Aerial Cameras, Aerial Films, and Film Processing

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Any discussion of the aerial camera must of necessity contain information regarding aerial films and aerial film processing, for the aerial camera is merely the instrument used to procure a precision photograph. An unbroken continuity of quality assurance procedures is mandatory from manufacture of the original aerial film through its use in the aerial camera, its photographic processing, and reproduction. A logical approach to the development of aerial photographic expertise, starting with the use of simple, low-cost systems, is outlined.

For over a hundred years man has been capable of leaving the surface of the Earth accompanied by the camera. A century ago, both his aerial vehicle and aerial camera were quite rudimentary. Figure 1 is a reproduction of a photograph made in 1860 by C. W. Black aboard a tethered balloon some 300 meters above Boston, Massachusetts. It is the first recorded aerial photograph taken in the United States and certainly one of the very first ever taken. The "wet plate" was immediately processed by Mr. Black and his eager young assistants. One assistant, Oliver Wendell Holmes, recorded in his diary, "This is indeed a most remarkable thing." Although Holmes did not achieve greatness in the photographic profession, he did become a most distinguished man of letters and a long-time Justice of the Supreme Court of the United States.

It truly was a most remarkable thing. Few modern engineering works involving the utilization of the surface of the Earth have been accomplished without the use of aerial photography.

Aerial photographic technology was quite dormant until the powered aircraft became a fairly efficient platform. Early aerial cameras were heavy and generally unreliable. Many used photographic emulsions on glass plates. Flexible films of nitrate base were highly flammable and dangerous in aircraft. Optical-mechanical devices used in mapping projects were rudimentary and far from precise.

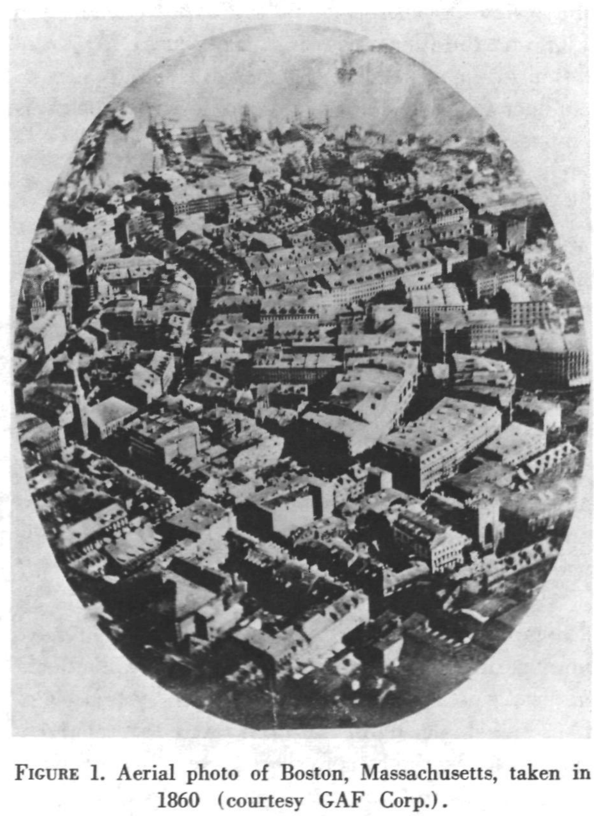

FIGURE 1. Aerial photo of Boston, Massachusetts, taken in 1860 (courtesy GAF Corp.).

But, as the needs for accurate information grew, greatly improved cameras, films, processing equipment, and plotting devices were developed.

In the past few years, it has become apparent that the aerial photograph is an essential tool working in concert with a multitude of remote sensors designed to secure information in other portions of the electromagnetic spectrum. The very limited portion of the spectrum available to photography practically coincides with the recording ability of the human eye. The unique combination of Earth-orbiting spacecraft or high-efficiency aircraft, photography, and other remote sensors has started a true renaissance in the ability to conduct detailed, comprehensive, and highly productive Earth resources surveys.

Actually, any camera used from an aircraft is capable of recording valuable information. It is a grave mistake, however, to attempt to secure information beyond the capabilities of any part of the system. It is absolutely mandatory that we discuss the system concept (that is, the aerial camera, the film, and the film processing techniques). Any violation of the system concept negates your ability to conduct accurate studies. This point cannot be overemphasized.

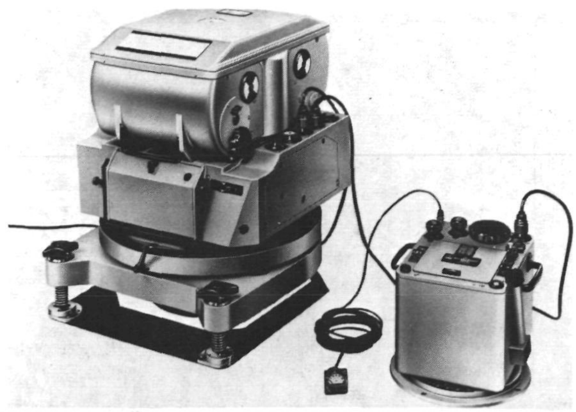

FIGURE 2. Zeiss RMK 15/23 aerial camera (courtesy Carl Zeiss Co.).

