Photo Interpretation in the Space Sciences

1963–1964 Report of Subcommittee VII
Photo Interpretation Committee
American Society of Photogrammetry

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INTRODUCTION

AN INTEGRAL PART of many space science programs is the acquisition and interpretation of photographs or photograph-like images. Imagery furnishes valuable information of the surface and atmospheric patterns of the Sun, Earth, Moon and planets. Acquisition of the photographs is or will be from such unique platforms as satellites, sounding rockets, balloons, space probes, and hard- or soft-landing spacecraft.

The field of space photography is not new, astronomers using terrestrially based telescopes having been concerned with the interpretation of photographic images for many years. Their concern has been largely with the relationships among celestial bodies and the characteristics of a body as a whole, whereas space science photographic interpretation is directed toward a study of a limited portion of a celestial body. Another difference is that imagery for the space scientist is often obtained from various space platforms or vehicles. Although differences exist, any dogmatic separation between the interests of astronomy and space science in photo interpretation would be undesirable.

In view of the rapid expansion of the use of photography in the space sciences, Subcommittee VII, Extraterrestrial Uses, of the American Society of Photogrammetry was formed. Its purpose is to keep members of the Society informed of the latest image-producing and image-interpretation concepts, and of equipment and techniques important in lunar and planetary or space science programs. The goal of the committee is to promote communication between people and organizations in the space sciences and those in aerial photographic and sensing research. Consequently, a review of existing and proposed space programs was undertaken to determine what has been accomplished and the equipment that was used, how the imagery was subsequently utilized and what the needs and future plans are. To achieve this, descriptions of several programs not directly concerned with image acquisition are presented and some programs are examined which either have been or will be cancelled. This broad approach was adopted to provide (a) better understanding of the scope of pertinent aspects of the space effort and associated equipment, (b) names of organizations and individuals active in image acquisition phases of the space program and (c) some information concerning the number and types of lunar and planetary photographs and images that will probably be available during the next several years. Although the bibliography included in the report is not comprehensive, it should provide further appreciation of the dynamic nature of the space program and a base or format for subsequent reports.

Although the basic report was compiled in 1963–1964, an attempt has been made to bring all factual information up to date as of the summer of 1965. It should be evident that if the report were to be completely rewritten today, there would be changes in the emphasis accorded the various programs of data acquisition. Since the pace of the space program makes it nearly impossible to produce a composite report that is both timely as to information and balanced as to emphasis, the first objective was favored.

Lunar Programs

Terrestrially Based Telescopes

IMAGE ACQUISITION

Lunar photographs using astronomical telescopes have been made for the past 70 years at various observatories using a wide range of equipment. Many of the photographic groups lacked any systematic program for their acquisition (Spradley, 1963), and as a result, coverage is meager. Impetus has been given to the acquisition of lunar photography by the program of the U. S. Air Force Aeronautical Chart and Information Center (ACIC) to make photographic compilations of 1:1,000,000 lunar charts (Carder, 1961). The ACIC project will utilize the best photographs from all sources, but volume coverage is being obtained at the Pic du Midi Observatory in the Pyrenees. Supplementary and confirming photography and interpretation is being carried out at the Lowell Observatory at Flagstaff. Of special interest at Pic du Midi is the 24-inch diameter long-focus refractor telescope equipped with a K-22 aerial camera capable of recording the entire lunar disk on a single negative.

Recent and current programs conducted by the Lunar and Planetary Laboratory of the University of Arizona (Kuiper, 1964) are also noteworthy. The organization has issued two lunar atlases, "Photographic Lunar Atlas" and "Orthographic Atlas of the Moon." A third, "Rectified Lunar Atlas" is in press, and a fourth, the "Consolidated Lunar Atlas," may be available shortly. Much of the photographic work of the Lunar and Planetary Laboratory has been conducted at the Yerkes and McDonald Observatories pending completion of facilities in the Tucson area. The laboratory will undoubtedly be a major center for lunar photography and lunar studies.

PHOTOGEOLOGIC MAPPING

A program of research on the geology and history of the moon was begun by the Branch of Astrogeology of the U. S. Geological Survey on behalf of the National Aeronautics and Space Administration on August 25, 1960. The program has objectives aimed mainly at gaining new knowledge about the surface of the Moon and is also aimed at the application of this knowledge to the solution of problems of the geology and geologic processes on the earth.

This new knowledge about the surface of the moon is gained by the study of the stratigraphy and structure of the rocks and fragmental material exposed on the Moon's surface. From this information the sequence of events that have led to the present conditions on the Moon's surface, and the processes by which these events took place may be determined.

Three closely interrelated lines of research are being followed to work towards these objectives. (1) photogeologic mapping of the Moon, (2) experimental and field studies of the mechanics and phenomena of high-speed impact and of cratering, and (3) investigation of the chemistry, petrology and physical properties of objects that may have been derived from the Moon, such as tektites, certain types of meteorites, and extraterrestrial dust.

Progress in research is reported to NASA semiannually. The semiannual report is also distributed to other scientists and organizations engaged in lunar research. Some of the results obtained have been published by the U. S. Geological Survey and in other appropriate scientific and technical journals. Those pertaining to photo interpretation or related fields are given in the accompanying bibliography.

Photo interpretation supplemented by an analysis of brightness changes measured with a microdensitometer and telescopic observation are playing a major role in the geologic mapping of the Moon. Photo interpretation of the lunar surface is the first step in the geologic exploration of the Moon.

The Moon has apparent oscillations (librations), which enable one to see a little more around the edge at one time than at another; as a result most lunar photographs taken at different librations can be viewed stereoscopically. In the photo interpretation of lunar geology, many enlarged lunar photographs are examined stereoscopically. The photographs are obtained principally from the Lick, Pic du Midi, Mount Wilson, McDonald and Yerkes Observatories. A film library of selected lunar plates has been established at the headquarters office of the Astrogeology Branch in Flagstaff, Arizona. Visual observations through the telescope are undertaken at both the Lowell Observatory at Flagstaff, Arizona and the Leander

McCormick Observatory, University of Virginia.

The criteria of size, shape, texture, pattern, position and shadow are valid in photo interpretation of the Moon just as they are on the earth, and the geologic law of superposition of rock units is also applicable to a study of the Moon. In applying interpretation procedures to the moon that were initially developed for terrestrial application, the interpreter is presently limited by the small scale and resolution of lunar photographs and differences resulting from an alien environment.

