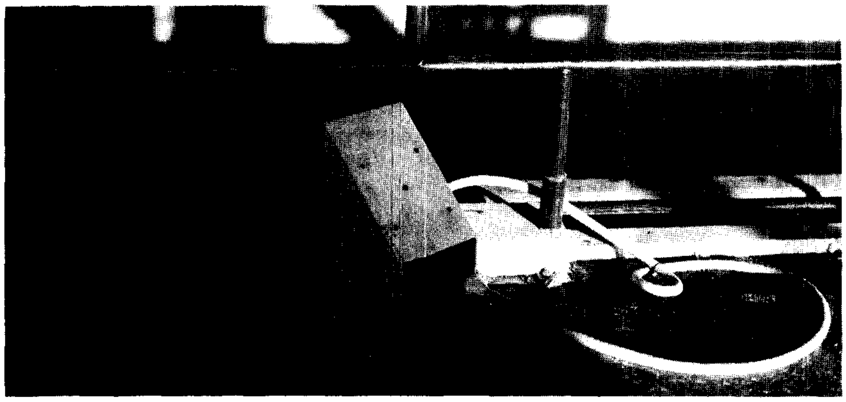


FIGURE 43.—A typical camera mount installation with thermally shielded cable ready to accept the camera in the flame trench of the launch platform.

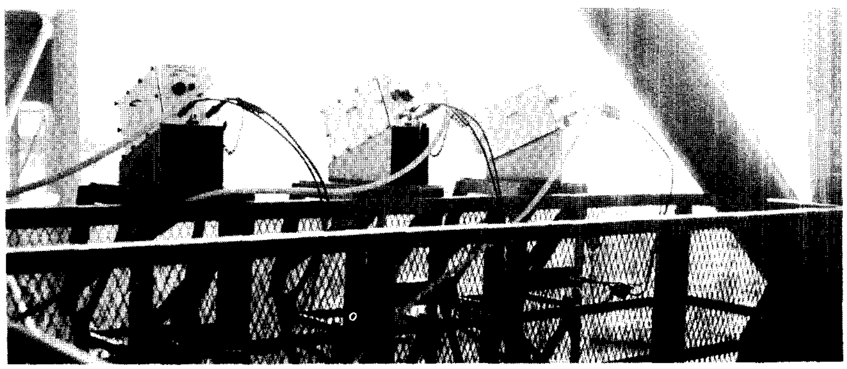


FIGURE 44.—A series of engineering cameras assembled on a low-level camera platform to record the initial stages of liftoff. Note the use of the ablative protective housings and the shielded power cables to each of the cameras. From the connectors it is obvious that the control circuits have all been prewired into the launch complex.

The camera systems used to record the rocket motor during liftoff appear at the bottom of the picture, two to the left and one to the right of the rocket. Other cameras are trained on various umbilical connections to record their separations when they break away during liftoff.

During a Saturn launch operation, 106 cameras are used. Typical of the locations is the camera-mount bracket and the flame trench shown in figure 43. Cameras in their ablative protective housing are shown assembled on a low level of the Launch Umbilical Tower in figure 44. It should be noted that the camera housing mounts have a significant degree of mechanical as well as thermal protection. On occasion, the entire housing has been knocked loose from its base during liftoff by the explosive nature of the exhaust. In these accidents, cameras have sustained little damage with no loss of the photographic record up to the point at which the camera housing was displaced from its position. Figure 45 is a typical high-level installation at one of the upper platforms of the Launch Umbilical Tower seen in figure 42.

Figure 41 indicates another area of technological innovation which is applied to the program, although it is not specifically photographic in nature. This is the improvement of the civil engineering procedures to define the locations of the cameras in the six different camera sites surrounding the launch complex so that the engineering photography may also be used for photogrammetric operations. These photogrammetric analyses de-

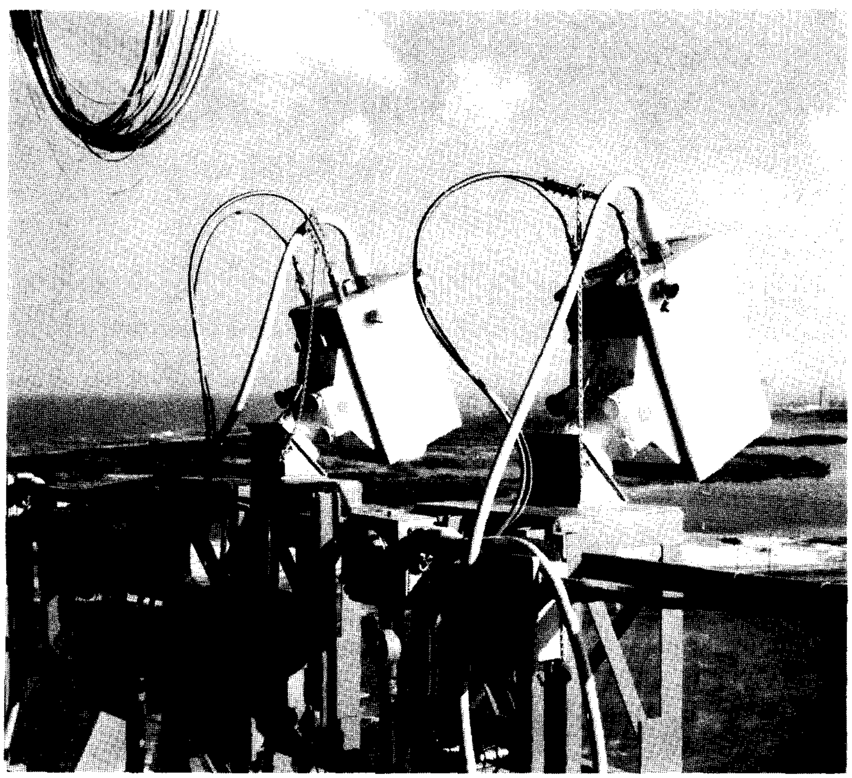


FIGURE 45.—A typical high-level installation on one of the upper camera platforms. This picture shows details of the electrical control systems and power distribution built into the facility.

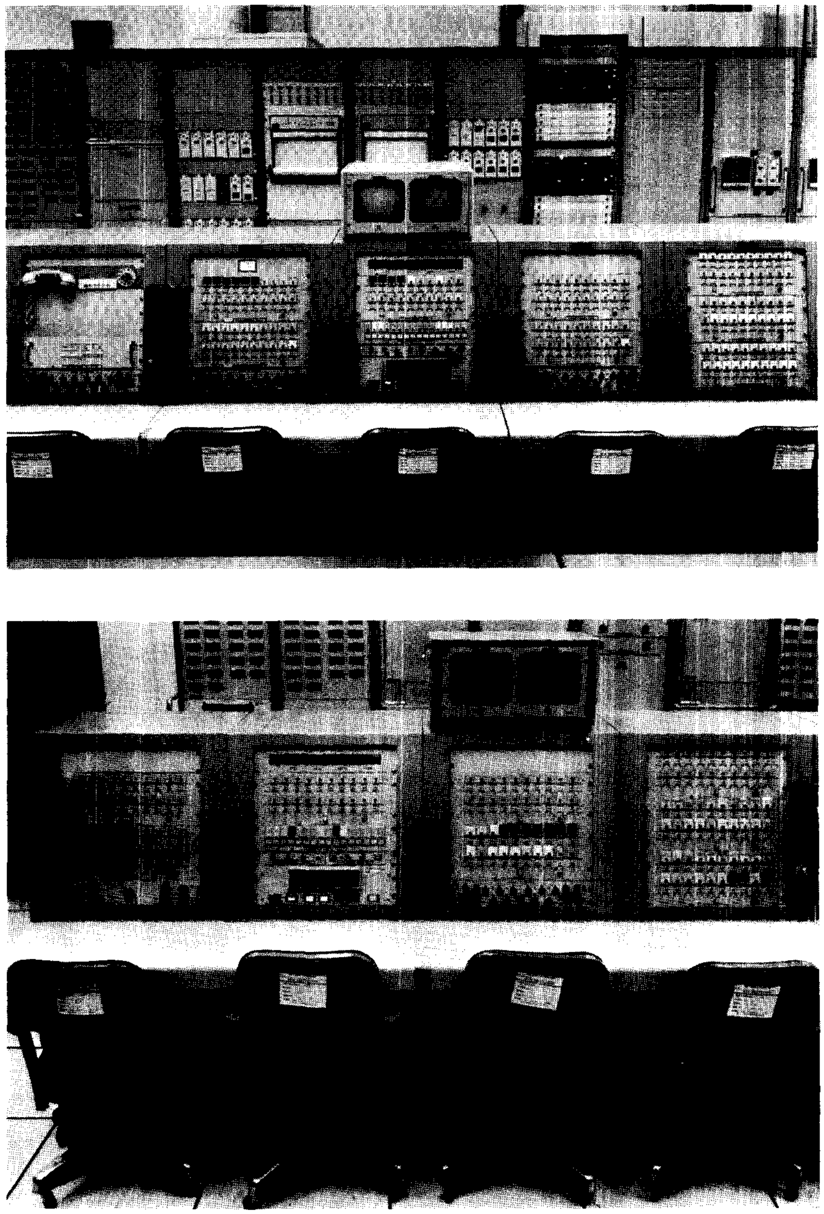


FIGURE 46.—General views of the remote photographic control complex in the Launch Control Center associated with Launch Complex 39A at Kennedy Space Center. Operation capability includes remote manual, automatic or emergency automatic, as well as change sequence. Control is available for each of the 130 cameras utilized during a launch operation.

