Color and False-Color Films for Aerial Photography

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ABSTRACT: *Color reproduction by the photographic process using three primary colors is discussed, and the use of these photographic and optical principles for false-color reproduction is explained. The characteristics of two new aerial films—Kodak Ektachrome Aero Film (Process E-3) and a false-color type, Kodak Ektachrome Infrared Aero Film (Process E-3)—are compared with those of the older products they replace. The new films have higher speed, improved definition, and less granularity.*

POPULAR processes of color photography are based upon the facts that (1) the colors perceived by the human eye can be produced by mixtures of only three suitably chosen colors called primaries; (2) photographic emulsions can be made to respond selectively to each of these three colors; and (3) chemical reactions exist which can produce three individual colorants, each capable of absorbing essentially only one of the chosen primary colors. Although theory imposes no single unique set of three primary colors, in practice the colors chosen are those produced by light from successive thirds of the visible spectrum: red, green, and blue. When these choices have been made for the primary colors, the colorants, each of which will absorb only one of these primaries, are uniquely specified, and are cyan which absorbs red, magenta which absorbs green, and yellow which absorbs blue. These latter colors are referred to as the complementary colors or as the subtractive primaries.[1]

A color photographic material based on the use of these primaries consists of three sensitive layers coated on a support, each layer sensitized to a different primary color and capable of producing the appropriate complementary color in situ (Figure 1). In addition, the amount of colorant produced in any area is related to the amount of silver developed; this is, in turn, related to the intensity of light in this area of the original scene. Thus each layer is a separate record of the brightnesses of a single primary color and, with the three layers of the film superimposed, the colors and brightnesses of the original scene are reproduced within the limits imposed by the process.

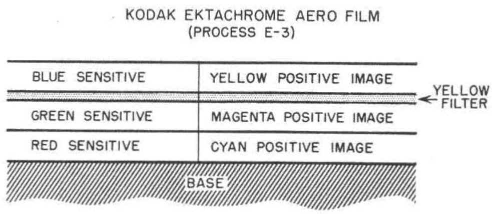


FIG. 1. Schematic representation of a multilayer color film.

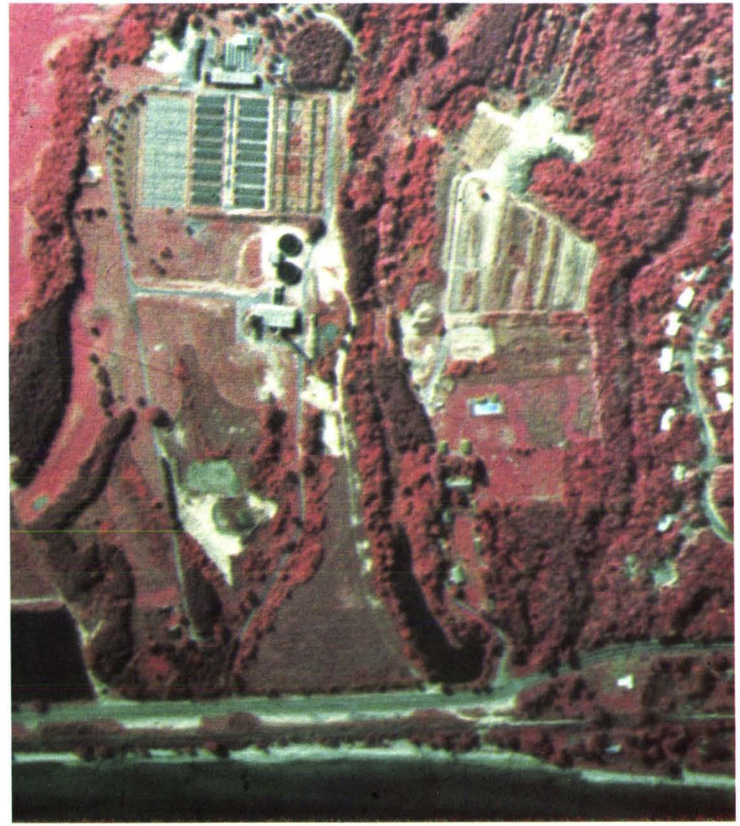
No process of color photography is available which can accurately reproduce all colors in a scene, but the results obtained with modern color photographic materials are remarkably realistic representations of the original scene. While a good representation of the original scene is completely satisfactory for practically all applications, an aerial color photograph of the ground taken from a high altitude without any modification in its characteristics would be unsuitable for most purposes.

