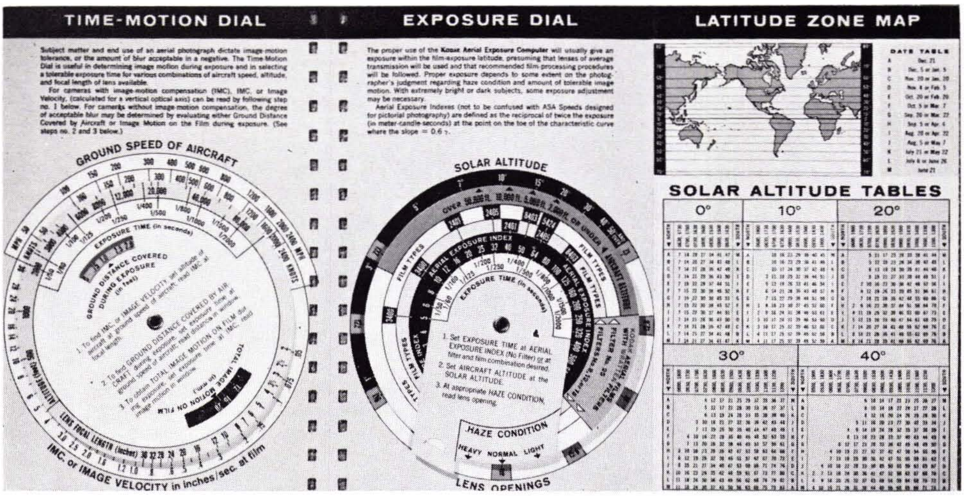

FRONTISPIECE. The Kodak Aerial Exposure Computer.

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Principles of Aerial Color Photography

Aerial photographers may have many new questions about exposure, filters, processing, and quality.

INTRODUCTION

AERIAL PHOTOGRAPHY IN COLOR is still a relatively new and untried technique to many aerial photographers despite the fact that the requisite materials and processes have been available for a long time. One explanation for this is the belief that the advantages are not commensurate with the increased cost, complexity, and uncertainty of using color materials. In the past two decades, however, a number of specialists in different fields who thought that the possible benefits of color should be explored, have produced some convincing demonstrations that color does offer worthwhile advantages over black-and-white photography. They have also shown that color information can be recorded even at high altitudes.

In 1952, Laylander[1] determined that aerial photographs in color could be used to locate bodies of ore, and Herness,[2] in 1955, concluded that such photographs, in conjunction with geological maps, represented the most effective and economical approach to mineral exploration. Ray and Fischer[3] provided further support for these conclusions in an article in *Science* dealing with applications of aerial photography in geological studies. Fischer[4] reported further studies of the geological uses of color aerial photography which indicated that many features were delineated with greater continuity and clarity in full-color photographs, and later[5] he discussed techniques by which abridged spectral reflectance characteristics can be estimated from color photographs. The detection of underground glacial deposits of water through the use of infrared-sensitive false-color film was reported in *Science News Letter*[6] in July, 1959. Further geologic mapping applications were described by Minard[7] in 1960. In his studies, interpretation of color aerial photo-

* Presented at the Annual Convention of the American Society of Photogrammetry in Washington, D. C., March 1967.

graphs particularly facilitated the mapping of two formational contacts which were extremely difficult to locate other than by extensive boring.

Haack[8] investigated the performance of photointerpreters in land- and forest-class recognition, from photographs taken on panchromatic, infrared, and color films. Although a complete study of the color films was not made because of the cost of the film and viewing equipment and the difficulty of obtaining correct exposures, which Haack did not think could be justified on the basis of preliminary results, he concluded that color would be desirable in regions containing a greater variety of tree species than the one studied, and that color transparencies best bring out minute tonal details.

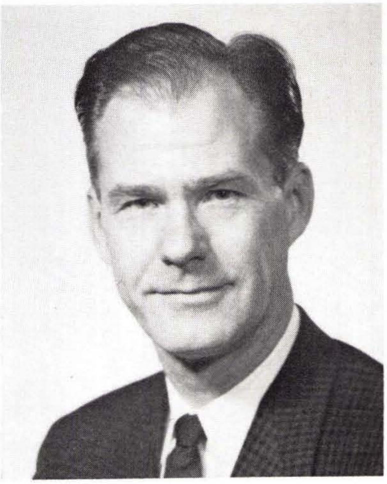
Smith[9] presented an excellent survey of the reasons why the U. S. Coast and Geodetic Survey has come to rely increasingly on color photography, and the historical background of its work with color. He also gave many valuable technical hints based on his experience.

