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Spacelab Development Status

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SPACELAB DEVELOPMENT STATUS

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Abstract

At the beginning of 1979, the SPACELAB program has attained one of its major objectives: the Engineering Model (EM) is fully assembled according to planned test configurations and is operating and demonstrating its functional capability at ERNOs Spacelab Integration Facility.

Delivery of Flight Unit Hardware to the ERNO Integration Center has started and preparations for FU Integration and Test activities are set up accordingly.

This paper describes the current SPACELAB development status in more detail by addressing the following areas: Implementation of Requirements; Model Philosophy; Spacelab Systems/ Subsystems; Industrial Organization; Qualification Program; and Status of Integration & Test activities.

Section 1:
SPACELAB and its Modular Philosophy

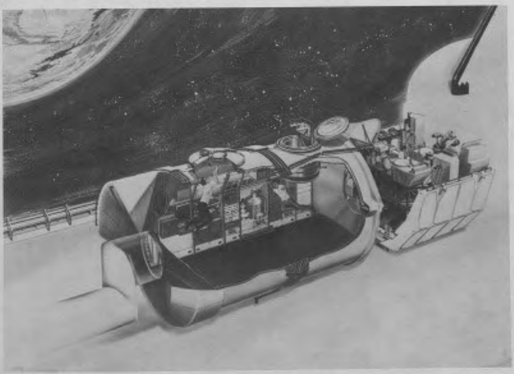
SPACELAB, the reusable, multi-mission laboratory represents Europe's first manned space venture and complements the U.S. Space Transportation System (STS). It is a program with not just one single end product but has a large variety of forms, depending on how the modular elements are put together. This approach is new. All previous projects in Europe and America have had one end product: a satellite, a probe or a rocket, designed for one task.

SPACELAB design and development commenced in June, 1974, when the European Space Agency (ESA) awarded the contract to an Industrial Consortium led by ERNO/VFW-Fokker.

A wide spectrum of objectives and requirements had to be met, e.g.

- Economic efficiency in terms of reusability and significant reduction of both time and cost required for space experimentation
- Provision of a general purpose support capability to be flown in low earth orbits for a large multi-disciplinary user community
- Provision of a shirt-sleeve environment for scientists and engineers without the need of full astronaut training
- Support STS program objectives.

To satisfy this variety of goals, a modular design (Figure 1) was developed by the ERNO team for building SPACELAB as a general purpose laboratory which can be combined to form different flight configurations (Figures 2 + 3) and provide utmost flexibility. During a mission, SPACELAB remains attached to the Shuttle Orbiter and represents a typical "working facility", with crew accommodations provided in the Orbiter.



Spacelab In Orbiter Bay (Artist's View)

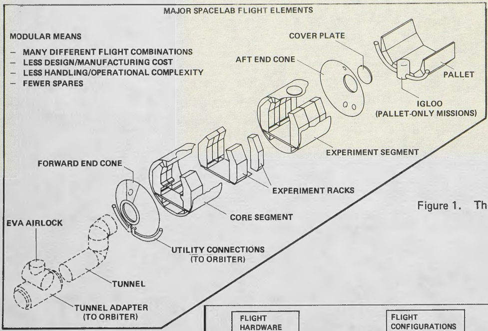


Figure 1. The Modular System

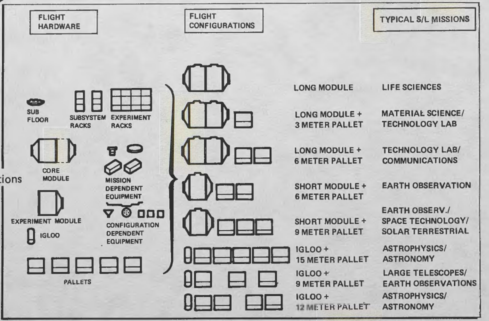


Figure 2. Typical SL Flight Configurations

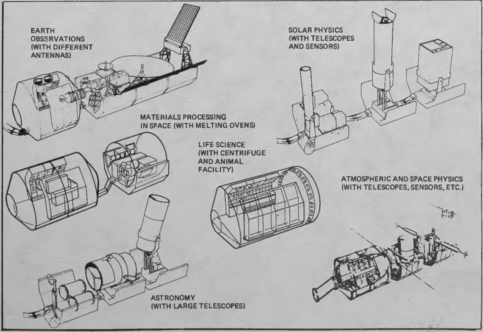


Figure 3. Typical Spacelab Payloads

Section 2: SPACELAB System/Subsystem Elements and Industrial Organization

SPACELAB is composed of three basic system elements – the Module, the Pallets and the Igloo, and subsystems spanning the three major system segments.

