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OVERVIEW OF ENVIRONMENTAL TEST PLANS FOR SPACE STATION FREEDOM WORK PACKAGE 4

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ABSTRACT

The generation and distribution of electric power for Space Station Freedom (SSF) is critical to the station's success. Work Package 4 (WP-04) has the responsibility for the design, development, test, and delivery of the Electric Power System (EPS) for the SSF. During launch, assembly, and operation, the EPS will be subjected to various environments. A test and verification approach has been developed to assure that the EPS will function in these environments. An overview of that test program is presented with emphasis on environmental testing of hardware.

Two key areas of the test program are highlighted in the overview. One area is the verification of the Solar Power Module (SPM) and associated cargo element hardware. This area includes detailing the plans for development and qualification testing of the SPM hardware. One series of tests, including modal and acoustic, has been completed on a development cargo element.

Another area highlighted is the acceptance testing of high-power Orbital Replacement Units (ORU). The environmental test equipment plans are presented and reviewed in light of an aggressive production rate, which delivers ORUs to the WP-04 and other Space Station Work Packages.

Through implementing the test program as outlined, the EPS hardware will be certified for flight and operation on the Space Station Freedom.

INTRODUCTION

The detailed verification plans for testing the SSF EPS were developed during the initial proposal effort in 1987. Refinement of the plans has continued from that time and has been subjected to several architectural and configuration changes since. Through these modifications, hardware designs for every item has changed along with the functional requirements and schedules.

The latest change, called Restructure, initiated a major redesign of SSF to comply with congressional requirements. A Restructure Design Review (RDR) was held in August 1991, which outlined all major requirement changes and gave approval to implement the Restructure changes.

The intent of this paper is to present an overview of the WP-04 test and verification plans with emphasis on environmental testing. The particular environmental requirements invoked on WP-04 are specified in the WP-04 Technical Requirements Document, LeRC-SS-0001. This document includes a section on test requirements (Appendix C) and invokes compliance with MIL-STD-1540B, Test Requirements for Space Vehicles; SSP 30467, Master Verification Requirements Documents, Volumes 1 and 2; and NSTS 07700J, Space Shuttle System Payload Accommodations Handbook, Volume 14.

BASIC PHILOSOPHY FOR TESTING

The basic building block of the EPS is the ORU. Due to the Station's anticipated 30-year life, the current design philosophy is to provide a configuration that could be built, serviced, and repaired easily and inexpensive. The concept of ORUs comes from the aircraft industry where Line Replaceable Units (LRU) are commonly used. The EPS utilizes the ORU for items such as electronics, batteries, pumps, radiators, solar arrays, cables, and gimbals.

The WP-04 verification planning utilizes the ORU as the basic element for the conduct of qualification and acceptance testing. The ORU is qualified so it can be replaced in a system or assembly meeting a set of common requirements and not modified as a one-of-a-kind item for a unique configuration. Where a configuration or assembly of ORUs are necessary to meet a higher level of operating requirements, an assembly test at the higher level for qualification and acceptance has been identified.

The WP-04 has developed a test program, incorporating development, qualification, and acceptance phases of hardware development (Figure 1). Progressively higher fidelities of hardware are used in the test phases and complement the iteration of the design development process. The fidelities are Breadboard, Mass Thermal/Acoustic Model (MT/AM), Engineering Model (EM), Flight

