NASA Technical Memorandum 100140
IAF-87-234

Space Station Electrical Power System

(NASA-TM-100140) SPACE STATION ELECTRICAL POWER SYSTEM (NASA) 19 p Avail: NTIS HC A02/MF A01 CSCL 22B

N87-26144

Unclas
G3/20 0090636

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Prepared for the
38th International Astronautical Federation Congress
Brighton, United Kingdom, October 10-17, 1987

NASA

SPACE STATION ELECTRICAL POWER SYSTEM

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E-3692

Abstract

The purpose of this paper is to describe the design of the Space Station Electrical Power System. This includes the Photovoltaic and Solar Dynamic Power Modules as well as the Power Management and Distribution System (PMAD). In addition, two programmatic options for developing the Electrical Power System will be presented. One approach is defined as the Enhanced Configuration and represents the results of the Phase B studies conducted by the NASA Lewis Research Center over the last 2 years. Another option, the Phased Program, represents a more measured approach to reaching about the same capability as the Enhanced Configuration.

Background

NASA Lewis is responsible for developing the electrical power system for the Space Station. This responsibility includes the end-to-end electric power systems for both the Space Station and the free-flying platforms. Aboard the Space Station, this encompasses the hybrid power system consisting of the Photovoltaic (PV) and Solar Dynamic (SD) modules as well as the 440 V, 20 kHz Power Management and Distribution (PMAD) system. Photovoltaic and PMAD orbital replacement units and/or component level hardware are delivered by NASA Lewis to other NASA field Centers for installation and integration into the platform elements. The first section of this paper describes the preliminary design of the Electrical Power System as it existed at the completion of the Phase B design effort. This activity was conducted by NASA Lewis in conjunction with its contractors and was completed in January, 1987 (NAS3-2466). The power levels for the presented designs represent a 75 kW Space Station with 25 kW PV and 50 kW SD. This was later modified to 37.5 kW Photovoltaic and 50 kW Solar Dynamic as a result of concerns raised over the amount of power (PV) available for users during the early phases of assembly. The platform power systems are all Photovoltaic and provide about 4 kW initially.

In response to key issues associated with user requirements and overall Space Station Program funding, NASA Lewis recommended another possible option to the Reagan Administration and the Congress. This option was termed the Phased Program for the development of the Space Station and platforms. During Phase 1, consisting of 12 assembly flights, the power level of the Station will reach 75 kW and consist of Photovoltaic modules only. During Phase 2, the Solar Dynamic power modules will be brought up to raise the total power level to 125 kW. A single Polar platform with 4 kW of power will be developed during Phase 1 followed by a co-orbiting platform of equal size during Phase 2.

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Description of Space Station Electric Power System

Overall Power System Description

An overall schematic depicting the Enhanced Configuration of the Space Station is shown in Fig. 1. Several of the key features of the Electrical Power System for either program option are apparent in this schematic. The Power Generation System is located on a truss (transverse boom) which runs perpendicular to the dual keels. For this configuration, two 18.75 kW Photovoltaic modules are located on the truss (one on each side) outboard of the articulating joints and inboard of the indicated Solar Dynamic modules. There are two 25 kW Solar Dynamic modules located on the truss (one on each end). In order to position the modules, articulating joints, termed alpha and beta, are used (Fig. 1). The alpha joints provide an ability for the modules to rotate with respect to the dual keels. They allow the modules to face the sun during each orbit of the earth. The beta joints, which are contained within each module, provide further articulation capability to account for seasonal changes as the earth rotates around the sun each year. The Power Management and Distribution is not shown but consists of all the hardware and software necessary to control power generation from all sources and distribute it to the variety of load centers throughout the Space Station structure and manned modules. The Electrical Power System is designed to have sufficient electro-chemical and thermal energy storage to provide power continuously, even during the eclipse portions of the orbit, which represent approximately one-third of the total orbital time.

Photovoltaic Power Modules

The Photovoltaic power system consists of 18.75 kW Photovoltaic modules located outboard of each alpha joint on the transverse boom. Each module contains the following major assemblies: solar array wings, thermal control radiator, beta gimbal, integrated equipment assembly, and integration hardware (Fig. 2). The integrated equipment assembly box contains the batteries, PV controller, and the dc-ac inverter.

PV Array Wings. The Photovoltaic system uses solar arrays for power generation during the sun portion of the orbit. They also supply power to charge the batteries which supply power to loads during the eclipse portion of the orbit. Each module contains two lightweight PV array wings, with a total of four array wings on the Space Station. As shown in Fig. 3, each wing consists of two identical blanket assemblies. The blanket assemblies are constructed with mechanically hinged, coated, flexible kapton panels. They are supported by a deployable/retractable center mast. The blanket assemblies also consist of a flexible substrate which supports the solar cells and a flat conductor cable which conducts electrical current to the base of the array.

The blanket assemblies utilize 8 by 8 cm gridded-back (higher efficiency) silicon solar cells having a thickness of 8 mils which operate at 160 V nominally. The cells are mounted on a kapton substrate. Each wing is approximately 33 by 96 ft. A key feature of the solar array wings is its stowability and deployability. The wings are stowed in the container cover assembly. As the wings are deployed, they are supported by a deployable coilable/longeron mast (Fig. 3). A blanket support tension assembly is used to supply tension to the blanket as it reaches complete extension. The entire wing is tied structurally to the transverse boom by means of the beta gimbal assembly.

Nickel-Hydrogen Batteries. Nickel-Hydrogen (NiH_2) batteries are used to supply power to loads during eclipse periods. The batteries are located within the integrated equipment assembly (Fig. 2). These batteries have a moderate capacity of about 62 A-hr. A total of eight batteries are used on the Space Station PV power system, four per PV module. A representative NiH_2 battery pack including wiring harness, mechanical and thermal support components is shown in Fig. 4. Nickel-Hydrogen batteries are also used on the platforms as well. In particular, these batteries satisfy the polar platform needs of minimum weight with high reliability and minimum redundancy.

Solar Dynamic Power Modules

The Solar Dynamic power system consists of two 25 kW Solar Dynamic modules located at each end of the transverse boom outboard of the Photovoltaic modules. Each module contains the following major assemblies: concentrator, receiver, power conversion unit (PCU), radiator, electrical equipment, integration hardware, interface support structure, and beta joint gimbal. Each module will supply 25 kW nominally during both the sunlit and eclipse portions of the orbit.

For the Solar Dynamic power system, two cycles were considered as candidates for development; the Closed Brayton Cycle (CBC) (Fig. 5), and Organic Rankine Cycle (ORC) (Fig. 6). Both candidate systems contain a concentrator to capture the incoming solar flux, a receiver which absorbs the solar energy and a power conversion unit which takes the working fluid which passes through the receiver and expands it through a turbo-alternator to produce electricity. Finally, a radiator rejects waste heat. An examination of Figs. 5 and 6 indicates that these candidate systems contain the same assemblies and are of roughly comparable size. The principal differences lie in the working fluid and operating temperatures. The CBC operates with Helium-Xenon gas as a working fluid with a turbine inlet temperature of approximately 1400 °F. In the CBC, the gas remains in a superheated state over the entire cycle. The ORC operates with toluene fluid as the working medium with a turbine inlet temperature of approximately 750 °F. The working fluid in the ORC undergoes phase changes ranging from compressed liquid, saturated two-phase liquid-vapor, superheated vapor, and supercritical fluid.

Concentrator. The concentrator assembly is shown in Fig. 7. The purpose of the concentrator is to capture and focus the incoming solar flux with a reflective concave surface and send it through the receiver aperture.

The concentrator shown is suitable for both the ORC and CBC power systems. The primary difference lies in the pointing accuracy and the total surface area requirements. The concentrator design is a parabolic offset reflector, gimbaled about the receiver aperture center. Fine pointing of the concentrator is provided by two linear actuators. The CBC concentrator requires 19 full-size hexagonal panels that are latched together on orbit. The ORC concentrator requires 19 full-size hexagonal panels and 12 smaller edge-wedge panels to provide required additional concentrator area.

