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Spacelab Ground Operations

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ABSTRACT

The Spacelab, which is designed and built principally by the European Space Agency and its contractor, ERNO, with certain elements provided by the McDonnell Douglas Technical Services Company, under contract to NASA, will be operated by NASA as a key element of the Space Transportation System. Like the Shuttle, the "operational base" for the Spacelab will be the Kennedy Space Center in Florida.

The Spacelab modular design and its operational interrelationship among the Shuttle, the Spacelab Payload and the ground facilities dictate a particular approach to the ground turnaround in order to achieve the projected mission model. Spacelab facilities and GSE are being prepared at KSC and intense planning is under way to develop a disciplined, systematic operational scheme which is key to the quick turnaround required of all STS elements.

A certain portion of the Spacelab ground operational cycle will be almost totally dependent upon the Shuttle turnaround functions, such as the period after Spacelab installation into the Orbiter for pre-launch processing, and the period immediately after landing, prior to removal of the Spacelab. During these times, the Spacelab is operationally an extension of the Orbiter systems and is functionally under Orbiter control.

The remainder of the Spacelab ground operational cycle will be spent in the Operations and Checkout Building where the Spacelab-unique facilities and GSE are located. Key functions to be conducted here are Payload integration and de-integration, rack and pallet reconfiguration and Spacelab maintenance and refurbishment.

The Spacelab ground operational flow will be responsive to Shuttle ground turnaround requirements and constraints and, likewise, will necessarily impose design and operational guidelines on the Spacelab payloads to assure that they can support the Spacelab turnaround.

KSC, as the Spacelab operations center, will also be responsible for continuing assessment of Spacelab hardware utilization, based on mission requirements and program hardware resources. Current data from these parameters will be factored into the follow-on procurement activity in order to refine the requirements and schedules for acquisition of additional Spacelab hardware.

SPACELAB PLANNING

This paper describes the concepts by which Spacelab ground operations will be conducted at the Kennedy Space Center (KSC) during the verification and operational phases of the Space Transportation System (STS). The National Aeronautics and Space Administration (NASA) has prepared a STS mission model. The current mission model used for our Program Operating Plan for the Spacelab Program through FY92 is shown in Figure 1. Spacelab missions begin in 1980 on STS flight 12. Mission activity increases every year with a total of 156 missions planned through 1992. Spacelab missions comprise 32% of the total 487 Shuttle operational flights planned through 1992. The scheduled arrival dates of the hardware at KSC to support the first two Spacelab missions are July 1980 for the Spacelab #1 module/pallet mission and November 1980 for the Spacelab #2 igloo/pallet mission. Additional hardware will be required as launch activity increases and is scheduled to begin arrival at KSC in 1981.

Assessing the entire activities required to process the Spacelab missions is a reiterative process. The assessment starts almost at the beginning of the Program with the participation of the launch operation personnel in the design reviews. Spacelab processing schedules have also been developed by a joint European Space Agency (ESA) and NASA effort. The detail schedules assume that the early learning process has been completed and the Spacelab flight hardware can be "turned around" between flights in an efficient production line manner. This scheduling information is then applied to the Spacelab processing beginning in FY81. Of course, some additional time is considered necessary for resolving early inefficiencies. This additional time for early learning is a factor that is based upon industrial processing history. Fourteen months are required to process the first Spacelab, and four months are required for processing the seventh Spacelab for launch. In addition to the learning curve, processing the
first two missions is based upon working one prime shift which subsequently changes to two shifts. Figure 2 shows the processing flows for the first seven Spacelab missions scheduled for launch from KSC between August 1981 and December 1982 (Fiscal 1983).

The 1981-83 manifest (Figure 2) is used for detail near term planning whereas the total “1981-92” mission model is used for long term concept planning. The 1981-83 manifest is used for immediate contract support required, flight hardware and ground support equipment (GSE) required to be provisioned in the near future. As we approach the mid-to-late 1980s, we will assess what additional procurements will be required and what adjustments in the mission model should be made.