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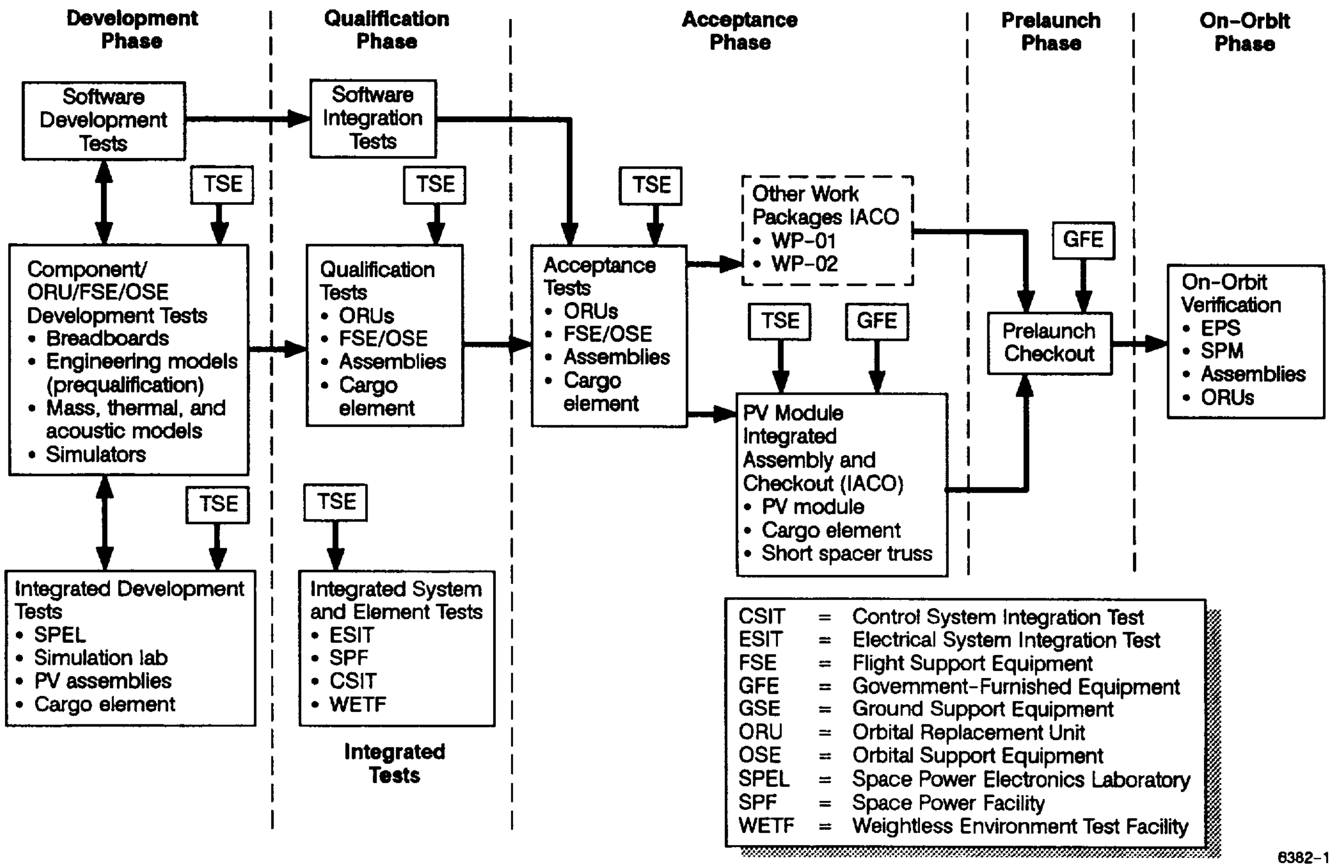


Figure 1. WP–04 Verification Test Logic

(qual), and Flight. Table I identifies the qualities of each fidelity.

EPS DESCRIPTION

WP-04 is responsible for the EPS and the associated SPM on the SSF (Figure 2). Rocketdyne is under contract to NASA Lewis Research Center (LeRC) for the design, development, test, and delivery of the EPS. Rocketdyne has several team member contractors that support this effort. The EPS is composed of ORUs and assemblies that

Table I. Hardware Fidelities

Hardware Fidelity	Functionality
Breadboard (BB)	Function only
Mass Thermal/Acoustic Model (MT/AM)	Physical weight, CG and configuration, nonfunctional
Engineering Model (EM)	Form, fit, and function of the flight hardware, "B" level EEE parts
Flight (Qual)	Flight hardware modified with qual instrumentation
Flight	Deliverable hardware for flight

D663-0005

control, store, and distribute power from sunlight to the power user. The WP-04 ORUs are housed in the SPMs, pallets attached on the Preintegrated Truss (PIT) and in all the SSF modules.

The SPMs are made up of one (port side) or two (starboard side) Photovoltaic Power Modules (PVPM) that are designed to produce 18.75 kW of power each. Major assemblies of the PVPM are the Integrated Equipment Assembly (IEA) and Photovoltaic Array/Beta Gimbal Assembly. Inboard PVPMs are attached to the SSF Solar Alpha Rotary Joint (SARJ). The outboard starboard side PVPM utilizes long and short truss sections to attach to the inboard PVPM (Figure 3).

The IEA includes the ORUs that house electrical power, control, and distribution electronics, battery cells, and ammonia coolant distribution hardware. Other hardware on the IEA comprise the Thermal Control Subsystem (TCS) and include a radiator, radiant finned heat exchanger plates, tubing, quick disconnects, and plumbing manifolds.

SPM hardware is launched on four National Space Transportation System (NSTS Space Shuttle) flights as preintegrated sections. Assembly and connection of the

