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REFLIGHT OF THE FIRST MICROGRAVITY SCIENCE LABORATORY: QUICK TURNAROUND OF A SPACE SHUTTLE MISSION

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Abstract

Due to the short flight of Space Shuttle Columbia, STS-83, in April 1997, NASA chose to refly the same crew, shuttle, and payload on STS-94 in July 1997. This was the first reflight of an entire mission complement. The reflight of the First Microgravity Science Laboratory (MSL-1) on STS-94 required an innovative approach to Space Shuttle payload ground processing. Ground processing time for the Spacelab Module, which served as the laboratory for MSL-1 experiments, was reduced by seventy-five percent. The Spacelab Module is a pressurized facility with avionics and thermal cooling and heating accommodations. Boeing-Huntsville, formerly McDonnell Douglas Aerospace, has been the Spacelab Integration Contractor since 1977. The first Spacelab Module flight was in 1983. An experienced team determined what was required to refurbish the Spacelab Module for reflight. Team members had diverse knowledge, skills, and background. An engineering assessment of subsystems, including mechanical, electrical power distribution, command and data management, and environmental control and life support, was performed. Recommendations for resolution of STS-83 Spacelab in-flight anomalies were provided. Inspections and tests that must be done on critical Spacelab components were identified. This assessment contributed to the successful reflight of MSL-1, the fifteenth Spacelab Module mission.

Introduction

When the Space Shuttle Columbia launched July 1, 1997, the National Aeronautics and Space Administration (NASA) demonstrated its efficiency in space transportation. STS-94 was the reflight of STS-83 that flew in April 1997. Columbia's primary payload was the First Microgravity Science Laboratory (MSL-1). The MSL payload development and the Spacelab program are managed by the NASA Marshall Space Flight Center (MSFC). In 1997, MSFC recognized Boeing-Huntsville (formerly McDonnell Douglas Aerospace) for it's years of excellent support to the Spacelab program. Boeing, in conjunction with NASA and other shuttle contractors, took an innovative approach to Spacelab Module integration to achieve flight readiness in three months for STS-94.

STS-83

STS-83 launched on April 4, 1997. It was planned to be a sixteen day mission. Concerns with the Orbiter fuel cells caused the mission to be cut short. Columbia landed on April 8, 1997 after only four days in orbit. MSL was the primary payload on STS-83. It consisted of two major components, the experiments and the facility where the experiments were performed. Experiments focused primarily in the areas of protein crystal growth, metals and alloys, combustion physics, and microgravity measurements. These experiments required a facility that could provide a wide range of resources. The facility was the Spacelab Module.

Spacelab Module Overview

The Spacelab Module is one of seven Spacelab carriers designed to support a variety of payloads in the Space Shuttle. Table 1 lists the Spacelab missions that have flown as of May 1998. The Spacelab Module is the most complex carrier and the only one that is pressurized. The Module provides a shirt sleeve environment in which Space Shuttle crews may perform microgravity and life science experiments. Crew members are shown in Figure 1 performing MSL experiments in the Spacelab Module. Experiments are designed to utilize the resources of the Spacelab Module. Resources include equipment stowage, electrical power distribution, command and data management, heating and cooling.

Spacelab hardware is installed in both the Orbiter Payload Bay and the Aft Flight Deck (AFD). The Module and Spacelab Transfer Tunnel (STT), through which the crew accesses the Module from the Orbiter cabin, are installed in the Payload Bay. The Module is a canister in which racks are mounted inside on the port and starboard sides. Experiments, Module subsystem components, and crew items are stowed in the racks. There is also stowage under the floor in the Module and some experiments mount to the floor.

The Electrical Power Distribution Subsystem (EPDS) provides Direct Current (DC) and Alternating Current (AC) power to Spacelab subsystems and experiments. DC power is distributed from the Orbiter fuel cells by the Spacelab Power Control Box and Emergency Box. The Spacelab Inverter generates AC power from the DC main power. There are separate Subsystem, Experiment and AFD Power Distribution Boxes. Experiment Power Switching Panels are located in the racks. Normal and emergency lighting is provided throughout the Module.

The Command and Data Management Subsystem (CDMS) supports both Spacelab subsystems and experiments. Components include Computers, Mass Memory Unit, High Data Rate Recorder, High Rate Multiplexer, Intercom Stations, Remote Acquisition Units, Input / Output Units, and Television Monitor. These components allow monitoring and control of the Spacelab subsystems and experiments by the crew and ground controllers. Acquired data is reviewed real-time and also stored for in-depth analysis after the mission has landed.

