NASA SP-5099

TECHNOLOGY UTILIZATION

PHOTOGRAPHY EQUIPMENT AND TECHNIQUES

A Survey of NASA Developments

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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A Survey of NASA Developments

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Science Information Services Department
The Franklin Institute Research Laboratories

Prepared for NASA under contract NASw-1981

Technology Utilization Office 1972
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

For sale by the Superintendent of Documents,
U.S. Government Printing Office, Washington, D.C. 20402
Price $1.50 Stock Number 3300–0453
Library of Congress Catalog Number 72–600108

Foreword

The Apollo program has been the most complex exploration ever attempted by man, requiring extensive research, development, and engineering in most of the sciences before the leap through space could begin. Photography has been used at each step of the way—to document the efforts and activities, isolate mistakes, reveal new phenomena, and to record much that cannot be seen by the human eye. At the same time, the capabilities of photography were extended because of the need of meeting space requirements. The results of this work have been applied to community planning and ecology, for example, as well as to space and engineering.

The National Aeronautics and Space Administration has established a program by which the results of aerospace research and development from a wide variety of sources are collected, evaluated, and disseminated widely for the benefit of the industrial, educational, and professional communities in the nation. This new technology is announced in appropriate documents, or by other means, by the Technology Utilization Office of NASA. Materials, processes, products, management systems, and design techniques are among the topic areas in which aerospace research has led to significant contributions.

This document describes special uses of standard equipment, modifications and new designs, as well as film combinations that indicate actual or potential ecological problems. It is hoped that the information contained will not only be of general interest, but that the text will also suggest potential solutions to problems for society, the various governmental groups, and many fields of technology.

Director
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Preface

For more than a century, photography has given us a unique and significant record of historical events. Who would be so bold as to assess the value of the information that was recorded by Matthew Brady and his coworkers during the Civil War? When the National Aeronautics and Space Administration began space exploration, it was only natural that these events be recorded for future generations.

Certainly, most of the measurements and physical events could have been, and actually were, recorded by direct-sensing transducers and electronic-analysis equipment. A transducer is a device which, when applied to the surface of an object, measures its temperature, pressure, vibration, or any one of a number of physical parameters, and generates an electrical signal, the magnitude of which is related to the magnitude of the parameter being measured. But few, if any, of these methods communicate information for the scientist or the layman as effectively as photography.

Photographic recording uses the visible and invisible light energy of the environment to produce a signal which is recorded on a photographic emulsion or film. In many cases, such photographic records provide information not only directly but also more efficiently than any of the other information measuring and recording techniques. A piece of film gives a direct visual picture of the phenomenon to the scientific investigator for immediate examination and analysis, and techniques for automatically reducing photographic images to mathematical forms for computer input are now available.

By certain criteria, photography may be said to be the most widely used technique or technology in the space program. Six general areas of photographic applications are identifiable:

(1.) Pictorial photography is used both for providing a permanent documentary record and for detailed technical recording and measuring purposes. This covers the range of applications from the hand-held "tourist" photography of Astronaut Aldrin, through the technical resolution of the measurement detail from the same photographs, to the technical measurements of launch-vehicle tracking provided by tracking cameras and phototheodolites. It also includes various techniques of aerial photography in which pictures of both the Earth and lunar surfaces are identified and charted. The largest volume of actual photography is used in various phases of engineering photography for the recording and analysis of many phenomena in research and development.

(2.) Photography for research investigations includes special techniques for picture formation and manipulation, such as Schlieren and shadowgraphy, holography, photomicrography, and electron microscopy.

(3.) Photosensitive materials are used for the direct recording of energy of the various wavelength bands of the electromagnetic spectrum for such scientific and technical purposes as radiography, spectrography, diffraction studies, and similar laboratory applications.

(4.) Photography is used for direct recording of electronic signals, whether they be image forming or coded information data signals. This includes both direct recording of electron energy and the use of optical conversion through cathode-ray-tube reconstruction.

(5.) Through the techniques of microphotography, such as microfilming and its derivatives, photographic systems are the basis of modern document-storage, retrieval, and distribution systems.

(6.) Graphic arts techniques such as process camera work, photoengraving, and photo-offset printing have resulted from extensions of photographic systems. The most recent active growth in photography has been its application in the preparation of microelectronic devices.

The first application is historically known as photography. This survey stresses only those applications which fall within this category. It includes photographic systems and techniques that have been used by NASA and developed either directly by NASA, or through contracts with outside organizations. Many advances in the state of the art have been accomplished by industry under its own initiative to meet the needs of the space program.

In the development of photographic equipment, many new ideas and suggestions for new equipment are generated. While many would promote small improvements, at times there must be a rational engineering tradeoff for the sake of simplicity, uniform quality, flexibility, and the amount of time that is involved in interfacing a new technique or camera into the system. Therefore, there has been a great tendency to standardize certain well-proven photographic cameras and systems. This makes it possible to interchange cameras and camera parts, and increases economical backup capability. This survey is organized according to general applications. An attempt will be made to direct the reader's attention to the photographic systems used in each application. Since the films are generally common to several of the applications, their characteristics are discussed in a separate chapter.

In chapter I, NASA-sponsored advances in hand-held photography for lunar exploration are described. The task of providing the astronauts with effective tools to document scenes that man would be seeing for the first time led to the development of a fully automatic hand-held camera system with high reliability. It also led to the development of a unique technique for photogrammetric data analysis from hand-held photography, a significant achievement.

Chapter II reviews the use of cameras mounted in spacecraft and aircraft for direct recording of the Earth, the Moon, and other astronomical phenomena. Chapter III discusses one segment of engineering photography as applied to space-vehicle launch operation. Chapter IV surveys the application of engineering photography to a diversity of research programs and demonstrates the flexibility of photographic systems for the recording and display of technical information.

In chapter V a brief discussion of multispectral photography as a technical tool is presented, and chapter VI reviews photographic Earth resources investigations. At the Kennedy Space Center, the author found that:

> The Photographic Branch Staff is of the opinion that the most significant photographic technological event will be realized in the utilization of multispectral space photography once a camera platform for that purpose is established in space. The Skylab program will permit opportunity for preliminary research for this utilization. The benefits to be derived from this utilization are far-reaching and will impact all mankind.

A survey of film characteristics and the typical films used in NASA operations is given in chapter VII. This is followed by some notes on special film-handling techniques in chapter VIII.

Acknowledgments

Photography is so widely used in NASA programs that the author received helpful suggestions and information from many more persons than can be listed. Specialists in airborne science, optics, data control, Earth observations, camera repairs, propulsion research, and various other fields provided much of the information summarized in this survey.

Technology Utilization Officers at NASA Headquarters and their colleagues at Ames Research Center, Goddard Space Flight Center, John F. Kennedy Space Center, Langley Research Center, Lewis Research Center, and Manned Spacecraft Center were extremely helpful. So, too, were the chiefs and staffs of the photographic technology divisions and branches at those NASA centers, and representatives of companies assisting those centers contractually. Helpful contacts also were made with personnel of the Smithsonian Institution, Paillard, Inc., GAF Corp., and Eastman Kodak Co., in the course of the survey.

Review consultants were Professors William Shoemaker, Hollis M. Todd, and Albert D. Rickmers of the Rochester Institute of Technology School of Photographic Arts and Sciences.

Contents

Hand-Held Systems

When the United States was about to send some of its most adventurous citizens on journeys that man had never before taken, it was evident that these adventurers should be given the necessary equipment to make a clear pictorial photographic record of what they saw—a record unmarred by the vagaries of memory and not confused by the many essential technical facts and functions important to the safe operation of spacecraft.

The concept of taking photographs as a permanent record from space is a silent tribute to the pioneers of a century before who (on October 13, 1860) had taken photographs from a height which, at that time, men had seldom achieved—1200 feet in a balloon (fig. 1).

Photography was not given high priority in the first two suborbital flights of American astronauts because it was essential that they concentrate on operating the spacecraft. It was not until Mercury-Atlas 6, when John Glenn made the first orbital flight, that a hand-held camera was included in the spacecraft equipment. The camera was the commercially available 35-mm Ansco Autoset (fig. 2).

All commercially available cameras present operating problems for an astronaut. His heavy gloves do not allow him to use the hand controls normally designed for such a camera. In addition, viewfinders on commercial cameras are designed to be placed next to the operator's eye. In fact, many viewfinders are difficult for people wearing ordinary glasses to use. In the environment within the early spacecraft, the astronaut was required to take pictures without removing his helmet. The camera, therefore, was equipped with a new viewfinder that made it possible for the astronaut to work with his eye farther from the camera than is normal for conventional photography. The camera was fitted by its manufacturer with a pistol grip and an oversized film advance. Fortunately, this camera was fully automatic so there was no need to adjust shutter speed or lens-diaphragm setting.

It was recognized that there would be a need to duplicate the photographs acquired and also to accommodate the high dynamic

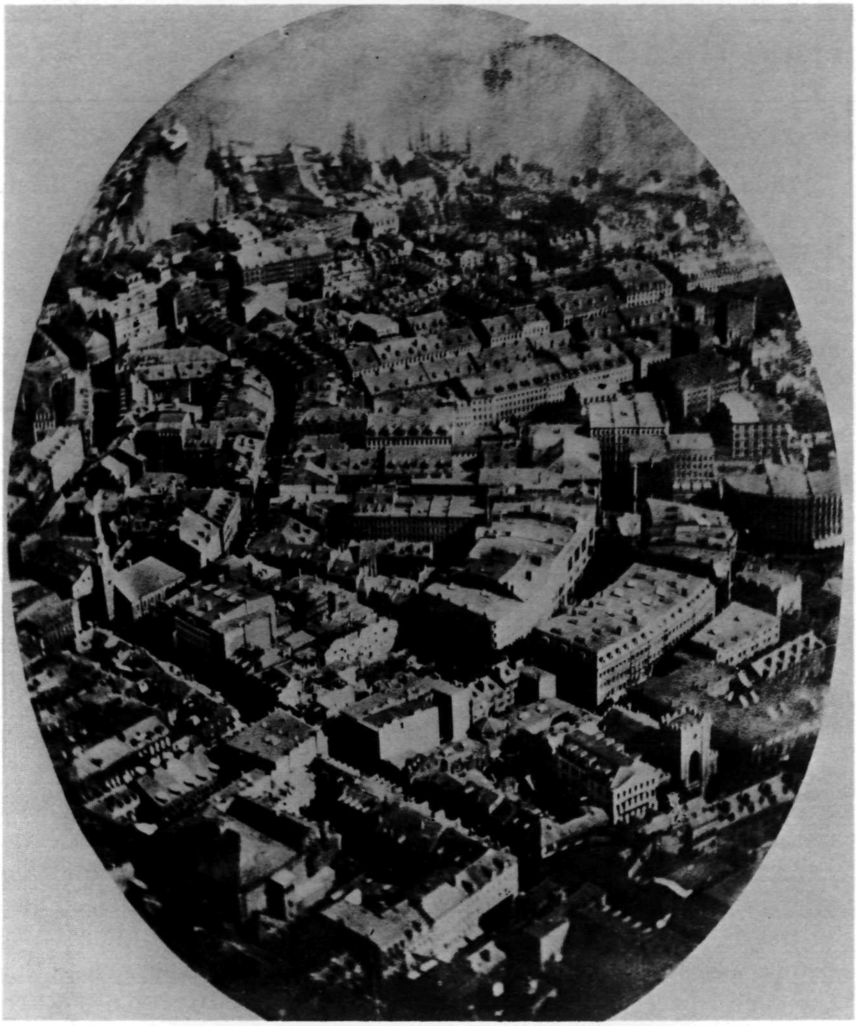

FIGURE 1.—This picture was taken from a balloon October 13, 1860, by C. W. Black, while 1,200 feet above the waterfront area in downtown Boston. (Courtesy of GAF Corp.)

range of scene luminance ratios that would be encountered in the outer atmosphere. Scene luminance range is the ratio of the light level that comes from the bright areas of a scene to that from the shadows. On an overcast day, the general scattering of light adds light to shadows and increases their luminance level; at the same time, it decreases the maximum light level of the bright areas, thus the range is reduced. In the outer atmosphere, and on the lunar surface, there is no light scattering to reduce the total scene

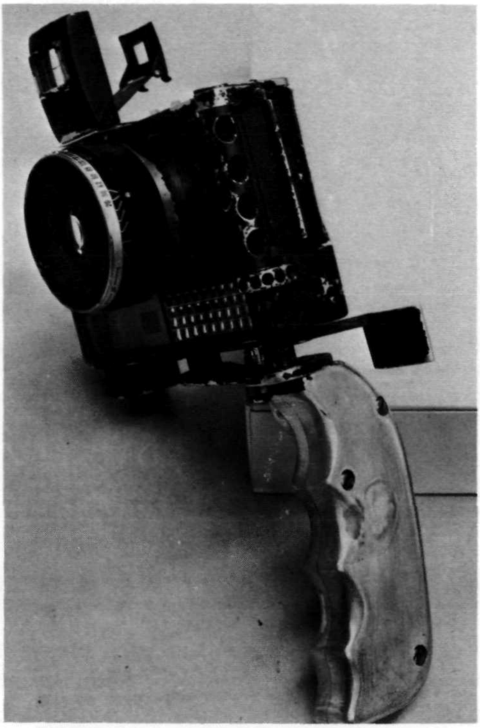

FIGURE 2.—The first hand-held camera taken into space was this modified commercial 35-mm camera used by John Glenn on the Mercury-Atlas 6 flight. It required only film advance by the astronaut.

luminance. It was anticipated, therefore, that a wide range of light levels might be encountered. The film selected for the first mission to include photographic experiments was a color negative film which provides maximum accommodation of the dynamic range, and is also an effective means for duplicating the pictures with reasonable retention of image quality. The result of this selection is illustrated by the picture which was taken by Astronaut John Glenn. (Color Plate 1(*a*)).

For the next flight, Mercury-Atlas 7, the decision was made to continue using a 35-mm camera. A Robot Recorder with well-developed automatic film advance features had been modified for easier use by the astronauts working in their spacesuits. This Robot camera was also used on the Mercury-Atlas 9 flight, where it was modified for dim-light photographic experiments to investigate the zodiacal light and the night airglow. The camera (fig. 3) had a fixed lens with a large aperture (*f*/0.95) to provide maximum efficiency in recording low-light phenomena. Exposures were timed manually. Three small supports or "feet" were provided to aid the pilot in positioning the camera against the window for aiming.

FIGURE 3.—A modified Robot Recorder was used on the Mercury-Atlas 9 flight by Gordon Cooper for experiments in dim-light photography.

A significant contribution to space photography was made during the Mercury-Atlas 8 flight. It was recognized that the optics of modern high-performance photographic systems for hand-held photography are essentially film limited in their capability; that is, the amount of information that can be recorded is determined by the ultimate performance of the film rather than by the lens. Thus, improvement in total information content within the capability of the camera mechanics may be achieved by simply increasing the size of the film used to record the image. It was also realized that a high-quality system for space photography should have interchangeable lenses to produce the optimum size image within the film-size format. It should also have interchangeable magazines to permit the choice of color films or black-and-white films and of several sensitivity levels in either film without requiring additional camera bodies and lenses. Basically, a camera body that could accommodate interchangeable lenses on the front and interchangeable magazines on the rear was needed. Such a system was commercially available in the Hasselblad camera. Early modifications were made by NASA technicians to insure ease of operation by a gloved astronaut (ref. 1).

The Hasselblad is basically a single-lens reflex camera. The reflex mirror arrangements were removed, however, since they could not be conveniently used in the spacecraft. They were replaced by a straight eye-level finder with a suitable base length, so that an astronaut could use it while wearing his spacesuit helmet.

The modifications by NASA technicians for ease of operation were further improved by the manufacturer of the camera and incorporated in new models. The commercially available magazines for the camera were designed to accommodate 12 exposures on roll film. Realizing that the bulk and weight of the backing paper are detrimental to the efficient operation of the camera system, a NASA contractor modified one of these magazines to accommodate 70-mm film (figs. 4 and 5). The camera manufacturer, having started on the development of a suitable magazine for 70-mm film, put additional emphasis on the program to make the magazine available in time for the space explorations. The commercial 70-mm magazine was designed to take approximately 18 feet of film, permitting 70 exposures on the 70-mm film that was then available. In the earlier magazines NASA had demonstrated the advantages of obtaining a large number of exposures on a relatively small volume of film and thus stimulated photographic manufacturers to expand development of thin polyester base for application to conventional color emulsions. By using this thin-based film with a magazine film gate modified to accommodate it, and eliminating the cartridge used in the commercial version, the same magazine could hold 38 to 42 feet of film for approximately 200 exposures. The first modified camera (fig. 6) had an auxiliary hand crank that was used for rapid film advance by a gloved hand. An electric advance system was used on later models (fig. 7) to allow an increased number of exposures without taking valuable time from the astronaut's other duties. Thus, NASA was shaping the system of the future for hand-held photography for its lunar exploration mission. Meanwhile, other considerations dictated additional developments for the hand-held photographic system.

The 6- x 6-cm format with general-purpose lenses was rather limited in its available angles of view. A model known as the "superwide" (fig. 8) was investigated and was found to give more satisfactory results. The superwide model was used with the hand advance, but a parallax-free viewfinder was designed for framing by the astronauts through their spacesuit helmets. The superwide gave a broad angle of view to pictures taken on orbital flights (Color Plate 2), maximizing the amount of picture coverage and minimizing errors of pointing. It was also more suitable for pictures taken inside small spacecraft.

Many significant developments were associated with making the camera convenient and easy to handle by astronauts in their various spacesuits and under space conditions. Typical of these

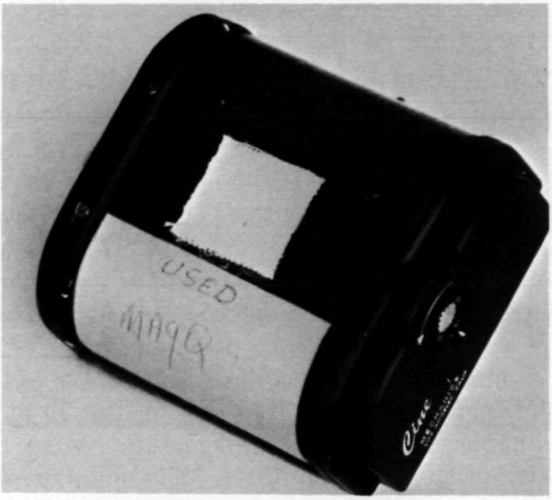

FIGURE 4.—This basic 70-mm magazine was developed under contract by Cine Mechanics for NASA for use with the Hasselblad camera. The magazine is shown as originally intended for the Mercury Program with a patch of Velcro for holding the dark slide. (Magazine Courtesy of Smithsonian Institution)

FIGURE 5.—A variation of the device shown in figure 4 was developed for the Gemini program, with a plate attached for storing the magazines. After experimenting with a silver finish, the decision was made to continue with a black finish until the lunar landing.

FIGURE 6.—The first version of the Hasselblad camera, as modified by NASA for use in the Mercury Program. The body is shown without lens and magazine. The magazine used is that of figure 4. (Camera courtesy Smithsonian Institution.)

FIGURE 7.—The improved, modified electric Hasselblad was developed by the manufacturer under the stimulation of the space program and is now available for commercial and industrial applications. (Paillard, Inc.)

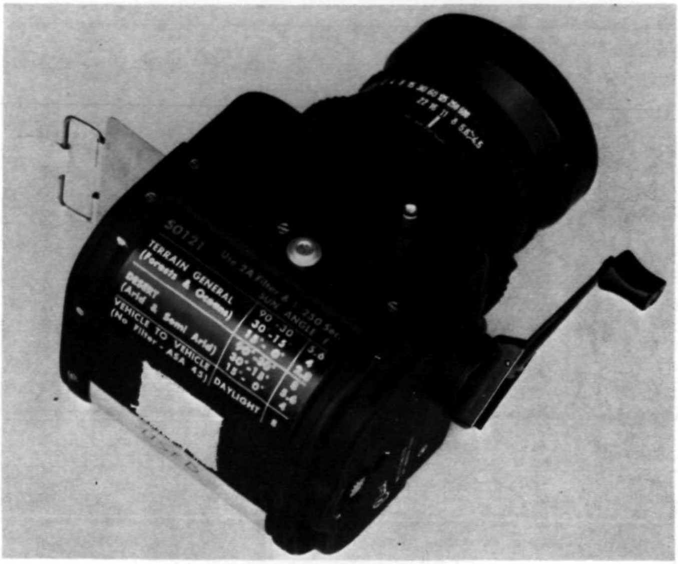

FIGURE 8.—The Hasselblad superwide camera was utilized in Gemini missions GT–9 through –12 to permit photography of broad areas of the Earth's surface with minimum effort. A later version had a Wireframe Viewfinder and improved shutter-release actuator. (Camera courtesy of Smithsonian Institution.)

developments was the chest pack used to support the Lunar Data Camera in operating position on an astronaut's chest while he worked on the lunar surface. An initial application of this principle took place on Gemini-Titan IV, when Edward H. White III was the first man to work outside the vehicle in space. The camera was incorporated as part of the extravehicular propulsion unit (fig. 9). A stock Contarex 35-mm camera, modified for White's operation with his suit and helmet, was used. It was incorporated as part of the propulsion unit for convenience, ease of use, and maximum safety.

A general program was initiated after the disastrous Apollo fire to insure high reliability and maximum safety in all spacecraft equipment. Electrically driven cameras were required to be capable of operating in a high oxygen environment without any significant danger of fire or explosion. To meet these standards, the camera system components were redesigned. Hermetically sealed switches were selected to minimize heat generated in the various components. Much attention was also paid to reliability of the system for continuous duty over a long period of time to insure a low probability of failure.

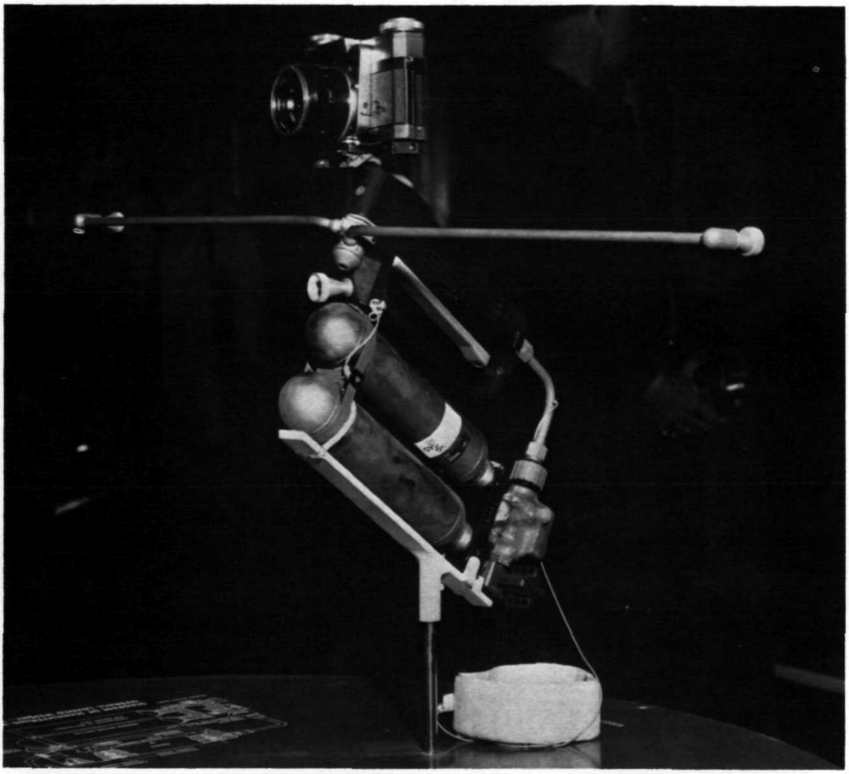

FIGURE 9.—The camera used by Edward H. White II on the Gemini IV mission, where he became the first man to work outside a vehicle in space, is shown here on the extravehicular propulsion unit. (Smithsonian Institution.)

Some of the parameters for the lunar exploration camera are given in reference 2. A hand-held lunar photographic system would be required to meet the following environmental criteria: (1) an acceleration up to ± 20 G's for 3 minutes in any direction; (2) a shock of 30 G's for a period of 11 milliseconds; (3) air pressure variations from sea level to less than 10^{-10} millimeter of mercury; (4) a temperature range from $-186°$ centigrade to $+114°$ centigrade; (5) solar flare radiation of 600 rads; and (6) the possibility of 100 percent relative humidity, including condensation for 5 days in a temperature range of 80° to 160° F.

Looking forward to the lunar landing, NASA technicians investigated methods of optimizing the information to be recovered from pictures which would be taken by hand-held systems. Richard Thompson and others developed a technique for orthoscopic rectification or geometrical correction of the two-dimensional scene, provided that the image fields were flat with sufficient accuracy. The Zeiss 60-mm Distagon lens had such capability. Under the stimulation of Thompson's technique, this lens was redesigned to accommodate a glass plate with fiducial marks (small hairline crosses) which is known as a reseau plate (fig. 10). This technique provides accurate locations in the film plane from which information about distances in the lunar scenes can be derived by means of calibration of the plate. The camera system, with the reseau plate installed, is known as the Lunar Data Camera (fig. 11). The calibration of the Lunar Data Camera system for photogrammetric purposes is detailed in reference 3.

The still photographs taken by the astronauts making the early lunar-surface excursions yielded additional scientific data because of the metric feature of the lunar-data camera with the glass reseau plate. The film format is small in comparison to the usual photogrammetric system, and compromises have been made to maintain lens 'focusing and interchangeability. However, the camera has many advantages over other cameras for lunar-surface photography, particularly in its ability to be hand held. Many potential applications of this technology outside the space

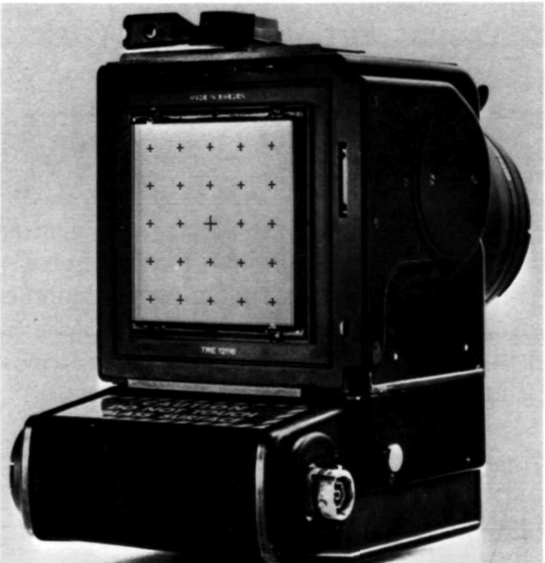

FIGURE 10.—A photograph of the Lunar Data Camera showing the reseau grid plate at the focal plane of the camera body. (Paillard, Inc.)

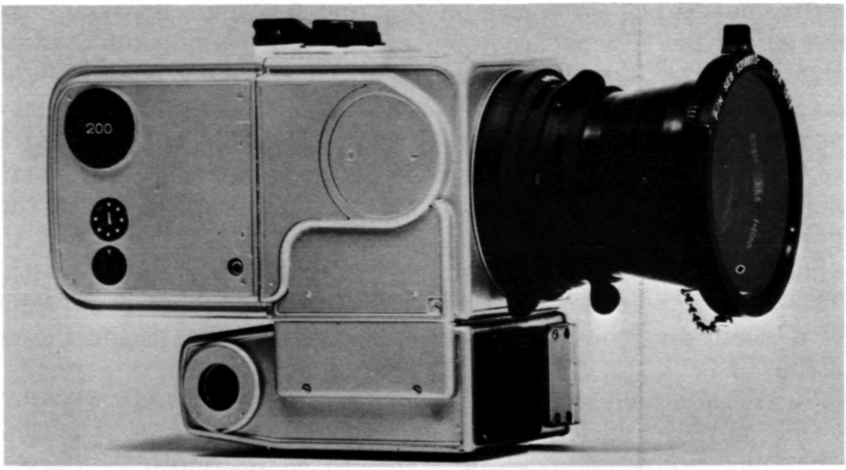

FIGURE 11.—A completely assembled Lunar Data Camera. Note particularly the silvered surfaces, a contrast to the all-black surface formerly used. The silver is intended to reflect radiation and heat energy, thus minimizing temperature variations within the camera and obviating the necessity for expensive control equipment. (Paillard, Inc.)

program should be anticipated. This camera system has the advantage of small size and moderate price, along with the necessary flexibility of film, lenses, and filters. A group of cameras can be combined easily for multispectral investigations (chap. V) to provide more precise scene measurement. A configuration of these cameras is small enough for easy handling and installation. A two-camera arrangement could easily be used as a stereometric system for accurate three-dimensional measurements of objects at close range. Its use in earthbound colorimetric analysis and experimental investigation is also indicated. The development of a wide spectral range lens, which was investigated as a possibility to be used on the lunar data camera, is discussed in reference 4.

All of the early cameras were painted completely black to minimize disturbances caused by the reflection of polished surfaces in the high solar intensity of outer space. The only exception to this rule is the Lunar Data Camera, which was painted matte silver to minimize the absorption of thermal radiation and to assist in maintaining a reasonably constant temperature environment within the camera.

One of the most unusual hand-held cameras specifically designed for the space program was the stereoscopic camera cane, officially designated the Apollo Lunar Surface Close-up Camera (ALSCC) (ref. 5). It was designed to record lunar-surface microstructure in its undisturbed state. The photographs provide scientific information on the size and cohesion of particles making up the undisturbed and freshly disturbed lunar surface. This camera provides closeup photography in stereo pairs. The image is approximately one-third the actual size of the object. Designed to be operated through the telescoping handle by an astronaut wearing a pressure suit and standing erect, the camera gives the impression of a cane camera. The exposed film is contained in a cassette, which is the only portion of the unit returned to Earth. This is the one camera for lunar-surface use which carries its own electronic flash-unit illuminating system. (See Color Plates 3 and 4.)

Representative hand-held and vehicle equipment (chap. II) that was used in the various missions is listed in table 1.

Among future applications of hand-held photographic instruments is the photographic sextant (ref. 6). The sextant is a navigational instrument that measures the angle above the horizon of a known star or the sun's limb on Earth, or the angle from a planetary body to a stellar reference for measuring a planet's subtense in space navigation. A sextant is a visual viewing and measuring instrument. The development of a photographic recording sextant suitable for use through the small windows of a spacecraft that would produce records for positive target star identification has been suggested. Techniques for immediate development of the film are expected to be similar to those used for unmanned vehicles where film is processed on board.

In addition to hand-held systems for space photography by the astronauts, a large volume of hand-held photography is utilized at all the NASA centers. The equipment used for such photography is straightforward. The standard Hasselblad has been widely used because of its versatility.

Typical of the significant applications are those performed at Kennedy Space Center in conjunction with the launch program. In these activities, photographic technicians work closely with the engineering people, documenting each item of work for review purposes in case of a critical malfunction. For example, before each connector is attached to the launch vehicle or the space capsule from the umbilical tower, a photograph is made of the connector and its receptacle. Another photograph is made immediately after it is connected. Every physical operation of this type is recorded as part of the engineering photographic program. Other photographs are even made of camera installations, particularly those that are remotely operated, to insure that a record exists of the installation prior to the event which it is to photograph.

Other hand-held photography utilized for public affairs purposes generally relies on acceptable techniques used by the professional and industrial photographic community. The films used in these operations are also the types used in projects described in the other chapters.

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

(a) Mercury Program

	Vehicle cameras 16 mm						Hand-held cameras		
Mission, date, and astronauts	Milliken DBM-4	Milliken DBM-7 instrument observation	Milliken DBM-8 pilot observer	Milliken DBM-8 periscope	Maurer 220G Earth and sky	McDonnell pilot observer	Robot 35 modified	Ansco Autoset 35 modified	Hasselblad 500C modified
MA-1; 7/29/60; unmanned	2-BW	----------	----------	----------	----------	----------	----------	----------	----------
MR-1A; 12/20/60; unmanned	----------	BW	----------	----------	BW	----------	----------	----------	----------
MR-2; 1/31/61; unmanned (Ham)	----------	BW	BW	----------	CR	----------	----------	----------	----------
MA-2; 2/21/61; unmanned	----------	----------	----------	----------	CR	----------	----------	----------	----------
MA-3; 4/25/61; unmanned	----------	BW	----------	CR	CR	----------	----------	----------	----------
MR-4; 5/5/61; Shepard	----------	BW	CR	----------	CR	----------	CR	----------	----------
MR-4; 7/21/61; Grissom	----------	CR	CR	----------	----------	----------	----------	----------	----------
MA-4; 9/13/61; unmanned	----------	BW	----------	CR	CR	----------	----------	----------	----------
MA-5; 11/29/61; unmanned (Enos)	----------	BW	CR	CR	CR	----------	----------	----------	----------

MA–6; 2/20/62; Glenn	----------	BW	CR	----------	----------	----------	----------	----------	----------
MA–7; 5/24/62; Carpenter	----------	----------	CR	----------	----------	----------	----------	CN	----------
MA–8; 10/3/62; Schirra	----------	----------	CR	----------	----------	----------	----------	----------	CR
MA–9; 5/16/63; Cooper	----------	----------	----------	----------	----------	BW/CR	----------	----------	M
GT–I; 4/18/64; unmanned		----------	----------	----------	----------	----------	----------	----------	----------
GT–II; 1/19/65; unmanned		3–BW	CR	----------	----------	----------	----------	----------	----------
GT–III; 3/24/65; Grissom and Young		----------	----------	----------	----------	CR	----------	CR	----------
GT–IV; 6/3/65; McDivitt and White		----------	CR	----------	----------	CR	CR	----------	----------
GT–V; 8/21–29/65; Cooper and Conrad		----------	CR	----------	----------	CR	CR/CIR	----------	----------
GT–VI–A; 12/14–16/65; Schirra and Stafford (GT–VI was unmanned)		----------	----------	2CR	----------	M	----------	----------	----------

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

Mission, date, and astronauts	Vehicle cameras				Hand-held cameras			
	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.

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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-

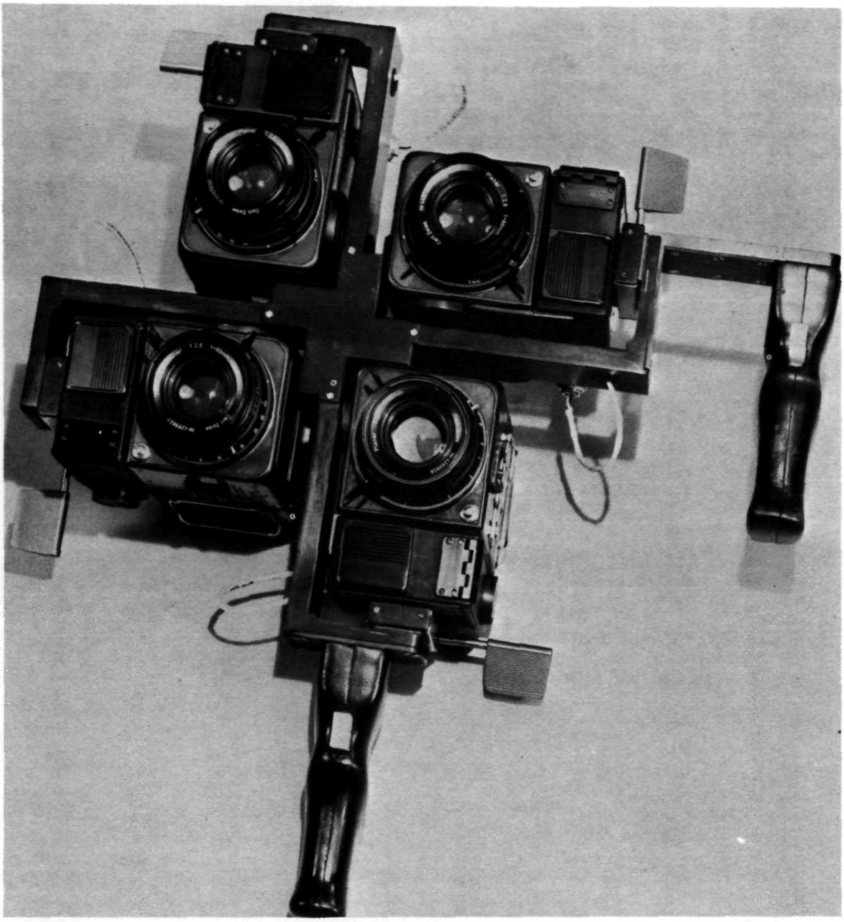

FIGURE 12.—An assembly of four Hasselblad EL 500 cameras, as modified for space missions, was used for multispectral photography. Each camera is equipped with a filter and black-and-white film recording the information of a single spectral band, or one of the cameras may be equipped with color film to 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

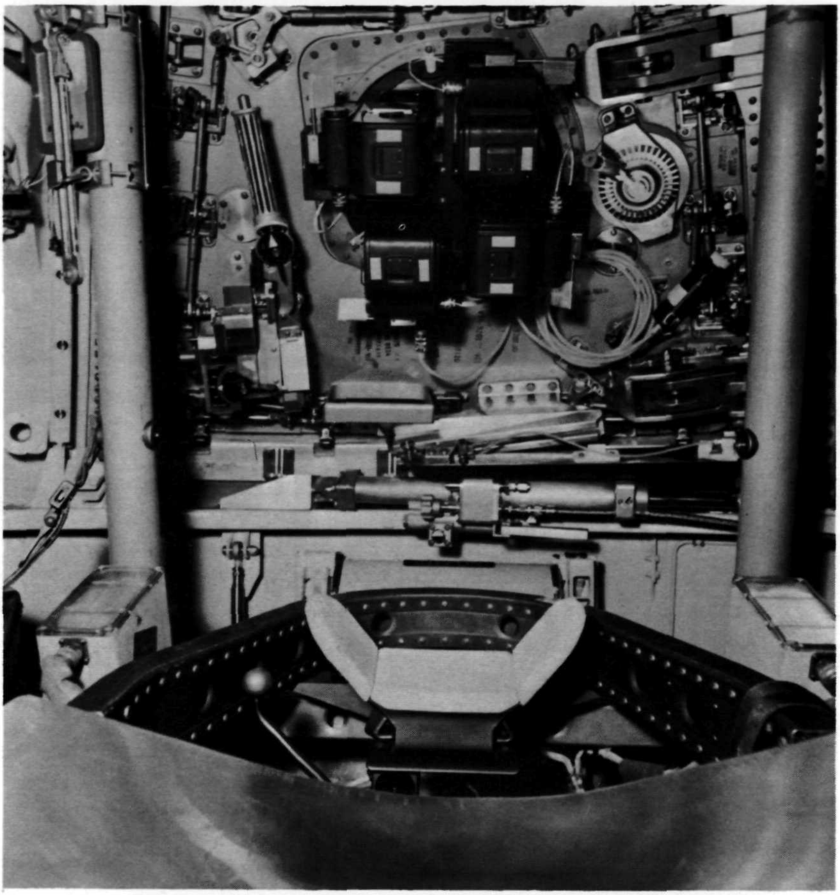

FIGURE 13.—This picture shows the installation of the four-camera multispectral assembly on a port in the Apollo spacecraft. To the center right is a stowed extension release to enable astronauts to operate a camera from several positions within their spacecraft.

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

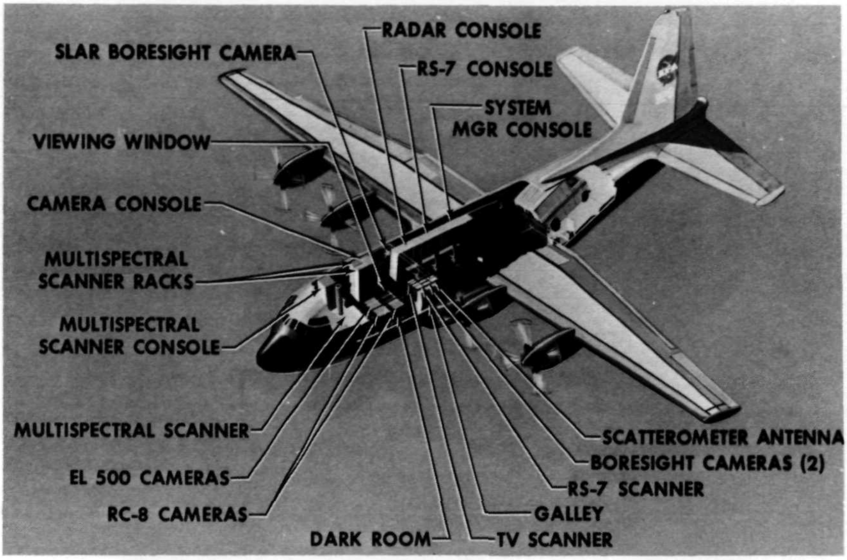

FIGURE 16.—A typical camera and sensor installation on the aircraft used in the Earth Resources Observation Program is shown in this cutaway view of the NC 130B flying camera platform.

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-

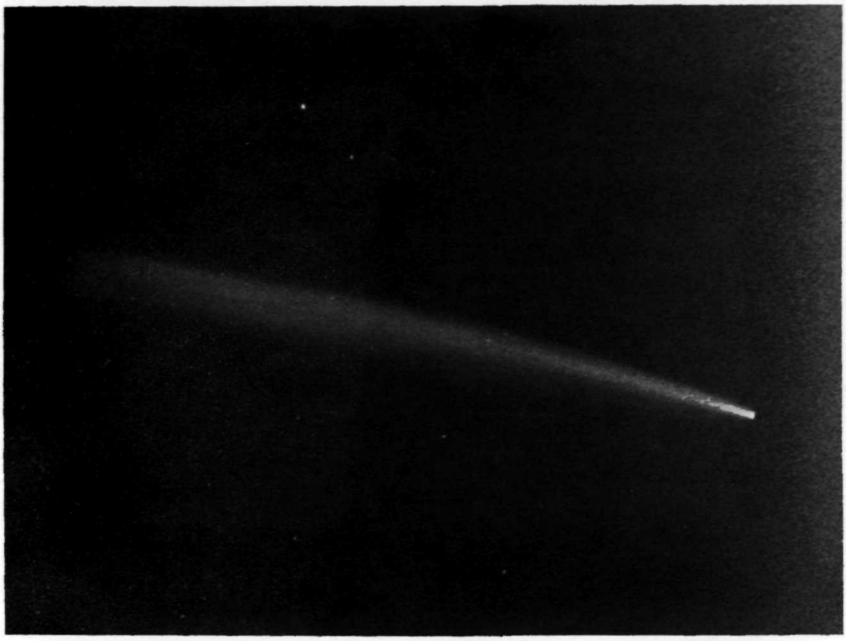

FIGURE 17.—View of the comet Ikeya-Seki taken in 1965 by R. Innes of the University of California at Berkeley in cooperation with Louis Haughney of Ames Research Center as part of the Airborne Science Program. This picture was taken from high altitude with the Convair 990 "Galileo" instrumentation and 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 $\pm 10\%$.