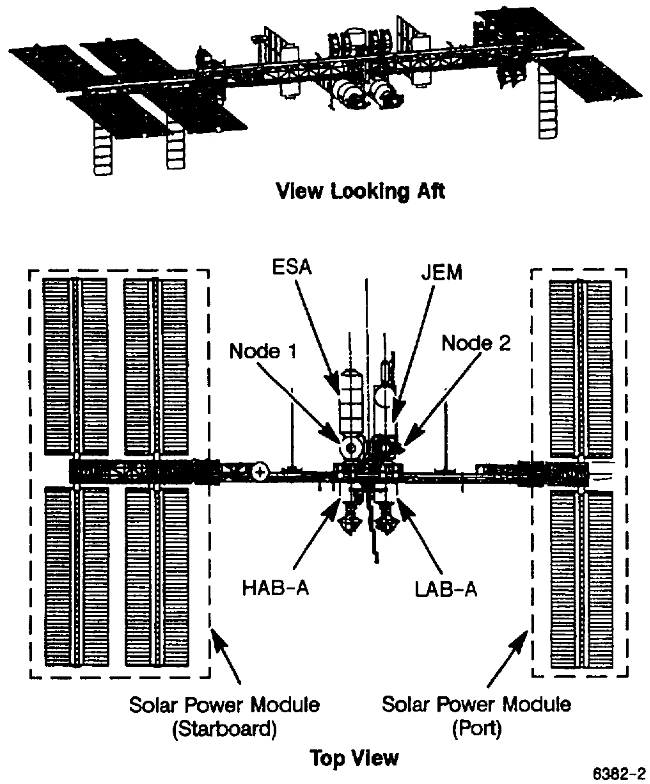


Figure 2. Space Station Freedom Permanently Manned Capability Configuration

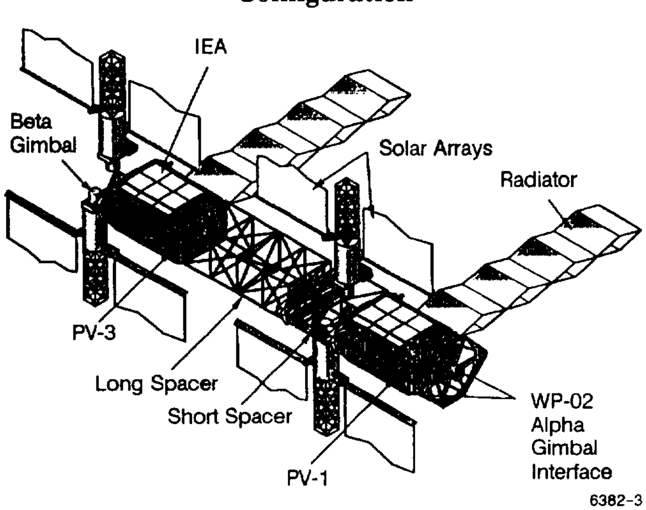


Figure 3. Solar Power Module

sections are made in orbit. The sections, identified as cargo elements, are identified as Types I though IV. Types I, II, and III include a PVPM. Type IV is the short spacer truss.

Other EPS hardware is distributed throughout the SSF to provide control, power distribution, and system protection. The hardware, as ORUs, is designed and manufactured by WP-04 and provided to WP-01, WP-02, and the international SSF partners [European Space Agency (ESA) and NASDA (Japan)]. Connection of the ORU hardware to the EPS is on-orbit.

CARGO ELEMENT VERIFICATION

Each cargo element will be subjected to a series of test activities at each verification phase to assure they meet the launch and on-orbit requirements. Types I and II cargo elements are identified as a combined element with element pieces from WP-04 and WP-02 (Figure 4). The cargo element will be subjected to a series of modal, acoustic, and static structural tests to qualify it for NSTS launch. Modal testing will fulfill the requirements of NSTS 07700J. Mechanical and electrical functional tests will be conducted after hardware is assembled and during the acoustic testing. Functional tests are not necessary during modal and static structural testing.

Types III and IV cargo elements will be subjected to a similar series of tests at qualification as Types I and II (Figure 5).

A key part of the verification of the PVPM in the on-orbit condition will be conducted at the LeRC Space Power

Test Matrix

Test	Qual	Flight Acceptance
Electrical functional	X	X
Mechanical functional	X	X
Modal	X[1]	
Acoustic	X	
Structural	X[1]	

[1] Qualification test with WP-04 hardware and WP-02 hardware

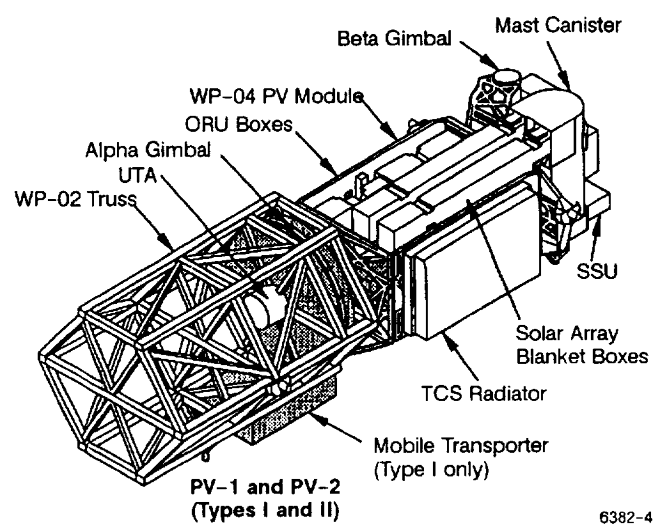


Figure 4. PV Cargo Elements Types I and II

Test Matrix

Test	Qual [1]	Accep
Electrical functional	X	X
Mechanical functional	X	X
Modal	X	
Acoustic	X	
Structural	X	