The techniques of using aerial color photographs in the U. S. Coast and Geodetic Survey were described in considerable detail by Swanson[10] in 1964. He presented many examples of the value of color photographs, particularly in the mapping of coastal and shallow-water areas. Using color diapositive plates in plotting instruments, he found that "A distinctive advantage has been experienced in color for aerotriangulation: the superior interpretative qualities enable one to make more accurate readings on the pass points used for connecting models, resulting in more accurate aerotriangulation. Color photography also permits the operator to see better into shadows, and is advantageous in finding those exact points identified by the field parties for control of the aerotriangulation." Both this and the preceding article have full-color illustrations.

Aldrich[11] experimented with large-scale, 70-mm. aerial color photographs for obtaining forest inventories, appraising insect damage, and recording the effects of fire and disease. He suggested further applications in range, wildlife, and watershed management. The results of similar studies are reported by Heller, Doverspike, and Aldrich[12] in Agriculture Handbook No. 261, and a quotation from their conclusions is appropriate here:

> "Color film is superior to panchromatic film for use in identifying individual tree species. Why? First, people are accustomed to seeing and identifying objects not only by shape and form but also by color. A ripe tomato is picked from the vine by its color rather than its shape, and cotton can be graded by the lightness and yellowness of the fiber. A forester trained to recognize trees by morphological features also associates a color with that tree. When he is trained to recognize the tree on aerial color photographs, he has one more factor on which to base his deter-

ABSTRACT: *The addition and subtraction of the three primary colors are basic concepts in the design and use of color photographic materials. A reproduction need not, and almost never does, have the same spectral characteristics as the original scene. Color-negative materials may offer significant advantages of flexibility over color-reversal types. Color diapositive plates are used successfully in stereoscopic mapping. An exposure computer is available to aid the aerial photographer, and the proper use of filters may require difficult decisions, whereas color processing may impose no real difficulty. The color characteristic of the viewing light may limit the amount of information retrievable from a system.*



ALLAN L. SOREM

mination. Thus, it requires more training for an interpreter to be able to recognize objects by tones of gray than by the normal colors with which he associates the object. . . ."

A recent paper by Mott[13] contains material which the reader will find helpful.

In the next few years we shall undoubtedly see many further experiments with aerial color photography, and, in some applications, a shift to the routine use of color materials. A new generation of photo interpreters will learn to utilize, and then to take for granted, the information that is available in increased quantity and with increased ease of interpretation in color photographs compared with that of black-and-white photographs.

The purpose of this paper is neither to present new data from experimental work, nor to describe color materials and processes in detail, but rather to bring together for aerial color photography some general information and observations which may be helpful in practical aerial work. Good amateur color pictures can be taken with little or no understanding of color vision or the principles of color photography, by following a few simple instructions on a data sheet. However, the aerial photographer who wants to, and should, get consistently good results will find it easier to develop his judgment and technique if he does understand some of the principles of color vision and color photography, and the complex interplay between scene characteristics, the degree of haziness, the sun angle, the choice of filters, and the selection of the required camera exposures. Although only a superficial review of the taking of color pictures is possible here, it is hoped this will be sufficient to help some readers achieve a degree of success which will stimulate further interest.

Principles of Photographic Color Reproduction

A color reproduction is superior to one in black-and-white because it looks more like the original scene, with many of the subtle shadings of hues and saturations represented. But in interpreting a photograph, either in color or in black-and-white, the viewer often reads more into the pictorial record than is actually there. Indeed, all viewing of photographs involves photo interpretation, albeit the ability to interpret pictorial photographs is learned at an early age and thereafter taken for granted. That the picture is not the original scene, or even a reasonable facsimile of it, is patently true. A vast difference exists between the quantity of information subjectively perceived and the degree of objective similarity between the picture and the original scene.

As an intermediary between the original scene and the eyes of the viewer, a picture does not literally record the scene, but rather captures clues that we have learned to decipher. Next to shapes and relative sizes, colors are the most important of these clues. As we are concerned here with a picture as a source of information rather than for its emotional content or artistic qualities, we assume that the more accurately it conveys the same sense impressions as the original, the better. But these impressions are evoked by pictorial clues which are not like the original in any exactly measurable sense. This is an obvious, yet subtle, point. Failure to understand it has been responsible for overly optimistic hopes for automated photointerpretation. Failure to understand it also leads some photographers to expect to be able to measure such things as the per cent reflectance, or the spectral reflectance characteristics of objects in photographs of them.