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

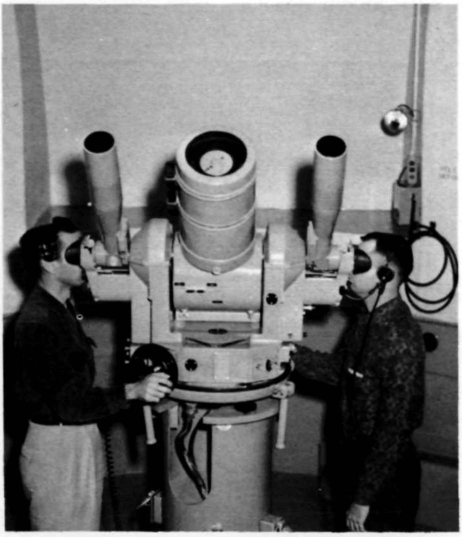

FIGURE 21.—This photograph was taken at the Air Force Eastern Test Range which has responsibility for tracking the vehicles after they leave the launch complexes at Cape Kennedy Air Force Station and Kennedy Space Center. It shows a cinetheodolite which, in addition to tracking the vehicle, records on 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.

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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

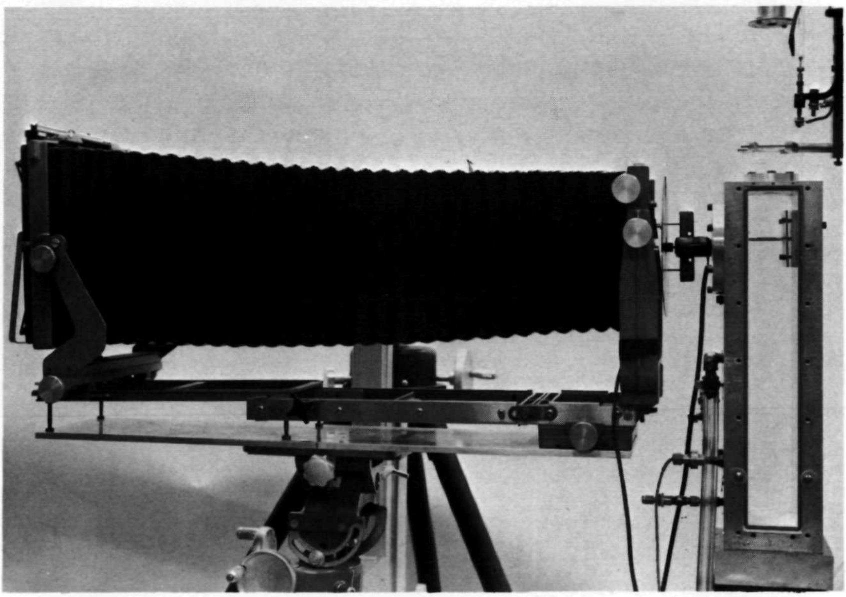


FIGURE 22.—An 8 × 10 view camera set up for the burning droplet experiment. It is set at inverted conjugate; that is, the lens is closer to the object than to the film. The rotating disk shutter seen in front of the lens permits a sequence of photographs at equal time intervals as the drop falls.

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

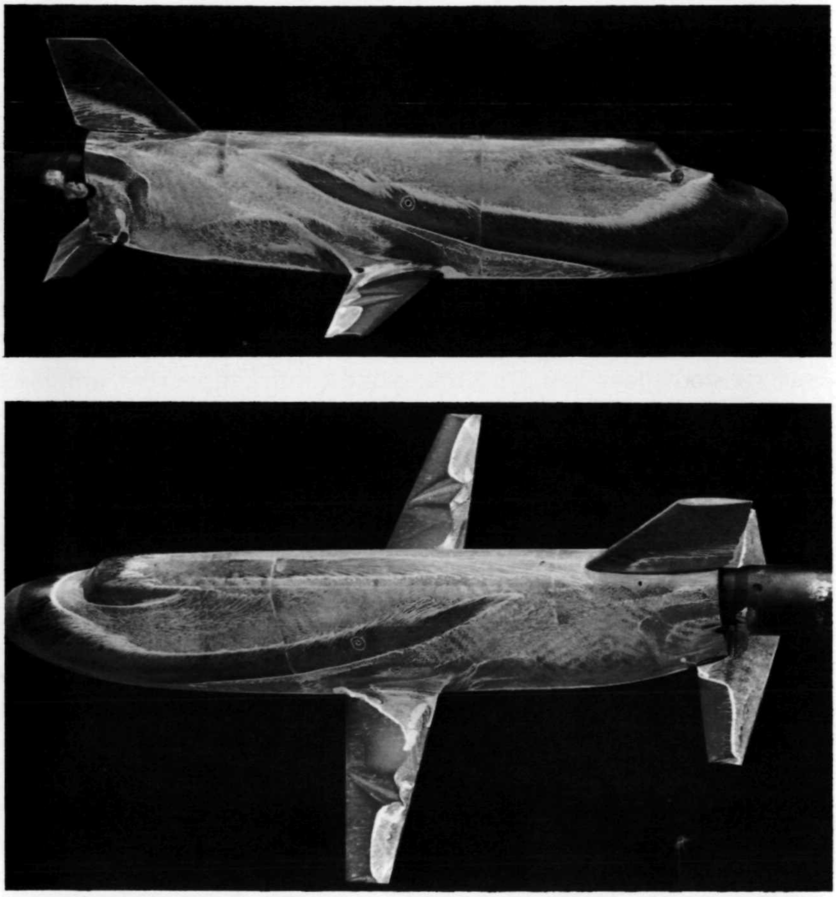


FIGURE 23.—These photographs show opposite sides of a flight model with surface air patterns visualized by the use of oil-flow techniques. The viscous oil visible in pictures retains its position on cooling, allowing the detailed photographs to be made after the air flow has been terminated.

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.

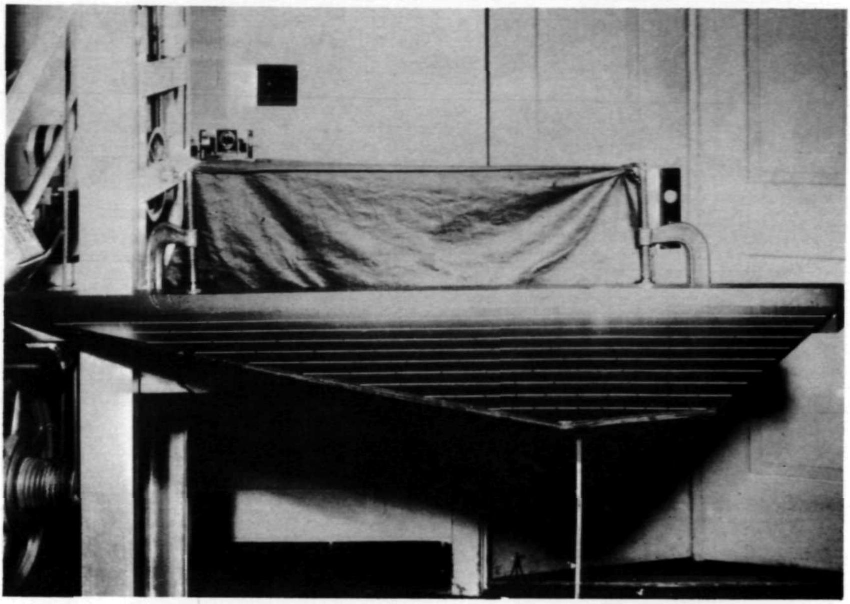
In wind-tunnel work at Lewis Research Center, automatic quantitative measurements of the manometer assembly are made by photography. A manometer board consists of a set of 20 or 40 manometers, i.e., liquid-filled tubes for measuring pressures, each manometer measuring the pressure at some point in the 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, cameras, in this case mostly K–22 aerial cameras, are set up to give a remotely actuated, precision record of the manometer board. These photographs and their time records provide the accurate data needed to analyze the behavior of the wind tunnel (fig. 26).

As an example of a recording of dynamic events by a data camera, figure 27 shows a fairing nose-cone deployment test photographed with a 70-mm, 30-frame-per-second, externally triggered data camera. The test was recorded at Goddard Space Flight Center. Similar tests are made at Lewis Research Center.

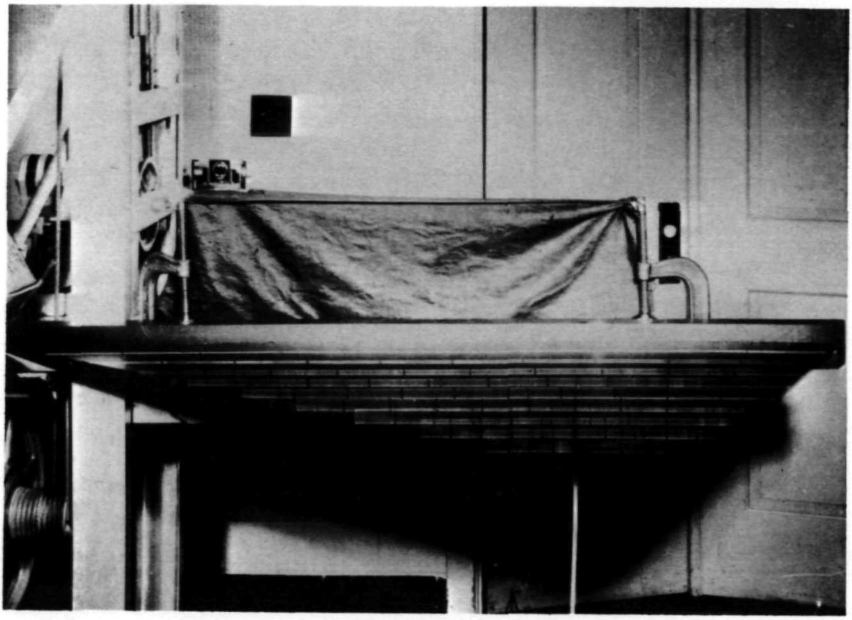
At Langley Research Center one analysis involved studying the dynamic action of a helicopter rotor blade by mounting a motion-picture camera on the rotor shaft facing in the direction of the blade. The power and controls of the camera were arranged through slipring commutators, so the camera recorded the dynamic motion of the blade independent of the background, which became smeared as the camera rotated with the blade.

Some excellent stroboscopic photography, which we have rigidly defined as using motion pictures to obtain a static or very slow moving reproduction of a cyclic event, has resulted from efforts of the staff at Lewis Research Center. Work on pump inducers and impellers is conducted in the test facility shown in figure 28. In this facility, high-speed stroboscopic photography is used to study the behavior of fluid flow around the pump blades and pump impellers. Studies are made of cavitation with the development of turbulence-generated foaming or bubbling. The close range from which a pump blade is typically photographed for a cavitation study is indicated by figure 29. The insert in the figure is an enlargement from a single frame. Figure 30, which shows a pump inducer at rest before fluid motion is imparted, demonstrates further the type of test assembly which must be photographed. Figure 31 is the arrangement of the 16-mm motion-picture camera which was specially modified to synchronize the illuminating electronic discharge lamp with the camera shutter A photograph recovered from the 16-mm individual frames in figure 32 shows the initiation of the cavitation at the impeller edge with increase in speed. Figure 33 shows the more extended development of turbulence at higher speed.

Figure 34 is a high-speed photograph taken axially and showing the travel of the developed cavitation from the pump rotor. The numbers observable in figures 32 and 33 are records of the frame number generated while the photographs were taken for subsequent engineering analysis. This technique is one of many that



a



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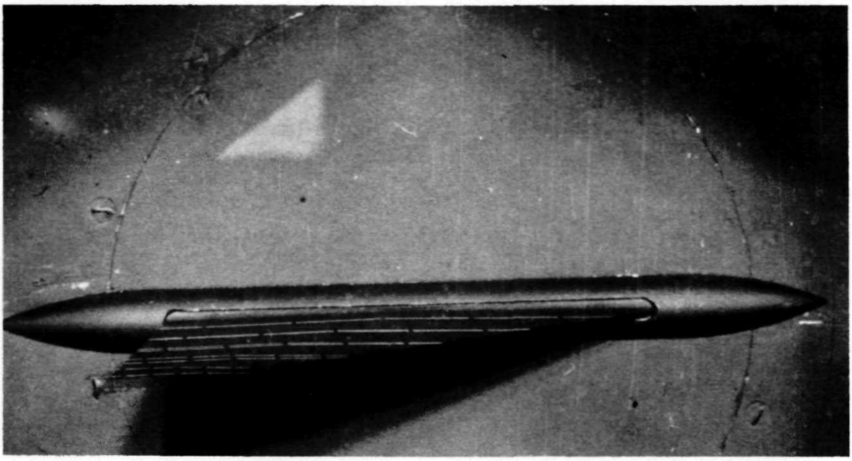


c

FIGURE 24.—The mode-shape analysis technique shown in these photographs is based on work done by Robert W. Herr of the Vibration and Flutter Section, Langley Research Center. It utilizes the photographic double-image and time-exposure methods to record amplitudes of oscillating subjects such as vibrations, mode shapes, static deflections, etc.

The subject is prepared by first painting it black, then scribing it with white lines, as in (*a*).

To obtain a negative of a vibrating subject, a time exposure is made which produces a "smear" image with the lines registering most heavily while at rest at the extremes of the stroke (*b*).

To record a study of static deflections a double exposure is made as shown in (*c*). The first exposure registers the white lines at the beginning of the deflection stroke (zero position) and the second exposure registers the lines when the subject is fully deflected. Each line on the subject then appears as two lines on the negative from which the measurements are taken.

The negatives are then placed in a reader and measurements taken at the points of interest. This information appears in typewritten and punched-card form. If desired, the punched cards can be further processed to furnish the information in tabular or graph form.

can be used for incorporating engineering data directly into the photographic frame with a record of the event.

Another technique used for engineering analysis is shown in figure 35, used for evaluation of the vibration pattern of the antenna boom of the Radio Astronomy Explorer satellite. This technique is very effective and, from an engineering measurement viewpoint, is one of the simplest. Very small light bulbs were placed at the end of the boom and a simple open shutter on the camera. As soon as the vibration of this boom was started, the camera shutter was opened and the light acted like a pencil,

FIGURE 25.—The line of demarcation in the photographic tone between the area of apparent matte finish and glossy finish represents a contour of constant temperature. The model is in a wind tunnel, and the variation of the line with time provides an engineering analysis of the rate at which thermal effects occur across the surface of the model.

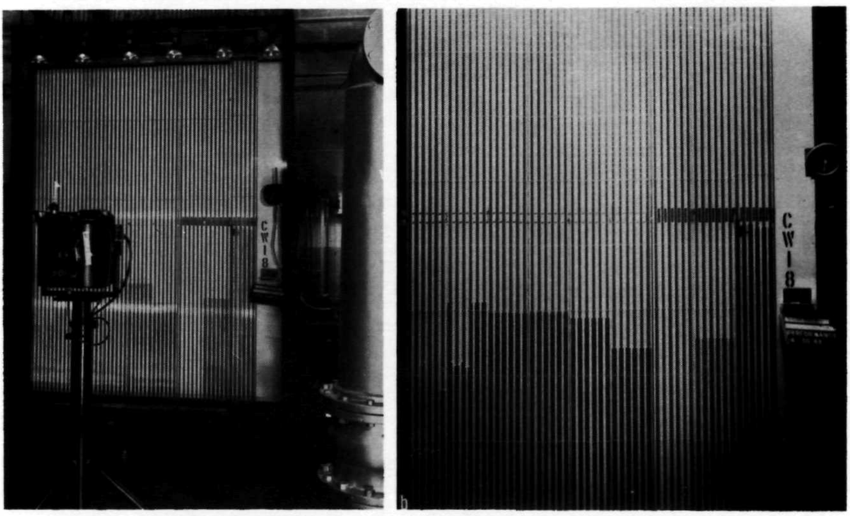
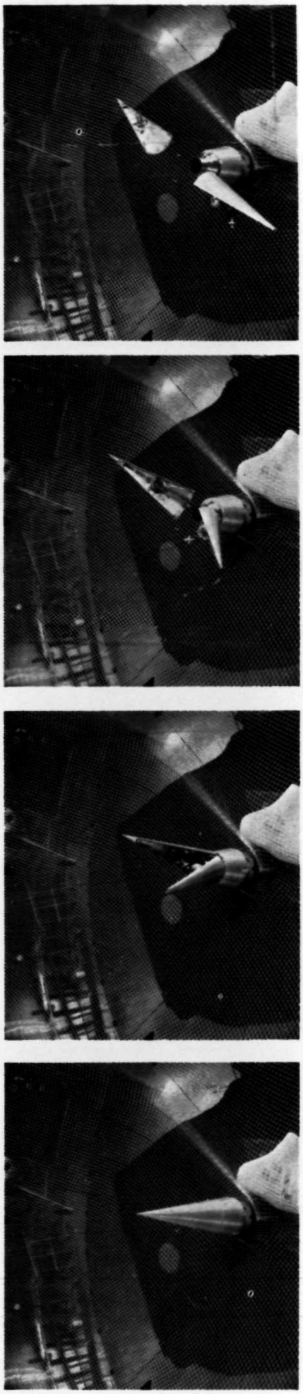


FIGURE 26.—These photographs of a manometer assembly demonstrate how photography may be used for instantaneous reading of a large number of recordings from devices of the direct, physical indication type. The manometers, individual U-tubes, are filled with liquid, the nature of which varies with the level of pressure to be measured. The manometers shown here indicate pressure levels at various points in a wind-tunnel test system. The camera assembly using a K–24 5-inch aerial camera with automatic advance is seen in (*a*) and (*b*) is a typical record made with this test arrangement.



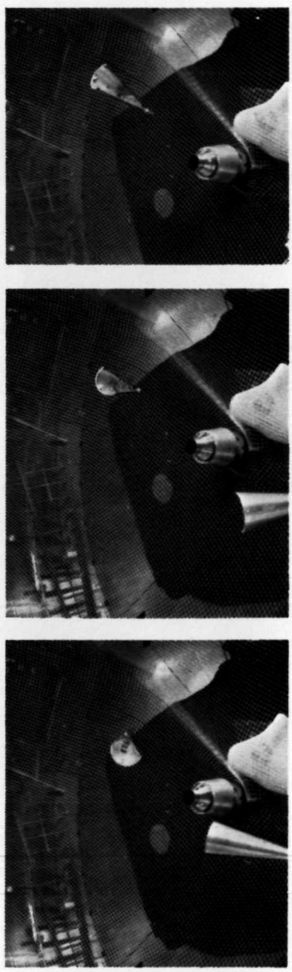


FIGURE 27.—The deployment of a nose-cone fairing taken with an automatic 70-mm data camera at 1/30-sec intervals. Pictures are printed from the filmstrip and read from left to right.

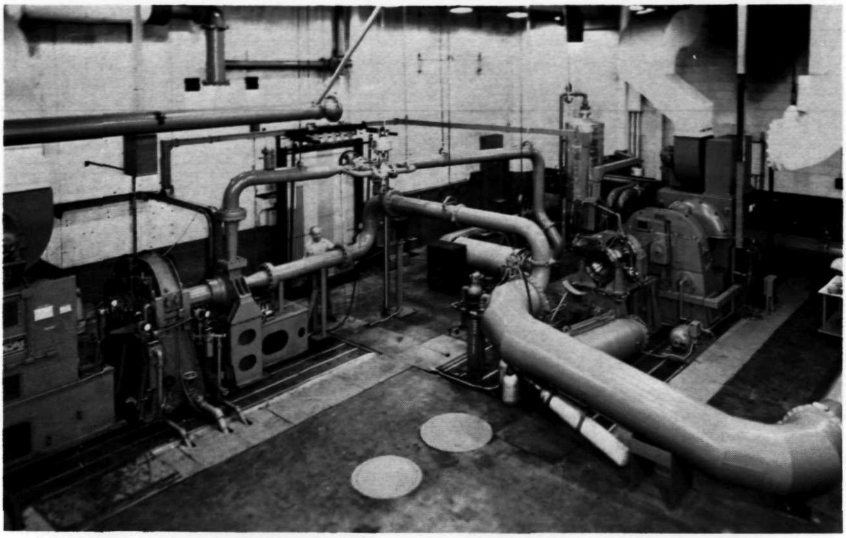


FIGURE 28.—A test facility at Lewis Research Center on which high-speed evaluations of pump inducers and impellers are made through stroboscopic techniques, which appear to slow down the action of the events that occur.

FIGURE 29.—In the test segment of the facility, a clear glass or plastic cylinder is used to inspect behavior at high speeds. This picture shows the test section and the lighting and camera arrangement. The inset shows a single frame of the motion pictures which give apparent still pictures of the pump blades, even when the blades are moving at very high speeds.

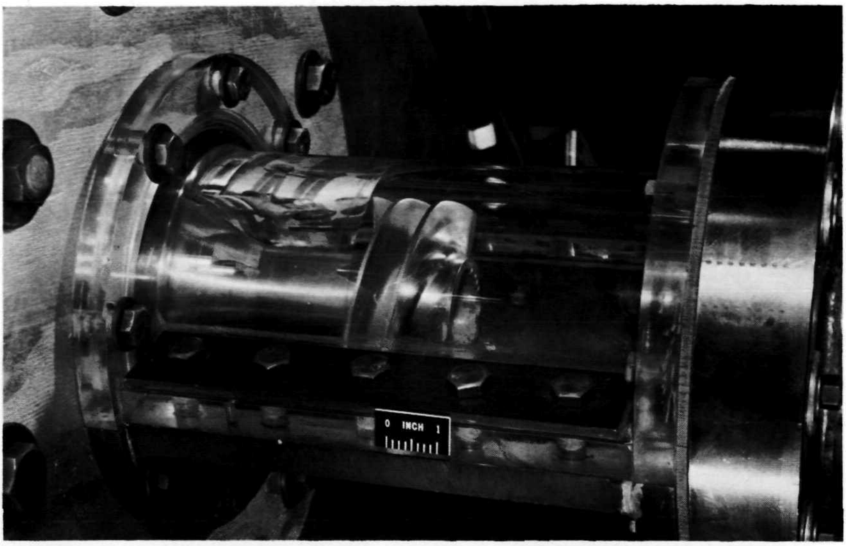


FIGURE 30.—A different plastic test chamber for evaluating a pump impeller, shown here at rest.

drawing the pattern tracing in space as recorded in these pictures.

At Ames Research Center, an interesting test program makes intensive use of photography in impaction studies. The test device consists of a vertical gun which fires a particle downward or at an angle into a soft sand model or sand target with high velocities to evaluate particle behavior on impact and the flow of material while it is cratering. Photographs are taken of the impact, as shown in Color Plate 11(*a*). After the impaction of the particles, the target, which consists of loose sand intermixed with epoxy resin, is baked until the whole becomes a hard mass. In preparing the target, vertical small-diameter cylinders of colored sand granules are inserted at accurately determined positions. After the target bakes and hardens, it is cut in half and an engineering photograph maintaining geometrical accuracy is made of the cross section, showing the change in position of the colored particles as a result of the impact. The photographs provide the data necessary to determine the flow of the material during cratering phenomena (Color Plate 11(*b*)).

Some of the earliest work performed at Langley was concerned with the design and development of recoverable photographic packages for early rocket tests. In investigative programs utilizing commercial equipment as the basic systems, the packages were subjected to large mechanical forces and (where recovery was made through the atmosphere) high-temperature variations.

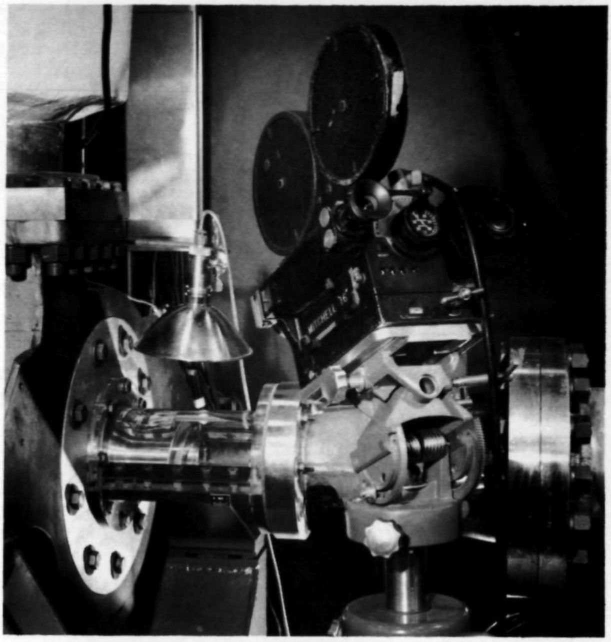


FIGURE 31.—A survey of the photographic test setup of the impeller shown in figure 30. The camera has been modified with synchronizing switches so that the electronic flash is discharged each time the frame is in the camera. The camera itself is synchronized to the rotating blade so that pictures are taken in a stroboscopic manner; that is, on each cycle of the rotation of the impeller.

FIGURE 32.—The test setup of the previous picture resulted in this photograph of the initiation of cavitation at the trailing edge of the impeller blade.

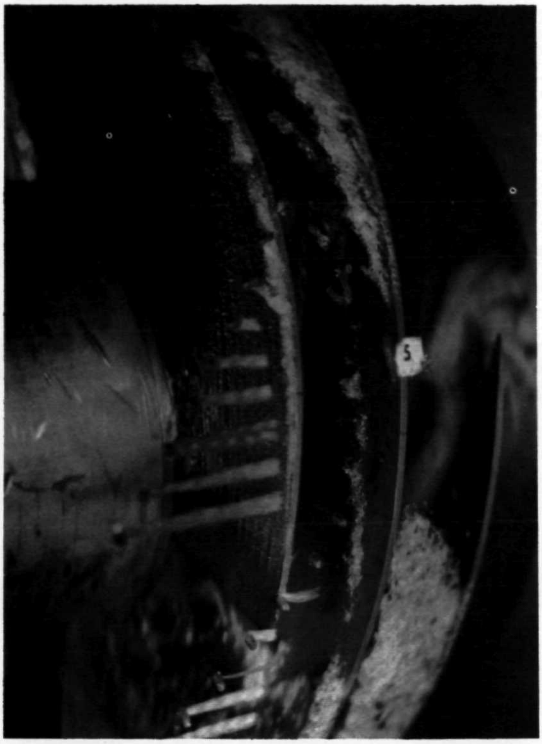


FIGURE 33.—The extended development of cavitation at high speed on the pump impeller blade, as achieved with the setup shown in figure 31.

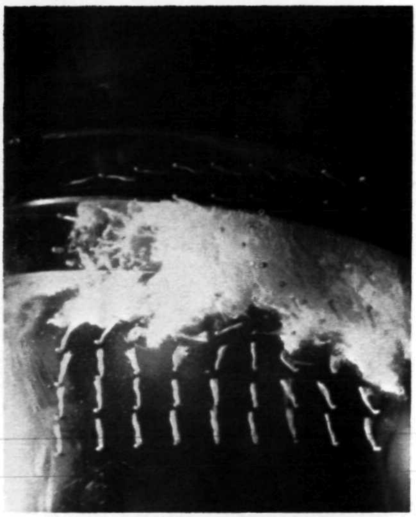


FIGURE 34.—A photograph taken by a camera focused axially along the pump impeller. It shows the cavitation of the leading edge of the impeller toward the lower part of the picture. This picture was made from a single frame of the 35-mm camera. The perforations and framing marks have been cropped off.

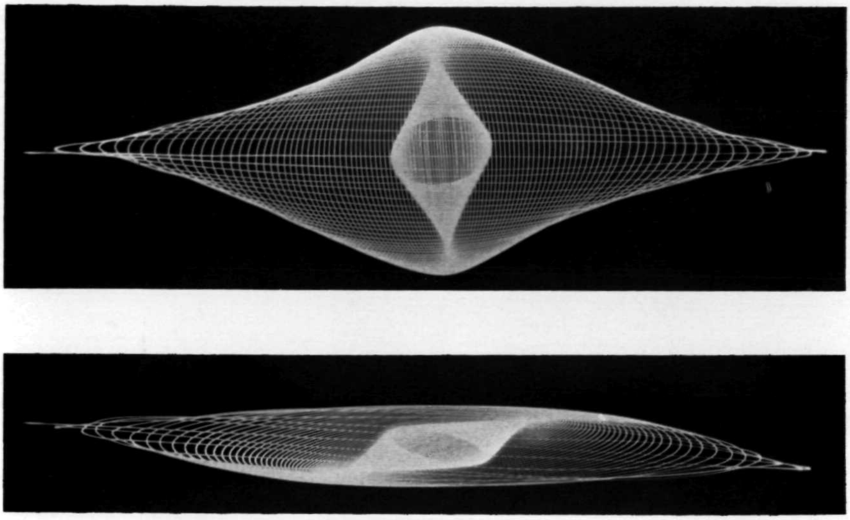


FIGURE 35.—A vibration test of the tip of the antenna boom on the Radio Astronomy Explorer yielded these photographs. A very small light attached to the boom tip is recorded by a camera with an open shutter in a darkened room. The amplitude and shape of the patterns are used to determine the complex vibration spectra of the boom assembly under varying load conditions.

Some packages were recovered directly from the rocket and others by means of deployment from the rocket. To protect the investment in programs such as the Thor and Echo, two instrumentation packages were used, video and photographic. The video package generated signals which were transmitted immediately to Earth, where they were recorded by means of a kinescope on the ground. This provided a small fraction of the total information that could be obtained by photography. When successfully recovered, the photographic package provided a very comprehensive engineering analysis of the events that were observed.

It was in these programs that early work was done on ablative protective capsules. An ablative material provides thermal protection by a combination of reflection from the white pigment, absorption of thermal energy, and the decomposition of the ablative material itself. Such material is more commonly known as the heat-shield material which protects astronauts in their spacecraft as they reenter the Earth's atmosphere. In several rocket tests where deployment procedures were used, a camera was the only mechanical item in the ablative capsule. The package was prepressurized at atmospheric level and was designed to be water resistant for recovery at sea. It was also required to survive the high-G environment of liftoff, though, normally, the camera does not operate during this portion of the test program. The camera was started by remote signal at the proper point in the flight sequence.

Significant advances in ablative package design have been in those packages for use at Kennedy Space Center, where engineering cameras are subjected directly to the hot exhaust of the lift off vehicle during spacecraft launching. Typical ablative packaging is shown in figure 36. The entire camera is mounted in a housing having the necessary electrical connections for synchronization to the launch control complex. Pictures are taken through a quartz window of double thickness which is installed in front of the camera lens and used only once.

The entire housing is coated with an ablative heat-shielding material that, in many ways, behaves as do the heat shields on manned space vehicles. The white color of the shielding material reflects primarily infrared radiation. The energy that is not reflected is absorbed by the material to prevent the transfer of heat by conduction to the interior of the camera housing. The absorbed energy is dissipated in burning off the ablative material. This material is basically an epoxy resin-based paint; it may be applied in coats as thick as 1 or 2 inches, depending on the temperature to which the housing will be exposed. In the course of operation, the interior of the camera housing is flushed with nitrogen at a pressure of 30 pounds per square inch, enough pressure to keep the cool nitrogen flowing from the supply system through the camera case and the exhaust. To be sure that the windows remain clean during the period of photographic operation, and to prevent deposition of residue from rocket exhaust or the ablative material, the front surface of each window is flushed with nitrogen at 30 pounds per square inch during the dormant period and at 50 pounds per square inch during the period when actual firing takes place. The ablative package of figure 36(*a*) is shown opened and with the camera and large magazine installed in figure 37.

On the other side of the environmental regimen to which cameras are subjected is the Launch Phase Simulator (LPS). Figure 38 shows the mounting of a camera subject to forces as high as 40 G's in the centrifuge device at the Goddard Space Flight Center. An antivibration mount filters out the continuing induced vibration of the system. The cameras are used in this Launch Phase Simulator to evaluate both men and materials under the high-G forces that occur during liftoff.

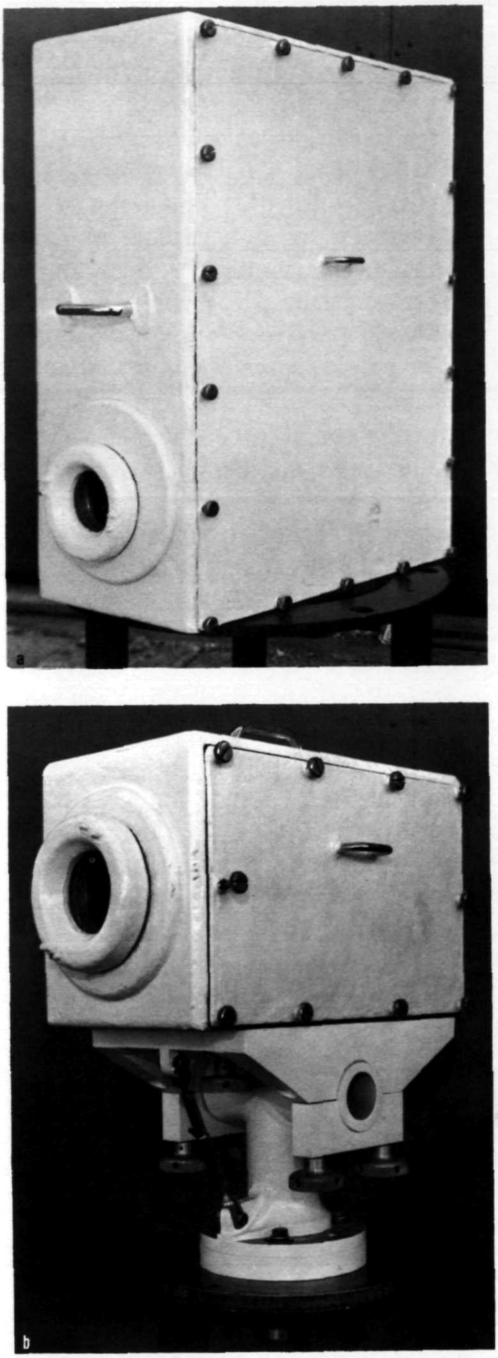


FIGURE 36.—Typical ablative protective housings for cameras are shown here; (*a*) is for a large, 400-foot camera, and (*b*) for small 100-foot, 16-mm or 35-mm cameras. The white coating is the Dynatherm epoxy resin paint which reflects infrared radiation and absorbs what is not reflected. The energy is dissipated by the burning of the material during its exposure to the high heat levels.

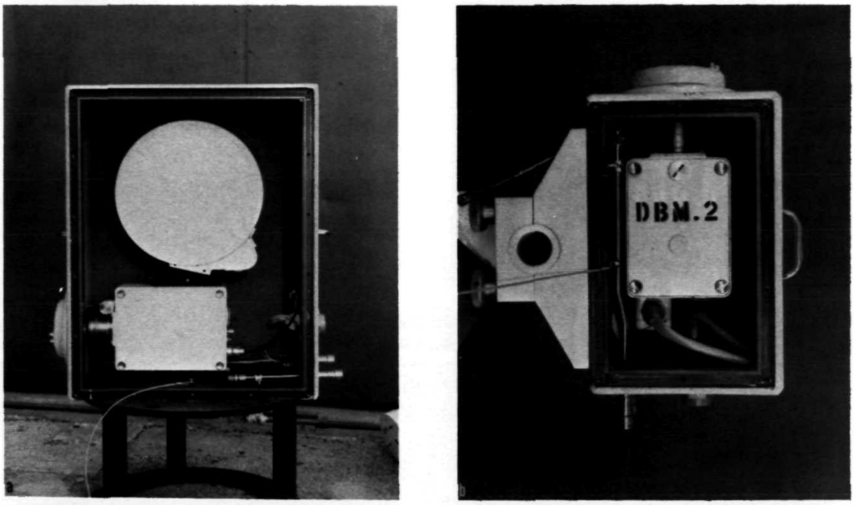


FIGURE 37.—The ablative protective housings with side covers removed. In (*a*) one sees the installation of the camera and large volume film magazine and the provision for electrical connections to the housing. In (*b*) one see the small 16-mm camera with an internal magazine. Electrical connectors facilitate removal of the camera for servicing.

Another high-G shock environment to which cameras are subjected occurs at Lewis Research Center in the zero-gravity drop towers (Color Plate 12(*a*)). While a camera operates in zero-gravity environment during free fall there is high-G deceleration at the end of the drop. These cameras are enclosed in the drop test packages which are dropped in a vacuum from as high as 450 feet. If a package is accelerated from the bottom of the shaft, the initial acceleration is 40 G's. After the package has fallen, deceleration reaches a mean rate of about 30 G's. Cameras contained in a drop test package photograph the events, the phenomena or reactions which are set up to take place in the package during the zero-G period. Because of size and weight restrictions, the cameras are generally 16-mm data or high-speed cameras, depending on the experiment, the event and the type of records desired.

Other cameras are utilized in the vacuum environment of the test chamber. The complexity of the installation, and difficulty of setting and retrieving cameras because of the 450 feet of smooth vertical walls in this facility can be seen in Color Plate 12(*b*).

When cameras and films must operate in high vacuum, camera lubricants are required which will not poison the vacuum environment if the camera is exposed to the full vacuum. Cameras have

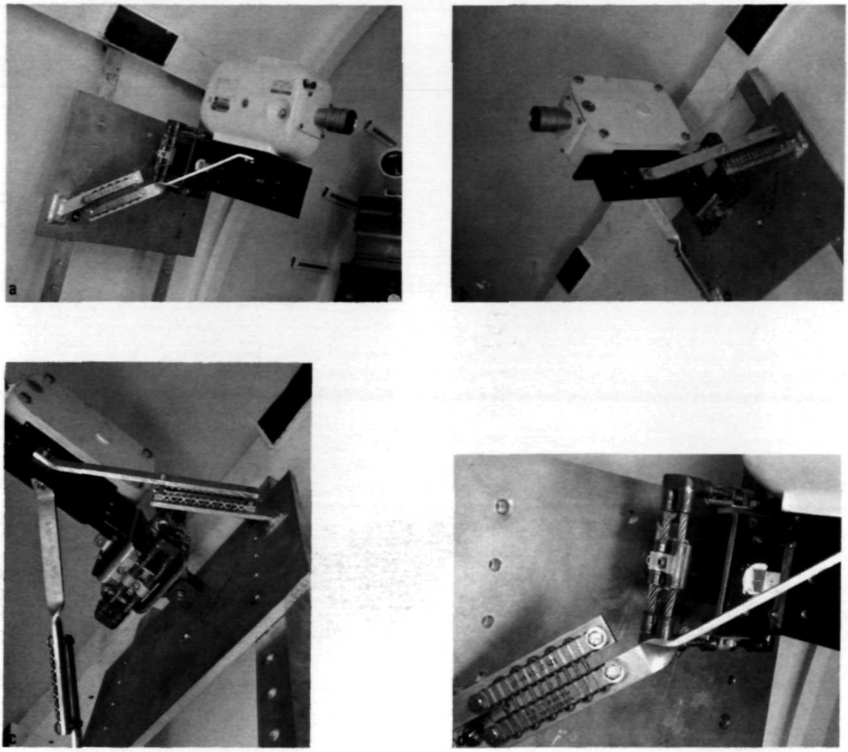


FIGURE 38.—Typical of the high-G camera mountings is that used in the Launch Phase Simulator (LPS) at Goddard Space Flight Center. In this centrifuge type device both personnel and components are subjected to forces as high as 40 G. Here (*a*) and (*b*) are opposite side views of the camera installed on the side wall of the LPS for observation of personnel and material during test; (*c*) is a bottom view of the mount showing the vibration absorbing mounts used for absorbing the high-frequency vibrations before they can adversely affect the camera, and (*d*) is the detail of the vibration isolator.

been used directly in vacuum, and in certain applications they have been enclosed in housings in which a partial pressure of air or nitrogen has been maintained. Few problems occur with respect to film exposure or its sensitivity in a vacuum. The major problems have been the generation of static, particularly with the high-speed cameras. In general, these problems are avoided by correct selection and treatment of film.