TEST OPERATIONS

With the overall schedule established, all work effort required prior to testing will be identified and scheduled. This work effort will include mission modifications to GSE or flight hardware, calibrations or pretest verifications of GSE, cable hook-up, etc.

Prior to the start of the test phase, a pretest briefing will be conducted to identify hazardous operations and insure that all team members are familiar with test sequences and discipline. In the test phase, the test conductor will verify that procedures are being performed in an orderly manner so that activities are coordinated and supported by the required personnel. The activities can be generally summarized into three primary functions. First, the Spacelab subsystems will be verified after the core module or igloo has undergone post-mission processing, maintenance, and required modification. Second, the racks and/or pallets will be mechanically integrated and their interfaces to the core segment/igloo will be verified. Finally, the completed Spacelab/experiment configuration will be operated in a simulated mission sequence. Each of these verifications is further described as follows:

a. During the subsystem reverification, each subsystem will be exercised through specified tests. These tests will verify the proper operation of each subsystem, including redundancies, and will verify each functional path. In general, each test will be made end-to-end to maximize the use of flight hardware configuration and minimize the test time. As a part of the subsystem reverification, the Scientific Airlock will be verified for the next flight.

b. Mated interfaces will be verified. Individual paths through the interface will be tested (as required) for proper continuity and configuration. Testing will be accomplished manually or by program procedures.

c. The last verification will be an abbreviated simulated Orbiter mission sequence. This test will simulate the basic on-orbit operations of the Spacelab, using the Orbiter simulation as provided by the Orbiter Interface Adapter (OIA) and Automatic Test Equipment (ATE) software. The intent is to preclude interface problems during Orbiter integration and mission operations by validating the flight software to the degree required or the extent possible in one “G” environment.

After completion of each test, a summary of the test results, the problems encountered, and unresolved issues will be recorded. Undefined open issues will be examined to determine impact on the next activity.

Test operations to be performed during integration will be continually evaluated to determine the cost-effectiveness of automating the procedures. Automated procedures will be used wherever possible for checkout of electrical, electronic, and electro-mechanical assemblies, subsystems and systems, and for control of integrated testing of systems. In general, checkout of retest procedures to be performed on a routine basis will be automated.

While no experiment performance data will be processed directly, raw data from the tests described above will be made available for experimenter use via the High Rate Multiplexer through the experiment interface distributor such that experimenter GSE can be used to process the user’s data in the Operations and Checkout (O&C) Building.

SPACELAB PROCESSING

Spacelab processing at KSC is a combination of various activities and processes which result in the assembly of experiments and Spacelab subsystems, and system elements into a predeteremined mission configuration. After this assembly, the verification of compatibility is established. The processing also includes refurbishment, maintenance, and reconfiguration of the various elements of the Spacelab system for the next missions and the dispositioning of the experiments. The major steps in Spacelab ground operations, from one mission to the next, are as follows:

1. Experiment Integration
2. Spacelab Integrated Operations
3. Orbiter Integrated Operations
4. Mission Operations Support
5. Post-Landing De-integration
6. Spacelab Maintenance and Refurbishment
7. Reconfiguration and Staging of Spacelab Components

Spacelab processing at KSC utilizes the O&C Building, the Orbiter Processing Facility (OPF), the Vehicle Assembly Building (VAB), and the Launch Pad (Figure 3). Figure 4 delineates a typical Spacelab and Spacelab flow at KSC, outlining the processing functions occurring in these areas.

The major portions of Spacelab/Payload staging, assembly, integration, and checkout are performed in the O&C Building Assembly and Test Area (Figure 5) with the objective of pro-
viding a mission-ready Spacelab, ready for installation into the Orbiter at the OPF. The O&C Building layout for Spacelab processing is outlined in Figure 6.

The initial functional activity is the receipt and unloading of the various experiment elements, followed by a preintegration and safety inspection of the Spacelab elements (racks and pallets) received at the experiment integration area. Spacelab elements which are not shipped to the experiments integration area will be refurbished and checked out prior to Spacelab/Experiment integration.