The Environmental Control Subsystem (ECS) provides both a pressurized environment for the crew and active thermal cooling for Spacelab and experiment avionics components. An extensive Fire Suppression

Table 1. Spacelab Missions as of May 1998

Seq.	Payload Designation	Spacelab Carrier	Shuttle Flight	Year
1	First Office of Space and Terrestrial Applications (OSTA-1)	Pallet	STS-2	1981
2	First Office of Space Science (OSS-1)	Pallet	STS-3	1982
3	OSTA-2	MPESS	STS-7	1983
4	Spacelab One (SL-1)	Module & Pallet	STS-9	1983
5	First Office of Aeronautics and Space Technology (OAST-1)	MPESS	41-D	1984
6	OSTA-3	MDMP	41-G	1984
7	Palapa B2 and Westar VI Retrieval	Pallets	51-A	1984
8	SL-3	Module	51-B	1985
9	SL-2	Igloo Pallet	51-F	1985
10	First German Spacelab (SL-D1)	Module	61-A	1985
11	Experimental Assembly of Structures in EVA / Assembly Concept for Construction of Erectable Space Structures (EASE/ACCESS)	MPESS	61-B	1985
12	Materials Science Laboratory Two (MSL-2)	MPESS	61-C	1986
13	Astronomy One (Astro-1)	Igloo Pallet	STS-35	1990
14	First Spacelab for Life Sciences (SLS-1)	Module	STS-40	1991
15	First International Microgravity Laboratory (IML-1)	Module	STS-42	1992
16	First Atmospheric Laboratory for Applications and Science (ATLAS-1)	Igloo Pallet	STS-45	1992
17	First United States Microgravity Laboratory (USML-1)	Module	STS-50	1992
18	First Tethered Satellite System (TSS-1)	EMP	STS-46	1992
19	Evaluation of Oxygen Interaction with Materials-III / Thermal Energy Management Process 2A-3 (EOIM-III/TEMP 2A-3)	MPESS	STS-46	1992
20	First Japanese Spacelab (SL-J)	Module	STS-47	1992
21	First United States Microgravity Payload (USMP-1)	MPESS-B	STS-52	1992
22	ATLAS-2	Igloo Pallet	STS-56	1993
23	SL-D2	Module	STS-55	1993
24	SLS-2	Module	STS-58	1993
25	USMP-2	MPESS-B	STS-62	1994
26	First Space Radar Laboratory (SRL-1)	MDMP	STS-59	1994
27	IML-2	Module	STS-65	1994

28	First Lidar In-Space Technology Experiment (LITE-1)	EMP	STS-64	1994
29	SRL-2	MDMP	STS-68	1994
30	ATLAS-3	Igloo Pallet	STS-66	1994
31	Astro-2	Igloo Pallet	STS-67	1995
32	Spacelab to Mir (SL-M)	Module	STS-71	1995
33	USML-2	Module	STS-73	1995
34	TSS-1R	EMP	STS-75	1996
35	USMP-3	MPESS-B	STS-75	1996
36	Life and Microgravity Spacelab (LMS)	Module	STS-78	1996
37	First Microgravity Science Laboratory (MSL-1)	Module	STS-83	1997
38	MSL-1 Reflight (MSL-1R)	Module	STS-94	1997
39	Manipulator Flight Demonstration (MFD)	MPESS	STS-85	1997
40	USMP-4	MPESS-B	STS-87	1997
41	Neurolab	Module	STS-90	1998

Figure 1. MSL-1 crew members performing experiments in the Spacelab Module.

Subsystem is also part of the ECS. Subsystems within the ECS utilize oxygen, nitrogen, and water. Components include pumps, accumulators, fans, vents, coldplates, and sensors.

Reflight Schedule

The day before STS-83 landed, managers of all the elements that comprised STS-83 were asked by NASA Space Transportation System (STS) management to begin assessing if it would be possible to refly the same crew and payload three months later in June 1997. A reflight was being considered since there had been minimal time to perform experiments. A Spacelab Module mission had never been prepared for flight that quickly. The standard Spacelab Module integration schedule allows thirteen months to install and test hardware and software for each mission. Spacelab integration normally begins in the Operations and Checkout (O&C) Building at Kennedy Space Center (KSC). Ten weeks before launch, the Spacelab Module, with experiments installed and systems operations verified, is transferred to the Orbiter Processing Facility (OPF). The Spacelab Module and STT are installed into the Orbiter at the OPF. Tests are run after the Module and STT are installed to verify the integrated systems. One month before flight, the integrated Orbiter is transferred to the Pad. Final systems verification tests are performed on the Pad. It was necessary to assume for the reflight assessment that the Orbiter Payload Bay Doors would be closed in the OPF one month before flight per standard Shuttle processing. Spacelab would have only two months to replace and system test hardware that was scheduled for replacement after STS-83, resolve STS-83 in-flight anomalies, implement planned software changes, and perform systems tests with the MSL-1 experiments prior to reflight.