The fact is that a black-and-white photograph tells us nothing about the proportion of the incident light reflected by an object in the scene, except what we can infer from prior knowledge of the object and its surroundings. Likewise, a color photograph tells us nothing about the proportion of the light of various wavelengths reflected by an object in the scene except, again, what we can infer from our knowledge of the object. To see why this is so, we turn to a consideration of the visual perception of colors, and the way in which color photographs are produced.

The characteristic of human vision that is of basic importance in understanding color photography is that a match for the color of practically any natural object can be produced by mixing lights of three properly chosen colors. Such sets of colors are called *primary colors*, and consist of shades of red, green, and blue. Rather large variations in the hues of these primaries are possible, without decreasing the effectiveness of matching a wide gamut of natural colors. If the three primaries are present in approximately equal amounts, a neutral hue is produced. Because the primaries are *added* to produce the desired color, they are termed *additive primaries*.

If, as in the case of viewing a typical color photograph, white light is present to begin with, then it is also possible to produce a desired color by *subtracting* the appropriate amounts of blue, green, and red from the white light. A color photographic image does

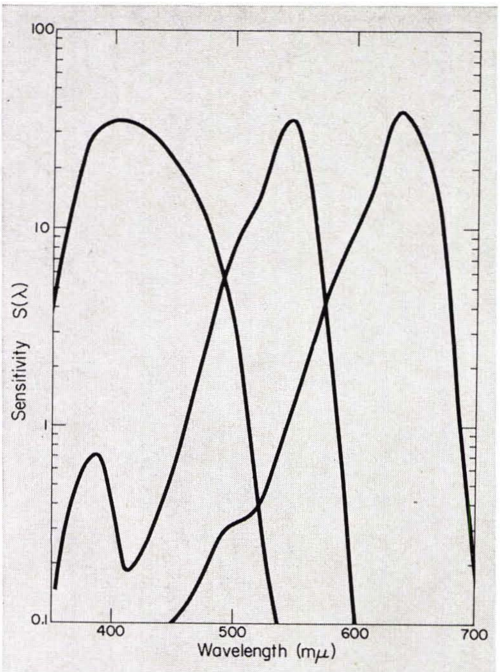


FIG. 1. Spectral sensitivity of Kodak Ektachrome MS Aerographic Film (Estar Base), Type SO-151. $S(\lambda)=E(\lambda)^{-1}$, where $E(\lambda)$ is the energy in ergs·Cm^{-2} of monochromatic radiation of wavelength λ required to reduce the dye image density in the individual layer to an equivalent neutral density of 1.0 above minimum density. Data are adjusted to correspond to an effective exposure time of 1/50 second.

just this through the action of three dyes, representing the *subtractive primaries:* yellow, which absorbs or subtracts blue light; magenta, which subtracts green light; and cyan, which subtracts red light. The appropriate quantity of each dye is produced in each area of the photograph as a result of the exposure and processing of the film.

Usually, a color film has three separate emulsions coated in three layers, one for each dye. The films that give a positive image having the same colors as the original scene are designed so that, after processing, the dyes are present in amounts roughly *inversely* proportional to the logarithm of the exposure reaching a given area and layer of the film. For negative color films, the dye quantities are approximately *directly* proportional to the log exposures, and the colors in the negative are complementary to those of the original scene. As the underlying principles are the same for the positive image that is viewed, whether it is in the camera film or in a print made from a camera negative, we shall be concerned here with positive images only.

Because three dyes in the correct relative proportions are needed to match the colors of each area of the original scene, it is necessary to design a color film so that the layer that will produce each dye is sensitive to exposures by light of the color the dye will modulate. The yellow dye layer thus must be exposed by blue light; the magenta layer must be sensitive to green light; the cyan layer must respond to red light. These different spectral sensitivities are obtained by adding optical sensitizers (which are themselves dyes) to the emulsions during manufacture. Figure 1 illustrates the spectral sensitivities of the three component layers of Kodak Ektachrome MS Aerographic Film (Estar Base), Type SO-151. The sensitivity curves have considerable overlap, which results partly from the limitations of the sensitizing materials available.