1. Experiment Integration

In the experiment integration area, Spacelab and the racks will be reconfigured from their previous use to the mission requirements of the next user, as described in Section 7. Reconfiguration and Staging. At this time, the experiments to be flown on the next mission will be installed on Spacelab racks and pallets and their satisfactory operation verified.

Mechanical buildup of the experiment train will be performed off-line from the Spacelab integration workstand in the experiments integration area. This buildup will include pallet-to-pallet mating, inter-rack connections, etc. The experiment rack shutoff valves and flow rate orifices will be adjusted (if required) and leak checks of the pallet freon lines and experiment water loop performed. Once the mechanical buildup is complete, the experiment train will be ready for integration with the Spacelab module/igloo. They will be transferred via bridge cranes from the experiments integration area to the Spacelab integration workstand (Figures 7, 8, 9).

2. Spacelab Integrated Operations

In parallel with the experiment integration and mechanical buildup of the racks and pallets, the Spacelab modules will have been refurbished and made ready for integration in the test and checkout stand. If required, the module experiment segment will be mated to the core module, and the experiment heat exchanger will be reconfigured and serviced. The necessary mission-unique Aft Flight Deck (AFD) equipment will be placed in the OIA on the Spacelab workstand. The rack and floor assemblies will be installed into the module, and the airflow balance for the subsystem and experiment rack assembly will be verified. Buildup of the Spacelab will be completed by mating the aft end cone to the module, transferring and positioning the pallet(s), connecting the utilities between the pallets and module, and servicing the coolant loop as required.

In the test phase of Integrated Operations, the Spacelab subsystems will be verified; the interfaces of the pallets to the core segment/igloo will be verified next, and finally, the completed Spacelab/experiment configuration will be verified by conducting a simulated mission sequence operation.

Handling and processing of the crew transfer tunnel in the O&C Building will be accomplished separately from the Spacelab, as the tunnel will be built up, checked out, and stored in the tunnel maintenance area until required. At that time, the tunnel will be placed in the forward end of the transportation canister and taken, with the Spacelab, to the OPF.

Spacelab and experiment stowage and a closeout inspection are performed to complete the O&C test operations. With Spacelab integrated test operations complete, the Spacelab will be hoisted by the bridge cranes and strongback, installed into the transportation canister, and secured to the canister support fittings which have been preset to the required Spacelab/Orbiter configuration. The Spacelab will be secured in the canister and the strongback placed on the strongback transporter and taken to the OPF. After the tunnel is installed in the canister, the canister doors will be closed, environmental conditioning and power/monitoring initiated, and the integrated Spacelab/Payload transported to the OPF for integration with the Orbiter.

Prior to the Spacelab leaving the O&C Building, a readiness review will be conducted to ensure proper mission configuration and to evaluate Spacelab and Payload testing and problem resolution.

3. Orbiter Integrated Operations

The integration of the total Spacelab system with the Orbiter in the OPF is preceded by the installation and servicing of Orbiter/Spacelab equipment earlier in the Orbiter work flow. This equipment consists of fluid lines, utility cables, and aft flight deck equipment peculiar to specific mission requirements.

Upon arrival at the OPF (Figure 10), the exterior of the Spacelab transportation canister will be cleaned, and it will be positioned next to the Orbiter. Environmental conditioning of the OPF will be verified, environmental conditioning of the canister will be secured, the canister doors opened, and the Spacelab system made ready for hoisting. Utilizing the OPF bridge cranes, a strongback will be positioned over the canister and lowered by the canister to a mating with the Spacelab system. The system will then be hoisted from the canister, moved into position, inspected, and lowered into the Orbiter payload bay and mated to the Orbiter (Figure 11).

