TABLE 1.—*Some Typical Camera Assignments for Space Missions*—Concluded

(b) Gemini Program

	Vehicle cameras					Hand-held cameras		
Mission, date and astronauts	Milliken DBM-7 16-mm panel camera	McDonnell 16-mm window camera	Maurer 16-mm window camera	Maurer 70-mm	Hasselblad 500C/EL modified	Neiss Contarex	McDonell 16-mm	Hasselblad Superwide
GT-VII; 12/4-18/65; Borman and Lovell	----------	----------	CR	----------	M	----------	----------	----------
GT-VIII; 3/16/66; Armstrong and Scott	----------	----------	CR	----------	CR	----------	----------	----------
GT-IX; 6/3-6/66; Stafford and Cernan	----------	----------	2CR	CR	CR	----------	----------	CR
GT-X; 7/18-21/66; Young and Collins	----------	----------	CR/BW	2-M	----------	----------	----------	CR
GT-XI; 9/12-15/66; Conrad and Gordon	----------	----------	CR	3-M	----------	----------	----------	CR
GT-XII; 11/11-15/66; Lovell and Aldrin	----------	----------	CR	3-M	----------	----------	----------	CR

(c) Apollo Program

	Vehicle cameras					Hand-held cameras		
Mission, date, and astronauts	Maurer 16-mm	Maurer 70-mm	16-mm Data Acquisition	Multispectral 4-camera assy.	Hasselblad 500C/EL Modified	Hasselblad Superwide	Hasselblad Lunar Data Camera	Closeup Stereo ALSSC
Apollo 7; 10/11–22/68; Schirra, Eisele, and Cunningham	CR	----------	----------	----------	CR	----------	----------	----------
Apollo 8; 12/21–27/68; Borman, Lovell, and Anders	----------	----------	CR	----------	CR	----------	----------	----------
Apollo 9; 3/3–13/69; McDivitt, Scott, and Schweikart	----------	----------	CR	M	CR	CR	----------	----------
Apollo 10; 5/18–26/69; Cernan, Young, and Stafford	----------	----------	CR	----------	2–CR	----------	----------	----------
Apollo 11; 7/16–24/69; Armstrong, Aldrin, and Collins	----------	----------	CR	----------	CR	----------	CR	CR
Apollo 12; 11/14–24/69; Conrad, Gordon, and Bean	----------	----------	CR	M	2–CR	----------	CR	CR
Apollo 13; 4/11–17/70; Lovell, Haise, and Swigert	----------	----------	2–CR	----------	CR	----------	CR	----------

BW: Black-and-white film; CR: Color reversal film; CN: Color negative film; CIR: Color infrared; M: Different film using several magazines.

CHAPTER II

Vehicle-Mounted Cameras

Early in the space program, it was recognized that photographic records of events taking place in unmanned vehicles would be of significant help. The photographic records recovered could provide significantly greater information than telemetered data and data which would not otherwise be collected. For example, pictures of the Earth were taken from unmanned vehicles in early programs and gave impressions of views not yet seen by man.

NASA's approach in this area was to use available equipment as often as possible and adapt it for the purpose. This kept the program within economic constraints and assured general, ready availability of duplicate equipment should difficulty arise. Backup capability is of prime concern in all aspects of the space program. One of the cameras chosen was a Maurer 220G time-lapse camera, used for automatic photography on unmanned Mercury flights and also included in the vehicle complement on the Mercury-Redstone III flight, which was the first manned suborbital flight of Astronaut Alan Shepard. The Maurer 220G time-lapse camera, which utilizes 100-feet-long 70-mm film, was used as an Earth and sky camera. The 220G took 2¼- x 2¼-in. pictures as individual still photographs (see ref. 7). It was through the use of this camera on the unmanned MA–IV flight that one of the most outstanding of the first pictures of Earth taken from space was obtained. This was the picture of the continent of Africa in Color Plate 1(*b*). A 16-mm camera was used as a periscope camera and another as the instrument observer camera.

Most of the onboard cameras were continuous or stop-action motion-picture cameras. These were basically off-the-shelf items which were adapted for remote automatic operation in the space vehicle. On the manned Mercury flights, the early suborbital flights, Milliken motion picture cameras were used. One camera was mounted in the control panel to photograph the pilot, while a duplicate was mounted behind the pilot to photograph the panel of the space vehicle. Such cameras utilize 16-mm films, a tradeoff involving size and weight but still retaining some degree of professionally acceptable quality. In the Gemini program, two basic types of 16-mm cameras were employed: a Maurer 16-mm which, again, was essentially a modified available camera, and a McDonald 16-mm camera whose design was directed toward the types of problems encountered with space vehicle photography. In all cases, NASA technicians incorporated detailed changes to meet immediate specific requirements. The McDonald had been used on the earlier Gemini flights, and the Maurer was introduced on Gemini-Titan 6. The basic Maurer camera for the Gemini program was Model 296. As a result of this experience, additional developments were incorporated into the Maurer Model 308 which became the Apollo 16-mm onboard camera. (Some early discussion of vehicle cameras for space exploration is given in ref. 8.)

One way to improve the quality of the photographic information being recorded is to increase the size of the film. In many cases photographic systems are optically film-limited in their performance. Because of space and weight, maximum film size throughout these programs was generally limited to 70-mm. Planned for use on later Apollo missions was a vehicle-mounted onboard camera, the largest to be taken into space. It is a modified version of a Hycon KA74. This camera will utilize 5-inch-wide film in 200-foot rolls. These will, of course, be a thin polyester base of 0.0025-inch thickness (see chap. VII). The camera will have an 18-inch focal-length lens with fixed focus. This camera is intended for the program known as "Bootstrap" photography, and it was designed to be used from the Command Module while orbiting the Moon during the period that the Lunar Excursion Module (LEM) was on the lunar surface.

Requirements which the geodesy and cartography working group formulated for photographic systems for space exploration are summarized in reference 9. While the group recommended a 9- x 9-inch format for the basic investigations, they recognized that space and weight limitations would require cartographic deviations from small format pictures. This report also emphasizes certain orientation control requirements necessary to maintain maximum accuracy in data reduction processes.

