Reports

The Spacelab Experience: A Synopsis

Abstract. *The Spacelab 1 mission, a joint venture of the European Space Agency and the National Aeronautics and Space Administration took place during the period 28 November through 8 December 1983. An overview of the first flight of the orbiting laboratory is presented here. The payload crew members' view of Spacelab operations and results of the scientific investigations carried out on this mission are presented in the following reports.*

The Spacelab 1 mission was carried out in the period 28 November through 8 December 1983. During the mission, it became apparent that this first flight of Spacelab would not only demonstrate the soundness of the engineering design but also produce a large amount of high-quality scientific data. The first preliminary scientific results from the mission were presented by the investigators at a symposium held at Marshall Space Flight Center from 27 to 29 March 1984. This special issue is based on reports presented at that symposium.

The ignition of the solid rocket boosters at 11:00 a.m. on 28 November 1983 brought an end to the planning and preparations of the previous years and started the mission time clock that would drive activities for the next 10 days, 8 hours, 47 minutes, and 23 seconds. The shuttle performance was perfect, placing Spacelab into orbit at an altitude of 240 kilometers with an inclination of 57°. The entry of the science crew into the Spacelab, 3 hours later, opened a new era in scientific research in space.

Excitement over the scientific return in all disciplines escalated throughout the mission. This excitement was shown in the faces of investigators at the Payload Operations Control Center who learned of the first results of their experiments by real-time data transmission from orbit. This moment of discovery when the results were revealed to the scientist after a decade of work brought home to those present the meaning of the new Spacelab capability for conducting scientific research in space.

Background. In the early 1970's, the European Space Agency (ESA) joined NASA in the enterprise of manned spaceflight. Ten European countries represented by ESA reached an agreement with NASA to develop Spacelab, a manned laboratory for scientific and technological research in space to be carried into orbit by the space shuttle. When the capabilities of the shuttle and the possibilities offered by Spacelab became known, planning and design of the first Spacelab mission were started.

The first mission (Spacelab 1) was conceived in 1975 when an Announcement of Opportunity was issued. In 1976 the experiments were selected, and in 1977 the selected investigators met for the first time at Marshall Space Flight Center, Huntsville, Alabama. In this first mission it was to be shown that the Spacelab-shuttle combination could be used for scientific research not only in the traditional space science disciplines but also in disciplines such as the life sciences and materials science.

NASA and ESA had selected 72 individual investigations for Spacelab 1. About half of these investigations could be technically combined into integrated facilities in the materials science and life science area. The investigators for the different experiments came from the United States, Canada, 11 European countries, and Japan. Half of the payload was selected by NASA and half by ESA. The total payload weight was close to 3000 kilograms.

The scientists on Spacelab 1 organized themselves into the Investigator's Working Group (IWG), a body which represented the scientific interests of the mission and which was given unprecedented responsibilities in the definition of the mission. The IWG was structured according to the different scientific disciplines represented in Spacelab 1. The main duties of the IWG members were to work with the project in allocating shuttle and Spacelab resources to different disciplines and investigations, to organize the inflight science operations, and to nominate and select four payload specialists, two for flight and two for critical roles in the ground-based operations activity.

The goal of the IWG was to ensure that as much science as possible was done on this first demonstration mission but to do so within the technical and financial limits of the project. The IWG was naturally divided as far as interests of the different disciplines were concerned. For example, it had to be decided how often and when the shuttle bay would be turned to targets such as the earth, sun, and stars, and whether the microgravity environment could be disturbed by significant crew movement or shuttle attitude changes. Some of the life scientists wanted to expose the crew to the sensations of rotating domes, mild electrical shocks, and provocative head movements that might induce space sickness, while others wanted the crew in good physical shape to look after experiments such as active beam-plasma interaction studies or growing crystals. Over the years of planning, the IWG was always able to arrive at a reasonable distribution of resources and solutions for conflicting interests.

For everyone involved in the project, it was an unforgettable experience to see the development of the hardware (shuttle, Spacelab, facilities, and experiments). The payload went through preliminary testing in Bremen, Huntsville, and other places. Two mission sequence tests at the Kennedy Space Center were completed after this and were most impressive in magnitude, complexity, and organization. During all phases of hardware development and testing, it was a pleasant and stimulating experience for the investigators to work with and train the payload and mission specialists. It was demonstrated during the actual flight that the crew had become masters in payload operation and, when necessary, troubleshooting. One of the most difficult tasks of the Spacelab 1 investigators was selecting two of the four payload specialists for the flight, because all four were well prepared to carry out the mission.

Time was a precious resource on the Spacelab 1 flight, so the preparation for flight operations was most important. It was necessary to prepare an optimized time line, develop procedures to cover normal and contingency situations, provide inflight replanning resources, and organize the science team to interact effectively with the flight operations engineers so that changes in the preflight time line could be implemented methodically, optimally, and quickly. On Spacelab 1, all this was achieved through close cooperation between investigators and operations engineers, active training at the experiment and discipline levels at

Marshall Space Flight Center, and finally integrated flight simulations at the Johnson Space Center in Houston, Texas, where the Payload Operations Control Center (POCC) for Spacelab 1 has been set up.