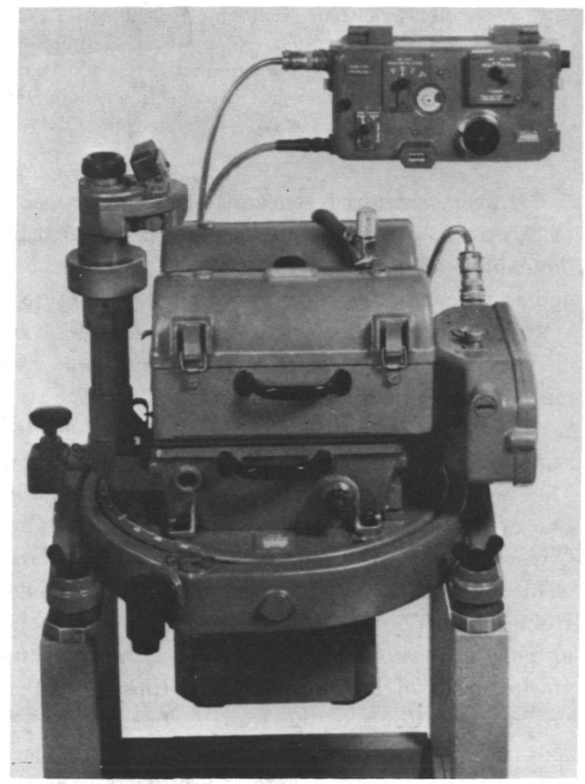

FIGURE 3. Wild RC–8 aerial camera (courtesy Wild-Heerbrugg Co.).

THE AERIAL CAMERA

Aerial cameras are available in numerous sizes with a variety of film formats, focal lengths, precisions, spectral responses, and costs. Selection depends primarily on the type of information the user wishes to secure. Typically, the conventional aerial camera has a focal length of 150 mm, a square film format of 23 cm, and uses film in lengths of 50 to 75 meters. The combination of focal plane flatness and lens distortions will be less than 0.01 mm. Examples of such cameras now in general worldwide use are shown in figures 2 and 3.

A careful study of all aerial cameras should be accomplished prior to final selection. If you have no experience whatever in aerial photographic techniques, you should start with simple system—perhaps a single-engine aircraft and a relatively inexpensive aerial camera such as the 70-mm Hasselblad EL (figure 4). Such equipment permits your aircraft pilots and cameramen, your photographic laboratory personnel, and your user-geoscientists to increase their level of expertise a great deal with a minimal investment of financial resources. As the level of technical competence improves, you should then consider more sophisticated systems and techniques up to the level required to accomplish your objectives (figures 5 and 6).

FIGURE 4. Hasselblad EL 70-mm data camera with reseau plate and interchangeable lenses (NASA photo).

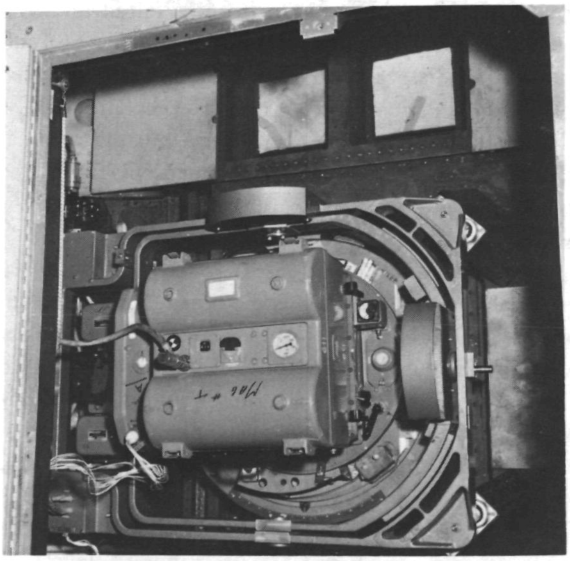

FIGURE 5. Wild RC–8 aerial camera mounted in aircraft.

FIGURE 6. Aerial photographer operates intervalometer for aerial cameras.

For high-quality aerial surveys using good commercially available cameras, you must give serious consideration to the following camera characteristics.

Focal Length

Aerial cameras are available with focal lengths from about 25 mm to more than a meter. The focal length governs the scale relationship of the actual size of the subject to its image size on the exposed film. For example, a camera with a focal length of 500 mm at an altitude of 1 km would yield an image scale of 1:2000. A ground distance of 100 meters would be 5 centimeters (or one part in 2000) in the photographic image. Longer focal lengths do indeed increase your image size, but not necessarily your ability to detect information.

If you wish to secure photographic coverage of large areas but are not greatly interested in absolute detail, you should use a short-focal-length lens. Because fewer flightlines will be required to obtain the desired coverage, savings can be made in costly aircraft operation hours. Additional small savings result in costs of film and processing. Conversely, if you need to obtain fine resolution, you will require a camera with a longer focal length. In many cases you may be attempting to secure various types of information simultaneously, and therefore both types of cameras will be required.

The conventional aerial camera (150-mm focal length with a 230-mm square format) is considered a wide-angle camera. The cone of light passing through the lens is approximately 90 degrees. The so-called superwide-angle aerial camera with a field of view of about 120 degrees uses the conventional 230-mm square format but has a lens with a focal length of approximately 88 mm. The user should also consider cameras with interchangeable lenses, which provide the ability to use various focal lengths with one camera body.