Spacelab MSL-1 Reflight Assessment Team

Integration of a Spacelab mission includes the design and maintenance of hardware and software. This requires engineers with degrees in aerospace, mechanical, electrical, computer engineering and other disciplines to support the hardware and software. Engineers responsible for the various Module subsystems are assigned to each mission at the beginning of the integration process. They support the mission until after it has landed. Some of these engineers provide real time support during the flight.

Spacelab quickly identified personnel to assess the possibility of reflying MSL. Engineers with detailed knowledge of the MSL mission, Module subsystems and integration process were assigned to the team. Many of the engineers were still on-console providing real-time support for STS-83. The Spacelab MSL Reflight Assessment core team consisted of fourteen Boeing personnel and one subcontractor. There were seven female and eight male team members. Thirteen team members are engineers. They hold degrees in Civil, Industrial, Electrical, Mechanical, and Aerospace Engineering. Spacelab experience of team members ranged from two to fifteen years. Team members had to draw extensively on their knowledge and experience of the subsystem they were responsible for and its interrelation with the other subsystems to perform the reflight assessment.

Reflight Assessment

There were many considerations that had to be taken into account while assessing the Spacelab Module for a quick turnaround reflight. Areas of assessment included:

a. time between initial mission and reflight mission
b. Orbiter landing location
c. payload location during ground processing
d. in-flight anomalies documented during initial mission
e. postflight tests and inspections of initial mission
f. preflight tests and inspections to support reflight
g. resolution of problems resulting from post/preflight testing
h. replacement of limited life hardware
i. special attention to testing of safety and reliability critical components

Orbiter Landing Location

The time available to access hardware installed in the Payload Bay would be reduced if the Orbiter landed at a facility other than KSC. Weather conditions have occasionally been unacceptable for the Orbiter to land at KSC, and it has been diverted to Edwards Air Force Base to land. Spacelab quickly identified components that might need to be removed immediately from the Orbiter after landing. Personnel were identified and travel arrangements were made in case they had to fly to Edwards Air Force Base to take those components to Spacelab test and checkout facilities. Fortunately STS-83 landed at KSC and this contingency was not required.

STS-83 Deintegration

NASA maintains an extensive database of Orbiter, Spacelab, and experiment installation, test and checkout requirements. Module integration and deintegration is based on KSC personnel implementing the designated requirements contained in the Operations and Maintenance Requirements and Specifications (OMRS) Document. Spacelab OMRS requirements are grouped by subsystem, such as EPDS, CDMS, and ECS. Not all of the Spacelab OMRS requirements were needed to support a reflight since the experiments were already installed in the Spacelab Module. A key factor in deciding the scope of the inspection and test requirements was where the Orbiter Columbia would be positioned after landing. It was quickly decided at KSC to place Columbia in the OPF and keep the Spacelab Module installed in its Payload Bay while preparations were made for STS-94. This had never been done before for a Spacelab Module mission. The Spacelab Module had always been returned to the O&C Building to remove hardware from the last mission and install and checkout the hardware and software for the next mission. None of the inspection and test requirements had ever been written for this situation. Requirements had to be modified or not performed in order to accommodate the lack of access to Ground Support Equipment. Much of the equipment could not be used in the OPF since it was not designed to access the Spacelab Module while installed in the Orbiter. It was also necessary to remove the STT in order to access the Orbiter fuel cells. All broken interfaces were reverified after the STT was reinstalled.