The difficulty in obtaining satisfactory aerial photographs is due to atmospheric haze which drastically lowers the luminance ratios of ground detail.[2] In color photography, in addition to lowering of the contrast in the image as in a black-and-white photograph, the color saturation is also markedly reduced. It has been established that photographic materials having a higher gradient characteristic curve will restore some of the loss in contrast and, in addition, with color materials color saturation is increased. Therefore, Kodak Ektachrome Aero Film (High Contrast),* which Eastman Kodak Company supplied to the Allied Armed Forces during World War II,[3] had a characteristic curve gradient about 100 per cent higher than that of comparable pictorial materials.

* Known as Kodacolor Aero Reversal Film when it was first introduced in 1942.

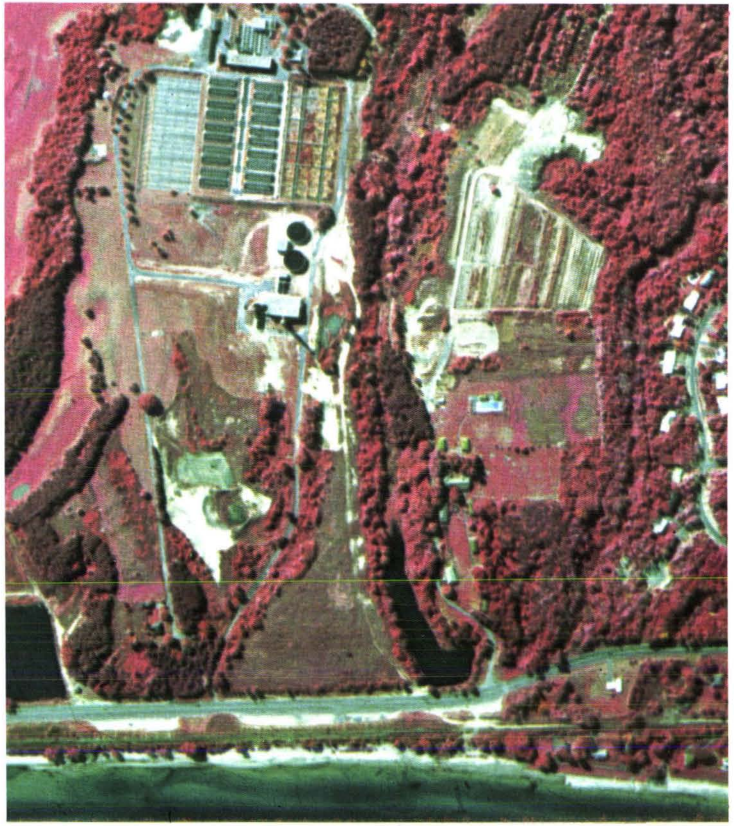
OLD PRODUCTS

KODAK EKTACHROME AERO FILM
(High Contrast)
Exposure 1/500 sec. at *f*/4.5



KODAK EKTACHROME AERO FILM
(Camouflage Detection)
Exposure 1/500 sec. at *f*/3.5

KODAK EKTACHROME AERO FILM
(Process E-3)
Exposure 1/500 sec. at $f/8.0$



KODAK EKTACHROME INFRARED AERO FILM
(Process E-3)
Exposure 1/500 sec. at $f/5.6$

Figure 8—Comparison of photographs on old and new Kodak color aerial films, taken from 8,000 feet altitude on days of average haze.

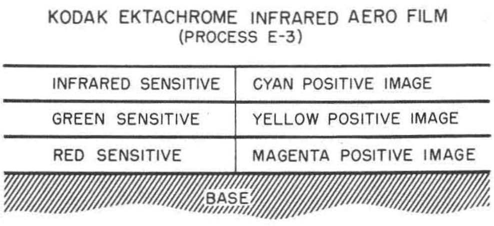


FIG. 2. Schematic representation of the structure (Process E-3).