termine the accurate measurement in three-dimensional space of the vehicle at every point of its trajectory.

Figure 46 shows the photographic Control Complex in the Launch Control Center, both the left- and right-hand sections showing details of the timing display, the camera enabling switches, the camera assignment tags, and the remote monitors with the video system that enables operators to see what is actually taking place at the launch complex site. Figure 47 is a closeup of another versatile camera-control system, with the ability to assign individual control elements to different cameras as required by the test program and the specific launch.

Chapter II described tracking cameras which are also operated remotely from the central Photographic Control Complex. These remote cameras carry a closed-circuit TV system for boresight purposes; that is, critical aiming purposes. The boresight TV is displayed on the monitor and, by means of the control lever in front of the operator, he can manually but remotely cause the tracking camera to follow the vehicle. This is shown in figure 48.

The use of drop-package cameras in the drop tower for zero-gravity studies at Lewis Research Center has been described. In addition, the tower also contains an assembly of cameras which photograph the drop package as it proceeds up and down the

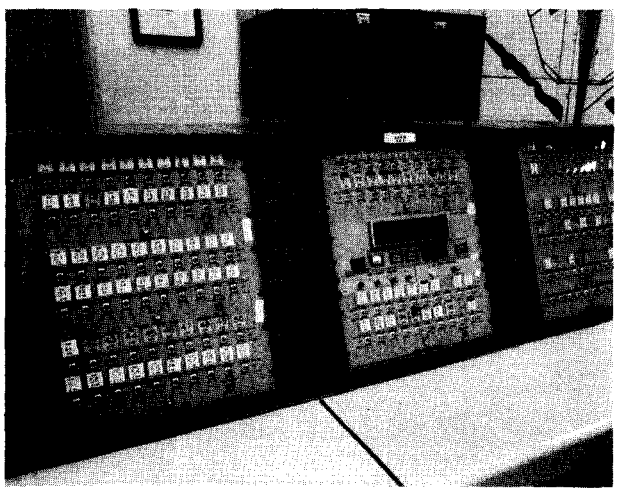


FIGURE 47.—A closeup of a smaller launch control center which shows how the individual circuits may be applied to different cameras for different launch operations and how they are identified on the control complex. For each of the positions, the camera circuit can be started manually or switched to the sequencer, the master timing control network.

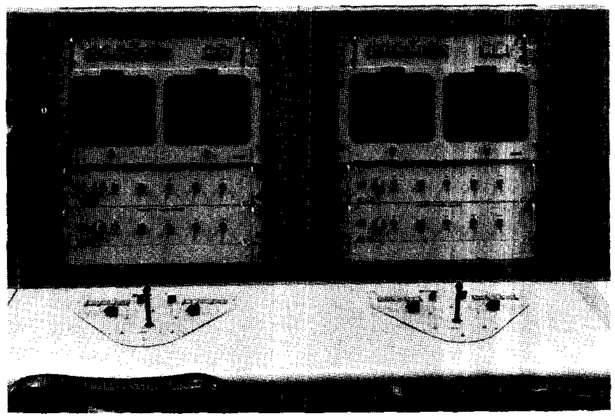


FIGURE 48.—This view of the photographic control center associated with the remote tracking cameras shows the monitors which are used with closed-circuit television boresight instruments for viewing events seen by the camera through remote TV. Through controls in front of and on the desk of the console, the operator can direct the tracking camera to follow any event during the launch cycle.

tower and into the deceleration unit. When the proper precautions are taken, these cameras can operate in the vacuum of the chamber. In such drop tower and other vacuum work, or closed environment systems, it has also been necessary to operate external cameras photographing through very small viewing ports. While the photographic system gives the highest resolution and maximum information capacity, it is also desirable to see in real time the events as they are taking place. Space in some of these systems does not permit the use of two systems, one photographic and one television. If closed-circuit television were used with remote photographic recording, it would suffer very strongly from a loss of information because of the limited bandwidth and information carrying capacity of the video system.

Photographic engineers at Lewis developed an interesting technique for the solution of the problem. Some cameras have been modified with a beam-splitting device so that the image formed by the lens through the small available port is diverted by means of the beam splitter, part of the energy being directed to a television camera tube. The remaining part, which passes through the beam splitter, creates a photographic image in the normal manner. The video camera system and closed-circuit television thus serve as a remote boresight for the camera. In these applications, a simultaneous picture is given on a monitor to the test

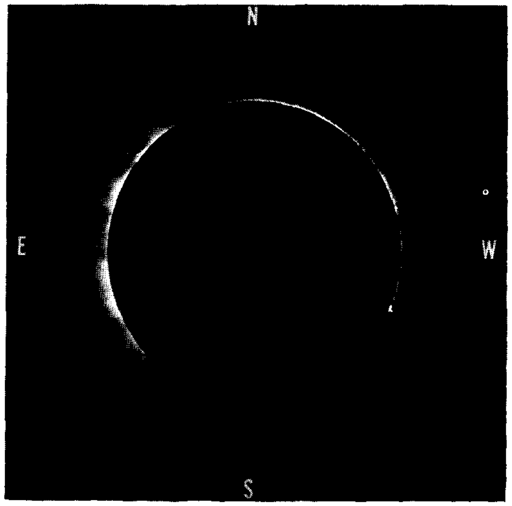


FIGURE 49.—This picture is one of the most impressive of the coronal photographs obtained at the 1970 solar eclipse. It was taken by Sheldon M. Smith, of the Ames Research Center, and Leonard M. Weinstein, of the Langley Research Center. They used a telescope modified at the Langley Research Center to incorporate a special filter to reduce the ex- extremely steep gradient of coronal brightness.

operators. The technique could also be employed for a closed-circuit boresight tracking system.

During launch preparation at Kennedy Space Center, a large number of engineering documentation photographs are made by hand-held cameras to verify that all preparations, particularly those that have to be accomplished manually, have been satisfactorily completed. Included in the preparations are connection of fuel lines and power cables. In these cases, pictures are taken of the connectors before and after a connection is made, or before and after it has separated, to determine whether the system works and is fitted together properly. In the event of an unusual occurrence, these records are invaluable in determining the probable source of the problem. The types of cameras and photography are discussed in chapter I.

Other scientific and technical photography has supported general scientific investigations. Some of the finest pictures of the 1970 solar eclipse were the result of NASA's work by the Airborne Science Office at Ames Research Center in cooperation with the Langley Research Center (fig. 49).

An interesting engineering study with immediate industrial application for regional and local governments concerns the use of engineering photography in the analysis of traffic problems. By this means, a photographic record is obtained of traffic flow, rates and behavior of vehicles at critical intersections or on critical highways. A typical example is shown in Figure 50.