The mission. As the crew on board began preparations for their scientific activities, the Spacelab 1 investigators began their own preparations in the POCC. There they had set up ground support equipment that permitted preliminary analysis of data transmitted in real time from orbit via the Tracking and Data Relay Satellite. The value of premission simulations became immediately obvious to the investigators as the mission operations began, because the POCC activities seemed to be "just another simulation." The difference, of course, became evident as the initial real-time television images from orbit showed their scientific colleagues floating into the Spacelab module rather than standing in the Spacelab simulator.

The advantages of having scientific colleagues in orbit became evident as the mission proceeded and the broad menu of investigations unfolded. From the beginning, with the life science experiments on the space adaptation syndrome (or space motion sickness), the science crewmen on board Spacelab and the investigators on the ground communicated directly and worked as colleagues on the operation of the experiments. Crucial information on the body's adaptation to microgravity was recorded in the first day of the flight. This direct communication between the onboard crew and scientists on the ground was a first for manned missions. Throughout the investigations, decisions on how to proceed were made jointly by those in space and those on the ground. Decisions were made as the onboard crew and the principal investigator on the ground learned from the initial results and based the subsequent steps of the investigation on these early findings. This collegial interaction grew throughout the mission as the availability of real-time television images from orbit over periods approaching an hour in length tied the ground and space scientists together as if they were in adjacent rooms rather than thousands of miles apart.

The experiment operations were demanding in their extent but ran smoothly. As they progressed, some problems with the instrumentation developed, and the value of the onboard crew was again evident. A balky isothermal heating facility, the mirror heating facility, the high data rate recorder, the metric camera film magazine, the camera for the rotating dome, the video-sync signal for the sunflower growth experiment were all repaired, replaced, or adjusted by the science crew on board. These repair operations were extensive and in several instances involved disassembly of the hardware in the Spacelab module. In many cases, by repairing these instruments the crew gave new life to what would otherwise have been short-lived experiments and ensured the successful outcome of investigations that spanned nearly a decade in conception and development.

As the mission progressed, the results poured in: new information on phenomena ranging from stellar x-ray sources to minute quantities of gas in the upper atmosphere to the intricate workings of the organs of balance in the inner ear. Throughout the experimental period, the new information obtained was used to alter the procedures for investigations to be carried out later in the mission. For example, in the series of experiments in the fluid physics module of the materials sciences double rack, results from the early experiments influenced subsequent steps in those experiments as well as approaches planned for later experiments in the mission. For these later experiments, major changes were made in the supporting plates of the apparatus that held a suspended column of silicon oil. After the crew learned how to control the oil with the plates, they were able to suspend a liquid column almost 4 inches long and test its stability to both rotational and oscillatory motions. These investigations gave fundamental insight into how to work with liquid columns in space—an important aspect of future crystal growth experiments (*1*).

Experiments in all disciplines benefited from the extra day that was added to the mission because of the excellent performance of the shuttle and Spacelab, which resulted in extra margins of the onboard resources of energy and propellant.

Scientific results. Already at this very early stage of data evaluation, Spacelab 1 can claim a number of discoveries and scientific firsts such as the measurement of water and methane in the mesosphere (*2*), the identification and quantization of deuterium in the thermosphere (*3*), and the observation of discrete emission lines superimposed on the thermal spectrum of celestial x-ray sources (*4*).

An unexpected result was the observation of caloric nystagmus in space as the eyes react to a thermal gradient in the inner ear (*5*). This phenomenon had previously been thought to result from convective motions of the fluids in the inner ear, which do not occur in the gravity-free environment of space. Also unexpected was the low central venous pressure measured for a payload specialist during the flight (*6*). The gravity-free environment eliminates the hydrostatic pressure in the cardiovascular system, which causes a rapid redistribution of body fluids. Despite this redistribution, the central venous pressure remained surprisingly low. New information has been obtained on the mechanism by which the brain determines orientation in microgravity—a key to understanding space motion sickness (*7*). Possible clues to predicting the susceptibility of an individual to space sickness were uncovered through studies of the changes in the Hoffman reflex of the calf muscle after periods of exposure to microgravity (*8*).

Spacelab brought back valuable photographs of the earth's surface which will be used in mapping a portion of the more than 60 percent of the earth that is yet uncharted (*9*). Although comprehensive results from the materials science experiments are not yet available, the preliminary results show that crystal growth, manufacture of metallic alloys and composite materials, and fluid physics research can be carried out effectively in Spacelab (*10, 11*).

