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Space Shuttle: A New Era in Terrestrial Remote Sensing

James V. Taranik and Mark Settle

Summary. The space shuttle will carry its first scientific cargo into orbit on its second test flight. The seven experiments to be conducted during this flight—investigations related to continental geology, atmospheric chemistry, meteorology, marine biology, and plant physiology—will demonstrate the potential usefulness of the shuttle for research in the earth and life sciences.

The space shuttle successfully completed its first orbital test flight in April 1981 and ushered in a new era of manned space flight. This new space transportation system possesses the capability to routinely carry men, equipment, and experiments into low earth orbit. The shuttle will be used to deploy and retrieve earth-orbiting satellites, and it will also be used as an orbital laboratory in which highly specialized experiments can be conducted in the weightless and vacuum conditions of space.

Remote sensing studies of the earth, an obvious application of the shuttle's capabilities, have recently been overshadowed by popular interest in industrial and military applications of the system. The shuttle will provide an ideal orbital platform for collecting experimental remote sensing data as well as for testing advanced sensor technology as it becomes available (*1*). In recognition of the potential utility of the shuttle for earth-related research, NASA has placed a high priority on demonstrating the shuttle's capability as a platform for terrestrial remote sensing observations. In 1976 the second orbital test flight of the shuttle was designated as an earth-viewing mission, and an announcement of opportunity was issued to solicit proposals for experiments. Six investigations were selected from a total of 32 proposals. A seventh experiment was added to the mission more recently. These experiments will involve several different types of scientific investigations related to the study of continental geology, atmospheric chemistry, meteorology, marine biology, and plant physiology. The experiments are collectively referred to as the OSTA-1 payload because most are managed by NASA's Office of Space and Terrestrial Applications.

The OSTA-1 payload represents the first scientific cargo that the shuttle will carry into orbit (Fig. 1). Five of the experiments selected for the mission are mounted on an engineering model of the Spacelab pallet manufactured by the European Space Agency (Fig. 2). The pallet, located in the shuttle's cargo bay, weighs 1218 kilograms, and the experiments mounted on it weigh 1016 kilograms and require 1452 watts of electrical power. Pallet experiments can be operated directly by the astronauts or by ground controllers at the Johnson Space Center in Houston, Texas. The other two experiments are located in the crew compartment.

The second shuttle test flight is scheduled for launch in early November from the Kennedy Space Center in Florida. The primary objective of the test flight program is to evaluate the performance and flight characteristics of the shuttle itself. Launch procedures and reentry maneuvers have been changed significantly from the first flight in order to obtain additional engineering flight data. The shuttle will be placed in a 137- to 142-kilometer circular orbit with an inclination of 38° during the period of actual data collection. The orbiter will fly in an inverted position with its cargo bay doors open, facing the earth's surface, for a total of 88 hours during the 5-day (120-hour) mission. All of the scientific data collected during the mission will be removed from the orbiter within 72 hours of its landing at Roger's Dry Lake Bed (NASA's Dryden Flight Research Facility) in California.

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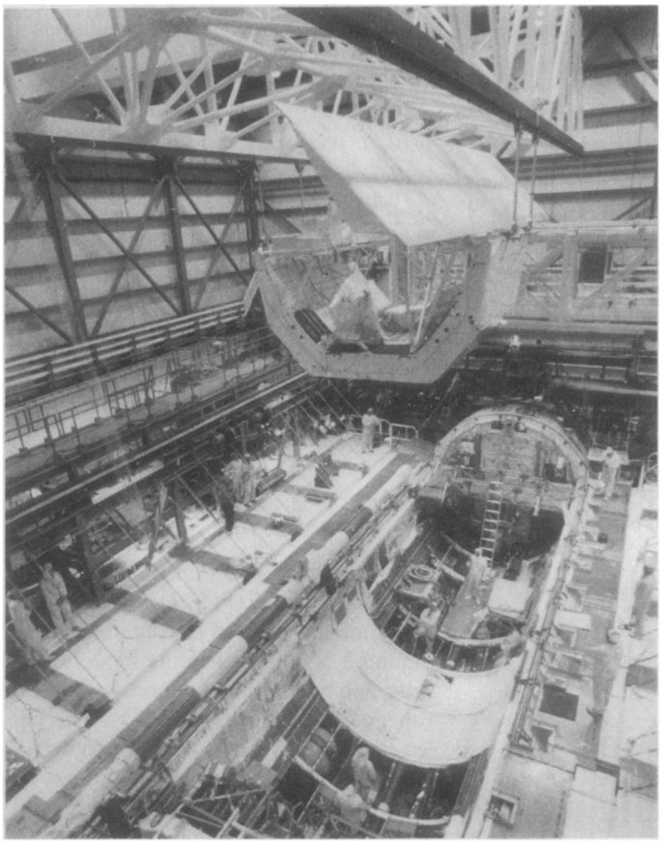


Fig. 1. Office of Space and Terrestrial Applications pallet with scientific instruments is lowered into the space shuttle *Columbia* in the orbiter processing facility at the Kennedy Space Flight Center, Florida. Five of the seven OSTA-1 experiments are located in the shuttle cargo bay and two are located in the cabin with the astronauts.

The primary experiments on the second shuttle flight, which are described below, represent incremental advances in current remote sensing capabilities within specific scientific disciplines. They are expected to produce new types of remote sensing data at orbital altitudes that will address specific scientific problems as well as to contribute to the design of future earth observation sensors. The members of the OSTA-1 science management team are listed in (*2*). All earth observation data collected by the OSTA-1 payload wil be archived at the National Space Science Data Center and should be available to the public within 6 to 12 months of the completion of the mission (*3*).