Summarizing, it has been shown that photography for engineering documentation and analysis has found very broad and diverse

FIGURE 50.—A sample photograph showing how low-level aerial photography might be used for traffic engineering analysis in evaluating flow patterns, delays and behavior of drivers at converging lanes. If one looks closely enough at the photograph, where the feeder lane converges from the viewer's left into the stream of traffic moving downward into the left, one can see a car tailgated bumper-to-bumper to prevent traffic from merging.

applications in the NASA space programs. Photography has proved to be an effective tool. In a very strict technical sense, it can be said that photography has an information capacity and an information rate higher than any other communication medium. In pragmatic terms, photography is a very simple and effective means of recording up to four dimensions of information: the two dimensions in space; the luminance or energy radiated from objects in space; and the time variation of the dynamic behavior of the objects in the space. With these fundamental concepts in mind, it appears obvious that photography will increasingly be applied in our industrial and commercial activities. The examples presented in this chapter are just a few of the many contributions made to techniques and methods of analysis by NASA personnel or through NASA-sponsored programs. It is hoped that the selection is diverse enough to suggest solutions to immediate problems encountered by the reader.

Multispectral Photography

One of the significant areas in which NASA has added a wealth of technology has been multispectral photography in the Earth Resources and Environmental Investigation programs.

In conventional photography the general tone range perceived by the observer is recorded through black-and-white systems and an approximation to true perceived colors is made by color systems. Multispectral photography, on the other hand, works with sensitivities in diverse spectral bands, and many times these will have narrow bandwidths.

For years photographers have used color filters to enhance black-and-white pictures. For example, yellow and red filters bring out the deep blue of the sky. Filters will correct for unbalanced sensitivity in certain types of emulsion. By scientific selection of filters, significant information can be obtained from photographs based on different wavelength bands of visible spectra. In spectral analysis, a laboratory scientist gathers important information about material by obtaining its spectral signature with a spectrophotometer. This is an instrument which divides light into its individual wavelength components and the behavior of the sample is determined for each individual wavelength component. An abridgment of the spectrophotometric technique is available for the photographic recording of a scene with two spatial dimensions.

A comprehensive analysis of basic multispectral techniques is given in reference 17. Reference 18 is a discussion of multispectral photography as applied to early experiments performed by the Air Force at the Cambridge Research Laboratories.

A fixed camera records a scene sequentially, or a multitude of cameras operating simultaneously photograph a scene under a dynamic environment, each camera equipped with an optical filter. These filters allow only one narrow band of wavelength of light to pass through. An assortment would give the equivalent of spectrophotometric photography. However, the spectral signatures of things in nature are not so discontinuous as to require the high resolution of many individual wavelength bands. Much useful information can be obtained by simply utilizing three to six selected broad bands of the spectrum. The choice of bands depends on the nature of the experiment, or the information desired. A typical example of three bands is ordinary color film which separates the information into red, green, and blue bands of light and reproduces it in color on a single film to give the observer a direct impression of the actual color of the original scene. In scientific work, the bands may be somewhat smaller to yield specific information or they may extend out of the visible region of the spectrum into the ultraviolet and infrared radiation bands.

The selection of films for multispectral photography depends on the purpose for which the information is wanted. Black-and-white films consisting of a single emulsion layer produce the information about the individually selected bands on separated sheets of film. This presentation is extremely useful in the case of automatic data reduction systems utilized to recover the information and put it in a form suitable for computer processing. It is the required method when photographic reconstruction techniques are used to make composites of individual selected sets of original photographs. On the other hand, color films, having two or three separately sensitive, individual emulsion layers, permit the direct recording of two or three bands, respectively, in a composite form for viewing convenience. In utilizing color film for multispectral work, all the colors reproduced in the composite are required to be those to which the eye is sensitive, if it is to recognize the scene. But in no respect are they required to show the true color of the original scene. For example, certain color films record the infrared, which is invisible to the human eye but, for convenience, produce it in red as compared to blue and green to show some other spectral aspect of the subject matter.

In many applications, multispectral photography is originally recorded on black-and-white film. A separate film is used for each band or spectral region for which information is desired. In addition to being able to analyze data by automatic data reduction to a computer, it is also possible to reconstruct the photographs in a color system by utilizing a key color for each spectral band. Experimental equipment for such reconstruction work has been constructed in the form of an Additive Color Viewer-Printer that is presently under evaluation by NASA.

Where separate cameras are used in a dynamic environment, it is essential that they be synchronized mechanically or electrically to insure that the individual pictures represent the same time window of the subject being photographed. In the Earth

Observation Program, multispectral camera sets have been used on aircraft as well as on spacecraft.

Black-and-white films used in multispectral photography have involved conventional, panchromatic-sensitized black-and-white emulsions and also infrared-sensitized black-and-white emulsions. All films are naturally sensitive to the near-ultraviolet spectrum. The wavelength band used in many of the experiments has varied widely depending on the nature of the information that the investigator desired.

With respect to color photography, natural color photography has, of course, been uniquely helpful; but the use of a two-layer color material for work over water has allowed greater penetration of the ocean depth. A three-layer color film which, in place of having a sensitivity that yields the true visual color of the natural object, utilizes green, red, and infrared spectral bands has been very effective in providing significant agricultural environment details. While photographic film has for many years been used to advantage in emission spectroscopy and spectrophotometry of passive materials, i.e., those that absorb, reflect or transmit light, it was the space program that gave the greatest impetus to utilization of photography as a means of obtaining spectral information while retaining the two-dimensional spatial integrity of the scene. Most of the achievements were stimulated by the need to gain large volumes of information quickly and efficiently in the dynamic and limited space environment of aircraft and, later, space vehicles.

The discussion of wavelength selection that follows is an edited excerpt from NASA SP-230, Ecological Surveys from Space, 1970:

The 400- to 900-nanometer range of wavelengths of light embraces all colors of the visible spectrum (violet, blue, green, yellow, orange, and red), together with wavelengths just a little longer than the visible red, known as the near infrared. It is often helpful to consider this 400- to 900-nanometer range as one composed of four "bands," three of which are in the visible and one in the infrared region. The three visible bands correspond to the three primary colors: blue, green, and red. With only moderate oversimplification, the wavelengths embraced by the four bands can be considered to be:

Band:	*Wavelength range, nanometers*
Blue	400 to 500
Green	500 to 600
Red	600 to 700
Infrared	700 to 900

An aerial or space photo can be taken in any one of these bands by (1) using a film sensitive to energy in that band and (2) employing a filter that transmits energy in that band but excludes energy of other wavelengths to which the film is sensitive.

The choice of a band to use for an aerial or space photo of the Earth depends largely on two factors: the degree to which the objects to be recorded reflect energy from each of the four bands, and the extent to which haze particles in the atmosphere scatter radiant energy from each band.

The more energy an object reflects to the camera in any given wavelength band, the brighter the image of that object will be on the positive print when a picture is taken in that band (i.e., the lighter its photographic tone becomes). Because the amount of energy reflected in a given band tends to be a function of the type of object, the tones obtained object by object when photographing in that band are important aids to the identification of objects.

Two types of objects may have virtually the same reflectivity in one of the four bands, but quite different reflectivities in some other band. Each type of object, jn other words, tends to exhibit a unique "tone

TABLE 2.—*Methods of Expressing Wavelength Range*

Terms used to describe the band	Wavelength range, nanometers		
	As taught in elementary physics	As flown on Apollo 9 (SO–65)	As proposed for ERTS*
Blue	400 to 500	------------	
Green	500 to 600	480 to 620	475 to 575
Red	600 to 700	590 to 720	580 to 680
Infrared (near infra-red)	700 to 900	720 to 900	690 to 830

*Earth Resources Technology Satellite.

TABLE 3.—*Optimum Wavelength Band for Types of Photo Identification To Be Made*

Photo identification to be made	Optimum wavelength band			
	Blue	Green	Red	Infrared
Presence or absence of vegetation	-------	-------	-------	X
Differentiating conifers from broadleaf vegetation	-------	-------	-------	X
Identifying individual species of plants	-------	X	X	X
Detecting earliest evidence of loss of vigor in vegetation	-------	-------	-------	X
Identifying type of agent that is causing the loss of vigor	-------	X	X	-------
Determining the exact channel of a meandering stream	-------	-------	-------	X
Obtaining maximum underwater detail (varies with turbidity)	-------	X	X	-------
Discerning maximum detail in shaded areas on low-altitude photos only	X	-------	-------	-------

signature" in multiband photography, and this signature is often of great value in recognizing an object.

The shape and texture of an object can also help identify it. Other factors being equal, however, the higher the altitude from which a photo of the Earth's surface is taken, the less detail can be seen in an object's shape and texture. The photographic interpreter (or image-analyzing machine) must place greater reliance on the tone signature when the shape and texture are indistinct.