In examining lunar transparencies under the stereoscope, electro luminescent panels have been used for varying the contrast on individual pictures as an aid in photo interpretation. Some experimental work is being done in the use of a closed circuit television system as an image enhancer in interpreting lunar photographs.

Microphotometric study of photographs of the lunar surface is being undertaken to explore ways of quantitatively describing and recognizing geologic units being mapped on the Moon. The investigations are pointed towards establishing norms of photometric characteristics for each geologic unit for purposes of stratigraphic correlation.

Measurements of film density in the Kepler and Copernicus region were made with a microdensitometer and recorded by standard graphic recording methods. Curves thus developed show relative amounts of light that pass through a film. From these curves, four kinds of data were obtained for evaluation: (1) *acutance*, the steepness of lines on the chart—the abruptness of change in density of the film. (2) *contrast*, the relative height of given parts of a curve—the magnitude of tone differences within a given unit. (3) *relative albedo*, the height of a given part or parts of a curve compared to other parts of the curve—average film density within a given unit. (4) *texture*, the number of significant fluctuations in a given part of a curve—the number of times per unit length of the curve that significant changes in film density are recorded.

Tests of various wave form analysis methods have been applied to digital records of microdensitometer curves derived from lunar photographs. The purposes of these tests were twofold: (1) to test by mathematical analysis the relationships between curve shape and lunar geologic unit suggested by previous empirical analyses, and (2) to develop methods of analysis that can be performed on the Burroughs 220 computer.

Methods of analysis included: (1) Fourier transform, in terms of both amplitude density vs. frequency and phase density vs. frequency; (2) autocorrelation function with lags of 0.1, 0.2, 0.3, 0.4, and 0.6 inches; and (3) analysis of second horizontal derivatives.

Amplitude density vs. frequency and second horizontal derivatives show differences among the various lunar geologic units that are believed significant. These results correspond closely with results predicted on the basis of previous empirical analyses. Autocorrelation techniques hold much promise of successful application.

Prior to the establishment of the Branch of Astrogeology a generalized photogeologic and physiographic map of the entire subterrestrial hemisphere of the moon, at an approximate scale of 1:3,800,000 was completed by the U. S. Geological Survey for the Office of the Chief of Engineers, U. S. Army. This map has been published by the U. S. Geological Survey.

The Astrogeology Branch is making stratigraphic and structural maps at a scale of 1:1,000,000 of portions of the lunar surface. The Kepler map is the first published map of this series. As with other geologic maps, the maps of this series show distribution and relative ages of lunar geologic units and the major structural features of the area. A special geologic time scale has been devised for the Moon as part of this general study, and four major systems or time-rock units are generally recognized over the visible hemisphere of the Moon. These maps are compiled on base maps prepared by the U. S. Air Force Aeronautical Chart and Information Center. Emphasis is being placed on a block of four of these quadrangles from which additional regional geologic studies will be made for correlation with information obtained from Ranger lunar probes.

The microphotometric studies of lunar photographs will be used for the purpose of comparison with the Ranger vidicon data and should be an aid in extracting as much relevant geologic information as possible from data acquired by the Ranger TV system. Of special interest are changes in texture or pattern within stratigraphic units as the scale of TV pictures increases with approach to the lunar surface.

Problems of recognition and interpretation of information obtained from the TV system on the Surveyor soft-landing spacecraft will be studied by closed circuit TV simulation. Some work will also be done with the Surveyor prototype TV camera.

LUNAR CHARTS

Topographic charts of the Moon's surface at a scale of 1:1,000,000 and a contour interval of 300 meters are being constructed by the Air Force Aeronautical Chart and Information Center. Surface features are displayed by contours, shaded relief and tonal variations. The appearance of the features is interpreted from photographs taken at the Pic du Midi, Lick, McDonald, Mt. Wilson and Yerkes Observatories, and finer detail is added from visual observations. Eighty-four sheets measuring 56 by 73 cm. will cover the visible side of the Moon. Three projections are used; the Mercator for the equatorial region, the Lambert Conformal for the mid-latitudes, and the Polar Stereographic for the polar regions.

The charts are prepared from mosaics of rectified photographs constructed on control grids at 1:1,000,000 scale; the basic control is furnished by 154 points determined by Franz and Saunder and revised by Schrutka-Rechtenstamm, and relative elevations are found by shadow-measuring techniques. Contours are sketched in on the basis of the vertical control points and supplementary slope information obtained by a variation of van Diggelen's photometric method. Problems in chart construction arise from inaccuracies in the basic control points and incomplete knowledge of regional gradients; nevertheless, the accuracy in position is believed to be within two kilometers.

Additional lunar charts are prepared by the Army Map Service. The Army program calls for topographic maps on modified stereographic projection at scales 1:5,000,000 and 1:2,500,000 of the visible surface. Photography of the Moon from terrestrial-based telescopes serves as the major source of information for the preparation of the charts.

THERMAL MAPPING OF THE MOON'S SURFACE

Infrared thermal radiation from the Moon was first measured as early as 1868. However, instrumentation developed in recent years has enabled greatly improved spatial resolution. The detector of the 73-inch reflecting telescope of the Dominion Astrophysical Observatory scans the lunar surface with a resolution of 7 seconds of arc. Isothermal maps are prepared from measurements obtained during lunation and also during lunar eclipses. From a comparison of the isothermal contours with the surface features, speculations about the nature of the surface are possible. For example, radiation measurements during a lunar eclipse yield rates of cooling for different areas of the surface. The bright rayed craters cool less rapidly than their surroundings during the penumbral phase of an eclipse and are warmer during the umbral phase. This might be explained by variations in dust thickness of the rayed craters with their surroundings (Shorthill, 1963).