Resolution of the Image

The quality of the lens is of major importance (figure 7). It should have a high factor of light transmission (that is, ability to permit all or nearly all the available light reflected from the subject to reach the film). It should be a fairly fast lens (that is, have the ability to transmit sufficient light to the film in a relatively short exposure time). Lenses of f/4.5 or f/5.6 are generally considered fast enough for most aerial applications. Basically, the f-number is a computation of the ratio of the calibrated focal length of the system to the diameter of the lens aperture. For example, an f/10 aperture would be about 10 mm for a 100-mm-focal-length lens. Several camera manufacturers are beginning to use T-numbers instead of f-numbers. The T-number system additionally takes into consideration the transmission capabilities of the lens system.

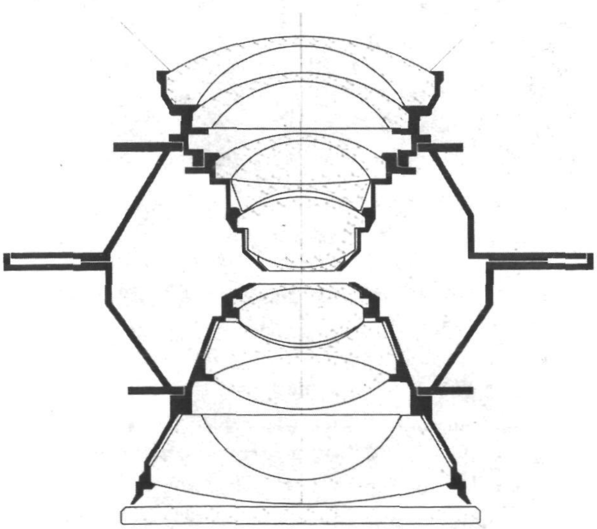

FIGURE 7. Modern aerial camera lenses are complicated and precise. Shown: the new 150-mm Universal-Aviogon II f/4 lens by Wild-Heerbrugg.

The true distortion-free lens is not yet a reality. Optical distortions are the result of many factors which cause deflection of a light ray from its true and correct location on the film. For precise mapping, residual distortions of less than 0.01 mm are required. When information to be secured does not require such precision, lenses of greater radial and tangential distortions can be tolerated, and they usually have superior resolving power. The flatness of the focal plane can also affect the total optical ray distortion. The degree of perpendicularity of the focal plane to the optical axis is another factor which must be considered.

The above considerations all affect the ability of a camera to record a specific image. In addition, the optical precision of the lens elements plays a very important part in the ability of the lens to resolve a subject. In total, the resolution capability can be expressed as the system's ability to distinguish two distinct line pairs of a specified width, with equal spacing, at varying contrast levels. The resolution will vary in different parts of the lens (best at the center) and with different levels of contrast.

Generally, you should not consider lenses that demonstrate static resolutions below 40 line pairs per millimeter at a contrast ratio of 1:1000 on the optical axis of the lens. If you are solely interested in information and not geometric fidelity, lenses of 80 or more line pairs per millimeter should be considered.

Spectral Responses

The modern aerial camera took on its basic design before the advent of practical and economical utilization of color films. It was not necessary then to manufacture lenses with polychromatic capability. A yellow filter was usually incorporated into the optical system to subdue the response to near ultraviolet and blue light, which is usually present due to suspended aerosols and other particulate matter found in the atmosphere.

In the past few years it has become economically feasible to use aerial color films. The beautiful color photographs of the Earth secured by Gemini astronauts made this fact dramatically clear. If your Earth survey plans call for the use of aerial color films, it is absolutely necessary that you use a polychromatic (color-corrected) lens in your aerial camera.

RESEAU CALIBRATION

There are aerial cameras which contain in the optical path, usually adjacent to the focal plane or film surface, a glass plate with fine line markings (usually crosses or dots) which are positioned very accurately. These calibration marks, called reseau marks, appear on the exposed film. Generally, they are located at 1-centimeter intervals, with a central mark coincident with the optical axis of the lens system. These marks, to be of any significant value, should be at known positions and accurately located within ± 0.0025 mm. The camera manufacturer should provide a very complete document regarding his calibration of the reseau mark positions and the precision capabilities of the measuring instruments used to generate such data.

It should be emphasized that a reseau calibration is not necessary for most work to be done with aerial cameras. However, if you require very accurate knowledge of the deformation of each exposure of film due to mechanical manipulation within the camera or film processor, or need to compute any movement of the emulsion with relationship to the film base during processing, or plan to perform very accurate aerial triangulation surveys, the reseau calibration is an invaluable asset.

Some aerial cameras have crosses, dots, or other identification marks in the corners or at the center of each side of the format. These fiducial marks are of great value in locating the optical axis of the system and in determining film deformation. For precise cartographic work, fiducial marks or a reseau are a requirement.

FILTERS

Usually filters will be introduced into the optical paths of aerial cameras. Their primary purpose is to reduce the effects of haze, both manmade and natural. Manmade haze will vary, depending on prevailing winds and other meteorological conditions. You will have to use your own particular experience to determine exactly how to handle the problem. It also is a major factor in aircraft navigation and can, under certain conditions, negate attempts to secure aerial photography on an otherwise cloudless day.