For haze particles of the size commonly encountered in the Earth's atmosphere, energy scattering is in conformity with Rayleigh's law; i.e., inversely proportional to the fourth power of the wavelength of the energy. Because scattering causes a loss of image sharpness, the shortest of the four wavelength bands (the blue band) is of little value when aerial or space photographs are taken of the Earth's surface. This band, consequently, was not recommended for use in SO-65 multispectral photographic experiment on the Apollo 9 flight in 1969.

Table 2 provides three authoritative expressions of the wavelength range encompassed by each of the four bands discussed here. Table 3 suggests optimum bands for various studies.

PHOTOGRAPHIC SAMPLES

The first multispectral photographs taken from spacecraft were recorded during the Mercury program. They were made on the Mercury-Atlas 8 mission by Walter Schirra with a 70-mm Hasselblad and a magazine incorporating a filter pack in place of the normal dark slide used to protect a film when the magazine is taken off the camera. Each section of the experimental filter holder was divided in three, and two filter assemblies were pro-

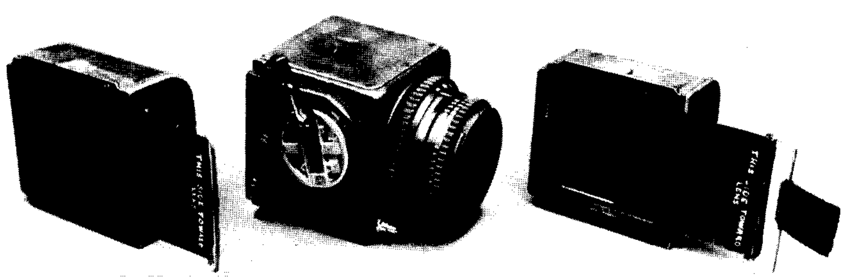


FIGURE 51.—The first multispectral camera was a modified version of the Hasselblad developed for ordinary picture taking from spacecraft. The basic camera shown in the center had two magazines. This figure demonstrates how the filters were incorporated into the dark slide to provide the first side-by-side multispectral photographs.

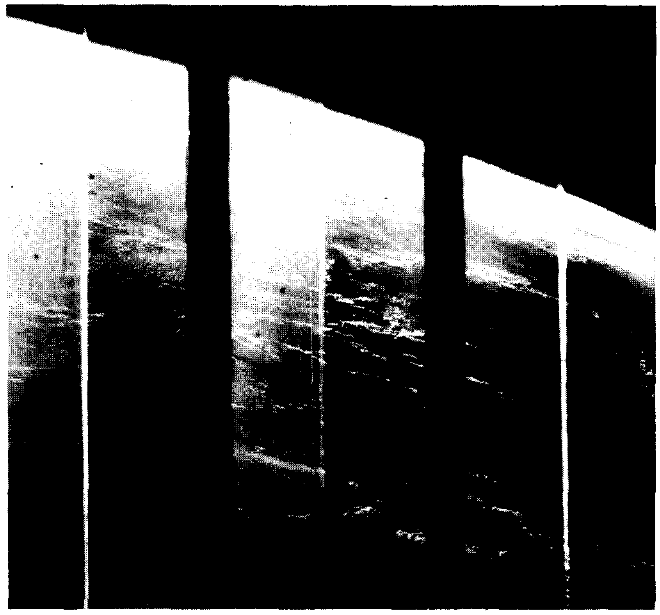


FIGURE 52.—For the Mercury-Atlas 8 experiment a fixed-band set of filters was incorporated in the dark slide. In this continuous picture of the surface of the Earth, the separate elements are recorded in the different spectral bands. Note the displacement in the horizon which was a significant target of this experiment. The picture was taken by Walter Schirra and shows the Atlantic southeast of Brazil.

vided to allow a choice of six spectral conditions: five narrow bands and one band that was used for the total neutral or total white-light spectrum. The cameras and the magazines used on both Mercury-Atlas 8 and Mercury-Atlas 9 are shown in figure 51. The results of that first experiment on Mercury-Atlas 8 are shown in figure 52. Of this first experimental photograph, it should be noted that no attempt was made to get individual pictures showing the same particular portion of the earth with the different filter conditions. Instead adjacent changes in the recorded information were obtained.

Astronaut Gordon Cooper used the same Hasselblad camera, a film sensitive to the far infrared and a three-filter set. This gave a picture (fig. 53) recorded by light of deep red and two regions of the near infrared.

Reference 19 describes airglow horizon photography in the Gemini program. Special cameras that photographed spectral

FIGURE 53.—The Mercury-Atlas 9 multispectral experiment involved only three filter sets. This picture shows Baja California from a point over southern Arizona, as seen by Gordon Cooper. Again note the difference in detail due to the spectral region and the definition of the horizon.

regions at 5577 Å and 5893 Å were used. Reference 20 is a report on Northwestern University's preliminary investigation of the feasibility of using multispectral photography in urban research. The study indicated that multispectral imagery would provide information about static, physical, and manmade elements in the urban environment. This potential application of multispectral photography is an outgrowth of NASA's need to employ multispectral photography in aircraft and space vehicles.

Earth Resources Photography

Ever since man first photographed his environment from a point above the Earth more than 100 years ago, he has continually looked for new and better ways to survey and evaluate that environment. When one considers the amount of information needed about our Earth, its resources, and the use of the surface, the enormity of the quantity becomes apparent. This is particularly true if one wants details with respect to small elements. Such large volumes of information require high-capacity storage media; and to collect the information in a short time under dynamic conditions requires a very fast acquisition rate.

Once man had learned to fly, it was only natural that he would want to record such information. The dynamics of flying dictated that it should be recorded by a process as nearly instantaneous as possible. Photography was fairly well developed when man learned to fly. It was logical then that a man in a plane or in a balloon would take a camera aboard.

A significant stimulus occurred during World War I, when it was desired to record information on "earth resources" and land use in military conflict. As a result, the development of aerial photography paralleled that of aircraft by the end of the war. Following that conflict, workers sought nonmilitary applications for aerial photography. Aerial surveys became an accepted tool in the 1930's and, albeit from low levels and in black-and-white imagery, for political regional analyses, transportation systems development, and civil engineering.

World War II stimulated further developments of equipment and technology. The advent of the faster and simpler tripack (three film layers exposed simultaneously) color films in the postwar period provided a new tool for scientists and technicians working in that assortment of disciplines loosely covered by the term "Earth resources."

Because of the altitude limitations of aircraft, large areas had to be reconstructed as mosaics by piecing together individual frames of photographic pictures. Automatic cameras to take pictures sequentially with some overlap were designed for such work.

Some corrections can be made in a mosaic process for fundamental geometric distortions (these occur because a camera has a fixed point of view and the next frame is from some different point, resulting in errors of perspective or "angle from which you look at the object"). If the fine detailed resolution that is required over a broad area exceeds the capability of lenses and films, the multiple photograph mosaic techniques are still used. An interesting summary of the information capability of the photographic system is given in reference 21.

When spacecraft became practical, one of their most important applications was to look at atmospheric conditions and use the knowledge gained to predict weather patterns for various parts of the world. A picture from the Gemini program, Color Plate 13, demonstrates this wide-range capability. This was one of the first achievements in Earth resource photography by NASA.

When satellites became the vehicle, the question of time of access to the information, as well as the potential of recoverability, made the choice of alternate systems a serious consideration. These systems will be described in simple terms, avoiding detailed technical derivations:

A. The photographic system, if it can be recovered, provides a maximum of information in the simplest storage form. Actual capability for recovery and the time delay until recovery have limited the use of this method.

B. Video transmission systems are similar or in some cases identical to those used for commercial entertainment purposes. Such systems are limited by the number of picture elements used to sample and reconstruct the picture and by the capabilities of the communication channel employed.

C. Video information from a television camera tube can be recorded on magnetic tape aboard the flight vehicle, then played back over a much longer period of time to overcome the limitations of the bandwidth of the communication channel.

A hybrid system, which was employed on the Mariner vehicle for Mars exploration, can be used to take a photograph by a camera aboard the flight vehicle and process this photograph immediately. Automatic video equipment then scans the photograph, taking a fractional sample of the information contained and transmitting this to Earth (there is no need to use magnetic tape since the photograph already serves as a storage medium, and the transmission to Earth can take as much time as required).

At the ground station, video signals are used to reconstruct the picture through photography. These provide a rapid access to the information, which although fractional is a useful sample of the total information. Some systems could transmit the total photographic information provided sufficient time were allowed for use of the communication channel. If and when the flight vehicle can be recovered, the original photograph is then recovered and the high-resolution, high-information content of the picture becomes usable.