Other vehicle cameras have basically been the modifications of the Hasselblad which has been used for hand-held photography. Of these, the most significant is the four-camera cluster used for multispectral photography. (Multispectral photography and its functions are described in chap. V.) The assembly is a cluster of four cameras, each equipped with a filter for a different spectral region or color of light by which the photographs are to be taken. Figure 12 shows the arrangement of the cameras and their orien-

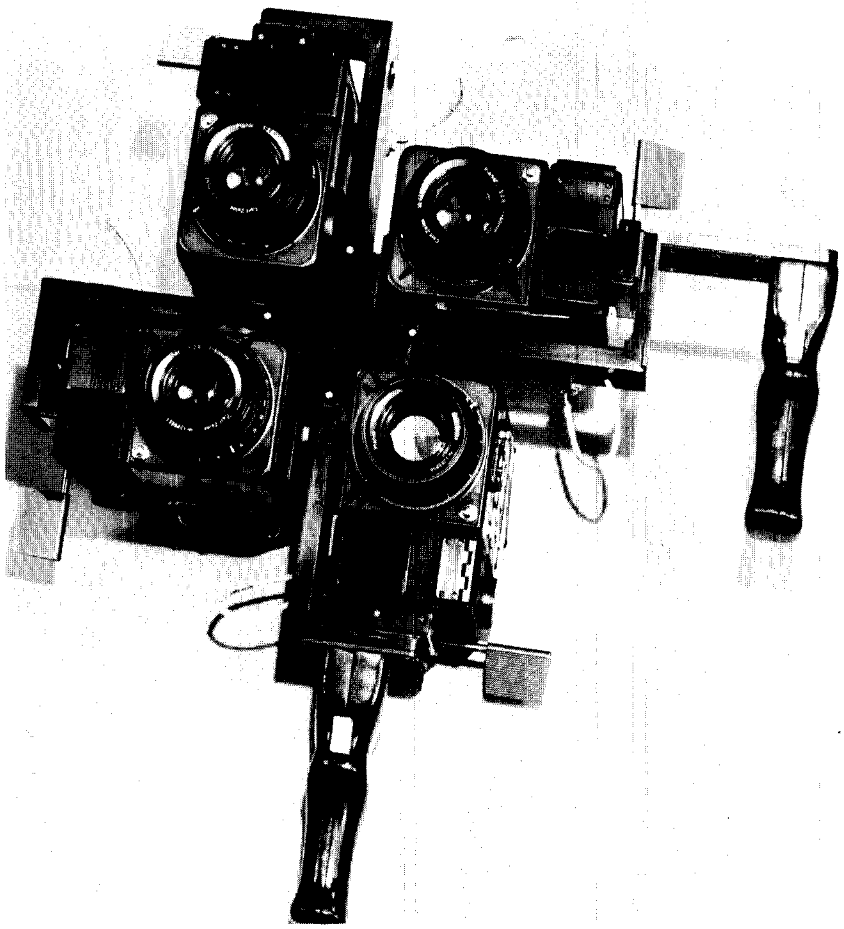

FIGURE 12.—An assembly of four Hasselblad EL 500 cameras, as modified for space missions, was used for multispectral photography. Each camera is equipped with a filter and black-and-white film recording the information of a single spectral band, or one of the cameras may be equipped with color film to give a pictorial rendition for control purposes. This manual assembly, which is presented here to depict camera orientation, was superseded by the fixed mounting installation in figure 13. (Courtesy of Paillard, Inc.)

tation. The unit is shown set up for manual handling and operation. Figure 13 shows the same bracket assembly mounted as a fixed installation in a space vehicle window. All the exposure conditions (shutter speed and lens openings) are predetermined and preset. In the vehicle mounting, the release is on a remote-control cord; the operator has the ability to select exposures on any combination of the four cameras as desired by the particular

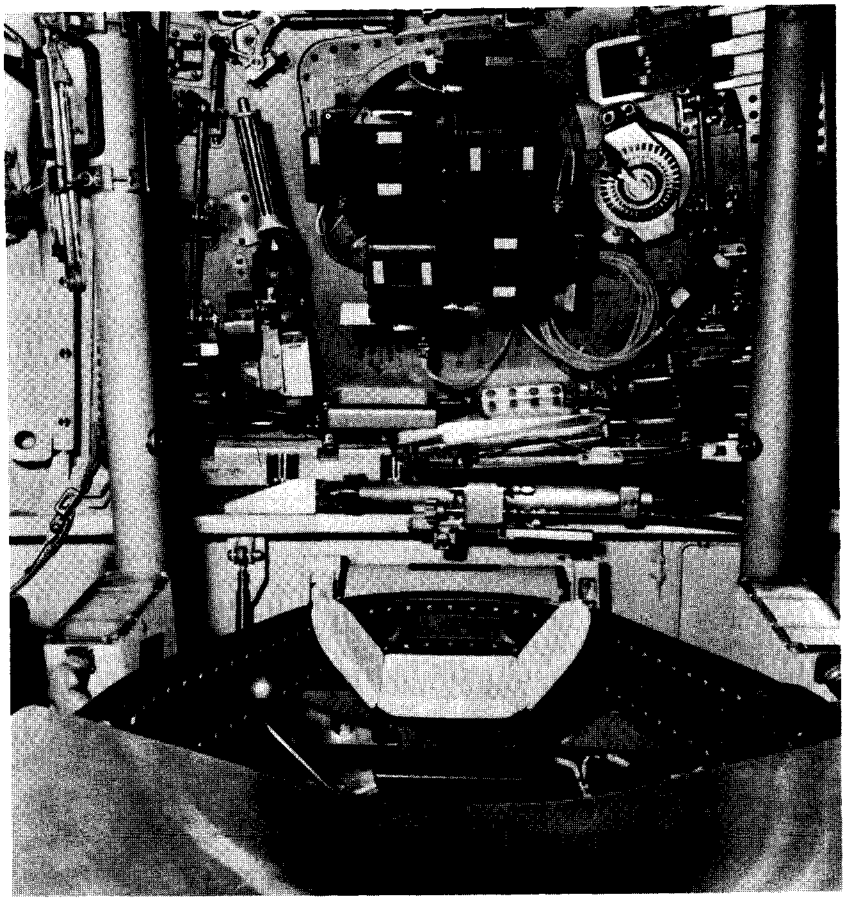

FIGURE 13.—This picture shows the installation of the four-camera multispectral assembly on a port in the Apollo spacecraft. To the center right is a stowed extension release to enable astronauts to operate a camera from several positions within their spacecraft.

experiment. In one experiment, the control of these cameras is also synchronized with the stop-frame action of one of the 16-mm cameras.