Many underdeveloped nations permit unrestricted agricultural burning during certain seasons. I found this to be true (15 years ago) over my wife's native Central America. The farmers would burn off the land prior to planting. Many March days were entirely cloudless, but the ground would be totally obscured even from an altitude of 1 km. Aerial photography, unless you were attempting to locate the offenders, would be practically useless under such conditions.

Certain areas of the world are also subject to natural haze in the atmosphere, which can degrade a photographic image.

The selection of filters is based solely on the job to be done. There are hundreds of kinds available. The publication *Kodak Filters for Scientific and Technical Use* will be of great value. One important rule to remember is: Never use any filter which might cause random or unknown distortions in the optical path if you plan to record accurate photogrammetric data.

CAMERA CALIBRATION INFORMATION

Before one can do any type of accurate work with an aerial camera, comprehensive knowledge of its calibration is mandatory. If you cannot secure the information from a reliable source or by means of measurements with your own laboratory equipment, you must consider the calibration an unknown factor and proceed accordingly.

You cannot tolerate unknown factors that might affect the accuracy or precision of your work. Therefore, do not attempt to make scientific deductions based on unknown or erroneous camera calibration information. You must know your camera thoroughly, including accurate knowledge of:

- radial lens distortion

- tangential lens distortion
- calibrated focal length
- transmission characteristics
- spectral characteristics
- resolution of lens
- flatness of focal plane with respect to optical axis
- accuracy of exposure at all shutter settings
- position of reseau markings and all other fiducial marks
- accuracy of any built-in accessories such as clocks, frame counters, altimeters, vacuum gages, data recorders, intervalometers, etc.

MULTISPECTRAL CAMERAS

If one wishes to record information from a discrete portion of the electromagnetic spectrum, a film highly sensitive to the desired portion of the spectrum is used in conjunction with a filter designed to eliminate unwanted information. If two or more such recordings are made simultaneously, the end result is multispectral photography. Multispectral cameras fall into two classifications:

(1) A single camera may be designed to secure multiple recordings on one or several film types. This may be accomplished by the use of two or more lenses, each with a specified filter, or through the use of a single lens and one or more beamsplitters consisting of special mirrors and/or filters to place the image at selected locations on the film. There may be a single roll of film in the magazine or several rolls having the same or different types of emulsion. A good example would be the Itek experimental camera shown in figure 8. It uses nine lenses to record simultaneously on three rolls of 70-mm film. There are several other cameras of this type available, using various techniques to achieve multispectral results.

(2) A gang of two or more cameras may be used to record with various lens-filter combinations simultaneously. Such an arrangement could employ several large-format aerial mapping cameras (figure 9) or, as I have seen, up to 12 of the 70-mm Hasselblad EL cameras (figure 10). In the Manned Spacecraft Center's Earth Resources Survey Program, multispectral photography has been successfully secured using the following camera systems:

FIGURE 8. Itek nine-lens experimental multispectral camera.

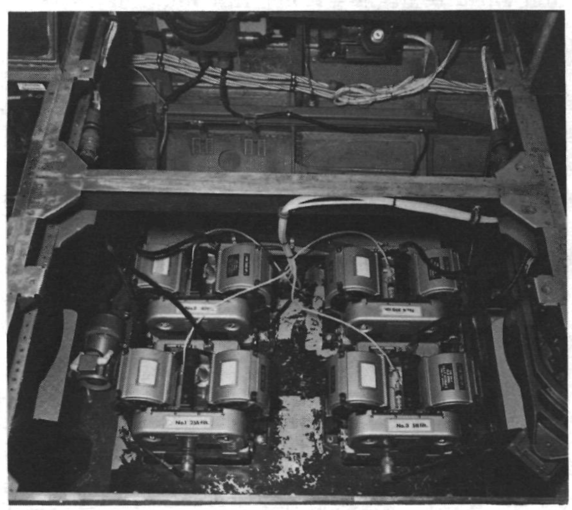

FIGURE 9. Four Chicago Aerial KS–62 75-mm multispectral cameras mounted in aircraft.

(a) Multiple 70-mm Hasselblad EL

(b) Itek nine-lens

(c) Multiple Wild RC–8 and Zeiss RMK systems

(d) Multiple Chicago Aerial KS–62 using 125-mm film

Apollo 9 used four Hasselblad EL cameras with various film-filter combinations to secure many multispectral space photographs.

In the Skylab Program, NASA will use a specially developed Itek multispectral system of high resolu-

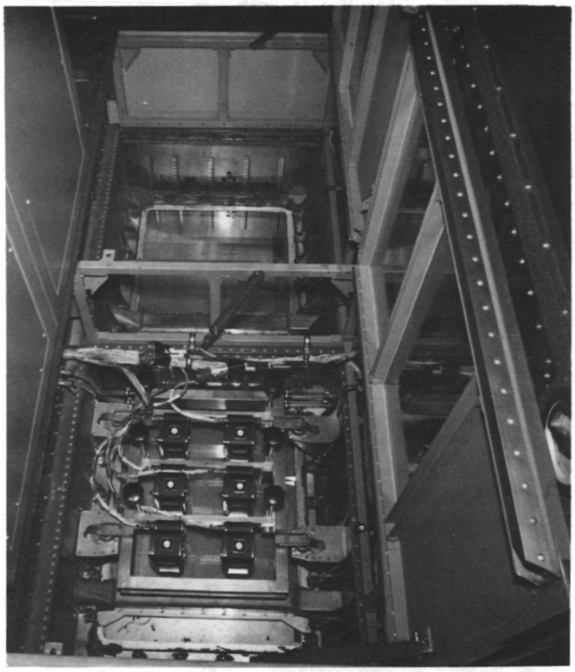

FIGURE 10. Six Hasselblad EL cameras for multispectral aerial photography.

tion and mapping precision, which takes six precisely matched photographs simultaneously.