[1] Type III cargo element tests utilize qual PV IEA

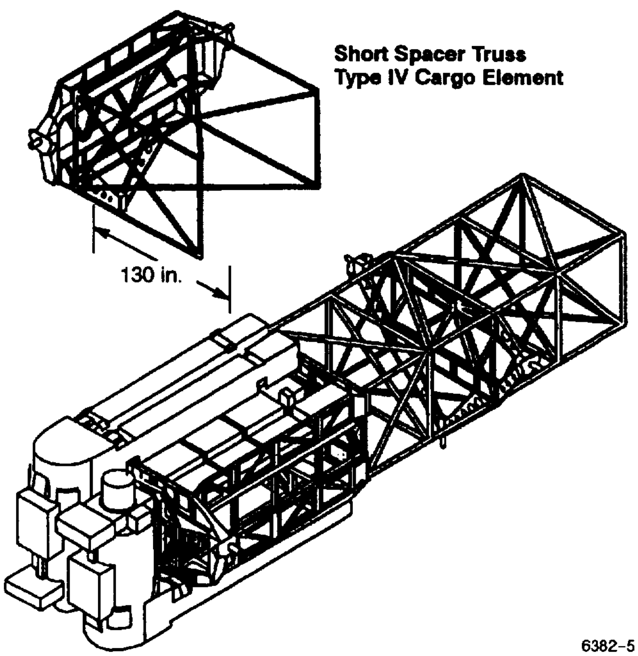
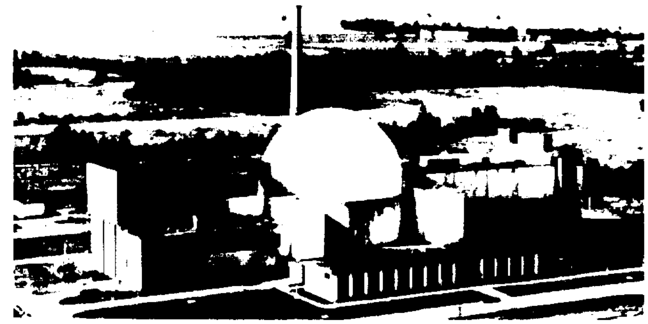


Figure 5. PV Cargo Elements Types III and IV



Space Power Facility
Plum Brook Station Ohio

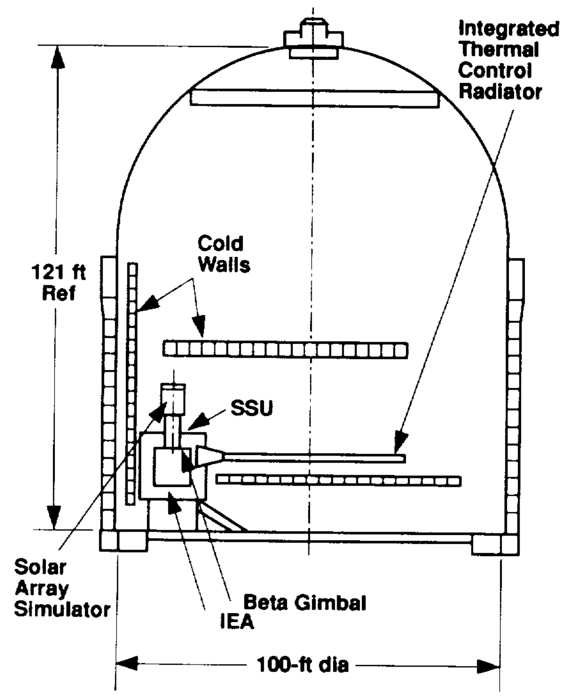


Figure 6. PV Module SPF Test

Facility (SPF) located at Plum Brook Station, Ohio (Figure 6). The test configuration will include a deployed Radiator and Beta Gimbal with Solar Array electrical and mechanical simulators attached. The test will be a mission simulation and will demonstrate PVPM start-up, operation, and shutdown in a space thermal and vacuum environment. One objective of the test is to verify the operation of the TCS used on the PV IEA. Functional tests will be conducted at peak, continuous, and contingency power modes.

The SPF will have several minor modifications performed on the facility to support PVPM testing. A backup power system will be installed and activation of the LN_2/GN_2 system is in work. A cryoshroud cold wall is currently being designed and will be installed at the facility in 1994.

Before shipment to Kennedy Space Center (KSC), each cargo element will be processed through an Installation, Assembly, and Checkout (IACO) (Figure 7). IACO will serve as the final factory acceptance test of the cargo element. The hardware will be configured in the launched configuration with checks of the mechanical and electrical interfaces, including the test of element-to-element interfaces.

The IACO process will involve the installation, alignment, and checkout of the PV Radiator (PVR), the Beta Gimbal/Solar Array Assembly and the installation of lighting and camera mounts to the cargo element. Checkout will verify data and communication interfaces and issue commands to the cargo element simulating SSF communications. These checks will be similar to those performed at KSC upon receipt of the hardware and before launch.

Integration of the WP-02 and WP-04 elements for the Types I and II cargo elements will be performed at KSC.

