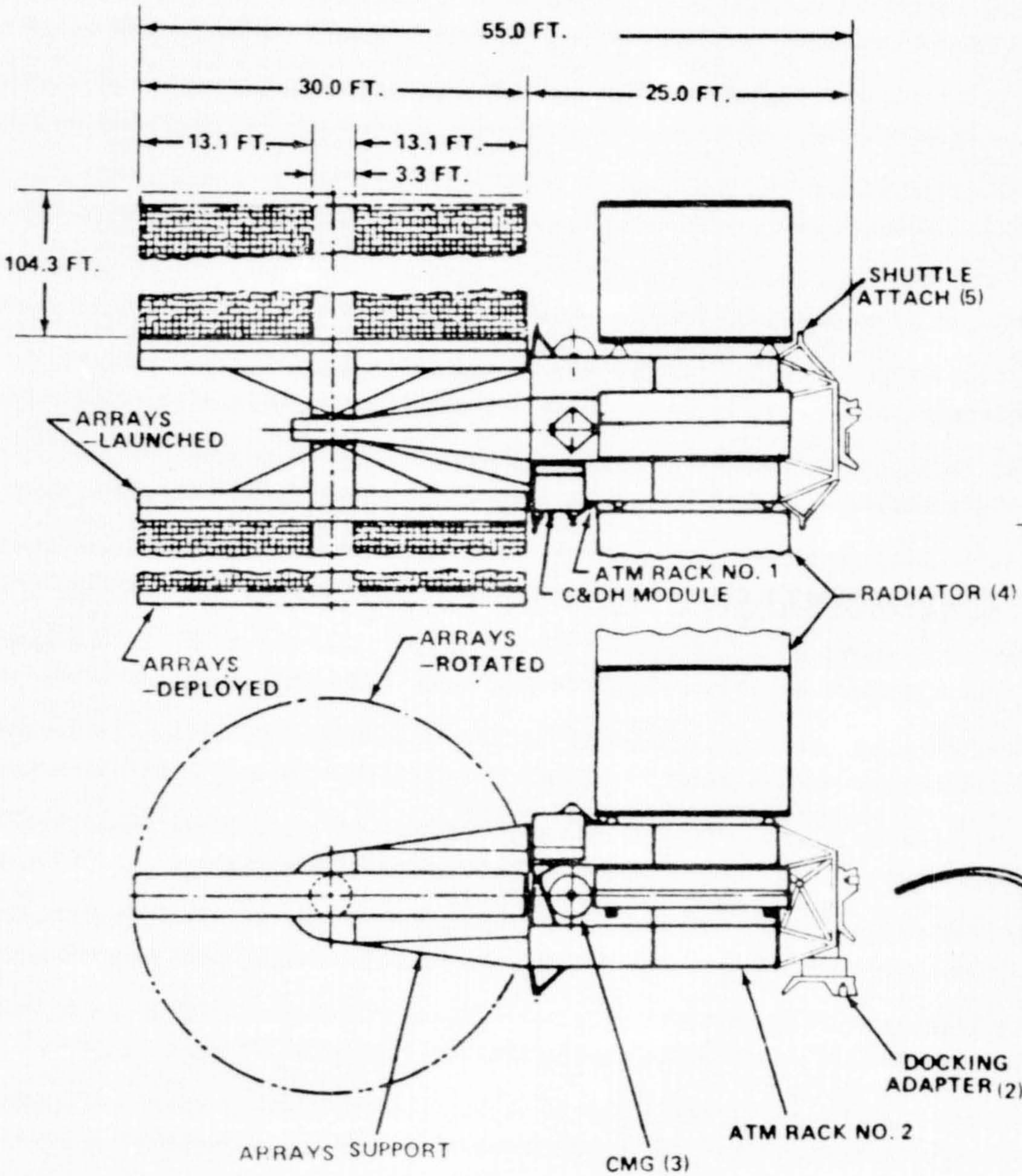
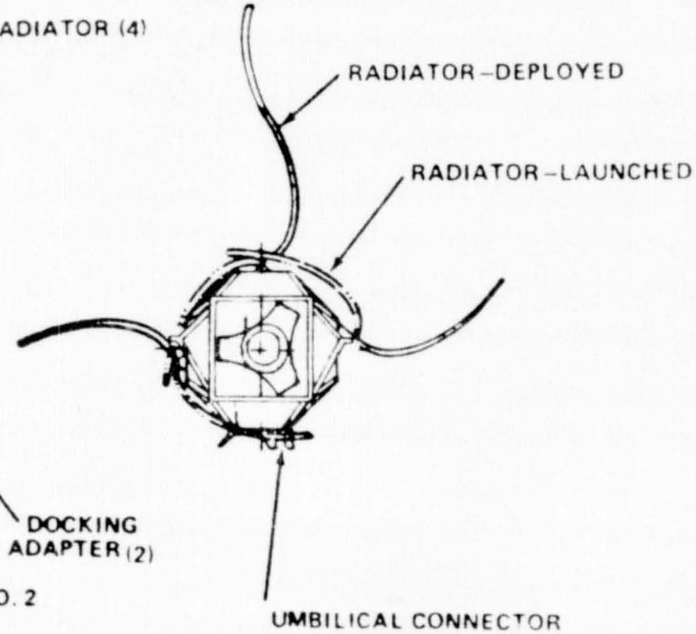


POWER MODULE WEIGHTS

	WEIGHT (LB)
ATM RACK STRUCTURE (2)	3906
SUPPORT AND DOCKING STRUCT.	3160
RADIATORS (4)	747
OTHER THERMAL CONTROL	776
SOLAR ARRAYS	2228
OTHER ELECT. POWER	15994
ATTITUDE STAB. AND CONTROL	1855
COMM. AND DATA	474
CREW SYSTEMS	60
CONTINGENCY (10%)	2684
TOTAL	31884



