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 closely. At times other experiments were controlled from the POCC directly. As each experiment was being run, the corresponding investigator team on the ground might use the voice loop to converse directly with the crew concerning their experiment. Even more frequently, the discussion on the experiment might be between a crewman and a ground communicator (the "crew interface coordinator") or the alternate payload specialist. Most frequent discussion topics included procedures used, experiment status, problems encountered, interpretation of observations (either onboard observations or sometimes the downlinked data), and further instructions. Of course, any modification to operations which required more crew time, spacecraft resources, or interaction with other experiments required prior coordination on the ground.

Principal investigator and payload crew involvement. In addition to the greatly expanded voice communication between crewmen and investigators, the POCC frequently had television images and limited real-time data on the conduct of the experiments. In the life sciences, data from and images of the subject crewmen led to postural correction, focus adjustment of eye images, real-time evaluation of muscle reflex data quality, and many other interactions with the crew. In the physical sciences, investigators could (and did) assist in interpretation of low-light-level television images of the horizon airglow and of beam-plasma interactions with an electron accelerator. Complete procedures were revised in real time in fluid physics experiments, based on fluid behavior observed by or described to the ground investigators. The growth of large single-crystal silicon rods by melting a sample moving slowly through the focus of a mirror heating furnace was essentially a joint effort between ground investigator and crewmen.

Crew participation could be categorized in three levels. First, for experiments in space plasma physics, the life sciences, and some materials science and fluid physics, the crew was highly involved in performance and real-time interpretation of the results. Modifications of procedures and decisions on future performances were made jointly with the ground. Second, the crew performed other technical tasks with little ground interaction, such as installation of cameras to a high-quality window (metric camera) or scientific air lock table (ultraviolet photography) and verification of their proper performance. Third, another set of experiments in atmospheric science, x-ray astronomy, and solar physics were largely controlled from the POCC, with crew participation when needed to verify experiment performance, manage computer software at times, and assist in malfunction analysis and correction. All investigators, however, were deeply involved in the real-time performance of their own experiment, with crew participation in varying degrees as appropriate.

Spacelab as a laboratory. Spacelab itself was a very pleasant and adequately sized laboratory for most experimentation. Cold plates and cooling loops functioned well and quietly within the module to maintain proper experiment temperatures. The atmosphere seemed fresh, with no odors, and the temperature was adjusted and maintained in a comfortable range. The availability of a high-quality optical window for photography and a 1-meter-diameter scientific air lock was quite important for several experiments. Three computers (one for Spacelab systems, one for experiment operations, and the third as a backup for either of the first two) provided very important automatic monitoring and control functions, but were deficient in memory capacity, resulting in heavy usage of the tape recorder "mass memory unit" to exchange experiment software programs. The intercom system allowed monitoring of only one channel at a time, and should be improved by increasing the number of voice loops available simultaneously. Two view ports provide minimal but adequate crew viewing either outward from the payload bay or into the bay, aft of the module. Overall, the Spacelab performed magnificently in a variety of research disciplines, and should be the site of many new and exciting discoveries on future flights.

Maintenance and repair. Although the great value of having men available for maintenance and repair tasks has been demonstrated on many flights, especially the Skylab series 10 years ago (*2*), it seems as if each new program has to repeat the lesson. At the time experiment design is first conceived, it is important to keep the possibility of maintenance and repair in mind so that later changes to accommodate repair will not become prohibitively expensive or impossible. Several examples from Spacelab 1 follow:

1) The high data rate recorder (HDRR) tape transport jammed and was cleared by hand. In preparation for flight, no maintenance training for this failure was provided, but the crew was helped by having become familiar with the unit during training for a tape change.

2) There was a film jam in the metric camera. Because the crewmen had never seen the inside of the film magazine, detailed procedures had to be developed on the ground. The jam was cleared but it would have proceeded with much more equanimity had the crewman been familiar with the magazine before, rather than "seeing" it for the first time by hand alone in the darkness of his sleeping bunk!

3) Eye movement in response to a rotating visual field was intended to be photographed with a flash camera. When the flash unit failed on its first operation, the onboard television was substituted with an extra close-up lens, added to stowage at a crew member's insistence, with even better data collection than originally envisaged.

4) Several modifications to the materials science hardware had to be made and the microprocessor memory was altered by using two input keys originally intended to be disconnected.

5) Fluid physics experiments had to be greatly modified when air bubbles appeared in the liquid containers, antispread barriers failed to prevent liquid spreading, and electrostatic effects and other surprises were encountered. Hardware modification and substitutions were made, along with new procedures, as mentioned before.

6) One experiment used a small tape recorder to generate visual images to present to one eye in a vestibular test. Although the tape recorder jammed, the crew was instructed not to attempt a repair. Postflight inspection revealed that the problem could have been readily fixed.

A substantial fraction of the experimental program was "saved" in the first five examples above. The earlier results of Skylab and now those of Spacelab 1 are probably not unique. With so many experiments represented, the fraction needing some repair is not unacceptably high or unexpected. The flexibility represented by having crew members available should certainly be used, but to do so effectively requires a compatible design approach and reasonable preflight crew training. General familiarity of the crew with almost all moving equipment is a good first rule. Tape recorder transports, motors, pumps, blowers, film transports, keyboards, and other moving mechanical devices should be designed for replacement or repair and the appropriate training provided to the crew.