The relative over-all sensitivities of the three individual layers of a color film to blue, green, and red light must be adjusted for the amounts of energy from the exposing light source present in the three portions of the spectrum so that, if a neutral area is photographed, effectively equal quantities of dye will be produced in each layer. The film is said to be balanced for the particular light source, such as daylight, or Photoflood lamps. Where the image is viewed with white light, equal quantities of blue, green, and red will be subtracted and the area will appear neutral. The dyes in this area will not absorb or subtract light of all wavelengths equally, how-

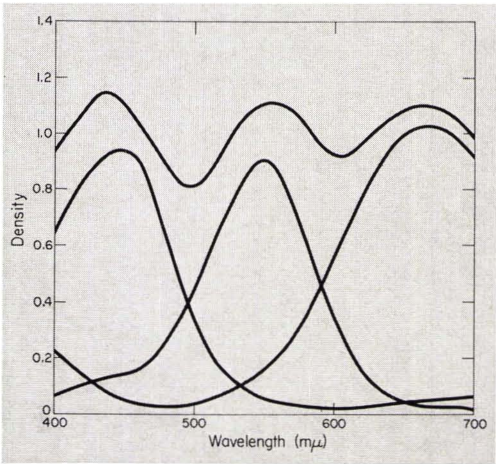


FIG. 2. Spectral densities of Kodak Ektachrome MS Aerographic Film (Estar Base), Type SO-151, normalized to form a unit neutral density.

ever, and if spectrophotometric measurements are made, the spectral transmittance or reflectance curve will be found to have three maxima corresponding to the peak absorptions of the dyes (Figure 2).

Where nonneutral objects are recorded, unequal exposures are produced in each of the three film components, and, after processing, unequal deposits of dye result. The relative amounts of each dye are such as to subtract the required proportions of red, green, and blue light and produce thereby a color matching the original. The spectral transmittance of the reproduction does *not* match the spectral reflectance of the original.[14] Figures 3 and 4 illustrate the spectral reflectances of two color samples compared with the curves for photographic reproductions. It is not possible to determine from these curves alone whether they represent matching colors, but they are necessary in making such a determination, unless the originals and the reproductions can be compared visually. The important point is that *the reproduction need not, and almost never does, have the same spectral characteristics as the original.* The objective of color photography is to provide good visual reproductions—not matching spectral characteristics.

Aerial Color Film Systems

The color film used in the camera, whether it be a negative or a reversal material, will in most applications be printed or copied on some other material. In photogrammetric work, positive images on glass plates, called *diapositives*, are needed. These may be in black and white or in color. Paper prints may be required for photomosaics, for field

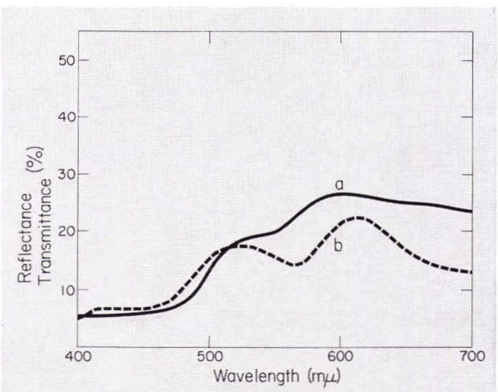


FIG. 3. Spectral reflectance curve (a) of a dark yellow sample, and spectral transmittance curve (b) of a typical photographic reproduction in a reversal color film.

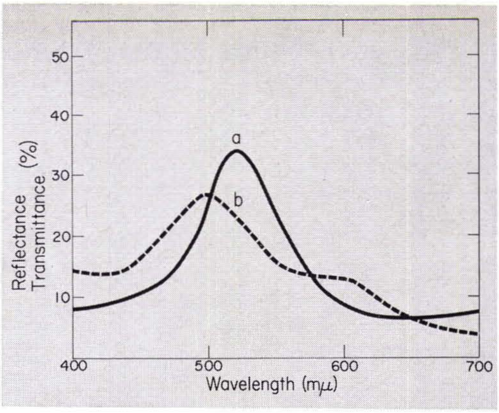


FIG. 4. Spectral reflectance curve (a) of a dark green sample and spectral transmittance curve (b) of a typical photographic reproduction in a reversal color film.

annotations, or for general photointerpretation work. Positive transparencies are also used to an increasing extent in photo interpretation. The materials used to provide the desired end products can be regarded as film systems, because the sensitometric characteristics of the different films as well as the dye transmittances and spectral sensitivities are designed to work together to give optimum results. Tables I, II, and III list films, plates, and print materials which can be used together in various combinations.

Although a reversal camera film is not usually used in black-and-white aerial photography, more color films are designed for reversal processing than for making negatives. In some aerial photography, as in amateur photography, the cost advantage of making a viewing positive from the camera film may dictate the use of a reversal material. Other advantages of using a reversal camera film are that such films usually have the ability to produce slightly sharper images than negative color films of the same speed and, if they are used as a viewing positive, they avoid the slight though inevitable loss in image quality that accompanies a printing step. If reflection color prints or transparencies are needed, however, materials are available for making them from positive color originals.