Structure

The Module (Figs. 4–7) is a pressure cylinder consisting of a combination of either one or two 4 m diameter segments of 2.7 m length. A core segment and the forward and aft end cones compose the short module. A core segment and experiment segment

Figure 4. Spacelab – Long Module with one Pallet (Engineering Model) during test preparations in the ERNO Integration Facility, representing first flight configuration (second pallet installed for electromagnetic compatibility test and preparation of pallet train handling)

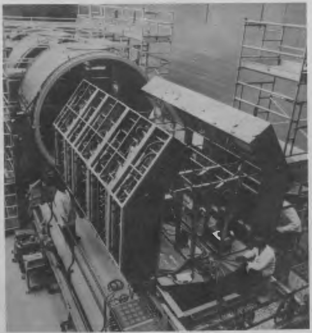


Figure 5. Spacelab – Long Module with Experiment Train (Racks) being installed (Engineering Model)

compose the long module. Main features include floors and standardized equipment racks. Subsystem equipment is mounted in two double racks and on a subfloor beneath the main floor, experiment equipment is accommodated within additional racks, which can be readily installed or removed from the module, facilitating the integration of experiments "off-line".

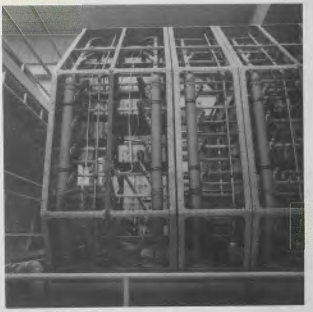


Figure 6. Provides a rear view into a double rack (center) and a single rack (left) showing the air cooling ducts and the fire suppression system.

Figure 7. Spacelab – view into long module; racks equipped with heat load dummies

A central aisle, handrails, foot restraints, storage containers and other provisions are standard crew-oriented features. The module segments are roll-formed waffle pattern aluminum alloy sheets welded at the seams, with end flanges of forged aluminum to provide for mechanical attachment between module segments and with the end cones. The flanged joints are bolted to provide for ease of assembly/disassembly. The module is designed to perform at least 50 missions resisting meteoroid and radiation impact. The long module can carry a maximum of 4600 kg of experiments.

The Pallets (Figures 8, 9) are identical modular units which can be mounted either separately or joined into pallet trains.

Their structural design accommodates heavy equipment on hardpoints which transfer loads to the Orbiter via the pallet trunnions and the Orbiter attachment points. Lighter equipment can be mounted with stand-offs to the inner panels of the pallet or on coldplates.

The pallet segments are an aluminum structure with aluminum honeycomb panels having a surface finish to give good thermal characteristics. Pallets are designed to carry a maximum load of 3000 kg each and are 3 m in length and 4 m wide.

Figure 8. Spacelab – Pallet (Engineering Model), equipped with Cold Plates, Command and Data Mangement Subsystem and Electrical Power and Distribution Subsystem

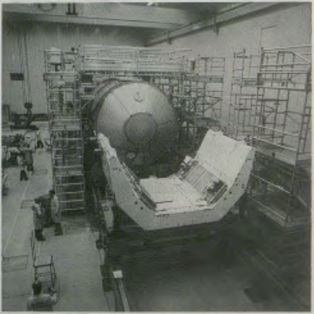


Figure 9. Test Preparations Pallet with Long Module (EM)

The first SPACELAB OFT-pallet (Orbital Flight Test Pallet) arrived at NASAs Kennedy Space Center in Florida on Dec. 4, 1978, and will be used by NASA on orbital tests of the Space Shuttle in 1980.

The pallet, packed in a special container, was shipped by sea mid-November from Bremen to the Cape via Savannah (Georgia) and the Intrastate Coastal Waterways.

The second OFT-pallet has just arrived at KSC (week of April 14, 1979). Altogether four OFT-pallets will be delivered to KSC, constituting part of the pre-orbital Orbiter payload, intended to collect data prior to the first operational flight of SPACELAB.