If one chooses to develop a program using multispectral photography, a great many options can be exercised. Before an effective and practical program can be introduced, a great deal of experimentation is necessary. The use of a camera system like the Hasselblad EL has a number of advantages for experimentation. It is fairly inexpensive, and it is readily available in most parts of the world. Several can be fairly easily synchronized. Filters and lenses are not expensive, and they are easily interchanged. The 70-mm film magazines hold approximately 150 exposures each, depending on film thickness, and are quickly changed. This permits a great many experiments to be performed quite quickly at a minimal cost. It should also be noted that camera servicing facilities are worldwide.

You may, of course wish to consider other systems of a simpler or a more complex nature. The important thing is that your geoscientists and photographic scientists become fully aware of both the unique advantages and the limitations of multispectral photography.

FILMS FOR AERIAL CAMERAS

Most of the world's leading film manufacturers produce films especially created for aerial survey photography. At the Manned Spacecraft Center, practically all films used in the Earth Resources Survey Program are manufactured by the Eastman Kodak Company. Although NASA has many good reasons for this choice of manufacturer, each user must make his own decisions based on his particular situation and other factors outlined in this paper.

In theory, almost any film could be used for airborne photography. As a practical matter, however, films not specially designed for aerial photography may yield undesirable and erratic results and therefore should not be considered.

Aerial films are usually formulated to be relatively insensitive to the blue portion of the electromagnetic spectrum and slightly more sensitive to the red portion. The reason for this is that atmospheric haze—both natural and manmade—is usually blue. The film is thus relatively insensitive to its major problem, haze. Aerial films can be purchased in several thicknesses, in many widths and lengths, and on several types of base material. For geometrically accurate work, films on a polyester material are best. They exhibit very little residual shrinkage or expansion due to handling in the camera and processing. In fact, polyester or equivalent films have image dimensional stability approaching that of glass plates. They are desirable but not necessary if your goal is not precise measurements.

Aerial films are manufactured with many levels of sensitivity to various intensities of light. This is usually referred to as the speed of a film. Fast films, being very sensitive to light, are usually used where the subject is poorly illuminated or when very short exposure times are necessary. Slow films are usually preferred for well illuminated subjects when highest resolution is a requirement. The camera is usually the limiting factor, and films are selected on the basis of subject illumination and camera capabilities.

Aerial films have varied contrast capabilities. A high-contrast film is advantageous when a subject is of low contrast, and vice versa. Low contrast is usually produced by either a hazy atmospheric condition, a very high altitude, or a very homogeneous subject. Conversely, a low-contrast film should give better results in low-altitude photography of a subject with high contrast. Many users prefer to manipulate contrast in the processing laboratory. Experience is the best guide to which technique will produce the best results in your own situation.

A good starting point would be with a fine-grain, medium-speed, polyester-base film such as Kodak Plus-X Aerographic Type 2402. For work in the infrared portion of the spectrum (to reduce haze effects, locate water or wet ground, or conduct forest surveys) and for multispectral photography, a film such as Kodak Infrared Aerographic Type 2424 should be considered.

When one reaches such a degree of sophistication in aerial photography that he feels ready to undertake color aerial photography, an entirely new dimension opens up. But it presents many problems. Probably the major decision will be whether to use color positive or color negative film. Both are readily available, and both have certain advantages as well as disadvantages (figures 11 and 12). One must consider the cost of the original material against its utility value, as well as the cost of reproduction.

My own experience indicates that you should consider color positive (i.e., color reversal materials) until both the photographic laboratory and user-geoscientists have developed the required skills of the trade. Color positive or color reversal materials have trade names that usually end in "chrome", such as Kodachrome, Ektachrome, Agfachrome, Anscochrome, and Fujichrome. The original film,

FIGURE 11. Aerial color photo (negative) of San Jacinto State Park, Texas (difficult to interpret).

FIGURE 12. Color positive of photo shown in figure 11 (much more easily interpreted).

when processed properly, yields a true and correct color viewing positive. The laboratory technician can use the original as a guide for his reproductions, and the geoscientist has a true spectral reproduction of the original scene.

Color negative films can be useless for interpretation (except for a few very skilled individuals), but they are somewhat easier to reproduce (that is, once the laboratory is skilled enough to insure true reproduction of the original scene). These films have trade names which usually end in "color", such as Kodacolor, Anscocolor, Agfacolor, etc. Eastman Kodak makes a large variety of excellent color positive and color negative aerial films. GAF Corporation and Agfa also make aerial color films which are in worldwide use.