A color-negative camera film permits great flexibility in meeting the requirements of aerial photography. Color negative camera films offer the advantages of greater exposure latitude and somewhat more control in obtaining the desired color balance during printing. Materials are available for making all the usual second-generation reproductions

TABLE I

CAMERA FILMS

	Recommended[a] Camera Aperture (for 1/500 second exposure time)
Camera Films (Negative)	
1. KODAK EKTACHROME MS AEROGRAPHIC Film (ESTAR Base), Type SO-151 (as processed in modified KODAK Color Film Process, C-22)	f/4.7
2. KODAK EKTACOLOR Aerial Film, Type SO-276	f/5.6
Camera Films (Reversal)	
1. KODAK EKTACHROME MS AEROGRAPHIC Film (ESTAR Base), Type SO-151	f/4
2. KODAK EKTACHROME MS AERECON Film, Type SO-282	f/4
3. KODAK EKTACHROME EF AERECON Film, Type SO-155	f/8
4. KODAK EKTACHROME EF AEROGRAPHIC Film (ESTAR Base), Type SO-397	f/8
5. KODAK EKTACHROME AERO Film, Type 8442	f/8

[a] For solar altitudes of 40° and above, clear days, and altitudes of 5,000 to 10,000 feet.

from the camera negative, including prints, transparencies, and diapositives; in addition, black-and-white reflection prints or transparencies can also be readily made. Many photographers are seriously considering a color-negative camera film for all photography. During the time when a gradual transition is being made from black-and-white to color photography, as many of the second-generation prints or transparencies can be in black and white as are desired.

Two Kodak aerial color films which have been available for many years are Kodak Ektachrome Aero Film, Type 8442, and Kodak Ektachrome Infrared Aero Film, Type 8443. These were described in a paper

TABLE II

PRINT MATERIALS

Film for Positive Color Transparencies from Color Negatives
KODAK EKTACOLOR Print Film
Film for Positive Color Transparencies from Positive Color Originals
KODAK Color Duplicating Film, Type SO-271
Paper for Color Prints from Color Negatives
KODAK EKTACOLOR Professional Paper
Paper for Color Prints from Positive Color Originals
KODAK EKTACHROME Paper
Paper for Black-and-White Prints from Color Negatives
KODAK Panalure Paper

TABLE III

PLATES

Plates for Color Diapositives from Color Negatives
KODAK Special Plate, Type 083-01
Plates for Color Diapositives from Positive Color Originals
KODAK Special Plate, Type 032-01
Plates for Black-and-White Diapositives from Color Negatives
KODAK Separation Negative Plate, Type 1
KODAK Separation Negative Plate, Type 2
KODAK Aerial Plotting Plate
KODAK AEROGRAPHIC Positive Plate
KODAK Super AEROGRAPHIC Positive Plate

by Tarkington and Sorem in 1963,[15] when improved speed, definition, and color-reproduction characteristics were incorporated as the result of technological advances. In addition to these, five more camera color films, a color duplicating film, and two color diapositive plates are now available, making possible the selection of a taking film having the contrast, speed, and image characteristics most appropriate for a variety of applications, and permitting the use of color diapositives in stero plotters for mapping purposes, as well as the production of high-quality duplicates.

Kodak Ektachrome MS Aerographic Film (Estar Base), Type SO-151, and Kodak Ektachrome MS Aerecon Film, Type SO-282, the former on dimensionally stable polyester base and the latter on acetate base, have similar photographic qualities. These films are intended for low-altitude mapping and reconnaissance, and therefore have lower contrast than the older Ektachrome Aero Film. They are also about one-fourth as fast as that film and exhibit an improvement in image quality commensurate with that speed difference. By increasing the time in the first developer, these films can be increased in speed by as much as a factor of four without a significant loss in contrast or image quality.

Kodak Ektachrome EF Aerecon Film, Type SO-155, is a fast, medium-gamma, reversal color film especially suitable for low-altitude photography at short exposure times.

Kodak Ektacolor Aerial Film, Type SO-276, is recommended for low-altitude pictorial work, particularly obliques. Negatives on this film can be printed onto Kodak Ektacolor Professional Paper.

For aerial color negatives from higher altitudes and general vertical photography, the Kodak AERO-NEG System is recommended. This is based on the use of either Kodak Ektachrome MS Aerographic Film (Estar Base), Type SO-151, or Kodak Ektachrome MS Aerecon Film, Type SO-282, developed to a negative in a modified Kodak Color Film Process C-22.