Figures 10,11. Arrival of OFT—Pallet at Kennedy Space Center, Florida

The Igloo (Figs. 12, 13) provides for environmental control of subsystem equipment in pallet-only configurations. Specifically, for equipment which is normally mounted within the module and requires a pressurized controlled environment. The main features of the Igloo are the Primary Structure, the Secondary Structure (which incorporates features for pressurization and plus or minus overpressure safety provisions). The Igloo is attached to the forward pallet in the pallet train. Thermal control of the Igloo is both active and passive, with most equipment coldplated to the freon system. The internal atmosphere is air, with a drying agent included to avoid condensation after closing. Nitrogen is added via a fill valve to assure sufficient internal pressure (accounting for possible leakage to space) during the mission. Overpressure safety protection is provided redundantly by a relief valve and a burst disk.

Environmental Control

The Environmental Control System (ECS) provides two general functions: thermal control, and environmental control and life support. Its specific functions include:

- Maintaining pressure, temperature, humidity and composition of the cabin air within specified limits.
- Provides for transfer of the heat loads generated within the module and on the pallets to the Orbiter thermal control system.
- Limits the heat flux (in both directions) between the module and its environment.
- Provides for fire detection and suppression in the module.

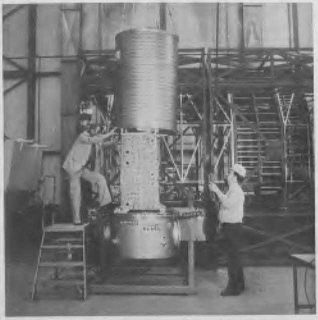


Figure 12. Igloo Cover Mating (EM).

Figure 13. Igloo Thermal Control Testing.

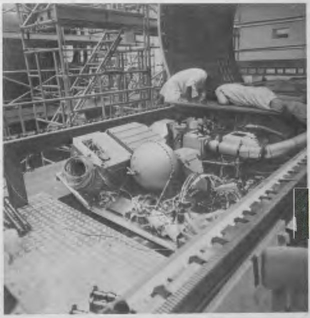


Figure 14. Spacelab Subfloor Installation Activities (EM).

Figure 15. Spacelab Module with integrated Subfloor.

Avionics

The avionics group contain the subsystems of the Command and Data Management (CDMS), Electrical Power and Distribution (EPDS) and System Activation and Monitoring (SAM).

The Command and Data Management subsystem provides for the transmission of commands to the Spacelab subsystems and experiments to onboard computers. Onboard display is available in the Module and Aft Flight Deck of the Orbiter. Transmission of high/low rate data is accomplished as well as data storage for periods when the Orbiter is not in communication with the ground. Voice intercom and digitized voice systems are also provided. Figure 16 shows primary items of CDMS equipment.

Figure 16a. Command and Data Management Subsystem (Ground Version).

Figure 16b. Data Display Unit/Keyboard

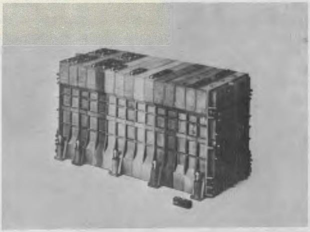


Figure 16c. Remote Acquisition Unit.

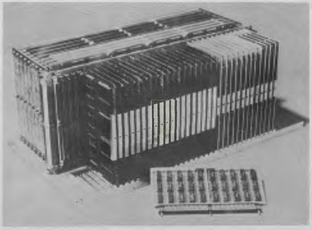


Figure 16d. On-Board Computer.

The Electrical Power Distribution Subsystem conditions and distributes power supplied by the Orbiter. A DC supply of 24 V is provided at the user inputs and EPDS inverters provide 400 Hz, 3-phase power at 115 and 200 V. Figure 17 shows the units of Electrical Power Distribution System.

Figure 17a. Experiment Power Distribution Box.

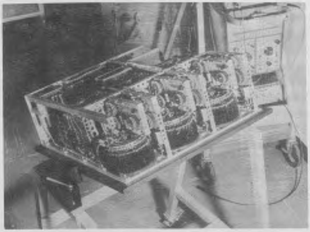


Figure 17b. Inverter

System Activation and Monitoring provides the only interface between SPACELAB and the Orbiter when SPACELAB is dormant. It provides for initial activation and monitors housekeeping data. The subsystem is composed of three subunits which are illustrated in Figure 18.