Under some conditions the degree of attenuation is dependent upon wave-length; for a "pure" atmosphere, according to Rayleigh, the scattering is inversely proportional to the fourth power of the wave-length. This means that blue light is scattered more than green light which, in turn, is scattered more than red light. It appears, therefore, that a color film should have a higher gradient in the blue-sensitive layer than in the green-sensitive layer which, in turn, should be higher than that in the red-sensitive layer. In fact, a limited investigation of this effect during World War II indicated that there was some wave-length-dependence, but the effect is extemely small except where the atmosphere is almost completely devoid of all aerosols. This later condition so seldom exists that for most practical aerial photographic conditions, the contrast-degrading effect of the atmospheric haze can be reduced by simply increasing the gradient of all three sensitive layers.

The principles just discussed apply only when a color photograph is desired which represents a scene as it appears visually or as it would appear if certain unwanted disturbing elements could be minimized. It is to be emphasized that while the colors in the scene can be approximated by photography based on these principles, a colorimetric match does not imply a spectral match.[4] Therefore, the recording of three separate regions of the visible spectrum and the choice of dyes are uniquely interrelated only when a natural-appearing color picture is desired. Technically, any portions of the spectrum to which photographic materials are sensitive (within or outside the visible spectrum) can be recorded, and the colorant developed by this record can be any that are available, without regard to the spectral region initially chosen. Such processes have been proposed for specialized purposes and are known as false-color systems.

In aerial photography, particularly for interpretation purposes, spectral regions can be chosen to emphasize differences between particular objects which are visually quite similar. These principles of false-color systems were used during World War II, and Kodak Ektachrome Aero Film (Camouflage Detection)* which, beginning in 1942, was supplied by the Eastman Kodak Company to the Allied Armed Forces[5]; this film emphasized the difference in infrared reflection between green vegetation and most visually similar green paints. The structure of this film material, showing the sensitivities and the colors developed in the different layers, is shown in Figure 2. The material was always used with a yellow filter over the camera lens which absorbed blue light to which all photographic emulsions are sensitive. The chlorophyll of green vegetation, which reflects strongly in the infrared region of the spectrum, would appear red in the photographs, whereas other objects visually similar to vegetation would be rendered as dull blue.

Any spectral differences that exist in the photographic sensitivity range can be similarly differentiated and emphasized by a suitable choice of emulsion sensitivities, filter absorptions, and developed dye in the layers. For this application of the techniques of false-color photography, only two different layers and colorants are needed for differentiation

* Then known as Kodacolor Aero Film, Camouflage Detection.

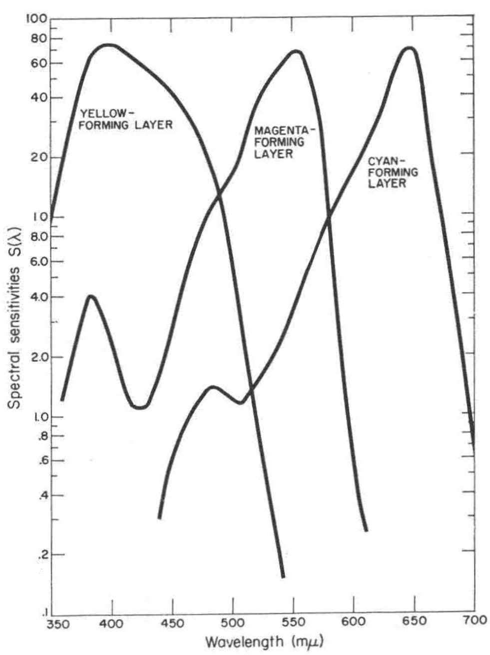


FIG. 3. Sensitivity curves for Kodak Ektachrome Aero Film (Process E-3).

between the two spectral regions of interest. However, two-color systems cannot produce as wide a gamut of colors, or approximate the appearance of colors, as well as can be produced by a three-color system; also if neutrals must be reproduced from neutrals in the original scene, the colors produced in the two-color system will be still less satisfactory. In the experimental work conducted by the Eastman Kodak Company which led to the manufacture of this material, two-color films were actually produced and tested; but from a side-by-side comparison between photographs taken by the two-color and the three-color types of film, the military and scientific people concerned chose the three-color material.