Shuttle Imaging Radar-A (SIR-A)

Radar imagery is a two-dimensional record of microwave radiation backscattered from a particular surface. The backscattering characteristics of natural terrestrial surfaces are determined by topographic slope and orientation with respect to the radar antenna, surface roughness relative to the wavelength of the incident microwave radiation, and the intrinsic electric properties of surface materials (*4*). Radar imagery is commonly used to detect variations in the gross morphology of natural surfaces and to correlate such variations with ocean current systems, geological structures, and man-made features. In land areas where surface topography can be determined, slope effects can be removed from radar imagery and the residual variations in scene brightness (that is, radar backscattering) can be used to differentiate specific types of surface material.

The first orbital radar imagery of the earth was collected by the Seasat satellite in 1978. The Seasat radar was an L-band (23-centimeter wavelength) synthetic aperture system that viewed a 100-km-wide swath of the earth's surface at an antenna depression angle of 70°. The depression angle is measured down to the earth from a plane perpendicular to the orbital plane of the spacecraft. Seasat was optimized for observing the earth's oceans, where surface slopes rarely exceed 20°. Subsequent analysis of data acquired over land areas has indicated that orbital radar imagery is also useful for geologic mapping.

Radar is an active remote sensing system that actually illuminates the earth's surface with microwave energy of a particular frequency and polarization. It is useful for observing areas that are commonly cloud covered or poorly illuminated by the sun. Orbital radar imagery is unique in two important respects: its synoptic scale and the nearly constant angle of illumination across an imaged scene. These attributes serve to lessen the problems that are encountered in analyzing mosaicked radar imagery obtained at aircraft altitudes. Seasat data have been particularly useful for geomorphological studies in relatively flat areas characterized by minor or moderate topographic relief (*4*).

The purpose of the SIR-A experiment is to evaluate the utility of orbital radar imagery for geological applications. Similar to the Seasat radar in many respects, SIR-A was, in fact, constructed from spare Seasat components. It is an L-band system that transmits and receives horizontally polarized microwave radiation. The 9.4-meter SIR-A antenna has a 43° depression angle, which will cause transmitted radar pulses to strike horizontal ground surfaces at an incidence angle of 47° (measured from the horizontal). Analysis of aerial radar imagery has shown that this comparatively smaller depression angle reduces slope distortion effects in areas of significant topographic relief (Fig. 3). Data from the SIR-A experiment will be analyzed to determine whether this antenna configuration is optimal for geologic mapping in different global environments.

The SIR-A system will obtain radar imagery with a swath width of 50 km and a ground resolution of 40 m by 40 m. The prime test sites for this experiment are in the United States, Central America, northern portions of South America, and central and eastern Africa. Imagery will also be obtained over certain coastal areas. The results of this experiment, together with the experience gained with Seasat, will lead to experimentation with multiple depression angles and dual frequencies on the next generation of shuttle microwave imaging systems.

Shuttle Multispectral Infrared Radiometer (SMIRR)

Multispectral measurements of solar radiation reflected from the earth's surface have been routinely collected during the past decade by the experimental series of Landsat satellites. The multispectral scanner sensor carried on Landsat obtains measurements in the visible (0.5 to 0.7 micrometer) and near infrared (0.7 to 1.1 μm) portions of the electromagnetic spectrum with a relatively coarse spectral resolution (measurement bandwidth ≥ 0.1 μm). Landsat has proved to be useful for a variety of geologic applications, including geomorphological studies of regional crustal structures (faults, folds, domes, and so forth), identification of rock outcrop exposures in remote areas, and mapping of limonitic alteration associated with iron-bearing rocks. Landsat imagery has also been used as a photographic base map for integrating aerial and ground-based geologic data.

The utility of multispectral scanner measurements for direct identification of specific rocks and soils has been somewhat limited because the scanner bandpasses do not encompass many of the significant spectral absorption features associated with common geological materials (*5*). Landsat-D, which will be launched in 1982, carries an improved imaging device called the thematic mapper. The mapper possesses additional measurement bands in the shortwave infrared (specifically at wavelengths of 1.6 and 2.2 μm) that will permit geologists to differentiate broad classes of clay minerals produced by hydrothermal alteration from those produced by surface weathering phenomena. However, the thematic mapper does not have the spectral resolution required to identify specific minerals.

Laboratory spectra of naturally occurring rock and clay minerals commonly have diagnostic narrowband absorption features (on the order of 0.02 μm) in the shortwave infrared portion of the spectrum, particularly at wavelengths of 2.0 to 2.5 μm (*6*). The purpose of the SMIRR experiment is to determine the extent to which these narrowband spectral features can be exploited for improved rock-type discrimination and lithologic mapping. The SMIRR instrument consists of a Cassegrain telescope, a spinning filter wheel, and two trimetal (mercury, cadmium, and tellurium) detectors. The filter wheel provides six bandpasses with a half-bandwidth of 0.1 μm centered at 0.5, 0.6, 1.05, 1.2, 1.6, and 2.1 μm;