Advances since Skylab. Spacelab 1

has been the most ambitious manned space science effort since Skylab, 10 years ago. The role of the crewmen in Skylab was reviewed soon after flight (*2*), and some forecasts for the shuttle/orbiter era were made. As expected, crew members have contributed to scientific return in many of the same ways as before (experiment setup, data quality, innovation and flexibility, and repair), but significant advances have been made in automatic control and data and voice interaction with ground investigators. Many routine tasks have been automated with microprocessor control, such as filter exchange, sequencing a series of experiment operations, and time line control. Crew members are now employed in the more difficult tasks associated with data quality and interpretation and task selection, assisted by the ground team when real-time data are available to them.

Operational viewpoint. We would emphasize that the operational viewpoint should be considered from the beginning of the design phase—for example, to maximize repair possibilities. Operational factors are at the very heart of decisions regarding time line alternatives, spacecraft attitude control, manual or automatic modes of operation and their combination, crew time required, joint participation with the ground investigators, data storage alternatives (film, tape, downlink), and even more. Often the payload crew members are in the best position to advise in these areas, as their responsibilities include the full range of activities and all experiments. This breadth is usually missing from a single team of investigators, even though expert in their own scientific disciplines.

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References and Notes

1. The payload crew members are defined as the two payload specialists selected by the Investigator Working Group and the two mission specialists assigned by NASA. These four individuals are the authors of this report and were responsible for the inflight conduct of most experiments, while the spacecraft commander and pilot spent most of their on-orbit time managing spacecraft attitude and systems.
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Atmospheric Physics and Earth Observations

Mapping from Space: The Metric Camera Experiment

Abstract. *The Spacelab metric camera experiment acquired stereoscopic high-resolution black-and-white and color infrared photographs of various regions of the world. In total, an area of about 11 million square kilometers was covered. Because of the delay in launching the shuttle until 28 November, illumination conditions were frequently poor over many candidate targets. However, unique high-quality images with a ground resolution of about 20 meters were obtained by increasing camera exposure time. Initial image analysis has shown that these images may be used for earth mapping at the scale 1:100,000.*

One of the earth observation experiments on board Spacelab 1, the metric camera experiment, was designed to take high-resolution large-format photographs with a photogrammetric mapping camera operating from the shuttle orbital platform. This instrument was a slightly modified Zeiss aerial survey camera with a focal length of 305 mm and an image size of 23 by 23 cm. This experiment was unique in that it was the first use of a calibrated mapping camera to photograph the earth from space. A calibrated camera is characterized by the fact that all distortions of the imaging geometry from the ideal central perspective are controlled and measured in the laboratory within a tolerance of ±1 to 2 μm. These measurements can be utilized as corrections in the photogrammetric restitution of the images during the mapping process.

The scientific objective of the experiment was to verify whether topographic and thematic maps, at medium-scale ranges (1:50,000 to 1:200,000), could be compiled from mapping camera images taken from orbital heights. Such topographic and thematic maps are required for earth resource planning and resource management on a worldwide basis. The current practice of mapping by conventional aerial photogrammetric techniques is so expensive and slow that mapping coverage of the remaining 60 percent of the land surface of the earth would require many years of observations. The lack of earth resource maps is particularly evident in the developing countries of Africa, South America, and Asia. Mapping from space could provide an economical and efficient means by which to meet these mapping requirements. A single photograph alone covers detail of several aerial map sheets.

During the Spacelab 1 mission approximately 1000 photographs were taken, of which 550 were on color infrared film

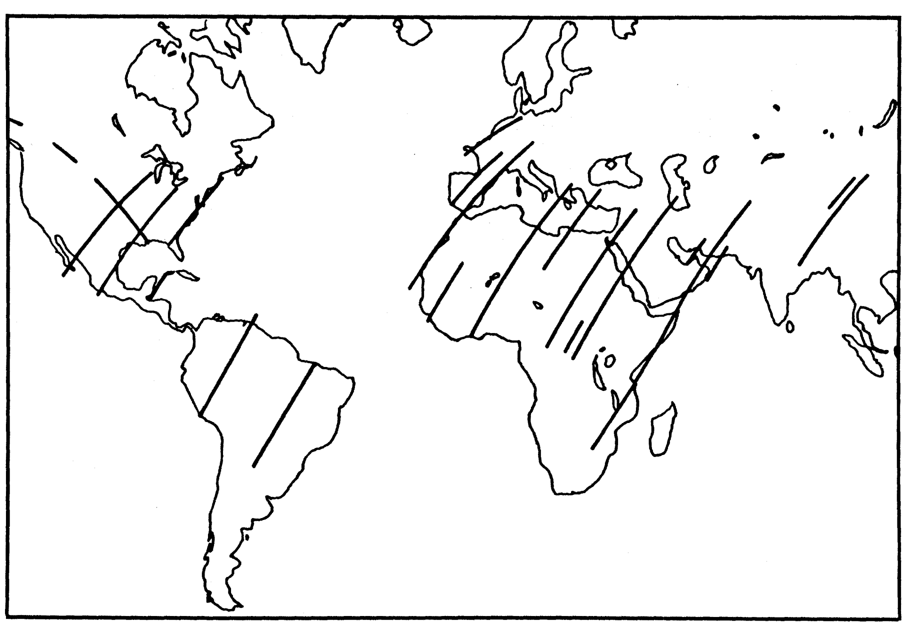

Fig. 1. Ground tracks where metric camera images were taken.