Receiver/Power Conversion Unit. Both the ORC and CBC systems contain a receiver which accepts and absorbs solar energy from the concentrator for use during both the sun and eclipse portions of the orbit. Both candidate receivers store thermal energy in a phase change salt to provide energy during the eclipse period. Both the ORC and CBC power conversion units (PCU) use a combined rotating unit consisting of a turbine, alternator, and pump (ORC) or compressor (CBC). The PCU also includes a recuperator/regenerator heat exchanger for improving cycle efficiency.

A schematic of the CBC receiver/PCU is shown in Fig. 8. The receiver consists of a cylindrical absorbing cavity whose walls are lined with 82 working fluid tubes. Each tube is encased in a series of small canisters containing the thermal energy storage salt ($LiF\ CaF_2$). The Brayton PCU with associated ducting is shown attached to the heat receiver.

A schematic of the ORC receiver/PCU is shown in Fig. 9. The ORC receiver consists of a cylindrical absorbing cavity whose walls are lined with 42 heat pipe assemblies. Each heat pipe contains two thermal energy storage canisters filled with lithium-hydroxide (LiOH) salt and a toluene vaporizer tube. As in the case of the CBC engine, the ORC PCU is attached to the backplate of the receiver.

As indicated in Figs. 5 and 6, both systems utilize heat rejection assemblies. The baseline heat rejection system for the ORC system uses a heat pipe radiator while the CBC system uses a pumped loop radiator.

Power Management and Distribution

Reference PMAD System Architecture. Figure 10 shows the Space Station hybrid architecture. The SD system is regulated to produce 208 V, 3-phase, 1200 Hz ac power. A frequency changer converts the power to 440 V, 1-phase, 20 kHz. The solar arrays are regulated to produce 160 V dc. The charging of the Ni-H_2 batteries is controlled by the individual charge and discharge regulators. The main inverters receive approximately 160 V dc from the arrays and batteries and convert it to regulated 440 V, 1-phase, 20 kHz ac power. The inverter sizing is such that the transmission of peak power (1.3 times average power) requires the full capacity of two inverters. The power is transmitted across the alpha joint by roll rings, which are sized to handle peak power requirements for a 300 kW growth Space Station.

Upper/Lower Station PMAD. The distribution of power to the upper and lower Space Station is shown in Fig. 11. A dual ring distribution system is used for both the upper and lower keels. There are main bus switching assemblies (MBSA) adjacent to each alpha joint and in-line power distribution and control assemblies (PDCA) at the various load locations.

Modules PMAD. Figure 12 shows the distribution of power to the modules. Two main distribution cables are provided to each of resource nodes 1 and 2, and one distribution cable each to resource nodes 3 and 4. The distribution cabling for the entire Space Station is sized to accommodate a growth power level of 175 kW. In addition to cables leading to the four resource nodes, there is a cable for the attached pressurized payload as shown in Fig. 12.

The PMAD system has been designed to be able to accommodate changes in load type and size as well as being amenable to growth. The electrical distribution system architecture for the free-flying platforms uses the same components as those selected for the Space Station. NASA Lewis is responsible for designing, developing, and producing all common hardware for the Space Station and the platforms. These common PMAD components will include remote bus isolators, cables/connectors, load converters, array regulators, etc.

Program Options

Enhanced Configuration

The Space Station design which basically resulted from the Phase B effort is defined as the Enhanced Program Configuration. The electrical power system for this configuration consists of two 18.75 Photovoltaic modules and two 25 kW Solar Dynamic Modules yielding a total power output of 87.5 kW. The Power Management and Distribution System has a distribution frequency of 20 KHz at 400 V.

The power modules for the Enhanced Programs are required to be launched on Flights 1, 2, and 9 of the 17 flight assembly sequence. On Flight 1, a single PV module is brought up along with associated truss structure and an aft resource node (Fig. 13). Between Flights 1 and 2, the Space Station flys in the arrow mode with the PV array feathered. (The arrays provide approximately 6 kW in this mode.) On Flight 2, the second PV module is brought up (Fig. 14). At this point, the horizontal boom is completed and approximately 12 kW are provided to the users. The use of PV modules on the first two flights is necessary because up to that point in the assembly sequence, the Space Station lacks solar pointing capability.

At Flight 3, with the capability of flying the Space Station in the normal mode, with the arrays unfeathered, 37.5 kW total power is available (28 kW to the user).

On Flight 9, two 25 kW Solar Dynamic modules are brought to the Space Station, thus completing the solar power module assembly process. This brings the final power level up to 87.5 kW. A schematic of the Space Station at the completion of Flight 9 is shown in Fig. 15. The fully assembled Space Station is as shown in Fig. 1.

The Enhanced Configuration total power availability is shown in Fig. 16 as a function of assembly Flight. This enhanced configuration satisfies the need for more user power early in the assembly sequence and is compatible with a reduced Shuttle performance and launch frequency. The available user power (Fig. 16), is the difference between the total available power and that required for Space Station housekeeping.

Phased Program

Concerns by the Administration and the Congress about the total cost of the Space Station and the amount of power available to the user at the completion of the assembly process led to the development of a Phase One/Phase Two approach in early 1987.

The principal impact on the power system for a Phased approach would be an increase in the amount of Photovoltaic power (75 kW) assembled initially during what is termed Phase 1. In addition, the Solar Dynamic power is postponed to the second Phase of the program at which time the power system will have a total capability of 125 kW.

Phase One of the program consists of launching one PV module each on assembly Flights 1 and 2 (18.75 kW per each module) and two PV modules on assembly Flight 9.

A schematic of the completed Space Station at the end of Phase 1 (consisting of 12 assembly flights) is shown in Fig. 17. Again, the primary impact to the Electrical Power System involves the PV arrays; there are 4 modules and 8 arrays in the Phased Program, compared to 2 modules and 4 arrays in the Enhanced Configuration Program.

On assembly Flight 13, during Phase 2, a 50 kW Solar Dynamic System is brought up (at this point 90 kW is available to the user). A schematic of the Space Station at the completion of Phase 2 is shown in Fig. 18.

Also indicated in Fig. 19 is the user power available as a function of assembly flight. There is approximately 85 kW available to the user at the completion of Phase 2.

In Table 1, a comparison of the key milestones for the Electric Power System is shown for both the Phased Program Option and the Enhanced Configuration Program option.

Summary

The preliminary design of the Space Station Electric Power System has been completed. It consists of a Hybrid Power generating system composed of Photovoltaic and Solar Dynamic Modules. There are two design options for the Solar Dynamic System; Closed Brayton Cycle and Organic Rankine Cycle. The Power Management and Distribution System consists of 440 V, 1-phase, 20 kHz ac power. The design of the Space Station power system is compatible with that of the free-flying platforms which have common hardware for the Space Station systems.

Two Program options are currently being considered. One option is called the Enhanced Configuration and yields an 87.5 kW Hybrid Power Space Station. A second approach, the Phased Program, also yields a hybrid power system, but takes two phases to accomplish and results in 125 kW at completion. Both options utilize a 20 Hz PMAD system.

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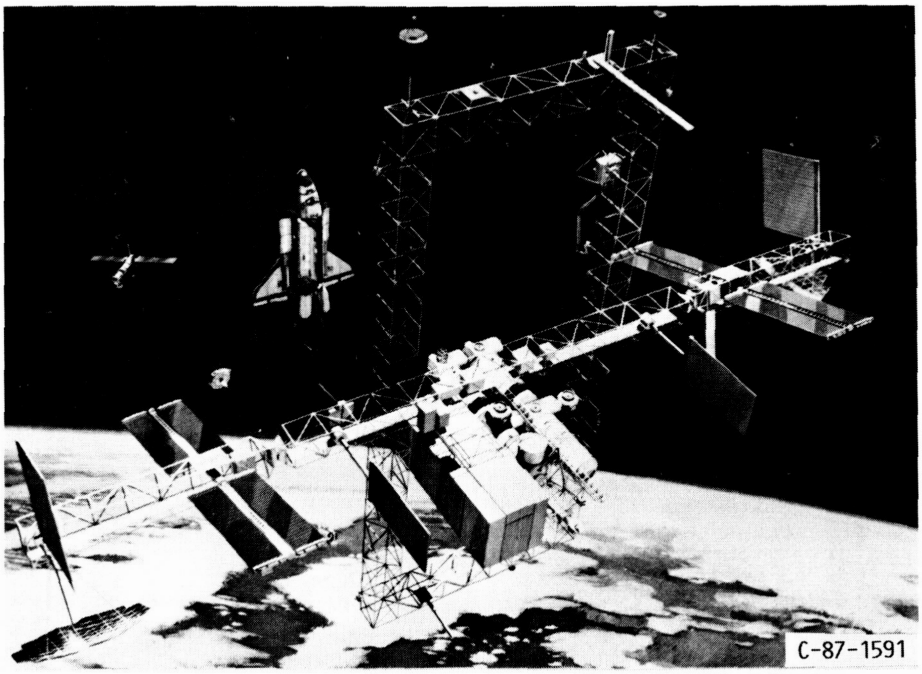


FIGURE 1. - SPACE STATION.