The Integrated Monitoring Control Panel (Figure 18a) is located in the Orbiter aft flight deck and provides manual command and status information of subsystem equipment, fire suppression and experiment safing. The Remote Amplification and Adaption Box (Figure 18b) provides for all electrical interfaces between SPACELAB and the Orbiter. It provides amplification and signal conditioning, clock signal distribution and heater activation. The Caution and Warning/Fire Suppression System (Figure 18c) is located in the Control Center Rack and provides commands and indication of the fire suppression system and caution and warning interfaces.

Figure 18b. Remote Amplification and Adaption Box (RAAB)

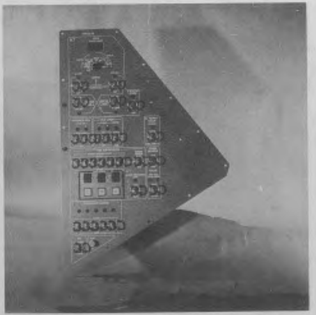


Figure 18a. Integrated Monitoring Control Panel — R7

Figure 18c. Caution and Warning/Fire Suppression Panel

Software

The Spacelab software was specifically developed for and tailored to the modular Spacelab design. The scope of the available Spacelab software comprises:

- The Software Subsystem used on board (Command and Data Management) to control the engineering environment of the SPACELAB via the Subsystem Computer and to provide capability for control and data management of the experiment hardware via the Experiment Computer.
- The Software Subsystems used on the ground. Firstly, the Automatic Test Equipment Subsystem (ATE) to provide capability for an operational ground checkout of all Spacelab features and secondly, the Data Base Generation and Maintenance Subsystem, to produce mission dependent data sets to be implemented into the operational onboard (CDMS) and ground (ATE) software.

The software is in production at each of the cocontractors. Preliminary deliveries of the software packages have been made to ERNO to allow an early start on system integration and preparation for planned hardware and software compatibility tests.

Industrial Organization

Figures 19 and 20 illustrate the Spacelab Industrial Team Organization and respective tasks, indicating the extent of multinational participation.

Working with the cocontractors are many subcontractors within Europe and the United States of America, giving a total of more than 50 companies. The multi-national/multi-lingual character of SPACELAB represents a significant management challenge which has been successfully met.

Moreover, the Spacelab industrial team is developing the basis for further European collaboration on future high technology projects in the area of manned space flight and its future application.

Figure 21 represents our latest Spacelab Program Schedule and indicates where we stand in relation to major deliveries and program activities.

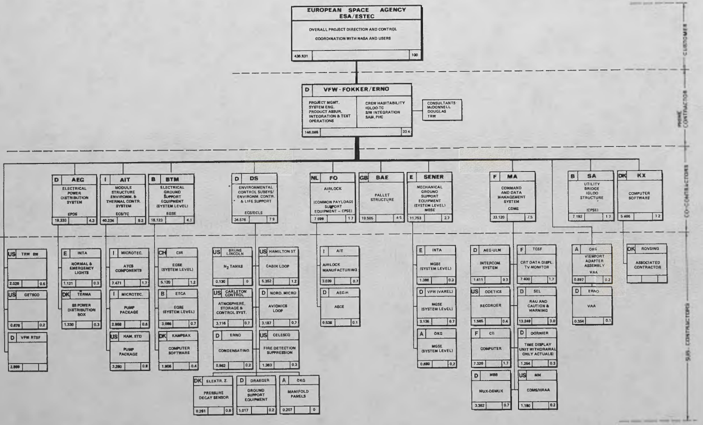


Figure 19. Spacelab Industrial Team Organization

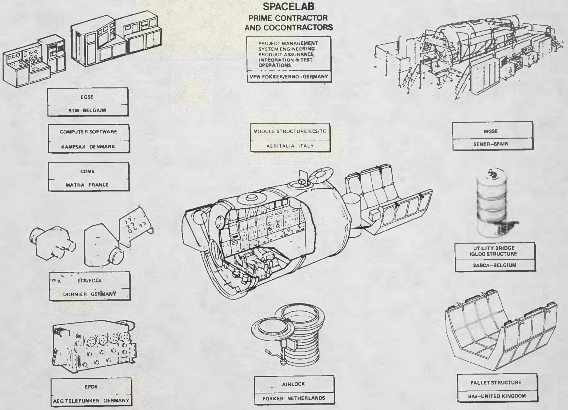


Figure 20. SL Prime Contractor's and Cocontractor's Contribution to Spacelab.