Preflight Tests and Inspections for MSL-1 Reflight

Immediately after NASA's request to assess the possibility of a reflight, the list of test and inspection requirements used for MSL-1 was reviewed to prioritize them. There are over five hundred fifteen separate inspections and tests that can be performed during Module integration. Not all of the inspections and tests are required for each mission. It was decided that since there would be minimal deintegration of hardware, tests and inspections would be performed primarily at the system level, both in the OPF and on the Pad. Also, tests and inspections that might be required to resolve STS-83 in-flight anomalies were identified. Any interfaces that had to be broken due to disconnecting cables or cooling lines would be reverified following standard procedures. After the inspections and tests were prioritized by the reflight assessment team the list was faxed to KSC. Four days after NASA asked if it was possible to refly a Spacelab Module mission within three months time, a real-time review of the prioritized inspections and tests was held via telecon between the reflight assessment team, MSL-1 experimenters, and NASA and contractor personnel responsible for Module integration. At the end of the telecon, representatives were polled for their recommendation. The consensus was that it would be a challenge to do but it was agreed that it was possible to refly the STS-83 Spacelab Module mission within three months after landing. This recommendation was forwarded to NASA STS management. NASA authorized the various elements of STS-83 to continue working on the reflight. The Spacelab team refined the list of tests and inspections to be performed while NASA management assessed whether or not to refly. An effort was made to identify only those portions of an inspection or test that absolutely must be done since time was so limited. These partial requirements were submitted, assessed by the appropriate review board at MSFC, KSC or Johnson Space Center, approved and then implemented. A record was set for the most number of requirement changes submitted and approved within one month for a Spacelab mission.

On April 25th NASA announced that STS-83 would refly and that the mission would be designated STS-94 with a planned launch date in early July. KSC had already begun doing some of the inspections and tests but now could schedule those remaining to be done. A major goal was met by having all inspections and lower level tests done in order to run a Spacelab/Orbiter Interface Verification Test in early May. There were problems with the Spacelab Mass Memory Unit during the test. The Mass Memory Unit was replaced due to limited time to troubleshoot. A planned software modification and STS-94 timelines were loaded in support of the test. Upon completion of all inspections and tests for STS-94, only thirty-five percent of the standard Spacelab OMRS Module requirements were performed.

STS-83 Post-Flight Tests and Inspections

Every Spacelab Module mission has avionics and thermal requirements that must be performed postflight. Decisions had to be made as to whether or not to perform the postflight requirements for STS-83. These requirements were assessed in conjunction with the preflight requirements necessary to support reflight. It was decided that some of the STS-83 postflight requirements had to be performed before the reflight. Other postflight requirements were waived since there was a similar preflight requirement that would be done soon enough to meet the intent of the requirement. The remaining postflight requirements were able to be deferred until after STS-94 landed.

STS-83 In-Flight Anomalies

Spacelab systems worked well on STS-83. However, three avionics units did not perform nominally. In-flight anomalies on a Remote Acquisition Unit, Experiment Input / Output Unit, and a Video Cassette Recorder had to be dispositioned. Each avionics unit was assessed using the same criteria. Could the unit be tested to isolate the problem, repaired, bench tested to verify the repair, reinstalled, and system tested within the time allotted? If it had to be replaced, what other components or subsystems were impacted? What was the minimum testing that could be done and still ensure a safe and successful mission? Two months is a very short time in which to isolate a problem and repair an avionics unit, especially if it has to be returned to the manufacturer for repairs. Anomalies that occur on-orbit are not always easily duplicated postflight. After reviewing the anomalies for the Remote Acquisition Unit and the Experiment Input / Output Unit it was decided to replace them due to lack of time to adequately assess the problem. The Video Cassette Recorder anomaly could be worked around while in-flight so it was decided to refly the recorder in the as-is condition.

Limited Life Hardware

The Spacelab Module and its subsystems has a design life of fifty missions. There are some components, however, that due to the complexity of the system, have less than a fifty mission life. These components are limited by the number of operational cycles that may accrue before a part fails or because a material may deteriorate as it ages. Consumables such as batteries, tape and trash bags must also be resupplied for each mission. This hardware is tracked by part number and serial number and replaced as required. Maintenance requirements were uniquely identified for STS-94 to ensure no hardware was overlooked during the abbreviated ground processing. Reports prepared for MSL-1 that summarized the limited life items and serialized parts were updated to note the hardware that was replaced.