Another significant application of the fixed-vehicle installation of camera equipment is associated with aircraft surveys in the Earth Observations Program. Three basic aircraft are used in this program: the NP 3A (fig. 14), which operates to an altitude of 25,000 feet; the NC 130B, which operates to an altitude of 30,000 feet; and the high-altitude RB 57F (fig. 15), which covers the range of 40,000–60,000 feet. A typical camera installation in the

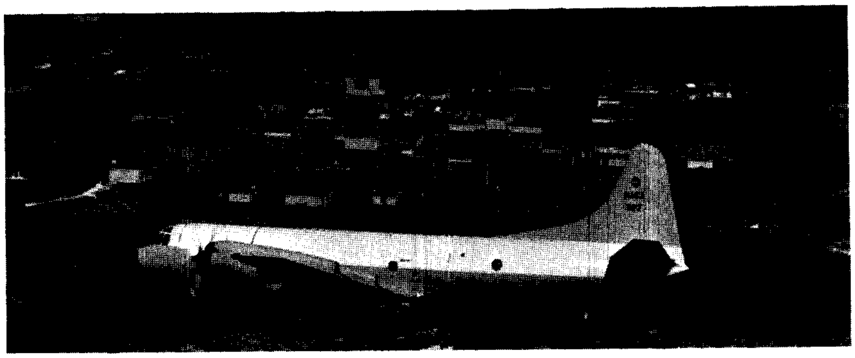

FIGURE 14.—The NASA flying camera platform and NP 3A Aircraft, a modified Lockheed Electra is used by NASA for the Earth Resources Observation Program. It is shown against the background of the Manned Spacecraft Center at Houston.

FIGURE 15.—The RB 57F high-altitude flying camera platform for the Earth Resources Observation Program.

NC 130B is shown in figure 16. Multispectral work with the aircraft is performed, as in the space vehicle, with the ganged assembly of cameras. However, six cameras with the capability of triggering in groups of three are used. Again, different filters are employed for different wavelength bands, as described later. The camera in all aircraft supporting basic operations is the Wild RC–8 standard aerial camera in a stabilized mount.

Another unique application of photography is made in connection with the Earth Observations Program. Beside the normal photographic equipment just mentioned, the Earth Observations Program relies on image-dissection scanning techniques with

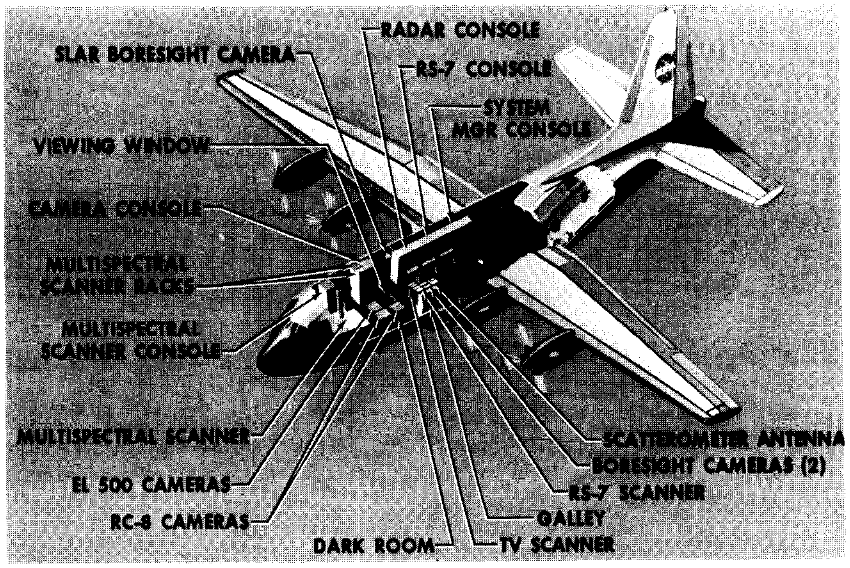

FIGURE 16.—A typical camera and sensor installation on the aircraft used in the Earth Resources Observation Program is shown in this cutaway view of the NC 130B flying camera platform.

major sensors in the far-infrared, side-looking radar, and an infrared scanning spectrometer. The reconstruction of imagery from all these image-dissection systems is mainly done on photographic film. With respect to image-forming photography, each one of these systems has parallel to it a boresight camera. This boresight camera gives a parallel-processed picture, that is, it works just like a standard motion picture camera; taking individual frames—one frame for several lines of the remote electrical optic sensing equipment. This capability gives research workers a full-frame, high-resolution picture of the particular area which the lower-resolution scanning systems are sampling. This boresight photography is an essential key to the interpretation of the results of this work.

The RC–8 cameras are in stabilized mounts which permit each camera to maintain its attitude independent of the deviations of the aircraft. The multispectral assemblies are hard-mounted; that is, attached directly to the aircraft frame. The boresight cameras are attached to and alined with their electro-optic scanning systems.

In addition, the NP 3A aircraft is equipped with four KA62 cameras. These are 5- x 5-in. aerial cameras manufactured by Chicago Aerial Industries and specially modified for other multispectral work. They use a roll of 5-inch film taking a 5- x 5-in.

picture and are equipped with a 3-inch focal length giving a wide angle of coverage. The RB 57F is also equipped with a Chicago Aerial KA50A wide-angle aerial camera covering a 120° field of view.

A third application of vehicle-mounted cameras using a different approach is the program operated by the Airborne Science Office at Ames Research Center. Two aircraft are used in the airborne research program; a four-engine jet transport, a Convair 990 model known as the "Galileo," which now reaches 40,000 feet, and a two-engine Lear Jet Model 23, with an altitude capability of 50,000 feet. The Lear Jet has been used so far mostly for infrared astronomy studies. The Airborne Science Office uses these aircraft as flying observatories for research in many scientific fields: meteorology, Earth resources, geophysics of the upper atmosphere (aurora and airglow), and astronomy. The characteristic which distinguishes it from the other NASA programs is that practically all experiments and equipment on the airplanes are provided and operated by scientists not affiliated with the Airborne Science Office, but from universities, research institutes, private industry, and other government agencies.