Reference 22 describes an orbiting photographic laboratory contained in the Lunar Orbiter. Its camera system was housed in a pressurized and temperature-controlled container. This system exposes the pictures, develops the film and, by video scanning techniques, converts the images on the negative into electrical signals for transmission to Earth. The technique permits high-resolution photographs to be taken at short exposure time; the pictures will depict objects as small as 3 feet across or, if the resolution is medium, features as small as 27 feet across. By using this technique and scanning back on a long-time basis, total photographic information can be transmitted to Earth for periods of 45 minutes. This is not possible with a single exposure on a video scan device because the vehicle moves too far. With the 45-minute time window and very low bandwidth transmission, an accurate reproduction of the picture is transmitted to Earth. Compared to ordinary television with its 525-line resolution, the video scan system on the Lunar Orbiter has 1700 lines per frame. A paper by George Bradley (ref. 23) describes this photo system in detail. A contact-type processor is used in which the film is wrapped around a heated drum with a processing web, the drum providing semidry processing. The film is pulled across a drum drier for final drying before passing through the video-scanner system.

Other variations and combinations of these systems are possible. When color film is used effectively, three separate photographs are involved, each represented by one of the three sensitive layers of the film. Thus, transmission requirements must be adjusted to handle triple the information.

Geologic applications of orbital photography (the subject of ref. 24) include surveying the Earth's resources for regional geologic mapping. Information was found to be obtainable on continental drifts, transcurrent faulting, and many other systems of geologic patterns.

In addition to NASA's vehicles for long-range photography of the Earth's resources, several other significant contributions should be noted. One of these was the development of automatic picture transmission and/or recovery systems. Obviously, photographs taken from a space vehicle should be recovered or transmitted in time to be of some use. This was particularly true of the early work on weather observation satellites, since the dynamics of weather required that the information be obtained within hours after it was recorded.

A second major significant achievement was the development of advances in the application of multilayer color films for technical applications. A typical example is an infrared sensitive color film that makes a "false color" reproduction of the invisible infrared radiation. The final picture must have colors that the eye can see and distinguish; however, instead of recording the true colors of the scene, the film presents in the several colors of the final picture information concerning the spectral wavelength which the eye does not normally see.

As indicated above, color basically requires three times the communication channel capability of black and white. Three-color systems have been developed for the high-altitude picture transmission satellites. They use a color reproduction system at the ground station to record the three channels of information on conventional color materials. In the ATS, the Applications Technology Satellite Program, these colors approximate visual true colors in that the satellite sensor bandwidth corresponds to the average sensitivity of the human eye. Color Plate 14 is a reconstructed photograph made at the ground station at Goddard Space Flight Center from an ATS picture. The outline of South America can be seen together with the west coast of Africa and, in the upper left-hand edge of the image, Mexico, the Gulf of Mexico, Florida, and Cuba. The cloud patterns that define the existing and anticipated weather conditions stand out readily.

One advantage of the reconstruction equipment that prepares a picture from information transmitted over a video communications channels is that sampling can create enlarged pictures of specific areas of the overall original. Color Plate 15, reproduced from a picture having the same general angle of coverage as Color Plate 16, shows in closer detail the weather over the Gulf of Mexico, which is surrounded by Mexico on the left and the Caribbean Islands in lower center. Also visible are Florida and the northeast coast of the United States, which stands out as cloudless at that particular time. Figure 54(*a*) and (*b*) show the electronic equipment needed to receive, store, and play back to

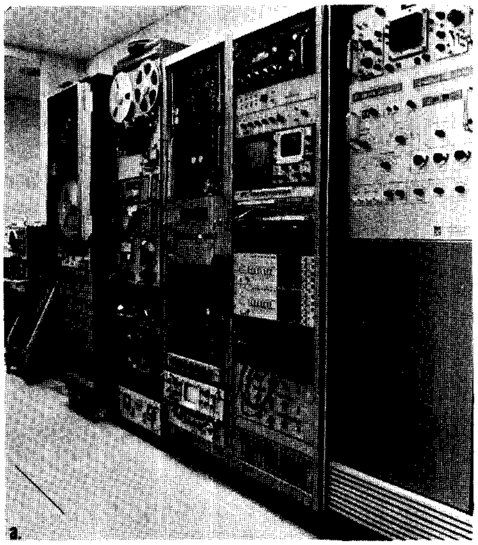
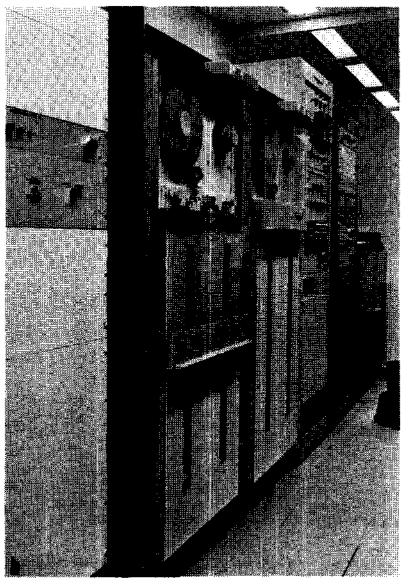
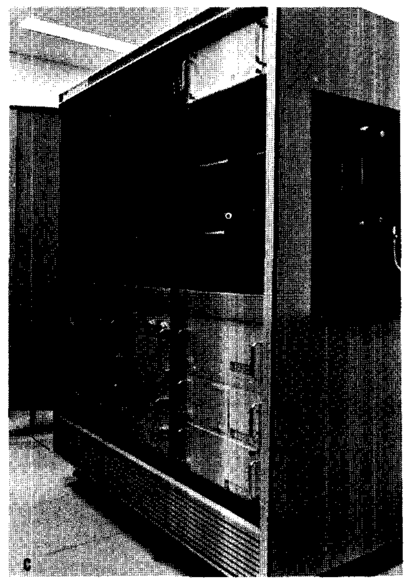


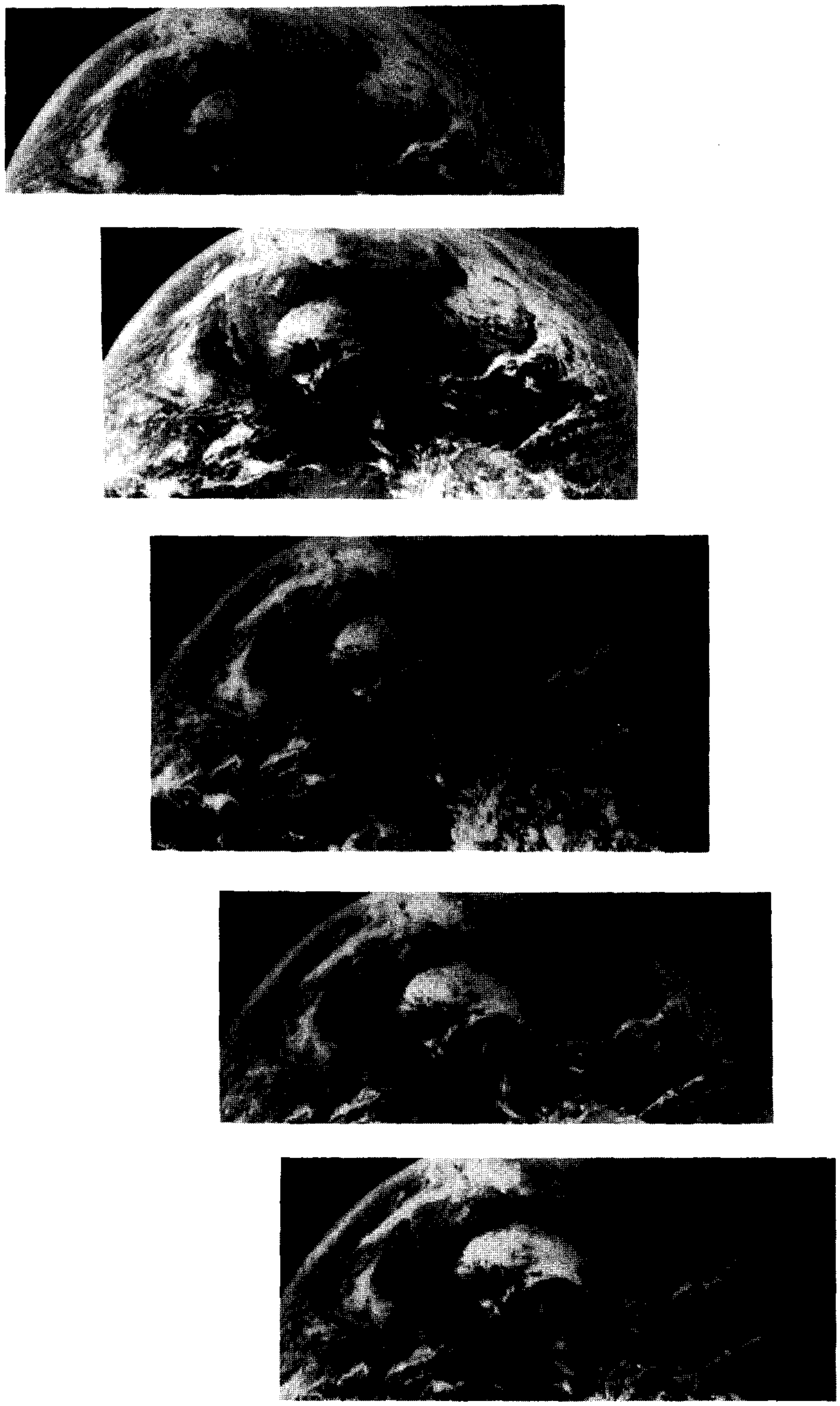
FIGURE 54.—The communication and photo-optical equipment used for reconstruction of color photographs from ATS III is shown (*a*), with magnetic tape units used for intermediate storage of picture information (*b*), and the electro-optical reconstruction equipment (*c*), which contains a very precise color cathode ray tube. The film holder is on the right of the cabinet.