Balloon-Borne Systems

Balloon astronomy was born with Project Stratoscope (Danielson, 1961, 1963) which was conceived by Dr. Martin Schwarzchild of Princeton University and initially conducted under the auspices of the Office of Naval Research. The advantage of the Stratoscope system is that at altitudes of 80,000 feet a balloon is above approximately 96 per cent of the Earth's atmosphere and most of the "seeing" problems that plague astronomers are eliminated. The first mission was launched on September 25, 1957 and a 12-inch telescope and guidance system in an unmanned balloon was used to obtain photographs of the surface patterns of the Sun. Stratoscope II (Danielson, 1963) in 1963 carried a 36-inch telescope and an on-board infrared spectrometer for scans of Mars, Jupiter, and 8 red giant stars. The results of project Stratoscope are discussed in more detail in the section on Planetary and Solar Programs. However, balloon-borne telescopes of the Stratoscope type could be utilized to obtain lunar imagery. On a smaller scale, several balloon programs have been conducted by the Air Force Cambridge Research Laboratories to monitor radiation from the Moon in several portions of the electromagnetic spectrum.

Ranger Program

The mission of the Ranger Program of the National Aeronautics and Space Administration was to gather data concerning lunar topography and to develop some of the required technologies, procedures and operational skills necessary for the Apollo program. Of the first six Ranger Launchings none was entirely successful and no imagery was obtained. However, Ranger 7 was launched from the Atlantic Missile Range in Florida on July 28, 1964 and for 16 minutes and 40 seconds on July 31, returned 4,316 photographs of the lunar surface in the vicinity of Mare Nubium. Ranger 8 impacted the Moon in the Southwestern part of the Sea of Tranquility on February 20, 1965. Ranger 8 returned approximately 7,500 photographs during the final 23 minutes and 6 seconds of its flight. On March 24, 1965 Ranger 9 impacted the Moon approximately 2.8 miles Northeast of the central peak of Alphonsus. During the 18 minutes prior to impact, Ranger 9 transmitted some 5,814 pictures of the lunar surface of a quality that exceeded even the excellent records made by Rangers 7 and 8. No additional Ranger flights are planned.

Photographic equipment of Ranger spacecraft consisted of a 382 pound television package mounted on the hexagonal base of the spacecraft. Sic 1-inch vidicon cameras arranged as two wide-angle cameras and four narrow-angle cameras, as well as a camera sequencer, video combiner, telemetry system, transmitters and power supplies comprised the photographic system. A dual channel transmitter separately returned wide- and narrow-angle data. Of the two wide-angle cameras, one had a 1-inch lens with a speed of $f/1$ and a field of 25° and the other a 3-inch, $f/2$ lens with a field of 8.4°. Two of the narrow-angle cameras were equipped with 3 inch $f/2$ lenses with 2.1° fields of view and the other two with 1-inch $f/1$ lenses with 6.3° fields. All cameras had high quality lenses with five elements and metallic focal plane or slit type shutters. Characteristics of the Ranger cameras are presented on Table 1.

The F-1 and F-2 cameras, used to photograph extended areas, had full-scan systems with image areas of 0.44 square inch and the pictures obtained were composed of 1152 lines. Since it was highly desirable to obtain pictures faster than the 2.56 seconds required for each full-scan cycle, the P-1 to P-4 cameras used a partial-scan technique with image areas of only 0.11 square inch from which pictures consisting of 300 lines were derived.

The main reason for using six different cameras was to provide for the uncertainty of lunar lighting conditions. The combinations provided for illumination levels between 30 and 2,600 foot lamberts, corresponding to average terrestrial lighting conditions from high noon to dusk.

Resolution of the first pictures taken by both Ranger 7 and 8 is roughly comparable to those taken by large telescopes on Earth. As the spacecraft descended on the Moon, imagery improved both in resolution and quality. Craters as small as three feet across and one foot deep are shown on the last frames obtained when the Ranger 7 spacecraft was 1,000 feet above the surface. Resolution of the final two photographs is approximately 1300 times better than the best photographs of the Moon taken from Earth for which the resolution is about ½ mile.

TABLE 1

RANGER 7 CAMERAS

Camera	*Focus (mm)*	*Speed*	*Field*	*Exposure (second)*
F-1	25	f/1	25°	1/200
F-2	75	f/2	8.4°	1/200
P-1, P-2	75	f/2	2.1°	1/500
P-3, P-4	25	f/1	6.3°	1/500

(From Watts, 1964)

In obtaining pictures of the rugged highlands West of the Sea of Tranquility, Ranger 8 required a higher horizontal velocity component than Ranger 7. Consequently, the highest possible resolution in the last photograph was sacrificed. The final full picture returned by the Ranger 8 P-2 camera shows a blur of about 4 feet. The best resolution was obtained on the next to the last frame where craters approximately 5 feet in diameter are observable. Resolution of approximately 10 inches was obtained on a final, partially-transmitted F frame from Ranger 9. Results of the Ranger program have been summarized by Kuiper (1965).

Surveyor Program

Moon flights are planned for 1966 by the National Aeronautics and Space Administration's Surveyor spacecraft, which is designed to soft-land instruments on the Moon and obtain information about the texture and form of lunar topography. The television subsystem will be used to acquire lunar imagery, monitor scientific experiments and perform independent experiments.

As Surveyor approaches the Moon, a downward-looking television camera will transmit imagery of the landing area. The 4-inch lens and vidicon tube will cover initially a 200 km. by 200 km. square at a resolution of 300 meters. Successive exposures will nest as the spacecraft descends. The camera will not operate all the way to the surface, because the rocket-powered descent necessary for a soft landing prevents effective downward photography.

After touchdown, the survey television cameras (one on each of the first four missions and two on each subsequent mission) will operate. The field of view of each survey camera can be shifted in azimuth and elevation by means of a mirror. Each has a zoom lens providing a 1-inch and a 4-inch focal length, and color and polarizing filters to permit colorimetric and polarimetric measurements. They can focus from the horizon (about a mile away at the camera height of 5 feet) down to the landing legs and the experimental instruments. The spacecraft carrying two survey cameras will provide a stereoscopic capability in favored directions with respect to the camera base. The television pictures will be transmitted to stations of the Deep Space Network and recorded on both magnetic tape and film.