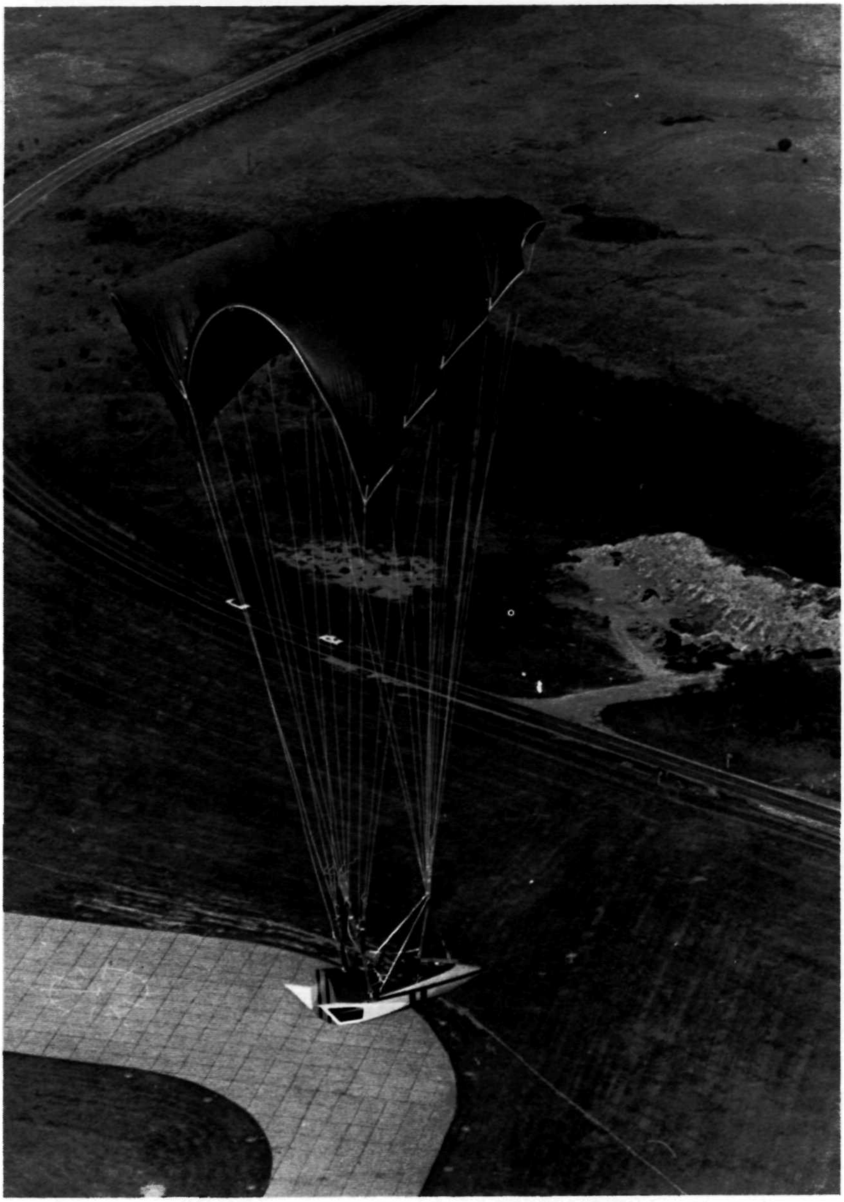
A number of interesting engineering photographic applications have been in fieldwork on projects such as vehicle-to-vehicle investigations. The photos in Figure 39 were taken during drop tests of Hi-Glide canopies at the Plum Tree facility associated with the Langley Research Center. These devices have glide ratios of 2½ to 1. They drop a foot for each 2½ feet of forward motion at fairly rapid speeds. They must be chased by an aircraft or helicopter. Generally, the cameras are tracked manually.

Reference 14 describes an electronic shutter control system developed under NASA management that can record automatically the times at which the exposures are made. Though primarily intended for planetary photography, it represents an operational achievement that might be used elsewhere. Other controls, such as a pulse-train generator and low power timing devices for use in space vehicles or other limited power environments, are described in references 15 and 16.

Extensive use of engineering photography has been made by the Kennedy Space Center. Typical is the photographic coverage of the entire launch area and vehicle operations, primarily for engineering analysis. The pictures obtained also provide historical records and public information. This Center's photography requirements are met by a rather large-scale photographic system which uses manually or sequentially operated data cameras and vehicle tracking cameras. In Launch Complex 39, the entire photographic complex is controlled remotely from the Launch Control Center. The equipment and its various modes of operation enable the engineers to obtain complete photographic coverage of a Saturn 5 operation including prelaunch functions, the actual liftoff, and events of the first 1300 feet of flight. Beyond this point in flight, events are photographed by tracking theodolite cameras of the Air Force Eastern Test Range.

As many as 130 cameras are specified for a typical launch. Of these, 90 are designated as engineering cameras. They range from data cameras that make still photographs as slow as two frames per second to high-speed motion-picture cameras with framing rates up to 1000 frames per second. The 16-, 35- or 70-mm films used for the cameras are either black-and-white, or color, depending on the type of information to be gathered.

A remote Photographic Control Console permits operation of all cameras associated with a given launch sequence at Launch Complex 39. These cameras are integrated with the launch sequence timing equipment and can be operated automatically from the launch sequence time signal. The operator may start and stop certain cameras in the course of activities that can be viewed through video monitors. A significant feature is that this installation is also interlocked with the master Launch Control Console; in event of any deviation from the normal launch pattern



that would result in destruction, an abort, or similar emergency situation, the Launch Controller, rather than the Photographic Controller, can activate all cameras to produce as quickly as possible a record of events as documentary evidence of the trouble.

The cameras associated with the Launch Control Complex can thus be operated in a start-stop sequence in conjunction with

FIGURE 39.—Engineering record photographs made of tests of Hy-Glide canopies at the Plum Tree facility of Langley Research Center. These are still photographs.

other activities, or automatically from the timing or other event sequences. Many of the manual remote start-stop cameras or data cameras are used to acquire pictures of the loading of fuel.

Figure 40(*a*) is a typical remote engineering data camera installed at one of the camera sites and complete with the sun hood over the mounting. A similar camera is shown without the cover in figure 40(*b*) to indicate the lower position of the main lens and the upper position of the lens of the automatic exposure control device. In figure 41, taken at one of the six camera sites that surround the Launch Complex, two data cameras are shown properly aimed to record certain liftoff events. Since each site allows a different view of the Launch Vehicle and the Launch

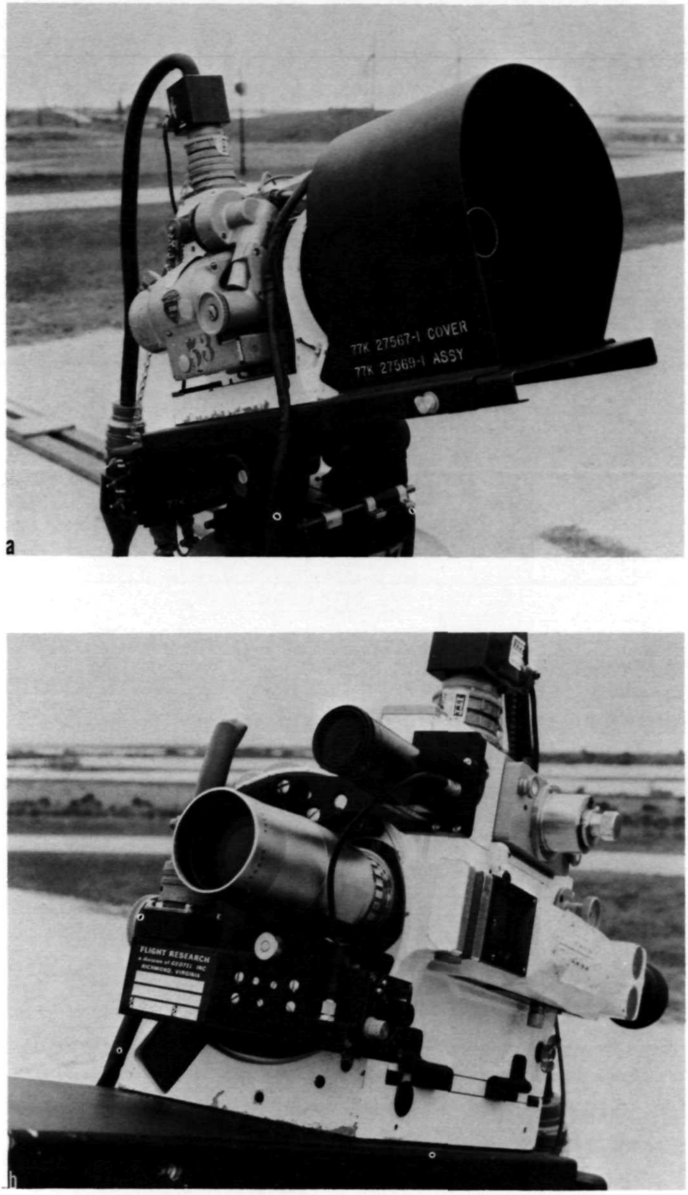


FIGURE 40.—Views of remote engineering data cameras installed at a photographic site at Launch Complex 39A at Kennedy Space Center. Figure 40(*b*) shows a camera with sun cover and shield removed. The silver finish barrel contains the main lens of the camera. The small black barrel holds the sensor lens that is used to adjust the main lens aperture in response to the instantaneous light level.

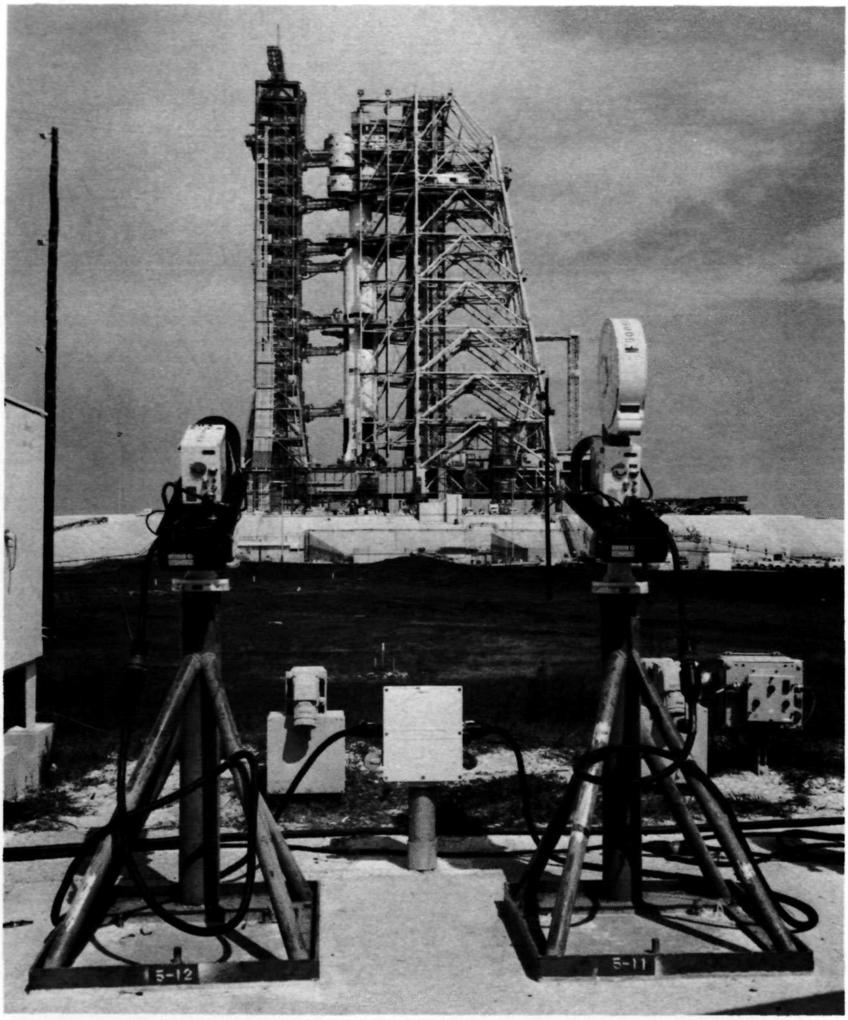


FIGURE 41.—Two engineering data cameras assembled and installed at one of the six camera sites that surround Launch Complex 39A at Kennedy Space Center. These cameras are aimed to record certain events during launch and are operated by remote control from the master photographic control console. The locations of the cameras are precisely determined by civil engineering techniques for photogrammetric reconstruction of liftoff events, should this be required.

Umbilical Tower, there is complete coverage. In figure 42 the Umbilical Tower appears behind a vehicle ready for launch. This photograph gives an excellent glimpse of the photographic recording equipment. Each of the extended platforms on the left contains the camera equipment for that level of the launch system.

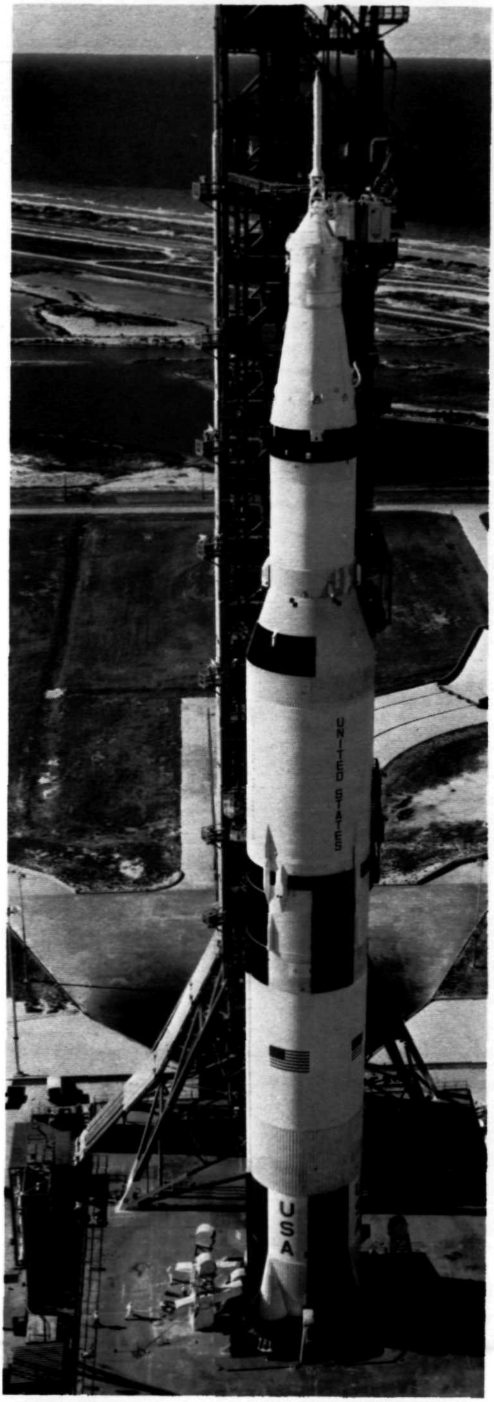


FIGURE 42.—This photograph of the Saturn vehicle nearing liftoff shows the launch umbilical tower immediately behind the vehicle. Note on the left the camera platforms on which the engineering data cameras are installed to record various events during liftoff procedure. Note also the cameras near the base of the vehicle for direct recording of the engines during the initial stages of operation.

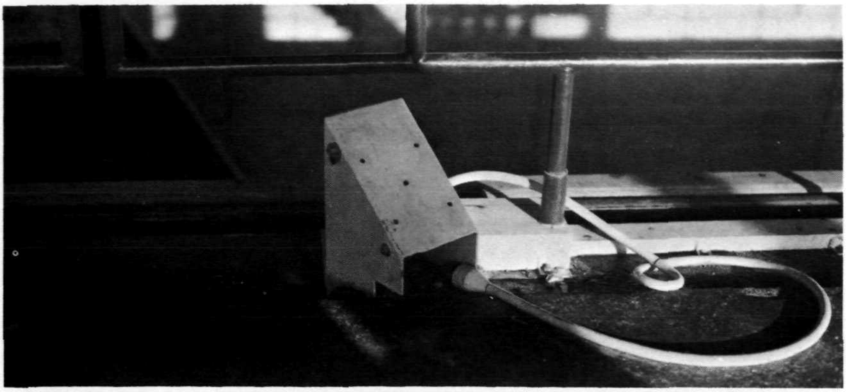


FIGURE 43.—A typical camera mount installation with thermally shielded cable ready to accept the camera in the flame trench of the launch platform.

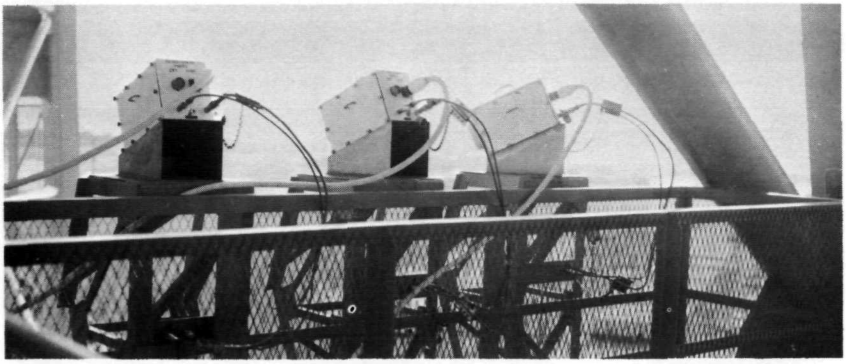


FIGURE 44.—A series of engineering cameras assembled on a low-level camera platform to record the initial stages of liftoff. Note the use of the ablative protective housings and the shielded power cables to each of the cameras. From the connectors it is obvious that the control circuits have all been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

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

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

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

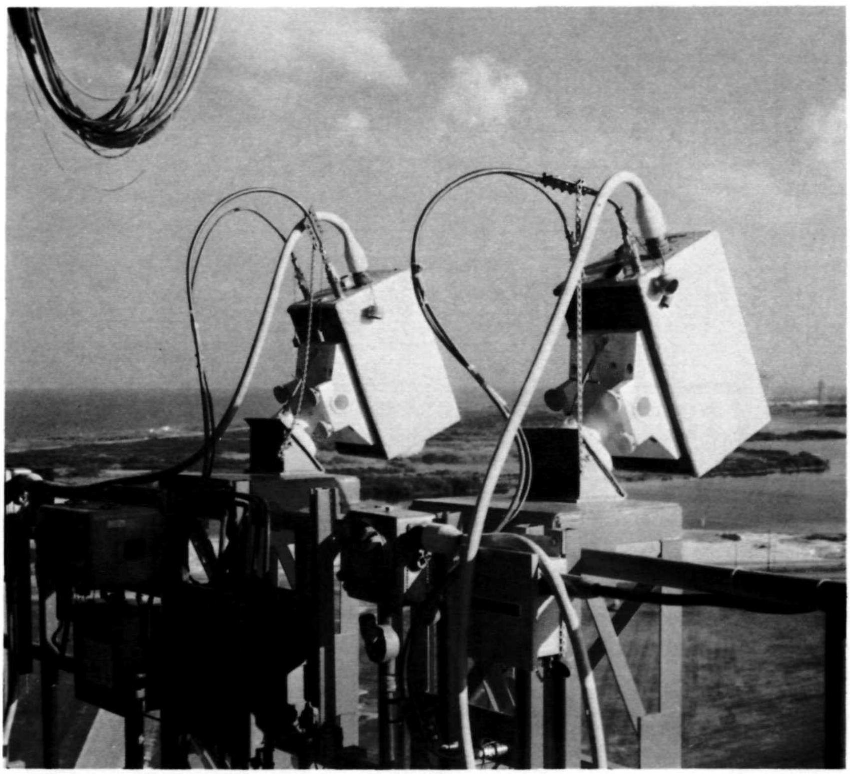


FIGURE 45.—A typical high-level installation on one of the upper camera platforms. This picture shows details of the electrical control systems and power distribution built into the facility.

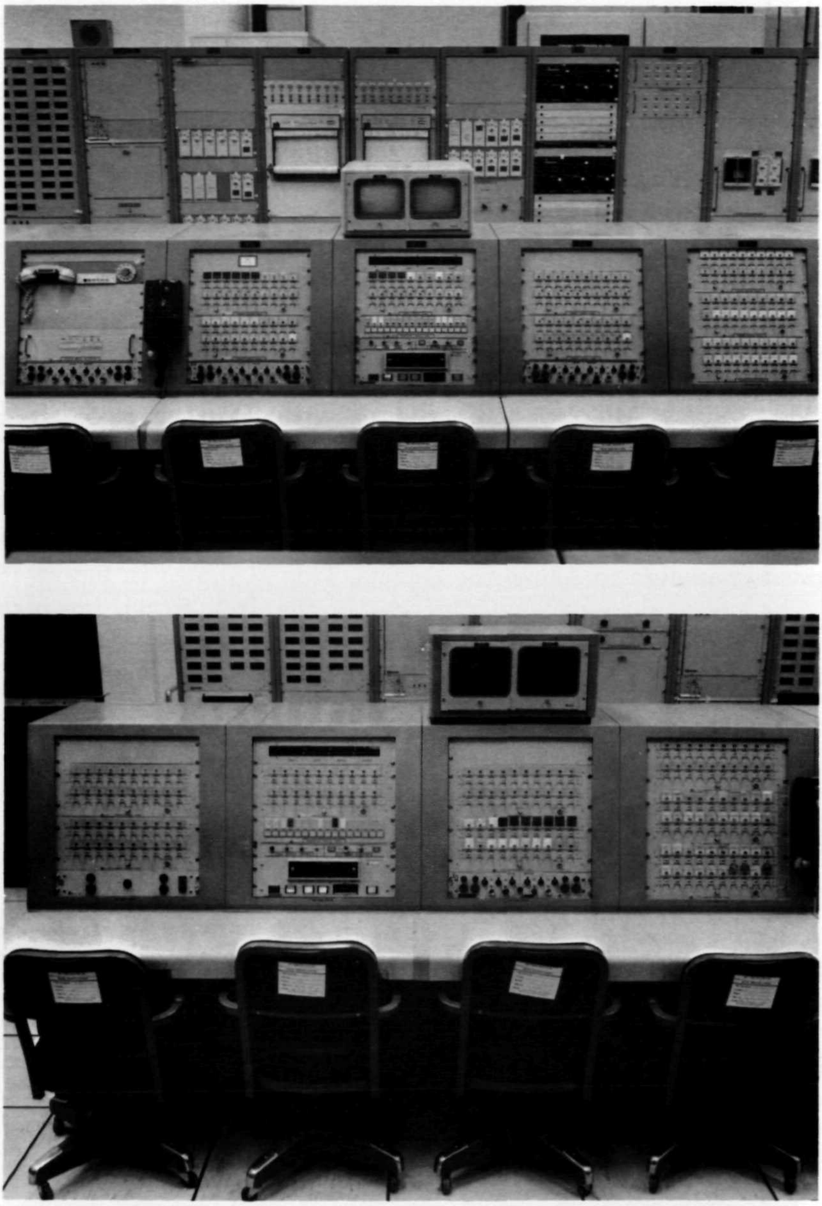


FIGURE 46.—General views of the remote photographic control complex in the Launch Control Center associated with Launch Complex 39A at Kennedy Space Center. Operation capability includes remote manual, automatic or emergency automatic, as well as change sequence. Control is available for each of the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

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

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

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

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

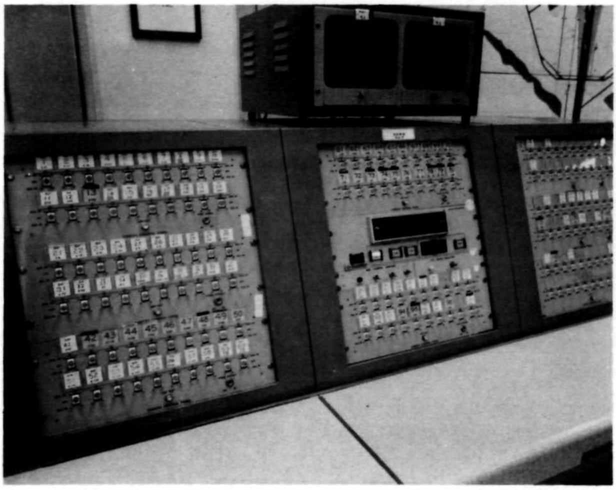


FIGURE 47.—A closeup of a smaller launch control center which shows how the individual circuits may be applied to different cameras for different launch operations and how they are identified on the control complex. For each of the positions, the camera circuit can be started manually or switched to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

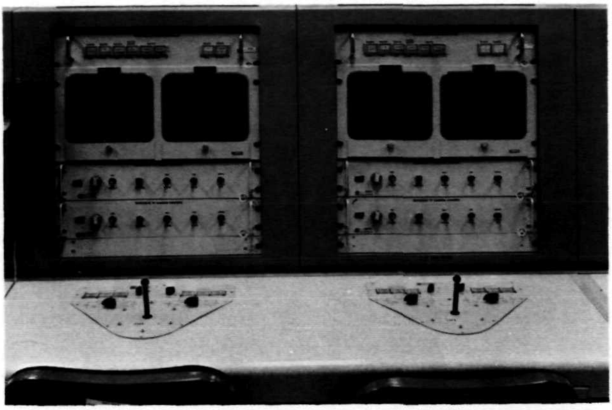


FIGURE 48.—This view of the photographic control center associated with the remote tracking cameras shows the monitors which are used with closed-circuit television boresight instruments for viewing events seen by the camera through remote TV. Through controls in front of and on the desk of the console,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

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

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

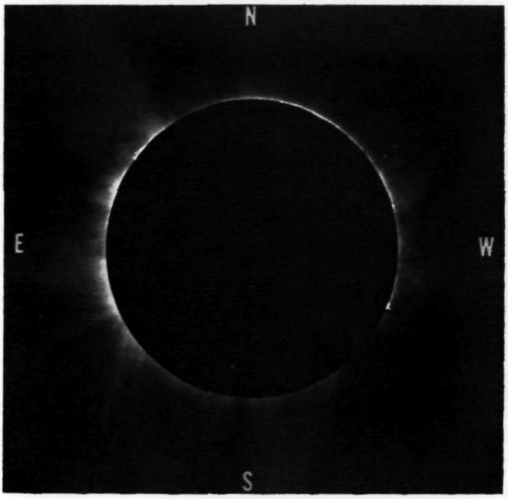


FIGURE 49.—This picture is one of the most impressive of the coronal photographs obtained at the 1970 solar eclipse. It was taken by Sheldon M. Smith, of the Ames Research Center, and Leonard M. Weinstein, of the Langley Research Center. They used a telescope modified at the Langley Research Center to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

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

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

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

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

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

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

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

Multispectral Photography

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

TABLE 2.—*Methods of Expressing Wavelength Range*

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

*Earth Resources Technology Satellite.

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

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

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

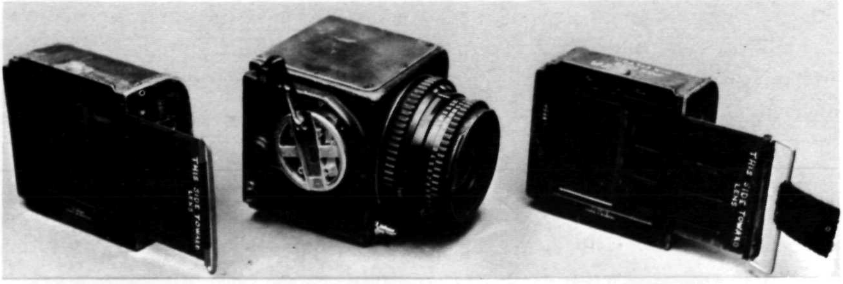
The shape and texture of an object can also help identify it. Other factors being equal, however, the higher the altitude from which a photo of the Earth's surface is taken, the less detail can be seen in an object's shape and texture. The photographic interpreter (or image-analyzing machine) must place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

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

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

PHOTOGRAPHIC SAMPLES

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



MA-8 Filter and magazine — 70mm Hasselblad — MA-9 Filter and magazine

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

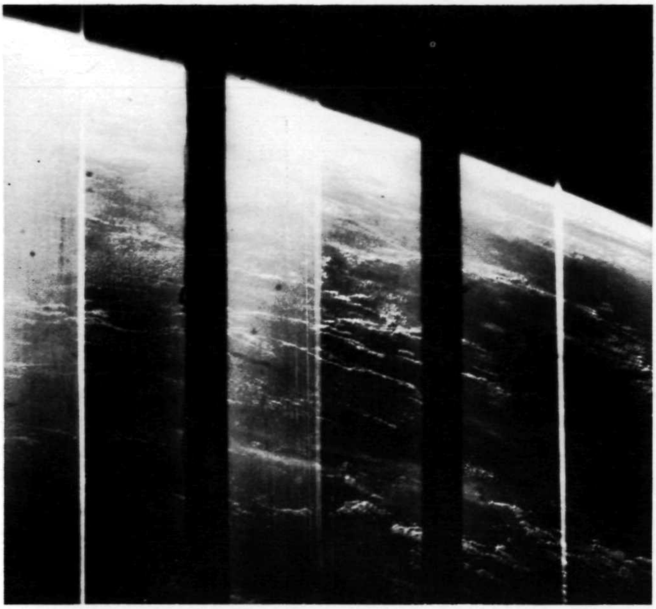


FIGURE 52.—For the Mercury-Atlas 8 experiment a fixed-band set of filters was incorporated in the dark slide. In this continuous picture of the surface of the Earth, the separate elements are recorded in the different spectral bands. Note the displacement in the horizon which was a significant target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

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

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

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

6,600 to 9,000 Å 7,300 to 9,000 Å 8,000 to 9,000 Å

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

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

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Earth Resources Photography

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

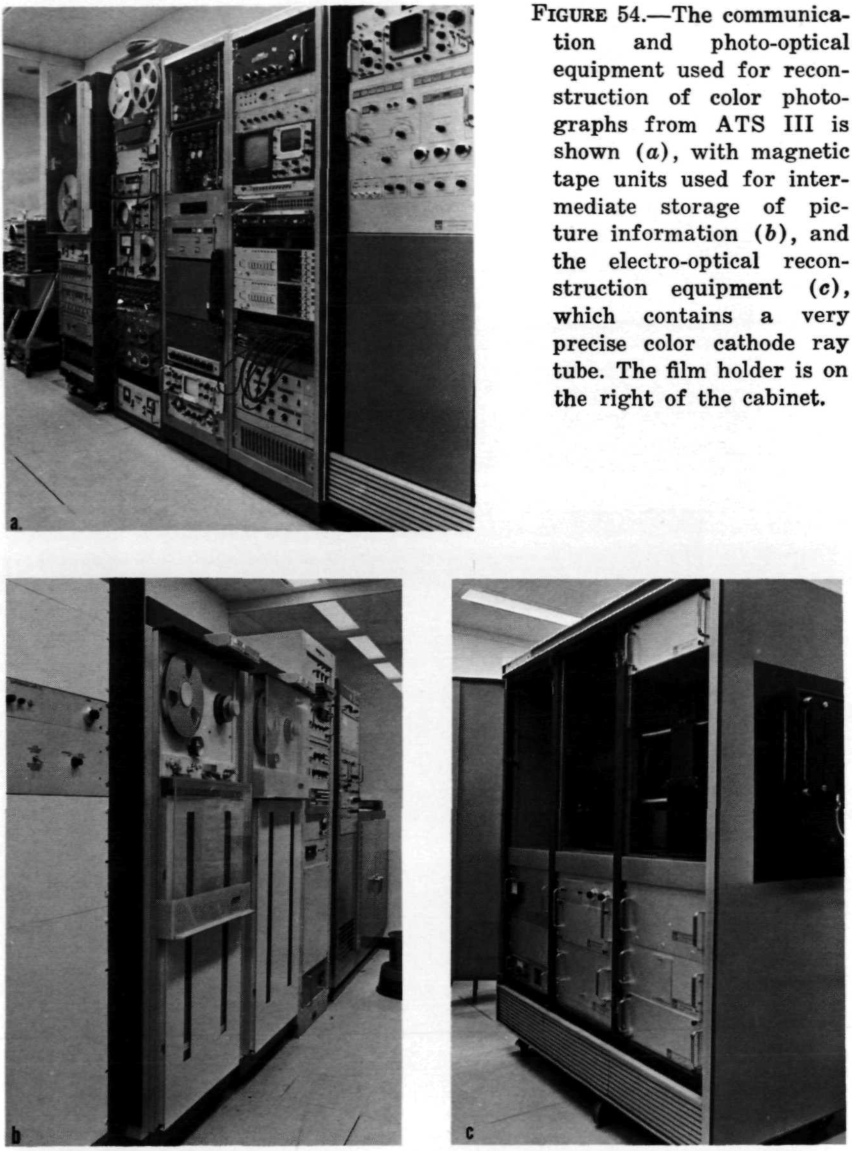
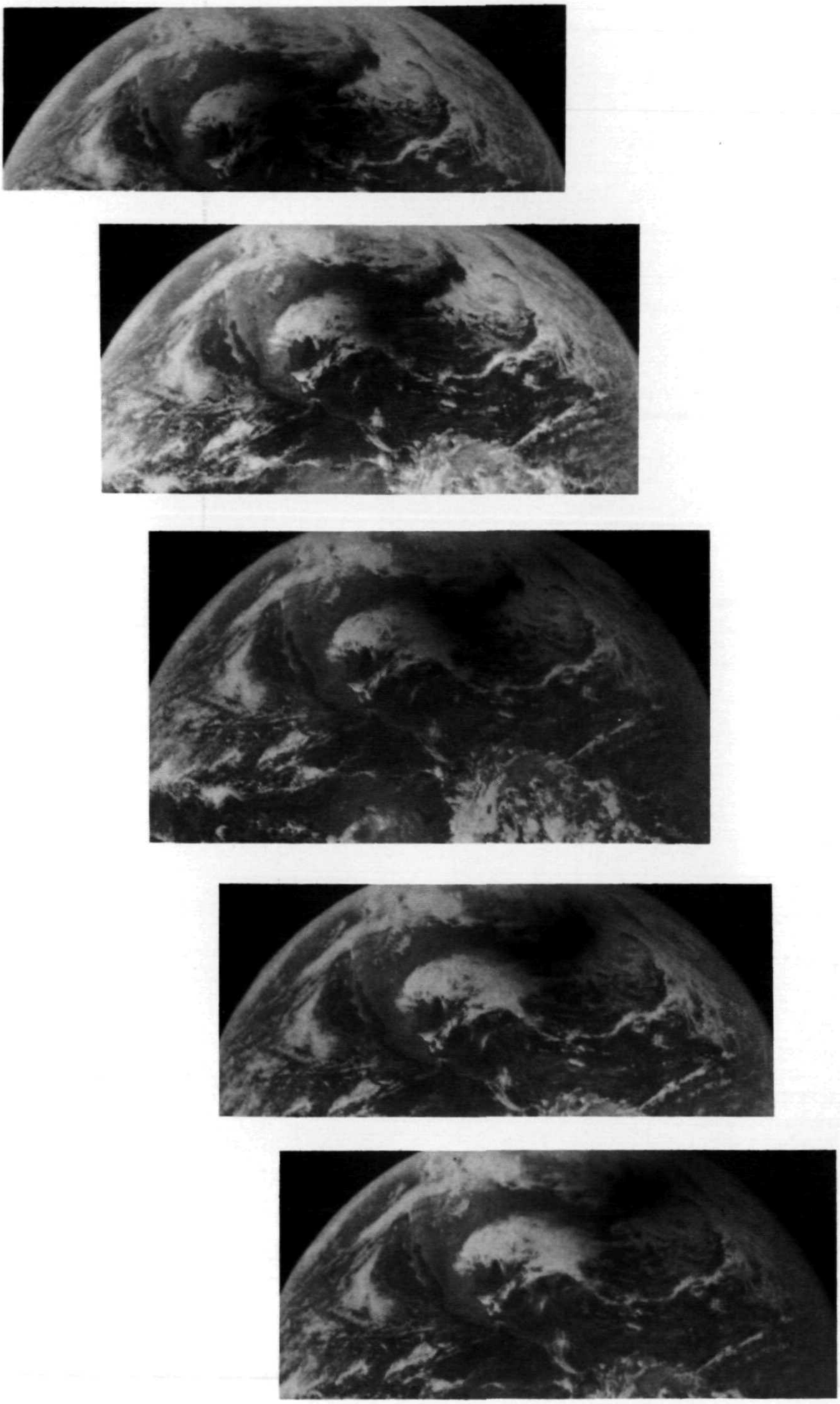


FIGURE 54.—The communication and photo-optical equipment used for reconstruction of color photographs from ATS III is shown (*a*), with magnetic tape units used for intermediate storage of picture information (*b*), and the electro-optical reconstruction equipment (*c*), which contains a very precise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

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

One of the most spectacular pieces of information recovered



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

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

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

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

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

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

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

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

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

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

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

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

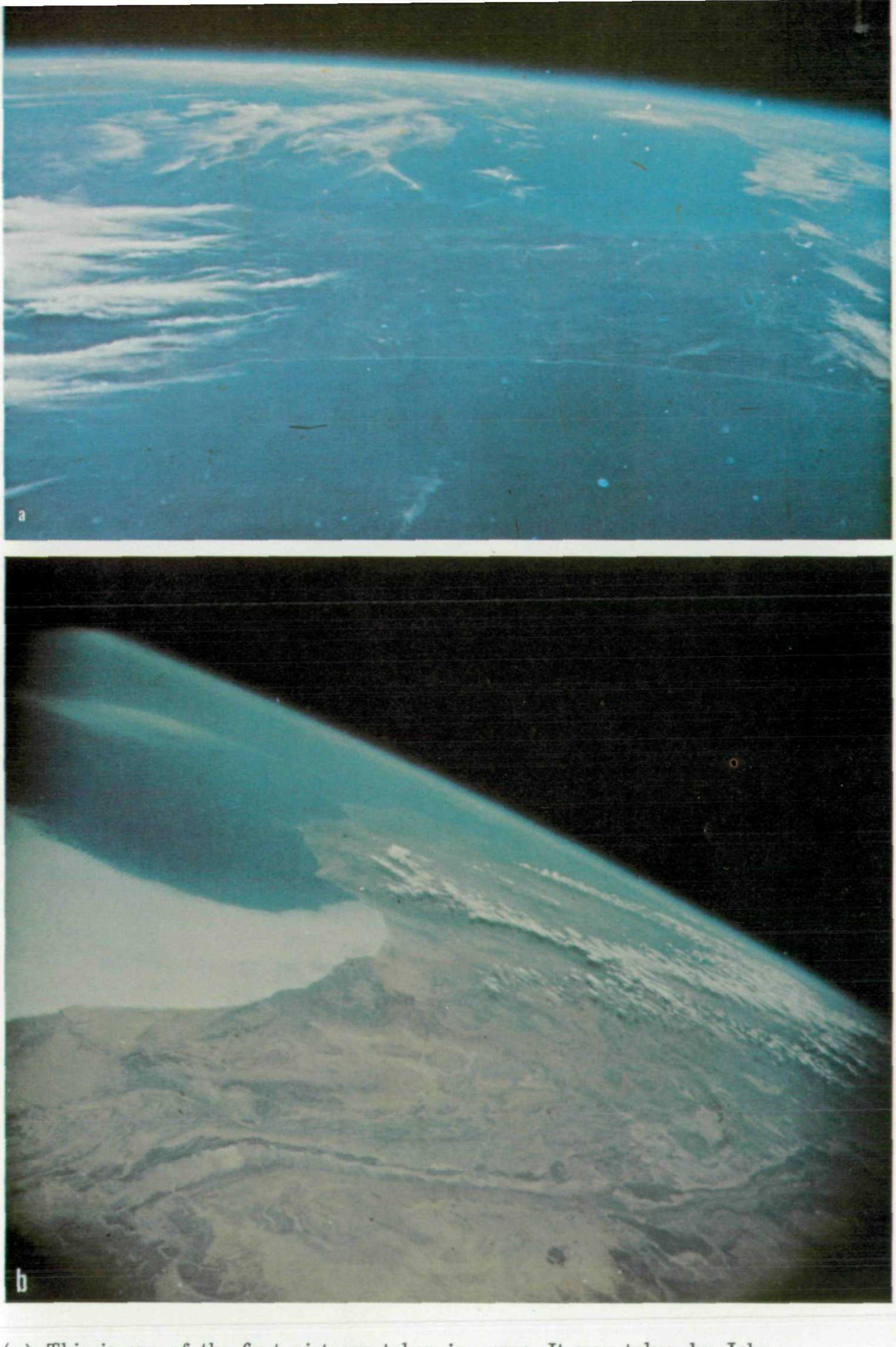
Another interesting application in atmospheric research occurred during the investigations of the aurora borealis on November 26, 1969. Color Plate 23 is typical of the many pictures of the aurora which were recorded by the Airborne Sciences Office of Ames Research Center with the "Galileo," a Convair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

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

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

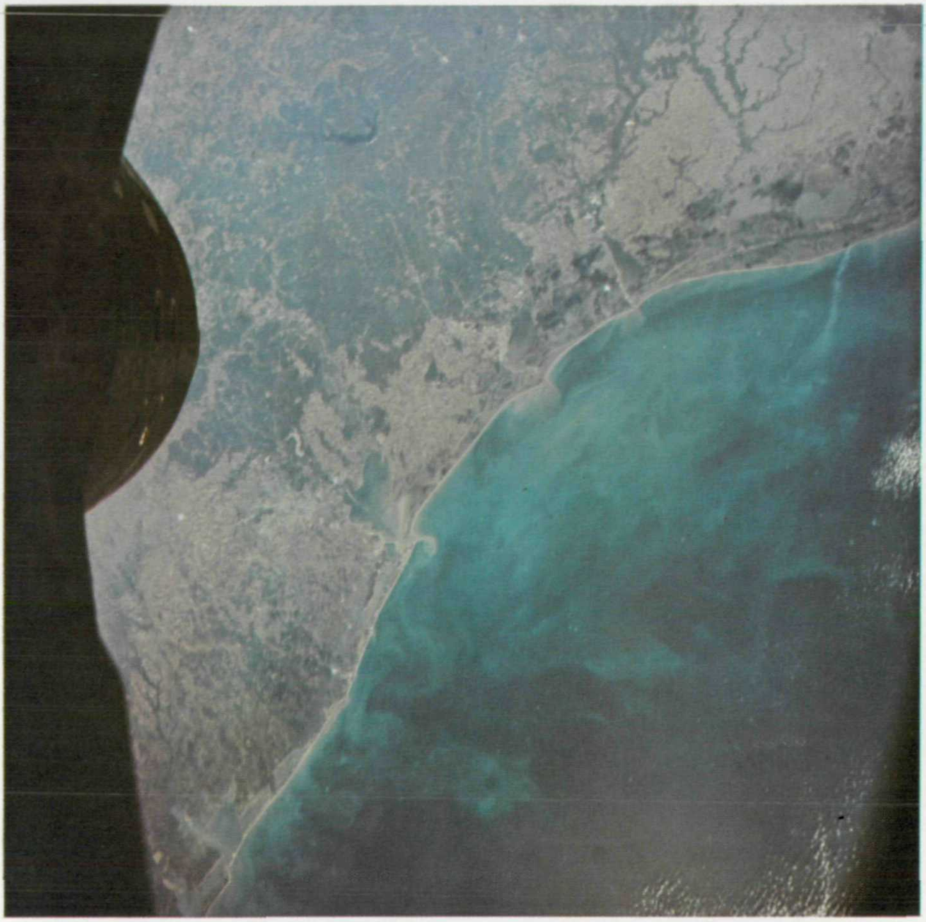
Two good sources for information on this subject are the American Society of Photogrammetry and the Society of Photo-Optical Instrumentation Engineers. Technical personnel in the fields of photogrammetry and photographic interpretation unanimously express excitement over its prospects and many outstanding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