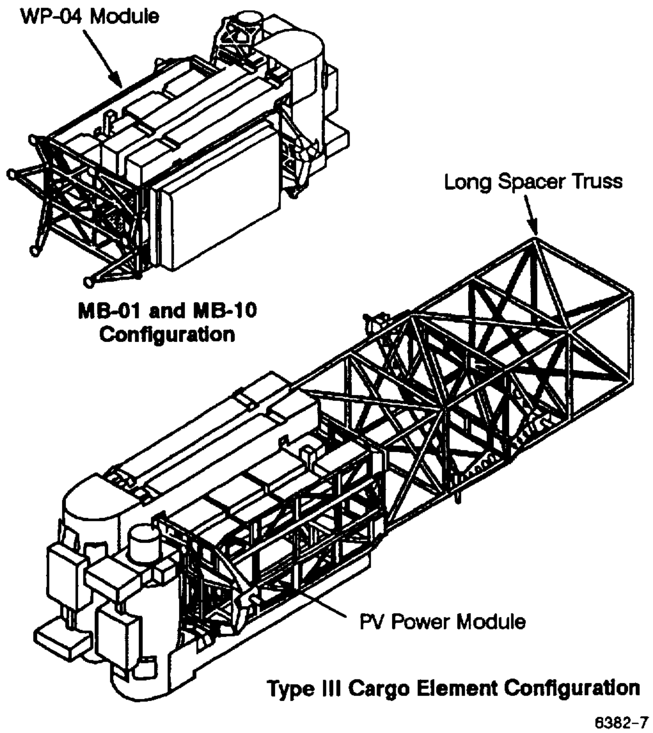


Figure 7. PV Module IACO

MAJOR ASSEMBLY AND ORU VERIFICATION

The IEA, which is the heart of the PVPM and weighs 34,000 lb, conditions and stores the electrical power collected by the PV arrays. It serves as the launch structure and supports the PVPM outboard of the SSF SARJ. The IEA houses the control, storage, and power ORUs for the PVPM. The IEA will be subjected to tests that affect its performance in space. Those tests are thermal vacuum and EMI/EMC (Figure 8). Structural tests, such as acoustic, static structural and modal, will be tested at the cargo element level.

The current test plan is to conduct the cargo element Type I testing and IEA tests for development and qualification at one facility. The planning includes shipment of all the hardware and support equipment for both IEA and cargo element to a single site after IEA assembly. The sequence of tests is shown in Table II.

Due to a tight test schedule (approximately 7 months), detailed plans have been generated to minimize the nontest time. The plan includes the installation of the electrical functional support equipment in a set of trailers. This will allow quick setup and checkout at the test facility.

The Beta Gimbal Assembly (BGA) provides the structural support and positioning for the Solar Array and allows control and power transfer through its rotating joint. The assembly is made up of Beta Gimbal Transition Structure (BGTS), bearing motor and roll ring module, and a platform. The tests planned for the BGA hardware are shown in Figure 9. The current plan is to utilize the test facilities at Rockwell Space Systems Division, Seal Beach, for BGA testing.

Other major PVPM hardware items are the Solar Array Wing and PV Radiator (PVR). The wing is supplied to Rocketdyne by Lockheed Missile and Space Company (LMSC). Two wings are required for each PVPM. The wing

Test Matrix

Test	Qual	Flight Acceptance
Electrical functional	X	X
Mechanical functional	X	X
Thermal vacuum	X	
EMI/EMC	X	

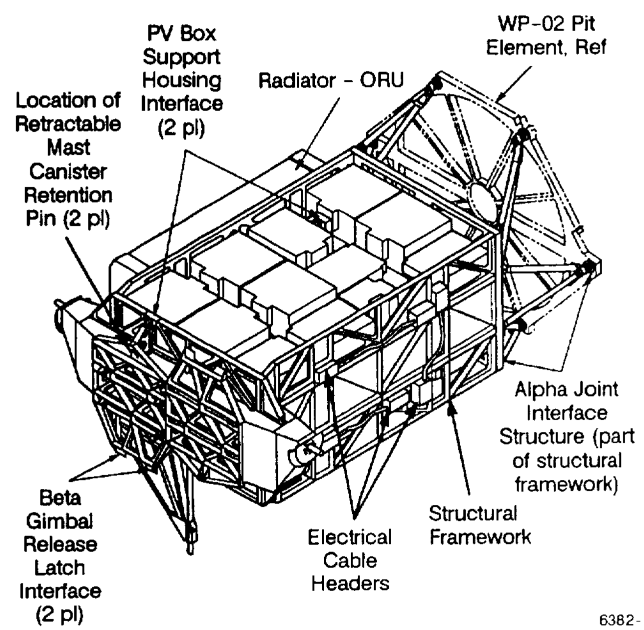


Figure 8. Integrated Equipment Assembly

Table II. PV IEA/Cargo Element Type I and II Test Sequence

Test	Hardware Configuration
EMI/EMC	PV IEA
Thermal Vacuum	PV IEA
Acoustic	Type I Cargo Element
Modal (development only)	Type I Cargo Element
Static Structural (qual only)	Type I Cargo Element