Lunik III

On October 4, 1959, the Soviet Union launched its third cosmic rocket, Lunik III, and obtained images of the far side of the Moon. Cameras with focal lengths of 200 and 500 mm. created images 10 mm. and 25 mm. in diameter that were recorded on 35 mm. film. Exposures were made over a 40 minute interval at a distance from the Moon of about 65,000 km. The film was automatically treated, developed and fixed. Negatives were stored in a special device for scanning and photo transmission to earth. The lunar pictures were transmitted by a command from earth which activated television apparatus, pulled through the film and connected the television apparatus to the transmitters. As the film scan could be designed to operate as slowly as necessary to obtain the best possible resolution, this method provided better resolution capabilities than direct television transmission. Nevertheless, it is estimated from released imagery, that the resolution is on the order of 10 to 20 miles. Contrast is extremely low because of the almost vertical incidence of solar illumination. Attempts were made (Singer, 1961) to enhance contrast by electronic means. Transmitted data were recorded on magnetic tape to allow electronic treatment at particular levels of intensity corresponding to levels of light intensity. The tape was reprocessed repeatedly to increase contrast at each level and areas of extremely low contrast were subdivided by this process of electronic amplification.

Analyses of the photographs were made by three independent study groups at Leningrad, Moscow and Kharkov. In spite of the very low resolution of the Lunik III photographs, new and worthwhile information was obtained. Fifty-six new features on the previously unseen side of the Moon were located and identified. A part of the Moon's surface which is visible from the Earth is shown on the photographs, permitting reliable connection with the new areas. The most significant fact revealed by the photographs is the lack of large seas on the far side in comparison with the near side; only one clearly outlined sea is evident (Sea of Moscow). Photometric measurements of the photographs showed that there is no limb darkening, suggesting that the surface texture of the far side is similar to that of the visible face.

Lunar Orbiter Program

NASA's Lunar Orbiter program will put a series of unmanned photographic spacecraft into orbit around the Moon, beginning in 1966. The primary objective is to produce information about the fine details of the topography of selected lunar areas which will, in conjunction with the point information supplied by Surveyor, permit the selection and certification of landing sites for the Apollo program. The areas photographed will therefore be primarily within the zone of Apollo interest (5 degrees north and south latitude and 45 degrees east and west longitude), although the spacecraft is capable of photographing any desired portion of the Moon, including the far side.

The 860-pound vehicle will be launched into an inclined, elliptical orbit. Exposure is on film, which is processed on board and then read out slowly for transmission to Earth. The dual framing camera puts two images on different portions of the same roll of film at each exposure. The wide-angle image covers about 32 km. by 37 km. at an effective ground resolution of 8 meters when the camera is vertical at the nominal perilune altitude of 46 km. The central portion of this coverage, a narrow rectangle of 4 km. by 16.6 km., is also covered by a high-resolution image at an effective ground resolution of 1 meter.

The forward overlap of exposures produces stereoscopic coverage with wide-angle photography and contiguous non-stereoscopic coverage with high-resolution photography. Large areas of coverage can be built up by the sidelap of successive orbital passes. The spacecraft has great flexibility in the size, shape and number of areas it can cover, up to its film capacity of 194 exposures. For details of the photographic capability, see Kosofsky and Broome (1965). The processed film is scanned by the readout system, and the video information is transmitted to the Deep Space Network stations, where it is recorded on both magnetic tape and kinescope film.

Apollo Program

The Apollo manned landing program is the succeeding project to Mercury and Gemini and has the objective of carrying three astronauts into lunar orbit, landing two of them on the Moon, and returning to Earth. The space vehicle will consist of three compartments: a 5-ton Command Module to house the crew during the $2\frac{1}{2}$-day flight to and from the Moon; a service module of 25 tons when fully loaded containing the propulsion equipment; and a lunar excursion module (LEM). The excursion module will separate from Apollo and carry two astronauts to the lunar surface and back to rendezvous in lunar orbit with the command and service modules. LEM will weigh 12 tons, stand about 20 feet in height and carry 250 pounds of scientific experiments including a package that will be left on the Moon. An analog-type television camera with a one-inch electrostatically focused vidicon tube will televise pictures on the lunar surface. The camera will have two lenses, one a 20–80 mm. zoom lens providing a field of 9 to 35°; the other a wide-angle 9 mm. lens with a 60° field of view. The camera, which will weigh 5.5 pounds and consume about 6 watts of power, will have an automatic sensitivity control to adjust exposure to ambient lighting conditions. It is expected that the astronauts will also be equipped with several types of cameras to make a pictorial record of the lunar surface, lunar landscape and of scientific observations and readings.

Earth Programs

Sounding Rockets

Image Acquisition. Hyperaltitude photography (greater than 30 mi.) has been obtained since 1946 using V-2, Viking, Aerobee, Thor and Atlas rockets. Atlas rockets have photographed the Earth from as much as 700 miles, but most photographing altitudes have ranged between 50 and 150 miles. None of the vehicles used were specifically designed for photographic purposes, nor were any of the flights scheduled exclusively for photography except for the Arctic Meteorology Photo Probe Project. A variety of light-weight cameras have been employed, including motion picture cameras. However, the photography most suitable for terrain analysis and photogeology has been taken with either the K-25 aircraft camera or the Maurer Model 220 camera using panchromatic or infrared films, which were returned to Earth. The infrared film was especially successful for high oblique photographs because of it haze penetrating ability. The purpose of this photography has been to monitor attitude stabilization and to determine the usefulness of space photographs for meteorological purposes and military reconnaissance. The success of early experiments led to the development of the weather satellites.

Interpretation. The photography obtained from launchings at White Sands, New Mexico indicates that a wealth of information about the surface is recorded on film from altitudes up to 150 miles. This vantage point affords a new perspective of the Earth's surface. The chief advantage of this photography is the large coverage possible. For example, pointed vertically, the K-25 aircraft camera is capable of photographing an area of nearly 11,000 square miles from an altitude of 150 miles. Costly mosaics of hundreds or thousands of conventional photographs would be necessary to achieve similar perspective.

Regional drainage as well as the distribution of surficial deposits, vegetation and rock outcrop are displayed. Geomorphic and physiographic features such as piedmonts and bajadas; hogbacks, cuestas and mesas; playas, deflation basins and sand dunes; volcanoes and lava fields can be identified. Individual large rock units are mappable in photographs of the southwestern United States, and structural features such as regional tectonic trends, fold belts and major faults are discernible in many photographs. Perhaps more important, the spatial relationships between gross features of processes such as volcanism to regional tectonic tends are sometimes apparent, whereas they might be overlooked in photographs covering smaller areas.