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



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

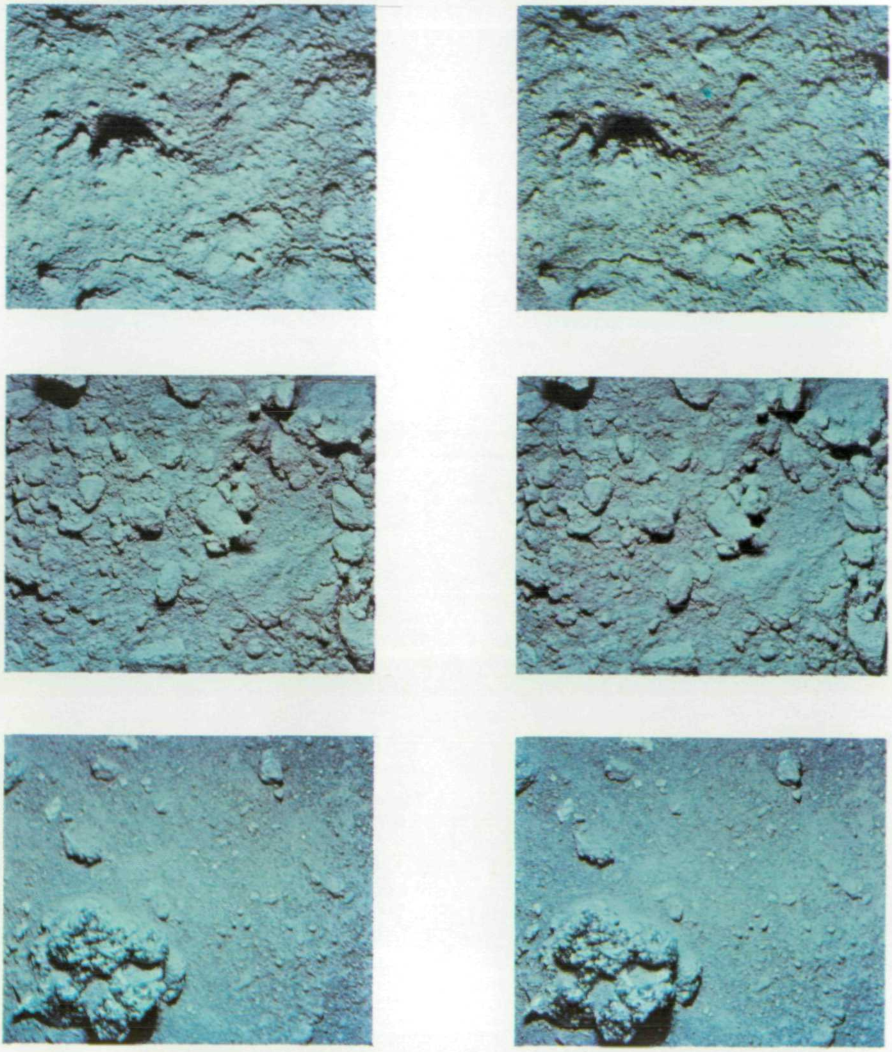
COLOR PLATE 1



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

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

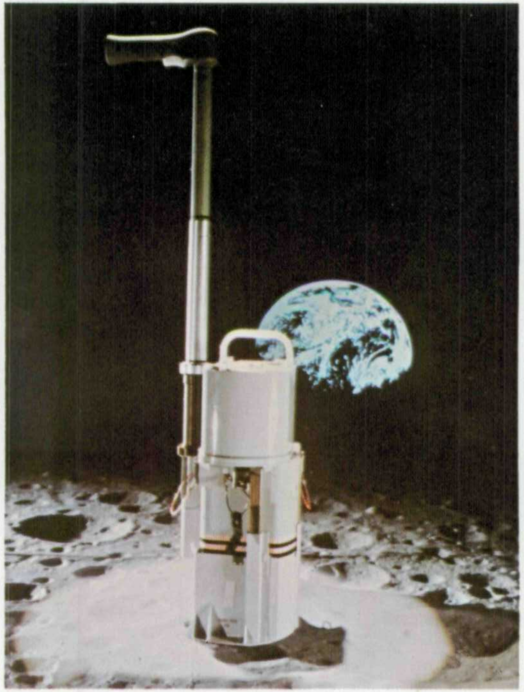
COLOR PLATE 2



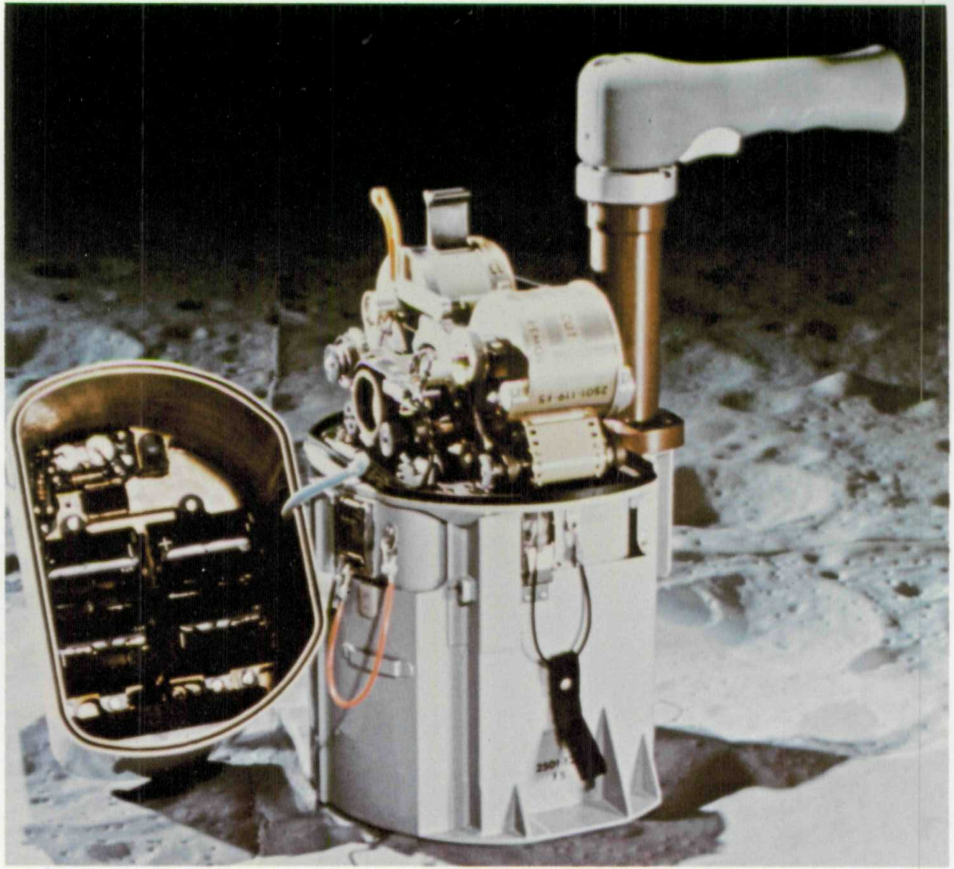
Stereo pairs were taken with the Apollo Lunar Surface Close-up Camera. This figure shows the type of detailed photographic information that was recovered. The photos are printed in proper relationship to permit three-dimensional viewing by means of any of the accepted techniques for viewing stereo pairs.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

COLOR
PLATE
3

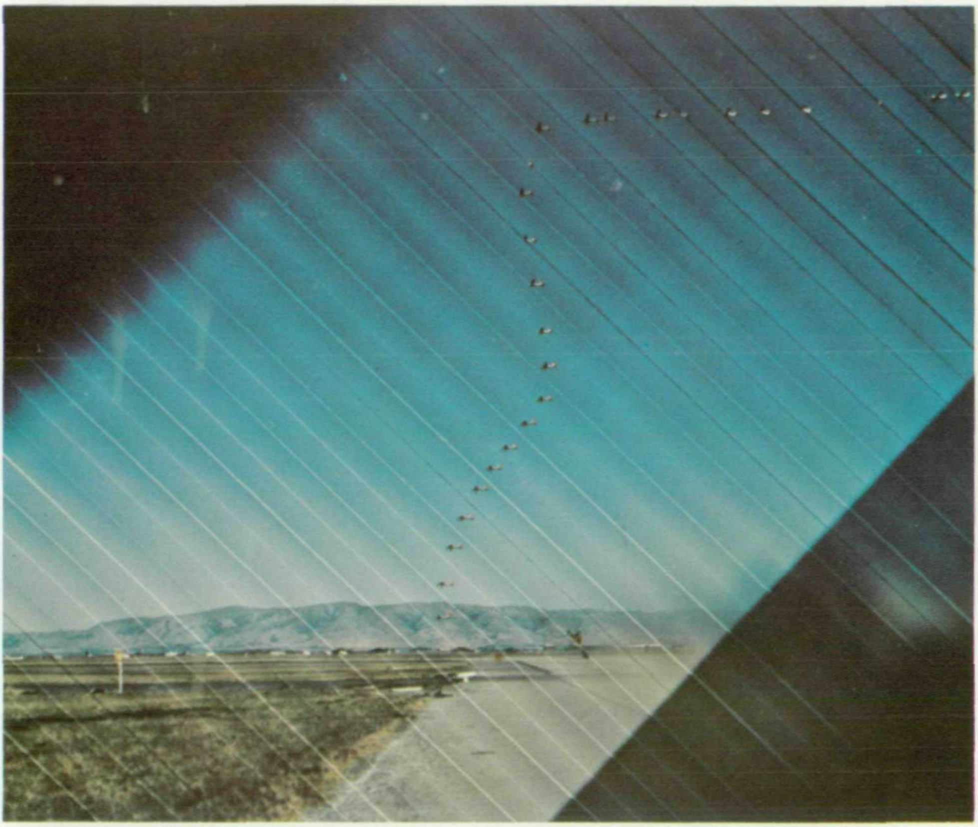
COLOR PLATE 4



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

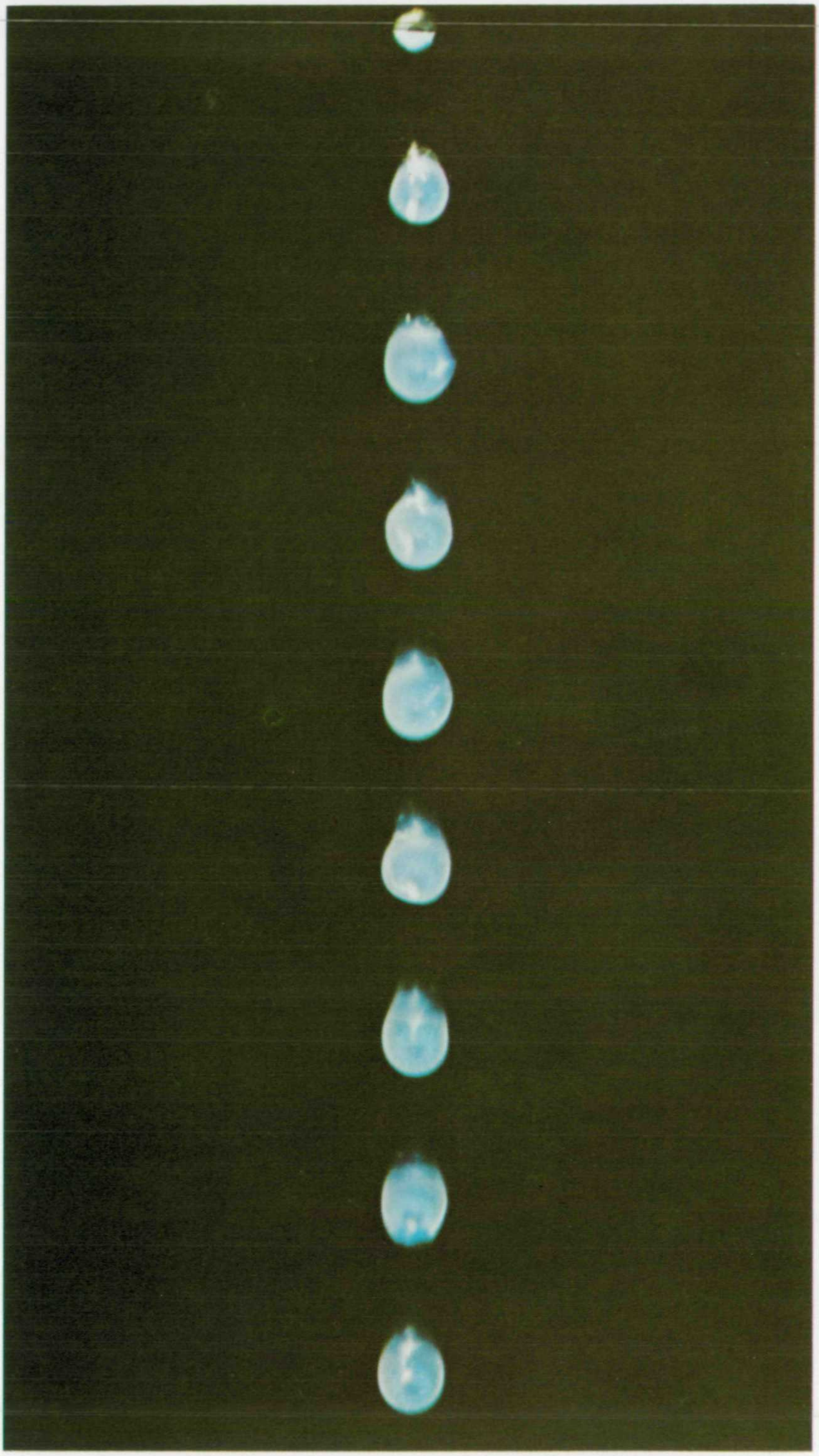


The Apollo Lunar Surface Close-Up Camera is shown here with the handle retracted and the cover removed. It has its own self-contained electronic flash equipment.



The time-displacement record of a V/TOL aircraft, the X–14, was made with a Fairchild Photographic Flight Analyzer Camera. The camera is arranged so that the entire background and fixed scene are properly exposed, but each element of the scene is exposed at the particular time when the aircraft passes over it. This time is determined by the tracking mechanism and the individual time of each image is recorded on the edge of a strip on the originally exposed film.

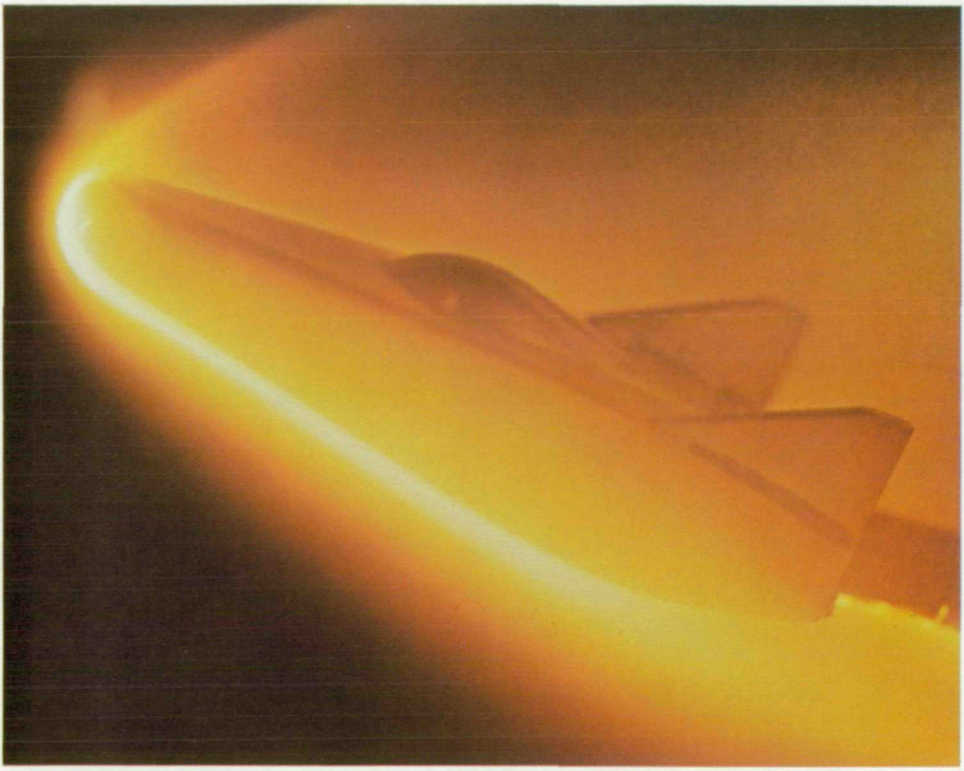
COLOR
PLATE
5



COLOR PLATE 6

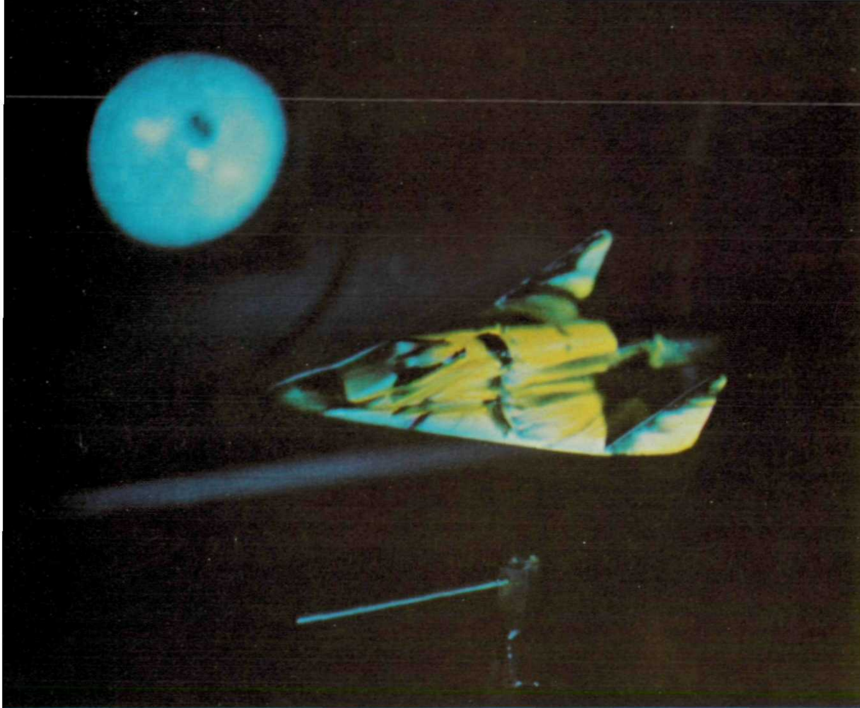
A time-displacement photograph of the burning of an aluminum droplet.

2



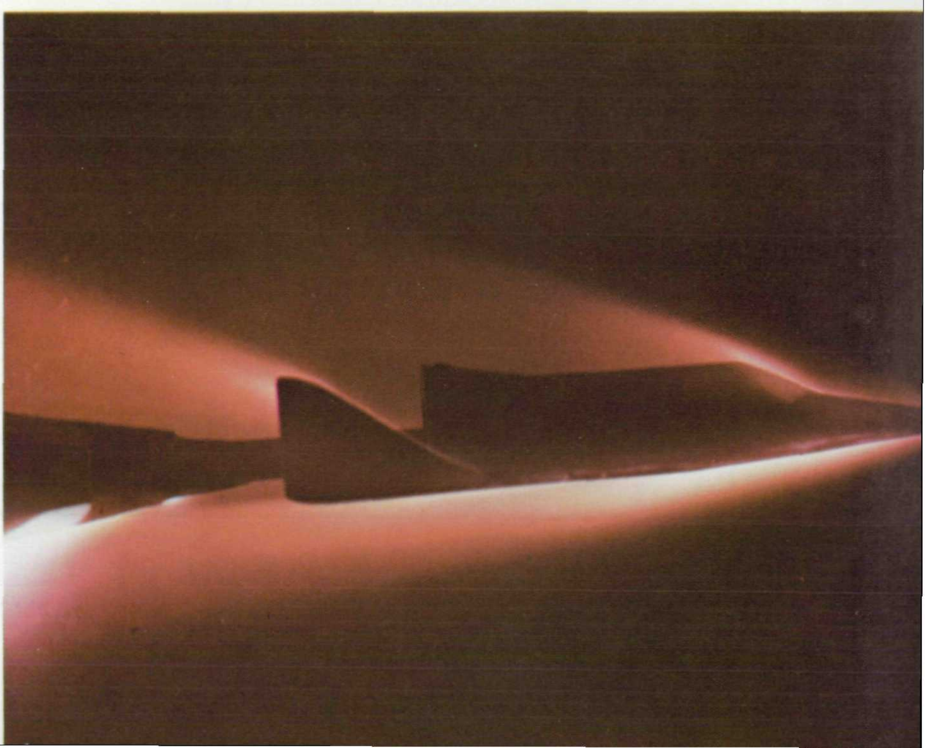
A model of the M–2 lifting body at Ames Research Center is shown during the heating phase of testing in a 1-foot Hypervelocity Wind Tunnel. The air flow velocity is 14,000 feet per second, producing gas temperatures at the blunt nose on the order of 9,000° F. Under certain conditions and at high altitudes, such a vehicle in actual flight would encounter temperatures well in excess of this level. When this picture was taken, the heat transfer distribution was being measured.

COLOR PLATE 7

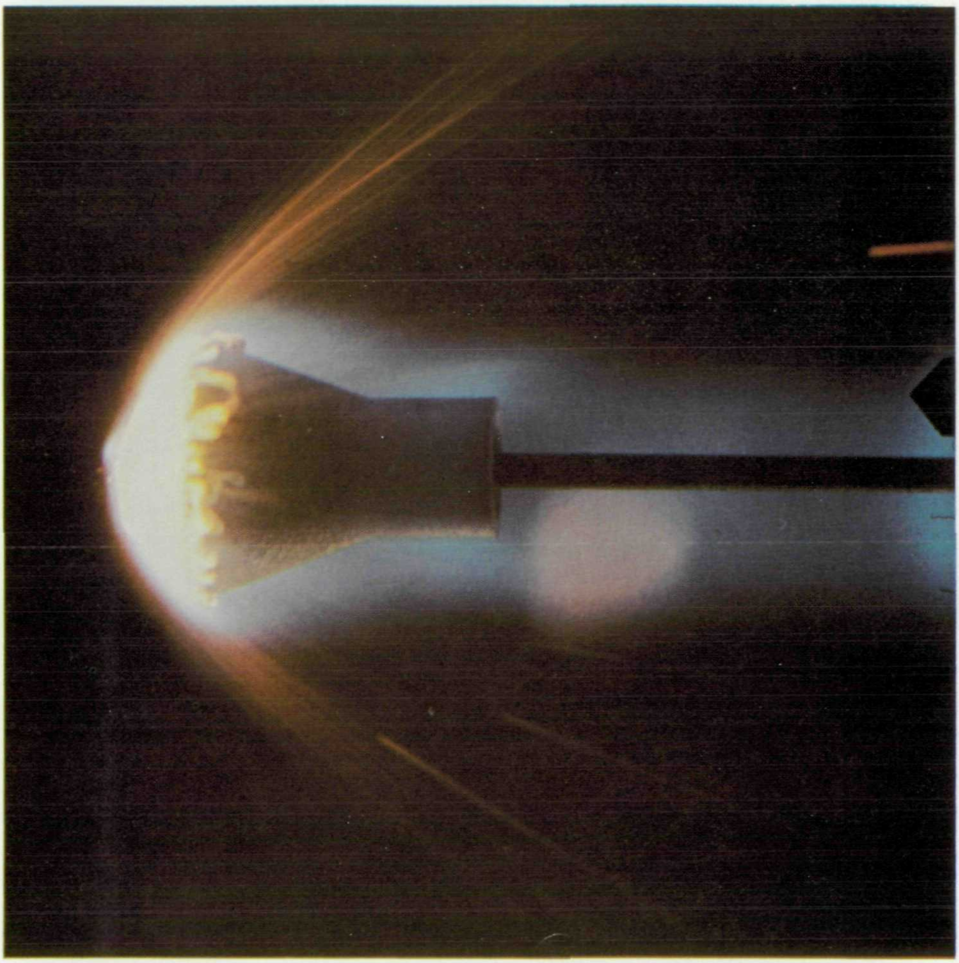


Evaluation of a wind-tunnel model by photography with ultraviolet light exciting a fluorescent oil to record oil patterns of air flow.

This delta-winged reentry glider shows evidence of glow discharge at high velocity in a hypersonic wind tunnel.

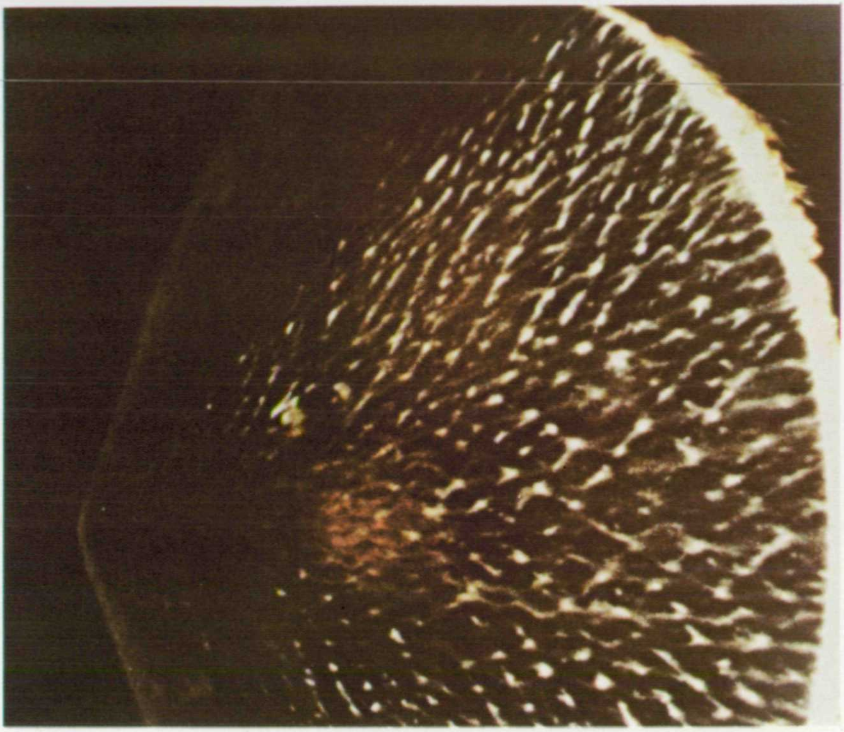


COLOR PLATE 8



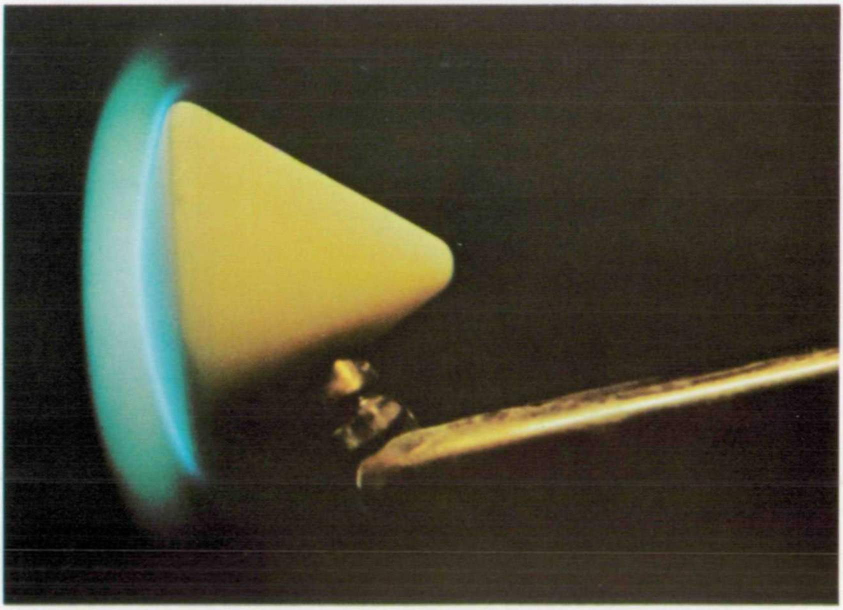
This photograph of an ablation test on the early Mercury capsule model was made in a wind tunnel which simulated reentry of the capsule through the Earth's atmosphere. The model, made of phenolic resin and fiber glass, was photographed during exposure to wind-tunnel conditions to determine the behavior of its components. Motion pictures are taken to obtain a full time sequence of the ablative behavior.

COLOR
PLATE
9



A closeup of patterns formed during ablation on a Lexan plastic model of a cone form. A sequence of pictures of this occurrence shows how the pattern forms as velocity increases and ablation develops.

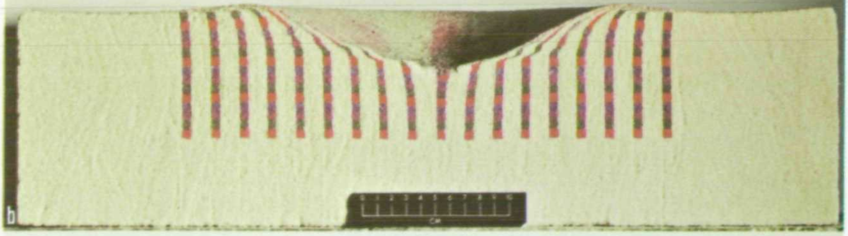
This striking picture of an Apollo model capsule is one of a series used to evaluate heat transfer to the afterbody of the model. It was taken during one of the ablation tests which simulate reentry phenomena in a wind tunnel.



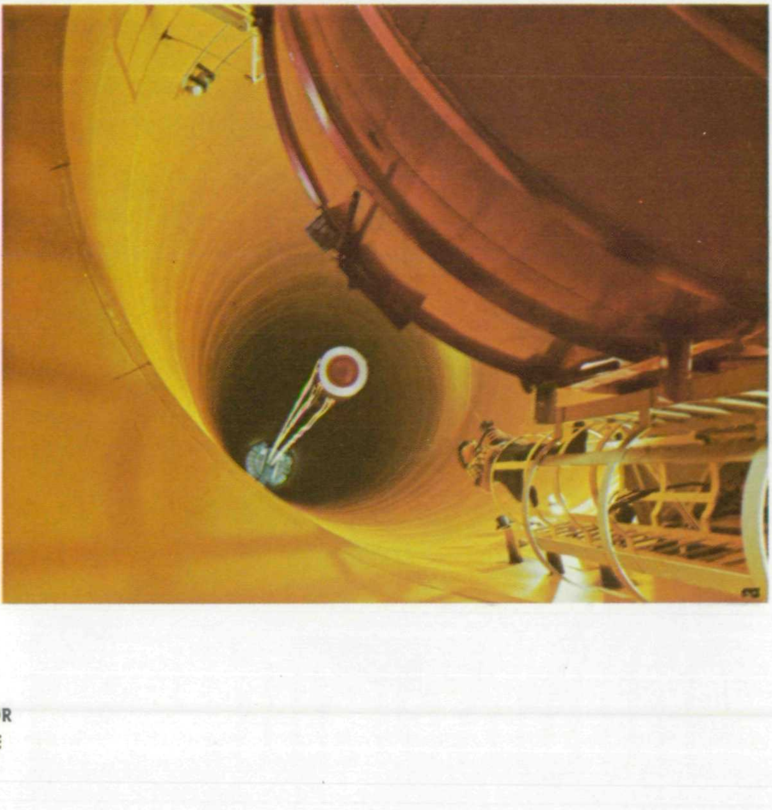
COLOR PLATE 10

This photograph was made during engineering impact studies. A high-speed gun generates high-velocity particles which impact on a bed of sand. This picture of the impaction shows the shock heating of the particles. The contact area of sand has also been used to simulate the lunar surface and study the formation of craters.

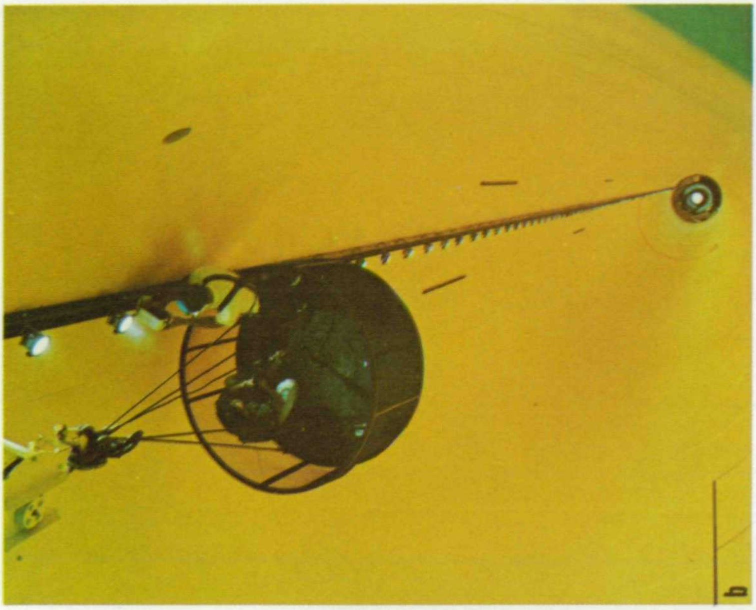
This is an analysis photograph of the high impact studies on the sand target. After an impact, the sand target is baked. The bed of sand is mixed with a thermosetting resin which, upon baking, causes the hardening of the sand in the pattern that occurred as a result of impact. The sand also contains the color segments which are added as vertical elements to show the flow of the sand as impact occurs. After this sand target was baked, it was sawed in half to take the picture shown here, with graphical precision so actual measurements can be taken from striped patterns.



COLOR PLATE 11

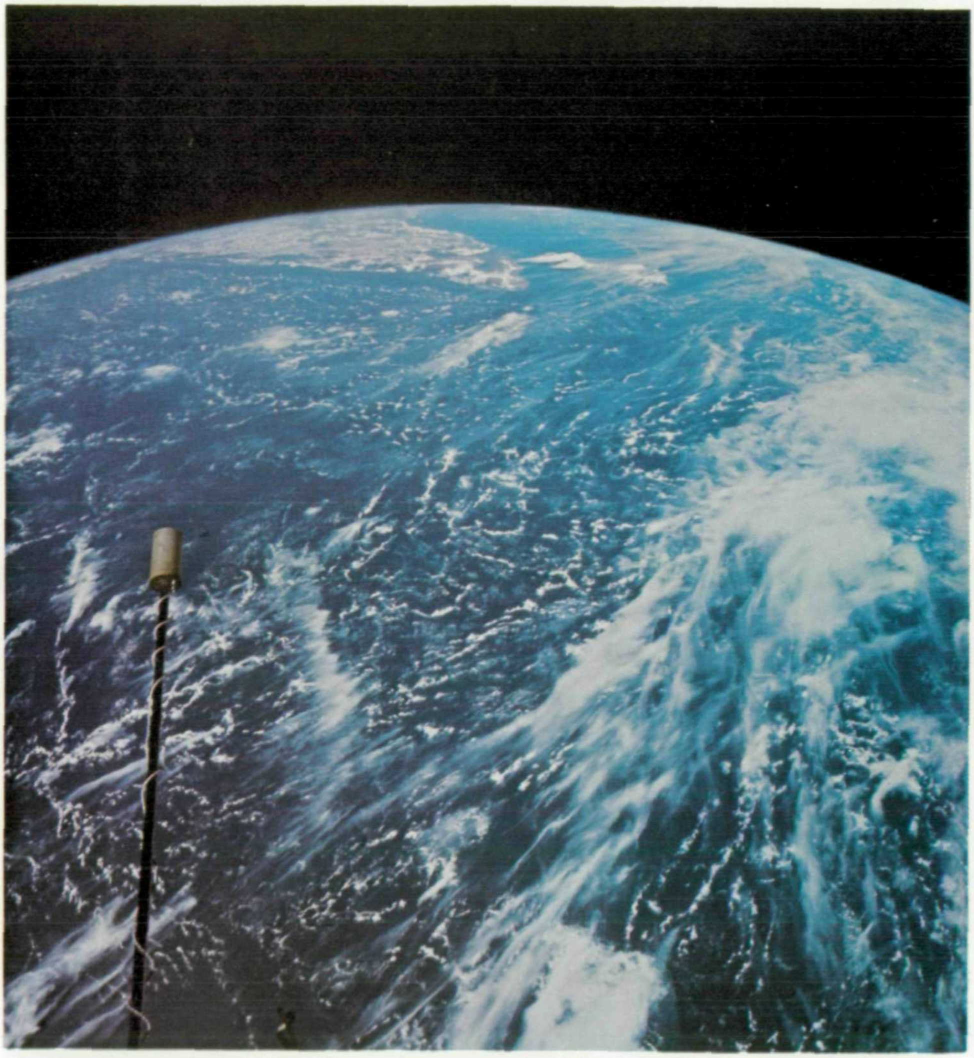


A photograph of the Zero Gravity Drop Tower at Lewis Research Center in which photographic equipment is in the drop packages to record test events.



The installation of lighting and cameras in the Zero Gravity Drop Tower at Lewis was difficult because of the immensity of the test chamber. This figure depicts the raceway assembly for camera location along the vertical test path. Lighting is shown installed while the technicians are preparing a camera.

COLOR PLATE 12



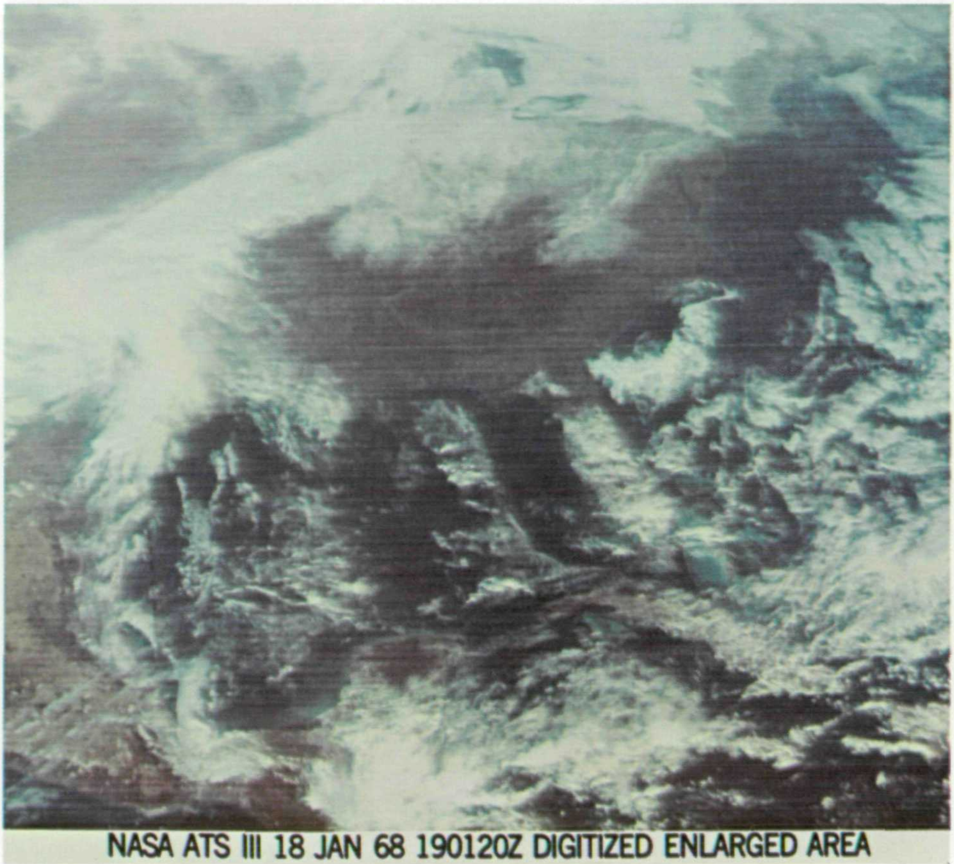
During the Gemini XI mission, the astronauts were able to see how clouds developed and changed in the brief time it took the spacecraft to circle the world. India and Ceylon are near the horizon at the left. Cumulus congestus, seen on the previous orbit over Ceylon, had become cumulonimbi, with elongated anvillike tops extending nearly 100 miles to the Indian coast, by the time this photo was taken. Over the Indian Ocean in foreground, dense cirrus and cirrostratus clouds hid many low-level convective clouds.

COLOR
PLATE
13

NASA ATS III MSSCC 18 NOV 67 150303Z SSP 49.16°W 00.03°S ALT 22240.59 SM

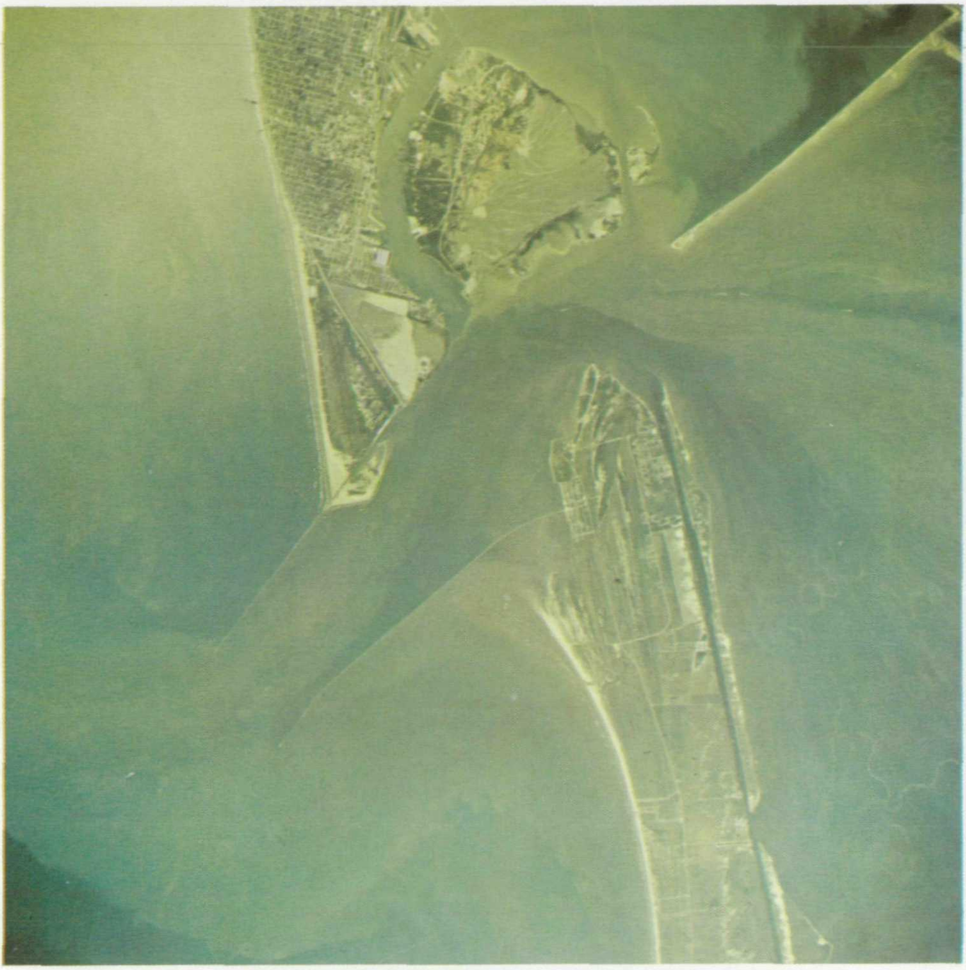
This color photograph of the Earth came from the Application Technology Satellite (ATS III). Real-time video scanners stored information on magnetic tape aboard the vehicle. The information was then transmitted to the ground and used by the Environmental Science Services Administration to reconstruct this view for weather analyses.