While these programs generally require the use of specialized astronomical instrumentation at high altitudes, a number of standard cameras are utilized on many missions. Unlike other programs with a fixed complement of equipment, this program is planned on an individual mission basis. When required, the Airborne Science Office reviews photographic techniques with the Photographic Technology Branch which specifies equipment and assigns the personnel in support of the guest scientists. Although most basic cameras are standard or modified available equipment, optical and photographic techniques are developed by NASA personnel to support the individual requirements of each mission. Results are spectacularly demonstrated in the photographs of the Ikeya-Seki comet supplied by Louis Haughney of Ames Research Center in 1965 (fig. 17).

In the unmanned Earth-orbiting vehicles a unique camera system was the spin-scan cloud camera for weather observations. This is described in reference 10. In its mechanical operation, this camera provides direct dissection for wider transmission of the picture information. The transmitted picture information is used to construct the photograph on the ground in a manner similar to that described in chapter VI. Developments in rocket-borne camera instruments are described in reference 11. For example, on the test program using the Aerobee rocket, a solid-state, wide-

FIGURE 17.—View of the comet Ikeya-Seki taken in 1965 by R. Innes of the University of California at Berkeley in cooperation with Louis Haughney of Ames Research Center as part of the Airborne Science Program. This picture was taken from high altitude with the Convair 990 "Galileo" instrumentation and camera aircraft of the Airborne Science Office.

range, low-power camera timer was developed to control the shutter over a large range within the tolerance of ±10%.

New ideas for vehicle-mounted cameras are continuously investigated. As an example, reference 12 reviews proposals for an Apollo telescope mount to carry advanced astronomical photographic equipment.

In summary, the major contributions of NASA to the development of vehicle-mounted cameras and stabilization systems have been in the operational mission-oriented aspects of the Airborne Science Office program, the automatic systems of the space exploration program, and the sophisticated hardware for multispectral photography in the earth resources program.

CHAPTER III

Tracking Photography

Most of the equipment and technology used by NASA to track its space vehicles photographically during the launch period was developed by the U.S. Air Force in conjunction with its work at the eastern range site of Cape Canaveral, Florida, adjacent to the Kennedy Space Center. In pre-NASA days these projects were conducted for Air Force programs and to support programs of NACA.

The distance at which an image, unobscured by weather or atmospherics within the range of the camera lens, can still be recovered by some sort of long focal-length camera is called the optically available range. Two major types of equipment are used to track vehicles from launch through the optically available range. The first and more comprehensive of these is the cinetheodolite. The theodolite is a version of the telescope that is more commonly known as a surveyor's transit with maximum capability for quantitative measurement and orientation of the optical axis. Theodolites have the capability of measuring both azimuth, which is the compass direction of the optical axis with reference to either true or magnetic north, and elevation, which is the angle of the optical axis with the true horizontal plane. A phototheodolite is a camera with provisions for making a pictorial record with these measurements for later analysis of the data.

A cinetheodolite is a similar device generally with larger, faster lenses than are normally used for visual viewing. It incorporates a pulse-operated recording camera that is capable of frequency rates of one to 30 frames per second. In conventional sound motion pictures the frame rate is 24 frames per second. Cinetheodolites may use slower or faster rates, depending upon the event to be recorded. The key capability of the cinetheodolite is the recording of a reference line to the axis of the system and a simultaneous recording of the coordinates of the axis. The focal length of lenses used with cinetheodolites may vary according to the task at hand. When long focal lengths may be required, many of these instruments are equipped with reflecting optics much like an astronomical telescope. The cameras can be operated manually to track an event or a vehicle. The distinct advantage of the theodolite is that it can be utilized for passive tracking of any missile or vehicle, requiring no external signal originating from the vehicle itself. It is, of course, desirable to keep the image of the vehicle or missile on the crosshairs or reference mark of the theodolite. But when the size of the film frame used, the location of the crosshairs, and the geometry of the film-lens combination are known, corrections can be determined directly from the film when the vehicle does not record exactly on the crosshairs. A theodolite contains all the information in the picture which is generated by the instrument itself.

On the other hand, there are a number of photographic systems known as tracking telescopes that make engineering documentation records of the vehicles as they are viewed from liftoff to the range of the camera. They generally have long focal-length lenses and are automatically tracked to the vehicle by radar systems. In actual practice, the longer the focal length of the lens and the narrower the angle of view, the more difficult it is to maintain reasonably good manual tracking. Advanced technology developed in the early space programs has resulted in various active radar-tracked cameras. The only data recorded on the film, besides the picture, are the time data for the event being recorded. The main purpose of these tracking cameras is to prepare a visual presentation of the behavior of the vehicle or missile during its launching flight. The timing record on the film gives a correlation to the time of any event. These cameras are used as an engineering tool. An evaluation of the vehicle is generally determined by independent electronic techniques. This evaluation, of course, requires additional equipment either on the vehicle or on the ground. Framing rates for tracking cameras run from the normal 24 frames per second to very high framing rates depending, again, on the type of event to be investigated. Film sizes for both the tracking telescopes vary from 35 mm to 70 mm, according to the test being conducted and the degree of resolution desired; cinetheodolites use 35 mm only. The optical photographic techniques for these instruments were developed for the earlier space and ballistic missile investigation programs during NACA investigations. NASA has continued to improve the equipment, the type of information acquired, and the data reduction techniques.