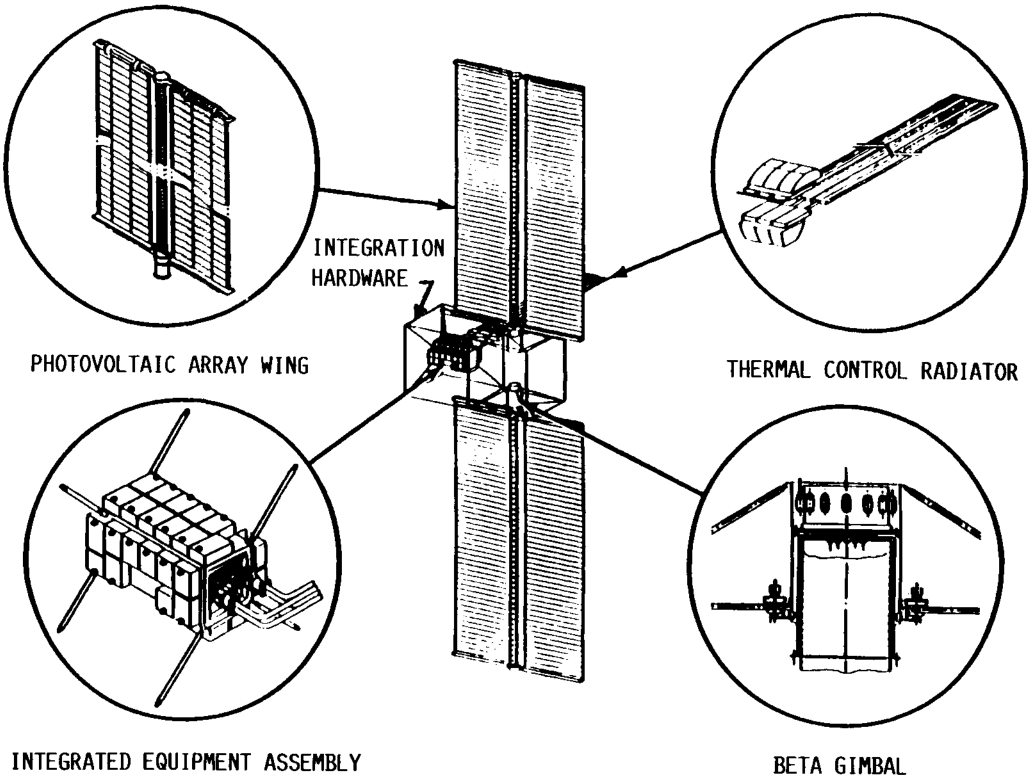


FIGURE 2. - PHOTOVOLTAIC MODULE CONFIGURATION.

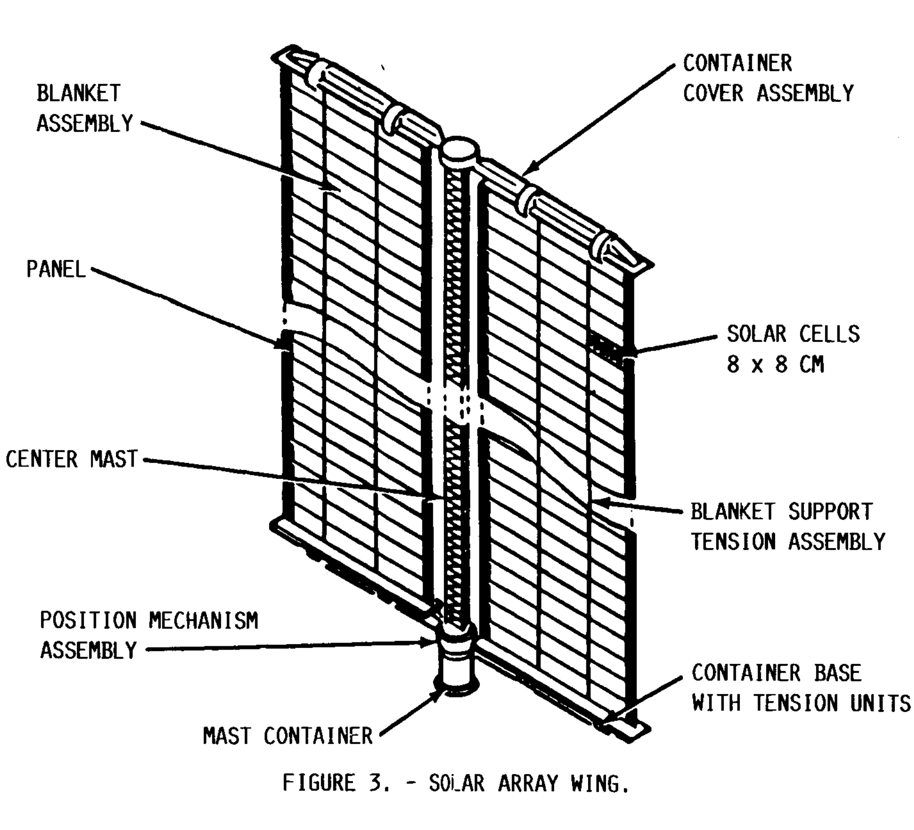


FIGURE 3. - SOLAR ARRAY WING.