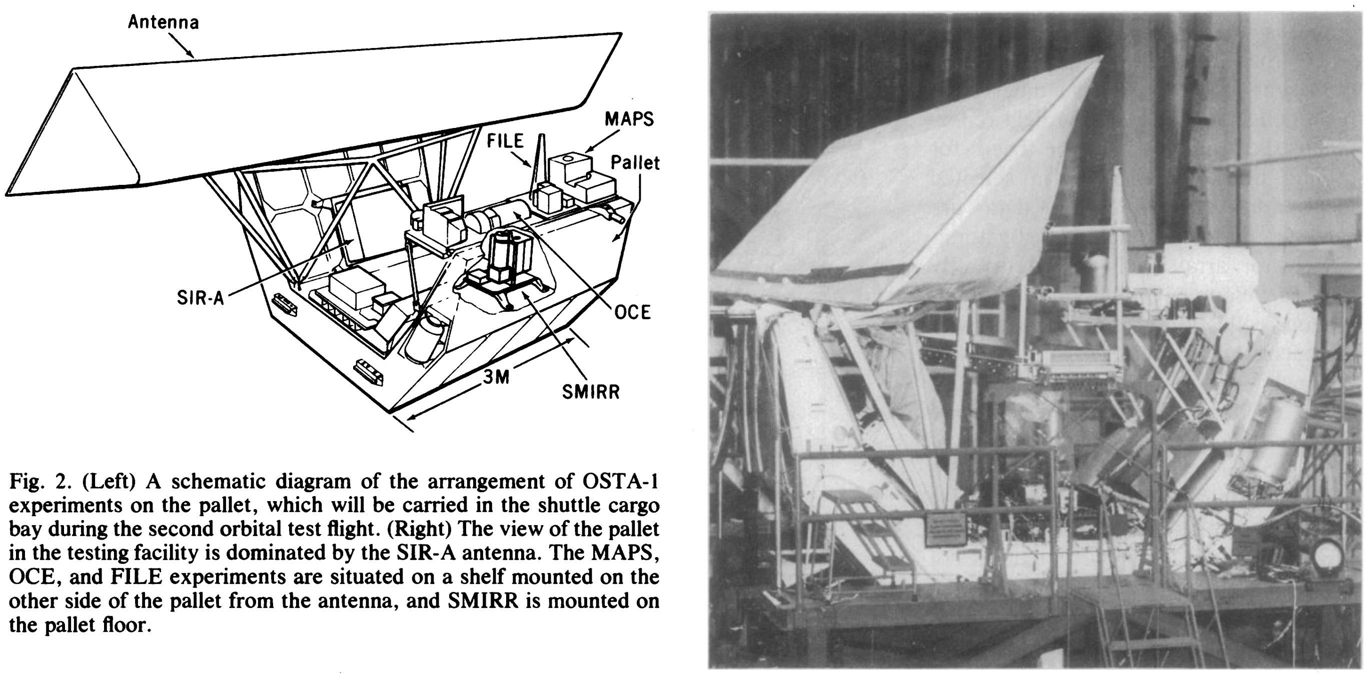


Fig. 2. (Left) A schematic diagram of the arrangement of OSTA-1 experiments on the pallet, which will be carried in the shuttle cargo bay during the second orbital test flight. (Right) The view of the pallet in the testing facility is dominated by the SIR-A antenna. The MAPS, OCE, and FILE experiments are situated on a shelf mounted on the other side of the pallet from the antenna, and SMIRR is mounted on the pallet floor.

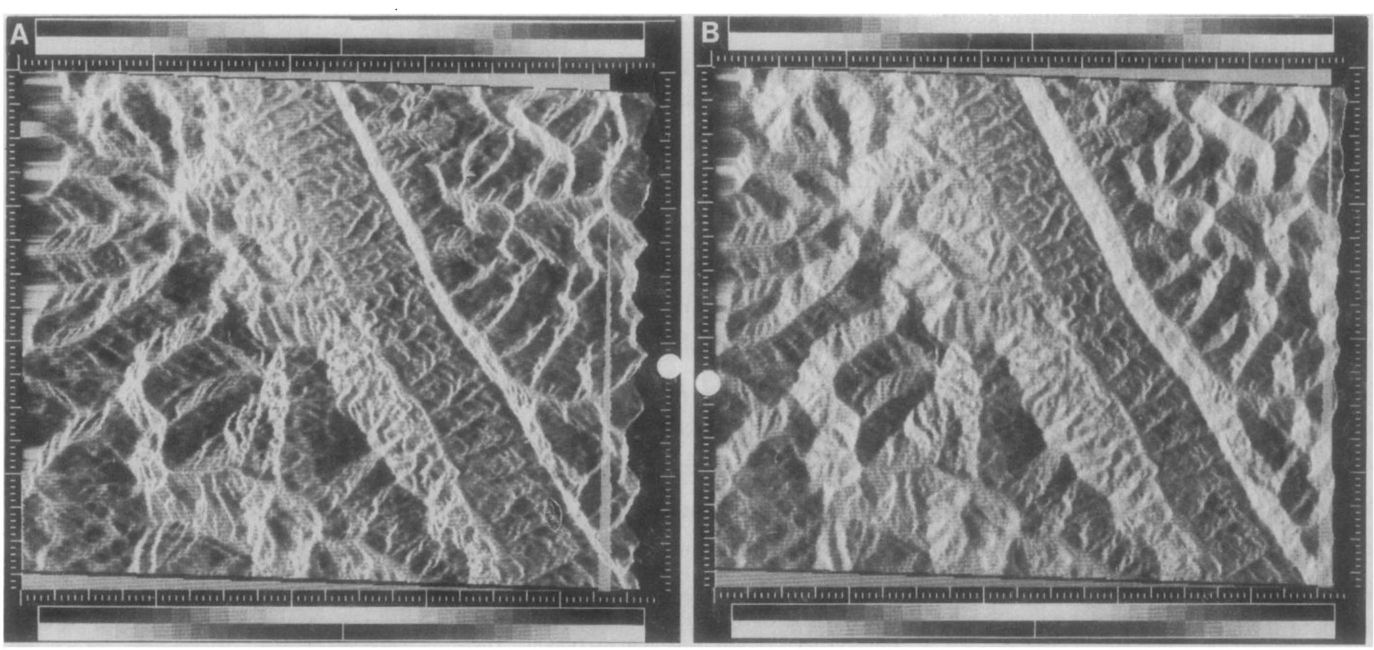


Fig. 3. Computerized simulations of orbital radar imagery made from U.S. Geological Survey digital elevation data. (A) View of Appalachian terrain in Kentucky with a radar antenna depression angle of 70°; (B) the same area with an antenna depression angle of 45°. Note the reduction of slope distortion effects in the simulated imagery at the lower depression angle in this relatively rugged area.

three bandpasses with a half-width of 0.02 μm centered at 2.17, 2.20, and 2.22 μm; and an additional bandpass at 2.35 μm with a half-width of 0.06 μm. SMIRR measurement bands in the 2.0- to 2.5-μm region coincide with spectral absorption features observed under laboratory conditions for several common types of rock and clay minerals, including calcite, alunite, montmorillonite, and kaolinite (Fig. 4).