A significant contribution was the development and installation of a portable, remotely controlled photographic tracking mount for use with the more advanced launch vehicles associated with Launch Complex 39A. This equipment is normally installed with

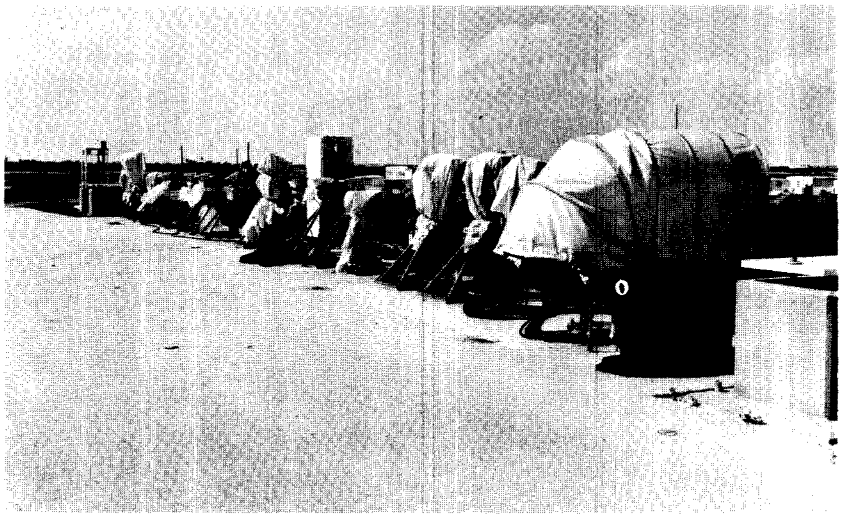

FIGURE 18.—Site 4 at Launch Complex 39A, Kennedy Space Center, with cameras installed and covered for protection until launch operations.

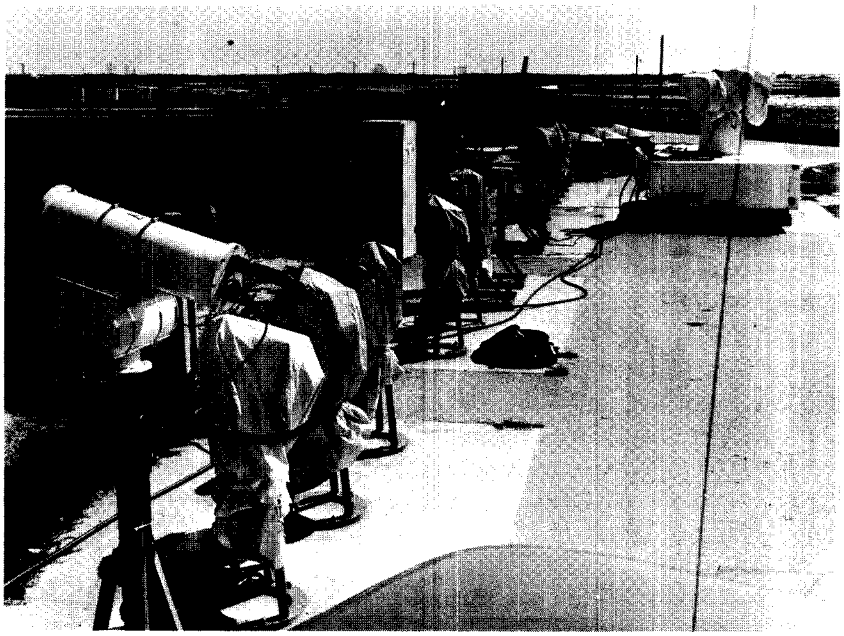

FIGURE 19.—Site 5 at Launch Complex 39A at the Kennedy Space Center, showing equipment as set up and covered until a countdown and liftoff. A large remote-controlled tracking camera appears on the trailer. Smaller cameras for recording individual events are mounted in fixed stands with known coordinate references.

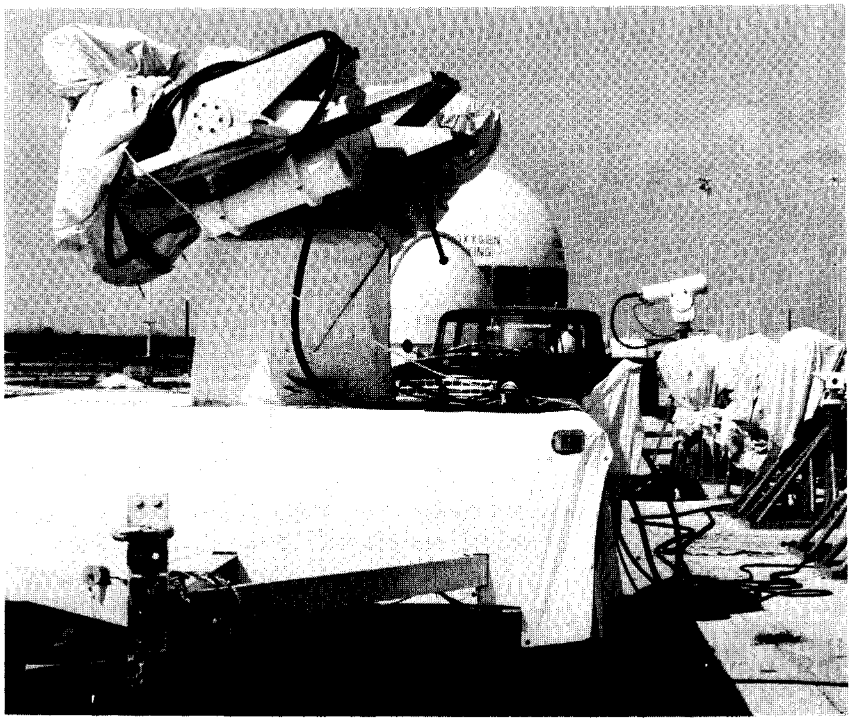

FIGURE 20.—A tracking mount at Site 5 at the Kennedy Launch Complex 39A. The picture was taken from the rear of the south side of the site complex and shows the remote-control tracking mount which is capable of handling a variety of camera sizes.

35-mm Mitchel GC cameras. As many as six units, all tied into a master control unit, can be used, each looking at a different part of the vehicle from a different station. (The master control unit will be discussed in chap. IV.) A tracking-camera technique is discussed in detail in reference 13, which describes work on the tracking of satellites from earth. The key element in the photographic system was the experimental utilization of a fixed-telescope system on the ground with an image motion compensating camera.