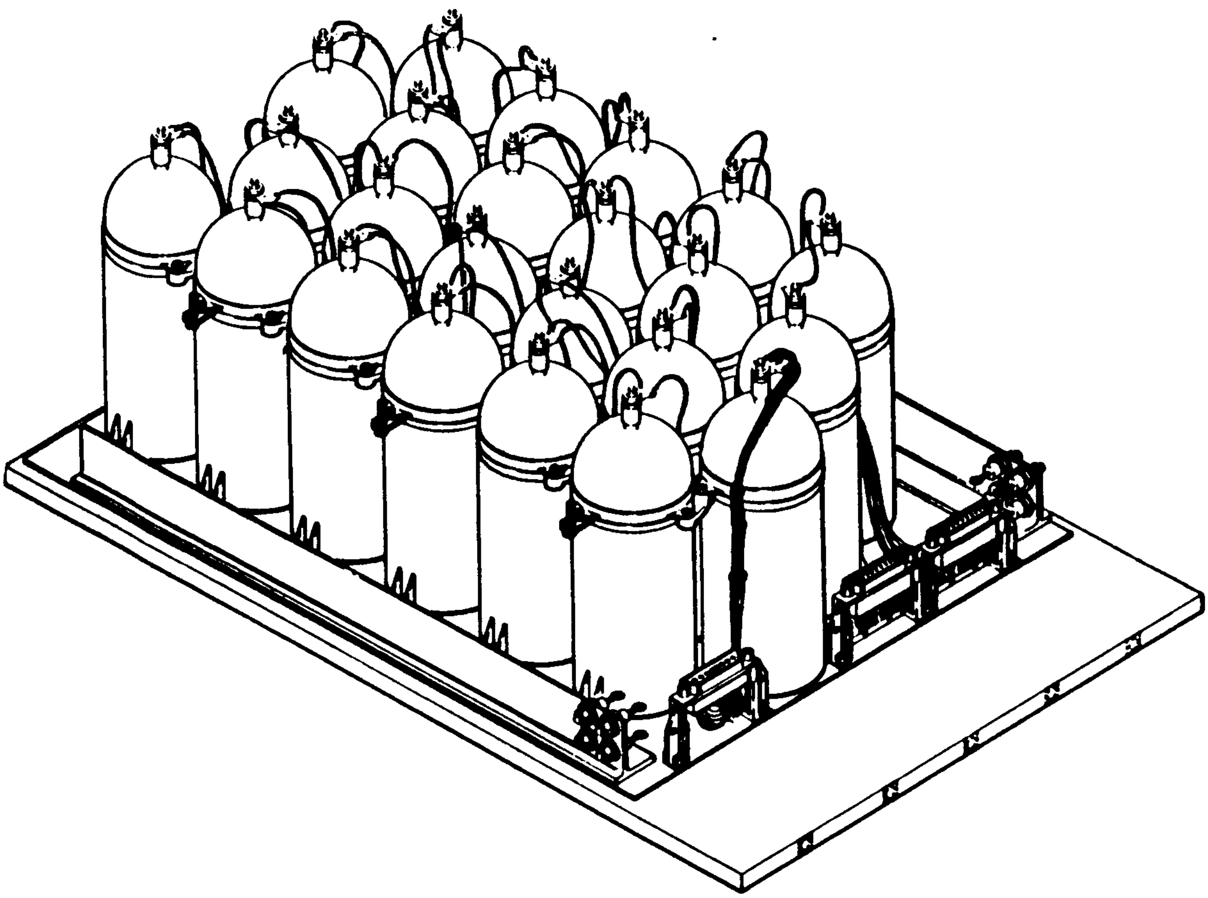


FIGURE 4. - REPRESENTATIVE $Ni-N_2$ BATTERY PACK.

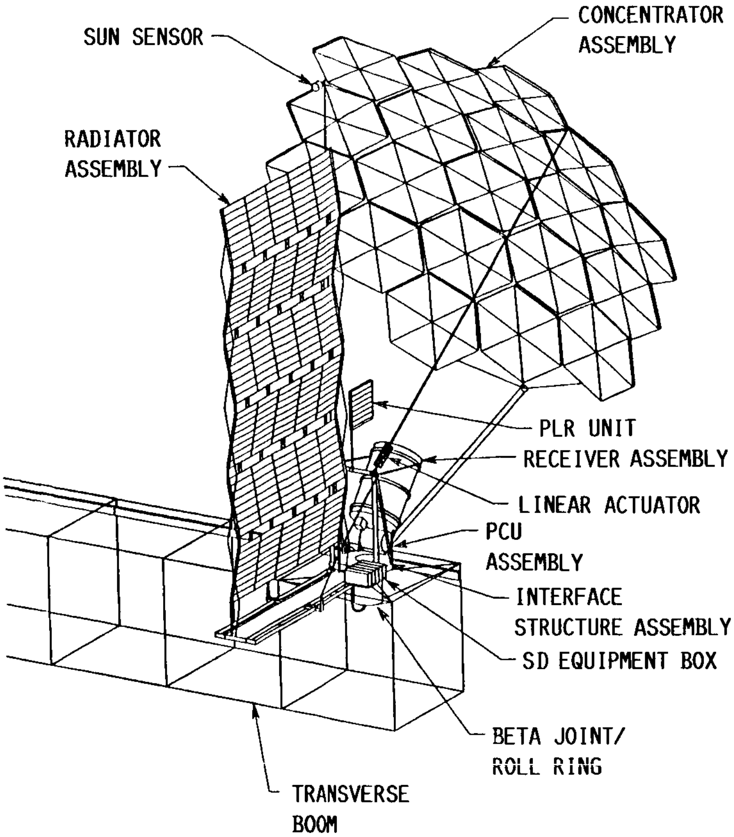


FIGURE 5. - CLOSED BRAYTON CYCLE SOLAR DYNAMIC MODULE.

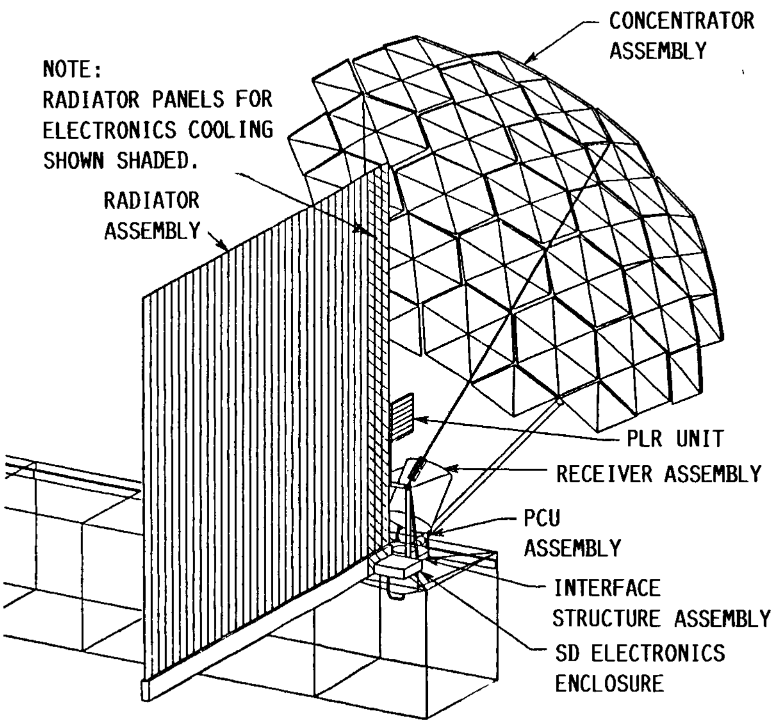


FIGURE 6. - ORGANIC RANKINE CYCLE SOLAR DYNAMIC POWER MODULE.

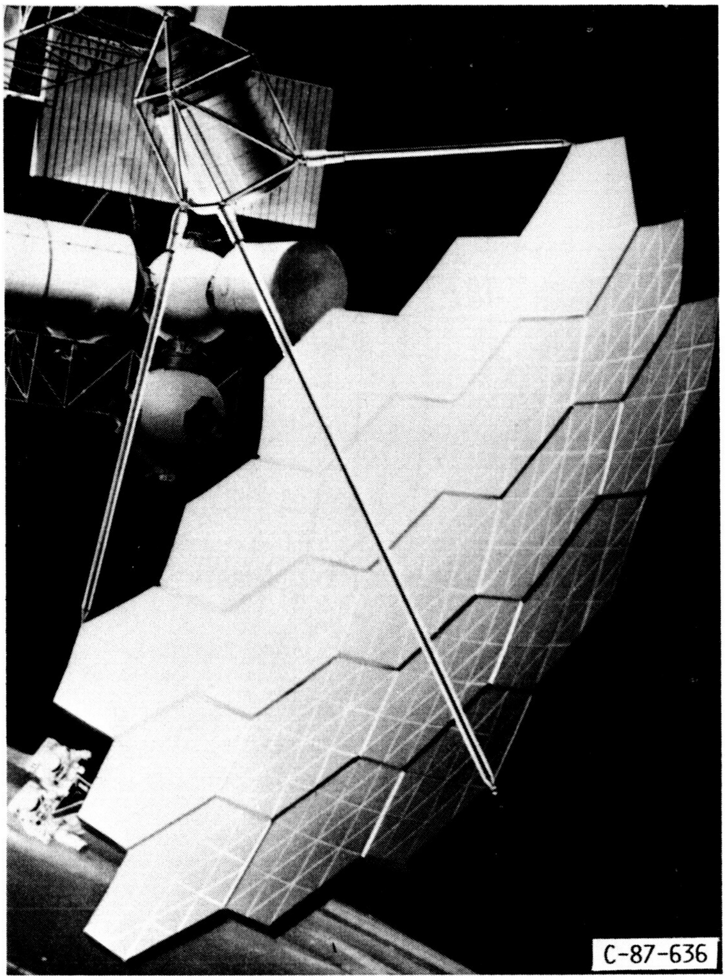


FIGURE 7. - SOLAR DYNAMIC CONCENTRATOR.

