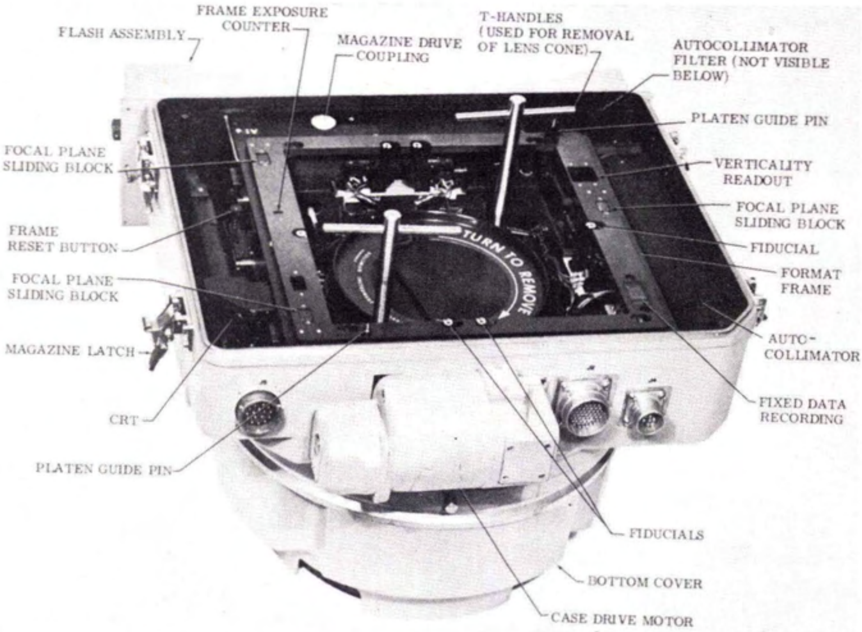

FRONTISPIECE. The Fairchild KC-6A 6-inch aerial camera containing the Geocon IV lens fabricated by Kollsman Instrument Corporation.

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Aerial Cameras for Color

The use of color will be a major contribution to the enlarging field of photogrammetry.

INTRODUCTION

If we view the life span of aerial photography, we observe that black-and-white film has been used almost exclusively to record images of the terrain. Super XX Aerial Film, Plus X, and Panchromatic X have been the reliable "work horses". Barring gross problems, repeatable results of familiar quality could always be predicted. On rare occasions during the first half of the last decade color would be used and then, if photographic conditions for exposing and processing were "just right", the results were impressive. In addition to esthetic appeal, photogrammetrists found that there was more information from color and a greater certainty of the position of the terrain objects. Such results led to the increased use of color by knowledgeable researchers and photographers giving what Smith[1] termed "a new dimension in aerial photography."

The trend to color and infrared photography began and gained strength. More scientific researchers and photogrammetrists employed it and published lauditory articles. One can now say with certainty that these color sensors will play a leading roll in our photo-

* Presented at the Annual Convention of the American Society of Photogrammetry, Washington, D. C., March 1967 under the title "The Requirements of Photogrammetric Aerial Color Cameras".

grammetric future. It seems appropriate at this time, therefore, to review the technical requirements of the various equipments and processes of the reconnaissance and mapping complex; to establish the present capability; and to direct efforts toward the improvement of new equipment and techniques that will support and further assist color photography. Within this framework, this paper will limit itself to selective functions of aerial cameras associated with the use of color and infrared film and to a discussion of the laboratory tests that prove the characteristics of these functions.

The Color Photo on the Front Cover

was taken over the Grand Canyon, Arizona, with a Fairchild KC-4 camera equipped with a Geocon I lens from an altitude of 40,000 feet

The Photographic Spectrum

The electromagnetic spectrum for aerial photography roughly covers the range from 300 to 1,000 milli-microns. As a comparison, the human eye begins to respond around 380, response peaks at 540, then falls off rapidly in the orange-red. Complete cut off occurs at about 700 milli-microns (Figure 1A).

The curve for black-and-white film represented by Plus X, (Figure 1B) is open ended at 400 milli-microns and cuts off at 720. The recorded energy is substantially uniform over this region. The characteristics of the #12 minus-blue filter are also included as they are usually employed with black-and-white film. As can be seen, the transmission curve of the minus-blue filter rises on a steep slope about 500 milli-microns and is almost flat from 520 on into the infrared.