COLOR
PLATE
14



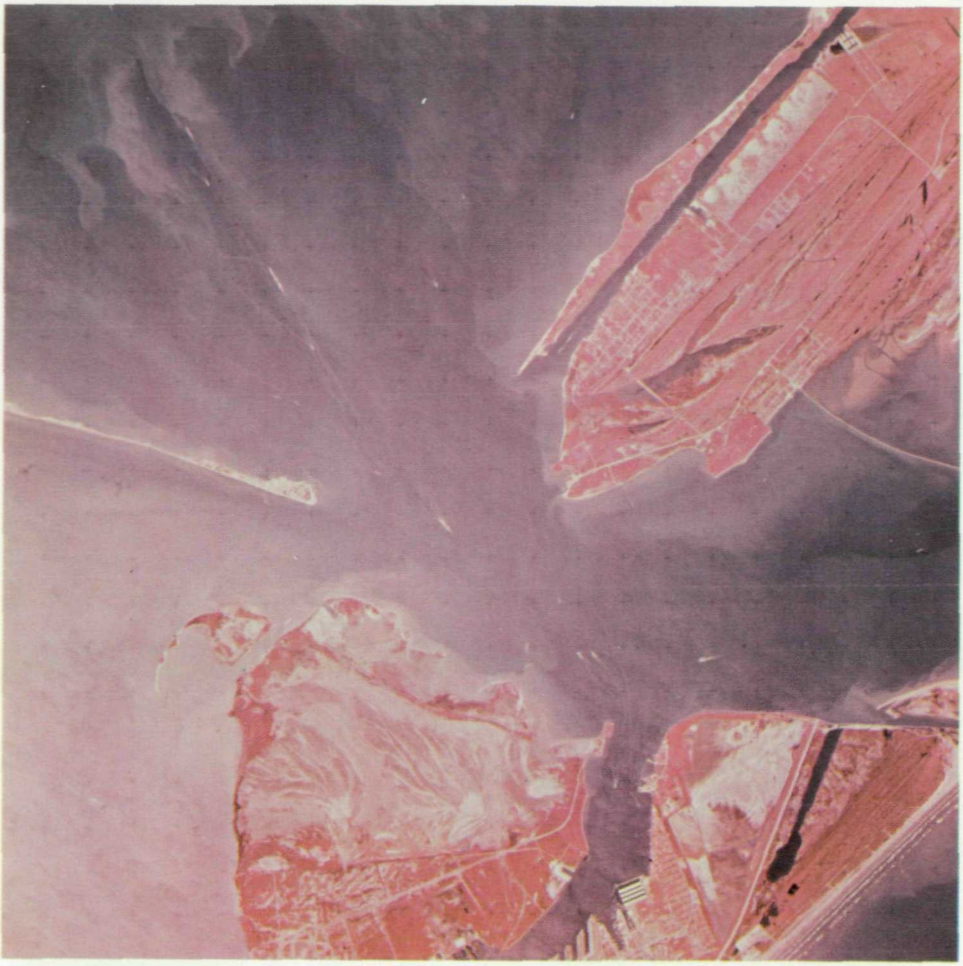
This figure demonstrates the sampling of a picture. It is a portion of a view of the entire world from the Application Technology Satellite (ATS III); it shows the Gulf of Mexico surrounded by Mexico, United States, Florida, and the Caribbean Islands. This reconstruction is done on a digital basis; commercial television reconstructs picture elements in an analog or continuous variation form.

COLOR
PLATE
15



For hydrology studies, pictures such as this taken with conventional color from aircraft, yield significant information about turbidity and the flow of turbulent materials, which can be helpful in dealing with air and water pictures.

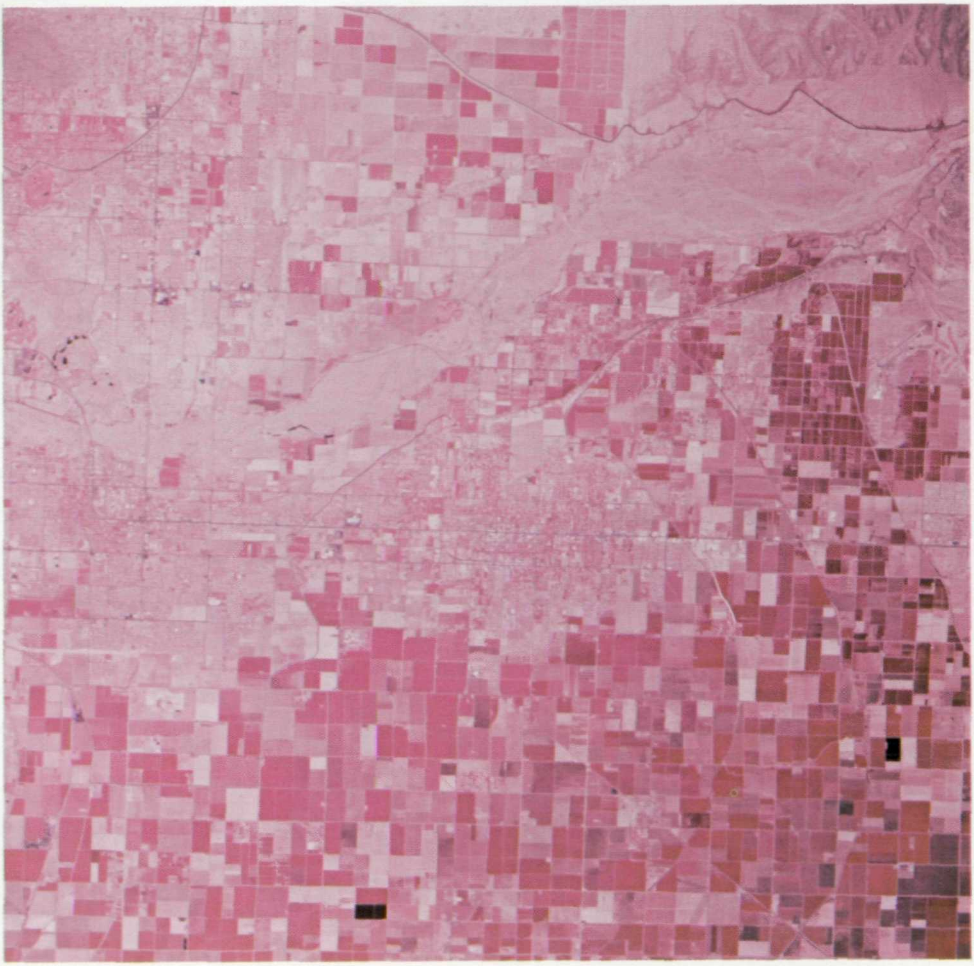
COLOR
PLATE
16



The false-color infrared pictures taken of water areas provide a high degree of sensitivity to botanical growth in water which influences feeding patterns of fish.

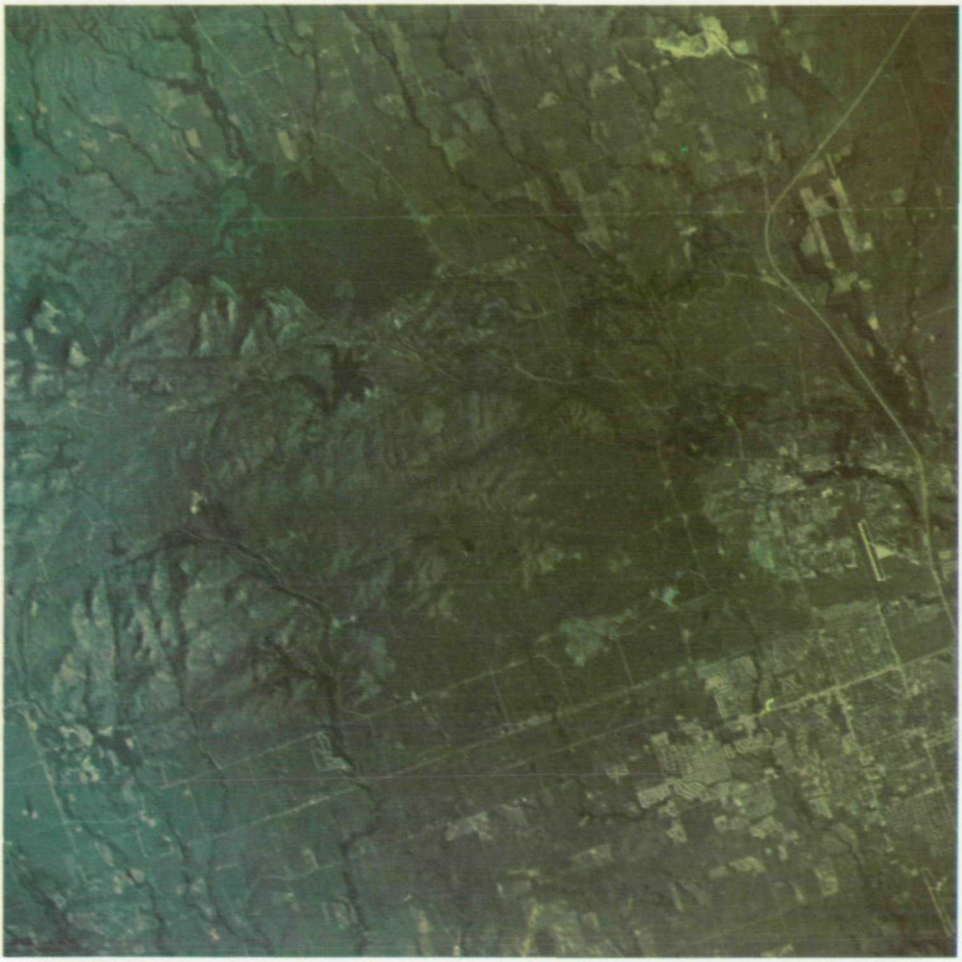
COLOR
PLATE
17

False-color infrared film is used to study agricultural problems. The high reflectivity of chlorophyll to infrared radiation is significant in noting plant growth. The arability of various land masses is reflected in the amount of chlorophyll developed in the plants and, consequently, in the depth of the infrared reflectivity.



COLOR
PLATE
18

This is a conventional color photograph from an aircraft. It shows land mass in a way applicable to recording geographical and cartographical information.



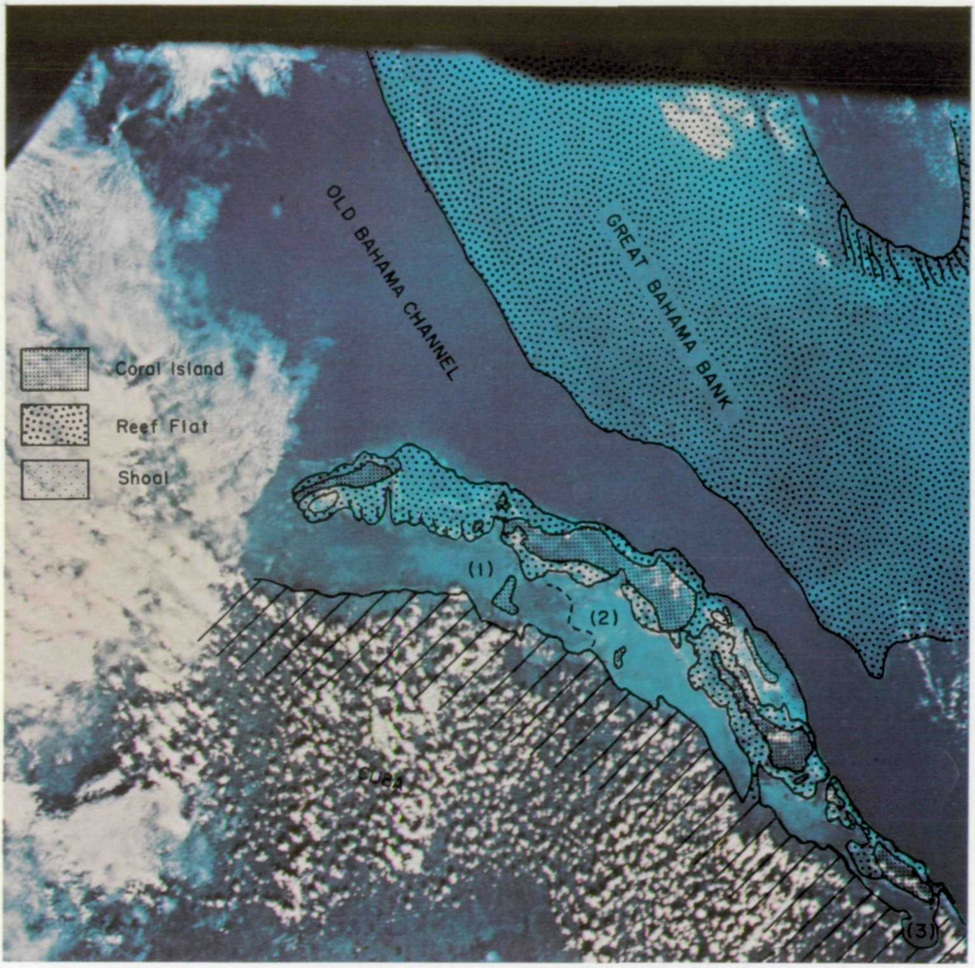
COLOR
PLATE
19

False-color infrared film is used to define geological structure in a more definitive manner than ordinary color film.

COLOR
PLATE
20

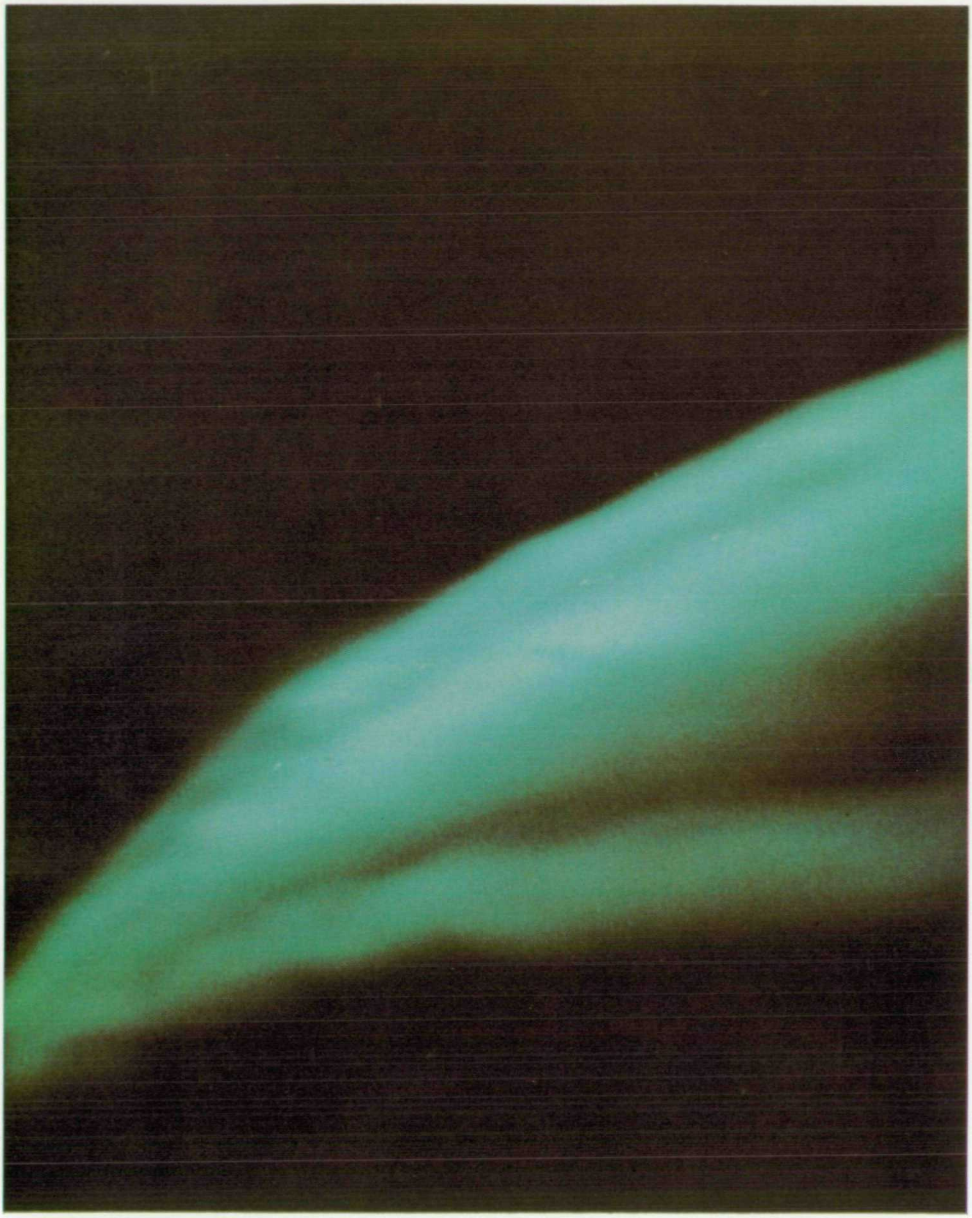
This photograph was taken at Walker Lake, Nevada, a desert region. The red patterns in the water show plankton algae growth.

COLOR
PLATE
21



A typical Earth Resource picture shown with overlay data printed on the picture. This is a view of Cuba's northern coast, the Great Bahama Bank, and the Tongue of the Ocean, taken from Gemini VII.

COLOR PLATE 22



In the 1968 and 1969 Airborne Auroral Expeditions, the NASA Convair 990 airplane, "Galileo," was used as a high-altitude, mobile platform for observing the aurora borealis. This photo is typical of the many taken from the airplane. It was taken just before midnight on November 26, 1969, from an altitude of 39,000 feet near Fort Churchill, Manitoba, Canada.

COLOR
PLATE
23

This low-level photo of the South Peninsula region along San Francisco Bay illustrates use of photography for regional and local control of land-use development and zoning conformity. Notice how well one can define the existence, style, and shape of improvements such as swimming pools and detect changes in housing and developments for which permits and specifications are required, and obtain rapid information for tax assessments. The color infrared sensitive film also shows the health of vegetation.

COLOR PLATE 24

Photographic Films

Many types of photographic film are available to NASA and several types are generally used in individual operations. This chapter presents a consolidated review of the principal film characteristics and a listing of the representative types of films that NASA has used, with comments on their general availability for use by industry in solving many similar problems. Reference 26 is a comprehensive report on requirements of photographic film on the lunar surface, with specific recommendations for films to meet operational requirements.

The photographic materials or films described here are those in which a silver-salt reaction is the basis of the photochemical process. Such silver-salt reactions provide the fastest speed or the greatest sensitivity to light or other radiation. Non-silver-salt processes are broadly applied, but they are not associated with pictorial or picture-taking photography. A general discussion of the basic principles of the photographic process, excerpted from a NASA report, is presented as an appendix.

Photographic films may be defined by the characteristics of the film material, application, color sensitivity, tone reproduction, contrast, and speed. The following is a set of generally accepted definitions, based on these parameters, of the various types of photographic film.

MATERIAL CHARACTERISTICS

A *negative-working material,* which is typical of the basic silver-salt process, is one in which the tones are reversed in making the reproduction. Where there is brightness or a highlight in the original scene, there is darkness in the picture that is generated. Conversely, the shadows or dark areas of the original scene appear as light areas in the reproduction. This is also true of materials which are used to reproduce other photographic originals. In these white becomes black and black becomes white, giving reverse tone rendition.

A *positive-working material,* which is characteristic of some nonsilver system, is able to reproduce a tone directly, lights appearing as lights in the reproduction and darks appearing as darks.

A *reversal material* is a silver material whose inherent characteristics may be reversed by means of a multiple-step process, so that a positive working image is produced on the material. The distinguishing characteristic of the film is that the positive rendition is generated in the subsequent processing of the film, rather than being an inherent characteristic of the photosensitive system itself.

APPLICATION

Unfortunately, ambiguities have crept into the vocabulary of photographic science over the years and the trade names of many products incorporate these ambiguous definitions. Thus, the term "negative" is used to define films both on the basis of their characteristics and that of their applications. A *negative* film is one which has negative working characteristics and is basically used as the camera film for taking the picture of the original scene.

A *positive* is also a negative-working material, but this identifying terminology derives from the fact that it is a reproducing material used, in the second stage of the photographic process, to print from the negative the tone values of the original scene. In basic photography, the negative is defined as that which is taken by the camera, while the positive is the paper or other print resulting from the development process. The term *positive* is also applied to print material used to make a working projection transparency or a motion-picture film that renders the tone of the original scene.

The term *reversal* is employed here in the same sense as implied under *Material Characteristics*. Reversal film is used to produce a first-generation positive working reproduction of the original scene by manipulation of the development process.

COLOR SENSITIVITY

The third characteristic used to define films is the basic color sensitivity of the photosensitive material.

A blue-sensitive material has the inherent sensitivity of the silver salt to the ultraviolet and blue light of the visible spectrum.

An orthochromatic material is one that has an extended sensitivity to provide response to both the blue and green regions of the visible spectrum.

A panchromatic material is one that has full sensitivity to all colors of the visible spectrum including the blues, greens, and reds.

An extended red panchromatic material is the basic panchromatic material but with the sensitivity extended as far as possible in the visible red region of the spectrum and approaching the very near infrared in its response.

An infrared-sensitive film is one that has been sensitized to respond to the near-infrared radiation of the spectrum. Such films retain their characteristic sensitivity to blue light and near ultraviolet and thus require a filter that absorbs the ultraviolet radiation if the full benefit of infrared recording is to be obtained.

TONE RENDITION

Films may also be defined by the type of tones that are reproduced. A *black and white,* or *monochromatic,* film is one that reproduces all the values of the luminance in the original scene in terms of a nearly neutral scale without respect to the color which produced original scene brightness. The basic silver process produces all tones, regardless of the color which caused them, in some shade of black, gray, or white.

A *color film* is one which, by using separate layers, is capable of reproducing different colors of the visible spectrum in terms of different colors in the reproduction. When not otherwise specified, a color film is identified as one which reproduces all the colors of the spectrum in terms of their original hue, saturation, and lightness as faithfully as the process will allow. Color negative films, in addition to reproducing reversed tone values, also reproduce in complementary colors so that a second generation, or copy, of a color negative produces the positive with approximately correct tone, hue, and saturation.

There are two basic types of color film: daylight A type which, as its name implies, is balanced for pictures taken under ordinary daylight conditions, and tungsten A type which is balanced for pictures taken under artificial studio lighting.

A color film which reproduces scenes in colors other than the naturally expected colors of the scene (and this has certain advantages in some scientific work) is generally called *false color* film. Reference 27 reports the decision to utilize outdoor-type color reversal films following experiments with calibrated color targets exposed during Gemini X extravehicular activity (EVA). The purpose of the experiment was to seek an explanation for the frequent differences between the crew's interpretation of color rendition and that shown in flight films. Normal outdoor color film is balanced for a combination of sunlight and blue skylight which is not present in space. It can be stated, nevertheless, that available color film is generally balanced to the solar spectrum in space and that the effect of ultraviolet energy appears to be negligible to image degradation.

CONTRAST

Another identification is by the contrast of the system. A physically ideal film would reproduce tone values in exactly the same order and magnitude as they appear in the original. It has been shown, however, that pictures acceptable for viewing generally reproduce tone values with somewhat larger differences than those in the original scene. Films that give reproduced tone values in which the degree of separation between individual tones is less than in the original are usually described as low-contrast materials. A low-contrast material is generally used as an intermediate step. High-contrast materials, where the degree of tone separation is greater than that reproduced, are generally employed as the end product for evaluation or inspection. For certain scientific applications, pictures are taken on high-contrast negatives that are evaluated without further reproduction.

SPEED

One other measured characteristic used to define films is speed or sensitivity. This is a measure related to how much or how little light is required to produce a usable image on the film. Films used

TABLE 4.—*Some Typical Photographic Films Used in Space Missions*

Name	Manu-facturer	Type	Speed*	Availability
Super Anscochrome	GAF	Color Reversal	125	Superseded
Ultraspeed Anscochrome	GAF	Color Reversal	200	Superseded
Anscochrome D–200	GAF	Color Reversal	200	Basic film—yes Special base—no

TABLE 4.—*Some Typical Photographic Films Used in Space Missions*

Name	Manufacturer	Type	Speed*	Availability
Anscochrome D-50	GAF	Color Reversal	50	Superseded
SO-217	EK	Color Reversal	64	Available as Ektachrome MS (this base on special order)
SO-368	EK	Color Reversal	64	Available as Ektachrome MS (this base on special order)
SO-168	EK	Color Reversal	160/1000	Available as Ektachrome EF
Eastman Color Negative	EK	Color Negative	32	Commercial Type 5251
Ektachrome Infrared Color SO-180	EK	False Color Reversal	100	Commercial Type 8443
Blue Insensitive SS48895	GAF	False Color Reversal	800/1000	Experimental—Special Request
SO-164	EK	Black and White or Negative	20	Available as Panatomic X Recording Type 3400
Type 2475	EK	Black and White or Negative	1250	Commercial
Type 2485	EK	Black and White or Negative	1250/8000	Commercial
SO-121	EK	Color Reversal	50	Commercial, High Definition Color Film
SO-246	EK	Black and White Infrared		Commercial, Type 5424
SO-267	EK	Black and White		Commercial, Type X 2405
Type 3400	EK	Black and White		Commercial, Plus Aerial
SO-349	EK	Black and White	20	

GAF=General Aniline & Film Corp.; EK=Eastman Kodak.

*Film speed is given in typical exposure index values that are used for determining camera settings.

for hand-held photography in pictorial work are conveniently characterized by an exposure index number that is used in calculating the proper exposure setting from the light level of the scene, which is usually measured with an exposure meter. The numbers given under the heading "Speed" in table 4 are those given by the manufacturer for use with exposure meters calibrated by the American Standards Association system (the ASA has recently been renamed the "United States of America Standards Institute"). The sizes of the films, which are given in the table as either 35 mm or 70 mm, indicate the width of the film in millimeters.

NASA relied on commercially available films for the initial missions, but the desire for a much greater number of photographs on the later missions required photographic films constructed on a much thinner film base to reduce the bulk and weight.

The pictorial photographic experiments on the missions did not dictate a need for changes in emulsion technology, but they did stimulate the development of modern high-speed color reversal films with film emulsion speeds up to 50 times that of color films of 20 years ago. In this area the major significant advance fostered by NASA requirements was the development of modern color photographic emulsions on a thin, dimensionally stable polyester-film base with good optical properties. These provide for the low-bulk, low-weight film necessary for the large number of photographs required of the space missions.

In its selection of films, NASA has attempted to avoid diversity in order to simplify and standardize the purchase, storage, use, and processing of the films and to enjoy great flexibility with respect to the films available at all points required. While all types of normal commercial films can be used for Earth activities, some special considerations apply to space films. They are normally made on a polyester-film base. This film base is available on a number of commercial films. Now, due primarily to the stimulation of NASA in specifying its use on films to be exposed in the space environment, a high-strength polyester film is available. This allows a thinner base to be used, thus permitting more effective usable exposure area of film in a given space in a camera. As an example, a specific magazine which would hold 20 exposures of a normal film base may hold as much as 40 exposures on the thinner base film.

The polyester base has good dimensional stability, which is an important asset in the photogrammetric analysis of the pictures with the Lunar Data Camera. The polyester-base films are also required in the low-pressure environment of space, because they have less tendency to give off solvent vapors than the normal cellulose-based film supports generally used for photographic films. Color negative films were used in early missions because of the extreme versatility of control in producing final prints, as well as the latitude of color negative films in permitting acceptable pictures to be obtained under a wide variety of adverse exposure conditions. It should be recognized, however, that within these capabilities, there lies a difficult technical deficiency in the program operations, that is, there is no control to permit proper printing of a color negative since one has no idea of the true color or expected color of the scene, as one does with pictures taken in the Earth-bound environment. For this reason, reversal films have been utilized for the color work taken from space.

In planning the Apollo missions, a hermetically sealed magazine was considered to maintain a suitable environment for the film. Many years of experience had included the use of photographic film in vacuum systems such as electron microscopy and electron beam recording, and this experience indicated that the disturbance caused by the vacuum environment should not prove too serious. This was confirmed by tests of extended exposure to vacuum conditions, and the Apollo 11 and Apollo 12 missions were carried out with a conventional unsealed magazine. Thus the film was exposed to the high-vacuum lunar environment. The results of these missions substantiated the validity of this decision and of the earlier observations.

FILM-HANDLING TECHNIQUES

The NASA centers use a wide variety of film-handling techniques, the choice depending on the film's use and ability to duplicate the pictures in the event that the film is lost or damaged. Obviously, the most critical films are those carried by the astronauts in flight. Approaching them in importance is the film used to record a nonrepetitive event, such as the liftoff of a launch vehicle. The level of critical conditions scales down through various levels to the simple case of publicity photos, which can be duplicated easily if something happens to the first set of exposures. The degree of control in film handling and processing is, therefore, a function of the subject of the photograph.

In the most critical cases, those of films used for the space missions, every effort is directed toward insuring positive control of flight films from the point of manufacture to archival storage.

The films are accepted directly at the manufacturer's plant by a courier who then transports them in special NASA-provided cases, which record humidity and temperature inside the case so that the courier can continuously monitor the environment of the film during transit. Upon receipt of the films at the Manned Spacecraft Center, random samples are given both physical and photographic tests. Until the films are used, these tests are repeated every 45 days so that the most subtle changes in film characteristics can be noted. Such testing is done in a clean room at the center.

A test section from the beginning of every roll of film is given a series of precisely controlled exposures, each consisting of an exact quantity of light of a specific color. After the film is used and processed, scientific measurements of these test exposures, known in the trade as sensitometric strips, are compared with standards to determine any existing variations.

Prior to a given mission, the film is again transported by courier and special packages from the Manned Spacecraft Center in Houston to the Kennedy Space Center in Florida. Very strict rules specify the amount of time that film can be held in controlled storage, in an uncontrolled environment, or in actual cameras between loading and use.

After a spacecraft returns to Earth, cameras and film magazines are taken from it as soon as it is put aboard the recovery ship. The technician in charge of the photographic operation at that point inspects the films and repacks them in one of the special film-handling cases that are monitored for both humidity and temperature. The astronauts also give him any special information about the film and the exposures used and some estimations of the most significant pictures. These are given priority in processing. The film is again transported under the watchful eyes of the courier. At the Manned Spacecraft Center, the package is opened in the presence of senior personnel and the film magazines are inspected for physical damage. Next the magazines are opened and the exposed film transferred to special storage cans to await processing.

Processing may involve both specially designed equipment and standard commercially available machines. Prior to receipt of the film, all processing facilities are prepared for critical demands of the program. Before a mission, the equipment is disassembled, cleaned, and overhauled. After it has been reassembled and the chemicals prepared, samples of the type of film from the same roll used on the mission, again with the test exposures or sensitometric strips, are processed so that the chemicals and equipment are at predetermined optimum operation. Such test strips are processed and evaluated immediately before space film is processed, the procedure being repeated at frequent periodic intervals to insure the continued stability of the chemical solutions. The test exposures used while the actual space films are processed represent those on film taken directly from storage, as well as those made before the flight. In this way, compensation can be made for differences due to carrying the film through the various environments of space.

Even though all processing takes place in a completely darkened room, trained technicians in the processing units know the exact location of a film at any time and are ready to take corrective action should a problem arise. As soon as the film has been completely processed, a master reproduction is made from the original, which is then committed to storage. This master, or first generation, reproduction is used to produce all the prints in the transparencies released to the press and public. Some of the steps used in making multiple sets of reproductions to produce duplicate and release copies with opportunities for editing are outlined in figure 56.

All films which require special processing by reason of overexposure or mishandling by the astronauts are generally processed last. If there is any doubt as to the effects, duplicate films are prepared and put through the same conditions as those reported by the astronauts, and a processing technique developed for them.

For pictures taken on the Moon, cameras, magazines, and films were put through a decontamination procedure at the Lunar Receiving Laboratory. Control films, again with the special test exposures, were also put through the decontamination procedures and checked for adverse effects so that necessary corrections could be introduced in the processing.

A magazine loaded with highly sensitive film was confused with one loaded with low-speed film during the Apollo 8 flight. The high-speed film received nearly 1000 times the required amount of exposure. Special development procedures were worked out nevertheless, which permitted the recovery of usable images on this overexposed film.

In addition to basic laboratory processing, film may be processed aboard space vehicles. References 28 and 29 describe systems that have been used by the military for a number of years. They are designed to expose film and put it through some sort of rapid processing system for immediate evaluation by onboard reconnais-

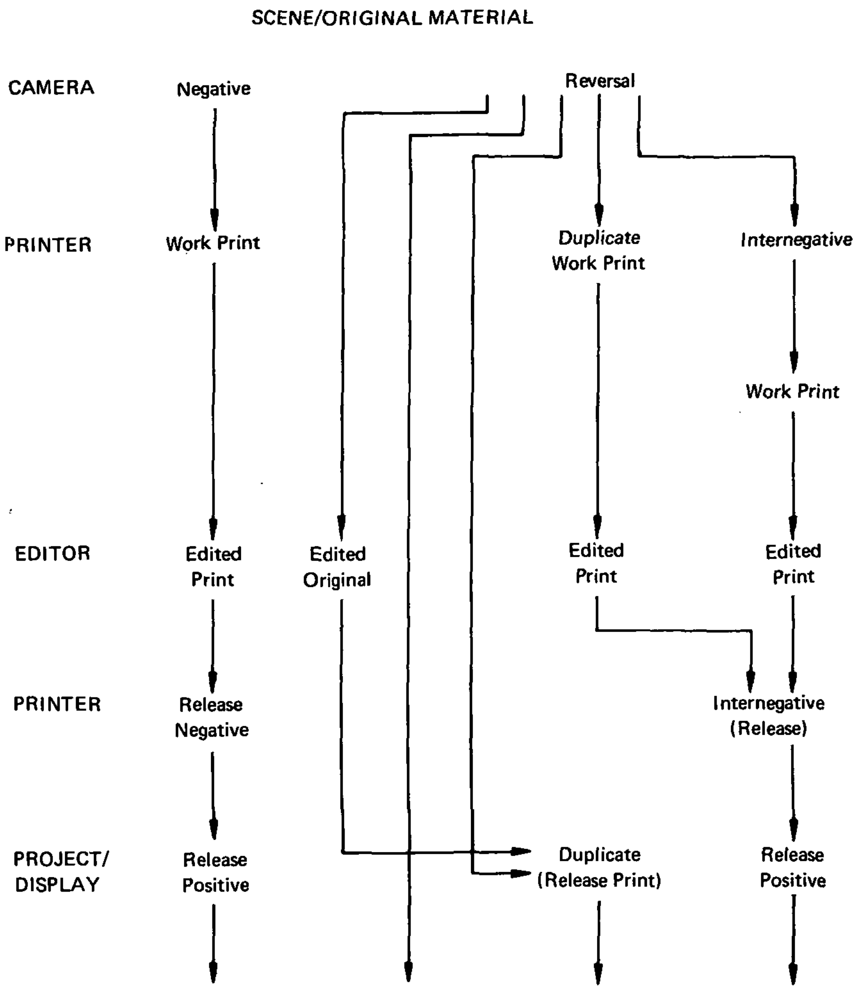


FIGURE 56.—Some of the alternate steps in preparing final pictures in both motion picture and still photography. The steps apply to both black and white and color, except that internegative processes have primarily been used in color.

sance officers. Such systems have been used for high-resolution or high-information capacity photorecording systems. The image is recorded on film, then put through a rapid processor for immediate scanning. The image is scanned with a low-bandwidth system which transmits large amounts of information over a longer period of time than the camera could focus on the subject for adequate scanning by video systems. The photographic film, in essence, becomes a time compression system and the video transmission becomes a time expansion system. The references describe such a system that is under investigation for use on planet-reconnaissance systems in the late 1970's.

SUMMARY

This survey of photographic systems in NASA programs may suggest to others what photography may do for them.

Some general contributions to photographic technology that have resulted from the NASA program are:

The development of techniques for making cameras more utilitarian in restricted operational environments, specifically leading to the development of techniques for one-hand operation by persons wearing heavy gloves. This could lead to a more general use of photography under adverse conditions.

The development of high reliability systems which may have significant applications in other scientific and technical fields, such as oceanographic studies, terrestrial exploration, and archeology, when cameras must be left in remote areas for extended periods and remain functional, or must be operated remotely for long experimental time periods.

The stimulation of the development of the high-speed color reversal films, which culminated in films having sensitivities 50 times those of the versions of 20 years ago.

The expanded development of the lightweight, low-bulk photographic films for applications where a large number of photographs must be acquired despite constraints on weigh and bulk.

The development of effective equipment and techniques to provide acquisition of cartographic data from hand-held cameras where the usual techniques are not feasible.

The development of camera systems capable of being operated in, and recovered from, remote environments in unmanned vehicle exploration programs.

The development of stabilization systems for vehicle-mounted cameras.

Improvements in the design, installation, and operation of multicamera systems for multispectral photography.

Improvements in long-range theodolite and tracking photographic systems and the development of suitable reference bases for engineering analysis.

Design, development, and implementation of a large number of diverse systems and equipment for quantitative analysis in support of engineering research programs. This has led to the use of such photographic systems as a valuable instrumentation technique.

Improvements in systems and techniques for the examination of the Earth from remote locations above the surface and in outer space.

The accomplishments of NASA in photographic recording and documentation can also be considered an example of visual communication for social ends.

References

1. BRINKMAN, J. R.; AND EGGLESTON, J. J.: Photographic Requirements for Manned Space Missions. S.P.I.E. J., vol. 3, no. 3, Feb.–Mar. 1965, pp. 83–89.
2. EGGLESTON, J. M., et al.: Space and the Moon—Photography's Challenge for Tomorrow. NASA TM X–51878, 1964.
3. BORGESON, W. T.; AND BAATSON, R. M.: Photogrammetric Calibration of Apollo Film Cameras. NASA CR–101363, 1969.
4. J. A. MAURER, Inc.: Wide Spectral Range Lens for 70mm Hand-Held Gemini Camera. Final Report. NASA CR–65097, 1965.
5. ELLE, B.; AND WILSON, W. C.: The Apollo Surface Close-up Camera. Paper presented at 23d SPSE Annual Conference (New York), May 1970.
6. WALSH, T. M.: Factors Affecting the Design and Use of a Photographic Sextant for Space Navigation. NASA TN D–4285, 1967.
7. MORRISON, A., et al.: Photography of the Western Sahara Desert from the Mercury MS–4 Spacecraft. NASA CR–124.
8. FITZ, J. F.: Solid State, Sequential Camera Trigger Circuits. NASA TN D–2826, 1965.
9. ANON.: Report of the Geodesy/Cartography Working Group. *In:* NASA 1965 Summer Conference on Lunar Exploration and Science, 1965, pp. 57–76.
10. ANON.: Proceedings of the Third Aerospace Mechanisms Symposium. NASA CR–97758, 1958.
11. THORNWALL, J. C.: Solid-State Wide-Range Low Power Camera Timer for Space Applications. NASA TM X–5529, 1966; now available as NASA TN D–3756, 1967.
12. ALLEN, J. D.: Photographic Study for the Apollo Telescope Mount. NASA CR–94389, 1967.
13. WEITBRECHT, R. H.: High-Definition Photography of Project Echo 1 Satellite. Final Report. NASA CR–53146.
14. LEE, R. S.: Pulse-Train Generator for Rocket Camera. NASA TM X–1390, 1967.
15. THORNWALL, J. C.: Solid-State Wide-Range Low Power Camera Timer for Space Applications. NASA TN D–3756, 1967.
16. MOZER, C. P.: Electronic Shutter Control for Planetary Photography with Automatic Time Recorder Capability. NASA CR–69488, 1965.
17. YOST, EDWARD; AND WENDEROTH, SONDRA: Precision Multispectral Photography for Earth Resources Applications. NASA CR–92360, 1967.
18. CRONIN, J. F.: Terrestrial Science Laboratories. NASA CR–84495, 1967.
19. KOOMAN, M. J.; SEAL, R. T., JR.; AND J. L. LINTOTT: Airglow Horizon

Photography from the Gemini Spacecraft. *In:* Report of Naval Research Laboratory Progress, Aug. 1967, pp. 5–11.