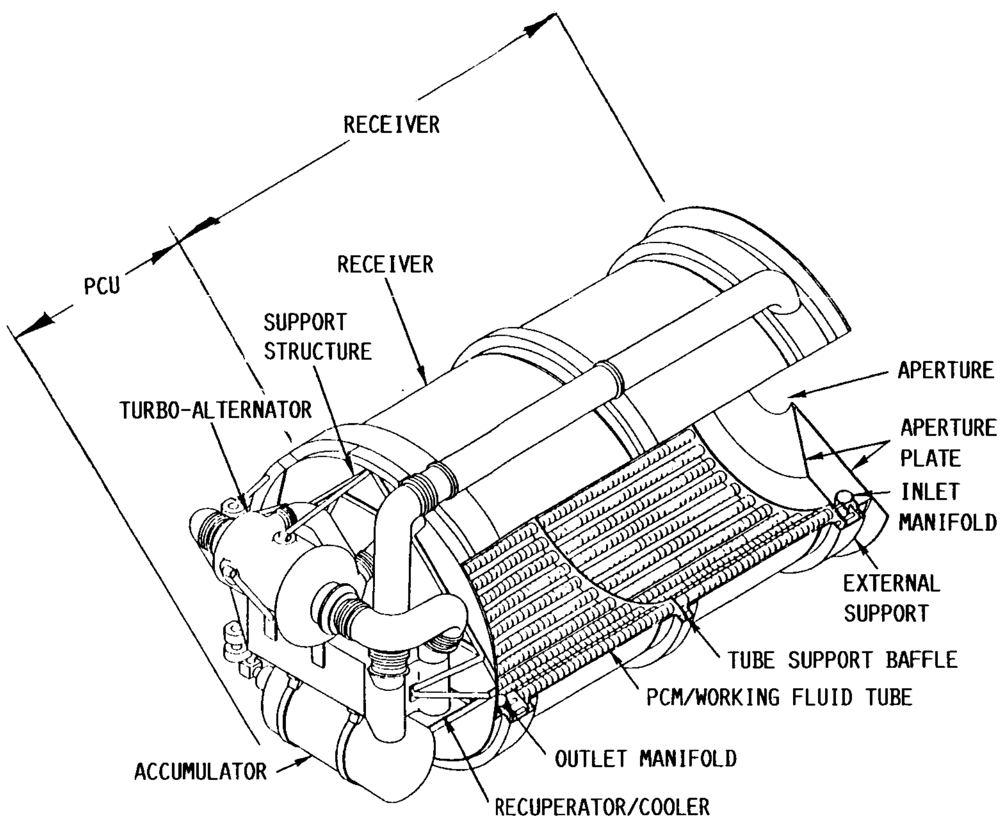
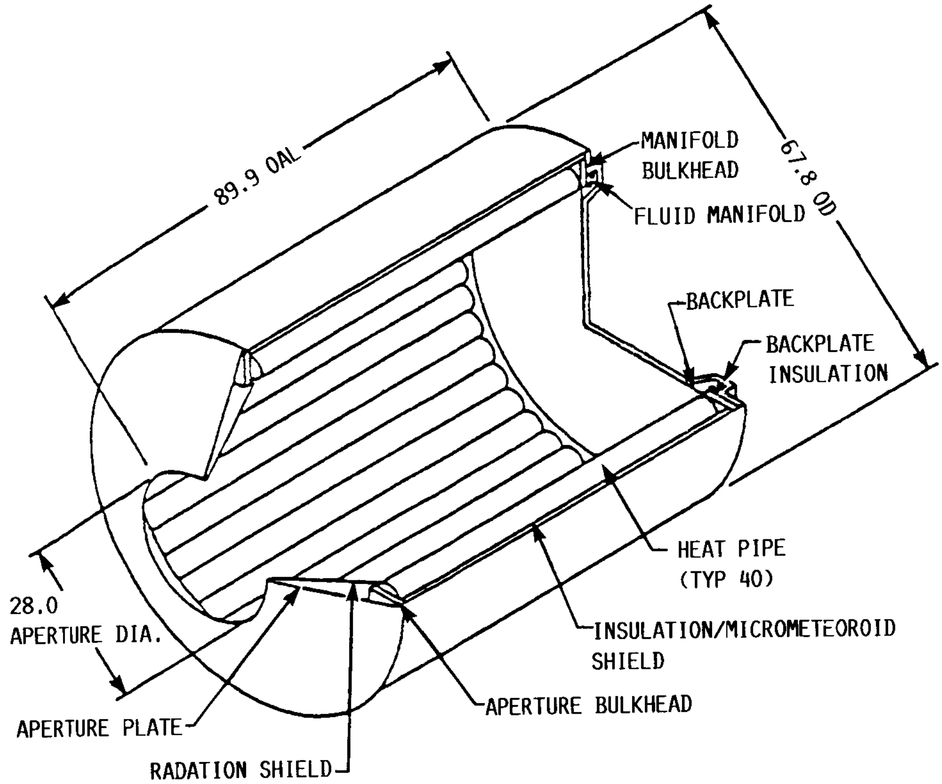
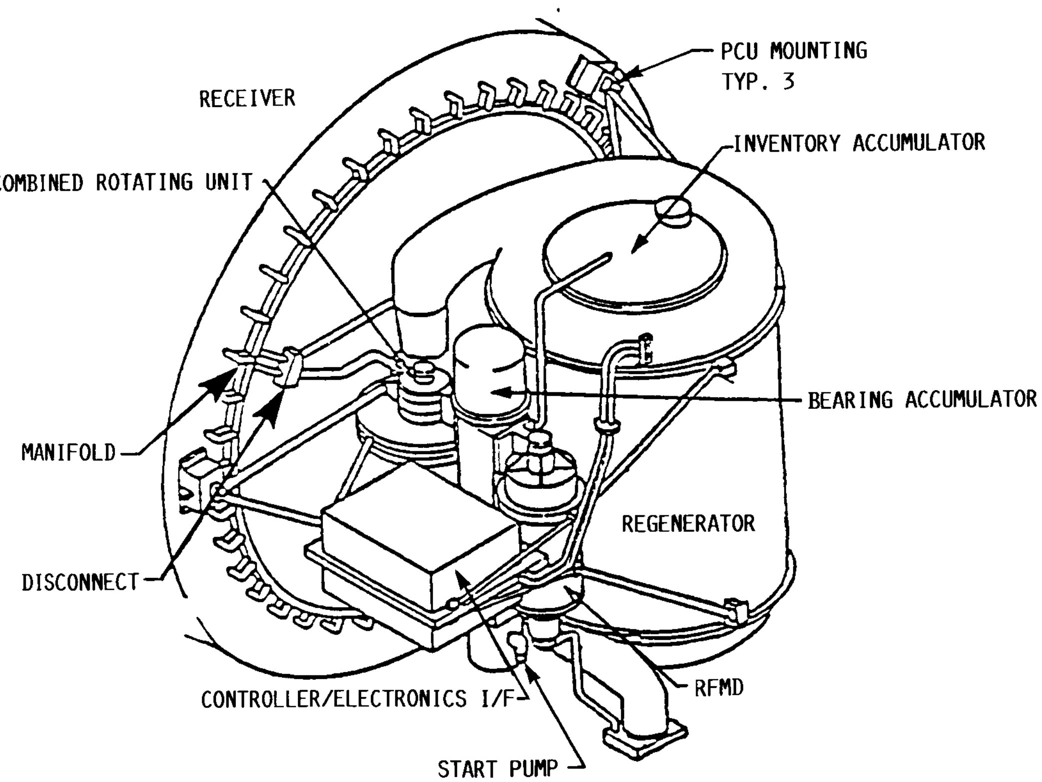


FIGURE 8. - CBC RECEIVER/PCU.



(A) ORC RECEIVER



(B) ORC PCU

FIGURE 9. - ORC RECIEVER/ORC PCU.