Figure 1C shows the curve for aerial Ektachrome color. It is composed of four layers; the blue sensitive layer is at the surface of the emulsion followed by a layer (not shown) which acts as a yellow-filter rejecting the blue and thereby preserving the purity of the third and fourth layers, the green and red.

Figure 1D shows the infrared film and the 89B filter which limits the recorded spectrum.

In the use of black-and-white film a yellow filter is usually employed to cut the haze and thereby sharpen image contrast. By referring again to Figure 1B, which shows the spectral characteristics of the combination for the minus-blue filter used with Plus X film, it is possible to predict the range of color objects which will be recorded. Because the filter rejects light below 500 milli-microns, blues against blues for instance, or blues against greens may be partially or completely lost in the black-and-white negative. This, however, is the familiar combination which has produced most of the aerial photographs to date. It is far from perfect, yet it has served us well these past 50 years, steadily improving as the individual components and techniques have improved.

Suppose, however, an important survey must be flown over the white snows of the Antarctic, or the blue-green jungles of Vietnam, and maximum information and positional accuracy of terrain objects are essential. Then, by substituting color film for black-and-white, and replacing the yellow filter with one which transmits the whole visual spec-

ABSTRACT: *In order to produce correctly balanced color and infrared photography, as well as black-and-white, an aerial photogrammetric camera requires a "distortionless" lens having good image quality with color and illumination fully corrected over the wide angular field. The camera should be serviced with a carefully selected automatic exposure control system (AEC) such that the exposure latitudes of all aerial films can be met. The lens and AEC requirements are discussed and the laboratory tests made to evaluate these camera performance characteristics are described.*

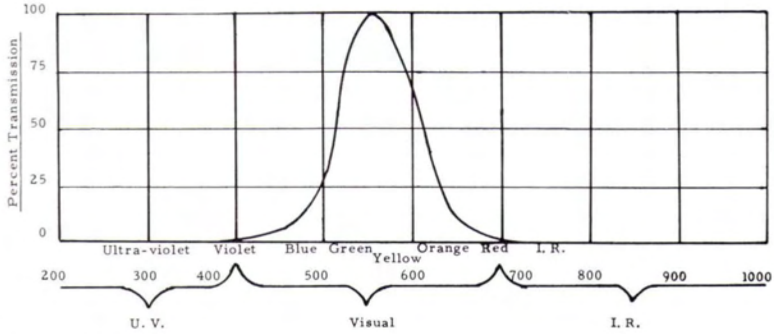

FIG. 1A. The electromagnetic spectrum showing the response of the human eye.

trum and the near infrared, the resulting photography could contain all of the discriminating color hues of the terrain in addition to supplying needed information in the blue region of the spectrum. The use of color could thereby be the critical key to a completely successful mission.

What could happen in this fictitious example has frequently happened in many real missions. We have only to refer to the work of Swanson,[2] Anson,[3] Strandberg[4] and many others to be convinced of these gains. Our immediate task then is to assure continuance of successes for all missions using color sensors.

The All-Purpose Lens and Selected Filters

The lens rates primary consideration because the quality of photography is completely dependent on it. Such quality is currently rated by the number of lines per millimeter the lens will resolve using high-, medium-, or low-contrast targets, or by its modulation transfer function. Any lens used for color and infrared must be fully corrected over the full photographic spectrum. The photogrammetric lens must, in addition, be corrected for distortion. The design of such a lens approaches the ultimate achievement while the fabrication requires the highest quality glass and maximum precision of machining, centering and spacing of the optical elements.

It is in no sense a simple task to design and produce a distortionless lens that has:

- High resolution and well defined image quality over the full, wide-angle field.
- Correction for color and infrared both longitudinally and laterally over the entire field.
- Even distribution of light, which is an exceedingly important requirement because colors vary with exposure.
- As large an aperture as possible in order that low-altitude surveying may be accomplished at reasonable vehicle speeds without loss of image quality due to forward image motion.

In the United States the two lenses most nearly achieving this ideal are the 6-inch f/5.6 Geocon I and the 6-inch f/5 Geocon IV, both designed by Dr. James G. Baker. The former lens (fabricated by both Perkin-Elmer and the Fairchild El Segundo facility) is rated at 40 lines/mm AWAR* on Plus X Aerocon and has less than 10 microns average distortion within a $42\frac{1}{2}°$ half field. This lens is in the Fairchild KC-4 camera which was used in the Phoenix color test conducted by the Committee on Color Photography of the American Society of Photogrammetry in June, 1966.