SMIRR is not an imaging instrument. Two 16-millimeter framing cameras are boresighted along the telescope axis to document the trace of the telescope's 100-m circular field of view along the ground. The prime site for SMIRR coverage is the western United States, where rock units are well exposed and numerous remote sensing studies have been conducted. A portable field reflectance spectrometer will be used for ground truth investigation in selected local areas after SMIRR data are screened by the principal investigators.

Detector array technology currently under development will permit the simultaneous collection of multispectral measurements in dozens of narrowband channels with ground spatial resolutions of 10 to 30 m. Limitations on future sensors that operate at wavelengths of 0.4 to 2.5 μm may no longer be related to spatial and spectral resolution but may be determined by the utility of acquiring, processing, and storing vast quantities of multispectral data. The results of the SMIRR experiment will contribute to better understanding of the trade-offs involved in improved spectral and spatial resolution for geological applications. In particular, these results will allow geologists to identify the specific spectral regions in the shortwave infrared that are best suited for discriminating between rock types. This information will assist in the design of advanced orbital sensors that may be launched into space in the late 1980's.

Measurement of Air Pollution from Satellites (MAPS)

Carbon monoxide is an important trace constituent of the earth's atmosphere. Past surveys of CO abundance indicated that CO occurs primarily within the troposphere in concentrations ranging from 40 to 300 parts per billion. Carbon monoxide plays a major role in the global photochemistry of the troposphere through its reaction with the hydroxyl radical, which in turn controls the lifetime of many other trace species in the troposphere.

Fossil fuel combustion is a major source of atmospheric CO. This is reflected in the asymmetrical distribution of tropospheric CO between the Northern and Southern hemispheres (Fig. 5). Ground-based and airborne measurements of CO concentration conducted in the past suggest that there is considerable interhemispheric transport of CO in the middle and upper troposphere (*7*).

The scientific objectives of the MAPS experiment are to survey CO concentrations in the middle and upper troposphere at low to middle latitudes and to determine the extent of interhemispheric air mass transport in the troposphere. Although other atmospheric constituents such as ozone and water vapor have been measured from space in the past, MAPS represents the first attempt to determine CO concentration from orbital altitudes. In addition, it will provide the first "instantaneous" global survey of CO abundance at low and middle latitudes.

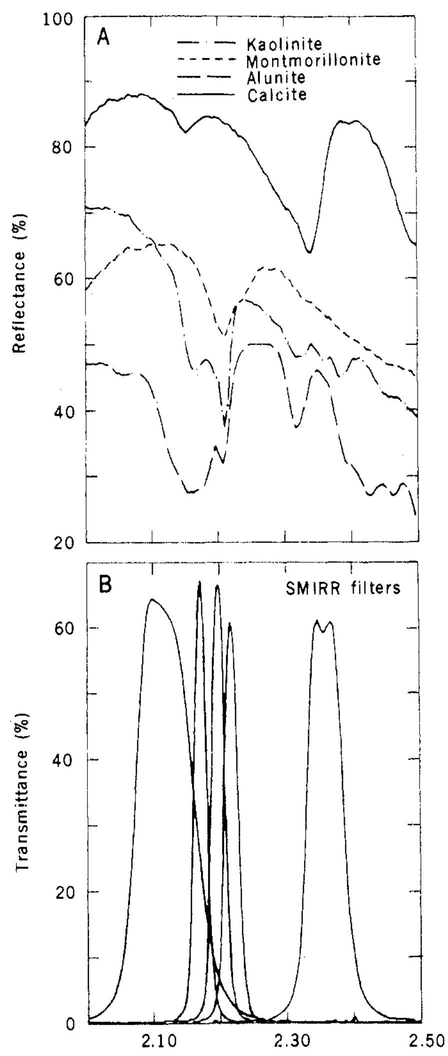


Fig. 4. (A) Variations in the reflectance properties of four common rock and clay minerals, as determined in the laboratory (*6*). (B) Position and size of SMIRR transmission filters in the 2.0 to 2.5 μm wavelength region. The SMIRR measurement bands were selected for the purpose of discriminating between different types of geological materials.

The MAPS experiment is based on the unique CO absorption band at 4.5 to 4.8 μm. The degree to which thermal radiation emitted at the earth's surface is attenuated in this spectral region during its passage through the atmosphere can be directly related to the CO concentration.

The MAPS instrument consists of a gas-filter correlation radiometer, an associated electronics module, a digital tape recorder, and 35-millimeter camera. Thermal radiation from a 22-km instantaneous ground field of view is focused through three independent optical paths onto three similar detectors. Two of the optical paths pass through cells that contain CO gas at pressures of 266 and 76 torr. The third optical path is focused directly onto a detector without passing through any gas filter. The high-pressure CO gas cell acts as a filter for CO present at altitudes of 7 to 8 km, and the low-pressure cell acts as a filter for CO present at altitudes of 10 to 12 km. The output from the three detectors is compared to obtain a measurement of absolute CO abundance at the two different altitudes. The correlation radiometer will be operated continuously throughout the earth observation portion of the shuttle flight, and the data will be digitally recorded on magnetic tape. The 35-mm camera will photograph the earth's surface during sunlit periods to evaluate the effects of cloud cover on measured values of CO concentration.