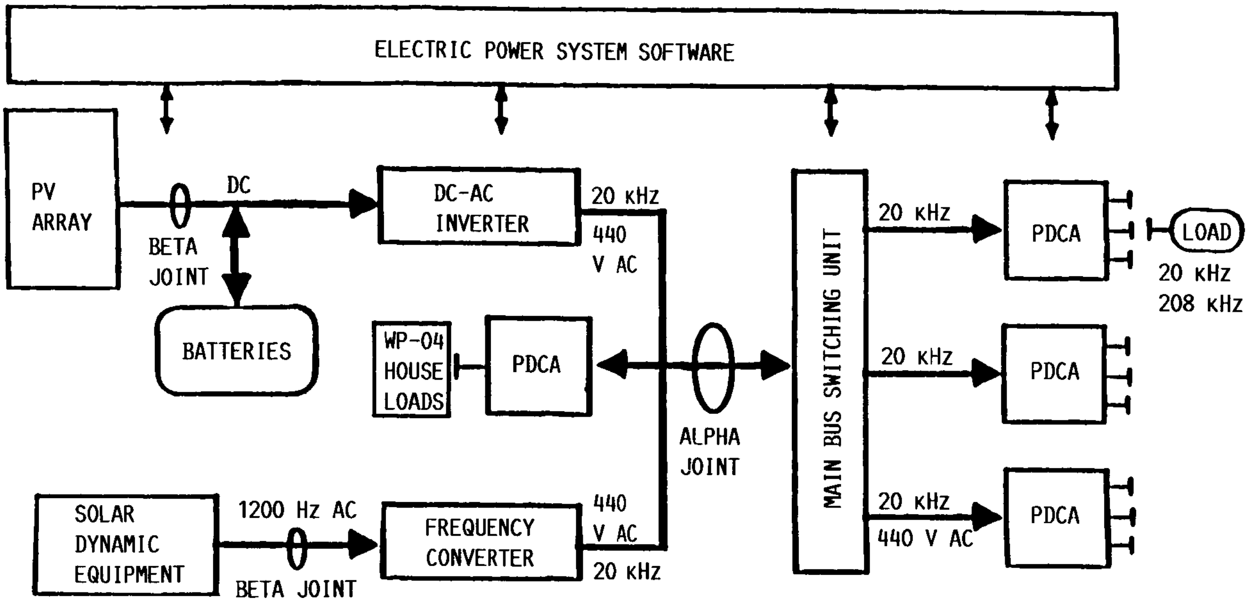


FIGURE 10.- SIMPLIFIED FEATURES OF THE EPS ARCHITECURE.

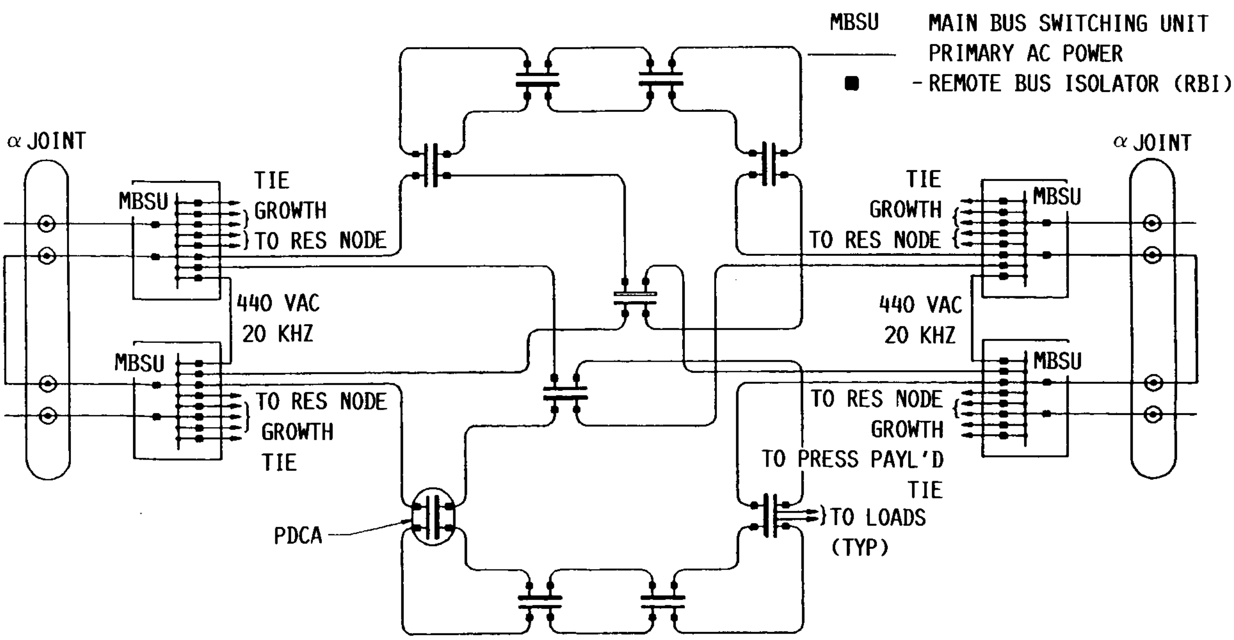


FIGURE 11. - SPACE STATION RING DISTRIBUTION SYSTEM (EXTERNAL LOAD AREAS ONLY).

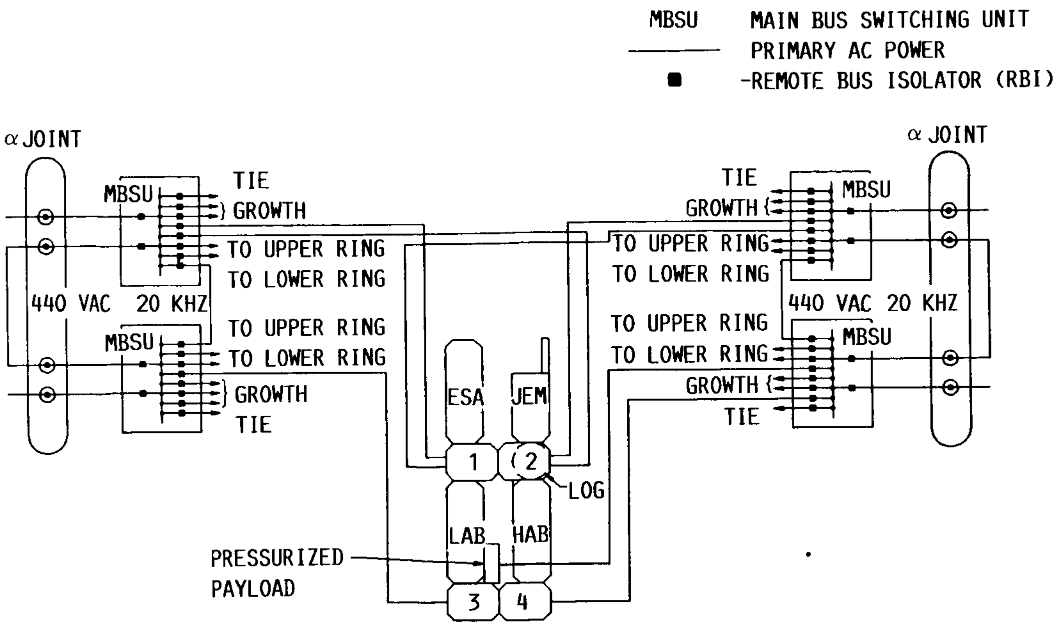


FIGURE 12. - PRIMARY DISTRIBUTION FOR TRANSVERSE BOOM.

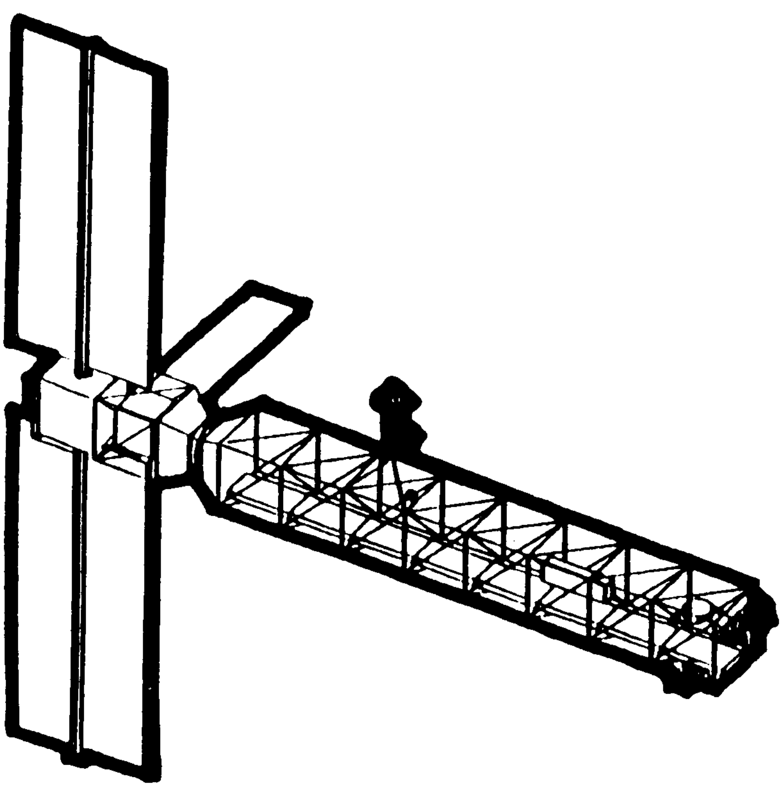


FIGURE 13. - ASSEMBLY FLIGHT NO. 1.