D663-0005

Beta Gimbal Assembly

Test	EM	Qual
Electrical functional	X	X
Mechanical functional	X	X
Modal		X
EMC/EMI	X	X
Random vibration	X	X
Structural	X	X
Thermal cycle	X	X
Thermal vacuum	X	X

Angular Contact Bearing

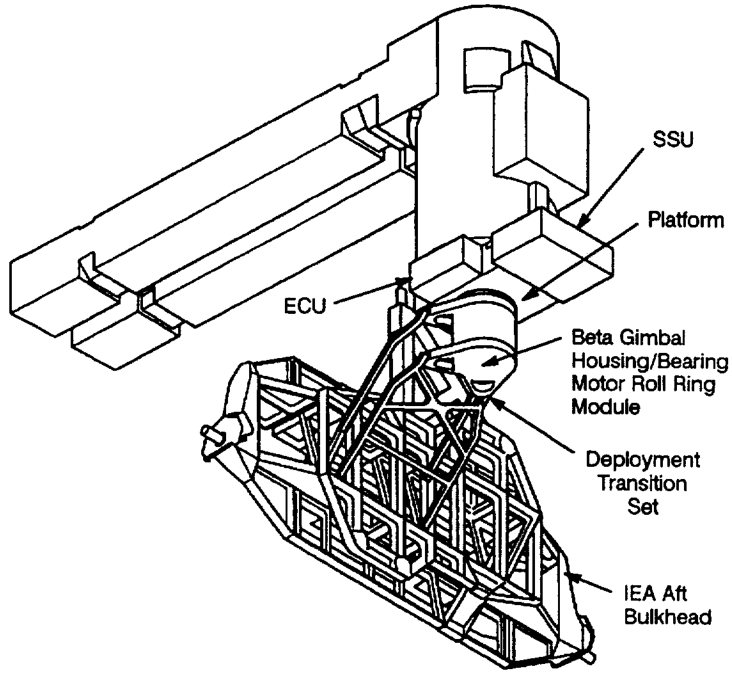
Test	EM	Accep
Life	X	
Mechanical functional	X	
Random vibration	X	
Proofload	X	

Deployment Transition Set

Test	Qual	Accep
Mechanical functional	X	X
Vibration	X	X
Structural	X	X

Bearing Motor and Roll Ring Module

Test	EM	Accep
Mechanical functional	X	X
Electrical functional	X	X
Random vibration		X
Thermal vacuum		X



Platform

Test	EM	Accep
Mechanical functional	X	X
Electrical functional	X	X
Random vibration		X

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Figure 9. Beta Gimbal Assembly

is made up of a mast ORU and two blanket and box ORUs. One blanket and box ORU, measuring 15.3 ft by 111.6 ft (when deployed) contains 16,400 8-cm square solar cells. The planned tests for the wing hardware are shown in Figure 10.

The PVR is built by LTV Aerospace and Defense Company and includes eight panels 11.7 ft by 6.5 ft. It is deployable in space and contains two thermal loops for radiation of waste heat from the IEA to space. The heat transfer fluid is single-phase ammonia. The test plans to the PVR are shown in Figure 11. A thermal vacuum deployment test of the PVR is currently planned to be conducted at SPF, Plum Brook, Ohio.

PMAD ORU TESTING

The Power Management and Distribution (PMAD) ORUs and the associated cabling control and manage the EPS power. They are located throughout the SSF to provide power feeds, conversion from 160 Vdc (primary power) to 120 Vdc (secondary power), and remote power control and distribution to the users. The ORU types are shown in Table III.

The DDCU(I) and DDCU(E) will be located throughout the SSF including attached to truss sections, housed in Nodes, Lab, Hab, Attached Pressurized Module (APM), ESA and Japanese Experiment Model (JEM) Modules and attached to the IEA. The DC Switching Unit (DCSU) is housed on the IEA also. The Electronic Control Unit (ECU) is attached to the Beta Gimbal Platform. Main Bus Switching Units (MBSU) will go on a truss section and Remote Power Controllers (RPC) will be located throughout the SSF.

Each ORU type will be subjected to an environmental development test series and formal qualification testing. The required tests for qualification of the ORUs are identified by LeRC-SS-0001 and MIL-STD-1540B. The ORU is classified as a component in MIL-STD-1540B terms. Table IV shows the tests identified for the PMAD ORUs.