Unmanned Satellites

TIROS

Image Acquisition. TIROS (Television and Infrared Observational Satellite) was conceived by Dr. Harry Wexler, Director of Research for the Weather Bureau. In 1954 he suggested that weather satellites containing television cameras, infrared and albedo sensors, and radar could be used as a global forecasting network. The TIROS cloud cover satellite series started with launching of TIROS I and April 1, 1960. Test objectives, which were quickly proven, were to determine if the satellite could transmit high quality television pictures containing useful weather data that could be analyzed and transmitted for weather forecasting.

The TIROS system includes an orbiting satellite, ground readout stations at Wallops Island, Virginia and Point Mugu, California, a backup station at the RCA Space Center, Princeton, New Jersey, and a Data Analysis Center at Suitland, Maryland.

TIROS I and II contained two vidicon scanner cameras, each with its own magnetic tape storage capable of storing 32 photographs on each orbit. One camera was equipped with a wide-angle lens allowing vertical coverage of about 800 square miles with a resolution of approximately 3 miles. The other camera was equipped with a narrow-angle lens which covered 80 square miles with a resolution of 0.3 miles. Narrow-angle cameras proved difficult to orient and later TIROS satellites were equipped with wide- and medium-angle cameras.

In addition to two television cameras, TIROS II, III and IV carried two radiometers. A nonscanning radiometer with a 55 degree field of view responded to a broad spectrum in the visible and infrared regions. The second was a scanning radiometer with a 5-degree field of view responding to five spectral bands.

TIROS IV, V and VI, launched in 1962, had their cameras programmed to function through a clock mechanism activated by ground stations. The timing system is set when the satellite passes over the ground stations and pictures are stored on magnetic tape. As the pictures are played back on command from a ground station the tape is erased. The satellite cameras can also do direct photography when within range of Wallops Island or Point Mugu.

TIROS VII and VIII were successfully launched in 1963. The latter has the same basic design as its predecessors but transmits signals that low-cost stations can receive with inexpensive and simple equipment. The new equipment, called APT for "automatic picture transmission ' requires on the ground a 15-foot helix antenna, a commercially available radio receiver, and a television type picture tube to reproduce the photo. For the initial testing of this system there are 40 such stations operated in the United States and abroad by NASA, the Weather Bureau, and the military. If the system is practicable, the number of stations could easily be greatly increased.

Seven more TIROS satellites have been added to the program, in part to compensate for the cancellation of the Nimbus program. Four are to be research and development satellites including one to be tested for effectiveness in a highly elliptical orbit, and three will be operational satellites.

The TIROS program will provide photo output in such quantities that manual methods of location and rectification of images will be too time-consuming for operational use. Rapid means of data processing are being developed to cope with the vast amount of data.

Interpretation. Over 300,000 pictures have been received to date from weather satellites of the TIROS series. TIROS was designed to photograph cloud cover for weather forecasting and meteorological research, and for these purposes the system has performed admirably. According to Wexler (1962), TIROS has proved to be of great value in synoptic weather analysis and forecasting. The satellites are particularly useful in supplying cloud information of areas where ground observations are missing or incomplete, such as over oceans and uninhabited land regions. Moreover, patterns and details are shown to a degree not obtainable by conventional means even in heavily populated areas. Cloud patterns measuring 1500 km. across down to individual clouds have been recognized, including spiraling vortices associated with cyclonic storms, tropical hurricanes, tornado-producing clouds, cloud cells, cloud "streets," cirrus cloud decks, and cloud waves showing interference-like wave patterns. The practicality of TIROS was dramatically demonstrated in September, 1961 when TIROS III spotted the previously undetected Hurricane Esther. Two days later the existence of the hurricane was confirmed by conventional means. The processing of TIROS data has advanced to the point where cloud information is available for dissemination within two or three hours after the pictures are telemetered to receiving stations on Earth. Electronic data processing is employed to locate, orient and grid the pictures for expeditious use by weather personnel. The TIROS pictures are indexed and stored at the National Weather Records Center, Asheville, North Carolina. Catlogues showing geographical coverage and nephanalyses of each satellite pass are available through the U. S. Government Printing Office. Consequently, the pictures may be exploited for meteorological reseach for years to come.

The infrared system apparently has even

more potential for weather forecasting than television pictures. The sensors can be used to determine the gain or loss of radiation from the Earth's atmosphere as well as to compare unusual radiations with weather behavior. The scanning radiometer furnished information from five spectral bands. The 0.2 to 7 micron band measured the energy reflected solar radiation. The narrow 0.50 to 0.75 micron band in the visible region provided data that could be correlated with television images, and the 8 to 12 micron band indicated the approximate temperature of the Earth's surface or the tops of clouds, whichever happened to be beneath the satellite. Data from the 8 to 12 micron band enabled the mapping of clouds (in middle and lower latitudes), since the cold cloud tops could be distinguished from the usually warmer Earth's surface. This was especially useful for mapping the night side of the Earth where the television cameras could not. The approximate heights of the clouds could also be calculated from these data. A very broad band from 8 to 30 microns responded to most of the terrestrial infrared radiation enabling determination of total emitted long-wave radiation over limited periods of time. The vast amount of data collected to date is still under study to uncover additional information about the energies radiated and reflected by the Earth and its atmosphere.

The camera systems of TIROS were designed to photograph clouds, and the cameras were set to produce a high contrast between clouds and the surface. Consequently, the Earth's surface, in general, appears quite dark. Furthermore, the tone rendition is low; only seven or eight tones of gray can be distinguished in the photographs with the eye. Subtle tonal and textual differences manifested by differing types of surfaces are not recorded.

In comparison with film, the resolution of the TIROS system is very low; moreover, only a small fraction of the pictures clearly show land surfaces—perhaps one in one hundred. This is because of the small portion of land areas overflown in comparison to the oceans, and the fact that much of the land areas of the Earth are covered by clouds much of the time. South America, the East Indies, Hawaii, Central America, Central Africa, and Central Europe are rarely seen free of clouds. On the other hand, the desert areas are generally cloud free, such as the southwestern United States, North Africa and the Middle East. Nevertheless, some investigations have been made into the nonmeteorological applications of TIROS. Ice and snow, having albedos approaching clouds, lend themselves readily to detection by TIROS. Studies by Wark and Popham (1960) indicate that TIROS can monitor the distribution and movement of ice in the lower latitudes. The narrow-angle camera of TIROS II resolved snow and ice particularly well. The breakup and migration of ice is of interest to the meteorologists and oceanographers for scientific purposes, but furthermore, the location and movement of icebergs is important to the operation of shipping lanes.