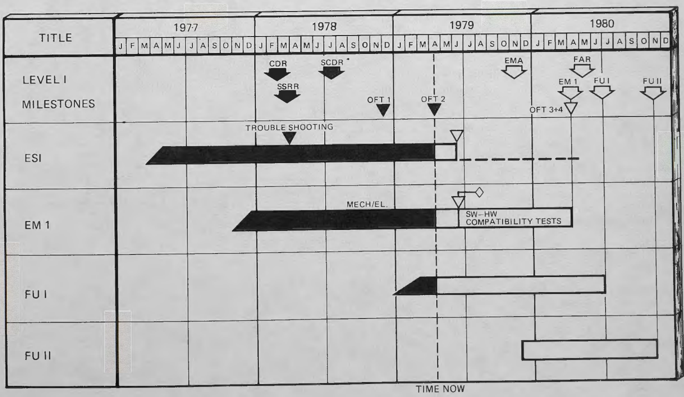


Figure 21. Spacelab Program Schedule.

Section 3:
Spacelab Qualification Program

The purpose of the Spacelab Qualification Program is to demonstrate and prove the SPACELAB is in conformance with its design requirements and is capable of meeting specified performance requirements under specified environmental, operational and design life conditions.

It is important to note that the qualification of SPACELAB is achieved by several verification techniques, such as

- physical test
- analysis
- similarity
- review of design.

This is done at the equipment level, the subsystem level and of course the system level.

The qualification program is also supported by major system and subsystem Critical Design Reviews, most of which were successfully accomplished in 1978. ESA and NASA jointly participated in these major design reviews. Further support is provided by the development and pre-qualification tests now mostly successfully completed. The formal qualification test program now underway is showing good results and is expected to be concluded by the end of this year, 1979.

Overall management tracking and control is exercised by the Spacelab Verification Control Program. Verification Control Documents account for specified requirements, identify the selected verification method and level, and document successful closeout.

Validation by the Verification Review Board certifies correctness and completeness of each entry to the Verification Control Documents, and leads to bi-lateral agreements that qualification is certified.

Spacelab hardware is thus qualified by incremental activities at all levels from the parts, materials and processes up to the system level. These activities are performed by all supplying agencies.

The Qualification Program results in the generation of Certificates of Qualification at three levels, equipment level, subsystem level and system level.

Figure 22 shows, how the System Requirements can be traced into the Qualification Program.

This program is unique in the sense that almost all requirements are identified, tracked and finally verified. Those, which are not handled by this system are omitted by agreement with ESA, largely because they are handled by other techniques or are not cost effective to be tracked in this system.

Specific attention is given to the Spacelab System Specification and some 19 Hardware and Software Subsystem and Equipment Specifications. Typical of the numbers of requirements being managed and controlled by this system are the following, representing the 9 most mature Verification Control Documents of 20 to be produced:

- 4966 requirements are identified; of which
  - 194 are most high priority requirements
  - 1173 are high priority requirements
  - 885 are lower priority requirements, and
  - 2714 requirements are not tracked because of redundancy or other reasons.

Examples of how these requirements are verified are as follows: on a system level basis the Engineering Model, currently assembled and functioning in the ERNO Integration facility at Bremen, provides the essential test results to verify/qualify requirements that can only be tested at the system level.

Figure 23 shows typical Engineering Model test requirements. Three examples are brought into sharp focus to show test objectives, which will provide the objective evidence that specified performance has been achieved and verified.

Many specification requirements can be verified by simpler techniques and Figure 24 shows examples taken from our system verification control document, where lesser priority requirements have been verified. On this sheet five specification requirements have been verified by analysis.

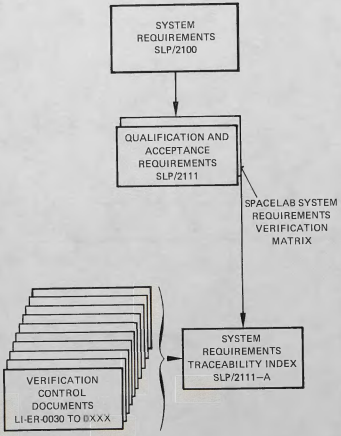


Figure 22. Traceability from System Requirements Document into Verification Control Program.