the picture simulator the information that is received from the satellite. Figure 54(*c*) shows the actual reconstruction camera which contains a color television tube and a lens that projects the image on the film. The major differences between this tube and a standard tube are its higher resolution and much slower writing rate. These assure the best possible image on the film.

One of the most spectacular pieces of information recovered



from the ATS satellite is shown in figure 55, which is a composite demonstrating the path of the shadow of the Moon across the North Atlantic during the 1970 Solar Eclipse. Taken on successive passes, or successive revolutions, of the satellite, the picture shows the ability of satellites to record astronomical events.

Satellite photography of the Earth has also generated maps showing snow coverage over large areas of the United States. This information, when correlated with snow depth as obtained remotely by certain ground-base sensors, provides valuable data for flood control programs on estimated runoff of water. Both the Earth analysis and snow analysis programs are conducted by NASA in conjunction with the Environmental Science Services Administration (ESSA). NASA is responsible for the operation of the vehicle and the picture-recovery equipment; ESSA does the actual analytical work on the pictures and handles the distribution and dissemination of the information.

Other applications of satellite photography pertain to hydrological studies, in particular the determination and mapping of surface water and/or surface moisture. Multispectral photography provides indications of the moisture in ground surfaces. Riverine and estuarine systems can also be traced by means of high-level or satellite Earth-resource photography, and changes can be analyzed from sequences of photographs. Color Plate 16, taken from an aircraft for a hydrological study, is a conventional color photograph of water masses. Color Plate 17 is a photograph taken for the same purposes with a false color infrared film. This film displays as red the actual spectral signatures, or reflectivities, that occur in the infrared part of the spectrum. The use of space photography in evaluating water pollution is shown in Color Plate 2(*a*), where pollution in and around the Galveston Bay area of Texas is visible.

Color Plate 18 is an infrared color picture demonstrating the appropriateness of environmental photography for detailed analyses of agricultural and forest areas. Typical of the importance of environmental photography for agriculture is the use of aerial and satellite photographs to construct agricultural usage and planning maps. We find a wealth of applications in agriculture inventory and planning. Equally significant for agriculture is the use of photography in hydrological surveys, in determining

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FIGURE 55.—The shadow of the moon as tracked across the surface of the earth from Florida to the North Atlantic by ATS during the March 7, 1970, solar eclipse from 1:10 to 1:50 p.m.

moisture levels and planning for and evaluating the effectiveness of irrigation projects. It is hoped that such environmental photography will make it possible to predict crop yields. Most certainly it will be of considerable help in regional development and in deciding whether farmland should be assigned for crop growing or reserved for grazing.

Color facilitates identification of land use for incorporation into development maps. Color Plate 19 is a typical aircraft color photograph providing the information needed in geographical studies.

Space photography does not penetrate the opaque surface of the Earth. But information gathered from space photographs can be coupled with other sensors, for example, microwave radar, to provide us with a capability to make evaluations not previously possible. In doing this, we combine the high-resolution, high-speed information acquisition of photography with the sensitivity of radar for ground structure differences. The combination is being investigated as a means of mapping geological features. It could be of significant help in charting inaccessible areas, such as parts of Alaska and South America. Such techniques are also being studied in connection with the more efficient exploration of metal deposits.

In our discussion of vehicle-mounted cameras, we talked about boresight cameras which are used to identify areas scanned by video, infrared, microwave and electromagnetic transducers. This application, in addition to pointing out the territory being scanned, gives a precision mapping of the territory. These synergistic combinations of capabilities are expected to be a most valuable tool for geologic mapping and monitoring geothermal and volcanic activity. Color Plate 20 is an infrared color photograph showing the myriad detail that is available for the type of picture that would be used for geological studies. Some of these applications are reviewed in reference 24.

Other applications concern the water resources of the Earth and are associated with oceanographic and marine studies. A significant example is given in reference 25, which discusses the uses of satellite and high-altitude aircraft photography and indicates that information from the photographic records has been used to correct errors in hydrographic charts. Such photography is important in monitoring variable structures such as shoals and sandbanks and in pinpointing the location of shipping hazards. With respect to marine life, the photographs provide significant information on fish behavior, particularly the location of their feeding areas. (See Color Plate 21.) Special two-layer color films, developed by manufacturers under the impetus of NASA requirements, allow greater penetration of water depth for these studies.

Color Plate 22 demonstrates how photographs with suitable overlays of analytical data may be utilized to expand the capabilities of photographic systems to present data.

Space photographs and high-altitude aerial photographs have been used in initial surveys of transportation facilities and capabilities and, later, to monitor changes as they occur. Normal techniques of dating maps are rather slow, tedious, and usually lag behind changes by a considerable length of time. Reference 25 cites how pictures of the Cape Kennedy area, obviously a well-photographed area, have been used to determine lag errors in updating of the maps of the region. Photographs taken from Gemini V and Gemini VII actually show changes which occurred within periods as short as a few months. Photography, whether low level or high level, may also be used advantageously in monitoring air pollution and the migration of polluted air masses.