NASA aircraft from the Langley and the Ames research centers will simultaneously measure CO concentration, dew point, and atmospheric temperature and pressure as functions of altitude during the shuttle overflight. MAPS will be evaluated as a possible satellite instrument to monitor long-term changes in tropospheric CO distribution and will be used on subsequent flights of the shuttle to establish the seasonal variations in global concentration of CO.

Night/Day Optical Survey of Lightning (NOSL)

By detecting and mapping electrical discharges associated with thunderstorms it may be possible to determine the intensity and trajectory of severe storms. At present, however, the relation between convective circulation in thunderstorms and the electrification process is not well understood. Spaceborne platforms are ideal for observation of the occurrence and distribution of lightning in thunderstorms because the electrical discharges can be analyzed synoptically in plan view.

Orbital observations of thunderstorms in the past have provided a new perspective on the scale and nature of lightning phenomena. Collective organization of lightning strikes has been observed over areas as large as 150 km. Luminous pillars of light and so-called ball lightning have been seen in clean air above major thunderstorms. Large-scale horizontal discharges have been reported by astronauts but have not been observed from the ground. In addition, analysis of data collected by the Defense Meteorological satellites has suggested that intensity of electrical activity may be a diagnostic precursor of tornadoes in the central United States (*8*).

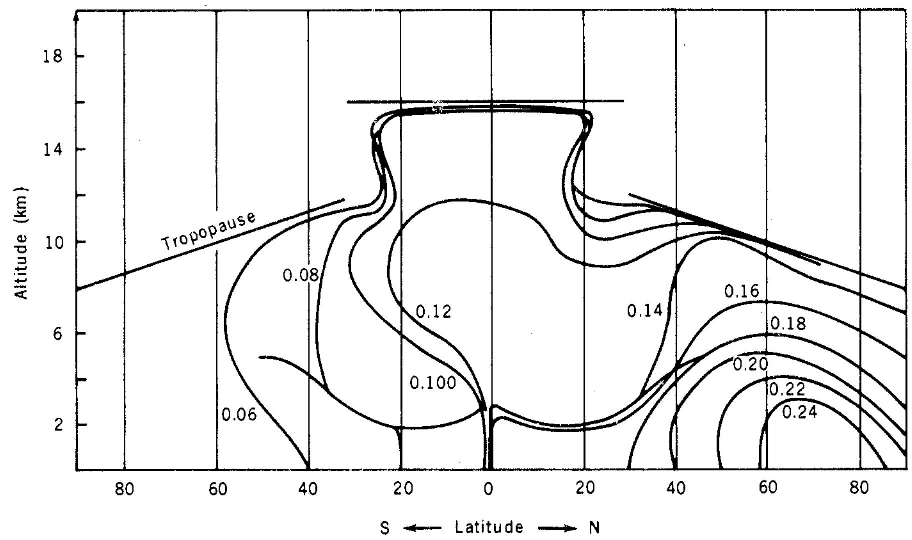


Fig 5. Averaged distributions of carbon monoxide in marine air in parts per million, as reported by Seiler (*7*). Note the asymmetry between the Northern and Southern hemispheres. The MAPS experiment will involve a nearly global survey of tropospheric CO abundance at lower latitudes (40°S to 40°N), where interhemispheric exchange of CO occurs.

The objective of the NOSL experiment is to obtain motion-picture films and correlated photocell sensor signals of lightning storms from orbit. A 16-mm motion-picture camera will film ordinary and severe thunderstorms. In addition to film records of the appearance of cloud systems and lightning, the magnitude, duration, and frequency of lightning discharges will be simultaneously measured by a photocell optical system and recorded on magnetic tape. The spatial resolution of the NOSL camera is 30 m at nadir while that of the photodetector is 20 km. A diffraction grating can be placed at the front of the camera lens, and spectral diffraction patterns associated with specific lightning flashes can be recorded on the 16-mm film. The grating attachment will be used under nighttime viewing conditions if observed lightning discharges are sufficiently intense.

The NOSL experiment, designed for observing a dynamic meteorological phenomenon, will be operated from the crew compartment by the shuttle astronauts. They will be advised of the location of thunderstorms by ground controllers who have access to meteorological satellite data. The NOSL photocell produces an audible pulsed tone in response to the detection of a lightning flash, much as a Geiger counter beeps in response to radioactivity; this feature will facilitate the accurate pointing and tracking of specific features.

A lightning event, which visually appears as a single flash, is usually composed of many separate discharges. Variations in the frequency and intensity of lightning discharges will be detected by the NOSL photocell and correlated with photographic records of cloud structure and convective circulation in individual storms. When thunderstorm clouds are observed at close range, calculations will be made to determine the convective energy of the cloud systems and to relate this to the frequency of lightning as indicated by the photocell data. If data are obtained from a sufficiently large number of continental and oceanic thunderstorms, the differences in the electrification process over land and water surfaces will be analyzed and quantified.

If photographic data are obtained on the long, horizontal discharges previously reported by astronauts, the film will be carefully analyzed to determine the speed of propagation, and the discharges will be compared with vertical discharges that have been observed beneath clouds. If useful spectral data are obtained with the camera grating attachment, the resultant diffraction patterns will be analyzed with a photometric apparatus. It is hoped that spectral differences will provide a basis for distinguishing between intracloud and cloud-to-ground lightning. The results of this experiment will be used to evaluate sensors and techniques to identify severe weather situations for use on meteorological satellites in the future.

Ocean Color Experiment (OCE)

Orbital earth observations during the past two decades have been used to monitor circulation patterns within the oceans and to detect certain types of marine flora. Marine algae have been identified on the basis of their pigmentation in panchromatic and multispectral imagery, and the temporal dispersion of algae has been monitored. Because marine algae play a fundamental role in global photosynthesis and the ocean food chain, their distribution is a key parameter in evaluating changing environmental conditions on a global scale.