SYSTEMS PERFORMANCE

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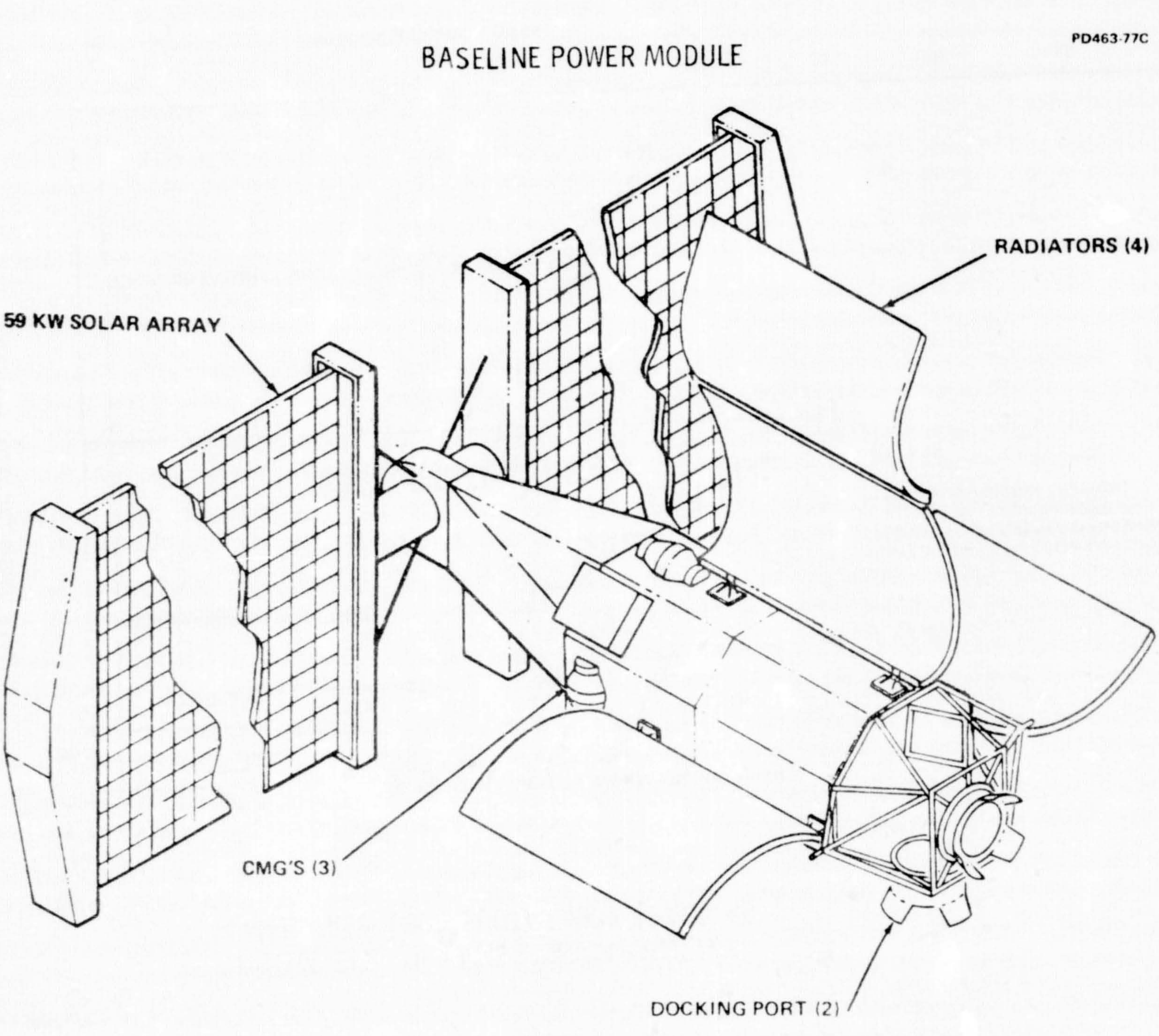
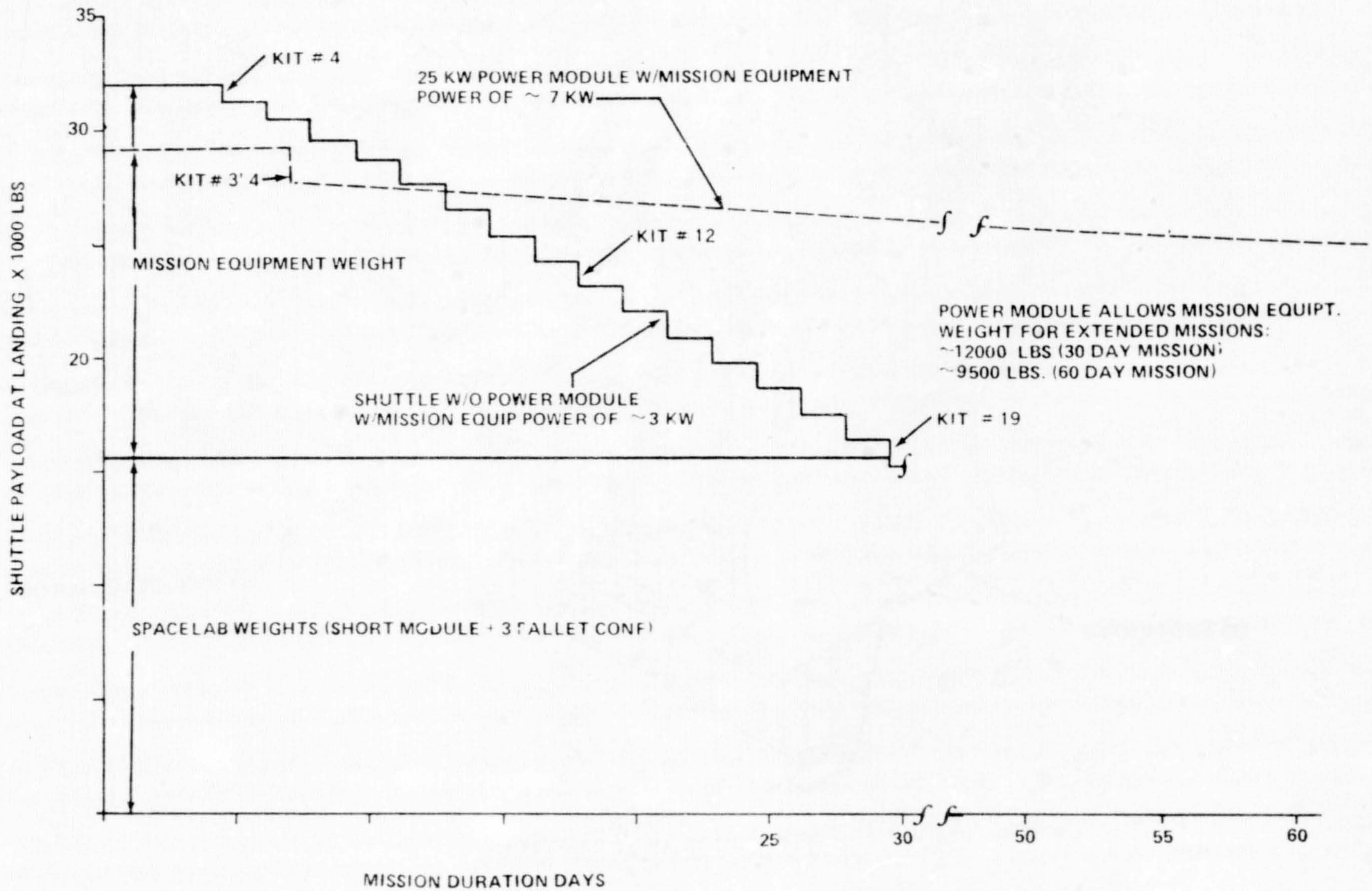
BASELINE POWER MODULE