After mate, payload bay GSE access platforms will provide access for connection of the utility cables and preparation of the Orbiterspaccelab interface verification testing. The tunnel will not be installed at this time so that the Orbiter/Spacelab/utilities interface and the module interior are more accessible.
The facility support available for use by the Spacelab system during processing in the OPF includes an environmental protective enclosure, facility air conditioning ducted into the module, GN₂, water and freon servicing equipment, and a GHE supply to perform environmental control subsystem leak checks. Access to the Spacelab while in the Orbiter payload bay is from overhead trolleys and bucket assemblies.

The Spacelab-to-Orbiter interface is verified during the Orbiter Interface Test (OIT). The Spacelab systems will be controlled during this test from the Launch Processing System (LPS) payloads console in the Launch Control Center (LCC) firing room and supported from the AFD as required. Data will be available during this test at the payload LPS console and the AFD. The avionics systems interface will be verified by performing an abbreviated mission sequence test.

All activities requiring support of Spacelab subsystems, such as powering on of experiments or Spacelab subsystems verification after component replacements, will also be performed under the control of the payloads console in the LCC.

After the Spacelab portion of the Orbiter Integrated Test, final time critical stowage and interior closeout inspections will be performed. All Spacelab interior activities will be completed at this time. The final switch checklist will be accomplished, and the interior floors covers removed at the time of last exit. The tunnel will be installed and all non-flight hardware removed and inventoried. After completion and verification of the tunnel interfaces, an external closeout inspection will be performed and the Orbiter payload bay doors closed.

After the Orbiter closeout at the Orbiter Processing Facility, the Orbiter/Spacelab combination is transported to the Vehicle Assembly Building (VAB) (Figure 12) for mating and integration with the Solid Rocket Booster/External Tank elements of the Shuttle (Figure 13). No Spacelab activities are planned for the VAB and no Spacelab-unique facilities or GSE are utilized in this phase of processing.

After the Orbiter/Solid Rocket Booster/External Tank mating and integration operation, the temperature, humidity, and cleanliness levels are maintained within the Orbiter payload bay consistent with the established requirements.

After Shuttle stacking operations at the VAB, the integrated Shuttle system will be transported to the launch pad utilizing the crawler transporter. During the transport to the pad, the payload bay will be purged with conditioned air. After Shuttle vehicle emplacement at the launch pad (Figure 14), the Spacelab will support Shuttle launch readiness verification tests and perform any final Spacelab servicing functions.

The launch processing system control of the Spacelab while at the launch pad is identical and from the same location as that provided while the Orbiter/Spacelab is being processed through the OPF. All activities associated with the Shuttle vehicle and the Spacelab integrated testing are controlled from the LPS console in the Launch Control Center.

Normal operations at the launch pad do not include access to the Orbiter payload bay. For missions requiring access to the Spacelab or payload at the launch pad, access capability can be provided via the Orbiter payload bay doors and payload access platforms on the Payload Ground Handling Mechanism (PGHM) part of the Rotating Service Structure (RSS) (Figure 14). This access will require additional serial time to the STS operational flow, and will require prior negotiation with NASA for assessment of time and operational impact.

Access to the internal portion of the Spacelab module while on the launch pad may be provided through the Viewport Adapter Assembly opening in the Spacelab Core Segment using Spacelab vertical access support equipment. Facility air conditioning, lighting, and communications will be supplied to the module interior through this opening. Removal of the internal GSE, which facilitates access to the Spacelab interior, must begin approximately 30 hours before launch.

In addition, in a contingency situation, the PGMH may be used for removal of the Spacelab from the Orbiter payload bay while the Shuttle is vertical in the stacked-on pad configuration.

Final servicing of the Spacelab GN₂ tank will be performed in conjunction with the Orbiter GN₂ tank servicing, utilizing the launch pad GN₂ system. Closeout of the T-0 umbilical will be accomplished, and payload servicing, if required, will also be performed.

Final countdown activities will include configuring the Orbiter and AFD Spacelab switches to the initial mission (ascent) configuration as defined by the countdown procedures.