In a similar manner, any two (or more) different portions of the spectrum, whether in the visual, ultraviolet, or infrared regions, can be selected to emphasize any spectral differences occurring in objects of interest. In general, each different portion of the spectrum used will require a particular combination of filter absorptions and emulsion sensitivities if the false-color technique is to be employed. Special multiple emulsion-coated materials, as was the case with the "Camouflage Detection" type of film, are not required, of course, because readily available conventional materials can be used with suitable techniques to produce the same visual end result. For instance, two pictures of a scene taken simultaneously—one on infrared-sensitive film with the visual region absorbed by a filter, and the other taken on a panchromatic film—can be used to prepare a color print (or transparency) exhibiting approximately the same differential between green foliage and visually similar green paint as is obtained with the "Camouflage Detection" material; or the same original picture can be used by additive projection techniques to produce approxi-

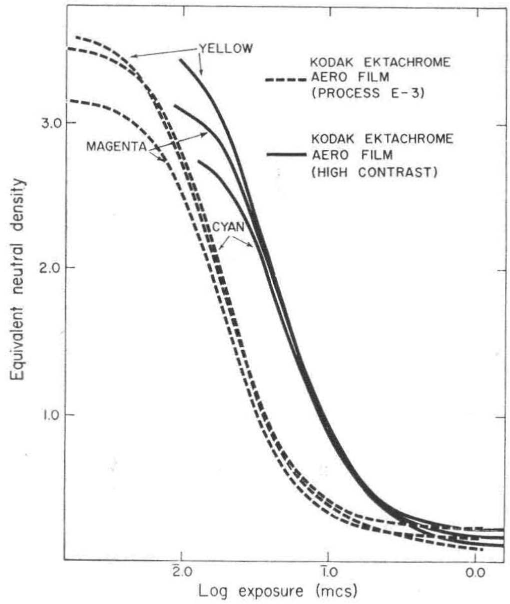


FIG. 5. Typical sensitometric curves for Kodak Ektachrome Aero Film (Process E-3) and for the older product.

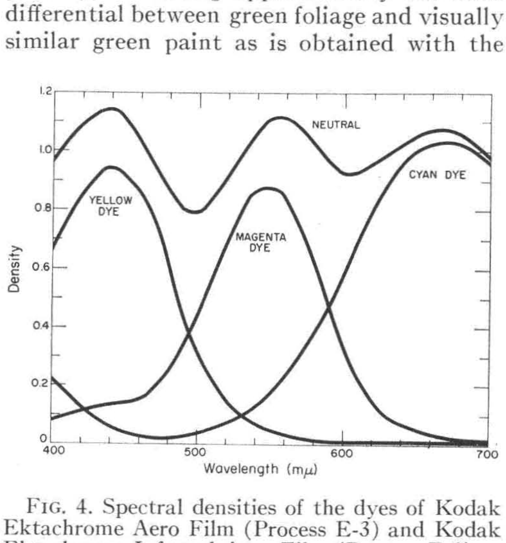


FIG. 4. Spectral densities of the dyes of Kodak Ektachrome Aero Film (Process E-3) and Kodak Ektachrome Infrared Aero Film (Process E-3).