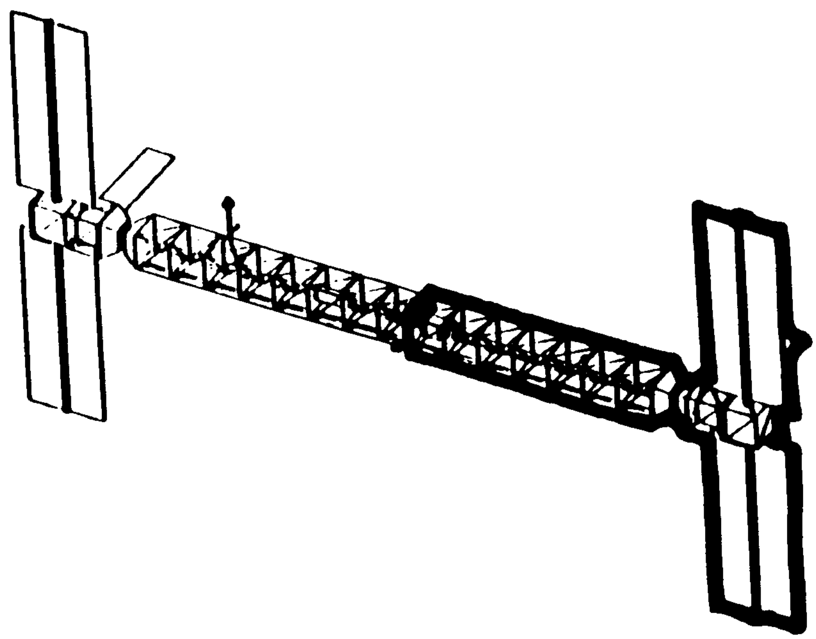


FIGURE 14. - ASSEMBLY FLIGHT NO. 2.

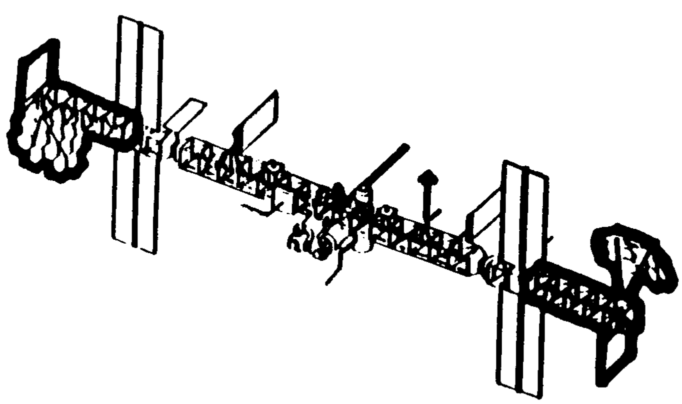


FIGURE 15. - ASSEMBLY FLIGHT NO. 9.

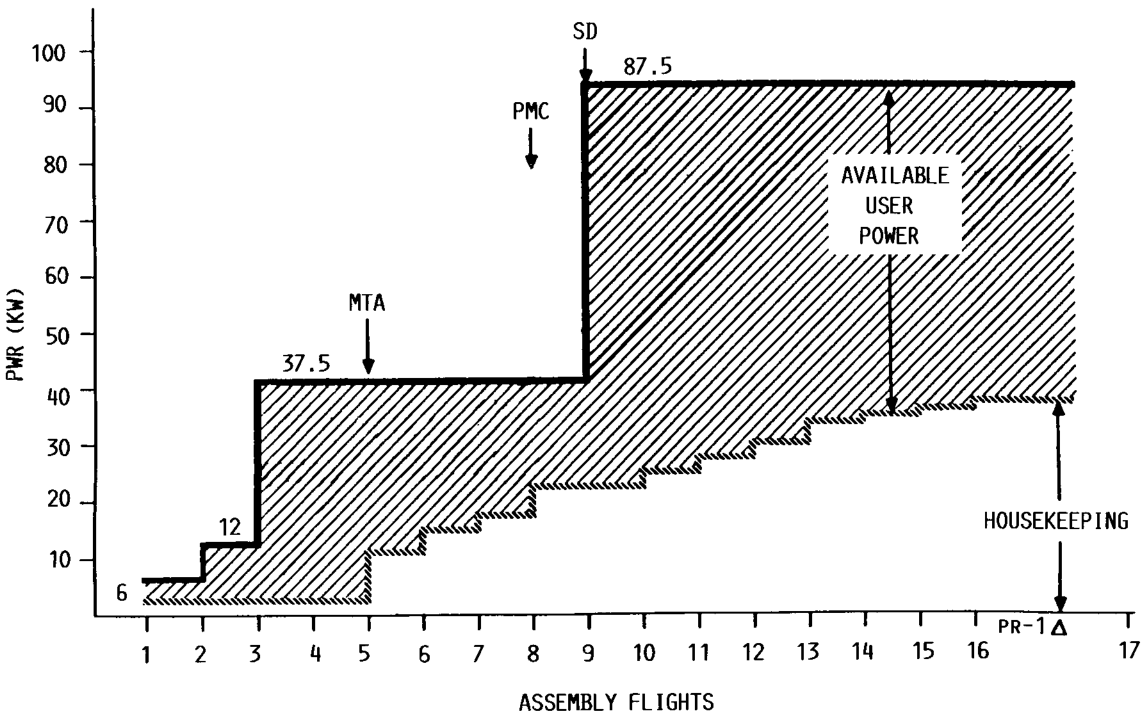


FIGURE 16. - ENHANCED CONFIGURATION USER POWER.

PHASE 1

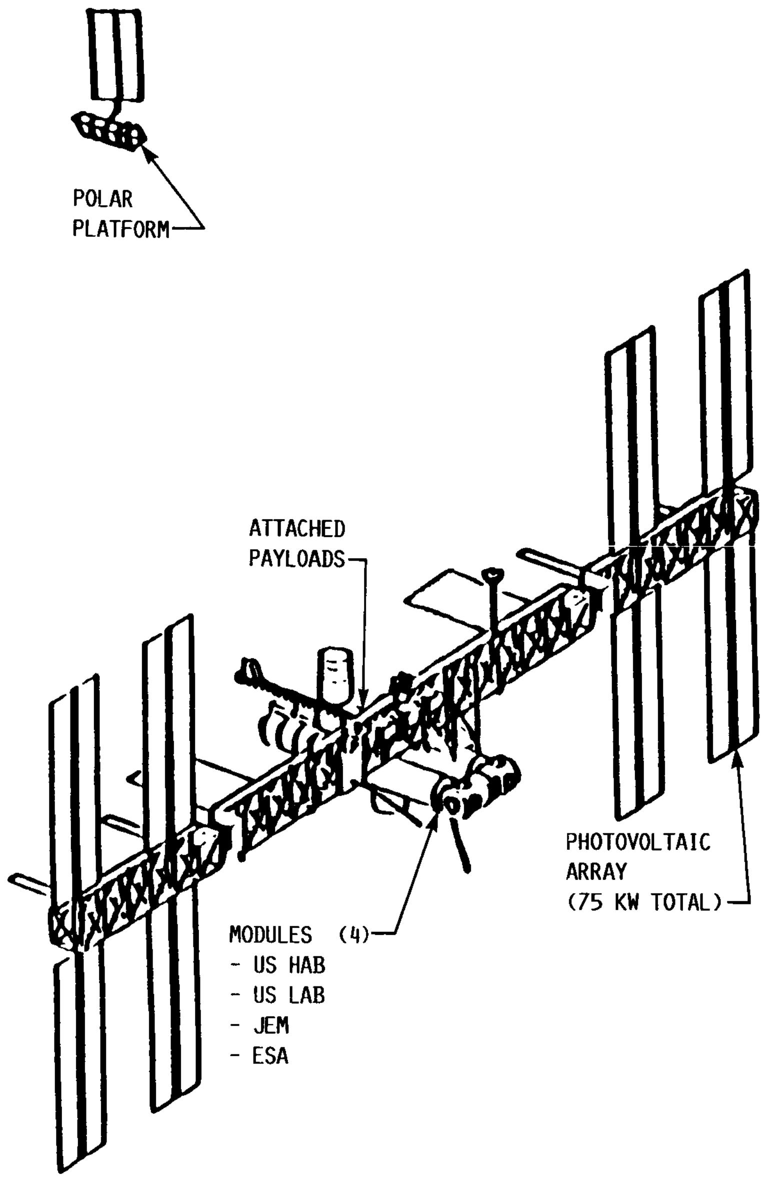


FIGURE 17. - SPACE STATION AT END OF PHASE 1.