For specialized work, you should be aware of such films as Kodak Aerochrome Infrared Type 2443, a film of especially great value in agricultural and geologic studies. Also, GAF has produced a two-color Anscochrome which is used in specialized oceanographic survey work. The user should survey the entire market and know the characteristics of all available films.

You will find that color films, like black-and-white films, require considerable experimentation before one is selected. Your research program will be a continuing one. Your photographic scientists will be required to test all the new and improved films being manufactured and the final selection must be based on whichever film best accomplishes your specific tasks.

SELECTION OF FILMS

Many factors must be considered before an aerial film is selected. These factors include:

(1) *Intended use of end product*

(a) Prior to selecting a specific film, the user must survey the technical literature of the various manufacturers to determine which film will best do the intended job. Of great importance is the film's sensitivity to light in the selected spectral region. In a film of wide spectral latitude, this is commonly called film speed and is measured in units of DIN or ASA. Speed is particularly important when low-transmission filters are to be introduced into the optical path.

(b) The granularity of the film must be considered. It usually bears a direct relationship to film speed. Slower or insensitive films are usually very fine grained. Fast, very sensitive films are usually coarse grained. There is little to be gained by using very fine-grained, highly resolving films unless your lens system is capable of producing a high-resolution image. As an example, it would be useless to have a film capable of recording 250 line pairs per millimeter. You would be making a great sacrifice in film speed with no possible gain in information.

(c) The physical properties of the film are another consideration. The film base material is of major importance. If you are considering making precise photogrammetric measurements, polyester-base films are highly recommended. It is also important to consider film thickness to insure proper passage through the camera system as well as the processing system.

(2) *Technical competence of the manufacturer.* This factor is of the greatest importance to your aerial surveys and will have a most profound effect upon your photographic results and the ultimate value of your programs. Remembering that your own specialized situations and experience will be your major guides, the following questions must be carefully considered:

(a) Do the available products meet your requirements?

(b) Does the manufacturer furnish detailed information on the physical and sensitometric properties of the film?

(c) Do your own studies and evaluations indicate that his information is reliable?

(d) Does he have specialized technicians and/or photographic scientists available to assist you with special problems and requirements?

(e) Do you find that a specific product yields essentially the same test results from one emulsion coating to the next?

(f) Will he help you analyze your water supply and chemicals and furnish recommendations based on his findings?

(g) Does he ship his product from his place of manufacture to your delivery point under conditions which will not cause degradation of sensitometric properties? Some films are exceptionally critical. Your Customs Office facilities must also be considered, if you import the film.

(h) Does he have a competent research staff which can help you?

(i) Is he easily accessible by cable, telephone, or letter? And does he respond to communications promptly?

(3) *Product availability.* There are a few manufacturers who advertise a wide variety of film products. Your problem may be in securing them. You should consider a manufacturer who keeps sufficient stock levels at strategic locations so that you can secure film in a reasonable time period. Some will manufacture a film only after sufficient orders are received to justify a profitable sale. In such cases your source is unreliable, particularly if you have a seasonal application. In some cases a manufacturer will prepare a very specialized film if you are willing to order a sufficient quantity. An example is Eastman Kodak S.O. (special order) films.

(4) *Level of laboratory competence.* You should secure testing samples of various films before you undertake any large-scale project. Your photographic scientists should conduct a series of studies to determine the sensitometric characteristics of each emulsion. Test films exposed in aircraft should then be processed in your laboratory. Processing should meet preestablished standards and goals. You should not consider using any film which cannot be processed and reproduced (if required) to meet the standards of your photographic scientists or user-geoscientists. If you do not secure reliable and repeatable results, you will find that you are furnishing your geoscientists with erroneous

materials, and hence erroneous deductions and conclusions will result.

(5) *Film cost.* There is one consideration in product selection which is valid only when all those that I have cited are absolutely equal, and that is the cost of the film. You will quickly discover that the cost of film is a very small portion of the cost of your program. Savings on the cost of a product which may be inferior can place your program efforts and results in serious jeopardy.

PREPROCESSING QUALITY CONTROL PROCEDURES

To create a photographic image of known properties with highly reliable information, the user cannot tolerate any break in the continuity of information about his aerial film. He must have a complete history of the environmental conditions to which the film has been exposed, from the moment the emulsion is coated through storage, shipment, and completion of processing. This consideration must include the environmental conditions in both the aircraft and the laboratory. The exact sensitometric characteristics of the emulsion are a function of the total environment to which it has been exposed as well as its manufacturing formulations. Each manufacturer will furnish a report as to the sensitometric and physical characteristics of each type of film to be manufactured. Experience has told us that this is generally an excellent guideline. It should not be considered absolute fact, however.

The manufacturer will usually use very exacting techniques and highly competent personnel in formulating an emulsion. It is then coated to the film base and cut into rolls. Each emulsion formulation is called a batch. For some usually unexplainable reason, each batch differs slightly from other batches of the same emulsion made under the same conditions. Hence, the user, planning to make exacting geoscientific measurements must conduct his own analyses of all films as soon as they are received. It therefore makes good sense to insist that all film in a specific shipment come from the same batch (that is, with the same emulsion number).

The user has a responsibility here also. He should secure his film in as large an order as practical and have adequate storage space with temperatures no higher that 15 °C and preferably 0 °C or below. Film will not greatly change in sensitometric response if stored frozen, even for long periods.