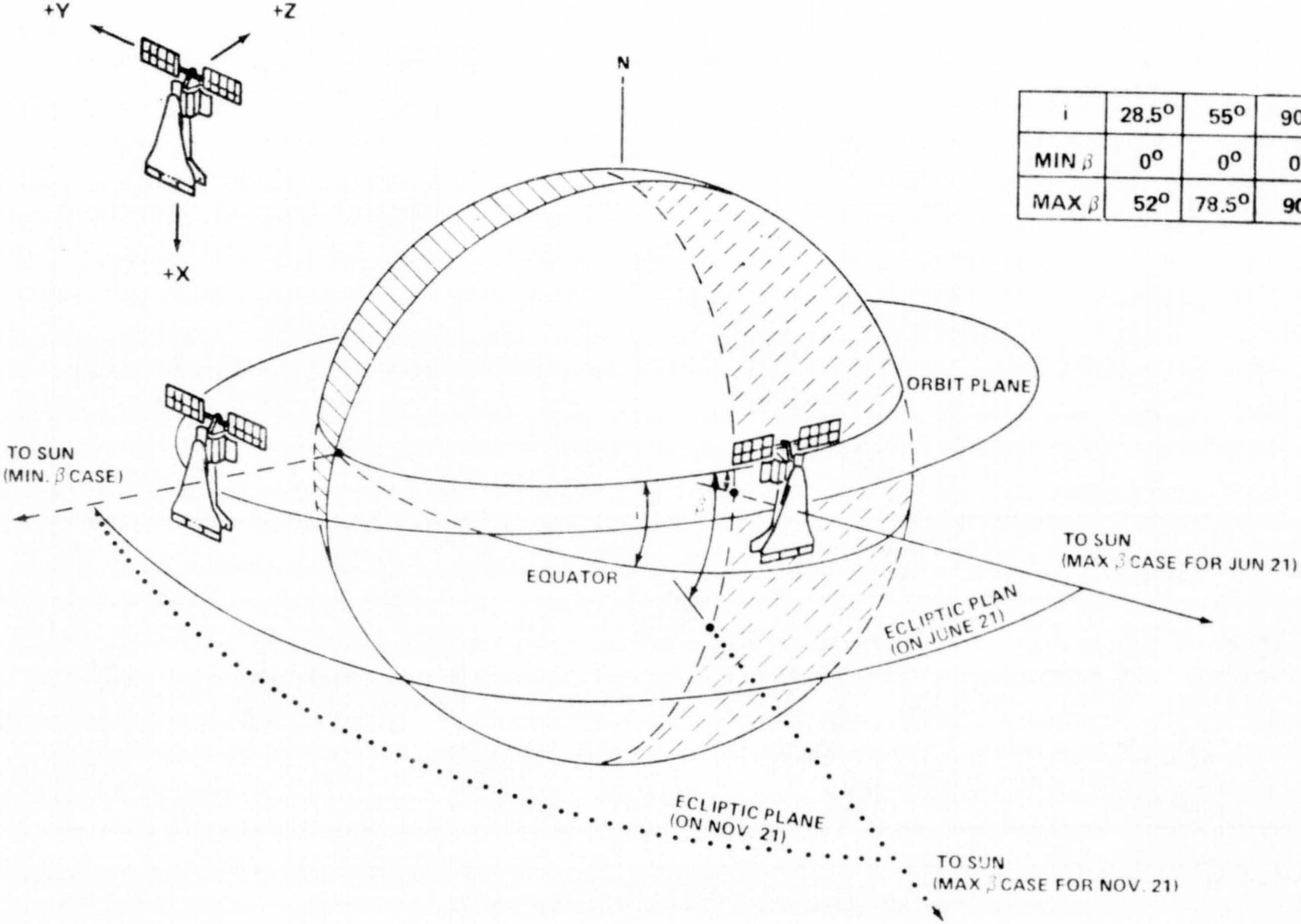
SHUTTLE EXTENDED MISSION CAPABILITY
4 MAN CREW 14KW SHUTTLE 4KW SPACELAB



PD303-77C

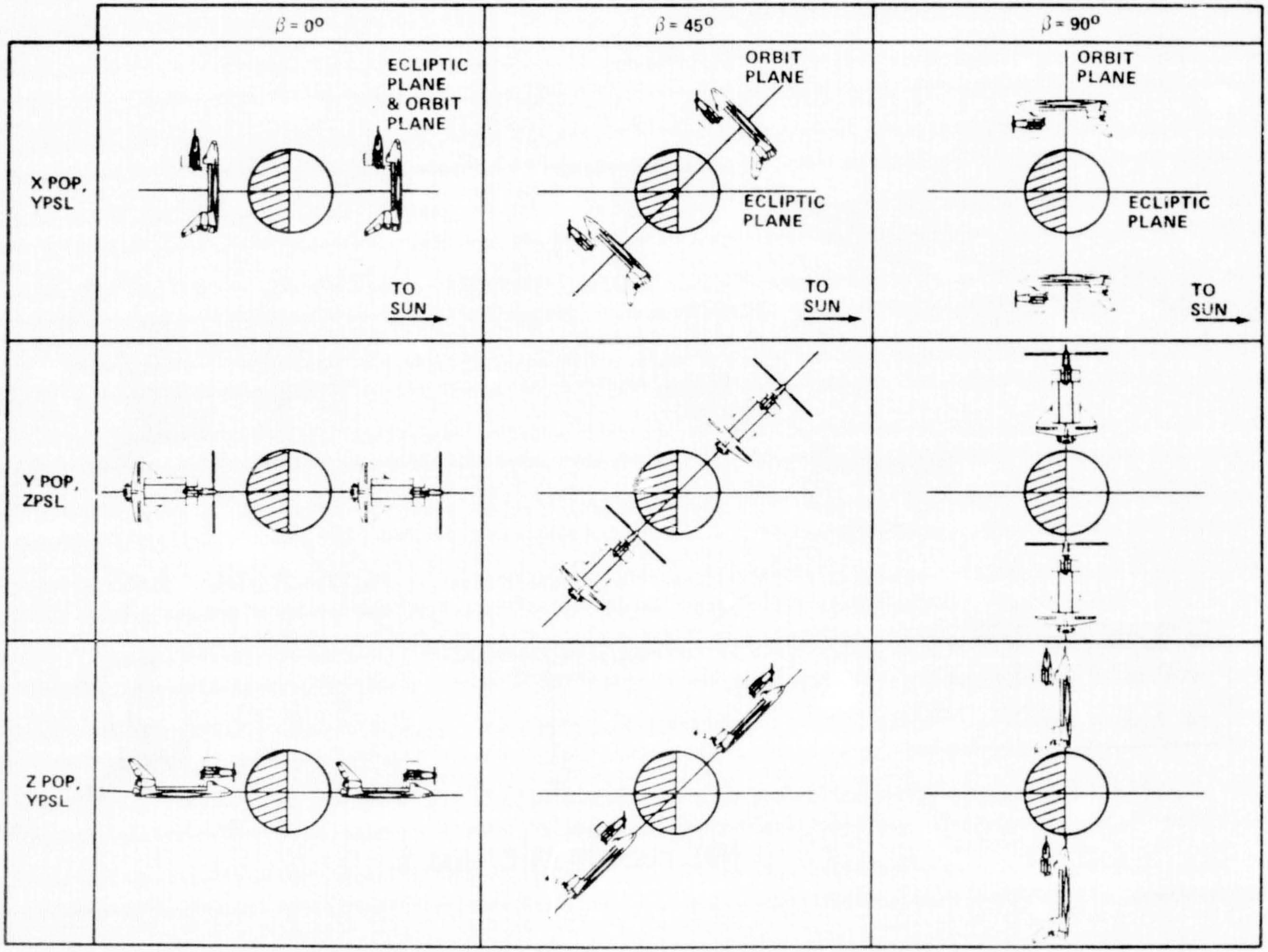
X-POP, Z-LV ORIENTATION

i	28.5°	55°	90°
MIN β	0°	0°	0°
MAX β	52°	78.5°	90°



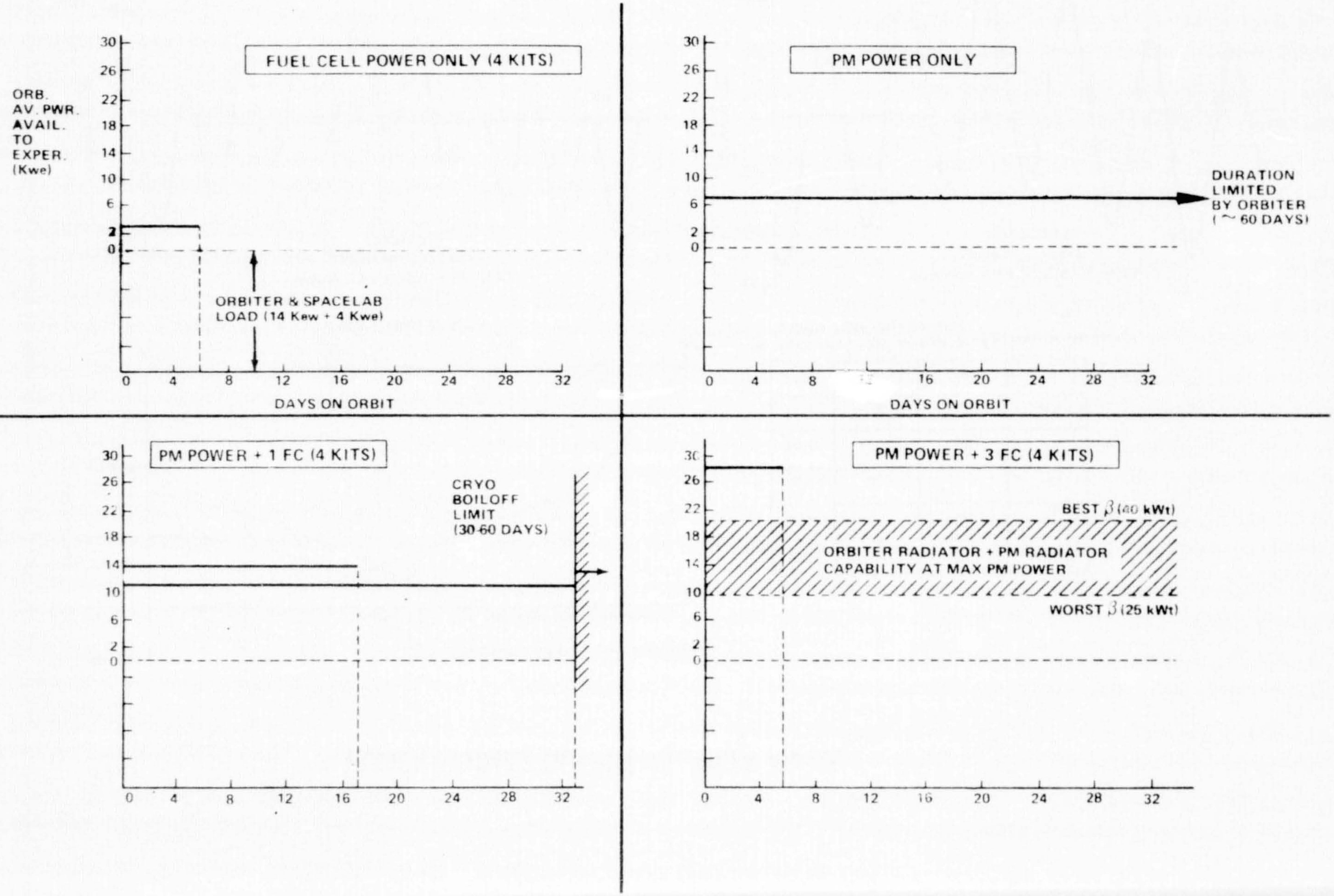