Typical installations are shown in figures 18 through 21. As a result of the programs of NACA and the Air Force and, more recently, NASA, industry will have, in tracking cameras and theodolites, new tools for handling photoinstrumentation problems. Tracking photography was probably the earliest of the advanced phototechniques to come out of the space program; many of the tracking techniques have already been incorporated

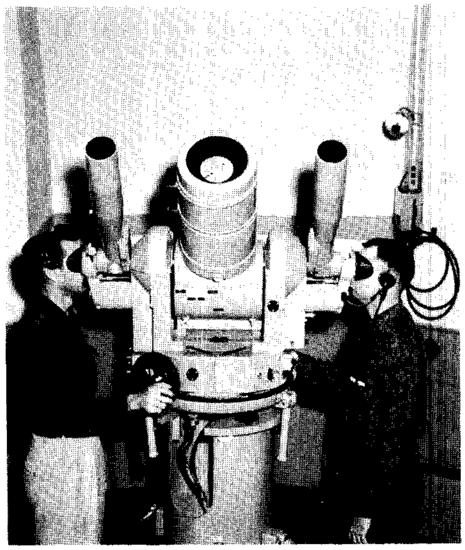

FIGURE 21.—This photograph was taken at the Air Force Eastern Test Range which has responsibility for tracking the vehicles after they leave the launch complexes at Cape Kennedy Air Force Station and Kennedy Space Center. It shows a cinetheodolite which, in addition to tracking the vehicle, records on film complete geometrical information with respect to azimuth elevation and the time each frame was taken.

in modern data-acquisition cameras and instrumentation cameras. Some are used in modern television programing of large-scale sports events and recording experimental investigations which take place over wide distances and for which proximate recording is neither convenient nor safe. More applications are foreseen for these techniques, albeit with still cameras using phototheodolite techniques for civil engineering. These applications will use smaller, portable equipment having the type of precision and accuracy that is presently obtainable with visual instruments. The civil engineer will then have a permanent record, plus the significant advantage inherent in the phototheodolite's ability to record a measure of the actual deviation from the sighting axis.

CHAPTER IV

Engineering Photography

In terms of the volume and diversity of records produced, the greatest use of pictorial photography by NASA has been in engineering applications.

A general definition of engineering photography might include pictures taken to (1) document engineering experiments and (2) present a space or time record of events as they occur. Other chapters of this survey describe photographic applications which might also be considered engineering photography. Here the only applications considered are those in which pictorial records are made.

First, it is pertinent to indicate working procedures of interest to business and industrial organizations to whom photographic techniques may be useful tools. Langley Research Center, one of the oldest research centers incorporated into NASA, was developed by NACA (National Advisory Committee on Aeronautics) in the early 1920's. The practice of operating a centralized photographic applications laboratory was established at Langley, and carried over to Lewis Research Center and Ames Research Center. The centralized operation provides equipment and manpower for photographic engineering applications and tests in all programs associated at the centers. This procedure permits the development of a centralized service organization staffed with specialists in photography and photographic instrumentation techniques. It also provides a central source for equipment and materials, thus offering a fast, responsive service to support research and test activities at any location within the center. Such an operation makes possible maximum use of equipment, a readily available supply of materials and spare equipment, as well as deployment of personnel efficiently. At the Kennedy Space Center, outside organizations provide similar specialized personnel for photographic operations.

As an engineering tool, a two-dimensional photograph actually contains three dimensions of information. It contains two dimensions of spatial information; that is, a record of the relative location of individual objects through the location of their images in the picture. The third dimension of information is that of the relative brightness, or luminance, of the object. This is recorded as a change in density, blackness, or color on the film. Fundamental principles of optics, as well as modern technology in lens design, assure the user of a very accurate reproduction of a given scene or object by the photographic film in a camera. A fourth dimension of information, time, is readily available by repetitious photographic techniques. These include both cinematographic and other techniques. If we know the instant at which a single photograph was taken, we have a record of the two dimensions of spatial information, as well as the energy or luminance information, and the time—an instantaneous record, as it were, of a dynamic event.

The usual techniques of motion-picture photography allow us to take individual pictures sequentially at fixed intervals of time. The motion picture, thus, gives us a four-dimensional record of an event because it provides the timespan information by the frame-to-frame sequence.

Other techniques of photography are also used to obtain time records. One of these is dramatically illustrated in Color Plate 5. It is a picture taken by a camera capable of exposing different sections of the picture at different times. This is one form of a time-displacement camera. This camera records the trajectory of a moving object against a constant background by taking each segment of the picture at a different time; i.e., the time at which the moving object passes through it. The stripes running diagonally through the picture can be rotated to a vertical position for horizontally moving objects or to a horizontal position for vertically moving objects. The diagonal 45-degree orientation is more practical for objects having several directions of motion, as in the example. Each segment of the picture was exposed at the point in time that the object passed through it. Not shown in this picture, but recorded on the original film record, is a numerical indication of the time interval at which a particular segment was exposed. In some respects, this is like a cinematographic or motion picture in that several panels or "frames" represent different sections of the spatial or two-dimensional space information of the picture. The final composite, as printed, is a two-dimensional picture of the location at which the test was taken and a sequence of pictures of the moving object. The record of the time during which these individual panels were exposed constitutes a fourth dimension, or time information, of the event.

Photographic techniques thus make it possible to record any or all of four dimensions of information. Some time-displacement cameras record only one dimension of space information and record the time function on a second portion of the film.

All engineering photography is generated and used in the context of recording information objectively or measurably. Some of the techniques of photography for engineering applications utilize special optical principles to reprocess information contained in a photograph. This is done to make the record more evident, to enhance certain characteristics, or to permit preferential treatment of certain object information. Among these techniques are shadowgraphy or Schlieren photography and, more recently, holography.