Upon receipt of a film shipment, the photographic scientist should make his own comprehensive analysis of its sensitometric characteristics. In some cases, he may call for storage of the film under certain temperature conditions for a specific time to shift its spectral characteristics to a desired condition. In other cases, he may require a change in exposure or a specific filter to be used. He may also modify the film processing techniques. In certain cases, he may reject the shipment as unusable for its intended purpose.

To accomplish such detailed investigations of aerial films, the photographic scientist must have accurate equipment. An accurate sensitometer, a controlled processing capability, and a densitometer are necessities. Other equipment can make his investigations even more detailed and accurate. The sensitometer permits him to expose emulsion samples to exact amounts of light in contact with an accurately calibrated density scale. The controlled processing usually includes accurately formulated chemicals, precise temperature regulation, precision timing, and accurate and thorough chemical agitation. The densitometer permits the scientist to determine accurately the response characteristics of the film.

When the film is removed from storage prior to an aerial photographic mission, the photographic scientist repeats his tests to insure that the film has not changed in sensitivity. He also places an exposed sensitometric density scale on the loading end of the film (occasionally both leading and trailing ends). During an actual photographic mission, the film should be subjected to a normal environment. Cold air in a high-flying aircraft will not degrade the film, but temperatures in excess of 35 °C can cause serious problems (depending on the type of film, the duration of the condition, and the humidity).

Upon return of the film to the laboratory, the photographic scientist will place another sensitometric density scale on the film. He may also remove an unexposed portion of the film, place a sensitometric density scale on it, process it, and determine if there has been any image degradation during the mission. Also he should simultaneously expose a sensitometric density scale on a laboratory controlled film from the same emulsion batch.

The resulting information will permit him either to alter the processing technique or to detect a change in the sensitometric characteristics significant enough to be brought to the attention of the geoscientists using the film.

The important message here is that quality control is mandatory for a quality product. These procedures will vary with each user and will evolve as your program develops. No matter how rudimentary or sophisticated your surveys are, you should always insist on the most comprehensive quality control practices commensurate with the desired end product.

PHOTOGRAPHIC PROCESSING OF AERIAL FILMS

The third link in the chain of aerial photography is the all-important work within the photographic laboratory. In this phase of workmanship, quality control and a comprehensive knowledge of photographic science are an absolute necessity. Poor work, incomplete records, or substandard quality control can totally negate the very expensive aircraft operations which are performed to secure a precision photographic record.

PROCESSING LABORATORY EQUIPMENT

Photographic laboratories vary in sophistication from a wooden sink in a darkroom to multimillion-dollar complexes designed to enhance the state of the art. I have seen aerial photographs made with the finest Zeiss or Wild aerial cameras in multimillion-dollar jet aircraft, then processed in a wooden sink using a hand rewind system, chemicals purchased in a hobby shop, and water from a city tap. The resulting film looked good, but no one would ever know if it really was.

Such a simple approach to aerial film processing usually does yield good pictorial quality; in reproduction, the technician can redeem many of his original mistakes. But much may be lost forever. If your goal is good pictorial quality, such a simple solution may be adequate for your needs. However, do not attempt to make any specialized scientific deductions from film processed in this manner.

If one is willing to invest great financial resources in aircraft and/or high-quality aerial cameras, one should never overlook the fact that the photographic laboratory must be equipped to make full use of the information secured. Here, too, one should commence operations with fairly simple equipment and techniques so that the photographic scientists and technicians can fully comprehend the science as well as the art.

The tank processor for rolls of aerial films has been in use for over 40 years. The Zeiss Model FE–120 (figure 13) does an excellent job.

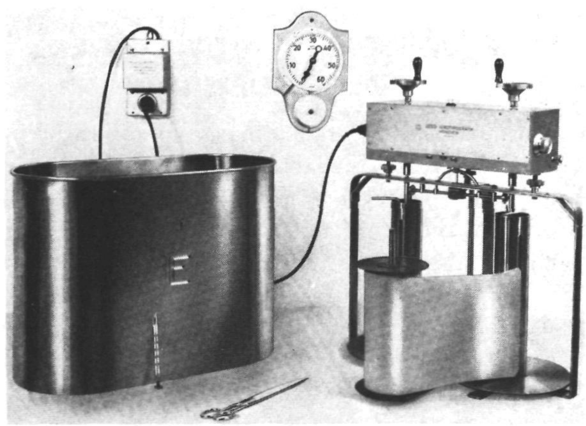

FIGURE 13. Zeiss FE–120 rewind aerial film processor (courtesy Carl Zeiss Co.).

Basically, the tank processor permits a technician to immerse roll film into tanks of chemicals, and an electric motor winds the film back and forth from spool to spool. A good tank arrangement for black-and-white film is:

(1) wetting agent
(2) developer
(3) stop bath
(4) fixation
(5) wash

Steps 1 and 3 are not always necessary.

For color films the process is very complex and time-consuming, and results can be both mediocre and erratic. It is a 16-step process which requires exacting adherence to procedures and is too complex to discuss in this paper. (See American Society of Photogrammetry *Manual of Color Aerial Photography.*) It should be noted that a dedicated technician can do high-quality work with a rewind system. He can introduce a number of excellent quality control procedures which greatly improve film quality and repeatability. These include:

(1) *Temperature control.* This can be accom-

plished by bringing the chemicals to temperature equilibrium with the darkroom. That would be a cool 20 °C in most cases. Another method entails the use of temperature-controlled mixing valves with sinks serving as a temperature-controlled water jacket to achieve equilibrium. A thermal heat exchanger, such as the Pako Corporation Pakotemp, could be used to recirculate and temper this water jacket.