POWER MODULE/ORBITER ORIENTATIONS

PD308-77C



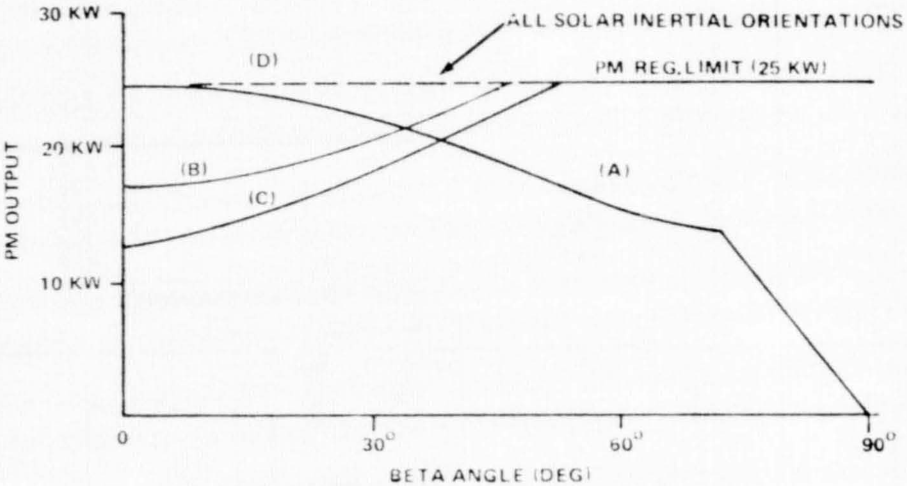
PD326-77C

POWER MODULE/ORBITER AVAILABLE POWER VS. MISSION DURATION



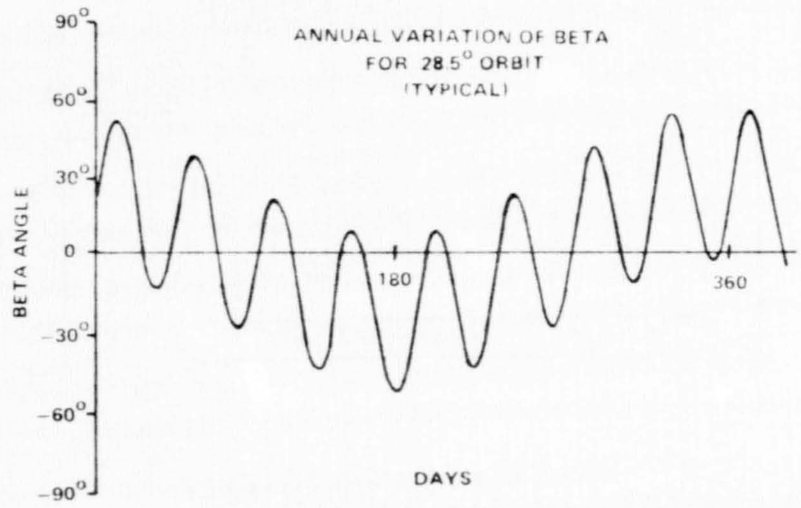
1774–77

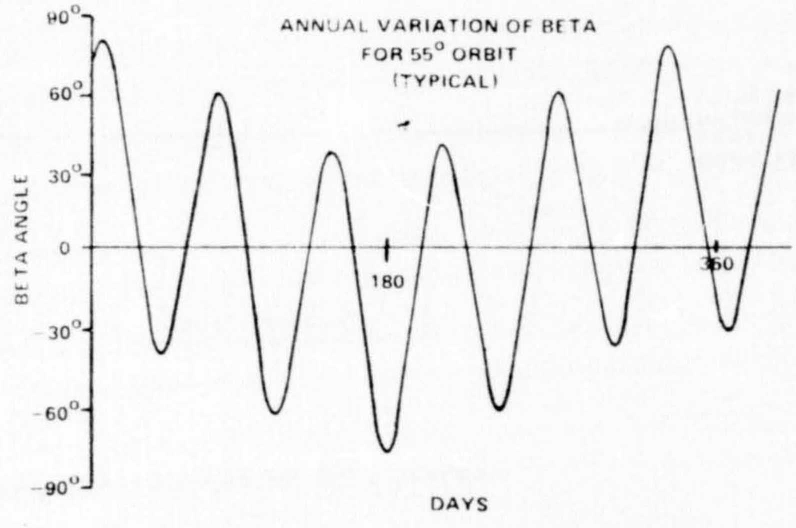
POWER MODULE OUTPUT VS. BETA ANGLE



ATT	X POP	Y POP	Z POP