Requirements for development testing of EM ORUs will be very close to the requirements of the qualification test. Tailoring of the test requirements will be specified for

Solar Array Wing

Test	Test Phase	
	Qual	Accep
Mechanical functional	X	X
Thermal vacuum	X	X
Thermal cycling		
Random vibration		
Acoustic EMC	X*	X

*Conducted with EM PV IEA test

Component and Assembly Tests

Test	Test Phase		
	Dev	Qual	Accep
Thermal vacuum		X	X
Thermal cycling	X	X	X
Random vibration		X	X

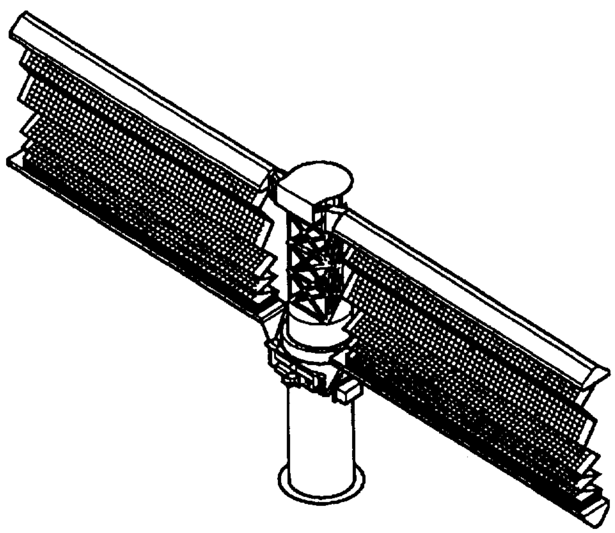

Figure 10. Solar Array Wing

unique environments that the hardware was designed to meet. The development testing will provide design data to support the release of the flight hardware drawings. The test will also be used as a lessons learned experience to assure that qualification testing progresses smoothly.

Qualification of the ORUs will be conducted on flight quality hardware and will utilize a dedicated unit for testing. Tailoring of the test requirements will also occur for the qualification test.

Acceptance testing of the ORUs follow the required tests as identified in requirement documents. Test tailoring includes the deletion of burn-in of ORUs, with the exception of RPCs. Burn-in of hardware items at the sub-ORU level is conducted before ORU assembly. This allows for

PV Radiator

Test	Test Phase		
	Dev	Qual	Accep
Functional	1	X	X
Thermal vacuum			
Panel	1	2	
Assembly		X	X
Acoustic		X[4]	
Leakage		X	X
Pressure		X	X
Flow	1	X	X
Thermal cycling		3	3
EMI/EMC		3	
Burn-in			3

[1] Element testing only
[2] One qual panel only
[3] Electronics only
[4] Conducted with qual PV IEA test

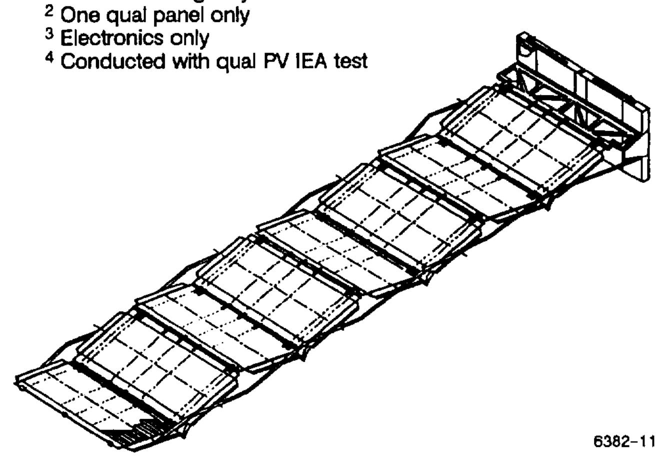

Figure 11. PV Radiator

Table III. Rocketdyne PMAD ORU Types

Acronym	Name	EM, F(Q), and F Qty (Units)
DDCU(E)	DC/DC Converter Unit (External)	38
DDCU(I)	DC/DC Converter Unit (Internal)	35
DCSU	DC Switching Unit	14
ECU	Electronic Control Unit	11
MBSU	Main Bus Switching Unit	13
RPC Type I	Remote Power Controller 8 Ch/12A	71
RPC Type II	Remote Power Controller 4 Ch/25A	48
RPC Type III	Remote Power Controller 2 Ch/50A	65
RPC Type IV	Remote Power Controller 1 Ch/65A	53
RPC Type V	Remote Power Controller 3.5A/12A	324
RPC Type VI (noncurrent limiting)	Remote Power Controller 4 Ch/25 A	32

D663-0005

Table IV. PMAD ORU Tests

Development and Qualification Tests	Acceptance Tests
Functional	Functional
Random Vibration	Random Vibration
Thermal Cycling	Thermal Cycling
Thermal Vacuum	Thermal Vacuum
Burn-in (RPCs only)	Burn-in (RPCs only)

D663-0005

less test time on the ORU saving manpower and test equipment and reducing failures at the ORU level.

Table III shows the quantity of each hardware type to be produced for ground test and for flight. Based on the quantities and the required tests, the challenge was to develop a method for testing space-rated hardware at rates up to 15 items per month and to keep costs at a minimum. Each item requires a series of acceptance tests. Due to the long duration of the testing and the high production rate, a study was conducted to determine attributes and requirements of a test system that would meet the test requirements and be cost efficient. As part of the study, a test equipment system was reviewed that provided the features of conducting all the thermal tests in one setup and thus utilizing a common vacuum system. The system, known as the Multiple Environments Test System (METS), is utilized by Rockwell Space Systems Division, Seal Beach, for thermal testing of Navstar Global Positioning Satellite (GPS) electronic hardware. The EPS hardware is larger than the GPS items, but the concept proved to be cheaper than a system of separate chambers and vacuum system.