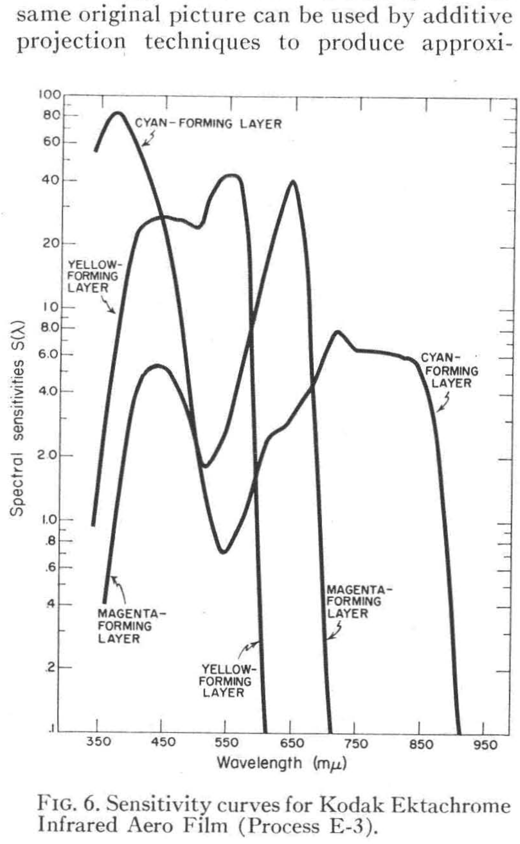


FIG. 6. Sensitivity curves for Kodak Ektachrome Infrared Aero Film (Process E-3).

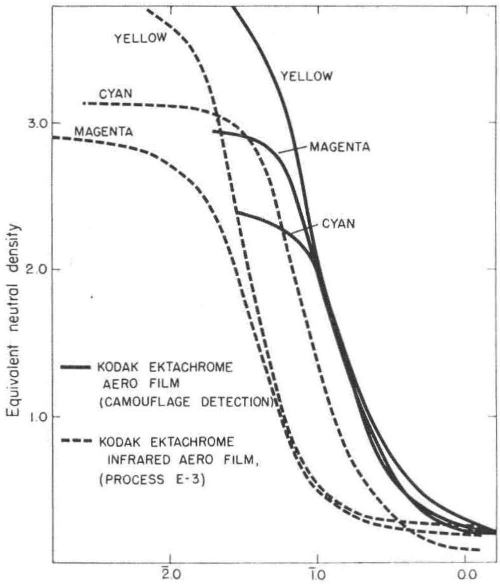


FIG. 7. Typical sensitometric curves for Kodak Ektachrome Infrared Aero Film (Process E-3) and for the older product.

mately the same result. If desired, three records can be made if the result would be more satisfactory.

In the last few years, significant advances have been made in color photographic technology which have provided improved speed and definition characteristics, color reproduction characteristics, and simplicity of handling of the materials. These gains have been applied to the two aerial color films discussed; improved products, Kodak Ektachrome Aero Film (Process E-3) and Kodak Ektachrome Infrared Aero Film (Process E-3), are now offered by the Eastman Kodak Company as replacements for the previous products.

The new Ektachrome Aero Film is three times as fast as the older product and has improved definition and less granularity. Typical sensitivity curves of the three layers are displayed in Figure 3, spectral characteristics of the dyes produced are plotted in Figure 4, and sensitometric characteristics of the old and new product are compared in Figure 5. The Ektachrome Infrared Aero Film is three times as fast as the older product, and has improved definition and less granularity. Typical sensitivity curves of the three layers are displayed in Figure 6, spectral characteristics of the dyes produced are plotted in Figure 4, and sensitometric characteristics of the old and new product are compared in Figure 7.

Typical exposure conditions for the two new materials under normal daylight illumination are: Kodak Ektachrome Aero Film, 1/250 second at f/11; and Kodak Ektachrome Infrared Aero Film with a Kodak Wratten Filter No. 15 over the lens, 1/250 second at f/8. The aerial indexes, which are for use with the Kodak Aerial Exposure Computer, are: 25 for the Ektachrome product and 10 for the Ektachrome Infrared product.

Figure 8—the insert—demonstrates the difference in color reproduction between the two types of film and the improved definition and color quality of the two new products. The area reproduced is a portion of Durand-Eastman Park, Rochester, New York. The photographs were made from 8,000 feet altitude on days of average haze using a 35 mm camera equipped with a 50mm focal-length lens and with the recommended filters installed. The same section of the frames has been enlarged to illustrate the improvement in definition obtained with the new products. The Ektachrome Infrared Aero Film and the Ektachrome Aero Film (Camouflage Detection) were exposed September 24, 1962. The two Ektachrome Aero Films were exposed October 19, 1962, after some leaves had begun to change color.

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