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.
2. O. K. Garriott, *Science* **186**, 219 (1974).

27 March 1984; accepted 1 June 1984

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

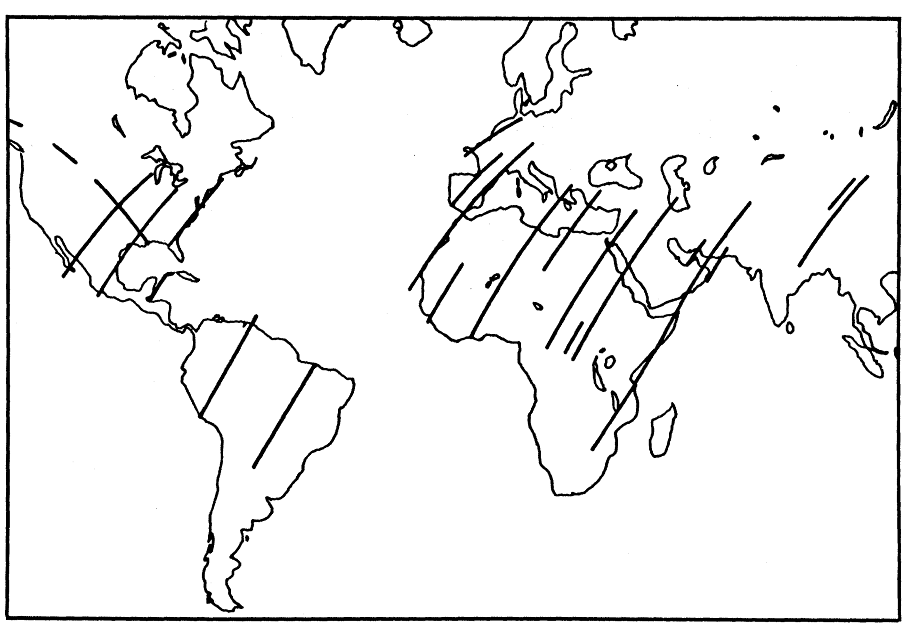

Fig. 1. Ground tracks where metric camera images were taken.

Fig. 2. Tenfold enlargement of an original image showing the city of Munich, Federal Republic of Germany.

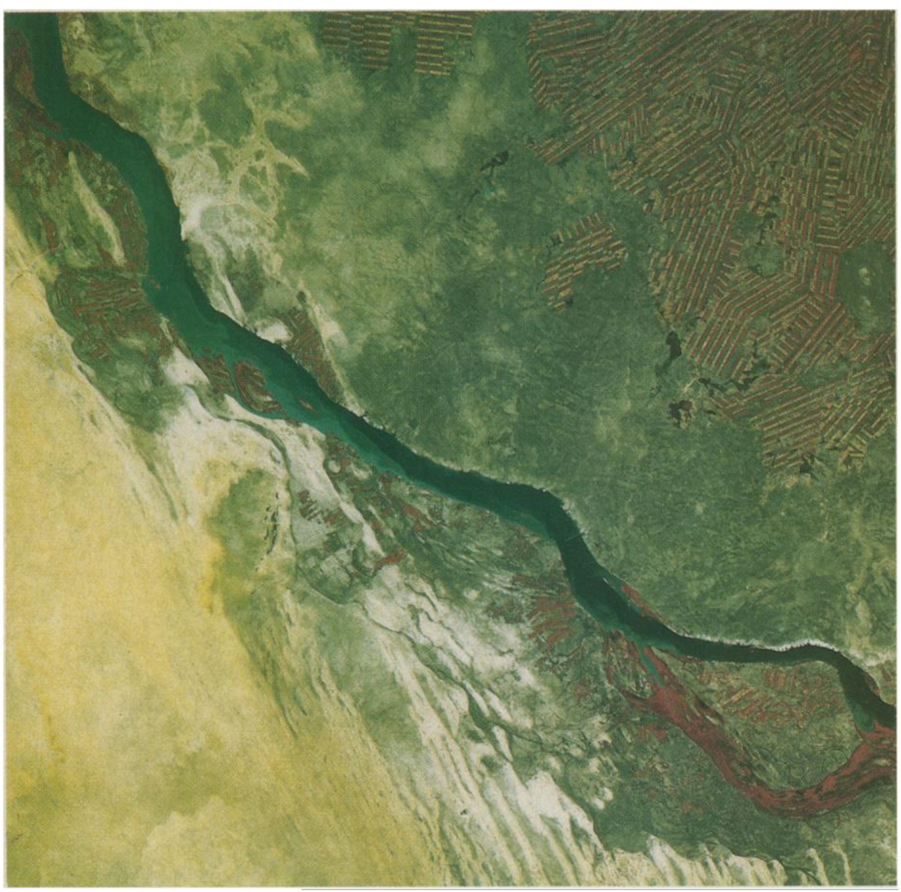

Fig. 3. Color infrared image of the Al Gezira area, Sudan.