Another possible application is the determination of snow cover in mountainous areas where snow melt is an important source of water, such as in the western United States. Estimates of the water supply for the ensuing year are determinable from the area of snow cover seen in TIROS pictures. The identification of a forest fire in a TIROS III picture suggests another use of TIROS. Satellite observations might supplement other sources of detection.

The geography department at the University of Montreal has produced an atlas of TIROS photographs showing as far as possible every state in the United States and every country in the world identified by distinctive and commonly recognized landmarks. Such an atlas enables a researcher interested in a particular region to tell at once whether TIROS photographs are likely to be of use to him. Selected reels of TIROS photo sequences on microfilm have been examined in a reader. Details of those which cover cloud-free land areas have been recorded on punched cards, in such a way that they can be tabulated by region covered, quality of image, probable nature of patterns visible on the ground, if any, and time of year when photo was taken. Such tabulations can be used to select the best photos for the atlas, and for more specific studies arising from it (Bird, Morrison, Chown, 1964).

Physiographic and geologic details are decipherable in only a small percentage of the TIROS pictures. An important reason for interest in terrain features of TIROS pictures is that systems akin to TIROS will obtain the first close-up pictures of the Moon and planets. Lunar and planetary probes will use television systems when film recovery is impossible, and Ranger VII has clearly demonstrated that high-quality TV pictures can be received from outer space. It is expedient to ascertain the nature of terrain information that can be gleaned from such low-resolution pictures. Even the most primitive information from the unknown surface of another planet will be important.

The desert areas of the World are most conducive to TIROS photography. The highly contrasting surfaces, unmasked by vegetation, show up well in some pictures. Varying albedos reflect differences in surface composition, relief and vegetation coverage, but commonly the tones cannot be identified with certainty. Land can be distinguished from water, as well as barren alluvial valleys and basins from areas of rock outcrop or vegetation; moreover, playas and beach deposits are identifiable from their tone, texture and associations. In North Africa, and to some degree in other desert regions, highly contrasting rock types can be separated if their outcrops cover areas considerably greater than the ground resolution of the picture.

Gross structural trends are revealed in some pictures, and major faults can be discerned where highly contrasting surfaces have been juxtaposed by movement. Surface detail is usually absent in pictures of uniformly vegetated areas, but tectonic and glacial lineaments become visible when accentuated by ice and snow. This is particularly true of the Canadian Shield region as shown by the TIROS II narrow-angle pictures (Merifield and Rammelkamp, 1964).

NIMBUS

The Weather Bureau has cancelled plans for Nimbus to replace TIROS in the National Meteorological Satellite System, but two versions of Nimbus research and development satellites will be tested by NASA. The first generation Nimbus A satellites weighing 730 pounds are equipped with an advanced vidicon camera system as well as a high-resolution infrared radiometer. Nimbus is designed to point toward the Earth at all times and occupy a retrograde polar orbit to enable coverage of the Earth's entire surface, viewing each part of the Earth twice daily during 14 orbits. The first Nimbus satellite, launched August 28, 1964 achieved an elliptical orbit, rather than the planned 575-mile circular orbit. This resulted in only 70% coverage of the Earth. Nimbus I ceased transmitting on September 23, 1964 when the solar panels locked and could not be dislodged. But the 27,000 pictures obtained during the period of operation were of good quality. The advanced vidicon system was capable of furnishing 100 pictures with one-half-mile resolution during each orbit when operating at full capacity, as well as up to ten strips of high-resolution, infrared, night time pictures. A midnight picture of Antarctica showed four black spots that correspond with the positions of mountains, suggesting volcanic activity. The second Nimbus A satellite will be launched sometime in the last quarter of 1964. Nimbus B generation satellites will not be launched before 1966 and 1967; they will be powered by two nuclear generators.

AEROS

The third generation NASA Meteorological Spacecraft was designed to complement Nimbus by being placed in synchronous equatorial orbit at an altitude of 22,300 miles and, like Nimbus, oriented to the Earth at all times. Three Aeros satellites spaced 120° apart would provide coverage of an area between 50° north and south of the equator. Using wide-angle cameras to view overall cloud patterns and a narrow-angle camera that is directable from the ground, any selected portion of this area could be brought into close-up view. The status of the program is in doubt.

Manned Satellites

MERCURY PROJECT

Mercury photographs were obtained from Mercury 4-9 missions. The Mercury astronauts used hand cameras to obtain pictures of the Earth which are generally better than similar images transmitted from space by television cameras. Theoretically television images can be made to equal the resolution of film, but severe limitations on available power and weight in existing spacecraft necessitate using narrow bandwidths for transmission of pictorial data.

Mercury astronauts used either 16 mm., 35 mm. or 70 mm. cameras to obtain pictures of the Earth's surface and high altitude phenomena. In all cases, photographic objectives of the flights were subordinate to the overall objective of the flights, i.e., to test pilot performance and the performance of the spacecraft and support operations.

The Mercury project has produced some spectacular photographs from altitudes in the vicinity of 100 miles. Of particular interest because of their high quality are the Mercury-Atlas No. 4 series of photographs taken of Africa between the Moroccan coast and Lake Chad with the 70 mm. Maurer 220. Geologic features of the Anti Atlas orogenic system are magnificiently displayed. Individual folds, faults, and lithologic formations are identifiable as well as longitudinal and transverse sand dunes, vegetation changes and geomorphic features (Morrison and Chown, 1964).

The thirty photographs taken by Astronaut Cooper (Mercury-Atlas No. 9) using a 70 mm. Hasselblad camera are also of high quality. Considerable geologic and geographic detail is recorded, including glaciers in the Himalayas; faults, domes and anticlines in Tibet (Lowman, 1965); and submarine topography of the Ganges delta.

Film returned from both satellites and rockets indicates that a new, important tool is available for the exploration of remote areas of the Earth, as well as the moons and planets of our solar system.

GEMINI

The Gemini program's two-man spacecraft is designed to bridge the time and technological gap between the Mercury and Apollo programs. It will have two missions: (1) to develop techniques for bringing together two vehicles in space, and (2) to perform Earth orbital flights lasting from a few days to as much as 14 days. Scientific investigations that require the participation and supervision of man will be undertaken. In the advanced stages of the Gemini program the astronauts may work outside the spacecraft while in orbit. As with the Mercury project, photographic objectives will be subordinate to overall flight objectives.