The systems devised, called the Thermal Vacuum and Cycle System (TVACS) and patterned after the METS, uses a configuration of four or eight chambers in a star configuration around a common cryogenic vacuum pump. The system would meet the requirements of thermal cycling, thermal vacuum, and burn-in tests in a single test setup minimizing setup and checkout times.

The TVACS and associated support equipment, along with functional checkout and vibration test areas, will be installed in a newly modified 100,000 class building at Rocketdyne. The area has been designated for the performance for development, qualification, and acceptance testing of the ORUs. The one exception is electromagnetic interference/electromagnetic compatibility (EMI/EMC) testing. That testing is planned for Rockwell Autonetics Marine & Aircraft Systems Division where EMI/EMC capabilities exist.

CURRENT PROGRESS

The early development testing of WP-04 hardware is progressing and is supporting the detailed design of the flight hardware. The major tests include efforts on ORU boxes and an acoustic test of an early version of the PVPM.

A series of tests on ORU boxes is continuing. These tests include vibration, thermal cycling, and thermal vacuum. The objectives of the testing are to verify the thermal analysis of the box design and to verify the structural design of the box.

A major development milestone was completed in the fall of 1990 with the successful completion of dynamic testing on the PV IEA MT/AM. The tests were key to the development of the IEA. The tests were also the first major test of a SSF cargo element in a dynamic environment.

The series of tests provide the detailed data to verify the analysis models generated by Rocketdyne. The analysis is being used to approve future IEAs and cargo element configurations for flight.

The test series include a modal test and an acoustic test of the IEA. The modal test was conducted on the bare IEA structure. The test, using low amplitude vibration excitation, measured the natural frequency and mode shapes of the IEA structure. The test was conducted by Rocketdyne Division at Rockwell North American Aviation Division located in El Segundo. The test involved the acquisition of 300 channels.

The acoustic test simulated the dynamic (noise) environment of a Space Shuttle launch, plus a 6 db design margin, and was used to verify and measure the dynamic environment each ORU would experience during an NSTS launch. This information will be used to assure each design would endure launch and operate during orbit.

The test involved configuring the IEA into a cargo element. This included the installation of ORU boxes simulating electronics, batteries, and other simulators for solar arrays, gimbal joints, and a radiator. The IEA was then instrumented, transported to the Martin Marietta facility in Denver, and placed in a 30 ft by 38 ft by 60 ft acoustic chamber at that facility (Figure 12).

The IEA was subjected to seven different acoustic levels in 3 db increments, including the NSTS launch level, and concluding at 6 db higher than the launch level. The IEA passed all test levels with no problems. Data review of the test indicated that the acquired information was as expected and invaluable to the development and design of the IEA.

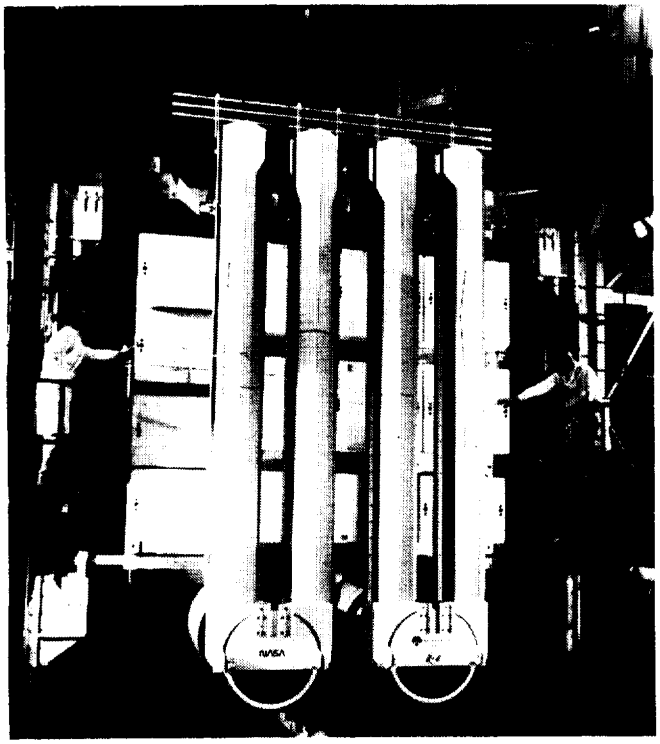

Figure 12. IEA Installed in Acoustic Test Facility

SUMMARY

WP-04 has a wide variety of hardware to test requiring extensive planning and utilization of several test facilities. The applicable requirements documents have been reviewed and a tailored approach to testing has been identified. The approach will meet the unique SSF requirements and will assure that the WP-04 hardware will function nominally when subject to the launch and on-orbit environments. Testing has begun with results being utilized in the flight hardware design.

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