(2) *Quality control of chemicals.* The technician can insure that each batch of chemicals is prepared with extreme care. This includes dilution at proper rates and temperatures, complete blending at proper temperature, and making sure the correct total quantity is made. In addition, he can conduct a number of tests on the resulting chemicals, including specific gravity, pH, and even a qualitative and quantitative analysis.

(3) *Water purity.* All water lines should contain efficient filters which are periodically changed. A complete laboratory analysis of the water should be conducted periodically.

(4) *Chemical replenishment.* A skilled technician can alter the chemical depletion characteristics of the rewind system by trial-and-error experimentation. A replenisher chemical must be added to each tank at a specific rate and time.

(5) *Proper film drying.* Film should be dried at the proper temperature and humidity in a room which is free of all airborne particulate matter. An air filtration system should be functioning for a number of hours prior to and during the drying operation.

(6) *Sensitometric controls.* The technician can preexpose a sensitometric scale on film which is processed with each roll of aerial film. A densitometer can then be used to record the final process and provide the information to the geoscientist.

(7) *Accurate recordkeeping.* A competent technician will keep comprehensive records of all information for every roll of aerial film processed.

(8) *Time-gamma studies.* The technician can conduct a series of tests which show the effects of various parameters on the sensitometric characteristics of processed film. He can vary development time, temperature, chemicals, replenishment rates, etc. These tests, in conjunction with his accurate recordkeeping will permit him to process and reproduce aerial photography with the wide variety of results which may be required by the geoscientist.

The automatic aerial film processor was introduced in the late 1940's. Early models were generally not too effective. Problems were numerous and results were generally no better than those achieved by a competent technician. Equipment costs were great when evaluated against results.

During the 1950's many improvements were made, and in the early 1960's an economically feasible automatic film processor came on the market (namely the Eastman Kodak Versamat, model M–11). This roller transport aerial film processor proved exceptionally reliable, extremely versatile, and economically practical. Using this equipment, a technician who could process two rolls a day could now process 20 or more to far more exacting specifications. This increase in production quickly offset the cost of the equipment.

The versatility of the Kodak Versamat is outstanding. The technician has a great range of chemicals available. He can quickly introduce and exactly hold a large range of temperatures. He can select from a wide range of processing times. Chemical replenishment is accurate and simple. In addition, film is properly dried in dust-free air, and sensitometric repeatability is excellent.

You may wish to investigate the photographic market and evaluate a number of automatic aerial film processors, but in my opinion the Kodak Versamat should be the standard that the others are evaluated against. At the present time, several Versamats are in constant use within the Earth Resources Survey Program at the Manned Spacecraft Center. For your particular application, however, you may find that other automatic film processors are better suited.

Following the development of the Kodak Versamat, the next logical step was to produce a similar device for aerial color films. The Kodak roller transport aerial color film processor, generally called the Color Versamat, was introduced in 1965. It is this device that made aerial color films totally utilitarian and economically feasible. It permits those who use color films in their geoscientific studies to secure accurate and repeatable results, and this equipment should be given serious consideration if color or color infrared photography is contemplated. These machines can process color positive or color negative aerial films with equal facility.

No matter which type of automatic equipment is utilized, the importance of high-standard quality control procedures cannot be overemphasized.

CONCLUSION

This paper has stressed the importance of having a complete knowledge of your films, cameras, processing, and reproduction equipment. This knowledge, coupled with comprehensive, well documented quality control techniques, will produce information of immense value and of great significance to your country and its people.

If these recommendations go unheeded, the very opposite may result. Consider, for example, the improper use of a specialized film designed to detect a virus-type infection in a nation with a one-crop economy. The source and spread of the virus may go undetected until the entire nation is infected, and catastrophic economic conditions as well as great human suffering can result.

This hypothetical situation, of course, is an extreme case. I have asked my wife what she would think if her beloved Honduras lost an entire crop of bananas, rice, beans, or coffee to a virus or insect plague. Her reaction was one of horror and dismay for our friends and relatives in her native land.

The information presented in this tutorial paper is based on knowledge gained through the mistakes and successes of a quarter century in the profession. My first attempt at aerial remote sensing began with a $20 camera and a small piece of infrared film in a rented Piper Cub, trying to locate a geologic fault zone hidden under glacial debris since before man occupied North America. It was an unqualified success and enabled me to complete a university thesis. Recent assignments have dealt with highly sophisticated cameras being used by our astronauts to record geologic information on the far side of the moon.

The most important point I have tried to establish here is that only you and your scientists can determine the best system to accomplish your specific requirements. It was, I think, best said 2500 years ago by one of the most important human beings ever to inhabit our Earth:

"Believe nothing merely because you have been told it, or because it is traditional, or because you have imagined it. But whatsoever after due examination you find to be conducive to the good and to the welfare of all being—that doctrine believe and cling to it, and take it as your guide." The author was Gautama Buddha.

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