Remote sensing techniques for detection and mapping of chlorophyll a–bearing phytoplankton in the ocean were first employed in 1969 by Clarke *et al.* (*9*). Because of their initial success, NASA's Goddard Space Flight Center developed an airborne multispectral scanner in 1974 called the ocean color scanner. This instrument was flown on the U-2 aircraft, and data analysis showed that reliable estimates of surface chlorophyll required accurate corrections for atmospheric and ocean radiance. A satellite instrument, the coastal zone color scanner, was launched on Nimbus-7 in 1978 to evaluate biological phenomena in the coastal zone. Analysis of the extensive data set collected by the Nimbus instrument has shown that it is difficult to infer surface chlorophyll concentrations unambiguously because of the presence of suspended sediment in coastal waters, variations in ocean depth and bottom conditions, and variations in sea surface state.

The shuttle OCE will build on the experience gained with the Nimbus scanner data. The experiment is designed to acquire ocean color data in deep ocean areas under different azimuths and inclinations of solar illumination. The range of color variations observed in the deep ocean will be compared with earlier coastal zone measurements. In addition, deep ocean observations will be correlated with major ocean circulation systems.

The OCE has an eight-channel optical-mechanical line-scanning instrument to collect multispectral data for evaluating pigmentation related to chlorophyll a. Table 1 shows the spectral bands for evaluating chlorophyll absorption, ocean and atmospheric radiance, and chlorophyll fluorescence. A typical example of spectral reflectance from ocean areas containing chlorophyll a is shown in Fig. 6. The OCE will collect data with a ground resolution of 1 to 2 km^2 over a ground swath of 511 km.

In situ data collection is an integral part of the OCE experiment and activities at four ground sites will support the OCE investigations. A West German aircraft carrying NASA's airborne ocean color scanner will conduct surveys off the coast of Senegal in West Africa that will coincide with the shuttle overflight, and both will examine phytoplankton populations in upwelling areas along the Atlantic gyre's outward flow. Mid-Atlantic warm core eddy rings will be studied in the general area of 40°N latitude and 70°W longitude by shipborne investigators from Woods Hole Oceanographic Institution. A third site located off the coast of the southeastern United States will be used to investigate the dynamics and biota associated with upwelling along the eastern edge of the Gulf Stream. Shipborne measurements of chlorophyll concentration and other ocean parameters will be taken by oceanographers from the Skidaway Institute of Oceanography in Savannah, Georgia. The last group of test site investigators is from the University of Delaware, the University of Costa Rica, and the National Oceanic and Atmospheric Administration/National Environmental Satellite Service. They will be in the Gulf of Nicoya off Costa Rica during the shuttle mission to study upwelling phenomena along the Central American coast.

Data from the OCE scanner will be recorded on magnetic tape. Corrections for atmospheric and oceanic radiance will subsequently be applied to the raw data at Goddard. Calibrated computer tapes will then be used to produce contour maps of chlorophyll concentration, and these will be compared with similar information developed from the analysis of ship and aircraft data. The results of the OCE will complement those obtained by the Nimbus coastal zone color scanner and will provide a comprehensive technical basis for monitoring marine chlorophyll concentrations from space, if such a capability is deemed desirable in the future.

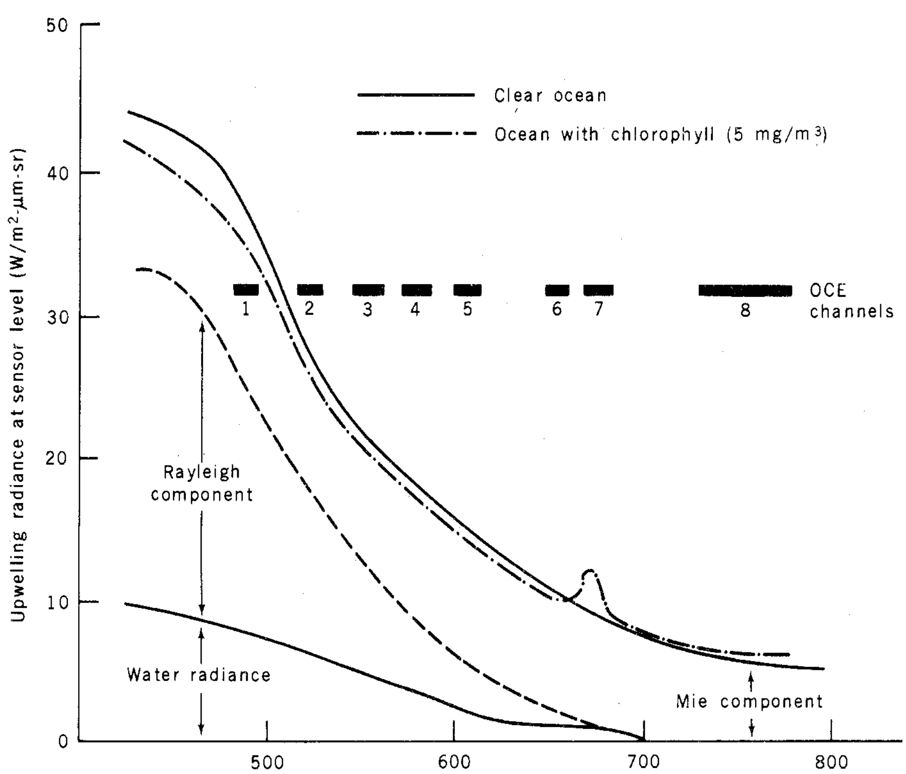


Fig. 6. Comparison of typical spectral radiance curves over ocean areas obtained with an airborne ocean color scanner. The clear ocean curve represents clear ocean water radiance combined with effects of atmospheric scattering (both Rayleigh and Mie scattering). The ocean with chlorophyll curve shows spectral effects of chlorophyll, at a concentration of 5 mg/m^3, in ocean surface. Note the decrease in radiance at shorter wavelengths and the small fluorescence peak at 685 nm produced by the presence of chlorophyll. The OCE measurement bands are indicated by horizontal bars; OCE spectral channels are given in Table 1.