XLV		A	C
* YLV	B		B
ZLV	C	A	
YPSL	D		D
ZPSL		A	

* REQUIRES 180° ARRAY ROTATION IN FAIRLY SHORT TIME ON SUN SIDE



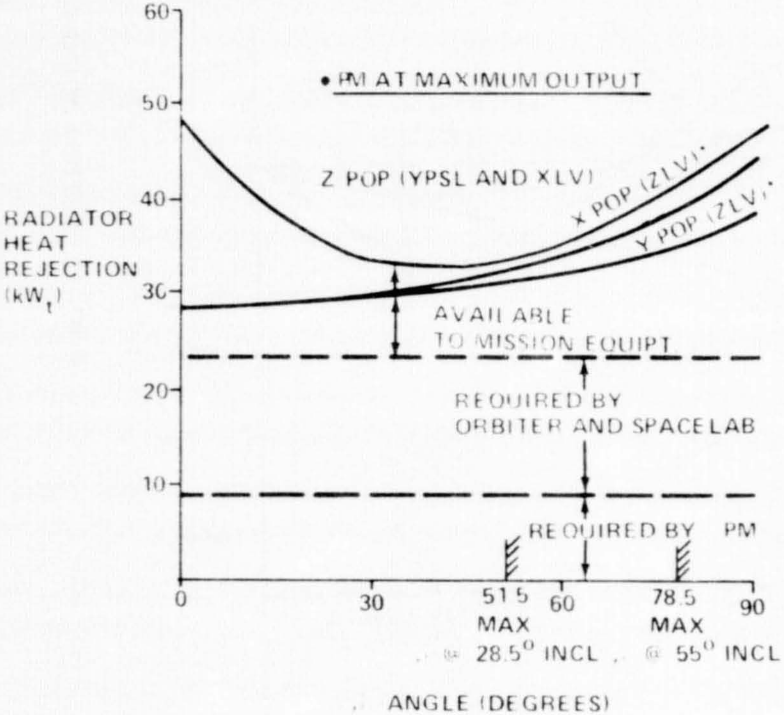


2565-77

POWER MODULE/ORBITER HEAT REJECTION CAPABILITY

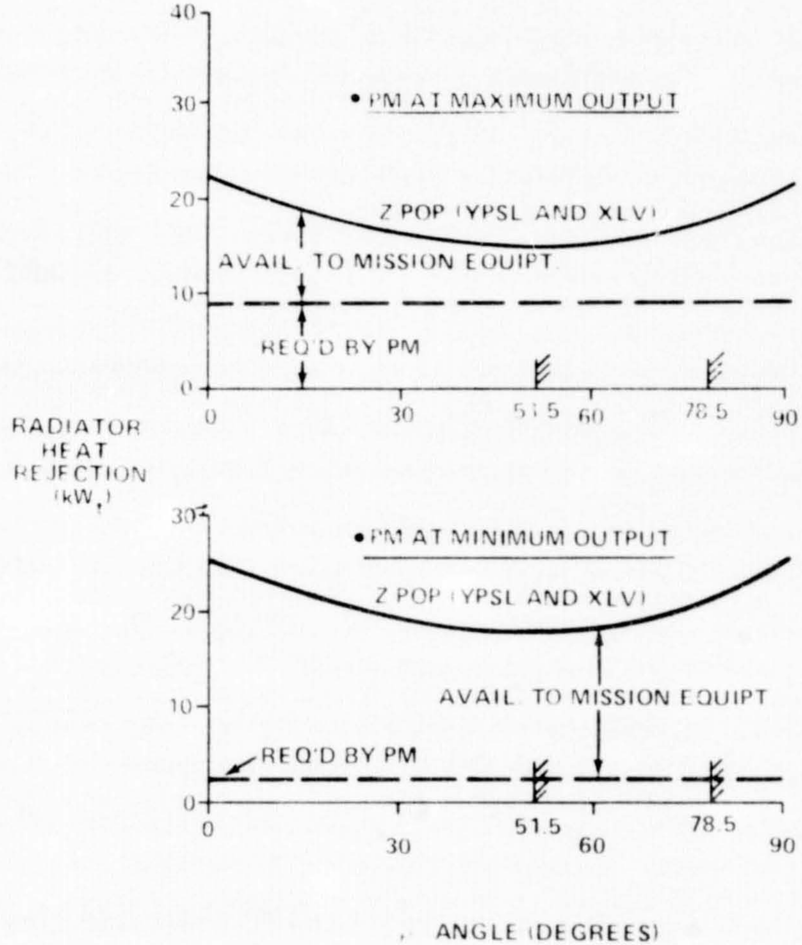
- 40°F FREON RADIATOR OUTLET TEMP
- 270 N MI