Where duplicates of original reversal color photographs are required, they can be made on Kodak Color Duplicating Film, Type SO-271. This film can be printed on enlargers, contact printers, and dodging contact printers having a light-source color temperature of about 3200° K. Reciprocity characteristics are such that color balance will not be adversely affected over the range of printing times customary with such devices.

Color Diapositive Plates

In 1963, the Eastman Kodak Company supplied experimental color plates to the U. S. Coast and Geodetic Survey for development work in photogrammetric equipment for the compilation of charts from color aerial camera films. As a result, Kodak Special Plate, Type 032-01, was made available early in 1964 and since that time has been used very successfully in photogrammetric operations.

Kodak Special Plate, Type 032-01, is the special-order designation for a product consisting of an unexposed color reversal duplicating film on a glass support. This multilayer color plate is designed for making high-quality color diapositives from originals on reversal color films such as have been described. It can be exposed on readily available equipment and processed with solutions prepared from the chemicals in the Kodak Ektachrome Film Processing Kit, Process E-2. Because of the unique method of manufacture, the Type 032-01 Plate has essentially the same dimensional stability characteristics as the glass base. These characteristics are highly important to the photogrammetric engineer.

Color diapositives produced with this plate can be used in direct-viewing stereoplotting equipment and are adaptable to projection-type plotters equipped with polarizing filters or other optical modifications replacing the anaglyphic system. The glass base is micro-flat glass 0.250 inch thick for maximum performance, and provides dimensional stability far superior to any type of film support. The micro-flat glass base is flat to 2×10^{-5} inch per linear inch. The plate can be exposed in ordinary contact, enlarging, or reduction printing equipment with illumination having a color temperature of about 3200° K. Appropriate balancing filters can be used in the light beam. These plates can be printed with a tungsten-filament light source and manual dodging procedures or with electronic scanning-type printers and a newly available cathode-ray-tube light source having a color temperature of about 3250° K.

A second plate material has been introduced as part of the Kodak AERO-NEG System. This is Kodak Special Plate, Type 083-01, which is a color print film on a glass support designed for making high-quality color diapositives from original negatives made on Kodak Ektachrome MS Aerographic Film (Estar Base), Type SO-151, when Type SO-151 Film has been processed to a negative in the modified Kodak Color Film Process C-22.

Type 083-01 Plates can be used for photogrammetry and for a wide variety of mapping and charting applications where full-color photography and the dimensional stability of a glass support are needed. Color diapositives produced with this plate can be used in direct-view stereo plotting equipment. They can be used also in projection-type plotters equipped with polarizing filters or other optical modifications replacing the usual red and green filters.

Almost any diffuse tungsten light source can be used for contact or projection printing Type 083-01 Plates. Electronic printers of the scanning type and conventional contact reduction printers can be used also. With the Type 083-01 Plate, it is possible to dodge or print an area of color negative to change the density of the color diapositive without affecting color balance. All of the normal black-and-white dodging procedures used in contact-printing operations or scanning-type printers usually can be used.

Adjustment of color balance in the printing operations is provided for with Type 083-01 Plates. If desired, color-balance differences between color aerial negatives can be compensated where color diapositives are exposed. Developing times for Type 083-01 Plates can be adjusted also to obtain small changes in contrast. Type 083-01 Plates are processed in Kodak Color Film Process C-22.

Exposure

Camera exposure is expressed in terms of an exposure time and a relative aperture, or *f*-stop. The importance of giving optimum camera exposure is directly related to the available exposure latitude, which is defined as the ratio between the maximum and minimum exposures that will give the desired quality in the final photograph. Where recording of information is the objective, the effective exposure latitude is generally less than for pictorial photography. The darkest areas of the scene, usually in shadow, must not be devoid of detail. Yet, the middletones and highlights will suffer a loss in image quality if they are overexposed. These considerations apply equally to black-and-white and color photography. In the case of color reversal camera films, an underexposed picture may appear undesirably dense, particularly in the shadow areas, and a very bright illuminator may be required for viewing such a transparency.

The height of the sun above the horizon is the primary determinant of exposure in aerial photography.[16] Figure 5 illustrates the relationship between solar altitude and the camera exposure. The shape of this curve does not vary significantly with the average reflectance of the aerial scene, the amount of aerial haze, or the scale, although at any given solar altitude these factors must be taken into account to determine the correct exposure.

The degree of haziness is next in importance to solar altitude because as the aerial haze increases, the apparent luminance of the darkest areas of the scene, which can never be less than that of the haze, also increases. With increasing haze, therefore, the camera exposure is decreased, because the apparent increase in minimum scene luminance more than offsets the effect of the decrease in average luminance resulting from the decreasing transmittance of the haze.