MANNED ORBITING LABORATORY (MOL)

The purpose of the Manned Orbital Laboratory is to provide a platform to study the possibilities of the military mission of man in space. MOL will orbit the Earth at 250 nautical miles in a circular orbit. The first model may carry four to six men and refined models from 12 to 24 men. A scientific payload of 1,500 pounds is planned and the laboratory can be resupplied by ferry vehicles every two weeks. An unmanned astronomical observatory weighting 20,000 pounds may be placed in orbit close to MOL.

Scientific equipment on the orbiting laboratory would include equipment for multispectral sensing and multiband photography. Simultaneous photography of planetary surfaces and atmospheres from near infrared through ultraviolet with several film and filter combinations is planned. This program is expected to have valuable applications for planetary surface geology, geography, oceanography and meterorology. The Air Force is responsible for the MOL project; a manned orbital research laboratory (MORL) is planned by NASA. The NASA project includes a major effort in the field of remote sensing (Badgley and Lyon, 1964).

OTHER PLANETS

Balloon-Borne Systems

STARGAZER

The Stargazer project, begun in January of 1959, utilizes a free balloon to lift an astronomical observatory, a pilot and an astronomer to 82,500 feet. The purposes of the project are to evaluate atmospheric effects on optical astronomy from 82,500 feet to ground level, to develop and test design criteria for a balloon aerostat observatory and to prove the feasibility and economy of a balloon aerostat astronomical observatory. The first flight of a series carried a $12\frac{1}{2}$-inch reflecting telescope aloft and was launched on 13 December 1962 from Holloman Air Force Base.

Motion pictures were taken of the flight and valuable ground photographs were obtained as well as spectroscopic data on pure light from stars and planets. Time exposure photography of several celestial bodies and planets were also recorded. Kittinger (1963) indicates that the information and data recovered by Stargazer I would have taken 50 unmanned flights to obtain.

STRATOSCOPE II

The eight-hour flight of Stratoscope II on March 1, 1963 analyzed the infrared spectra of light received from Mars. The Stratoscope balloon raised a 36-inch telescope with a theoretical resolution of 0.14 second of arc to over 80,000 feet. At this altitude the telescope was above all but 0.03 of the carbon dioxide and 0.001 of the water vapor in the Earth's atmosphere. A study of the spectral pattern (Danielson, 1963) revealed that the partial pressure of water vapor in the atmosphere of Mars is not more than four microns of mercury and it may be as low as 10 microns. Carbon dioxide content of the total atmosphere of Mars constitutes two per cent.

Future flights of Stratoscope II are planned to scan the atmosphere of Jupiter to determine what gases, in addition to ammonia and methane, might be present and to scan Venus, Saturn and possibly Uranus and Neptune.

Probes and Satellites

ORBITING ASTRONOMICAL OBSERVATORY (OAO)

The Orbiting Astronomical Observatory is another of NASA's future spacecraft. The octagonal vehicle is scheduled for launching in 1961 with subsequent flights at 6-month intervals. Precisely stabilized, the 3,200-pound satellite will be placed in a circular orbit about 475 miles above the Earth, making possible observations without the interference of the Earth's atmosphere. One end of the spacecraft will be equipped with three 12-inch Schwartzchild telescopes and a fourth telescope serving as a slitless spectroscope. These will be utilized to catalog over 100,000 stars. At the other end there will be one 16-inch and four 8-inch telescopes with filter photometers and two diffraction grating spectometers. This equipment will be used to measure the distribution of ultraviolet light in 200 selected stars and emission nebulae.

MARINER

This unmanned spacecraft program was designed for early interplanetary missions to the vicinity of Mars and Venus. The first launch was unsuccessful, but the second Mariner passed within 21,594 miles of Venus on December 14, 1962. The probe contained microwave and infrared radiometers for determining the surface temperature of Venus and the nature of its atmosphere.

Two Mariner spacecraft were launched in November, 1964 to fly past the planet Mars and transmit information about its atmosphere and surface. Mariner 3 failed when the fiberglass nose shroud collapsed during launch. Mariner 4 was successfully launched, and on July 14, 1965 passed within 5,400 miles of the Martian surface. Its television camera, comprising a one-inch vidicon tube and a 12-inch Cassegrainian telescope with a field of view of one degree, produced a series of 20 pictures. Alternate pictures were taken through a red and a green filter, and there is some overlap in the pairs. The pictures were stored on magnetic tape and then read out over a two-week period. Because of the communication distance, which exceeded 134 million miles, the photographic information was transmitted in digital form, at a rate of $8\frac{1}{3}$ bits per second. Each picture consisted of 200 by 200 picture elements.

On November 30, 1964 the Russians launched the Zond 2 spacecraft toward Mars, presumably on a similar mission. It ceased operating during the voyage to the planet.

VOYAGER

Voyager is an unmanned spacecraft which will act as a follow-on vehicle to the Mariner program. Voyagers will orbit Mars and Venus and inject soft-landing instrumented payloads on the surface. In addition, Voyagers will be launched on fly-by missions to Mercury and/or Jupiter. The first spacecraft of 6,000 pounds is expected to be launched during the 1968–1970 period. Inasmuch as the weight of Voyager is appreciably greater than that of Mariner, more sophisticated imagery equipment will undoubtedly be used.

SOLAR PHOTOGRAPHY

Terrestrial Telescopes

Narrow-band photography of the Sun is taken throughout the world, mainly to monitor solar flares and other solar activity. High-resolution photography in integrated white light is obtained at locations where the seeing is exceptionally good, such as Mt. Wilson, California and Sacramento Peak, New Mexico.

In 1958, the Lockheed-California Company initiated a program of time-lapse photography, photographing the Sun every ten seconds during most of the daylight hours. Light entering the 3-inch telescope is filtered to admit a narrow band of the Sun's spectrum centered on the Hydrogen Alpha line (656.356 millimicrons), and the Sun's image is recorded with a resolution of one second of arc on 35 mm. film. The excellent quality of the photographs as well as the continuous time coverage has proved valuable in the study of the development of solar flares and other chromospheric phenomena. The prediction of flares as an outgrowth of these studies is a principal objective. The capability of capturing events lasting only a few minutes has resulted in the discovery of new phenomena. For example, waves traveling across the Sun's photosphere at speeds of 2,500 km./sec were detected for the first time.