SORTIE MODE



*ASSUMED THAT PERFORMANCE IN X POP (YPSL) AND Y POP (ZPSL) ORIENTATIONS WERE SIMILAR TO THESE

FREE-FLYER MODE



2568-77

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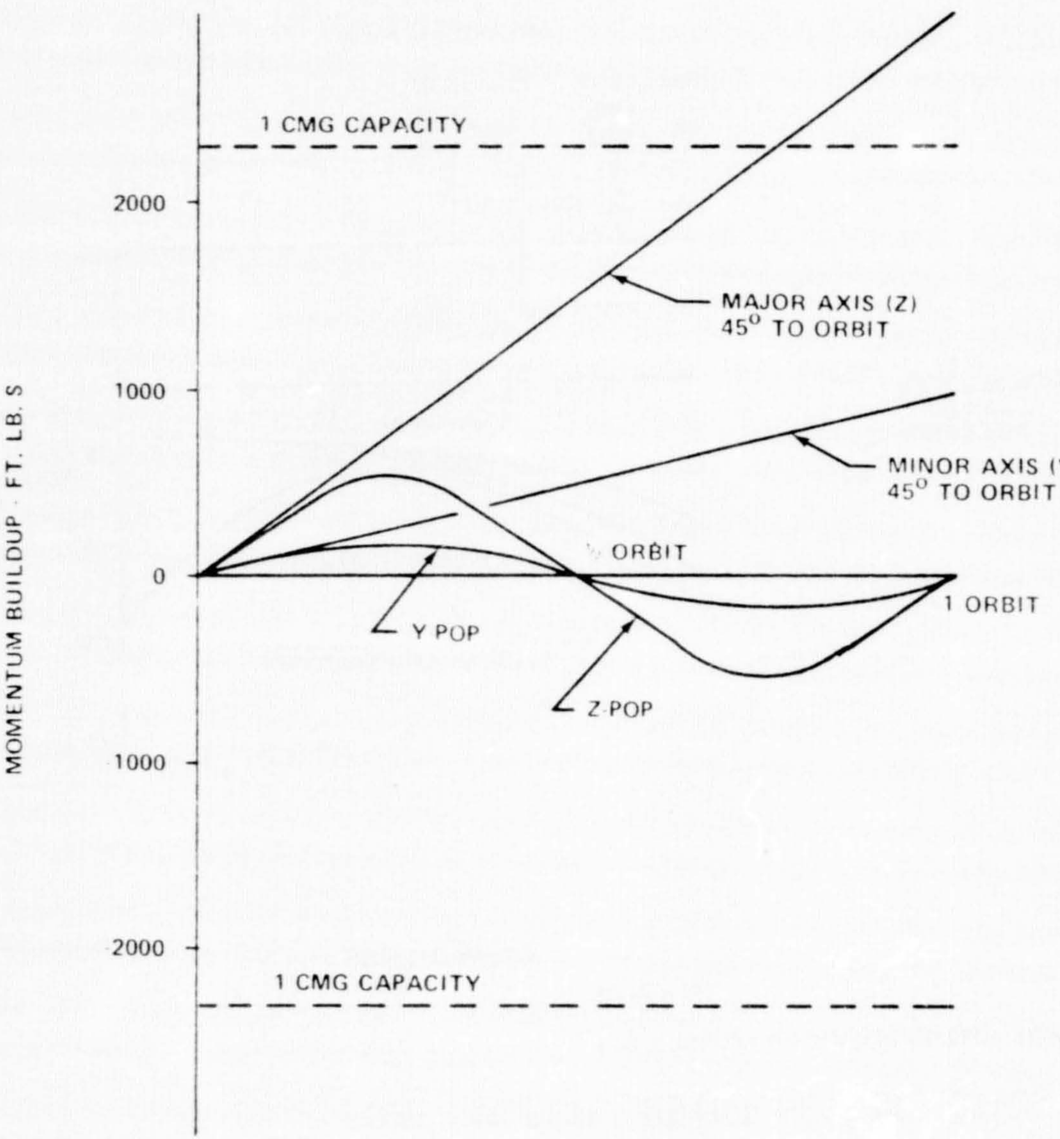
TYPICAL MOMENTUM BUILDUP ON POWER MODULE WITH FREE-FLYER PAYLOAD