The total haze in a vertical line of sight increases with increasing altitude up to the tropopause, or approximately 40,000 feet, but usually there is an insignificant change above 20,000 feet. This requires that camera

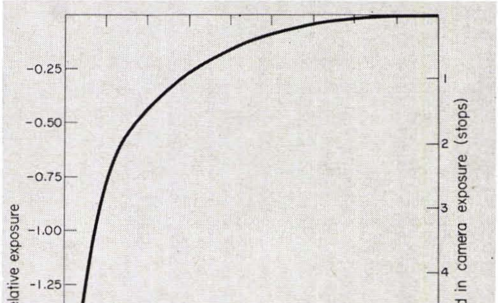


FIG. 5. The relation between the logarithm of the average minimum luminance of ground objects viewed from 10,000 feet and solar altitude, in degrees above the horizon.[14]

exposures be reduced as altitude increases. Although the average conditions that have been determined through experiments in the vicinity of Rochester, New York, can serve as a guide, and have been used as a basis for the Kodak Aerial Exposure Computer, large local variations from these conditions may occur. The photographer will need to rely on his experience and judgment in assessing the degree of haziness.

The average reflectance, or brightness, of the scene plays a relatively small role in determining exposure, except for very bright scenes such as deserts or snow-covered areas.

The Kodak Aerial Exposure Computer (Frontispiece), which is based on empirical relationships between the various determinants of camera exposure, affords a convenient method for arriving at the correct camera settings based on these variables. The only additional information needed to use this device is the aerial exposure index of the film. This is the number assigned by the film manufacturer that indicates the film speed relative to that of any other film, and the number to be used with computers or meters to arrive at camera exposure settings.

At present, no universally accepted method exists for assigning these exposure indexes to aerial films, although in the United States a Subcommittee of the United States of America Standards Institute has been studying the matter of determining such figures for black-and-white aerial films. It would be premature to predict the final action of the Committee on a sensitometric criterion for determining black-and-white aerial film exposure indexes, but a change in the number scale is to be expected. It is not likely that any action will be taken in the near future to standardize the method for determining aerial color film exposure indexes. The numbers assigned by film manufacturers will be kept in the correct relationship to those of black-and-white aerial films, as determined from actual picture tests. In view of the changes expected in the aerial exposure indexes, the recommended basic camera exposures for various Kodak films are given in Table I, instead of exposure indexes. A new edition of the Exposure Computer will be published with the new exposure index values.

FILTERS

If a selectively absorbing filter is used over the camera lens, the increase in camera exposure required may be less than the smallest change afforded by the exposure controls, in which case it is usually best to make no change at all. A Kodak Wratten Filter No. 2B or the Kodak HF-3 Haze Filter will usually compensate for the effect of scattered blue and ultraviolet radiation encountered at medium altitudes. An exposure increase is usually not necessary when any of these filters is used. Figure 6 shows their spectral transmittance characteristics.

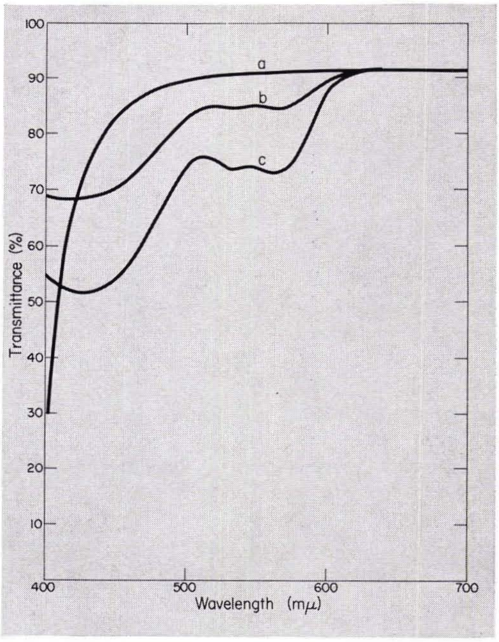


FIG. 6. Transmittance characteristics of (a) the Kodak Wratten Filter No. 2B, (b) Kodak Haze Filter, HF-4, and (c) HF-5.

Spectrally selective scattering of light by aerial haze occurs primarily under conditions of light haze at high altitudes. Filters which tend to exclude blue and ultraviolet radiation will therefore be most beneficial where the photographs are taken under these conditions. Light of all wavelengths is scattered in about equal amounts by haze consisting of suspended particles such as dust or water droplets. Therefore, if such haze is present, the main thing to be gained by the use of a filter excluding blue light or ultraviolet radiation is improved color balance.