and about 450 on black-and-white film. Figure 1 shows the ground tracks along which photographs covering 190 by 190 km were taken at an image scale of 1:820,000. All photos were taken with overlap of at least 60 percent in the flight direction so that stereoscopic observation and evaluation of the overlapping photographic pairs would be possible. In total, an area of 11 million square kilometers was photographed. Seventy percent of this area was either cloud-free or only partly covered by clouds, and is suitable for evaluation.

Since the launch, originally planned for the summer months, had to be delayed to 28 November 1983, the lighting conditions over the earth became very unfavorable as the sun elevation for all camera operations never exceeded 30°. In the northern hemisphere over Europe and North America it only reached 5° to 20°. To compensate for these low lighting conditions, longer exposure times of 1/500 to 1/250 seconds had to be used, while originally an exposure time of 1/1000 seconds was planned to reduce the effect of image motion during the exposure. In spite of the unfavorable conditions, it was possible to produce the best photographic images of the earth's surface that have been obtained from space for civilian purposes.

The current objective of the data analysis is to investigate the scale at which topographic and thematic maps can be compiled from those images. The mapping capability of the imagery depends mainly on ground resolution, which determines the identification of objects. A first analysis of the image has shown that

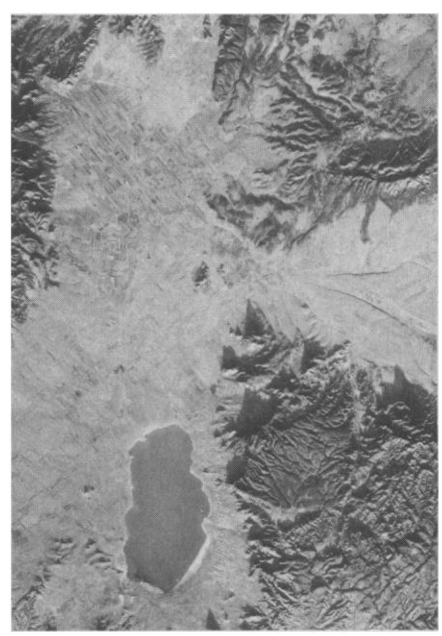

Fig. 4. Low-sun-angle photograph of an area northwest on Chihuahua, Mexico.

roads with a width of 10 m or more can be recognized on the black-and-white photographs. Figure 2 shows a tenfold enlargement of the original image taken over the city of Munich in the Federal Republic of Germany. Nearly every street is visible as well as major buildings. From preliminary results it can be expected that photomaps at the scale 1:100,000 can be produced from the metric camera photographs.

The color infrared images can also be used to produce 1:100,000 photomaps. In addition, they will mainly be useful for land-use interpretation in the countries of the Third World. For example, Fig. 3 shows the Al Gezira area of Sudan with the White Nile on the left and the irrigated fields by the Blue Nile at the right in contrast with the desert.

Many black-and-white photographs were taken at extremely low sun angles over North America. Nevertheless, they reveal the morphology of the terrain, especially in arid zones, and may be suitable for geological studies (Fig. 4).

Mapping will also be carried out by stereophotogrammetric techniques, producing topographic maps with 50-m contours.

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References and Notes

1. Analysis of the results of this experiment, in which over 100 institutions are participating worldwide, will be presented in preliminary form at the International Congress for Photogrammetry and Remote Sensing in Rio de Janeiro in June 1984 and in final form during a user symposium in late 1984 in the Federal Republic of Germany. There is great expectation that the camera experiment has provided an economical and efficient mapping tool leading to new and unique observation of the earth's surface.