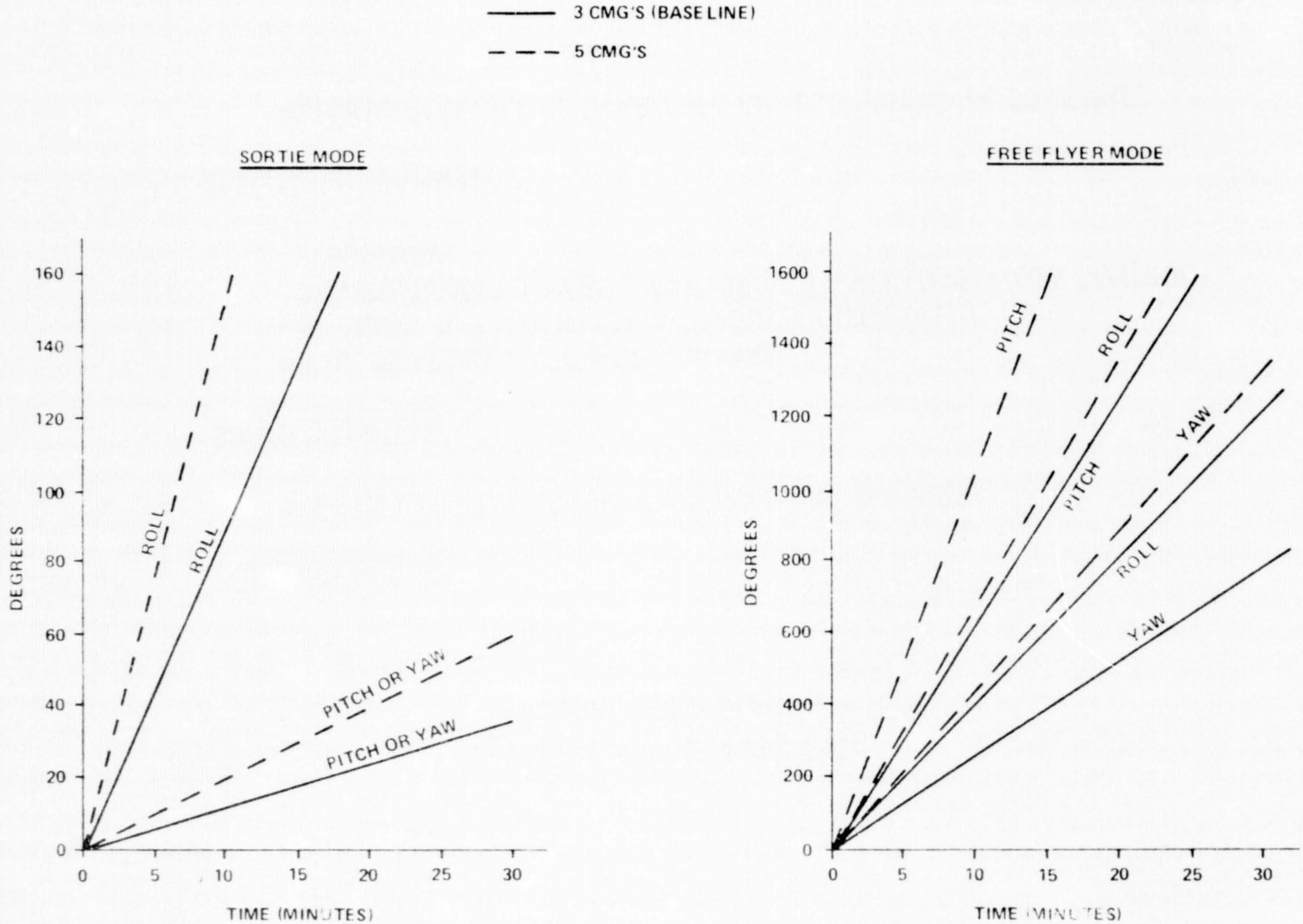


NOTES:

- X-POP PERFORMANCE LIES BETWEEN Y-POP AND Z-POP
- ALL LOCAL VERTICAL ORIENTATIONS ARE NEAR ZERO

2511-77

FM MAXIMUM MANEUVER CAPABILITY



2569-77

POWER MODULE POINTING ACCURACY AND STABILITY

POINTING ACCURACY

- DEPENDS ON THE ACCURACY OF PAYLOAD SENSORS.

SORTIE STABILITY

- WILL BE ABOUT 1 ARC MIN COMPARED TO ABOUT 10 ARC MIN FOR A THRUSTER CONTROLLED SHUTTLE (LIMITED BY MAN MOTION AND A RELATIVELY LOW CONTROL FREQUENCY)

FREE-FLYER STABILITY

- STABILITY LEVELS OF 10 ARC SEC OR LESS SHOULD BE POSSIBLE.

1768–77

POWER MODULE BASELINE USER APPLICATION ASSESSMENT

MISSION TYPE / PM RESOURCE AVAILABLE FOR PAYLOAD	DEGREE OF SATISFACTION OF P_L REQ.			
	MISSION DURATION	ELECTRICAL POWER	ATTITUDE CONTROL	THERMAL CONTROL
EARTH VIEWING	GOOD	GOOD	GOOD	MOD-GOOD
CELESTIAL VIEWING	GOOD	GOOD	MOD (LIMITED RCS SUPPORT)	GOOD
SOLAR VIEWING	GOOD	GOOD	MOD (LIMITED RCS SUPPORT)	MOD-GOOD
NON POINTING (SPACE PROCESSING, LIFE SCIENCES, AND OTHERS)	GOOD	GOOD	GOOD	MOD-GOOD