Feature Identification and Location Experiment (FILE)

Earth observation satellites, which acquire global multispectral data repeatedly, are capable of collecting large quantities of data in regions where the earth's surface is partially or wholly obscured by clouds. Control of an orbital sensor from the ground, to minimize the acquisition of data from cloud-covered regions, is an expensive, labor-intensive process that requires near real-time satellite meteorological data. The need to develop so-called smart sensors, which can be programmed to acquire only desired data, will increase as the spectral and spatial resolution of earth observation sensors improves over the next decade (*10*).

FILE is a feature classification experiment designed to identify four main groups of landscape cover: vegetation, rocks and soils, water, and clouds, snow, and ice. The principle used for discriminating between these types of cover is to compare reflected solar radiation in two wavelength bands, one in the visible at 0.65 μm (red) and the other in the near infrared at 0.85 μm. The spectral curves for the four different types of cover listed above are shown in Fig. 7A. Automated classification of landscape cover material is based on the ratio and absolute values of the two measurement bands. Figure 7B shows the results of a simulated classification experiment employing laboratory and field measurements of spectral reflectance at 0.65 and 0.85 μm.

FILE uses two solid-state charge-coupled device cameras with red and infrared filters centered at the appropriate wavelengths. The filters each have a bandwidth of 0.02 μm. The cameras are both boresighted onto the same area (90 km by 90 km), which is examined by a 100 by 100 element array of detectors in each camera. The instantaneous ground field of view of a single detector is 1.04 by 0.87 km. A Hasselblad camera will simultaneously take 70-mm color photographs of the imaged area with a spatial resolution of 100 m. Data for each frame of imagery will include digital values for each detector, a count of the number of picture elements in the scene that were classified in each category, and the date and time of day. Four-color images will be constructed from the detector array values to display graphically the results of automated scene classification. These classification maps will be compared with landscape cover boundaries detected in the Hasselblad photography to evaluate the accuracy of the FILE classification procedures. To test the ability of the instrument to make real-time data acquisition decisions, and to ensure that a variety of natural scenes are observed, the dominant cover type in each scene will be determined, and data acquisition will be terminated after a particular landscape cover type is found to dominate 32 separate scenes.

Subsequent shuttle experiments in feature identification and location may include the addition of a 1.55-μm channel and modification of the decision logic to permit separation of cloud and snow or ice cover types. If these techniques are successful, they will form the basis for future advanced studies with the shuttle related to automated sensor tracking and navigation for data acquisition.

Table 1. Ocean color experiment measurement capabilities.

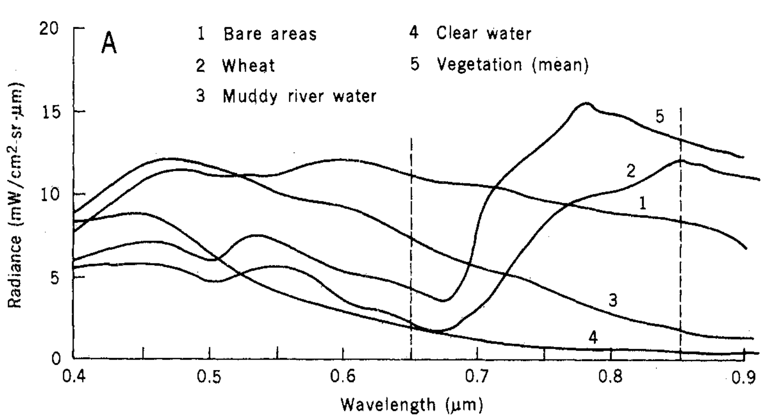
Spectral channel	Center wavelength (nm)	Bandwidth (nm)	Type of light	Purpose
1	485.9	23	Blue	Chlorophyll absorption (maximum); Rayleigh scattering (atmosphere)
2	518.4	23		Chlorophyll hinge point
3	552.6	23	Green	Chlorophyll absorption (minimum)
4	584.5	23		Backscattering (water and atmosphere)
5	620.6	23		Backscattering (water and atmosphere)
6	655.1	23	Red	Nonfluorescence band
7	685.1	23		Chlorophyll fluorescence at 685 nm
8	786.6	52.4	Near infrared	Mie backscattering (atmosphere)

Heflex Bioengineering Test (HBT)

From the study of plant germination and growth in the zero gravity environment of space, insight is gained into plant physiology (*11*), and this study has major implications for man's ability to operate in a self-contained environment in space for extended periods of time. Russian experiments during the past two decades have demonstrated the sensitivity of plants to soil moisture in near zero gravity. In particular, moisture conditions that lead to normal plant growth on the earth can exceed a plant's moisture requirements in near zero gravity.

A plant growth experiment will be conducted on the first Spacelab mission to be flown on the shuttle in 1983. This experiment, known as the *Helianthus annuus* Flight Experiment, or Heflex, is designed to study oscillatory plant growth behavior (nutation) under weightless conditions. On the earth, this nutation effect typically results in an elliptical or circular pattern of motion in the plane parallel to the ground surface during plant growth and development. A dwarf sunflower species (*Helianthus annuus*) has been selected for the Spacelab experiment because of its rapid growth characteristics. Dwarf sunflower plants will be grown to an appropriate stage of development on Spacelab; a centrifuge will impose a 1*g* centripetal acceleration on the plants. Each day in orbit the plants will be removed from the centrifuge and photographed with time-lapse photography. The Spacelab experiment will determine whether plant nutation occurs in a weightless state and, if so, the period, amplitude, ellipticity, and directional preference of the nutation effect will be measured.