Safety and Reliability Critical Components

Crew safety is always the highest priority for every shuttle mission. There was a concern that with the shorter ground processing schedule safety issues could be overlooked. Spacelab took extra steps to ensure that did not happen. Spacelab maintains an extensive database of safety and reliability critical items. Inspection and test requirements that are performed during Module integration are specially coded if they pertain to a safety or reliability critical item. Sixty-seven requirements were associated with hardware that has the potential to cause loss of life or loss of the Orbiter if the hardware fails. These requirements were thoroughly reviewed. Nine requirements were maintenance requirements that were performed as required based on the age and/or operational cycle limits of the hardware. Twenty-eight requirements were able to be done in the OPF or on the Pad. Eleven requirements were intended to be performed in the O&C Building and were not done since the Module was not returned there. These eleven requirements were similar to requirements that were being performed in the OPF or on the Pad. Another eleven requirements were not done because the Ground Support Equipment could not be used in the OPF. Three requirements were not performed because the hardware could not be accessed while the Module was installed in the Orbiter. Five requirements had unique conditions that allowed for not disturbing the interface. An assessment was made of every requirement that could not be performed to confirm that it had been done, as required, before STS-83 launched and that no interfaces associated with it had been broken since then. Also, an overall systems check of the safety and reliability critical components was performed before the launch of STS-94 to confirm that the system was working properly.

Conclusions

The standard Spacelab Module mission integration ground processing schedule was reduced by seventy-five percent. Critical schedules were met by thoroughly planning and implementing them. The ability to work several tasks in parallel was a key factor in being ready to refly in three months. Experienced personnel, knowledgeable of the Module subsystems and interaction within the system, who were readily available and could quickly review data and make immediate decisions was essential. Only thirty-five percent of the standard Spacelab OMRS Module requirements were performed. Requirements were prioritized with emphasis placed on the system level performance, limited life hardware, and safety and reliability critical components.

In-flight anomalies create configurations that deviate from the generic assessed configuration. Each mission is unique and should be assessed accordingly. The reflight of the first Microgravity Science Laboratory, STS-94, was the fifteenth Spacelab Module mission and the thirty-eighth Spacelab mission. It was very successful. There was time to perform all experiments and data was gathered for each one. Subsystems on the Spacelab Module performed even better than on STS-83. The results were so positive that the possibility of flying reflights of future Spacelab Module missions has been discussed.

Curriculum Vitae

Yvonne Simms has nineteen years aerospace experience in mechanical hardware design, systems analysis, and mission support. She is currently working as a Principal Engineer in the Spacelab Systems department for The Boeing Company, formerly McDonnell Douglas Aerospace. Yvonne has worked on the Spacelab program for sixteen years and was lead engineer on the MSL Reflight Assessment Team. Prior to transferring to the Spacelab program, she was a design engineer of DC-9 interior structures at the Douglas Aircraft Company for three years. Yvonne holds a Bachelor of Science degree in Civil Engineering which she received from Michigan Technological University in 1979. She is a member of the Society of Women Engineers, originally joining the society as an undergraduate.

Acronyms and Abbreviations

AC	Alternating Current
ACCESS	Assembly Concept for Construction of Erectable Space Structures
AFD	Aft Flight Deck
Astro	Astronomy
ATLAS	Atmospheric Laboratory for Applications and Science
B	Bridged
CDMS	Command and Data Management Subsystem
D	Deutsch
DC	Direct Current
DC	Douglas Company
EASE	Experimental Assembly of Structures in EVA
ECS	Environmental Control Subsystem
EMP	Enhanced MDM Pallet
EOIM	Evaluation of Oxygen Interaction with Materials
EPDS	Electrical Power Distribution Subsystem
EVA	Extravehicular Activity
IML	International Microgravity Laboratory
J	Japanese
KSC	Kennedy Space Center
LITE	Lidar In-Space Technology Experiment
LMS	Life and Microgravity Spacelab
M	Mir (Russian for Peace)
MDMP	Multiplexer-Demultiplexer Pallet
MFD	Manipulator Flight Demonstration
MPESS	Multi-Purpose Experiment Support Structure
MSFC	Marshall Space Flight Center
MSL	Materials Science Laboratory
MSL	Microgravity Science Laboratory
NASA	National Aeronautics and Space Administration
O&C	Operations and Checkout
OAST	Office of Aeronautics and Space Technology
OMRS	Operations and Maintenance Requirements and Specifications
OPF	Orbiter Processing Facility
OSS	Office of Space Science
OSTA	Office of Space and Terrestrial Applications
R	Reflight
Seq.	Sequence
SL	Spacelab
SLS	Spacelab for Life Sciences
SRL	Space Radar Laboratory
STS	Space Transportation System
STT	Spacelab Transfer Tunnel
TEMP	Thermal Energy Management Process
TSS	Tethered Satellite System
USML	United States Microgravity Laboratory
USMP	United States Microgravity Payload