POTENTIAL APPLICATION OF PM TO STO

2566-77

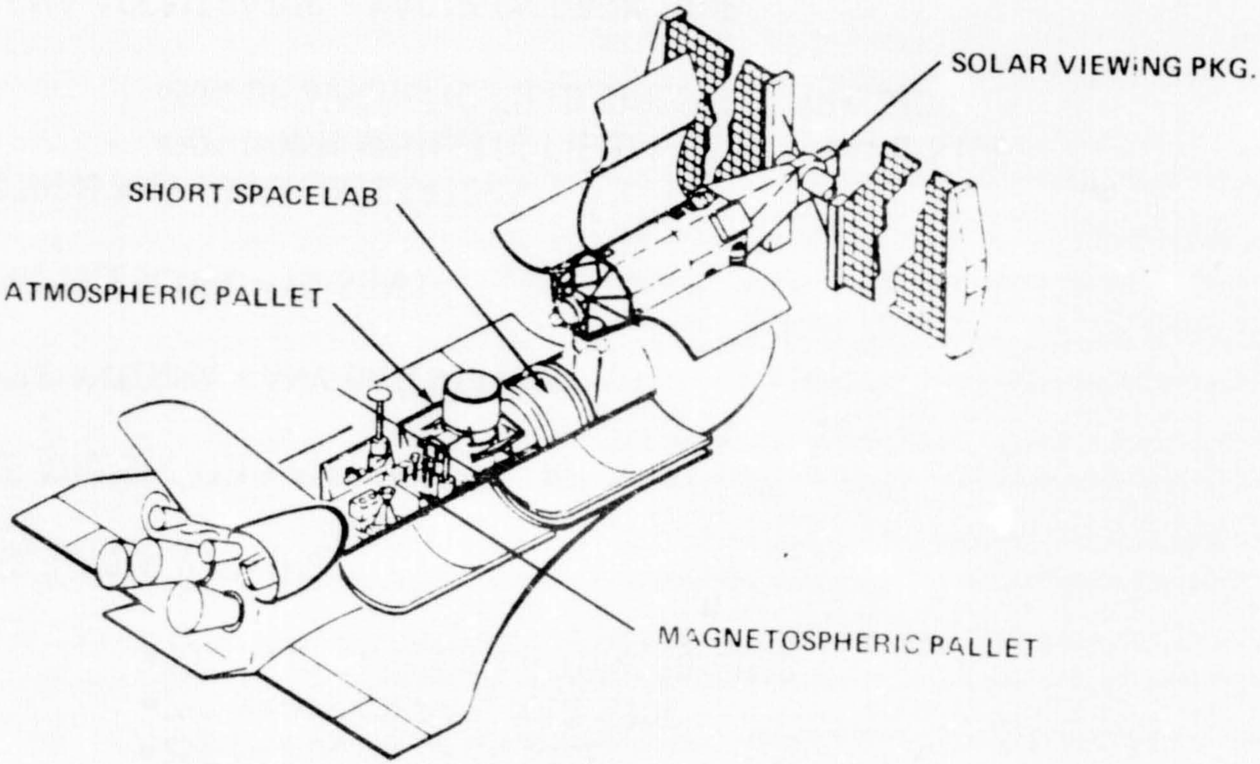
TYPICAL STO INSTRUMENT POINTING REQUIREMENTS

- REMOTE SENSING PLATFORM
  - 25% NADIR ON DARK SIDE
  - 25% NADIR ON DAYLIGHT SIDE
  - 50% IN DARK LOOKING TOWARD LIMB
- LIDAR-NADIR VIEWING
- WAKE AND SHEATH - ANY ORIENTATION
- DIPOLE ANTENNA - ANY ORIENTATION
- SOLAR TELESCOPE - TO SUN
- ELECTRON AND ION ACCELERATORS
  - 50% DOWN MAGNETIC FIELD LINES ON DARK SIDE
  - 50% UP MAGNETIC FIELD LINES ON DARK SIDE
- PLASMA ACCELERATOR - NADIR ON DARK SIDE
- SIMULTANEOUS VIEWING OF SUN (WITH SOLAR TELESCOPE) AND EACH OF THE OTHER VIEWING DIRECTIONS/INSTRUMENTS SHOWN ABOVE

NOTE: MAX. TIME REQUIRED FOR TAKING DATA TO SUPPORT A SUB-OBJECTIVE IS 15-30 MINUTES

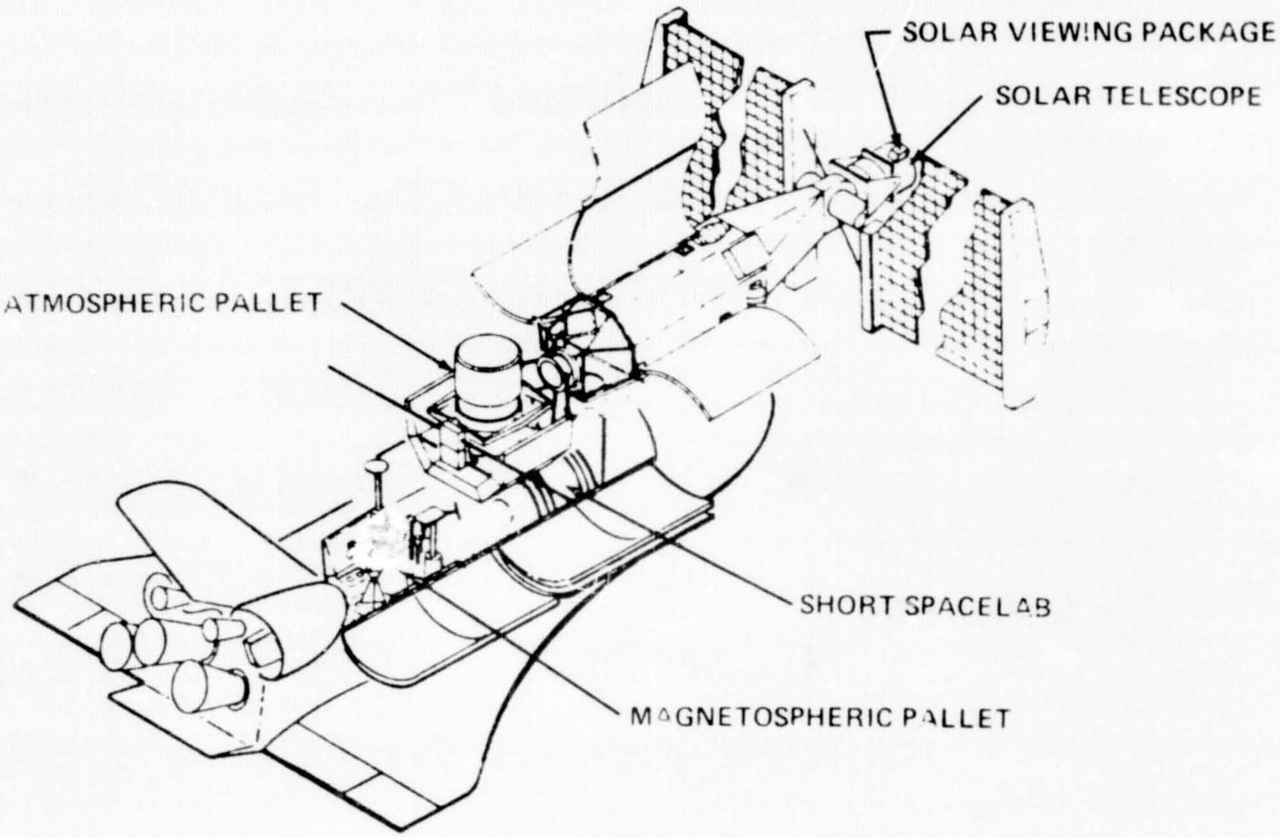
TYPICAL PM/ORBITER/STO SORTIE MISSION

PD469-77C



TYPICAL PM/ORBITER/STO SORTIE MISSION

PD470 77C



PM/ORBITER PROVIDES TO PAYLOADS IN STO MISSIONS

- 30-60 DAY SORTIES (LIMITED ONLY BY ORBITER)
- * 11 KW POWER AND 12 KW HEAT REJECTION (SORTIES)
- * 25 KW POWER AND 6 KW REJECTION, OR
- * 13 KW POWER AND 10 KW HEAT REJECTION

  (FREE-FLYER)
- CONTAMINATION-FREE (CMG) STABILIZATION
- RELAXED ORIENTATION CONSTRAINTS
- INCREASED VIEWING TIME OF EARTH AND SUN
- REDUCED USER CHARGES FOR EXTENDED MISSIONS
- FREE-FLYER OPERATIONAL POTENTIAL

* AT BEST ORIENTATIONS AND WORST β ANGLES

APPROVAL

GUNTERSVILLE WORKSHOP ON SOLAR-TERRESTRIAL STUDIES

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

Charles A. Lundquist

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