The HBT will be used to calibrate the Heflex Spacelab experiment. The HBT is being conducted specifically to determine the optimal soil moisture conditions for germination and growth of *H. annuus* in a near zero gravity environment. A suitcase-like container will be loaded with 72 sealed plant modules with soil moisture content varying from 58 percent by weight (below which plant growth is minimal) to 80 percent (above which anaerobic conditions inhibit growth). The plant container will be carried into the shuttle approximately 7 hours before launch and it will be stored in a locker in the crew compartment. A small, battery-powered temperature recorder will provide a record of temperatures during the flight. The case containing the HBT will be turned over to the principal investigator within 1 hour of



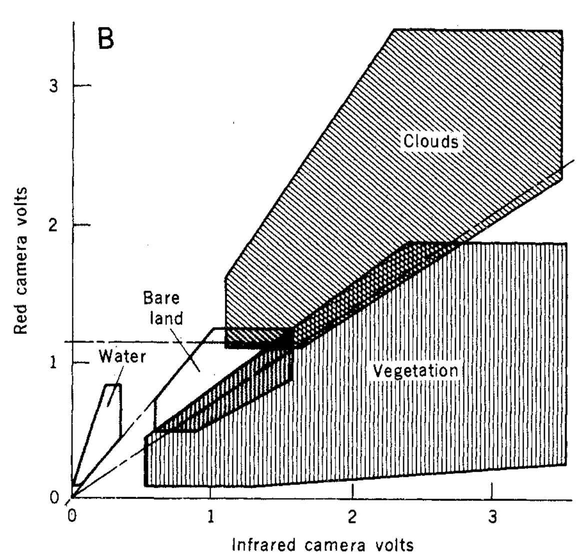


Fig. 7. (A) Typical spectral radiance curves for common types of landscape cover materials as observed at aerial elevations. The position of FILE spectral measurement bands is indicated by vertical dashed lines. (B) Scatter diagram, based on laboratory and field data, showing the extent to which major types of cover classes can be differentiated from spectral measurements at FILE wavelengths of 0.65 (red) and 0.85 μm (near infrared). Boundaries of cover type polygons represent 99 percent confidence intervals for correct classification.

the shuttle landing in California. Plant photographs will be taken after the experiment is removed from the shuttle, and measurements of plant height, stem length, and soil moisture loss will be taken.

Shuttle Research Capabilities

The space shuttle has several advantages over previous types of earth orbital platforms in terms of both the types of experiments that can be performed and the design and operation of scientific instrumentation. The most obvious advantage is the shuttle's ability to safely return payload instruments to the experimenter on the ground. This capability will allow significant relaxation of standards of instrument reliability and redundancy that have made even simple space-qualified experiments very costly in the past. In the event of a critical failure of a particular experiment during a shuttle mission or an aborted attempt to achieve orbit, instruments can be recovered, repaired if necessary, and quickly reflown. Furthermore, shuttle payload instruments will be returned to researchers at the conclusion of an orbital experiment for reuse in the field or laboratory.

The shuttle will enable scientific investigators to evaluate new types of earth sensors more quickly and at lower cost. In the past the use of costly experimental satellites to evaluate new sensor technology has necessitated the development of expensive ground-based facilities to process and archive large quantities of data. The shuttle will be able to collect limited quantities of experimental remote sensing data over a wide variety of test sites. Data can also be collected on a multitemporal basis by a series of shuttle flights to study seasonal, annual, or longer term phenomena. Ground facilities to support the reduction and storage of data collected in this manner will be designed to meet the needs of experimenters and will not be relied on for long-term data production. This should reduce costs and facilitate the evaluation of new technological capabilities, such as multispectral linear array instruments and multifrequency-multipolarization radar systems, as engineering prototypes become available.

Finally, the shuttle affords a researcher a new dimension of flexibility in designing earth observation experiments. Future shuttle payloads could be specifically configured to study dynamic, short-term phenomena such as variations in ocean currents, hurricane formation and evolution, and the atmospheric impact of explosive volcanic eruptions. In addition, scientifically trained mission specialists will be included on future shuttle missions, and these specialists will be able to collect data over targets of opportunity identified from orbit.

Future Prospects

The OSTA-1 payload will provide a preliminary demonstration of the shuttle's research capabilities. However, these capabilities can be expected to expand in the future to include larger orbital inclinations, which will permit observations of high latitude regions; simultaneous orbital flights of more than one shuttle spacecraft; longer duration shuttle missions; and, later in the decade, the development of orbital platforms serviced by the shuttle. The shuttle will fundamentally change the way in which earth-related research is conducted in space, and earth scientists of all disciplines should be prepared to fully exploit it (*12*).

References and Notes

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2. Members of the OSTA-1 science management team include program scientist, James V. Taranik, NASA Headquarters; mission scientist, Andrew Potter, NASA–Johnson Space Center; and the following principal investigators: shuttle imaging radar-A (SIR-A), Charles Elachi, NASA–Jet Propulsion Laboratory; shuttle multispectral infrared radiometer (SMIRR), Alexander F. H. Goetz, NASA–Jet Propulsion Laboratory, and Lawrence C. Rowan, U.S. Geological Survey; measurement of air pollution from satellites (MAPS), Henry G. Reichle, Jr., NASA–Langley Research Center; night/day optical survey of lightning (NOSL), Bernard Vonnegut, State University of New York at Albany; ocean color experiment (OCE), Hongsuk H. Kim, NASA–Goddard Space Flight Center; feature identification and location experiment (FILE), Roger T. Schappell, Martin Marietta Aerospace; and Heflex bioengineering test (HBT), Allan H. Brown, University of Pennsylvania.
3. Individuals interested in obtaining earth observation data collected by the OSTA-1 payload should contact the National Space Science Data Center, Code 601, NASA–Goddard Space Flight Center, Greenbelt, Md., 20771.
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