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Atmospheric Spectral Imaging

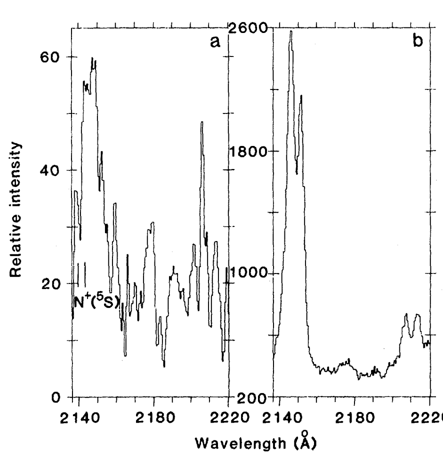
Abstract. *An array of imaging spectrometers flown on the Spacelab 1 mission was capable of providing spectra of the atmospheric emissions over a broad wavelength range from 300 to 12,700 angstroms and acquiring each complete spectrum nearly simultaneously. The instrument was used to make observations on the day side and night side of the earth, looking down in the nadir direction, radially away from the earth, and in various limb-scanning modes. Observations were made looking at various angles to the vehicle velocity vector and during thruster firings and water dumps as well as at times when such events were inhibited. As a result of the mission a data base has been acquired that is valuable for studies of both the upper atmosphere and the shuttle-Spacelab vehicle environment.*

During the mid-1970's developments in ionospheric and thermospheric physics indicated a need for multispectral measurements over a relatively broad region of the optical spectrum. Measurements of atmospheric emissions in the ultraviolet, visible, and near infrared contain significant information concerning concentrations of species, solar and magnetospheric energy influx, and the ensuing chemical and radiative processes. Such measurements made from an orbiting space platform can provide the dependence of these parameters on altitude, latitude, and longitude, provided the data are acquired in a time period that is short compared with the typical 90-minute orbiting period of the vehicle. The opportunity to design an instrument capable of operating over such a wide wavelength range and measuring relatively low light levels in a suitably short time interval was provided by the payload capacity of the shuttle-Spacelab system.

Such an instrument was flown on the Spacelab 1 mission (28 November to 6 December 1983) and is called the imaging spectrometric observatory. The instrument consists of an array of five spectrometers, each of which covers a portion of the spectrum from 300 to 12,700 Å. The five spectrometers operate in parallel and each has a focal-plane detector which is optimized for a particular region of the full spectral range and which comprises an intensified two-dimensional charge-coupled device array. The spectrum is imaged in one dimension and spatial information (corresponding to the length of the entrance slit of the spectrometer) is imaged in the other. The five spectrometers are located on the instrument pallet in the shuttle cargo bay, and a dedicated microcomputer system, which acts as the array controller and data handler, is located in the Spacelab module. The instrument has been described in detail (*1–3*).

The primary scientific objectives of the instrument on the Spacelab 1 mission were as follows (*4*): to survey the emission spectrum of the atmospheric dayglow over the range 300 to 12,700 Å; to obtain limb scan profiles of these emissions (particularly in the vacuum ultraviolet); and to make observations over a wide variety of vehicle orientations and solar illumination conditions in order to assess the suitability of the Spacelab-shuttle system as a platform from which to make such optical measurements.

During the course of the 10-day Spacelab 1 mission, the imaging spectrometric observatory operated on 60 different occasions for periods ranging from 8 minutes to over 9 hours. A fairly extensive data base was acquired and, as the data rate of the instrument is 125 kilobits per second, the volume of data acquired is very large. The instrument is highly programmable but essentially measures 12,400 Å of the spectrum at 3- to 6-Å spectral resolution every few minutes.



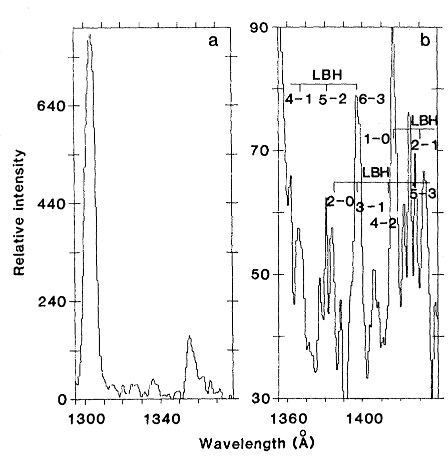


Fig. 1 (left). Spectral segment from dayglow limb scan experiment showing two points in the scan corresponding to approximately (a) 235 km and (b) 90 km. Fig. 2 (right). Two spectral segments from dayglow limb scan.