Under no circumstances do we recommend for normal color aerial photography the use of filters such as the Kodak Wratten Filter No. 12, or equivalent glass filters which exclude almost all blue light. It is almost impossible to compensate in printing for the strongly yellow color balance produced by minus-blue filters having a transmission cutoff at wavelengths of 450 mμ or greater.

Many existing aerial camera lenses were designed on the assumption that a filter like the Kodak Wratten No. 12 would always be used, as it is for much black-and-white aerial photography. These lenses were achromatized for the green and red portions of the spectrum, and some of them produce images of noticeably lower quality in blue light. Although some such lenses have been successfully used for color photography, the best results can of course be obtained only with lenses specifically corrected for this purpose.

When an antivignetting filter is recommended with a particular lens, it should always be used for color photography, because the effect of illumination falloff at the edges of the frame is more noticeable in color and more difficult to correct by dodging during printing than it is with black and white. If this filter happens to be available only in combination with a yellow filter, it may be necessary to decide which is the lesser of two evils: a color balance that is very yellow (resulting from using the combination filter), or dark areas with poor color balance around the outer portion of each frame if it is left off; and an exposure given that is correct for the center of the frame. If the antivignetting filter can be obtained on clear glass, it will be well worth the cost.

Processing

Detailed instructions for processing color films in the rewind-type of equipment that is still widely used are given in the data sheets packaged with the film and need not be repeated here. Experience has shown that a skilled operator of such equipment can produce results of excellent quality. If several frames of film are left unused at each end of the roll, the cross bands of varying density or color balance that often occur because of pressure effects near the cores of the spools will be prevented from appearing in picture areas. Apart from such cross bands, the use of rewind processors present no other problems which cannot be avoided with appropriate techniques which are well known to experienced operators.

The Kodak Ektachrome RT Processor, Model 1411-M, which has recently become available, represents a logical extension of the Versamat principle to color applications, and is a reliable and versatile device for processing both camera and print films.

Viewing Color Reproductions

In the discussion of color-film spectral sensitivities, it was mentioned that these are balanced for the exposing light source so that neutral objects will be neutral in the color reproduction. It might be thought that some provision would have to be made for the color of the illuminant by which the photograph is finally viewed, for the same purpose. However, the property of the visual mechanism of adapting to the color of the prevailing or predominant illumination makes this unnecessary. For example, a white shirt appears white, or neutral, under illuminants as widely different as north skylight, sunlight, and artificial sources such as incandescent tungsten lamps or fluorescent lamps. As a more extreme example, where color slides are projected on the wall of a darkened room, if the color of the wall is any light pastel hue, the eye adapts almost immediately to this color, and white or gray areas in the pictures appear white or gray. It follows that, in viewing aerial color transparencies, if the eye becomes adapted to the color of the light in the illuminator, or if this is about the same as the room illumination, areas of the picture will appear neutral where equal amounts of each of the three dyes are present. In short, it is necessary to expose a color film with the illuminant for which it was designed, but it can be viewed with a wide variety of illuminants and still appear to have satisfactory balance.

Some illuminants, however, give less than optimum quality by virtue of being deficient in one or another of the additive primaries. Obvious examples are light sources such as sodium- or mercury-vapor lamps. Less obviously deficient, and therefore more likely to be used inadvertently to the detriment of color quality, are ordinary fluorescent lamps and cold-cathode lamps. These are often deficient in red output and cause the apparent balance of photographs to shift toward cyan. Although this may not be so immediately objectionable in an aerial photograph as, for example, in a portrait, it can result in decreasing the information obtained from the photograph by restricting the range of colors that can be discriminated.

Light sources recommended for viewing color reproductions are natural daylight, incandescent tungsten light, and "Deluxe" fluorescent lamps. Some other suitable illuminants are less generally used or available than these, including some especially designed for color viewing. One that gives very good results is the Macbeth Avlite Tube, as supplied in the Avlite Standard Viewer manufactured by the Macbeth Daylighting Corporation.

Conclusions

The full advantages of color will only be realized as each photographer gains experience with it in his specific application, because the extraction of information from any aerial photograph requires a great deal of skill. Even more important than the need for suitable equipment and films is the training of photo interpreters and other ultimate users to exploit the potentialities of color. When this has been accomplished, and users have become accustomed to color photographs, it is likely that many of them will never again be entirely satisfied with black-and-white aerial photographs.

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