20. MARBLE, DUANE; AND THOMAS, EDWIN: Some Observations on the Validity of Multispectral Photography for Urban Research. *In:* Proceedings of the Fourth Symposium on Remote Sensing of the Environment, June 1, 1966, pp. 135–144.
21. DERR, ALBERT J.: A Challenge to Photography for Information Recording: Introduction to Seminar on Depth Image Information Recovery, Society of Photo-optical Instrumentation Engineers, Philadelphia, Pa., Oct. 24, 1968. SPIE Proceedings, pp. 86 and 327.
22. ANON.: Lunar Orbiter. NASA Facts, vol. 4, 1967.
23. BRADLEY, GEORGE: Lunar Orbiter Photo-Subsystems Mechanisms: In Jet Propulsion Laboratories Second Aerospace Mechanisms Symposium, Aug. 15, 1967, pp. 33–40 (Contract NAS1–3800).
24. LOWMAN, PAUL D., JR.: Geologic Applications of Orbital Photography. NASA TM X–55274, 1967.
25. ANON.: Ecological Surveys from Space. NASA SP–230.
26. WYCKOFF, C. W., et al.: A Study to Determine the Optimum Design of a Photographic Film for the Lunar Surface Hand-Held Camera. Final Report. NASA CR–92015, 1965. (Portion reproduced as Appendix.)
27. ANON.: Manned Spaceflight Experiments and Film Process or Final Engineering Report. NASA CR–68973, 1965.
28. HAINES, G. L.: Camera and Film Process or Final Engineering Report. NASA CR–68973, 1965.
29. KOSOFSKY, L. J., et al.: Lunar Orbiter: A Photographic Satellite. NASA TM X–56207, 1965.

Bibliography

ANON.: Canaveral Council of Technical Societies: Third Space Congress: The Challenge of Space, 1966.

ANON.: Data Systems Div.: Scan Converter Feasibility Study. Final Report. NASA CR-65050, 1965.

ANON.: Eastman Kodak Co., Rochester, N.Y., Apparatus and Optical Div.: Photographic Laboratory, Portable ES 39 (XH 11) (Contract AF 33 657 10437). (Available from CFST, DDC as AD 615619.)

ANON.: Fairchild Camera and Instrument Co.: Photogrammetric and Photometric Objectives and Capabilities of the Surveyor Lander TV Experiments. Final Report. NASA CR-59879.

ANON.: Gemini Midprogram Conference Including Experimental Results. NASA SP-121, 1962.

ANON.: Gemini Summary Conference, Chapter on Space Photography, NASA SP-138, 1967.

ANON.: General Electric Co.: Voyager Spacecraft Phase B, Task D, Vol. 4: Engineering Tasks. Book 5: Photo Imaging. Final Report. NASA CR-93351.

ANON.: Goerz Optical Co., Inc.: Engineering Study Program to Determine the Optimum Design for a Hand-Held Camera to be Used on the Lunar Surface: Final Report. NASA CR-65051, 1965.

ANON.: ITT Industrial Labs.: Continuous Scanning Meteorological Camera System for ATS. Final Report, Sept. 22, 1965–Sept. 10, 1967. NASA CR-92709, 1967.

ANON.: ITT Industrial Labs.: Image Dissector Camera Subsystem, Associated Group Support Equipment, and Integration Support for Applications Technology Satellite. Quarterly Report, Nov. 17, 1966–Feb. 17, 1967. NASA CR-91350, 1967.

ANON.: ITT Aerospace, Optical Div.: Image Dissector Camera Subsystem Associated Group Support Equipment and Integration Support for Applications Technology Satellite. Final Report, May 17, 1966–Nov. 17, 1968. NASA CR-100328, 1968.

ANON.: Jet Propulsion Lab., California Inst. Technol., Pasadena,: Second Aerospace Mechanisms Symposium, Aug. 15, 1967.

ANON.: Jet Propulsion Lab., California Inst. Technol.: Surveyor I Mission Report. Part II. Scientific Data and Results. NASA CR-79150, 1966.

ANON.: Jet Propulsion Lab.: Surveyor III Mission Report. Part II. Scientific Results. NASA CR-88952, 1967.

ANON.: Lunar Orbiter, NASA Facts, vol. 4, no. 4, 1967.

ANON.: Lunar Orbiter 5: Photography. Final Report. NASA CR-1094, 1968.

ANON.: Manned Space-Flight Experiments, Gemini IX Mission. Interim Report. NASA TM X-59315, 1966.

ANON.: Nimbus I Automatic Picture Transmission (APT) TV-Camera System. NASA TM X-55669, 1966.

ANON.: Proceedings of the Conference on the Exploration of Mars and Venus. Virginia Polytechnic Inst., Aug. 1965. NASA CR-76363.

ANON.: Proceedings of the Third Symposium on Remote Sensing of Environment, Oct. 14–16, 1964. Report No. 4864-X (CFSTI No. AD 614032).

ANON.: Proceedings of the Fourth Symposium on Remote Sensing of Environment, Apr. 12–14, 1966 (Contract NONR-1224(44)), CFSTI No. AD 614032).

ANON.: Proceedings of the Space Optical Technology Conference, Vol. I: NASA TM X-61037, 1966.

ANON.: Publications of Goddard Space Flight Center, 1964. Vol. II: Space Technology. NASA TM X-57970, 1965.

ANON.: Radio Corp. of America: Design Report for the Tiros Operational Satellite (TOS) System. NASA CR-75197, 1964.

ANON.: Radio Corp. of America: Ranger TV Subsystem Flight Evaluation Report for Flight Model III (RA-8). NASA CR-83784, 1965.

ANON.: Radio Corp. of America: Ranger TV Subsystem Flight Evaluation Report for Flight Model III-L (RA-6) and Design Review Report. NASA CR-73783, 1966.

ANON.: Radio Corp. of America: Tiros X Meteorological Satellite System, Vol. 1. Final Engineering Report. NASA CR-75257, 1966.

ANON.: Report of Geodesy/Cartography Working Group: *In:* Conference on Lunar Exploration and Science, July 1965, pp. 57–76. NASA SP-88.

ANON.: TEW Systems Group: Voyager Spacecraft, Phase B. Task D, Vol. II: Engineering Study Task: Photoimaging System. Final Report. NASA CR-93526.

ANON.: Tiros, the First Weather Satellite. NASA, 1964.

ALLEN, J. D.; HAPPE, R. A.; MICHAEL, L. M.; REHNBORG, E. H.; AND L. M. SYNDER: Photoheliograph Study for the Apollo Telescope Mount. NASA CR-94389, 1967.

BADER, M.; AND WAGONER, C. B.: NASA Program of Airborne Optical Observations. Appl. Opt., vol. 9, no. 2, Feb. 1970, pp. 265–270.

BASHE, R.; AND KENNEDY, S.: Martian Orbital Photographic Study. Technical Summary Report. NASA CR-61854, 1967.

BASHE, ET AL.: Planetary Film Reconnaissance System. NASA CR-1358.

BILLINGSLEY, F. C.: Bimat Processing for Ranger IX. *In:* Space Programs Summary No. 37-33, vol. IV, pp. 38–40. NASA CR-64605.

BORGESON, W. T., ET AL.: Photogrammetric Calibration of Apollo Film Cameras. NASA CR-101363, 1969.

BOWLES, WILLIAM A.: Exploring in Aerospace Rocketry. 14: Rocket Launch Photography. NASA TM X-52401, 1968.

BRADLEY, GEORGE: Lunar Orbiter Photo-Subsystems Mechanisms. *In:* Jet Propulsion Lab. Second Aerospace Mechanisms Symposium, Aug. 15, 1967, pp. 33–40. NASA CR-87990.

BRINKMAN, JOHN R.; AND EGGLESTON, JOHN: Photographic Requirements for Manned Space Missions, S.P.I.E. J., vol. 3, no. 3, Feb.–Mar. 1954, pp. 83–89.

BUCHELE, D. R.: Optics at the Lewis Research Center. Appl. Opt., vol. 9, no. 2, Feb. 1970, pp. 399–403.

CARNEGGIE, D. M., ET AL.: The Evaluation of Rangeland Resources by Means of Multispectral Imagery. Annual Progress Report. NASA CR-93181, 1967.

CARNEGGIE, DAVID M.; DRAEGER, WILLIAM C.; AND LAUER, DONALD T.: The Use of High Altitude Color and Spectrozonal Imagery for the Inventory of Wildland Resources. vol. 1: The Timber Resource. NASA CR-82963, 1966.

CARNEGGIE, DAVID M.; ROBERTS, EDWIN H.; AND COLWELL, ROBERT N.: The Use of High Altitude Color and Spectrozonal Imagery for the Inventory of Wildland Resources. Vol. II: The Range Resource. NASA CR-78879, 1966.

CLOUD, J. D., ET AL.: Surveyor Spacecraft Systems: Surveyor 3 Flight Performance. Final Report. NASA CR-94392, 1967.

CLOUD, J. D., ET AL.: Surveyor Spacecraft Systems: Surveyor 3 Flight Performance. Final Report. NASA CR-93488, 1967.

CLOUGH, NESTOR; AND LIEBLEIN, SEYMOUR: Significance of Photographic Meteor Data in the Design of Meteoroid Protection for Large Space Vehicles. NASA TN D-2958, 1965.

CONROD, A.; KELLY, M.; AND BOERSMA, A.: Aerial Photography for Shallow Water Studies on the West Edge of Th—ETC(U) (Contract No. N62306-2082, CFSTI No. AD 684146), Massachusetts Inst. of Technol., Nov. 1968.

CRUMBLY, K. H.: Optics at Langley Research Center. Appl. Opt., vol. 9, no. 2, Feb. 1970, pp. 317-320.

CUSHMAN, S. F.: An Evaluation of the Stellar-Moon Camera System (CFSTI, No. AD 673270), Dept. of Geodetic Science, Ohio State Univ., June 1968.

DENNIS, L. F.; AND CARDWELL, W. L.: Optical Instrumentation Data Evaluation of the SA-204/LM-1 Saturn 18 Launch Vehicle. NASA CR-97587, 1968.

DIMEFF, J.: The Role of Optics in Research at Ames Research Center. Appl. Opt., vol. 9, no. 2, Feb. 1970, pp. 245-250.

DUNKELMAN, LAWRENCE; AND MERCER, ROBERT D.: Dim-Light Photography. *In:* Gemini Midprogram Conference Including Experiment Results. NASA SP-121, 1966, pp. 325-328.

DUNKELMAN, L.; AND PAUL, F. W.: Optics at Goddard Space Flight Center. Appl. Opt., vol. 9, no. 5, May 1970, pp. 1003-1005.

EGGLESTON, JOHN M.; AND BRINKMAN, JOHN R.: Space and the Moon—Photography's Challenge for Tomorrow. Paper presented at 9th Annual Technical Symposium, Soc. of Photographic Instrumentation Engr. (Miami Beach, Fla.), Aug. 1964. NASA TM X-51878, 1964.

FORD, ALLEN G.: Double-Acting, Rotary-Solenoid Shutter. *In:* Second Jet Propulsion Lab., Aerospace Mechanisms Symposium, Aug. 15, 1967.

GAMBARO, ERNEST U.: The Initiation of DOD Photo/Optical Experiments Aboard the Gemini Spacecraft (Contract AF-04(695)-269), Aerospace Corp., El Segundo, Calif., Manned Systems Div.

GEBEL, RADAMES K. H.; DUKE, GARY L.; AND HERMANN, R.: Basic Parameters for Films and Image Intensifier-Film Combinations and Performance. Final Report (ARL-68-0073), Aerospace Research Labs, Wright-Patterson AFB, Ohio, Apr. 1968.

HARRIS, DAVID W.; AND BERBERT, JOHN H.: NASA/MOTS Optical Observations of the Anna 1B Satellite. NASA TN D-3174, 1966.

HELLER, ROBERT C.; MCCAMBRIDGE, WILLIAM F.; ALDRICH, ROBERT C.; AND FREDERICK, WEBER: The Use of Multispectral Sensing Techniques to

Detect Ponderosa Pine Trees Under Stress From Insect or Pathogenic Organisms. Annual Progress Report. NASA CR-34, 1966.

IIZUKA, KEIGO: A Method for Photographing Microwave with a Polaroid Film. Interim Report. NASA CR-94305, 1968.

JOHNSON, W. G.: Optics at Marshall Space Flight Center, vol. 9, no. 2, Feb. 1970, pp. 369-372.

JOHNSTON, A. R.; AND POWELL, R. V.: Optics at the Jet Propulsion Laboratory. Appl. Opt., vol. 9, no. 2, Feb. 1970, pp. 271-275.

KINDT, D. H., ET AL.: The Design of the Ranger Television System to Obtain High-Resolution Photographs of the Lunar Surface. NASA CR-62189.

KOOMEN, M. J.; AND SEAL, R. T., JR.: Experiment S-11, Airglow Horizon Photography. *In:* Manned Space-Flight Experiments, pp. 13-25. NASA TM-X-59315, 1966.

KOSOFSKY, L. J., ET AL.: *Lunar Orbiter: A Photographic Satellite.* NASA TM X-56207, 1965.

LAUER, DONALD T.: The Feasibility of Identifying Forest Species and Delineating Major Timber Types in California by Means of High Altitude Small Scale Aerial Photography. Annual Progress Report. NASA CR-78757, 1966.

LEE, R. S.: Pulse Train Generator for Rocket Camera. NASA TM X-55454, 1966.

LEE, R. S.: Pulse-Train Generator for Rocket Camera. NASA TM X-1390, 1967.

LINDSEY, W. F.: An Expansion of the EV System. NASA TM X-57747, 1965.

LOWMAN, PAUL D., JR.: Experiment S-5, Synoptic Terrain Photography During Gemini IV. *In:* Manned Spaceflight Experimental Symposium: Gemini Missions III and IV, 1965, pp. 15-28.

LOWMAN, PAUL D., JR.: Geologic Orbital Photography: Experience From the Gemini Program. NASA TM X-63244, 1968.

LOWMAN, PAUL D., JR.: Geologic Applications of Orbital Photography. NASA TN D-4155, 1967.

LOWMAN, PAUL D., JR.: *Geologic Applications of Orbital Photography.* NASA TM X-55724, 1967.

LOWMAN, PAUL D., JR.: *In:* Manned Spacecraft Center Gemini Midprogram Conference Including Experimental Results. NASA SP-121, 1966, pp. 347-351.

LOWMAN, PAUL D., JR.: A Review of Photography of the Earth From Sounding Rockets and Satellites. NASA TN D-1869, 1964.

LOWMAN, PAUL D., JR.: Space Photography: A Review. *In:* Oceanography from Space. Woods Hole Oceanographic Inst., Apr. 1965, pp. 73-89.

LOWMAN, PAUL D., JR.; MCDIVITT, JAMES A.; AND WHITE, EDWARD H.: Terrain Photography on the Gemini IV Mission. Preliminary Report. NASA TN D-3982, 1967.

MALLING, L. R.: Planetary Photography: Television Camera for a Geological Survey of the Planet Mars. NASA CR-68127, 1962.

MARBLE, DUANE F.; AND THOMAS, EDWIN N.: *In:* Proceedings of the Fourth Symposium on Remote Sensing of Environment, Michigan Univ., June 1966, pp. 135-144.

MASON, CURTIS C.; AND KING, ELBERT A., JR.: Lunar Surface Activities.

In: Contribution of Manned Spacecraft Center Personnel to the Manned Lunar Exploration Symposium, 1964, pp. 31–39.

MAURER (J. A.), Inc.,: Wide Spectral Range Lens for 70mm Hand-Held Gemini Camera. Final Report. NASA CR–65097, 1965.

MAYFIELD, E. B.; AND ROGERS, E. H.: Star-Field Photography and Laser Ranging Techniques for Satellite-Based Geodetic Measurements (Contract AF–04 (695)269), Aerospace Corp., El Segundo, Calif., Space Physics Lab.

MAZUROWSKI, M. J., ET AL.: Project Slope—Analysis of the Performance of the Lunar Orbiter 1 and 2 Imaging Systems. NASA CR–66494, 1967.

MCKEE, D.: Experiments D1, D2, and D6: Basic Object, Nearby Object, and Surface Photography. *In:* Manned Spaceflight Experimental Symposium: Gemini Missions III and IV. NASA, 1966, pp. 169–181.

MILLIKEN (D. B.) Co.: NASA Proptype Film Transport System. Final Report. NASA CR–80743, 1966.

MINTZER, OLIN W.: A Comparative Study of Photography for Soils and Terrain Data (CFSTI No. AD 670012), Army Engineering Photographic Labs, Fort Belvoir, Va., Apr. 1968.

MONTGOMERY, D. R.; AND ADAMS, L. A.: Optics and the Mariner Imaging Instrument. Appl. Opt., vol. 9, no. 2, Feb. 1970, pp. 277–287.

MOZER, C. F.: Electronic Shutter Control for Planetary Photography With Automatic Recording Capability. NASA CR–69488, 1965.

NAGLER, KENNETH M.; AND SOULES, STANLEY D.: Experiment S–6, Synoptic Weather Photography. *In:* Manned Spacecraft Center Gemini Midprogram Conference Including Experimental Results. NASA SP–121, 1966, pp. 353–357.

NAGLER, KENNETH M.; AND SOULES, STANLEY D.: Experiment S–6, Synoptic Weather Photography During Gemini IV. *In:* Manned Spaceflight Experimental Symposium: Gemini Missions III and IV. NASA, 1965, pp. 29, 40.

NEY, E. P.; AND HUCH, W. F.: Experimental S–1, Zodiacal Light Photography. *In:* Manned Space-flight Experiments, Gemini IX Mission, pp. 1–5. NASA TM X–59315, 1966.

PAUL, FRED. W.: Optics in NASA—a Preface. Appl. Opt., vol. 9, no. 2, Feb. 1970, p. 243.

PARIS, JACK F.: Preliminary Results from Convair 240A Mission 50, 12 June 1967, Over Mississippi Delta Area. Preliminary Report. NASA CR–96238, 1968.

PEASE, ROBERT W.; AND BWODEN, LEONARD: Making Color Infrared Film a More Effective High Altitude Sensor. Tech. Letter. NASA–117, NASA CR–101465, 1968.

RALSTON, DERWOOD, ET AL.: The Effects of Waves and Currents on Submerged Pipelines. Sea Grant Pub. 301, COE 101, Coastal and Engineering Div., Texas Engineering Experiment Station, 1969.

ROBERTS, L. W.: Optics at the Electronics Research Center. Appl. Opt., vol. 9, no. 2, Feb. 1970, pp. 335–337.

ROHRER, DONALD J.: Camera and Film Processor. NASA CR–81649, 1966.

ROSSMAN, T. G., ET AL.: Photographic Investigation of Propellant Stream Behavior in a Firing Rocket Engine, Vol. II. Tech. Summary Report, 1 August 1969–28 February 1966. NASA CR–76722, 1966.

SAGAN, CARL: High-Resolution Planetary Photography and the Detection of Life. *In:* Proceedings of the Caltech-JPL Lunar and Planetary Conference, pp. 279–287. NASA CR–76142, 1966.

SCULL, J. R.: A System for Lunar Photography and Data Transmission. NASA CR–57157, 1960.

SERPAN, C. Z., ET AL.: Report of NRL Progress. Naval Research Labs, Apr. 1967.

SHELTON, R. D., et al.: Analysis of Radiation Damage to ATM Film. NASA TM X–53666, 1967.

SIDRAN, M.: Photography. NACA RM 325J, 1966.

SMITH, O. J.: Camera Set, Still Picture, KS–71 (CFSTI No. AD 673853), Chicago Aerial Industries, Barrington, Ill., June 1968.

STAMPF, RUDOLF A.: System Performance of Meteorological Satellites. NASA TM X–54565, 1963.

STRICKHOLM, N.: HRIR Image Rectification. Final Report. NASA CR–83890, 1966.

SUMMERS, ROBERT L.: Techniques of Space Photography. Paper presented at National Electron. Conference; 1967 Student Program (Chicago, Ill.), Oct. 24, 1967. NASA TM X–52341.

TAVENNER, M. S., ET AL.: Test Results of a High-Speed Capping Shutter for Large-Aperture Geodetic Cameras (AFCRL 1P 101, AFCRL 64 405, CFSTI No. AD 640589), Air Force Cambridge Research Labs, June 1966.

THOMPSON, WILLIAM T.: Advanced Mars Orbiter and Surveyor: A Conceptual Design by the NASA Space Technology Summer Institute. NASA CR–96625, 1968.

THORNWALL, JOSEPH C.: Solid-State Wide-Range Low Power Camera Timer for Space Applications. NASA TM X–614–66–192, 1966.

TIFFT, W. G.; AND MEINEL, A. B.: Six-Inch Ultraviolet Camera for Apollo. Final Tech. Report. NASA CR–65360, 1966.

TIFFT, W. G.: Technical Support Systems for Manned Space Astronomy. Semiannual Report for Period Ending 1 Oct. 1962. NASA CR–97780, 1968.

VERMER, S. S.: Optical Imagers for the Small Earth Resources Satellite. NASA CR–88212, 1967.

WALSH, THOMAS: Factors Affecting the Design and Use of a Photographic Sextant for Space Navigation. NASA TN D–4285, 1967.

WHITNEY, M. B., ET AL.: Processing and Display Experiments Using Digitized ATS–1 Spin Scan Camera Data. NESC–44, 1968.

WILSON, D. W., ET AL.: An All-Sky Camera for Continuously Monitoring Cloud Coverage. NASA CR–99525, 1967.

WILSON, D. W.; DORR, R.; DANIEL, W.; RAFF, M. I.; SECTON, J. A.; ET AL.: An All-Sky Camera for Continuously Monitoring Cloud Coverage. Ser. No. 8, Issue No. 57. NASA CR–88525, 1967.

YOST, EDWARD; AND WENDEROTH, SONDRA: Precision Multispectral Photography for Earth Resources Applications. NASA CR–92360, 1968.

YOST, EDWARD, ET AL.: Environmental Measurements and Instrumentation Data in Support of NAVOCEANO Aerial Color Photography Test. (CFSTI No. AD 671847), Long Island Univ., Apr. 1968.

UPTON, D. T.: Mechanical Design of the Spin-Scan Cloud Camera. Jet Propulsion Lab. Proceedings of the Third Aerospace Mechanisms Symposium, Oct. 1, 1968, pp. 117–123. NASA CR–97758.

A Summary of the Photographic Process*

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THE PHOTOGRAPHIC PROCESS

The word "photograph" is a combination of two Greek words: "photos" meaning light, and "graphos" meaning to write. A photographic film is literally a "light-writing" film or one which records the pattern of light that strikes it. Photographic material in common use today is so highly sensitive to light that it must be manufactured and stored in almost complete darkness. Since it can be thoroughly examined only after it has recorded an image and has been chemically processed, the structure and mechanism of photographic films in common usage are not known to the average user.

Construction

The light-sensitive element of photographic materials consists of one or more extremely thin coatings of silver halide microcrystals embedded in a colloidal medium-like gelatin. These coatings or photographic emulsions are generally less than a thousandth-of-an-inch thick and are exceedingly delicate and susceptible to damage by abrasion and scratching. The emulsion is coated on top of a material whose primary function is to support and strengthen the delicate light-sensitive element. The support for roll-films and motion-picture films is usually colorless, transparent, and flexible, and the support is many times thicker than the emulsion. The overall thickness seldom exceeds five- or six-thou-

*Excerpted from NASA Report NAS CR-92015; B3076 (1965); CFSTI N68-19742 (Contract NAS9-3613).

sandths of an inch and, for special applications, is sometimes less than three-thousandths of an inch. Glass plates serve as the support for certain applications, while different types of paper are used to support photographic-printing emulsions.

The silver halide microcrystals, or grains, are the actual light-sensitive elements of photographic emulsions. These very small grains of silver chloride, silver bromide, silver iodide, or mixed salts range in size from one-half to several microns in diameter and tend to be flat or platelike in shape. Their function is to absorb radiant energy and undergo a change in state which can be amplified millions of times by subsequent treatment in the proper chemical solutions.

Clear gelatin is used to control the quality of the microcrystals and to hold them in suspension. At the same time, the retaining gelatin must be inert to processing procedures and yet permit liquid chemicals to penetrate and to react with the suspended crystals. Emulsions generally have a greater volume of gelatin than silver halide grains and are somewhat elastic besides being capable of absorbing liquids.

The support or base material generally does not participate in the mechanism of image formation, recording, or processing and serves essentially as a means of mechanical support for the delicate emulsion. The transparent flexible support for sheet, roll-type, and motion-picture films consists of an acetate material which is strong and dimensionally stable. Another support material, introduced a few years ago, is often used in applications where overall film thickness must be minimized; this polyester material has many times the shear strength of acetate and provides sufficient strength for a photographic emulsion with a thickness of only two-thousandths of an inch. Because of difficulty in splicing pieces of this material, it is not widely used for motion-picture films.

Theory of the Photographic Process (refs. 1, 2, and 3)

The light-sensitive elements of a photographic film consist of microcrystals of certain silver salts. Emulsions with high photographic speed have large grains of silver bromide containing small amounts of silver iodide. Smaller grains of the same silver halide combination result in films with less speed. Materials used for making photographic prints are generally made with silver chloride grains of very small dimensions.

The Latent Image

The action which takes place when light impinges upon the photosensitive emulsion is basically one involving energy absorption. The lattice structure of the silver halide crystals contains impurities which constitute a structural weakness. After exposure to light and subsequent immersion in the proper chemical solution, conversion of the grains to free metallic silver appears to commence at the points of structural weakness. These points, or sensitivity centers, contain small amounts of silver sulfide and are often located at many places throughout the crystal. Grains which do not contain such centers do not appear to be sensitive to light. Thus, it is assumed that the silver sulfide specks act as catalysts to collect silver atoms, liberated by the action of light upon the silver halide crystal. The average sensitivity usually increases with the size of the grain because the number of sensitivity centers is usually increased in direct proportion to grain size.

Quantum mechanics explains latent-image formation by assuming that the absorption of light quanta by silver halide grains injects electrons from the halide ions into conduction bands where they are free to wander throughout the crystal lattice. Some of these electrons become trapped in the sensitivity centers and produce a negative charge which prevents additional electrons from entering the center until the negative charge is reduced by recombination with interstitial silver ions. The silver ions which migrate throughout the crystal enter the sensitivity centers and use the trapped electrons to form neutral atoms of silver. When a sufficient number of neutral silver atoms have coagulated, a stable latent image is established.

A quantum of light liberates only one electron if it is absorbed. Experiments have shown that a grain requires absorption of several quanta if developability is to be achieved. High-energy particles, such as alpha particles, release thousands of electrons into the conduction bands while passing through an emulsion. Many small latent-image centers are established throughout the grain with which the high-energy particles have collided. Further collisions by high-energy particles increase the number of the silver atoms in the centers, producing larger centers which develop more readily.

The incidence of a large amount of energy over a short time period on a silver halide grain produces an avalanche of electrons and appears to favor the formation of many small latent-image centers. A single high-energy particle or a large number of light quanta can liberate a surplus of electrons. The effect of the surplus negative charge on the sensitivity center which is produced by the first few trapped electrons prevents additional trapping. By the time a sufficient number of interstitial silver ions have migrated into the centers, neutralizing the charge by forming neutral silver atoms, the avalanche of electrons has dissipated. This gives rise to a nonlinear effect which is termed "short exposure time" or "high intensity reciprocity failure." The latent-image centers, although plentiful in number, do not trap a sufficient number of silver atoms to permit formation of a developable center. Prolonged development will minimize the effect but often at the expense of increased-background density.

Quanta arriving at a lower rate and corresponding to a low intensity over a very long time period tend to produce large latent-image specks but fewer in number. This is termed "long exposure time" or "low intensity reciprocity failure." Thermal motion causes some of the silver atoms formed in the specks to break up. Latent-image specks are not stable until they contain a critical number of silver atoms. When the rate at which the light quanta arrive is so low that the breakup rate of the silver aggregates exceeds the rate of addition of new silver atoms, the latent image never attains a stable level. With insufficient numbers of silver atoms in the single speck, the grain is not capable of development. The exposure effect is an apparent loss of sensitivity as the low-intensity reciprocity failure manifests itself.

Processing

The latent image produced in a photographic emulsion by the action of sufficient radiant energy becomes detectable as a darkened image on an otherwise light-colored background of silver halide. The use of developing agents reduces by millions of times the radiant energy required to produce the same darkening, making the photographic process a most sensitive and practical recording system.

The process of development is one of reducing the silver halide grains to free metallic silver which is readily detectable as a black deposit. Because developing agents will ultimately reduce all grains, a practical developer is one which will reduce exposed silver halide grains to the free metallic state at a greater rate than those grains which have not been exposed. Thus, practical development is a rate-dependent phenomenon which affords a means of discrimination between exposed and unexposed portions of the photographic emulsion. Development is terminated by the simple procedure of inactivating the developing agents before the unexposed grains are significantly affected. At this point, the remaining unreduced silver halide grains may be removed by immersion in silver halide solvents known as fixing agents, or development may be continued by reactivation of the developing agents. If the remaining silver halide is removed by a fixer, further reduction will not take place and the film may be examined in the light.

There are two distinct types of development processes which will allow discrimination between exposed and unexposed silver halide grains. One is termed physical development in which many silver atoms are deposited from solution onto those few silver atoms comprising the latent-image centers. The other process is referred to as chemical or direct development and, for many practical reasons, is the one in common use. Physical development undoubtedly accompanies, to some extent, the process of chemical development. In a chemical developer containing a silver halide solvent, the main part of development appears to be an intensification reaction. Silver dissolved in the developer solution is deposited on grains which have already been partially reduced to free-silver and thus intensifies and increases the size of the original grains.

Each grain suspended in the gelatin is surrounded by a negatively charged barrier layer of absorbed gelatin and halide ions which present a retarding force to the penetration of developer to the grain. Those grains which have been exposed contain potentially weak points in the barrier at the latent-image centers. Silver ions from the crystal lattice which are put into solution by the liquid of the developer penetrate the charge barrier and soon become absorbed on the silver specks of the latent-image centers. Once such adsorption occurs on the crystal, the protective charge barrier layer is broken, and the developing agent can then easily penetrate the grain, thus allowing reduction of the entire grain to proceed.

The protection afforded the silver halide grains by the gelatin produces a further complication in restricting the transport of chemicals in and out of the emulsion. Once reduction of a grain commences, the chemical complexes formed by the interaction must be removed and replaced by fresh chemicals if further reduction is to proceed. The transport of these chemicals through the gelatin depends for the most part upon diffusion. Within the gelatin emulsion, the transport is limited by internal pressures and temperature effects. At the boundary between the gelatin emulsion surface and the developer solution, the complexes which are formed at the grain sites and which have diffused to the surface present a boundary-layer barrier to incoming fresh solution. This barrier severely restricts the interchange of chemicals and slows down the process of silver reduction of the exposed grains. The unexposed grains, on the other hand, are not so restricted and in time will be reduced to free silver, resulting in a high fog value.

Agitation of the film during processing tends to break up the emulsion surface barrier of the developer complexes, permitting fresh solution to be transported by diffusion into the emulsion. The complex byproducts removed from the surface are then diffused into the remaining developer solution and, to a degree, exhaust the developer. With sufficient concentration of these byproducts, the developer action becomes ineffective and must be replaced with fresh chemicals.

Silver reduction is most active in highly alkaline-developer solutions and slows down as the developed pH is lowered. At a sufficiently low pH, usually an acid condition, development activity ceases. Thus, development of a latent image can be brought to an abrupt halt by a rapid reduction of the solution pH. A common practice in the processing cycle includes immersion of the films in an acid stop bath after the desired developing time has expired. Further reduction of silver halide ceases immediately in the acid stop bath. The film is then placed in a fixing bath which removes the remaining silver halide grains and leaves only a visible black silver image in those areas where light struck the emulsion. The black image will ultimately be attacked and destroyed by the dissolved chemicals if not removed by water-washing to leave only the permanent image in the emulsion.

Exposure Response Characteristics

The previous paragraphs have described the general mechanisms, leading to the production of black silver deposits in photographic emulsions which have been exposed to radiant energy and treated in suitable chemical solutions. The response of silver halide grains to absorbed energy varies with the size of the grain, the larger grains being more sensitive. Most photographic emulsions consist of a random mixture of different-sized grains resulting in different degrees of blackening as a function of exposure. The exposure is further attenuated as the light is absorbed in traversing the emulsion. Both factors are instrumental in producing the different degrees of sensitivity in a photographic emulsion.

Negative film

The photographic response to varying amounts of exposure can best be described by means of a graph which plots the degree of blackening as a function of exposure. Exposure is defined as the product of intensity of illumination, *I*, and exposure time, *t*. The degree of blackening is represented by the term density *D*, which is the logarithm to the base 10 of the ratio of the incident to the transmitted light of the developed image. Practical reasons dictate that the exposure should also be expressed logarithmically to the base 10. The resulting graph, shown in figure A–1, is known as an *H and D, characteristic* or *D-log E* curve and represents the response of a typical negative photographic film to the action of different amounts of exposing energy when processed with a fixed set of processing conditions.

At the left of the graph, the resulting density is uniformly low and represents that value produced by development action without benefit of exposure to light. It is referred to as "fog density," but is more appropriately termed "background density," since it includes any discoloration or density of the emulsion and its support. At a threshold level, the film starts to respond to greater exposure by a measurable increase in density. Additional exposure produces greater amounts of density, resulting in an upswing to the

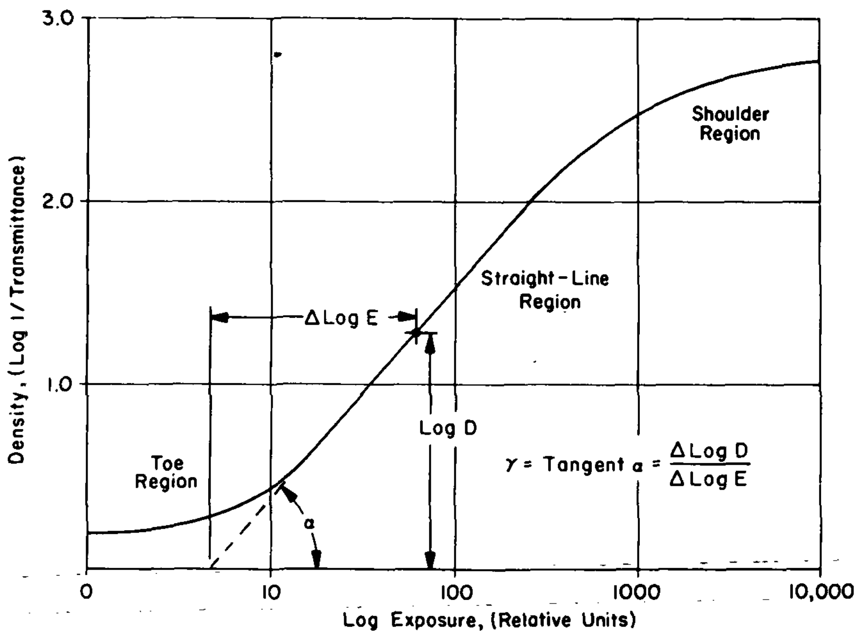


Figure A–1.—*D*-log *E* curve for a typical photographic negative film.

curve, finally reaching a point where density becomes uniform with increasing exposure. The upswing in the curve, or the toe region, shows an increasing effect of the response system. Beyond the toe region, the system attains a uniform rate of change in response in the straight-line portion and density changes linearly with the logarithm of exposure. The slope of the angle α, formed by the exposure axis and the straight line is termed gamma γ, and its value is determined by the ratio of $\Delta D/\Delta \log E$. Ultimately all grains become exposed and no additional density is produced. The gradual reduction in slope beyond the straight line is termed the shoulder region.

The slope of the straight-line region or gamma is affected by the amount of development the film receives. Prolonged development increases gamma up to a limiting value, gamma infinity, which, while not mathematically infinite, is the greatest slope which the emulsion is capable of attaining. Prolonged development beyond this point produces excessive background density with no increase in maximum density and effectively reduces the slope of the straight line. Values of gamma approaching gamma infinity tend to compress the exposure range over which the film is responsive thus creating a narrow-latitude film. For purposes of scientific data reduction on the original negative, this is often an advantage because of the increased measuring precision. Relatively large differences in density are produced by small changes in exposure or scene luminance. The precise value of gamma desired is dictated by the intended use for the negative.

Negatives for which the primary purpose is pictorial must be printed onto a positive-type photosensitive material and require low gamma values. Both optical and photographic characteristics of positive-printing materials restrict their exposure latitude to narrow limits. Since the density contained in the negative image serves as the exposure modulator for the narrow latitude positive print material, it is necessary to maintain a low gamma in the negative in order to make a print of acceptable range. A gamma of 0.6 to 0.8 is best suited for pictorial negatives, while a value of 1.0 is used for scientific films. The latter value is a compromise value which permits satisfactory prints from the original negative.

Reversal film

Modifications of the processing procedure will permit most negative photographic films to be developed into direct positive images. Called reversal processing and yielding a positive image, the negative image has been destroyed during the chemical treatment.

For optimum results with reversal processing, the construction of the film is usually altered and produces a positive image with somewhat finer grain than the negative image. The exposure response of a film processed by reversal processing can be described by a *D*-log *E* curve whose general shape exhibits the reverse characteristics of the curve for negative materials. A typical reversal positive *D*-log *E* graph is shown in figure A–2. Maximum density for reversal-processed films occurs below the threshold value where no exposure is received. A threshold exposure for reversals is the value at which reduction in maximum density commences and the shoulder region corresponds to the toe region of a negative *D*-log *E* curve. Density changes linearly with the logarithm of the exposure in the straight-line region but opposite in slope to that of the negative material. The actual slope for reversal processing is considerably greater than that for a negative film. The toe region represents saturation or the leveling-off in exposure response beyond which the film is no longer effective.

The major advantage of reversal processing is that it produces a direct positive image suitable for projection onto a screen. Due to the optics of image projection, a great deal of unwanted non-image-forming light is present with such systems. Undesirable

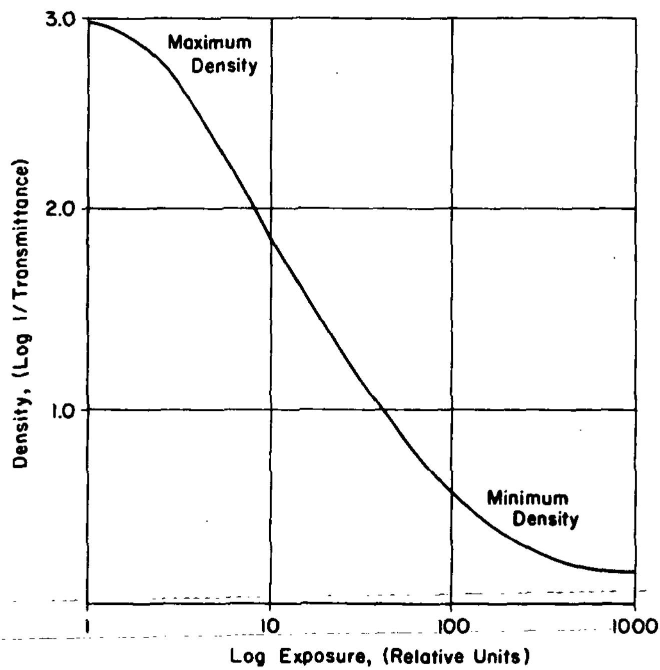


Figure A–2.—*D*-log *E* curve for a typical reversal film used for projection.

scattered light reduces the maximum density of the projected image resulting in a washed-out and tonally distorted facsimile of the original scene. Such tone distortion may be effectively reduced by producing an intentional increase in contrast of an image intended for projection. Inspection of the characteristic curve of figure A–2 shows that the gamma is considerably higher than the corresponding value for a negative film. This is accompanied by a greater maximum density and results in a film image of increased contrast. The scattered light produced during projection of the image on the screen has the effect of reducing the maximum density. The screen-image contrast is thus reduced and the projected image appears to be a faithful tonal representation of the original scene.

Sensitivity

Photographic films undergo changes upon the absorption of radiant energy and only that energy which is absorbed will cause a photochemical change to occur. Silver halide grains have peak absorption at short wavelengths. However, because the grains are held in place by gelatin, the energy contained in the short ultraviolet will not expose the grains because it is absorbed by the gelatin before reaching the silver halide crystals. The transmission of gelatin, plotted in terms of density as a function of wavelength in figure A–3, shows that appreciable attenuation occurs at 2900 Å and that almost complete absorption takes place below 2500 Å (ref. 4). Hence, ordinary photographic film exhibits little or no sensitivity to ultraviolet below 2500 Å, without special sensitization. Application to the surface of the emulsion of a layer of ultraviolet fluorescing material extends the sensitivity to wavelengths considerably shorter than 2000 Å, but the magnitude of the added effective sensitivity is no more than 1/100 the sensitivity at 3000 Å. The curve in figure A–4 shows the spectral sensitivity response of a high-speed emulsion with the extension to very short wavelengths affected by a flourescing sensitizer (ref. 5). Short-wavelength energy is absorbed by the material and causes fluorescence which emits a very-low-level blue light. The visible light emission is responsible for the exposure of the film even though the exciting radiation was ultraviolet.

Spectral sensitivity curves of the various silver halides characteristically show peak sensitivity in the ultraviolet and blue portions of the spectrum. Toward the red end of the spectrum, the photochemical effect for unsensitized films monotonically decreases, becoming very small above a wavelength of 5000 Å.

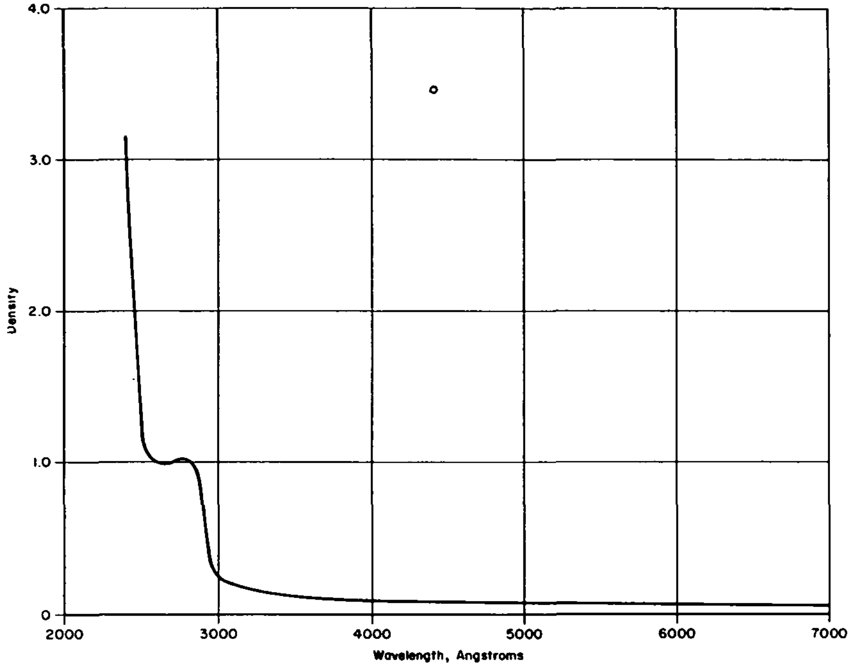


Figure A-3.—Spectral density characteristics of clear gelatin, 0.1 mm thick (from Kodak Wratten Filters, Kodak Publication No. B-3).