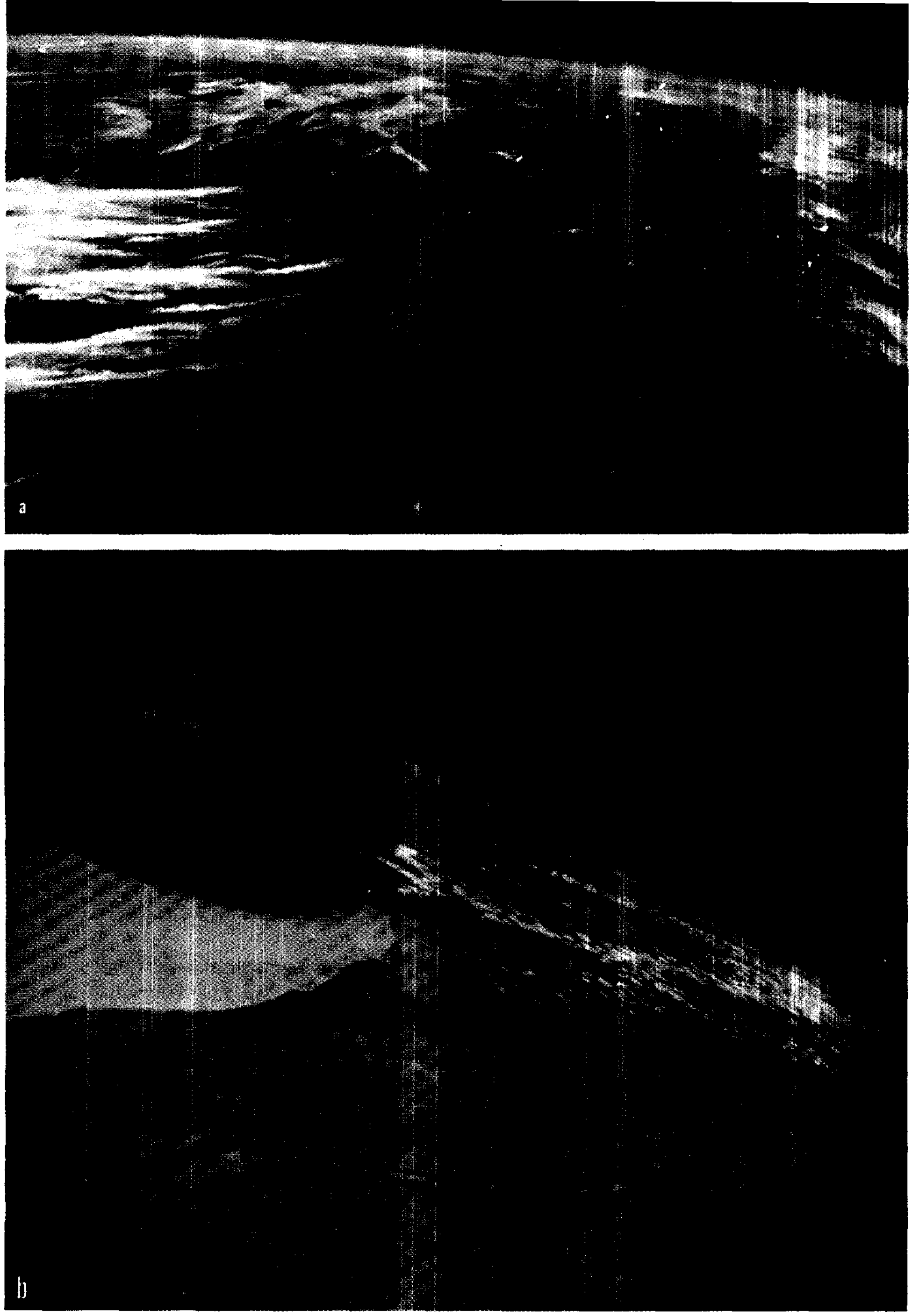
Another interesting application in atmospheric research occurred during the investigations of the aurora borealis on November 26, 1969. Color Plate 23 is typical of the many pictures of the aurora which were recorded by the Airborne Sciences Office of Ames Research Center with the "Galileo," a Convair 990 aircraft.

An anticipated application of the NASA-generated information, will be its use by local and regional governmental authorities for analysis and planning in urban development. For local governmental authorities in particular, some low-level photography is still very useful and will continue to be generated. Color Plate 24 is typical of very-low-level photographs that can be used to survey individual property changes for assessment and conformance to pertinent ordinances and local codes. Low-level photography will be basic to a close-detail property-by-property analysis by local authorities. In contrast, regional governments will be interested in a broad area land use, but will probably find suitable information for their various applications in photographs which will be generated by programs initiated by NASA.

NASA's greatest contribution is that it has been able to get us "out of this world" for a look back at our own habitat. While NASA has not made direct improvements in photographic materials, the generation of new application concepts by NASA personnel has stimulated the photographic manufacturer to provide better and newer materials to meet these requirements. According to Lee Du Goff of Kennedy Space Center:

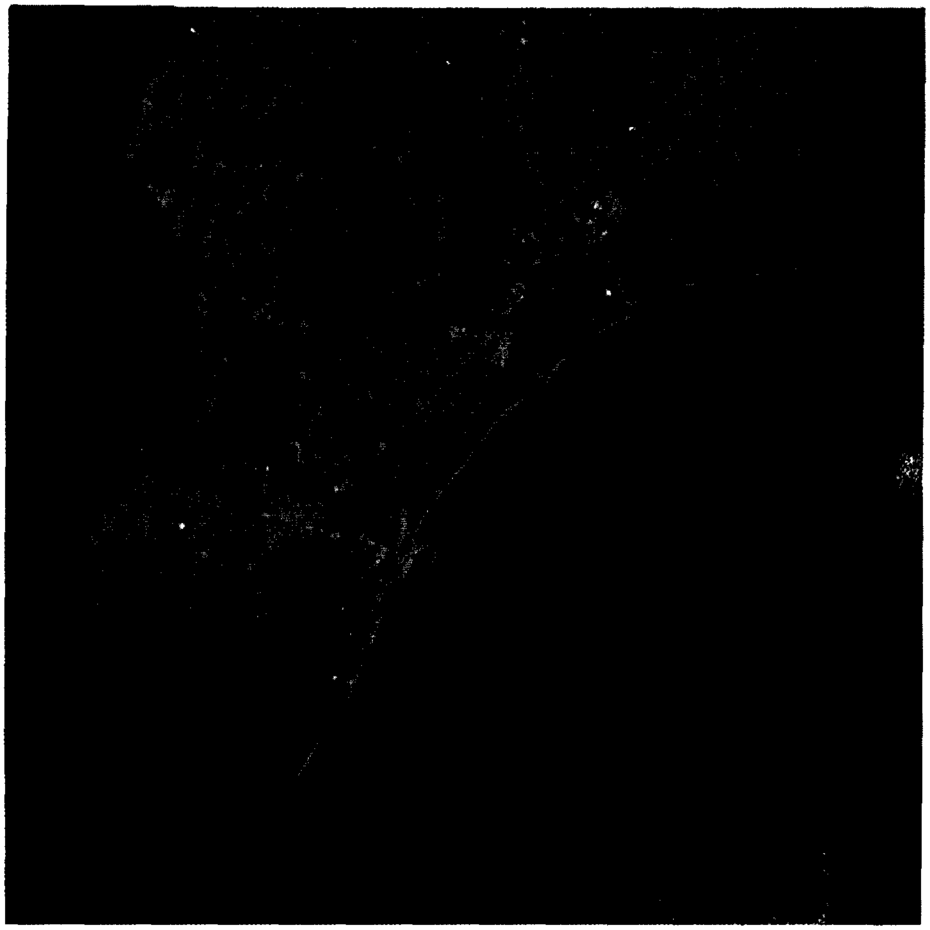
> Two good sources for information on this subject are the American Society of Photogrammetry and the Society of Photo-Optical Instrumentation Engineers. Technical personnel in the fields of photogrammetry and photographic interpretation unanimously express excitement over its prospects and many outstanding papers on this subject have been submitted to these societies for publication.

In considering achievements of the space program in terms of benefits to mankind here on Earth, the Earth Resource documentation and analysis program is outstanding. With respect to this application of photographic technology, no one would dispute such a claim. Thanks to this spinoff from the space program, man will know more about where he is living and what is happening to his home.

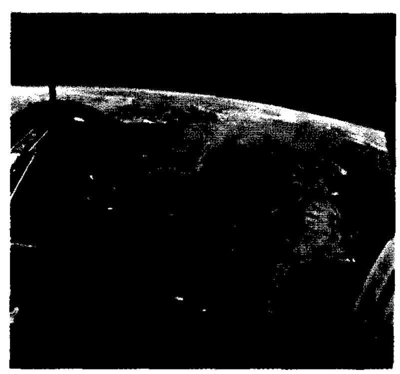


(*a*) This is one of the first pictures taken in space. It was taken by John Glenn with the hand-held 35-mm camera from a point over the Gulf of Mexico looking east across the Florida peninsula. Cape Canaveral can be seen on the distant eastern shoreline. (*b*) This picture, taken from the unmanned Mercury-Atlas IV spacecraft, shows another of the first views of Earth from the high altitudes achievable in the NASA space program. The view is of the west coast of North Africa and shows the Anti-Atlas mountains and clouds over the western Sahara in the distance.