ENGINEERING MODEL TEST REQUIREMENTS SUMMARY			
Test Category	**Objectives**	**Test Req.**	**Test Req. Doc. Number**
ECS Performance Test	Specific characterization test performed on full LM/1P Configuration Humidity Control will be verified along with Exp. Heat Exchanger. Impact on the Water Loop will be determined	TR 30 XX	PAQ 1056389 Sh. 4
H/W-S/W Compatibility	Demonstrate correct system functional operation and timing across the full range of SL operation with the operational S/W	TR 37 XX	PAQ 1056389 Sh. 11
High Rate Data Assembly	Verify the performance of the HRDA under nominal and specific EM 1 situations	TR 4200 – TR 4220	PAQ 1056389 Sh. 23

Figure 23. Typical List of EM test requirements

VFW-FOKKER ERNO Modular SPACELAB

SUBSYSTEM VERIFICATION CONTROL SHEET

SPEC. TITLE : SPACELAB SYSTEM
SPEC. No. : SY-ER-0001 ISSUE: III CHANGE DATE: 29.07.78

DOC. NO.: LI-ER-0030
ISSUE: 3 DATE DEC. 77
CHANGE: C DATE: JAN. 79
PAGE: 2–2

IDENT. NO.	SS/EQ SPEC. PARAGRAPH	VERIFICATION REQUIREMENTS	VERIFICATION METHOD EQUIPMT LEVEL	SUBSYST LEVEL	SYSTEM LEVEL	TRACE NO.	VERIFICATION REF. DOC.	FINAL VERIFIC. DOCUMENT (E.G. TEST, ANALYSIS, INSP. REPORT)	REMARKS
101 006 C	3.4.1/a	Payload allocated cylindrical sidewall length of the Module. CONF / PARAM/FUNCT. LM 4338 (mm) SM 1638 (mm)	—	—	Anal	—	—	TN-ER-37-003-78 VRB 3 16.11.78	
101 007 C		Verify Module, total equipment allocated volume along sidewalls. CONF / PARAM/FUNCT. LM 17.30 (m^3) SM 8.65 (m^3)	—	—	Anal	—	—	TN-ER-37-003-78 VRB 3 16.11.78	
101 008 C		Verify Module, payload allocated volume along sidewalls. CONF / PARAM/FUNCT. LM 13.88 m^3 SM 5.24 m^3	—	—	Anal	—	—	TN-ER-37-003-78 VRB 3 16.11.78	
101 009 C		Verify Module, total equipment volume ceiling center aisle subfloor. CONF / PARAM/FUNCT. LM 10.94 m^3 SM 5.9 m^3	—	—	Anal	—	—	TN-ER-37-003-78 VRB 3 16.11.78	
101 010 C		Verify Module, payload allocated volume ceiling center aisle subfloor. CONF / PARAM/FUNCT. LM 8.34 (m^3) SM 2.42 (m^3)	—	—	Anal	—	—	TN-ER-37-003-78 VRB 3 16.11.78	

VRB 3 16.11.78 VRB 3 VRB 3 VRB 3 16.11.78 VRB 3 VRB 3 16.11.78 VRB 3 VRB 3 16.11.78 VRB 3 16.11.78 VRB 3 16.11.78 VRB 3

Figure 24. System Verification Control Sheet

Section 4:
Integration and Test Status

Integration and Test activities with the SPACELAB Engineering Model (EM) commenced in the first part of 1978, after more than three years of subsystem development at the production plants of the various cocontractors. This was the first time a complete vehicle was assembled.

Being almost physically and functionally identical to the Flight Unit (FU), the EM is serving the following major purposes:

- Verification of the integratability of the mechanical layout
- Qualification of the functional and operational hardware and software design of the modular SPACELAB system. This includes the SPACELAB itself as well as the corresponding Mechanical and Electrical Ground Support Equipment.

These tasks form an essential part of the Spacelab Qualification Test Program. The program is characterized by a concept which required early design feedback and a low cost approach, resulting in the following determining features:

a) All environmental qualification testing (vibration, acoustic noise, thermal vacuum, etc.) is performed on equipment level
b) Functional qualification of individual equipment (mechanical, avionic, fluid) is performed on equipment level
c) Qualification of integrated functional and operational performance is performed at system level.