In space plasma physics, Spacelab served as an excellent platform for active and passive experimentation (*12–15*), and in atmospheric remote sensing, global measurements of key minor constituents were carried out with unprecedented sensitivity and accuracy (*16*). The combination of shuttle and Spacelab proved to be an ideal platform for astronomy, with measured backgrounds a factor of 3 lower than those of the simultaneous EXOSAT satellite observations at x-ray wavelengths. High-resolution energy spectral measurements of a dozen different stellar sources were completed, and an interesting variability in x-ray intensity over short time spans was observed in the emissions from Centaurus X-3 (*4*). Ultraviolet astronomical observations also appear feasible provided orbit and altitude are properly chosen (*17, 18*). Since the instruments are returned after the flight, postflight calibration is possible, which makes Spacelab attractive for instruments that measure solar output with very high absolute accuracy (*19, 20*).

Spacelab offers unique opportunities for life science and materials science investigations in a microgravity environment, because crew on board can act as both experimenters and subjects of the experiments while maintaining close interaction with their colleagues on the ground. For example, new techniques for manufacturing crystals in space were used successfully. Protein crystals up to 1000 times larger by volume than those previously obtained on the earth were grown within a few days (*21*). These samples should yield basic new knowledge about the molecular structure of these important substances. New information was also acquired on how the immune mechanisms in the body respond to the environment of space (*22*, *23*), and in an experiment on the fungus *Neurospora*, it was possible to test whether circadian patterns persist away from the periodicities of the earth's rotation (*24*).

The time between December and March has allowed only a preliminary analysis of limited data sets. Moreover, the availability of data was different for different disciplines. Some investigators had telemetry data immediately available during the flight, while others had to wait for films and specimens to be returned after the flight. Life scientists had to carry out a number of postflight tests on the science crew to complete their data sets, and most materials scientists obtained their samples only recently. Nevertheless, the scientific bounty to date from the first Spacelab mission has been exceptional, and the prospects for more major results are obvious.

Spacelab proved to be an excellent laboratory for all the disciplines represented on the mission. Initial results from these experiments are presented in the following reports. The experience of Spacelab 1 was indeed memorable. Comments from the investigators such as "thrilling" and "an enormous success" were common. We have certainly entered a new era in our ability to carry out space science research.

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Payload Crew Members' View of Spacelab Operations

Abstract. *Various operational aspects of the Spacelab 1 mission are reviewed by the four payload crew members. Two-shift operations, voice communication with ground investigators, joint participation in experiment activity, Spacelab performance, and recent advances are discussed.*

This report will provide the comments of crew members (*1*) on a variety of operational aspects of the Spacelab 1 mission, rather than review the scientific accomplishments, which are covered by the reports of individual investigators in this issue. It is hoped that the descriptions given will provide useful insight into operations aboard the new Spacelab laboratory and will be of value in planning future manned flight activity.

Two-shift operations. Only 9 days (extended to 10 days while in flight) were available for the performance of roughly 70 experiments in at least seven different disciplines, and it is clear that many more performances of each experiment would have been desirable and productive. Virtually every discipline, even individual experiment, would have benefited from added operational time. Some experiments such as photographing a given ground location, had to be performed at a particular time (Greenwich mean time) to achieve their objectives. In order to maximize these opportunities, experiment operations were conducted around the clock, with two shifts operating on alternating 12-hour duty periods. Each shift consisted of a payload specialist (PS) and a mission specialist (MS), usually at work in the Spacelab module, and either the commander or the pilot on duty on the orbiter flight deck.

All six crew members were awake for about 4 hours at the beginning and end of each 8-hour sleep shift. During these periods the breakfast and dinner meals were prepared and consumed, exercise was performed as desired, and other tasks requiring the whole crew could be conducted. During the sleep intervals, the on-duty crew tried to minimize the noise level in the mid-deck area where the sleeping bunks are located, but some use of galley and waste management facility was permitted. As the bunks were fully enclosed and well isolated acoustically, sleep was accomplished with negligible interruption. All crew members reported adequate and restful sleep throughout the mission. Since operations were maintained continually from the time of Spacelab activation at about 6 hours after launch until the normal deactivation time of about 230 hours, Spacelab utilization was substantially greater than with a single 12- to 16-hour shift.

Voice communication. Voice communication was drastically altered from that on any previous space mission. Preflight planning included one voice loop for the Mission Operations Control Room (MOCR) for vehicle-related discussions and a second voice loop for the Payload Operations Control Center (POCC) for payload-related discussions. When difficulty was encountered a few weeks before Spacelab launch with voice circuits via the Tracking and Data Relay Satellite (TDRS), only one circuit was made available. The MOCR used an ultrahigh-frequency ground station network and gave primary use of the TDRS voice loop to the POCC (or "Marshall Operations"). The TDRS loop, however, was still available for MOCR use whenever high-priority information needed to be exchanged and the ground-station network was not adequate. Shared in this way, there was remarkably little difficulty or friction generated; no mission objectives were compromised and all parties were adequately served.

The two payload crewmen on duty were usually involved in experimental work, sometimes on different experiments in different disciplines, and the POCC (with principal investigators and their teams) followed these activities