The next major aspect of engineering photography under consideration is the scale at which these records are taken, whether that of an airplane flying on its V/TOL trajectory or that of the drop of burning aluminum photographed in the time pattern shown in Color Plate 6. In this case, an 8-inch x 10-inch piece of film, as the recording medium, was set up in an inverted conjugate system (fig. 22). The lens was closer to the object than

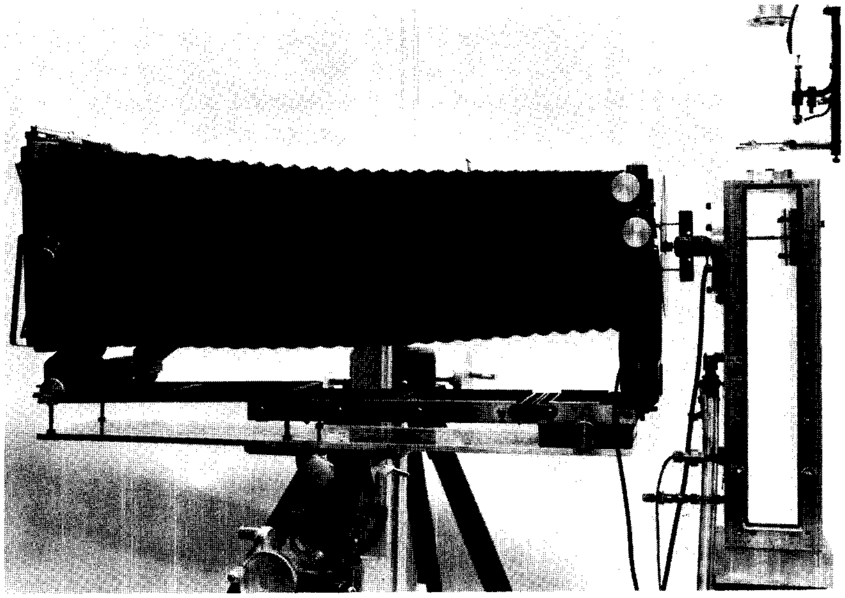

FIGURE 22.—An 8 × 10 view camera set up for the burning droplet experiment. It is set at inverted conjugate; that is, the lens is closer to the object than to the film. The rotating disk shutter seen in front of the lens permits a sequence of photographs at equal time intervals as the drop falls.

it was to the film and the picture produced was a magnified image of the object. With this system, noting the black background, it was not necessary to use a segmented technique but simply to expose the burning aluminum droplet, which is a self-luminous object, at time intervals on the same piece of film. In this instance, time intervals were equally spaced by utilizing a rotating disk shutter having a slit aperture located in front of the lens. The aperture causes a very short, or high-speed, exposure, to occur at each rotation of the blade. The slit segment of the rotating disk is small enough to provide a high-speed exposure and an effective stopping of the motion. To get good spacing of the drop pictures, the dead time, or blanked-out time, between successive passings of the slit must be sufficiently long that the picture at one position does not overlap that of the prior position.

Further applications of engineering photography involve the use of cinematographic and high-speed cameras. Conventional motion pictures, as used for entertainment, are projected at a rate of 16 or 24 frames per second. The latter is generally preferred for all newer applications. If correct time scale of motion is desired, the camera operates at 24 frames per second for sound applications or 16 frames per second for silent systems. Within a limited range, time expansion and compression, commonly known as "fast motion" and "slow motion," are achieved by running the camera at speeds respectively slower or faster than normal and projecting at the stated normal speed.

These motion-picture cameras have what is referred to as an intermittent motion. In a stop-and-start action, each frame of the film is pulled into the film gate of the camera, exposed and the film advanced to the next frame position. In engineering applications of photography, certain work is done using standard cinematography equipment and techniques at the 24-frame-per-second projection. Available camera speeds range from approximately six frames per second up to about 97 frames per second.

Engineering data cameras are used that operate by means of external programing. These also operate in an intermittent mode; that is, each frame is placed sequentially in the gate of the camera and exposed individually while the film is standing still. These cameras operate under external control by means of a control device known as an "intervalometer" or through remote or manual sequencing. Rates less than one frame per second have been used. Rates range up to cine speed (24 frames per second) and occasionally higher (about 100 frames per second), depending on the equipment capability.

High-speed cameras are those that can operate significantly faster than the cine speeds; generally in excess of 100 frames per second. In those equipped with intermittent motion, speeds up to 1000 frames per second have been achieved. Other high-speed cameras use a moving-film technique but optical devices, such as a rotating prism or a mirror, stop the motion of the image on the film. The capability of these cameras overlaps that of intermittent mechanisms in the lower speeds, but speeds up to 10,000 frames per second are possible.

In a third category of high-speed cameras, the film is held stationary around a semicircular focal plate, and the image is moved from frame to frame on the film by means of the optical devices. These cameras provide a rather short record but extremely high frame rates of a short-duration event. Some cameras of this type have reached 10^5 frames per second.

Other cameras with automatic advance features, including some 70-mm automatic advance cameras for commercial photography and such large format cameras as the K–22 or K–24 standard aerial cameras, have been adapted for data recording. These cameras utilize external programing within the capability of their automatic film advance, generally requiring 1 to about 3 seconds per cycle.

Most of the cameras developed to meet the needs of NASA programs are now readily obtainable from commercial or military suppliers. Many present models may be further modified at the factory or center to meet specifications. Modifications are required for cameras that are intended for use in vacuum or in high vibration environments such as in a 40-G centrifuge. In many of these cases, the changes provided by the camera manufacturers in response to NASA needs have been incorporated in cameras for commercial applications.

Two other basic techniques involved in engineering photography are clarified here in a general manner, since they apply across the board to any of the camera types used. The first of these, and the most confusing with respect to definition and identification of equipment and procedures, is stroboscopic analysis. Unfortunately, the general term "stroboscopic" and its derivatives have come to imply almost any application of a high-speed discharge tube as a light source, even to the single exposure of an electronic flash on an amateur's camera. The preferred definition retains the connotation of "electronic flash" for the single discharge flash for still pictures taken with any of a large variety of cameras for both commercial and amateur work. The original concept of stroboscopy was associated with the examination of such fast cycling events as a rotating shaft by synchronizing the viewing to a very small sample of the shaft in the same position each time. Concise statement defines that stroboscopic techniques, while generally accomplished by a high-speed pulsating light, do not essentially require this light. Any high-speed, repetitious control of the recording exposure, either through the light source or through a shutter, will produce the same effect. In a strict sense, stroboscopic photography uses time sampling to make a high-speed cyclic motion appear to stand still or progress very slowly. (The classic example of a stroboscopic effect is the impression of stagecoach wheels apparently standing still or turning backward in a movie.) Stroboscopic pictures can be made by a motion-picture technique synchronized to the event or with a very small synchronization lag to allow the event to appear to move very slowly. The use of a repeating light to obtain multiple imagery on the same piece of film is more strictly a time-displacement rather than a stroboscopic technique. It gives a time and motion record of the event.