Figure 25 shows the top integration and test flow of the Engineering Model. It can be divided into two principle phases.

1) Phase 1 is related to integration and the verification that the final hardware configuration conforms to the designed status. The Open Long Module, which is a ground operation configuration, is assembled. Performance characteristics are verified from here on.
2) Phase 2 is related to qualification testing. After the Open Long Module, a Long Module plus one Pallet configuration is built identical to the first flight configuration and used for the qualification of those functional flight performance characteristics which can be tested in the 1 g ground environment.

The most important elements of this test program are:

- Interface tests
- Integrated System Performance Tests
- Operational demonstration

Hardware testing will be followed by software compatibility tests. This approach has been chosen to allow easier and faster resolution of failures both on the hardware and software sides.

The modularity of SPACELAB allows a variety of different configurations to be built. The funding and time scales would be exceeded if we were to perform qualification testing on all of them, so a selection of two representative configurations has been made. The flow described above is designed to cover the Module only and the Module-plus-Pallet configuration.

A separate program has been selected for the Pallet-only mode which will undergo a similar test program to the Module-plus Pallet configuration.

Figure 26 shows this pallet flow for the Flight Unit.

Flight Unit Hardware Integration is following the same flow, as the Engineering Model and will be subjected to acceptance testing.

Figure 27 shows the overall Spacelab Integration and Test Schedule.

Spacelab Development and Integration and Test Activities are accompanied by a detailed operational analysis to verify the operability of SPACELAB during ground and flight operations. Results of these analyses are used to either change the design detail or change the operational procedures.

An increased logistics support effort has been applied to support NASA during the initial operational phase until the second SPACELAB flight.

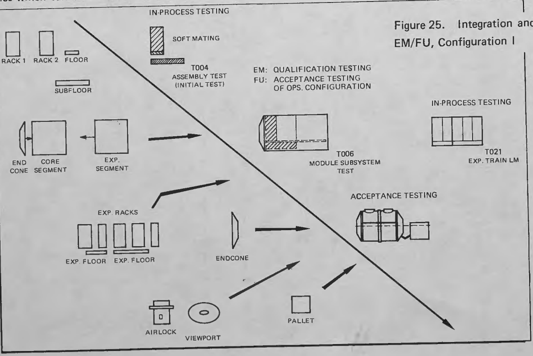


Figure 25. Integration and Test Flow EM/FU, Configuration I

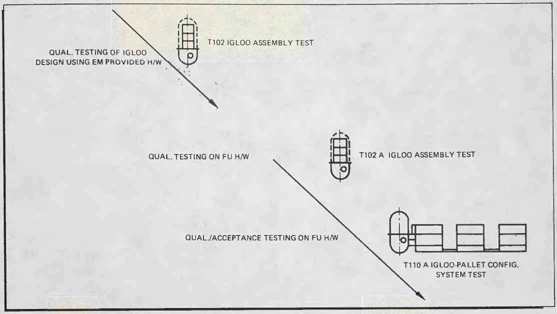


Figure 26. Integration and Test Flow FU, Configuration II

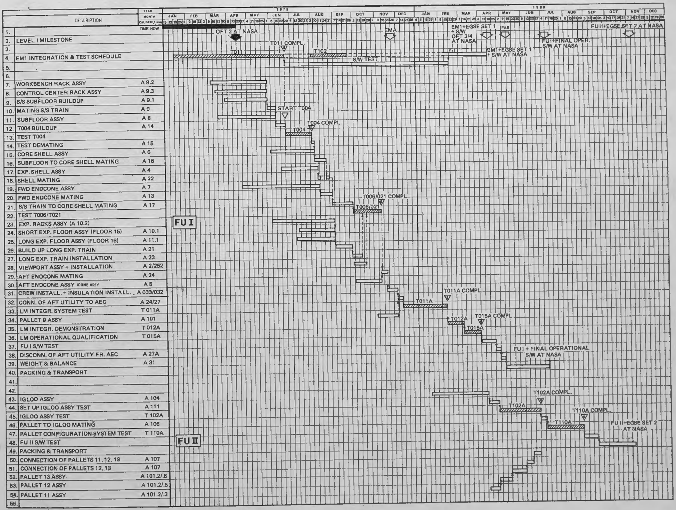


Figure 27. Overall I&T Hardware Integration & Test Schedule