COLOR PLATE 1

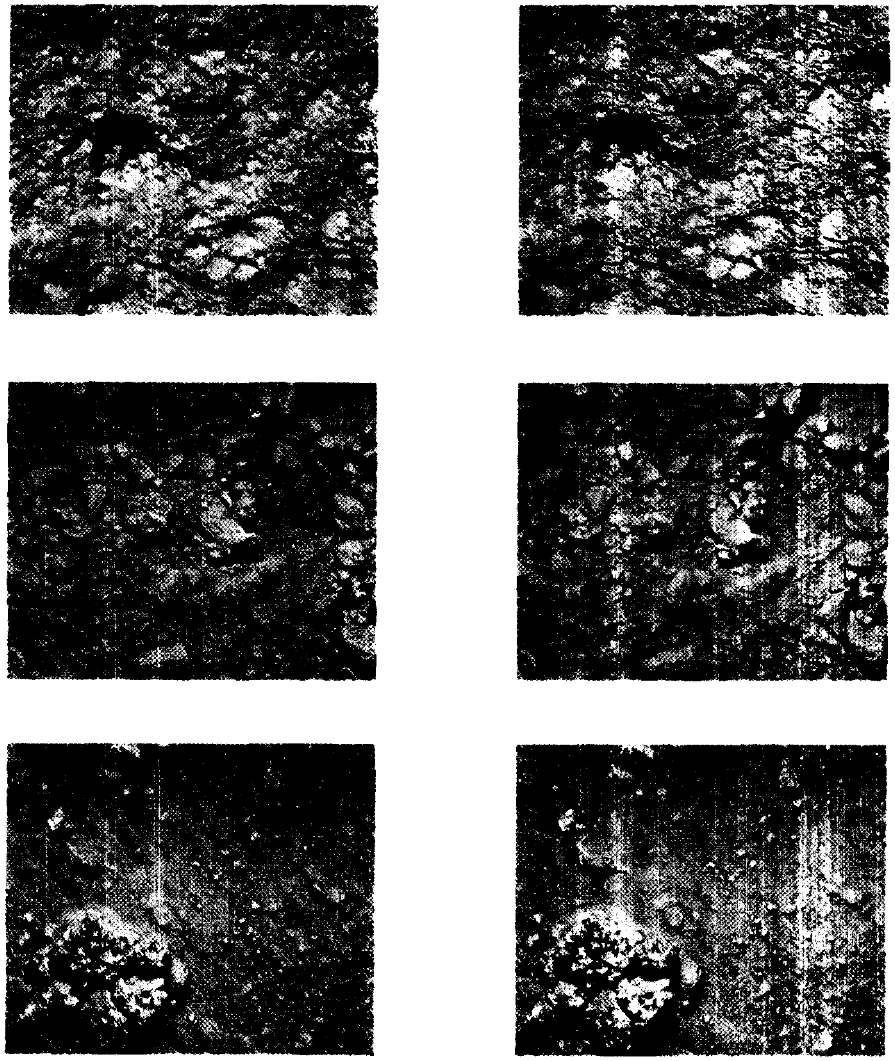


Taken by the Gemini XII crew along the Texas-Louisiana Gulf Coast, this picture shows Houston, the Manned Spacecraft Center, the Harris County Domed Stadium, the Houston Ship Channel, and many other features of the area. The distribution of very polluted water in Galveston Bay and other waterborne sediment in such passes as Bolivar Roads, Sabine, and Calcasieu can be clearly seen, and the movement of currents in the Gulf of Mexico is also quite evident. Such pictures have helped in studies of the movement and distribution of larval commercial shrimp.



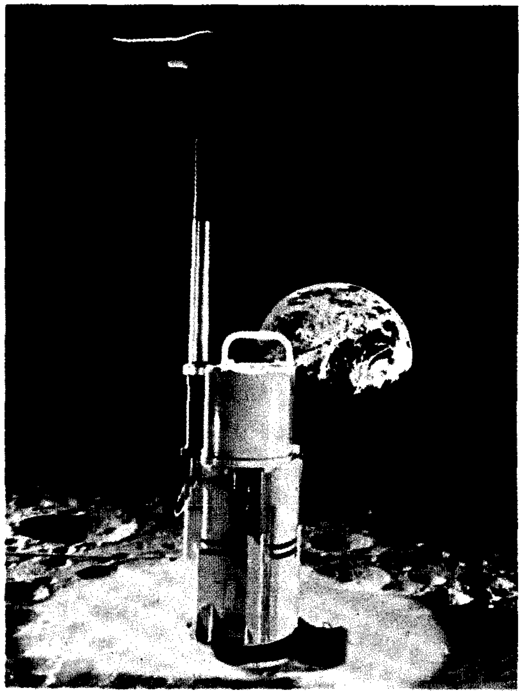
The performance of the superwide camera is evident in this photograph taken out of the open hatch on the Gemini 9 mission, June 5, 1966, by Eugene A. Cernan. The wide angle of the camera caught the nose cone of the Gemini vehicle as well as the hatch door in the lower right. In the center of the picture is the Gulf of California. To the right is the southern end of Baja California. On the left, just ahead of the space vehicle and parallel to the Gulf of California, is the Sierra Madre Occidental.

COLOR PLATE 2

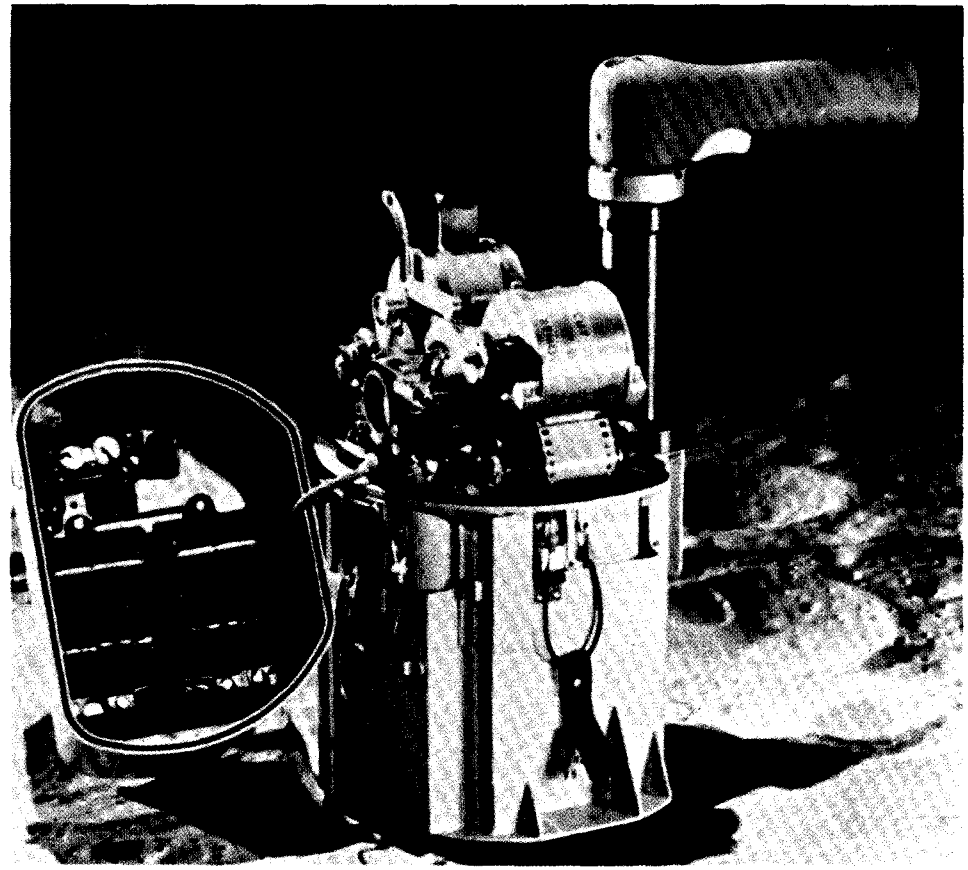


Stereo pairs were taken with the Apollo Lunar Surface Close-up Camera. This figure shows the type of detailed photographic information that was recovered. The photos are printed in proper relationship to permit three-dimensional viewing by means of any of the accepted techniques for viewing stereo pairs. The techniques might include a stereopticon or stereo glasses. Persons who can accommodate closely, particularly nearsighted persons who can remove their glasses, may be able to obtain the stereo effect by direct viewing. Others might need to place a barrier, such as a piece of cardboard, between their nose and the centerline between the pairs to train, respectively, the left eye to observe the picture on the left and the right eye to observe the picture on the right.

COLOR PLATE 4



The Apollo Lunar Surface Close-Up Camera (ALSCC) was designed to photograph small objects on the surface of the Moon. When the handle was extended, as shown, the camera could be used by an astronaut without stooping over. The camera is placed in contact with the ground and is fired by the trigger switch on the handle.



The Apollo Lunar Surface Close-Up Camera is shown here with the handle retracted and the cover removed. It has its own self-contained electronic flash equipment.