Another major type of picture taking that occurs occasionally in engineering photography involves the use of stereo techniques in the production of three-dimensional information in photographic records. This three-dimensional information can be viewed with aids that enable the observer to see a three-dimensional presentation of a scene, or the information can be reduced from stereo photographs and processed through a computer for such analysis as required. The basic principle of stereoscopic photography is to take two pictures with lenses that are separated by approximately 2¾ inches, the normal average separation of the human eye. If each of the pictures taken with these lenses is presented so that the eye looks at the proper picture, the observer will be given the same three-dimensional view he would see if looking at the object itself. This occurs because each eye looks at a picture from its own point of view, the brain utilizing the information received by the eyes to construct a third, or depth, dimension of the scene. Through stereo photography we record and present to each eye the information that it alone normally receives. Without going into technical details, it should be noted that modification of the stereo effect can be accomplished by changing the focal length of the lens and/or the viewing device to create a different point-of-view perspective as related to stereo perspective. The result is a modification of the impression of depth in the stereo presentation. Another variation in the presentation is created by manipulating the base line.

Many of the examples of engineering photography presented here were performed for the first time under NASA guidance or in response to NASA engineering-analysis problems. Some of the techniques used for engineering photography are illustrated in the figures and color plates.

In wind-tunnel work, many direct photographs are made of models to analyze their behavior and the behavior of the stream passing them. In Color Plate 7, a model test in a wind tunnel at

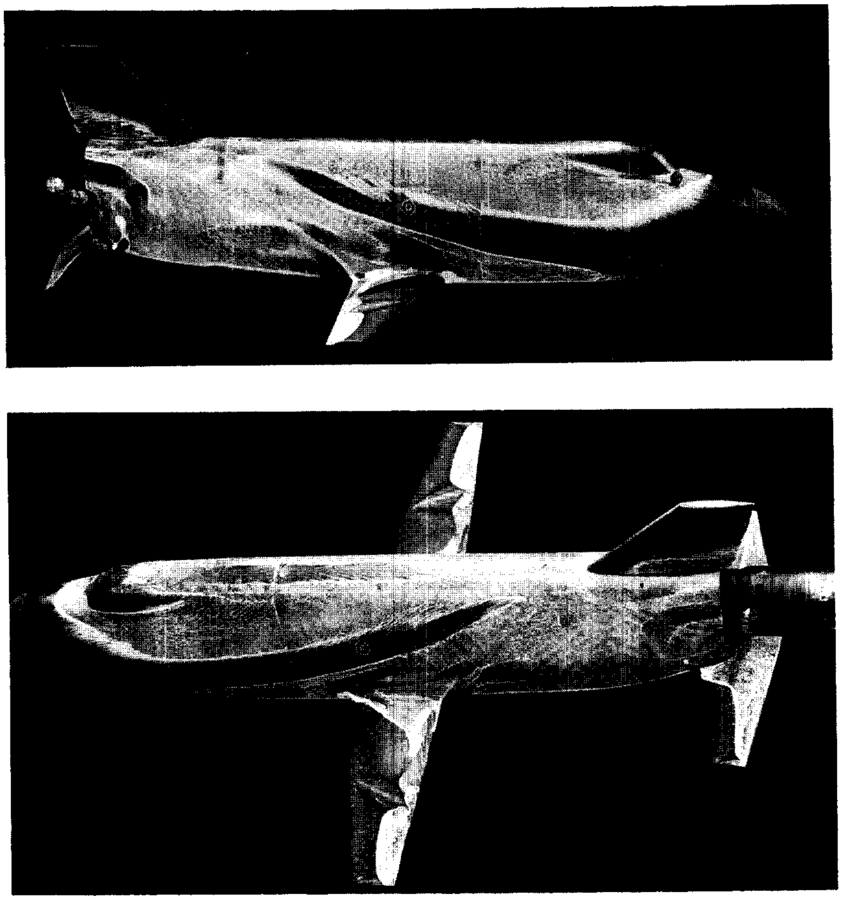

FIGURE 23.—These photographs show opposite sides of a flight model with surface air patterns visualized by the use of oil-flow techniques. The viscous oil visible in pictures retains its position on cooling, allowing the detailed photographs to be made after the air flow has been terminated.

Ames Research Center displays the type of information that can be obtained in evaluating the heating and ionization effects in the model. In some of this model work at supersonic speeds, the pattern of the wind turbulence is made evident by utilizing models coated with heavy oil. When the oil flows, its pattern is representative of the behavior of the wind patterns. Figure 23 is an example of an oil-flow model used for airstream analysis. One feature of this oil-flow model is that the oil is sufficiently viscous to retain its location after the test is completed; it can be photographed independently to obtain a clearer picture for detailed analysis. Color Plate 8(*a*) shows the direct evaluation of a model in the test tunnel with a fluorescent oil applied to it. The photograph was recorded by ultraviolet radiation. Color Plate 8(*b*) is a wind-tunnel test of a model which shows evidence of glow discharge.

Both in wind-tunnel work and in vibration studies, mode-shape analysis is another technique where photographic recording provides significant information. Stripes are painted on the various forms or bodies and then subjected to vibration caused either by the wind or by a vibration transducer. The amplitude of the vibration is determined from the spread of the striped images. Twisting and deformation is also given by the change in the pattern of the stripes. Figure 24 shows typical models with the mode stripes under test. In other wind-tunnel tests that simulate reentry phenomena for spacecraft development programs, analysis is made of ablation or the burnoff of protective material. Color Plate 9 is a photograph of the model of the Mercury capsule under reentry simulation from which the ablation behavior was determined. In such tests, motion pictures may be used for a complete time record, but individual still photographs give indication of what occurs. Color Plate 10 shows closeup details of ablation patterns and heat transfer effects. Photographic techniques are employed in wind-tunnel and thermal analysis work where models are coated with temperature sensitive paints, as in figure 25, to determine the dynamics of thermal behavior.

In wind-tunnel work at Lewis Research Center, automatic quantitative measurements of the manometer assembly are made by photography. A manometer board consists of a set of 20 or 40 manometers, i.e., liquid-filled tubes for measuring pressures, each manometer measuring the pressure at some point in the wind-tunnel system. It is advisable to keep these points as close as possible to the actual event where no observer could participate. So that all manometers can be read instantaneously,