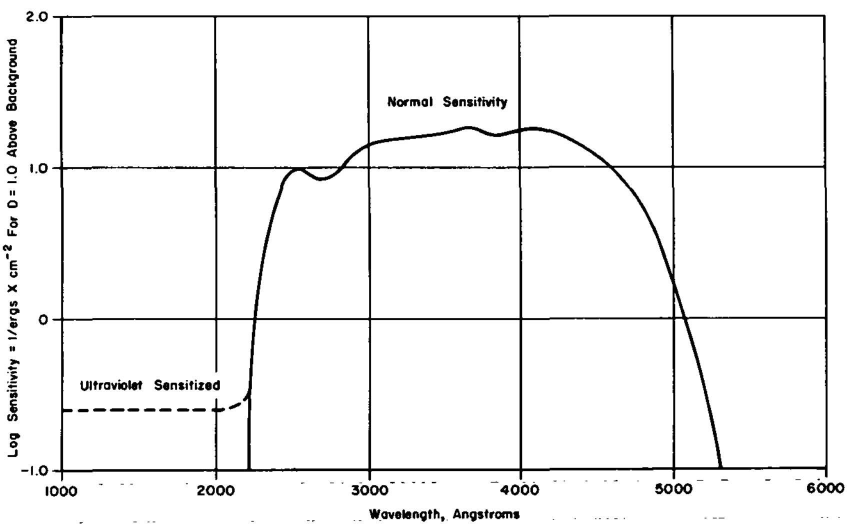


Figure A-4.—Spectral sensitivity response of Spectroscopic Type 103-0 which has been sensitized to ultraviolet with Kodak Ultraviolet Sensitizer No. 2.

The addition of certain dyes to the silver halide grains in the emulsion increases the sensitivity to longer wavelengths. When sufficient energy is absorbed by the absorbed-sensitizing dye, a photochemical reaction occurs and the emulsion becomes effectively sensitive to those wavelengths where previously there was little or no response. Not all dyes will react in this manner. Only a certain few are considered as spectral sensitizers for photographic films and only when they are absorbed in critical amounts to the silver halide grains.

Sensitizing dyes are available which extend the photosensitive capabilities to wavelengths somewhat beyond 1 micrometer (10,000 Å). The resultant peak sensitivity in the infrared seldom occurs at wavelengths greater than 10,000 to 11,000 Å and the sensitivity beyond 13,000 Å is negligible. For practical exposures in recording pictorial scenes, spectral sensitivity beyond 9000 Å is of little value because of the rapid decline in sensitivity just short of this wavelength. The spectral response of a high-speed infrared sensitive film is plotted in figure A–5 along with a common type of negative material, Eastman Kodak Plus-X, for purposes of comparison.

Image Quality

The ability of a photographic emulsion to produce sharply defined detail in an exposed and processed image may be described

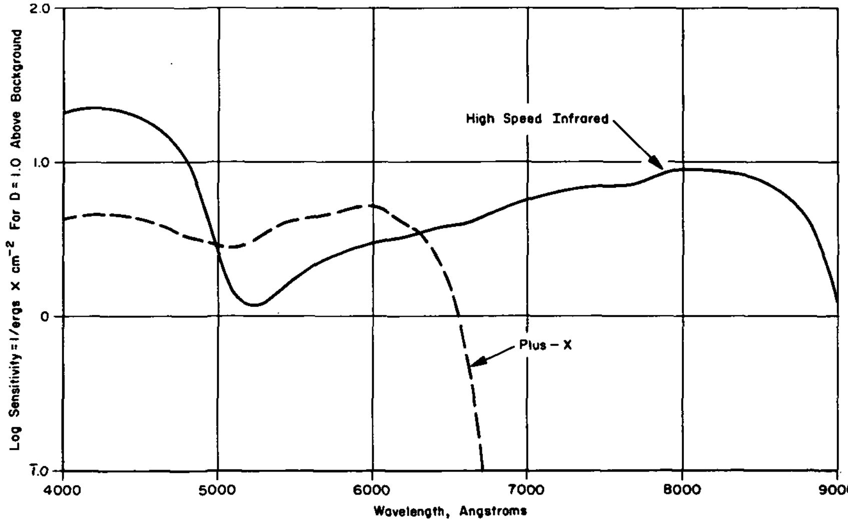


Figure A–5.—Comparison of spectral response of Kodak High-Speed Infrared and Kodak Plus-X negative films plotted at the same scale.

in terms of the film's resolving power and acutance. The resolving power of an emulsion is a measure of the limit to which fine detail in an image can be recorded, while acutance is a measure of the degree of sharpness apparent in the borders or edges of the recorded-image elements. The combined effects of an emulsion in altering resolution and acutance are included in the modulation transfer characteristics of the film. These characteristics describe the overall effect of diffusion and scattering of light upon the elementary image structure.

Resolving power

Photographic resolution is associated with the emulsion characteristics of granularity, turbidity, and sharpness as well as the exposure used. A measure of the resolving power of an emulsion is obtained by imaging a test pattern of alternating dark and light lines of varying sizes onto the film. The result, after processing, is usually expressed as the maximum number of dark lines per millimeter just distinguishable in the developed image. The range of brightness between the dark and light lines of the test-target influences the photographic resolving power. Resolution increases as the target brightness range increases, reaching a maximum at a range of 1000. It is, therefore, customary to test resolving power of photographic films using a target contrast of 1000.

Most of the popular camera films show a resolving power limit of the order of 100 lines per millimeter. Many of the less-sensitive materials have higher values, whereas ultrafast films are generally limited to somewhat lower resolution. The grains of even the fastest films are small by comparison to the resolution values obtained. Hence it is believed that individual grain size does not limit resolving power. Regardless of film speed, which is governed basically by grain size, the best emulsion resolution is attained when the grains are all small and nearly the same size.

Photographic emulsions are suspensions of silver halide grains in a layer of gelatin and, except for silver chloride which is nearly transparent, exhibit a considerable degree of turbidity. Incident light, upon striking the various grains, is partially absorbed, reflected, and diffused as it progresses through the emulsion. The reflected and scattered light affects nearby grains outside the area of the image pattern. These accidental exposures cause a spreading of the image elements and result in loss of resolving power. Restriction of exposure to the emulsion surface minimizes the solution. However, if the surface grains are widely separated, the edges of the image elements are not continuous and this results in an apparent reduction of sharpness.

Acutance (Refs. 1 and 6)

The density distribution across the border of an image element affects judgment of picture sharpness. Turbid emulsions scatter and generally diffuse the incident light in all directions. This causes elementary image edges to diffuse and the image appears to be unsharp if contrast of the elementary image border increases the apparent sharpness. The term "acutance" is a measure of the density distribution across the boundaries of microimages, produced by diffusion of non-image-forming light. Acutance, hence apparent sharpness, increases as the edge density gradient increases. Although emulsion turbidity plays a dominant role in the mechanism of image sharpness, emulsion composition appears to be the governing factor in controlling acutance. Emulsions, containing grains of predominantly uniform size regardless of film speed, produce sharper images than those containing a large distribution in grain size.

Modulation transfer function (Refs. 7 and 8)

The modulation transfer characteristics describe the behavior of an emulsion as influenced by the factors of exposure, acutance, and resolving power. Instead of using the normal sharp-edged parallel-line test pattern, a special target is employed which has a sine-wave-type density distribution across the edges. The target consists of a series of straight parallel lines varying arithmetically in both width and spacing from one end of the pattern to the other. The density distribution across each line of the series varies sinusoidally, as shown in figure A–6, with a density difference between minimum and maximum of the order of 3.0.

The test pattern is used as a negative with which printed images are exposed onto the photographic film to be evaluated. The varying density serves as the exposure modulator, and the changing frequency of line spacing tests the reproduction capacity of the emulsion. Figure A–7 shows the density distribution across each line of the exposed and processed image. Except for opposition values of density, an ideal response would produce an exact duplicate of the original test-pattern negative. Deviation in the minimum and maximum densities, as spatial frequency increases, represents the modulation change occurring in the response of the film. This modulation change is caused by the effects of emulsion

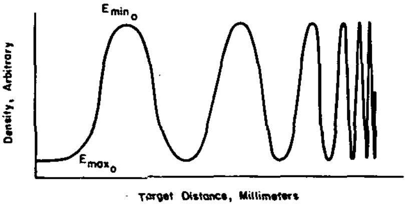
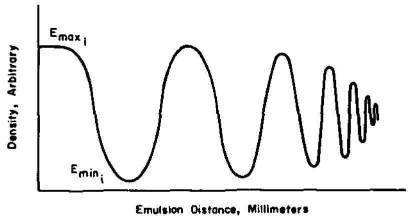


Figure A-7.—Density distribution across lines of film being tested.

Figure A-6.—Density distribution across lines of test pattern.



turbidity and the edge contrast of microimages. At low spatial frequencies the pattern is faithfully duplicated with little distortion. Distortion occurs as frequency increases, and the areas which should be low in density commence filling-in while the corresponding high-density areas show a decrease in value. Ultimately, both levels attain an intermediate but uniform density as the limit of response is reached. A plot of the ratio of modulation in the image and the original pattern as a function of the spatial frequency is the modulation transfer characteristic of the emulsion being tested and is illustrated in figure A–8.

Spectral Sensitivity

Natural

The silver halide grains suspended in gelatin have an inherent spectral sensitivity which is closely associated with their absorption of radiant energy. All primitive silver halide grains have strong absorption in the ultraviolet and violet portions of the energy spectrum, and this is in close agreement with their spectral photographic response. Energy absorption in the emulsion increases with decreasing wavelength and becomes so efficient at 3000 Å that very little energy is transmitted beneath the first few layers of grains. Being restricted to the topmost grains, an image exposed by ultraviolet radiation and subsequently processed will be found to suffer from lack of density and contrast. At still shorter wavelengths, the gelatin containing the suspended grains further absorbs the incident energy before it reaches the silver halide. Below 2500 Å the effect of absorption by the gelatin is so

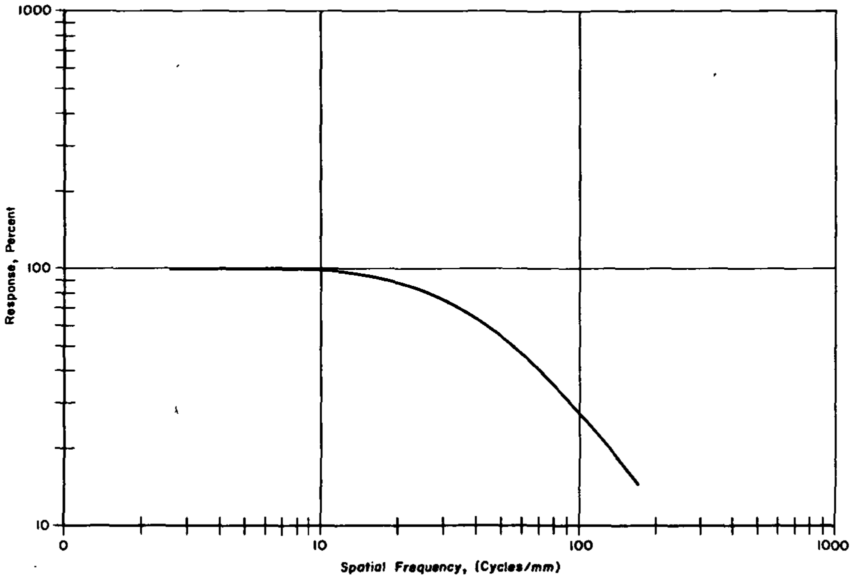


Figure A–8.—Modulation transfer characteristic of Kodak Panatomic-X film (ref. 8).

severe that no effective energy reaches the grains, and film sensitivity approaches zero. Commercially available films with considerable improvement in sensitivity to short-wavelength radiation contain a minimal amount of gelatin with the grains almost on top of the binder. Such films are extremely delicate and difficult to handle because the gelatin affords little protection to the grains. The gelatin cannot be completely eliminated because of its required protective capacity for the silver halide. Practical considerations demand that the grains be physically held in place by an adequate bond and this function is suitably performed by gelatin. An additional protective factor required of the gelatin is provision of the mechanism whereby the developing agent can discriminate between exposed and unexposed silver halide grains. Without a thin layer of gelatin surrounding them, all grains, whether exposed or not, would be reduced to metallic silver by the developing agent and there would be no detectable image.

Ultraviolet

The special photographic emulsions available for short-wavelength radiation are intended for spectrographic recording. Although they are sensitive to wavelengths shorter than 2500 Å and even respond to wavelengths approaching 500 Å, they are not suitable for practical pictorial recording because of low sensitivity, low contrast, and limited-exposure latitude. In addition, such emulsions have greater sensitivity to longer wavelengths than they have at 2500 Å. A spectrograph physically separates, by dispersion, the various wavelength regions and prevents overlap of other spectral zones to which the emulsion is more sensitive. Thus, spectral lines, even though weak, can be recorded without interference from those spectral regions to which the emulsion is much more sensitive. A nonspectrographic pictorial record, on the other hand, cannot be successfully obtained in the 2000- to 2500-Å range unless all longer wavelengths are excluded. This prevents the weak image, produced by the short wavelengths, from being dominated and effectively masked by the much stronger image from longer wavelength radiation. Optical filters required to accomplish this task are not available, and since the solar light source radiates less energy in this region than in the longer wavelengths, it will not be possible to obtain pictorial records with wavelengths shorter than 2500 Å.

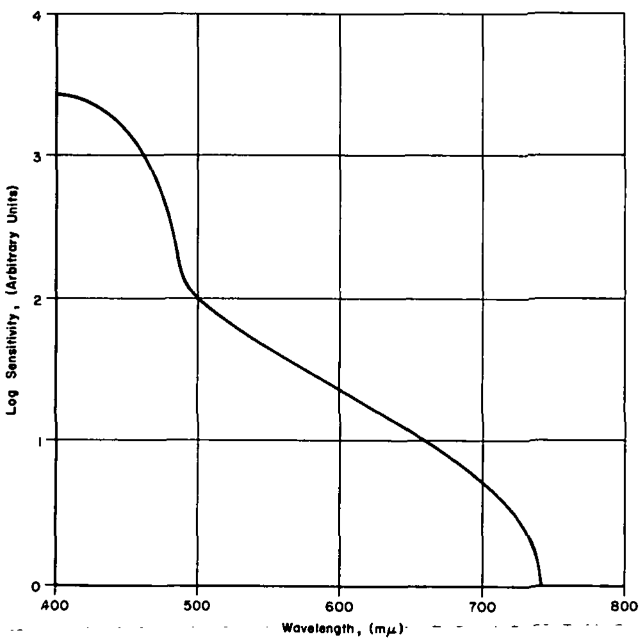


Figure A-9.—Spectral sensitivity of a typical silver bromide emulsion showing sensitivity extending to the near infrared (from Mees, Theory of the Photographic Process, revised edition, 1954).

Visible

Chemical sensitization

A silver chloride emulsion is colorless and appears to be translucent to the eye. It has a spectral sensitivity extending from the ultraviolet into the visible spectrum of blue or violet. Silver bromide emulsions, pale yellow in color, have ultraviolet sensitivity in addition to a considerable sensitivity to the blue-green portion of the visible spectrum. As noted in the curves of figure A–9, the sensitivity of silver bromide emulsions, even though exceedingly low, extends through the visible and into the near-infrared spectrum. The photographical limit, however, does not extend beyond 4900 Å. The addition of varying proportions of silver iodide to a silver bromide emulsion increases the sensitivity to longer wavelengths as shown in figure A–10. Extended spectral sensitivity produced by these and other chemical methods is limited in a practical sense to wavelengths barely in the visible green region. Optical

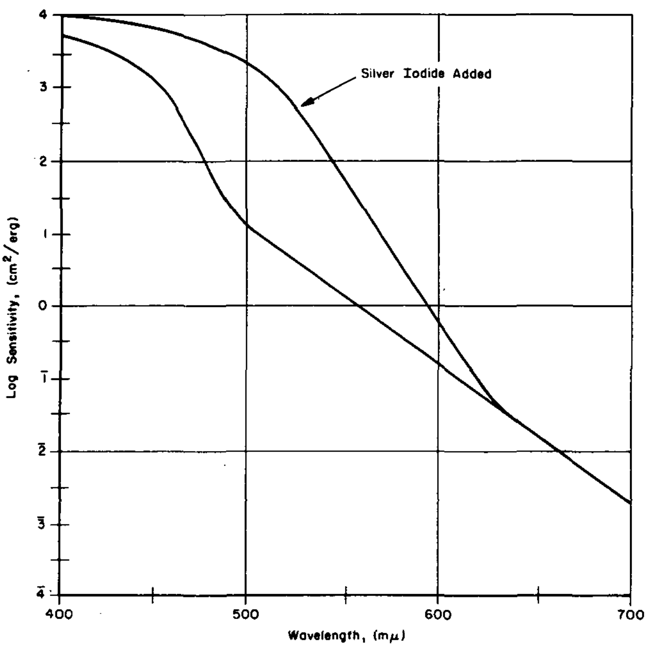


Figure A–10.—Spectral sensitivity of silver bromide emulsion showing increased sensitivity toward longer wavelengths when silver iodide is added (from Mees, Theory of the Photographic Process, revised edition, 1954).

sensitization of the silver halide grains is a more effective method for extending spectral response.

Optical sensitization

Optical sensitization requires the absorption of a critical amount of certain organic dyes to silver halide grains. This gives sensitivity in spectral regions of longer wavelengths to which the primitive grains are insensitive. The resultant extended sensitivity depends upon the light-sensitive characteristics of the absorbed dye. The dye is tightly held to the silver halide crystal by strong van der Waals forces and provides a source of energy transfer through photochemical action of light absorbed by the dye.

Although the spectral absorption characteristics of the absorbed dye dictate the effective photosensitivity created, the action of the colored dye is not one of simple filtration of the incident energy. The effectiveness of the dye to confer sensitivity to the silver halide depends completely upon absorption of the energy by the dye and the transfer of the liberated electrons to the grain sensitivity centers. For optimum efficiency of the reaction, the absorbed dye seldom covers the grain completely and is never present in more than a monomolecular layer. Excessive amounts of dye tend to produce desensitization of the grain.

Infrared

Effective sensitization may be achieved in almost any portion of the visible and near-infrared spectrum through use of the numerous dyes or dye combinations now available. However, no dye has yet been discovered which will optically sensitize a film to the far infrared. The practical limit for peak sensitivity to the infrared appears to be about 8000 Å, although satisfactory pictorial records at practical exposure levels can be obtained at 9000 Å. Special sensitizers are available which extend the photographic response beyond 13,000 Å, but the level of sensitivity is extremely low and emulsions thus sensitized are of little value for pictorial photography at wavelengths of about 9000 Å.

Film Speed

The speed of a photographic material is a numerical expression of its sensitivity to light for conditions of normal exposure and development (ref. 9).

Throughout the evolution of the photographic process, various methods have been used to describe the relative speed of photographic emulsions. Only in recent years, however, has there been an attempt made for standardization between manufacturers and users of photographic products. In the United States the two most common methods now being used to define film speed are the *ASA* method and the Exposure Index method.

Film-speed numbers are derived from the *D*-log *E* curve of a particular type of film which describes the inherent sensitivity of an emulsion for specific conditions of exposure and development. Arithmetic film speed is defined as the reciprocal of the exposure required to produce a specific tonal value (density) as indicated by the equation

$$S = \frac{k}{E}$$

where k is a constant and E is the exposure which produces a density 0.10 above background.

It is necessary that a rigidly fixed procedure be followed to determine the speed of an emulsion. Specifications must be set on the exposure time, modulator, type of light source, and spectral filtration. Processing of the sample must be accomplished in a special formula developer at a specified temperature and in a container of a certain size. Agitation, fixing, washing, and drying are also thoroughly stated in the procedures.

The characteristic curve of the emulsion is measured, using the *ASA's* units of diffuse density. The density, thus obtained, is plotted against the log of the exposure to form the characteristics curve for the emulsion.

ASA Film Speed—Black-and-White Negative Material

The new *ASA* procedure for determining film speed is illustrated in figure A–11, where two points, *M* and *N*, are shown on the curve. Point *M* is located 0.1 density units above fog-plus-base density. Point *N* lies 1.3 log-exposure units from Point *M* in the direction of greater exposure. The developing time of the negative material is so chosen that Point *N* lies at a density interval $\Delta D = 0.80$ above the density at Point *M*. When this condition is satisfied, the exposure E_m, corresponding to Point *M*, represents the parameter from which film speed is computed.

The arithmetic speed is computed by use of the formula $S_x = 0.8/E_m$ where S_x is the arithmetic speed, and E_m is the exposure (expressed in meter-candle-seconds) corresponding to the Point *M* on the *D*-log *E* curve.

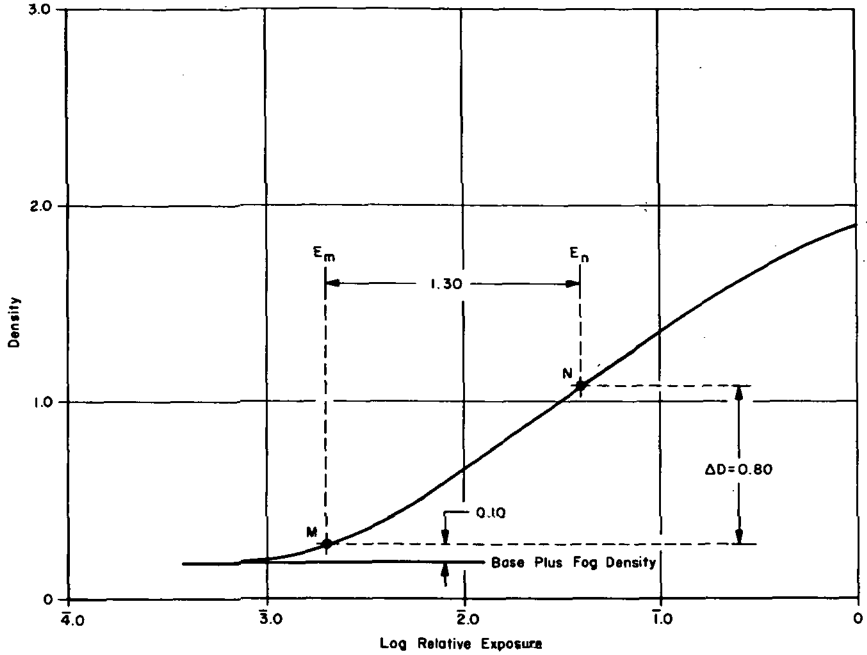


Figure A–11.—Method for determining speed.

Exposure Index

An exposure index is a measure of the speed of a photographic film and is used to determine the proper camera settings to produce a high-quality pictorial record.

Forced development of a film can produce an apparent increase in film speed because it permits an acceptable picture, but not of high quality, to be obtained with less exposure. In any method of determining film speed, a true increase in speed is represented on the *D*-log *E* curve by a lateral shift along the exposure axis. By definition, this is only possible by altering the emulsion composition and not by changes in the development procedure, since the developing procedure is fixed. The exposure index of an emulsion can be altered by forced development, creating the effect of incrased speed.

Exposure Reciprocity Effects on Film Speed

Exposure is defined as the product of intensity of illumination *I*, and exposure time *t*. The photographic reciprocity law states that identical film response should result if the product of *I* and *t* remains constant. Although this law is valid over a normal range of intensities, it fails seriously at both low- and high-intensity levels and is perhaps best known for its failure.

Failure of the reciprocity law quite often results in an apparent increase or decrease in film speed. Most photographic emulsions exhibit both a high- and a low-intensity speed change with a minimum effect occurring usually between 0.1 and 10 seconds. A true failure of the reciprocity law is sensitometrically illustrated by a shifting of the *D*-log *E* curve along the exposure axis. This is characteristic of a loss or gain of film speed. Some emulsions do not exhibit a change in apparent speed but are subject to a lowering or an increase of the slope of the curve. Most emulsions, besides exhibiting a change in effective speed, are also subject to a change in slope of the characteristic curve, resulting in a change in image contrast. Figure A–12 illustrates the relationship between the reciprocity failure and the reciprocity effect.

Color Photography

Color is a natural extension of black-and-white photography and adds another dimension to the pictorial representation of the original scene. The general theory describing the photographic

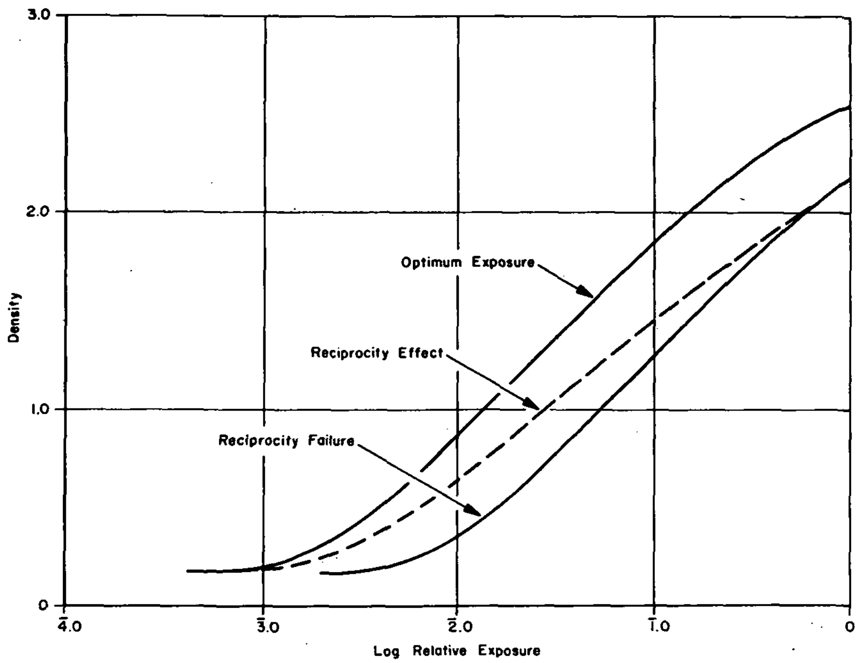


Figure A–12.—Exposure reciprocity.

process for black-and-white materials is also applicable for color films because silver halide grains are the light-sensitive elements for both systems. Major differences are in the film construction and chemical ingredients of the processing chemicals.

Theory

Color rendition in photography is based upon color sensations produced in normal vision. Circumstantial evidence suggests that the mechanism of human vision is responsive over no more than three broad spectral bands in which variation in stimulation produces a multitude of color sensations. A goal of color photography is, therefore, photographic representation of a scene in which the mechanism of vision receives the proper stimulus to create the same illusion of color as that produced from direct observation of the scene.

An ideal photographic color process would generate separate spectral band pictures of a scene in which each recorded image would stimulate only one of the eye's color sensors. Current physiological knowledge of the human eye lacks sufficient detail for such a color process.

Attempts have been made to define the ideal division of the spectrum to produce satisfactory color reproduction by means of photography. The minimum number of spectral bands which photographically produces an effect of color vision appears to be two, and a variation of the two-color concept was most recently reported by Land (ref. 10). Limitation of two spectral recording bands introduces considerable distortion in color fidelity in which certain color sensations are conspicuously poor. The minimum spectral division for practical color photography producing satisfactory color fidelity appears to be three, with one band covering the blue, another the green, and a third the red spectral region (refs. 1, 2, 3, and 11).

Methods

Three-color photography may be generally described by two different processes called additive and subtractive color. Each process employs the same spectral bands for recording the primary exposure. The major difference between them is the method of final presentation to the observer. The additive process most nearly duplicates the eye's response because each record is presented as a separate primary color.

Additive color

Stimulation of the human eye color receptors by appropriate amounts of the primary colors—blue, green, red—produces a neutral color sensation ranging from white to black depending upon the degree of stimulus. Maximum stimulation of all three colors produces white, hence the terminology "additive" wherein the addition of all colors produces white. Unequal portions of primary colored light produce a color differing from the primaries. For example, yellow is the color sensation produced by equal portions of green and red light with a deficiency of blue light. Yellow is, therefore, considered as minus blue because of the absence of a blue stimulus. A deficiency of green is a color sensation called magenta or minus green. The closest natural color of magenta is the flower of the fuchsia plant. Likewise the sensation of cyan, which is a blue-green, is referred to as minus red or the absence of a red stimulus.

Dye colors of the three primaries—blue, green, red—cannot be intermixed or superposed because each color absorbs two thirds of the spectrum. A mixture of only two would absorb all the spectral colors and the mixture would appear black. For this reason blue, green, and red colored photographic images cannot be registered together to form a color photograph. They can, however, be separately projected with all three images being registered at the screen.

Taking advantage of a psychological phenomenon associated with color vision, it is possible to produce a color picture with a single film. Because the eye will fuse small adjacent areas of different colors into a single color sensation, the photographic image may be composed of a geometric pattern of small areas of blue, green, and red. Colored light from each area is visually fused and produces the proper color sensation in the eye. Thus, the picture appears to be a color photograph. A similar process is the basis of color television.

Subtractive color

The subtractive process does not require direct superposition of the primary colors previously described and, therefore, is a more practical approach to color photography. The three colors contained in the superimposed picture presented to an observer are complementary to the blue, green, and red primaries. Ideally each of these complementary colors would absorb only one-third of the spectrum and completely transmit or reflect the remaining two-thirds. Superposition of equal amounts of any two would not affect one-third of the spectrum and would modulate the remaining two-thirds in proportion to the concentration of the colors. Addition of the third color of equal concentration would produce a neutral gray or black, depending upon the degree of light absorption. The colors used in the subtractive process are yellow, magenta, and cyan, and are the colors which artists use and improperly term primaries of yellow, red, and blue.

Negative

The ability to superimpose colored photographic images of the subtractive process permits use of a single film in which three images are recorded in separate layers. Such multilayer color films can be processed as negatives or reversal positives. Although the exposure of each layer is accomplished using the primary spectral bands of blue, green and red, the color comprising the images of either negative or positive system must always be yellow, magenta, and cyan, respectively. In all negative systems, the tonal scale of the original scene ranging from white to black is reproduced in an opposite relation with white producing the greatest density. Color must also be reproduced in the opposite manner in a color negative. For example, yellow in the original scene will be reproduced as a primary blue in the negative and a primary red would produce a cyan image.

Reversal

Color reversal films reproduce both tonal and color scales in proportion to the original scene because the intended use is usually for direct viewing or projection. The dyes used in the subtractive process have certain deficiencies which do not permit attainment of complete color fidelity. Although reproduction by reversal gives a close approximation to the original scene, the color deficiencies are amplified with a considerable departure from fidelity when making duplicates. The effect of color distortion when making duplicates can be minimized by use of a special color negative which contains integral color correcting masks (ref. 12). This procedure distorts the appearance of the color negative but is effective in removing undesirable color from the succeeding prints.

A primary objective of a color photograph is the creation of an impression which is consistent with the viewer's concept of the appearance of the original scene. In particular, the picture must faithfully reproduce neutral tones as contained in the scene. A color film is essentially a combination of three separate films operating as a unit. Each of the separate emulsions, after processing, produces a colored image which may be described by a *D*-log *E* characteristic curve. Ideally, all three curves would have the same shape and would be coincident along the exposure axis. When an approximation of the ideal match is attained, the color film will reproduce neutral tones, and it is in color balance. A change in the color of the exposure illumination will cause an unequal shift in position of the *D*-log *E* curves, and the film will no longer reproduce neutral tones. This deviation in apparent speed of the three emulsions may be rectified during exposure by use of colored filters. Essentially, this procedure repositions the *D*-log *E* curves back into coincidence to achieve a new color balance which is a prime requirement for reversal films.

Color negatives have a somewhat greater exposure range than reversal films and therefore are less critical to color balance during exposure. A color negative may be used over a broad change in effective color temperature of the light source. Proper color balance is achieved in making the print. Commercially available Kodacolor negative film has sufficient exposure range to cover color temperature differences ranging from tungsten to daylight illumination, whereas no available color reversal film can tolerate more than a 200° K shift in color temperature.

Image Quality

The same factors which influence the quality of a black-and-white photographic image also apply to color photography. Instead of having a single emulsion to contend with, the image quality of color films is modified by the effects produced in three separate images. The turbidity effects upon acutance and resolving power are most noticeable in the bottom layer of a multilayer color film. Unfortunately, the cyan image color of the bottom layer is the most predominant visual color of the three colors used and thus most strongly influences the visual appearance of total image quality.

In order to minimize the effects of diffusion of image-forming light, the various emulsion layers are held to minimal thickness. Red light must be transmitted by both the blue and green sensitive layers before reacting with the red sensitive layer. In traversing the blue and green emulsions, it becomes diffused, thereby modifying the image quality of the bottom layer. Reduction in thickness and turbidity of the blue and green sensitive layers also reduces the diffusion and permits better image quality to be achieved in the bottom layer. As a result of the precautions taken in the construction of multilayer color films, the image quality is only slightly inferior to black-and-white films. Although many black-and-white films are capable of resolving 100 lines per millimeter or better, the average photograph as normally recorded is limited to a much lower value because of inaccuracies in lens focus. A nominal value of 30 lines per millimeter appears to be the practical level most often achieved. For this reason, an image-quality difference is seldom encountered between color pictures and black-and-white photography. Image resolution of 75 to 100 lines per millimeter appears to be the order of magnitude for multilayer color films.

REFERENCES TO APPENDIX A

(Original Citations)

1. MEES, C. E. K.: The Theory of the Photographic Process. Revised edition. The Macmillan Co., New York, 1954, pp. 23–530.
2. NEBLETTE, C. B.: Photography, Its Materials and Processes. D. Van Nostrand Co., Inc., New York, 1962, pp. 118–196.
3. EVANS, R. M.; HANSON, W. T.; AND BREWER, W. L.: Principles of Color Photography. John Wiley & Sons, Inc., New York, 1953, pp. 173–225.
4. ANON.: Kodak Wratten Filters. Kodak Publication No. B–3, 1965.
5. ANON.: Spectral Sensitivity Curve of Type II–O and Type II–O UV Plates. Kodak, 1961.
6. HIGGINS, G. C.; AND JONES, L. A.: Evaluation of Image Sharpness. Jour. SMPTE, vol. 58, 1959, pp. 277–290.
7. PERRIN, F. H.: Methods of Appraising Photographic Systems, Parts I and II. Jour. SMPTE, vol. 50, 1960, pp. 151–156, 239–248.
8. ANON.: Modulation Transfer Data for Kodak Films. Kodak Pamphlet No. P–49, 1962.
9. ANON.: Speed of Photographic Negative Materials (Monochrome, Continuous-tones). American Standards Association, PH 2.5, New York, 1960.
10. LAND, E. H.: Experiments in Color Vision. Scientific American, May 1959, p. 84.
11. HARDY, A. C.; AND PERRIN, F. H.: Principles of Optics. McGraw-Hill Book Co., Inc., New York, 1932.
12. ANON.: Color as Seen and Photographed. Kodak Publication No. E–74, 1962, pp. 39–42.

Abbreviations

A.S.A.: American Standards Association. Now known as United States of American Standards Institute (USASI).
A.S.C.: American Society of Cinematographers.
CC: color compensating (filter).
cd: candlepower.
cm: centimeter.
D.I.N.: Deutsche Industrie Norm, a German system of film-speed designations.
DW: double-weight (paper).
f.p.m.: feet per minute, also: fpm.
f.p.s.: feet per second, also: fps.
m: meter or meters.
ND: neutral density.
ortho.: orthochromatic (preferably spelled out).
P.S.A.: Photographic Society of America.
R.H.: relative humidity.
rpm: revolutions per minute.
S.M.P.T.E.: Society of Motion Picture and Television Engineers.
std.: standard or standards.
SW: single-weight (paper).

Glossary

A

aberration: an optical defect in a lens.

absorption: in an optical sense, the property of a material to absorb a part of the energy falling upon it while the remainder of the energy is reflected or transmitted.

absorption band: in the spectrum of a dye or other substance, a more or less broad region in which light is absorbed.

achromatic: without color; applied to a lense corrected for chromatic aberration at two different wavelengths of light.

acutance: the objective measure of the image characteristic which relates to the subjective impression of sharpness.

actinic light: light capable of causing photochemical changes.

additive process: a photographic color process which produces color by the superimposition of the separate primary color lights in the same viewing plane.

aerial image: a real image existing in space; it can be received on a ground-glass, film, or other surface, or picked up by another lens system.

aerial perspective: an impression of depth or distance in a photograph by means of progressively diminishing detail due to aerial haze.

aero: applied to a lens, camera, or film intended for use in photography from aircraft.

afocal: applied to a lens system which has both foci at infinity; afocal systems include certain wide angle and telephoto attachments for lenses which do not change the lens extension.

agitation: the action or techniques for keeping film surface exposed to fresh processing solutions.

Airy disk: the image of an infinitely distant point as focused by a lens. Due to the wave structure of light, this image is a small disk, no matter how perfect the lens corrections. Distinguished from *circle of confusion*, the result of tolerance in focusing, and residual aberrations.

amplifying: the process by which a signal is increased. In photography, the physical chemical process by which exposed silver is developed; to amplify the optical signal.

amplitude: the maximum height, or maximum depth of a wave or varying signal as measured from the baseline or zero reference.

anamorphic: a lens or optical system in which the magnification is different in two directions at right angles; used in wide-screen movie processes to "squeeze" a wide image into standard format and to "unsqueeze" it in projection on a wide screen.

anastigmatic lens: a lens which is free from astigmatic aberrations, focusing both vertical and horizontal lines without distortion and with equal brightness and definition.

angle finder: a viewfinder containing a mirror or prism so that pictures may be taken while aiming the camera sideways.

angle-of-view: the angle formed when two lines are plotted from the center of a lens to the two distant corners of the film record.

answer-print: the first combined sound and picture print from a completely edited motion picture negative.

antiabrasion: a protective layer on film emulsion, intended to avoid markings due to pressure or rubbing.

antihalations: a film or plate, treated with an opaque backing, to prevent halation; abbr. AH.

aperture: the opening of a lens, its size being controlled by means of a diaphragm; in a motion-picture camera or projector, the opening in the film track which outlines the picture.

apochromatic lens: a lens which is corrected for chromatic aberration for three wavelengths of light rather than two as in the achromatic lens; generally used by photoengravers and color photographers for very precise color-separation work.

art work: a term applied to the retouching, lettering, and drawing which may be added to a photograph.

A.S.A.: refers to the American Standards Association (now the United States of American Standards Institute) through whose offices industry-wide standardization of photography is executed. The ASA rating of a film is a uniform method of rating the speed or sensitivity of camera films.

astigmatism: a lens defect which appears as an inability to focus vertical and horizontal lines in the same plane near the edges of the field.

asymmetrical (nonsymmetrical): applied to a lens having differently shaped elements on either side of the diaphragm.

attenuation: reduction of intensity; applied to an electric current, sound wave, optical energy, etc.

auxiliary lens: a lens element which is added to the regular camera lens to shorten or increase its focal length.

available light: photography is said to be available light photography if the sole source of illumination is the light provided by the natural environment.

B

back lighting: the illumination of the picture, whether by artificial or natural light, where the predominant source of illumination is on the side of the subject away from the camera or "in back of the subject" as he faces the camera.

barrel distortion: a condition in a lens which causes the lines in an image to be bowed outward from the center.

barrel mount: a simple tube in which a lens is mounted; no shutter is provided, though an iris or other type of diaphragm may be supplied.

beam-splitter: a prism or mirror, or combination of prisms and/or mirrors, so designed that a certain fraction of the incident light is transmitted without change, the remainder being reflected at some angle to the axis of the unit.

between the lens: the location of the shutter mechanism in the same mechanical support as the lens, with the shutter blades located in the central region of the lens between the principal planes.

boresight: an optical device for alining an engineering or motion picture camera by viewing through the lens.

boresight camera: a camera used to photographically record a scene being observed by some other photo-optical devices as a visual record for orientation and/or calibration.

brightness range: the scene luminance range which is the range of luminance being presented by the scene to the camera. Scene luminance range in excess of that capable of being recorded by the camera film system will result in a loss of information at either the high or low end of the scale, depending on the choice of exposure level.

bulb: shutter setting in which the shutter remains open as long as the actuator is depressed and closes as soon as the actuator is released; marked "B" on cameras.

burned out:. applied to an overexposed negative or print lacking in highlight detail.

burning in: a method of darkening parts of a print in which certain parts of the image are given extra exposure while the rest of the image is protected from the light.