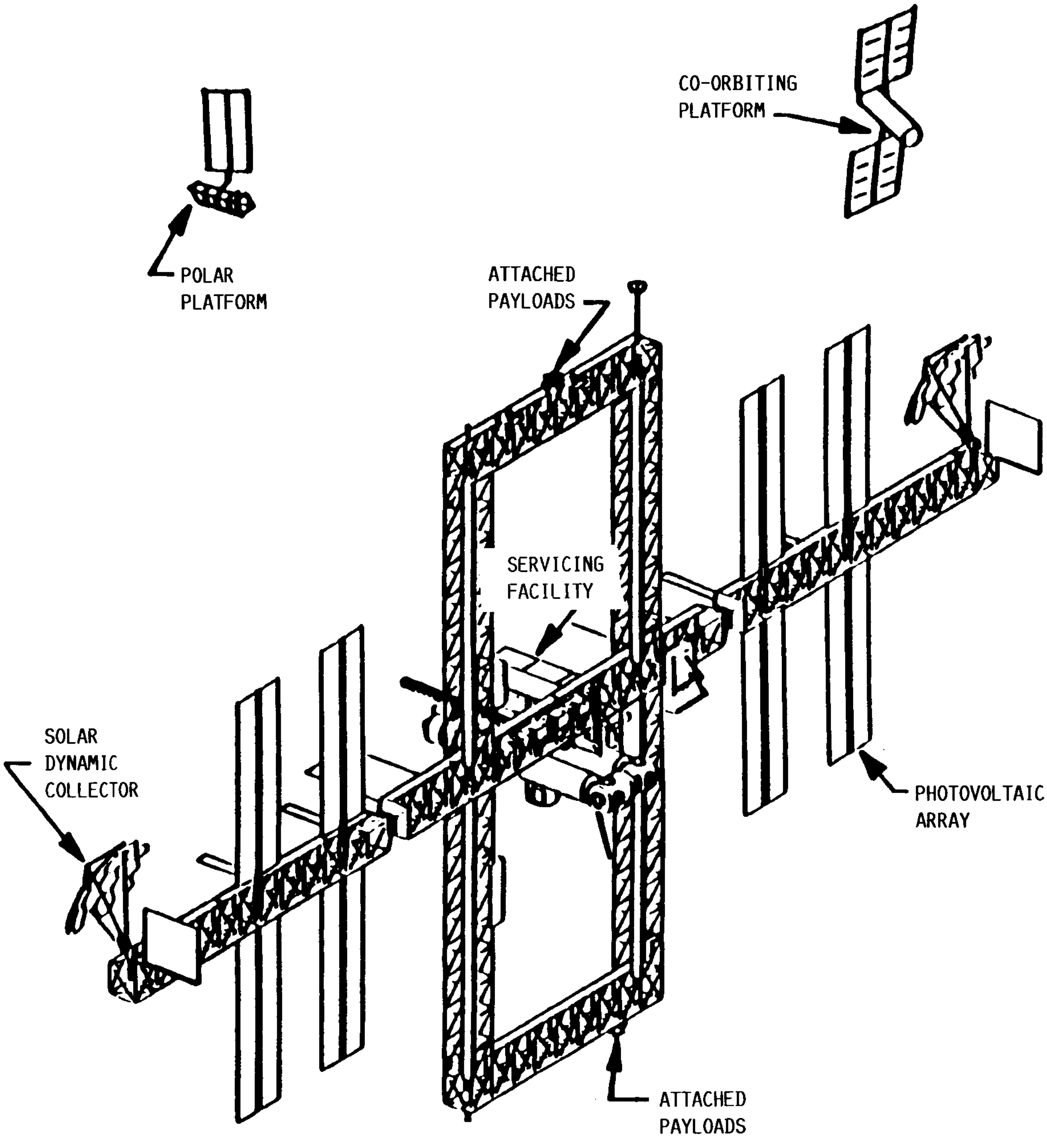


FIGURE 18. - SPACE STATION AT END OF PHASE 2.

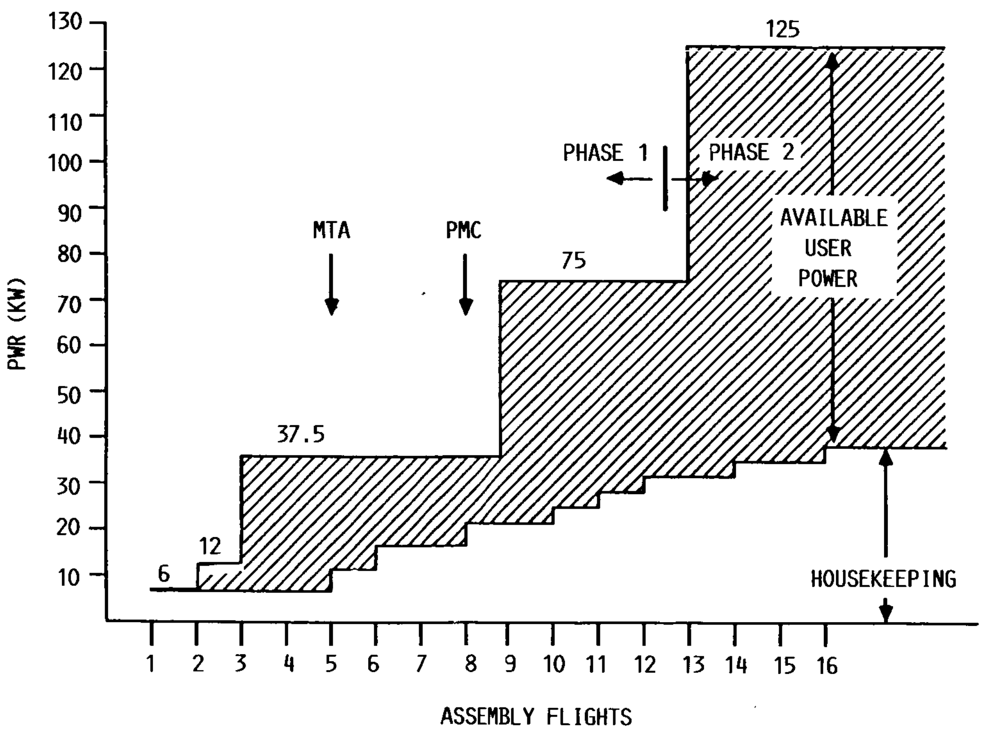


FIGURE 19. - PHASED PROGRAM USER POWER.

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Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-100140 IAF-87-234		

4. Title and Subtitle Space Station Electrical Power System	5. Report Date 6. Performing Organization Code 481-51-02
7. Author(s) Thomas L. Labus and Thomas H. Cochran	8. Performing Organization Report No. E-3692 10. Work Unit No.
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135	11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546	13. Type of Report and Period Covered Technical Memorandum 14. Sponsoring Agency Code

15. Supplementary Notes

Prepared for the 38th International Astronautical Federation Congress, Brighton, United Kingdom, October 10-17, 1987.

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17. Key Words (Suggested by Author(s))	18. Distribution Statement
Space station; Electrical power; Photovoltaic; Solar dynamic; Power management and distribution	Unclassified - unlimited STAR Category 20

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No of pages	22. Price*
Unclassified	Unclassified	18	A02

NASA FORM 1626 OCT 86

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