4. Mission Operations Support

Spacelab systems performance during on-orbit operations will be monitored (via the JSC Mission Control Center Communications Systems) at KSC, where Spacelab systems expertise will be utilized to analyze and evaluate anomalies, problems, and operational incompatibilities; recommend solutions for inflight correction; assist in planning ground turnaround activities; and compile systems trend data for long range maintenance planning. Engineering analyses of the Spacelab mission flight data will be required to evaluate flight hardware, operating policies, and procedures, and identify hardware/software design or operating deficiencies.

KSC support to on-orbit operations may involve assistance to user personnel in the analysis of experiment operating data for identification and resolution of problems. This support could include review of configuration layouts and operational procedures to identify problem/anomaly areas and propose mission procedure changes to correct deficiencies.
5. Post-Landing De-Integration

Upon landing, the Orbiter will be towed to the OPF, where safing operations will be performed. Although no access is planned to the Spacelab interior during these safing operations, contingency access to the Spacelab interior would be through the Orbiter crew compartment and the crew transfer tunnel.

After the payload bay doors have been opened in the OPF, approximately 10 hours after landing, access will be gained to the Spacelab module and pallets. At this time, any time critical user materials will be removed, and sensitive experimenter equipment will be protected. The tunnel will then be removed using the overhead crane and tunnel sling kit, and the Spacelab module and/or pallets will be removed using the overhead crane and strongback. Both tunnel, module, and pallets will be installed in the transportation canister, and transported to the O&C Building for de-integration of experiments and maintenance and refurbishment of Spacelab systems.

Upon return of the transportation canister to the O&C Building, the bridge crane and strongback will be used to remove the Spacelab system and position it into the Spacelab integrated workstand. The tunnel, when removed, will be moved to the tunnel maintenance area, also in the O&C Building. The freon loop will be deserviced and the pallets removed to the pallet stand where the experiments will be removed and returned to the experiment integration area. On the module flights, the aft end cone will be removed, the experiment water loop drained, and the racks and floor removed and returned to the experiment integration area. The core segment and experiment segment will also be demated if reconfiguration to a small module is required for the next mission.

6. Spacelab Maintenance and Refurbishment

After post-flight inspection, the Spacelab refurbishment cycle begins with connections to the core segment/igloo to support power-up as required. Flight data will have been evaluated for anomalies and the required diagnostic action will be taken to determine unscheduled maintenance. All scheduled maintenance will be performed prior to subsystem checkout and verification. This maintenance and refurbishment activity is the systematic inspection, servicing, fault detection, repair, replacement of racks and/or pallets subsystems to restore degraded equipment and subsystems to a flight status.

7. Reconfiguration and Staging

When required for the next mission, the racks and pallets will be processed after maintenance and refurbishment from an earlier mission or from storage and placed in the rack and pallet stands for mission reconfiguration. Also at this time on the Spacelab workstand, the module core segment will be, if required, reconfigured for the next mission, and the necessary mission-unique AFD equipment will be placed in the OIA. After reconfiguration, verification testing is accomplished, and the racks and pallets are moved to the Experiments Integration Area for installation of experiments and a repeat of the Spacelab processing cycle.
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Figure 1.
SPACELAB PROGRAM MANIFEST

1980

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<th>A</th>
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1981

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8/12/81

STS-12 (SL-1) LM+P

2/3/82

STS-17 (SL-2) I+3P+UNIQUE STRU.

4/23/82

STS-21 (SL-3) LM+P

8/17/82

STS-27 (SL-4) LM+P

9/30/82

STS-29 (SL-5) SM+3P

11/10/82

STS-31 (SL-6) I+4P

1/5/83

STS-33 (SL-7) LM+P

1982

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1983

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NOTE: FLT. CONFIGURATION LEGEND:

LM – LONG MODULE
SM – SMALL MODULE
P – PALLET
3P – 3 PALLETS
4P – 4 PALLETS
I – IGLOO

Figure 2.
Figure 3.
### Typical Spacelab and Spacelab Payload Flow at KSC

<table>
<thead>
<tr>
<th>LANDING, O&amp;P</th>
<th>O&amp;C BUILDING</th>
<th>O&amp;C BUILDING</th>
<th>OPF, VAB, LAUNCH PAD</th>
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<td>LANDING, RECOVERY</td>
<td>SPACELAB MAINTENANCE AND EXPERIMENT INTEGRATION</td>
<td>SPACELAB INTEGRATION</td>
<td>ORBITER INTEGRATION AND LAUNCH OPERATION</td>
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<td>SAFE ORBITER AND SPACELAB</td>
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<td>REMOVE SPACELAB AND TRANSPORT TO O&amp;C BUILDING</td>
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<tr>
<td>2 DAYS</td>
<td>TBD DAYS</td>
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<tr>
<td>SPACELAB</td>
<td>SPACELAB</td>
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<tr>
<td>REMOVE RACKS/PALLETS; TRANSFER TO EXPERIMENT INTEGRATION FOR REMOVAL OF EXPERIMENTS</td>
<td>RECEIVE INTEGRATED PAYLOAD ASSEMBLY FROM EXPERIMENT INTEGRATION</td>
<td>INSTALL SPACELAB/PAYLOAD INTO ORBITER</td>
<td></td>
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<tr>
<td>PERFORM MAINTENANCE AND REVERIFICATION ON SPACELAB SYSTEMS</td>
<td>MATE NEW PAYLOAD AND SPACELAB FLIGHT SYSTEMS</td>
<td>CONNECT AND VERIFY SPACELAB-TO-ORBITER INTERFACES</td>
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</tr>
<tr>
<td>RECEIVE RACKS/PALLETS FROM EXPERIMENT INTEGRATION AND RECONFIGURE FOR NEXT PAYLOAD (&quot;STAGING&quot;)</td>
<td>SERVICE FLUID LOOPS</td>
<td>SUPPORT ORBITER INTEGRATED TEST</td>
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<td>TRANSFER RECONFIGURED RACKS/PALLETS TO EXPERIMENT INTEGRATION FOR INSTALLATION OF EXPERIMENTS</td>
<td>CALIBRATE/ADJUST RACK AIR FLOW</td>
<td>PERFORM FINAL CLOSEOUT</td>
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<td>EXPERIMENT INTEGRATION</td>
<td>VERIFY SPACELAB-TO-ORBITER INTERFACES USING OIA/ATE</td>
<td>VAB</td>
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<tr>
<td>TBD DAYS</td>
<td>PERFORM SPACELAB/PAYLOAD STOWAGE AND INSPECTION</td>
<td>PERFORM FINAL SHUTTLE ASSEMBLY AND TRANSFER TO LAUNCH PAD</td>
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<tr>
<td>REMOVE EXPERIMENTS FROM SPACELAB RACKS/PALLETS; TRANSFER EXPERIMENTS TO USER, RACKS/PALLETS TO SPACELAB</td>
<td>TRANSFER INTEGRATED SPACELAB/PAYLOAD TO O&amp;P</td>
<td>LAUNCH PAD</td>
<td></td>
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<tr>
<td>RECEIVE RECONFIGURED RACKS/PALLETS FROM SPACELAB AND BEGIN INTEGRATION OF NEXT PAYLOAD</td>
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<td>PERFORM SHUTTLE-TO-LAUNCH PAD MATE</td>
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<td>TBD DAYS</td>
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<td>SUPPORT SHUTTLE LAUNCH READINESS VERIFICATION</td>
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<td>INSTALL EXPERIMENTS ON RACKS/PALLETS AND VERIFY INTERFACES</td>
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<td>PERFORM SPACELAB/PAYLOAD FINAL SERVICING</td>
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<td>TRANSFER INTEGRATED ASSEMBLY TO SPACELAB FOR SPACELAB INTEGRATION</td>
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Figure 4.
Figure 5. O&C Building Assembly and Test Area
Figure 8.
Figure 9.
Figure 10. Orbiter Processing Facility
Figure 11. Orbiter Payload Bay
Figure 12. Vehicle Assembly Building
Figure 13. Solid Rocket Booster/External Tank
Figure 14. Rotating Service Structure