C

candela: a unit of luminous intensity; the luminance of a blackbody radiator at the temperature of solidification of molten platinum is 60 candelas per sq cm.

candlepower: luminous intensity expressed in terms of the standard candle.

cartridge: a light-tight container which is supplied loaded with film and can be placed in the camera in daylight.

cassette: an alternate term for cartridge.

characteristic curve: a graphical plot of the input-output relationship of a photographic process. It is a plot of the optical density of the photographic emulsion which results from a given exposure plotted on a log exposure scale. The logarithmic scales are used because they most closely resemble behavior of the human eye.

chromatic aberration: a defect in a lens in which rays of light of different colors are not brought to a focus in the same plane.

chromatic difference of magnification: a lens defect differing from chromatic aberration in that the rays of various colors are brought to a focus in the same plane, but at different points; in color-separation work, this defect produces three-color images of different sizes; sometimes called lateral color.

cinching: tightening a roll of film by holding the spool and pulling the free end; invariably results in parallel scratches or abrasion marks.

cine: word or prefix referring to motion picture.

claw: metal tooth or finger which advances the film frame by frame in a motion-picture camera.

closeup picture: picture which is taken from a point nearer than the normal viewing perspective of the scene.

coating, lens: a thin, transparent coating applied to a lens to reduce surface reflections and internal reflections; also cuts down transmission of ultraviolet rays, acting somewhat like a haze filter.

collimate: to produce parallel rays of light by means of a lens or a concave mirror.

collimating lens: a lens so adjusted as to produce a parallel beam of light.

color-blind: applied to an emulsion sensitive only to blue, violet, and ultraviolet light; see **color-sensitive.**

color-sensitive: an emulsion which is not colorblind; for example, an emulsion sensitive not only to blue, violet, and ultraviolet, but also to yellow and green, is called orthochromatic; if sensitive to red as well, it is called panchromatic.

coma: a lens aberration affecting the rays which are not parallel to the lens axis; images of points near the edges of the picture appear as ovals pointing toward the center of the picture.

complementary colors: colors of pigment which when mixed produce a gray; colors of light which when mixed produce white light.

composite: a film that contains both the picture and sound records.

concave: hollowed out; curved inward; applied to negative lenses which are thinnest in the center.

concave lens: a lens having one or two concave surfaces.

concavo-convex lens: a lens having one concave and one convex surface.

condenser: a lens used in an enlarger or a projector to collect the light rays from the source and direct them through the negative or the slide to the objective lens.

conjugate (adj.): applied to the position of the object and image points of a given lens; for every possible position of an object from the front focal point of the lens to an infinite distance, there is a corresponding (or conjugate) image point on the opposite side of the lens.

conjugate foci: the distance from lens to image and from lens to subject when the image is in focus.

contact print: a print made by placing a negative in contact with sensitive paper while exposure is being made.

continuity: plan and order of sequences in a motion picture.

continuous printer: a motion-picture or still-picture printer in which the negative and positive films travel continuously past the exposing light source; also applied to a machine which prints microfilm negatives on a continuous roll of paper.

contrast: generally used to describe the rate of change in the brightness or luminance values of the scene. When used with relationship to the characteristic curves, it indicates the change of the density with respect to the change of the logarithm of the exposure.

contrast filter: a color filter so chosen as to make a colored subject stand out distinctly from surrounding objects.

contrast paper: photographic paper having a contrasty emulsion in order to produce good prints from soft negatives; also called hard paper.

convergent lens: a lens which bends rays of light passing through it toward its axis.

convex: the opposite of concave; curved outward; applied to a lens which is thicker in the center than at the edges.

core: a wood, plastic, or metal spindle which is removable from the camera on which film is wound, having a cylindrical form. No part extends along the side of the film and thus unexposed photographic film on cores must be handled in the dark room.

coupled rangefinder: a rangefinder connected to the focusing mechanism of the lens that measures the distance to the subject while the lens is focused.

cover glass: thin glass plates used to protect lantern slides or transparencies.

covering power: applied to a lens, referring to the area of image plane where a sharp image is formed by the lens.

critical focus: exact focus, usually attained with the aid of a focusing magnifier.

curvature of field: a lens aberration in which the image is not formed on a plane but in a concave surface; thus the entire image cannot be brought into focus on a flat film or plate.

curvilinear distortion: a lens aberration in which straight lines near the edges of the picture are imaged as curves. (See **barrel distortion** and **pillow distortion.**)

cut-film: a term for sheet film.

cutoff: an obstruction of light rays to the lens, either by the sunshade, the camera bed, or an adjacent lens on a turret.

D

daylight loading: any arrangement on a camera, a film magazine, or a developing tank permitting insertion of film in daylight without the use of a darkroom or a changing bag.

definition: the clarity, sharpness, resolution, and brilliancy of an image formed by a lens.

dense: very dark; applied to a negative or positive transparency which is overexposed, overdeveloped, or both.

densitometer: an instrument designed to measure the density of a negative or a print.

density: the measure of the optical absorption of material on a logarithmic scale. The specific definition of density is the logarithm of the ratio of the energy incident upon an object to that which results from the modulation whether it be absorption, scattering, or transmission of the object.

depth of field: the range of distances when a camera has a given setting through which all objects are said to be in acceptable focus.

depth of focus: the allowable error in lens-to-film distance within which an acceptably sharp image of the subject focused upon will still be obtained.

development: the process by which the final image is generated on photosensitive material by means of chemical or physical treatment which effectively amplifies the basic photochemical reaction which took place at the moment of exposure.

development by inspection: development of negatives or prints by inspection, depending on the operator's judgement as to when development is complete.

diaphragm: a mechanical device inserted in the center of a lens between the principal planes for controlling the amount of light passing through the lens.

diffraction: the bending of a light ray in passing the edge of an opaque barrier.

diffraction disk: see **Airy disk.**

diffused light: light which does not reach the subject in a single beam, but is scattered by a medium such as clouds, groundglass, spun glass, or thin fabric.

diffuser: a tracing cloth or glass-wool screen placed in front of a light source to soften the light.

diffusion: an optical process by which a material modulates light so as to cause partial or total disturbance of the light beams, resulting in partial or total reduction in the total information in an image.

diffusion transfer process: a method of producing a positive image by transfer of unused silver salts from the negative during development; used in office copying machines, Polaroid-Land cameras, etc.

direct finder: a viewfinder through which the subject is seen directly, such as the wire finder on various cameras.

direct positive: a positive image obtained in a basic photochemical process directly without the use of a negative or negative step in the process. (Distinguish from reversal.)

dispersion: the separation of a single ray of white light into a group of colored rays by a prism or other optical device.

distortion: an incorrect rendering of the shape of a subject.

divergent lens: a lens which bends the rays of light away from its axis; also called a **negative element.**

double coating: the coating of a fast emulsion on top of a slow one, to secure greater latitude of exposure.

double exposure: two exposures on a single negative, either by accident or by design.

double weight: the heavier weight in which photographic papers are supplied.

duplicates: photographic copies made of photographic originals having same tone scale (positive from positive; negative from negative) and generally the same size.

E

easel: a device used to keep sensitive paper flat while enlarging; occasionally used to hold photographs flat while they are being copied.

edge fog: fog on film due to leakage of light between the flanges of the spool on which it is wound.

effective aperture: the diameter of the lens diaphragm as measured through the front lens element; the unobstructed useful area of a lens; it may actually be larger than the opening in the lens diaphragm, owing to the converging action of the front lens element.

emulsion: the combination of silver salts and gelatin support which constitutes a light-sensitive system and is coated on the base support to create a photographic film or plate.

emulsion speed: the inherent sensitivity of the photographic emulsion to light as measured as a reciprocal of the amount of energy required to produce a given effect.

enlarged negative: a negative made from a smaller one by optical projection.

enlargement: a print made from a smaller negative through a projection process.

exposure: the actual act of allowing image forming energy to strike the photographic film. Also, a measure of the total energy allowed to the film. This energy is a product of intensity (a unit of power) times time.

exposure index: a measure of the sensitivity of the film as derived from the reciprocal of the exposure required to produce a given effect.

exposure indicator: a device attached to a camera to indicate the number of exposures; also to a plate holder to show whether the plate has been exposed.

exposure meter: a device for measuring the light level of a scene together with a calculator for determining a desirable photographic exposure.

exposure time: the time period during which the exposure takes place.

extension tube: a tube device placed between the lens and the camera to extend its focusable range, primarily for using the camera very close to objects.

eyepiece: the lens element of a microscope, viewfinder, or telescope to which the eye is applied in order to view the image.

F

f/ (as: f/2.8; f/5.6; f/11): the designation of the relative aperture of a lens; it is calculated by dividing the focal length of the lens by its effective aperture.

far point: the farthest object from the camera which is still acceptably sharp when the camera is focused at a given distance.

ferrotype plate: a highly polished plate used to produce a glossy finish on prints.

ferrotyping: the procedure of drying a glossy photograph in intimate contact with a highly polished surface in order to impart a high gloss on its surface finish to the photograph.

film base: the transparent material on which an emulsion is coated.

film cement: a solution of cellulose acetate or nitrate used to join strips of motion-picture film in editing.

film chamber: the section of a motion-picture film camera which contains the film, film gate, and the film-moving mechanism during operation.

film cleaner: a liquid used to remove dirt, dust, and grease from a film without injuring the base or the emulsion.

film gate: a combination of the aperture plate, film channel, pressure plate, pads and springs used to maintain the position of the film in the focal point of the lens. May be applied either to a motion-picture camera or projector.

film pack: a metal case containing a number of films, so arranged that films may be changed by pulling out paper tabs.

film-pack adapter: a holder by means of which the film packs may be used in a camera designed for plates or sheet films.

film-slide: most commonly identified as individual frames mounted in cardboard or glass mounts for projection.

filmstrips: a series of still pictures on motion-picture film, generally in the same format of motion-picture films which are shown by a special projector one picture at a time. It is convenient for audiovisual work as the bulkiness of slide mounts is eliminated.

film tank: a container holding solutions and films to be processed therein.

filter factor: the number of times exposure must be increased to compensate for light absorbed by the filter.

filter ratio: the ratio between the factors of two or more filters used with the same film and illuminant; frequently used in color separation work in preference to the actual filter factors, since no exposure is normally made without filters in such work.

filters: transparent material having a specific absorption characteristic to modify the spectral distribution of energy in a light source or passing through a lens.

finder: a viewer through which the picture to be taken may be seen and centered.

fine-grain developer: a developer of low potential which prevents a mottled image formed by the clumping of silver grains.

fine-grained: applied to a negative with very little granularity; one which may be enlarged from 7 to 10 diameters or more with satisfactory quality.

fixed-focus: applied to a simple camera (box camera) or folding camera having a short-focus, small-aperture lens, whose great depth of field makes focusing unnecessary; also called **universal focus.** In aerial photography many cameras are fixed-focus with the lens set for the infinity focus condition.

fixing: that part of the chemical processing which takes place after development is completed which removes or neutralizes unwanted sensitive components of the film. This permits it to be viewed in direct light without further photochemical reaction.

flange: a threaded metal ring used to fasten lenses and/or shutters to the front of a camera.

flare: light reaching the photosensitive emulsion, resulting from internal reflections within the lens, such as occur from noncoated air-glass lens surfaces.

flash gun: formerly, an apparatus for firing flash powder; now used as a term for the battery case, lamp socket, and reflector used with photoflash lamps or electronic flash units.

flashtube: a glass or quartz tube, usually wound in helical shape, containing two electrodes and filled with xenon or other inert gases at a very low pressure; it is used as the light source in electronic-flash units and stroboscopic lighting.

flat: lacking in contrast.

flood: a light source providing a wide, diffused beam of light.

floodlamp: in general, any lamp or lighting unit producing a broad beam or flood of light; colloquially used as a contraction for photoflood lamp; see **photoflood lamp.**

fluorescence: the property possessed by certain substances of emitting light of longer wavelength when exposed to light of short wavelength.

***f*-number (*f*/stop)** (*f*/5.6; *f*/8; *f*/11): the relative aperture of a photographic lens, expressed as the ratio of the focal length to the effective aperture diameter.

focal length: a general term used to designate the characteristic of the lens in terms of the distance between the point of focus and the corresponding principal plane of the lens.

focal plane: the position in a camera occupied by the plate or film.

focal-plane shutter: a shutter consisting of a curtain or a roller-blind with slits of various sizes, traveling as close to the film as possible.

focal point: where all light rays transmitted from a given object point intersect. With the object at infinity, i.e., the incident rays parallel to the axis of the lens, the image is the principal focal point. The principal focal point lies on the lens axis.

focus (n): the point at which converging rays of light from a lens meet.

focus (v): the act of adjusting a photographic system for best image formation.

focusing magnifier: a lens through which the image on the groundglass is viewed for critical focusing.

focusing mount: a spirally threaded tube in which a lens is mounted; focusing is accomplished by rotating the mount, which moves the lens to and from the film.

focusing scale: a graduated scale on a lens or a camera, permitting focusing on a given subject by estimating its distance from the camera and setting an indicator to correspond.

focusing screen: the groundglass in a camera on which the subject is focused.

fog: a dark, hazy deposit over the entire film or paper, or portions thereof.

foot-candle: a measure of light intensity.

foot-lambert: a measure of source brightness or luminance.

frame: one individual picture on a strip of motion-picture film, microfilm, or 35-mm film.

frame counter: a dial counter indicating the number of frames passing through a camera.

frame line: narrow exposed area between adjacent frames or pictures on a strip of film.

front lens: the first element of a lens system; that which the ray enters; also sometimes used for a supplementary lens to be placed in front of a lens system.

full aperture: the maximum opening of a lens or lens diaphragm.

G

gamma: a numerical index of the rate of change of density with log exposure derived from the characteristic curve.

gamma infinity: since characteristic curve varies with the type and duration of development, this variation is reflected as a change in the gamma value; gamma infinity is a numerical value indicative of the steepest rate of change obtainable with a particular film and developer combination.

gate: see **film gate.**

ghost: the reflection of an image on one or more lens surfaces recorded by the negative.

global photography: a term used by meteorologists to define photographs of the Earth and its environment in a very comprehensive picture that gives a scale of the entire photograph covering distances greater than 5,000 kilometers.

glossy: photographic papers heavily coated with gelatin so that they may be ferrotyped.

gradation: a term applied to the negative or positive; the rate of increase of density with exposure, as one factor of contrast.

gradient: applied to the characteristic curve, the slope of any chosen part of the curve; distinguished from gamma, which refers to the slope of the straight-line portion of the curve only.

grain: the random assortment of silver deposits in a developed photographic image in varying particle sizes and shapes.

graininess: the subjective impression of variation in density resulting from the grain structure of the photographic sample when viewed at a high magnification.

granularity: the objectively determined characteristic of the developed photographic material which results from the image being formed by elements having perceptible size and shape which are referred to by the general term grain.

gray scale: a test pattern consisting of patches of various shades of gray, or having different reflections without color, which is used for control purposes in precision photography.

groundglass: a screen at the back or top of the camera upon which the image may be focused.

gun camera: a special aerial motion-picture camera which automatically photographs any subject being fired upon by the gun to which it is connected.

H

halation: in its simplest terms, a designation of unwanted flare resulting from reflection of light which has passed through the photographic emulsion by the back of the film support.

haze: An atmospheric phenomenon which tends to destroy the contrast and image quality in photographs taken from high altitudes or from long distances across ground.

helical mount: a spirally threaded lens mount permitting focusing by rotating the movable part of the lens tube.

high-speed camera: a framing motion-picture camera capable of very fast frame rates for engineering studies. Generally greater than 100 fps., may work up to 10,000 fps.

hypo: sodium thiosulfate (incorrectly called sodium hyposulfite), a chemical used in fixing baths; the word is also applied to the complete fixing bath, containing sodium thiosulfate and various acids, hardening agents, etc.

hypo test: a method of checking the completeness of washing by running the drippings of wash water from the film or print into various testing solutions; also, commercial solution used to test strength of hypo.

I

image: the representation of an object formed by optical means and its recording by photochemical means.

image, anamorphic: an image which has been produced by an optical system having different horizontal and vertical magnifications.

image dissection: the technique by which the information contained in the photograph which is a two-dimensional record in space is scanned so as to produce the information sequentially in a one-dimensional record generally on a time base; a significant technique when it is desired to transmit pictures over a long distance or to enter picture information into a computer for further analysis.

incident light: the light which falls on a subject, either from natural or artificial sources, by which the photographic record is made.

index of refraction: the mathematical expression of the deviation of a light ray entering a given medium at an angle to its surface.

infinity: photographically, a distance from which light appears to reach the lens in parallel rays; symbol: ∞.

infrared rays: invisible radiation whose wavelength is greater than 700 nanometers; the shorter wavelengths of heat rays.

intensification: a postprocessing procedure by which the density or contrast of the image is increased.

interference: an effect resulting from the meeting of two light rays of identical wavelength but different phase; when the phase difference is ½ wavelength, the two light waves cancel and darkness results; interference between two rays of heterochromatic light results in colored patterns similar to the spectra produced by a prism.

intermittent movement: a mechanism in a camera or projector which causes film to move past the exposing aperture one frame at a time instead of a continuous flow.

intervalometer: a device used on aerial or engineering data cameras which automatically operates the camera at predetermined intervals.

inverse square law: the intensity of light received at a point varies inversely as the square of the distance from the source.

invisible rays: light rays which cannot be seen by the eye, such as ultraviolet and infrared rays.

iris diaphragm: a lens control composed of a series of overlapping leaves operated by a revolving ring to vary the aperture of the lens.

K

kinescope recording: a motion-picture film of a television broadcast, made by photographing the image on the face of a kinescope or cathode-ray tube.

L

laboratory packing: unexposed motion-picture film which is wound on a core, instead of a daylight-loading spool.

lambert: a photometric unit of surface luminance.

lamphouse: that part of a projector or an enlarger which contains the light source.

lantern slides: small transparencies, either 2 × 2, 3¼ × 3¼, or 3¼ × 4, intended for projection. In recent times used to distinguish 3¼ × 4" slides from smaller sizes.

latensification: a form of hypersensitization which consists of applying the hypersensitizer after exposure but before development; usually applied to the use of a long exposure to very dim light to raise the threshold of exposure of the emulsion.

latent image: the image recorded by light on the sensitive emulsion, remaining invisible until developed.

lateral color: see **chromatic difference of magnification.**

latitude of exposure: the amount by which a negative may be overexposed or underexposed without appreciable loss of image quality.

leader: unusable film or a special opaque material supplied at the beginning and end of the roll to facilitate threading and to protect the basic film from damage by light. On motion-picture projection prints it will contain identification and cueing information.

lens: an optical element, generally glass, with properly designed curved surfaces for the purpose of creating a real image of a scene.

lens board: a detachable board carrying a lens and a shutter, which is fastened to the front of the camera to permit interchange.

lens cap: a cover used to protect a lens from dust and damage when not in use.

lens hood: a shade to keep extraneous light from the surface of a lens.

lens paper: a fine soft tissue paper used for cleaning lenses.

lens turret: a revolving plate carrying several lenses attached to the front of the camera in such a way that any lens may be placed in position for use by revolving the plate.

light filter: see **filter.**

light fog: the fog produced over an image by accidental exposure of film to extraneous light.

light trap: a system of staggered passageways or double doors so that a darkroom may be entered or left without light being admitted.

linear perspective: the impression of depth or distance in a photograph due to the diminishing of the size of objects in proportion to their distance from the camera.

line copy: original material to be copied, containing only black-and-white areas or lines, without intermediate tones.

line original: see **line copy.**

loop: the slack portion of the film between sprockets and aperture which absorbs the shock of intermittent motion imparted to the film by the advance mechanism.

lumen: photometric unit, equal to the luminous flux on 1 square foot of surface from a standard candle 1 foot away.

luminance: that characteristic of an object which defines the amount of light radiated from the surface.

lux: lumen per square meter.

M

magazine: the container holding the film feed and takeup spools of a motion-picture or still camera, also a device for holding and exposing from 12 to 18 sheet films or plates in succession. The container is reusable and is reloaded in the darkroom by the operator.

mask: a sheet of opaque material or controlled density used to control the exposure on certain areas of the film or paper.

matte: a thin metal plate containing an opening which may be one of various shapes, such as circle, oval, double circle (binoculars), etc., used to frame the scene taken by a motion-picture camera; also applied to a dull-surfaced photographic material.

matte back: a film frosted on the reverse side for easier retouching.

matte box: a large sunshade for a motion-picture camera, containing a slide to hold mattes of various shapes before the lens.

meniscus: see **concavo-convex.**

meter-candle-second: a unit of exposure in sensitometry; 1 second of exposure at a distance of 1 meter from a light source of 1 candlepower.

microdensitometer: a special form of densitometer for reading densities in very small areas; used for studying astronomical images, spectroscopic records, and for measuring graininess in films.

microfiche: a micro reproduction system for the storage and retrieval of documents where the images are contained on a 4- by 6-inch piece of film with manual storage and retrieval much like index cards.

microfilming: a generic name used for microreproduction of documents for efficient storage and retrieval systems.

micrometer: a unit of length; 1/1000 of a millimeter; abbr.: μ. formerly called a micron.

micrometer mount: a very precise, helical lens mount; see **helical mount.**

microphotography: a process for making minute, precision photographs of an object, or little pictures of large subjects. The microfilming of a check produces a microphotograph.

miniature camera: a generic name originally used for cameras taking still pictures on 35-mm motion-picture stock. Generally refers to any cameras taking pictures on 35 mm or smaller size films.

monochromatic: containing light of one wavelength or color.

mottling: a nonuniformity of density which appears in negatives or prints and is more gross than that caused by grain. It is generally associated with an agglomeration of silver grains due to deficiencies during processing.

multilayer: a film or glass plate coated with two or more layers of emulsion of differing characteristics; these include double-coated plates for reduction of halation effects and for change in latitude and the two- or three-layer films used for color photography.

multilayer color film: a color film in which the red, green, and blue recording emulsions are coated superimposed on a single film base. The three emulsions yield color images which, because of the superimposition, present a full color reproduction of the original scene.

N

nanometer: a unit of length; 1/1,000,000 of a millimeter, or 1/1000 of a micron; abbr.: $m\mu$. Originally known as a millimicron.

near point: the nearest object to the camera which is still acceptably sharp when the camera is focused for a given distance.

negative: a photographic image in which the amount of silver present is more or less proportional to the quantity of light reflected from the original object; thus bright objects are black and dim ones white: abbr.: neg.

negative element: another name for divergent lens; see **divergent lens.**

neutral: without color; gray; chemically, a solution which is neither acid or alkaline.

neutral density filter: a gray filter used to reduce exposure when a lens cannot be stopped down sufficiently. It produces no measurable color change in the light which it transmits.

non-color-sensitized: a photographic emulsion having only the inherent sensitivity of the silver salt; sensitive only to blue, violet, and near ultraviolet light; see **color blind.**

noncurling: applied to film which has a clear gelatin coating on the back to minimize curl caused by shrinkage of the emulsion in drying.

nonhalation: see **antihalation.**

numerical aperture: the sine of half the angular aperture, used as a measure of the transmission and optical power of an objective lens.

O

objective: the lens which actually forms the primary image in an optical system; it may be used in conjunction with a condenser to direct the light rays through the object and in the case of a microscope, finder, etc., with an eyepiece to magnify further the image formed by the objective.

oblique: applied to an aerial photograph taken at an angle from the airplane.

opacity: the light-stopping power of the silver deposit in a negative.

opal glass: a white, milky, translucent glass used as a maximum diffusion medium in optical systems.

opaque: not capable of transmitting light; also a term applied to a red or black pigment used to block out portions of a negative which are not to be printed.

optical axis: an imaginary line passing through the centers of all the lens elements in a compound lens.

optical center: the point, usually within a lens, at which the light rays are assumed to cross; certain types of telephoto lenses may have this point outside the combination.

optical contact: the adhesion of two glass surfaces by means of a transparent medium so that there is no air between them.

optical flat: a filter or other glass plate, ground to a plane-parallel condition with a high degree of precision.

ortho: an abbreviation for orthochromatic; see **orthochromatic.**

orthochromatic: the word actually means correct color; in photography, a term applied to film which is sensitive to blue and green light but not to red.

overdevelopment: the result of permitting film or paper to remain in the developer too long, resulting in excessive contrast or density.

overexposure: the result of too much light being permitted to act on a negative, with either too great a lens aperture or too slow a shutter speed or both.

oxidation: the loss of activity of a developer due to contact with the air.

P

pan: an abbreviation for panchromatic; see **panchromatic.**

panchromatic: applied to photographic material sensitive throughout the entire visible spectrum.

panning: allowing the camera to scan across the scene while taking motion pictures in order to produce a general overall view of a scene or to follow a moving object through a scene over a distance greater than the normal field of view of the camera.

panoram: to move a motion-picture camera while it is operating so as to include a sweeping view.

panoramic head: a revolving tripod head, so graduated that successive photographs may be taken which can be joined into one long panoramic print.

parallax: the error caused by using the viewfinder at any point closer than nominal infinity. It occurs in a camera system when the viewfinder has an optical axis parallel to, but displaced from, the optical axis of the lens.

parallax adjustment: adjustment for tilting a viewfinder so that its field is the same as that of the picture-taking lens for a given distance.

paraxial: referring to the space or rays closely surrounding the principal axis of a lens system.

parfocalized: a group of lenses, all mounted so that they will come into focus when secured in the same mount, are said to be parfocalized; term applies especially to sets of microscope objectives to be used in a multiple revolving nosepiece.

pellicle: a thin film or membrane; for example, the extremely thin, semi-transparent mirrors used as a beam-splitter in a camera making more than one picture at a time.

pentaprism: a five-sided prism used in single-lens reflex viewing hoods to turn the image right-side-up and laterally correct.

perspective: the relative size and alinement of objects as recorded on a plane surface.

photoengraving: a method of producing etched printing plates by photographic means.

photofinishing: the commercial processing and printing of amateur photographs in high-volume operations.

photoflash lamp: a light bulb filled with aluminum wire or shreds in an atmosphere of oxygen; the heating of the filament ignites the primer which in turn fires the aluminum, giving a short brilliant flash of light.

photoflood lamp: an electric lamp designed to be worked at higher than normal voltage, giving brilliant illumination at the expense of lamp life.

photogrammetry: the science of mapping by the use of aerial photographs; the science of precision determination of geometrical dimensions from a photograph.

photomacrography: a process for making either moderately magnified or unmagnified pictures of small objects. Note that no compound microscope is used. Often it is considered that a photomacrograph represents an enlargement of no more than about $\times 20$ diameters. A photograph of a coin at twice life-size is a photomacrograph.

photometer: device for measuring light energy.

photomicrography: a process for making greatly magnified photographs of minute objects through a compound microscope, or for making big pictures of microscopic subjects. A photograph of a gnat's eyebrow is a photomicrograph.

phototheodolite: a camera characterized by its ability to measure and record the principal geometric data on the film while simultaneously taking the picture. A cinetheodolite uses motion picture techniques.

phototopography: the mapping or surveying of terrain by means of photography.

physical development: a method of developing a photographic image by the deposition of metallic silver on the latent image nucleus.

pillow distortion: a type of distortion in a lens system which causes the lines in the image to be bowed inward toward the center of the field. Sometimes called "pincushion" distortion.

pinhole camera: a camera that creates an image by pure diffraction techniques utilizing an extremely small opening in the camera wall without requiring a lens.

pinholes: tiny clear spots on negative or positive images, caused by dust, air bells, or undissolved chemicals.

plano-concave lens: a lens having one side convex and one side flat.

plate back: an attachment to certain roll-film cameras such as the older Kodaks, the Rolleiflex, etc., now used with optical reconstruction equipment to permit the use of plates or sheet film; incorrectly used as a description of a camera primarily designed for use with plates; such cameras are plate cameras, not plate-back cameras.

plate holder: a lightproof holder in which sensitized plates are held for exposure in the camera.

plate magazine: a lightproof box containing mechanism to expose a number of plates successively in a camera.

polarized light: light energy which has a preferred direction of orientation about the axis of the direction of propagation; the orientation refers to the wave nature of light energy in propagation.

portrait attachment: a supplementary lens permitting the camera to be focused on objects closer than is normally possible.

positive: an image in which the tones correspond to those of the original, light objects being light and dark objects being dark; abbr.: pos.

power (of a lens): the reciprocal of the focal length of a lens in meters; expressed in diopters. This terminology is derived from and is primarily used in the science of ophthalmology.

preexposure: exposure of a sensitized material to light either during manufacture or by the user before exposure in the camera, as a means of intensifying the latent image, particularly in shadow areas.

prefocused: applied to a lamp having a special type of base and socket which automatically centers the filament with respect to an optical system.

pressure plate: the movable channel plate which by means of light spring tension holds a film flat against the aperture which is the focal plane of the lens.

principal focus: of a lens or spherical mirror, the point of convergence of light coming from a source of infinity.

principal plane: a set of planes perpendicular to the axis of a lens, passing through the principal points such that a ray of light entering the lens in the direction of one leaves the lens as if it originated in the other and parallel to the original direction.

printer: a machine for making photographic reproductions of photographic master copies, such as a negative or reversal transparency, which performs in several ways. A contact printer makes the reproduction by direct contact of a receiving sheet to a transparent master. A projection printer projects the master onto the sheet. In addition to printers for still films, there are continuous printers for motion pictures, in which the film runs at a constant rate through the printer, and a step printer, in which the film is stepped and printed frame by frame. In motion-picture work a projection printer is often called an optical printer.

printing: the generic name for the process of producing reproductions of photographic originals in a final form ready for display and viewing. This applies both to production of opaque or reflection type originals of single photographs, as well as for the final copy of a motion picture which is projected for final viewing.

printing frame: a frame designed to hold a negative in contact with paper, under pressure, for the purpose of making prints.

printing-out paper: a photographic paper forming a visible image immediately on exposure, without development; it must be fixed, however, for permanence of the image.

prism: an optical device which directs a ray of light at a different angle than that at which it entered; it is sometimes used to break down white light into its component colors in certain optical instruments.

process camera: a specially designed camera for high precision and metric photography generally associated with photoengraving, lithography, and cartography. It has found very recent application in the preparation of photographic masters for the manufacture of microelectronics. It is characterized by solid, unit construction, mechanical design to minimize vibration errors.

process lens: a highly corrected lens used for precise color-separation work and/or critical geometry in process camera work.

projection print: an enlarged or reduced photographic print made by projection of an image of the negative on the sensitized material.

projection printer: an enlarger.

projection screen: the screen on which transparent photographic images are displayed by projection, whether they be slides or motion pictures. The screen must be designed to provide maximum optical efficiency to the viewing audience.

projector: an optical device for the projection of transparent photographic images, whether slides or motion pictures, in an enlarged format for comfortable viewing.

Q

quartz lens: a special lens used for ultraviolet photography.

R

radiography: the application of photography for recording images produced by energy in the X-ray spectrum. Such energy is capable of penetrating human tissues and, at higher levels, metal parts.

rangefinder: an optical device for measuring distance.

ratio: the degree of enlargement or reduction of a photographic copy with respect to the original.

raw film: unexposed, undeveloped film.

reading machine: a projector with a self-contained screen, used for reading microfilm copies.

real image: any image formed by a lens or mirror which can be focused on a screen, plate, film, or other surface; such an image exists in space, as can be proved by blowing smoke across the image space; this space image is called an aerial image; distinguished from virtual image; see **virtual image.**

rear projection: projection of a motion picture or still picture from behind a translucent screen or from the side of the screen opposite that of the viewer.

reciprocity law: the photosensitive effect produced by the response of the photographic film to incident energy or, in photographic terms, exposure. There are two reciprocal components to the quality of exposure: the intensity (or power), the rate at which energy is delivered; and time, the duration through which it is delivered. The reciprocity law states that the photosensitive reaction should be independent of intensity, or time, at a constant energy, or exposure. Silver photographic systems, as well as others, fail to obey this reciprocity law.

reduce: to make a print smaller than the original negative; for example, to make lantern slides from large negatives, or to make a print on 16-mm motion-picture film from a 35-mm negative.

reel: a version of the spool, but with open flanges, used for finished film in projector systems. Arbitrarily, 1000 feet of 35-mm film or 400 feet of 16-mm.

reflection: the redirection of a beam of light from a surface.

reflex camera: a camera in which the primary image in a vertical plane is bent at 90 degrees by means of a mirror to a horizontal plane for more convenient viewing and focusing.

relative aperture: the ratio between the effective aperture of a lens and its focal length; the relative aperture is usually given in inverse whole numbers rather than fractions; thus a lens whose relative aperture is ¼ is called an *f*/4 lens, etc.

reseau plate: a glass plate, which contains high precision calibrated marks, incorporated as part of a precision photogrammetric camera system to provide both a reference point for subsequent data reduction and a means for correcting for lack of film stability.

resist: in photoengraving, a material applied to the image, and other parts of the plate, to protect the metal from the action of the etch bath. A photoresist permits the formation of image by photographic means.

resolving power: a characteristic of a film which defines its ability to make a distinguishable record of small periodic images.

reticle: a scale or grid engraved on a glass plate, placed in an optical system for measurement or to provide a reference point; also, but less correctly, spelled *reticule:* British preference is for the word *graticule.*

rewind: to reroll the film in its original order. Also, devices used to wind film from one reel to another or to rewind motion pictures after they have been projected.

roll: film supplied in long lengths at working width. May be supplied on cores, spools, in cassettes, or in bulk, depending on the system in which it is to be used.

roll film: a strip of flexible film, wound on a spool between turns of a longer paper strip, for daylight loading into roll-film cameras. Distinguish from long lengths supplied in bulk for motion picture and automatic cameras.

roll-film holder: an accessory permitting the use of roll film in sheet-film cameras.

rotating stops: a series of different-sized holes in a rotating metal disk used in place of the iris diaphragm in certain lens systems.

S

safelight: a nonactinic light used for darkroom illumination.

safety film: film with a cellulose acetate base; so called because it burns very slowly.

safety shutter: a shutter of metal or heat-absorbing glass which is automatically inserted between the lamp and the film whenever a motion-picture projector stops for any reason, to avoid burning or blistering the film.

scale: the entire range of tones of a photographic paper or film; also, the distance markings to which a lens may be set for focusing.

Schlieren photography: an optical technique for making visible and photographing original phenomena which are occurrences of purely a change in index of refraction, or density, of gas or other optical media.

screen: a glass plate, ruled with intersecting lines, used by photoengravers to produce a dot image on halftone plates.

screw mount: a lens mount which is threaded to fit the front of the camera.

self-capping shutter: a focal-plane shutter in which the slit automatically closes while the curtain is being rewound, to avoid fogging the film.

semi-matte: applied to smooth-surfaced papers with a slight luster.

sensitizing: a process in which the basic inherent sensitivity of a photochemical process is increased or made responsive to other wavelengths of light over its natural response.

sensitometer: an instrument which exposes a photographic film in a known manner so that its light-sensitive properties may be measured.

sensitometry: the science of determining the characteristic responses of a photosensitive product.

sequence camera: an engineering camera used to make a series of pictures in rapid sequence or in very short time intervals between pictures; the frame rate is fast enough to require automatic mechanical drive in ranges up to motion-picture speeds which is generally 24 frames per second.

sheet film: individual films loaded into separate holders for exposure; usually on a heavier base than roll films and film packs.

shutter: a mechanical device which regulates the time that light is allowed to act on the photographic film.

shutter efficiency: as applied to shutters, the percental relationship between the total time a shutter remains open (counting from half-open to half-closed position) and the time required for the shutter to reach the half-open and the fully closed positions.

single weight: applied to a photographic paper with a lightweight stock.

slide: a positive print on glass, or a film transparency bound between glasses for projection; also the removable cover of a sheetfilm, plate or film-pack holder.

slidefilm: another name for filmstrip; see **filmstrip.**

slow motion: action, filmed with the camera running at high speed and projected at normal rates.

soft-focus (adj.): applied to a lens which has been deliberately under-corrected to produce a diffused image; also applied to pictures made with such a lens.

sound track: the strip with variable area or variable density which is photographed on the edge of a motion-picture film and carries the sound signals.

spectrogram: a photograph of a spectrum, made by the use of a spectrograph.

spectophotometer: an instrument for comparing the intensities at the corresponding wavelengths of two spectra.

spectrum: a colored band formed when light is passed through a prism or a diffraction grating; it contains all the colors of which the light is composed; plural: **spectra.**

specular (adj.): (1) in sensitometry, applied to a measurement made by collimated or essentially parallel light rays; (2) referring to direct reflection, without scattering or diffusion.

spherical aberration: a lens defect in which the various rays forming a single image point on the axis are not brought to a focus in the same plane.

splice: a joint where two sections of the film are fastened together.

splicer: a mechanical device for joining strips of film.

spool: a cylindrical spindle with side flanges for use in handling film. Most spools are designed with solid flanges and permit daylight loading of certain film which is properly packaged with leader and trailer.

step tablet: see wedge, gray scale.

stereo camera: a camera having two lenses or the equivalent through which the pair of pictures making up a stereogram may be taken simultaneously.

stereogram: a pair of pictures taken from positions separated by a definite distance laterally, and mounted side by side for viewing.

stereoscope: a device containing lenses, prisms, or mirrors, through which a stereogram is seen as a single, three-dimensional picture.

stereoscopic photography: the application of photography utilizing a camera with dual lens taking two simultaneous pictures separated by a suitable base line for the purpose of creating a stereogram.

stills: photographs as distinguished from motion pictures.

stripping film: a film whose emulsion may easily be removed from the base and transferred to another support; used mainly by photoengravers.

stroboscopic photography: a technique for reproducing pictures of high-speed events by synchronization of the photographs to the event cycles.

subminiature camera: a still camera using 16-mm or smaller film for size and packaging advantages.

substratum: the binding layer which causes the emulsion to adhere to the glass or film base.

subsynoptic photography: in a meteorological definition any photography of the earth's environment which is done at relatively close distance yielding a camera scale of overall coverage, less than 1,000 kilometers.

subtractive process: a color photographic system where yellow (minus blue), magenta (minus green), or cyan (minus red) dyes are used to control the amount of absorption or subtraction of light energy in its process. All multilayer color proceses must be, by definition, subtractive processes.

sunshade: a hood placed over a lens to keep stray light from its surface; similar to **lens hood.**

symmetrical lens: a lens combination with identical front and rear elements.

synchronizer: a device which trips the camera shutter simultaneously with the firing of a flashlamp.

synoptic photography: in a meteorological sense photography of the Earth's surface and the environment in a camera scale that produces coverage over the range of approximately 1,000 to 5,000 kilometers.

synoptic terrain photography: high-quality photography of selected areas of the Earth for multiple purposes such as geologic, geographic, and oceanographic study. In a meteorological sense the scale of picture coverage is in the range of 1,000 to 5,000 kilometers.

T

takeup: that part of a camera or a projector which winds up the film after it has passed through the mechanism.

target: microcopying term denoting identification or filing information photographed on a microfilm.

telephoto lens: a lens of long focal length having a separate negative rear element; it is used to form larger images of distant objects; it is similar in results to a telescope.

test strip: an exposed strip of photographic material containing several different exposures used to determine the correct exposure for printing. Also known as sensitometric strip.

thermoplastic recording: a system of recording television images as waves or ripples in a plastic material; the resulting image is barely visible to the eye but can be projected in full contrast through a special optical system based on the Schlieren principle.

thin: applied to a weak negative lacking density in the highlights and detail in the shadows.

thread: to insert film in the various guides, tracks, apertures, and through sprockets of a camera or projector. Also, to insert films through the various rollers on a processing machine.

tilt-top: a device attached to a tripod head to permit the camera to be set at various angles in elevation.

time condensation: single frames taken at intervals and projected at normal rate to speed action and shorten time for a given operation commonly referred to as time lapse photography.

time exposure: an exposure in which the shutter is opened and closed manually with a relatively long interval between.

time lapse photography: see **time condensation.**

timer: a special darkroom clock giving audible or visible indications of various time intervals.

T-number, T-stop: a system of marking lens apertures in accordance with their actual light transmission, rather than by their geometrical dimensions as in the *f*-stop system.

tone: any one density of a photographic image; sometimes, the general color of a photographic image; for example, a blue-black tone.

trailer: a piece of black film or other opaque material at the end of the reel which wraps up and protects the film from exposure to light. See **leader.**

translucent: permitting the passage of light but scattering light sufficiently so that no image can be formed through the material.

transparent: permitting the passage of light without scattering, so that an image may be formed.

tri-metrogon: a system of three cameras used in aerial reconnaissance taking sets of three pictures, one vertical, the other two, high obliques, so that each set of three pictures is a complete view from horizon to horizon.

tropical packing: moisture-resistant containers in which film is packed at the factory when intended for shipment to hot climates.

turret-head: a revolving plate on the front of the camera used to hold two or more lenses allowing them to be interchanged quickly.

U

ultraviolet absorbing filter: a filter used mainly for cutting atmospheric haze in photography with color films to avoid excessive bluishness in the pictures; usual designations are U.V.; Haze; Wratten 2A.

ultraviolet filter: a filter which transmits ultraviolet light, as used for photography by the reflected ultraviolet light method.

ultraviolet photography: photographs made with the invisible radiation of the near-ultraviolet spectrum provides images showing details based on differential reaction to this ultraviolet light which is not normally perceived by the human eye.

ultraviolet rays: invisible rays whose wavelength is shorter than the visible ray of light.

underdevelopment: insufficient development; due to developing either for too short a time in a weakened developer or, occasionally, at too low a temperature.

underexposure: the result of insufficient light being allowed to pass through the lens to produce all the tones of an image; or of sufficient light being allowed to pass for too short a period of time.

universal finder: a finder which can be adjusted to show the field covered by various lenses.

universal focus: see **fixed focus.**

V

variable area: type of motion picture sound track in which the density of silver image is constant. The sound signals are caused by varying the area or width of the black part of the sound track.

variable contrast papers: photographic papers having emulsions of mixed sensitivity so that by choice of exposing filter different contrasts are produced.

variable density track: a sound track of constant width. The signals are caused by variation in the optical density of the line.

view camera: a camera generally made in larger sizes which has several degrees of freedom of motion on both the lens board and film or focal plane. These motions, known as "swings and tilts" permit maximum versatility in "drawing" or correcting the perspective and focal plane of a photograph.

viewer: a device which magnifies film for inspection during editing.

viewfinder: see **finder.**

viewpoint: the place from which a picture is taken or viewed.

vignetting: underexposure of the extreme edges of a photographic image; occasionally caused by improper design of lenses or too small a sunshade; also sometimes intentionally done in portraiture.

virtual image: an image having no actual existence in space; it is the image which is seen in a mirror, or through a lens of negative power.

visual angle: the angle at the eye subtended by the limits of the object; if the object is at the threshold of resolution, the angle is from 0°1′ to 0°2′.

W

wavelength: the distance from crest to crest, or from trough to trough, of any regularly recurring wave.

wedge: a series of tones continuously ranging from white to black, usually on film or a glass plate; when the variations are in discrete steps, it is called a gray scale or sometimes a step tablet.

wide-angle lens: a lens of short focal length and great covering power used to cover a larger angle of view than a normal lens will include from a given viewpoint.

X

X-rays: electromagnetic waves shorter than light or ultraviolet rays, which affect the photographic emulsion and have the property of passing through certain otherwise opaque objects.

Z

zonal aberration: a defect in a lens in which the point of focus shifts when the lens is stopped down.

zoom lens: a lens which can be varied in effective focal length while maintaining focus on a given object; it gives the effect of change of angle of coverage.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1972 O—468-190

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