Because the Sun rotates on its axis about once every twenty-seven days, paired photographs taken at intervals of several hours produce a perceptible stereoscopic effect. An interval of six hours yields a displacement of 3.3° for an assumed interocular distance of 2.5 inches; this is comparable to viewing a tennis ball at 4.3 feet. Although longer intervals would produce a greater stereoscopic effect, surface features are continually altering their appearance, so that the stereoscopic effect is destroyed at longer intervals.

The three-dimensional effect has revealed some startling topography on the Sun's surface. Sites of dark hydrogen filaments (hedgerow-type prominences) appear as deep valleys, and sunspots appear as great depressions. One measured sunspot, for example, occurred at the center of a depression 150,000 km. in diameter and 15,000 km. in depth.

The latitudinal variation of the rotation rate of the photosphere imparts a peculiar prolate shape to the Sun viewed in stereoscopic pairs taken six hours apart. The equatorial regions, moving faster than the higher latitudes, are interpreted by the eye to lie above the mean surface of the spherical Sun. The differential rotation further hampers interpretation of solar phenomena by contributing to changes in the appearance and relative position of the features.

Balloon-Borne Systems

Stratoscope I

Stratoscope I made two flights to 82,000 and 83,000 feet carrying a 12-inch telescope aloft to make infrared measurement of sunspot umbras and the extreme edge of the sun. On the first flight on September 25, 1957 several photographs of the granulation on the surface of the Sun were made with unprecedented definition. On the second flight on October 17, 1957 the telescope was programmed to scan slowly across the edge of the Sun and high definition photographs were taken.

Images of the Sun from the 12-inch telescope were photographed by a 35 mm. movie camera taking an exposure each second with an exposure time of 1/1,000 sec. The photographs cover a wavelength band of 80 millimicrons centered at about 545 millimicrons. A photoelectric tracking device pointed the telescope at the Sun.

A cellular, but irregular character of the solar granulation (speckled appearance of the photosphere) was revealed by the photographs, which resolved features as small as 150 miles ($\frac{1}{3}$ seconds of arc) in diameter. Bright cells are separated by dark lines, which apparently represent descending gases surrounding the rising columns of hotter gases. Near sunspots, bright knots show changes in structure and a systematic motion away from the center of the spot. The "proper motions" of the knots represent the Evershed effect, seen for the first time in integrated light. Project Stratoscope was supported by the Office of Naval Research and the Air Force Cambridge Research Center.

Coronascope

This is a project of the High Altitude Observatory at Boulder, Colorado that is sponsored largely by the Office of Naval Research. A balloon is used to lift a 1,300 pound telescope and telemetry system over 80,000 feet above the Earth. Coronascope III, launched in the first quarter of 1964, created an artificial eclipse of the Sun in order to photograph its corona.

Probes and Satellites

Orbiting Solar Observatory (OSO)

OSO 1 was successfully launched on March 7, 1962. The 458-pound vehicle transmitted data from 13 experiments providing a survey of the solar disc and data on the centers of solar activity. Equipment used in the experiments included an optical system, X-ray and Lyman Alpha spectrometers, neutron flux sensors, and gamma ray monitors. The first solar observatory opened the ultraviolet and soft X-ray regions to essentially continuous observation; the second will be able to scan the disc of the Sun at several ultraviolet wavelengths with an aperture of about 0.5 minutes of arc. It will also provide routine monitoring of the Lyman-alpha and the helium wavelengths and of two X-ray bands. The normal solar spectrum in the far ultraviolet will provide data on the upper atmosphere of the Sun and will permit identification of elements whose presence are only presently suspected (Roman, 1960).

As many as seven additional OSO's will be launched in the next five years.

Advanced Orbiting Solar Observatory (AOSO)

The follow-on to the OSO program is the Advanced Orbiting Solar Observatory which is scheduled for launching in late 1967. AOSO will weigh about 850 pounds, over a quarter of which will be for experiments. AOSO will have superior experimental instrumentation, pointing accuracy, and data handling capacity than OSO. The optical system will be 10 feet in length and 22 feet in diameter. The longer and heavier optics are necessary to take advantage of improved angular resolutions and because of the high spectral resolution required for detailed analysis of the ultraviolet spectrum and the visible spectrum.

Vulcan

Feasibility studies are in progress on the Vulcan program. It will be an eccentrically orbiting satellite with a perihelion of about $\frac{1}{3}$ astronomical unit and will make precise observation of different regions of the Sun in several wavelengths of the spectrum. Of particular interest is the ultraviolet spectrum.

Vulcan will perform new studies in solar regions that have not been examined in detail.

Problems and Potential of Space Science Photo Interpretation

Improved terrestrial-based photography is not to be expected in the foreseeable future owing to limitations imposed by atmospheric turbulence. On the other hand, photography from space platforms is essentially free from these limitations. The photographic systems used to date are not optimum systems for space photography. Longer focal lengths and larger film formats are desirable. The use of larger cameras has been prevented by severe weight and space requirements, but the recent development of large booster systems has erased this as a serious problem. Consequently, experimentation is needed in camera design and film-filter combinations.

For unmanned satellites, reliable attitude control is required to point the cameras in the desired direction. Spin stabilization of TIROS limits views of the Earth during only one-half of the orbital period. Attitude control which will maintain the cameras in the local vertical are desirable. Photo interpreters are accustomed to working with essentially vertical photography. All of the available rocket and satellite photographs, however, are oblique; this complicates orientation of the photograph, and measurements of distances as well as interpretation because of foreshortening.

Attitude sensing which is precise to a fraction of a second of arc, however, is promised by star trackers, such as that developed for the Orbiting Astronomical Observatory. Coupled with present orbit determination schemes, star trackers will make feasible the automatic recording of the position and orientation of the satellite camera at the time of each exposure, thus eliminating the necessity for ground control, which may be poor or absent in the case of remote areas of the Earth and planets.

Surface features take on a new appearance when viewed at ground resolutions of tens or hundreds of feet rather than one or two feet with conventional aerial photography. A necessary task of the photo interpreter will be to gain experience in the recognition of common features at widely different scales and resolutions in order to make optimum use of space photography.

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