The KC-4 is a modification of a Fairchild KC-1B Camera which substitutes the Geocon I for the Planigon lens and provides a closely spaced reseau which is recorded on the film by small optical projection systems embedded in the platen, at the same time the open shutter cycle records the terrain. The color photo-

* Area Weighted Average Resolution.

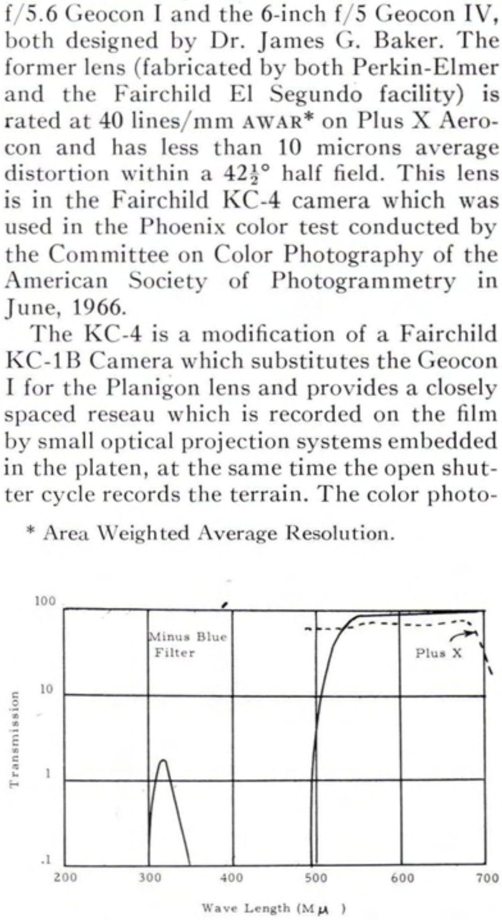

FIG. 1B. The response curve for black-and-white Plus X film is open ended at 400 mu and cuts off at 720. The yellow filter limits the lower end.

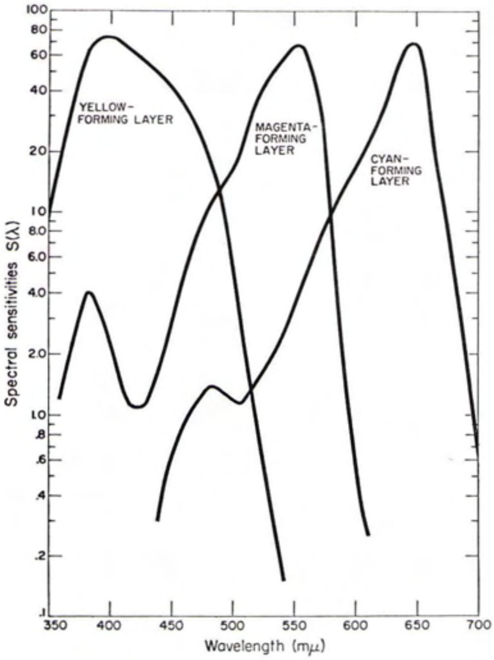

FIG. 1C. Response curve for Eastman Ektachrome Aero Film, Type 8442, Kodak process E-3. Spectral sensitivities $S(\lambda)=1/E(\lambda)$ where $E(\lambda)$ is the energy, in ergs/cm², of monochromatic radiation at wavelength λ required to reduce the dye image density in the individual layer to an END of 1.0 above minimum density. Data are adjusted to correspond to an effective exposure time of 1/100 second. (Reprinted by permission of Eastman Kodak Co.)

graph (Front Cover) taken with the KC-4 Camera over the Grand Canyon at 40,000 feet shows the fine detail of this rugged terrain, detail which would not be differentiated on black-and-white photography.

Another highly detailed photograph of Los Angeles, taken by the KC-4 Camera, was included in Captain Swanson's paper, presented in the 1964 Congress of the International Society of Photogrammetry at Lisbon, as an example of the increased information available with color. In order to be assured that color photography of at least the quality of these two samples can be obtained whenever weather conditions permit, it is the stated goal of the ASP Color Committee to investigate the equipment and methods leading to specifications and laboratory tests which will certify the color capability of our mapping equipment complex.

The Geocon IV is the second American lens referenced. It is fabricated by Kollsman Instrument Corporation and is mounted in the Fairchild KC-6A Camera. The optical requirements of this lens exceeds those of previous 6-inch mapping lenses. A resolution of 45 lines/mm AWAR must be met on Plus X Aerographic film with distortion and resolution both being evaluated within a 90° full field rather than the 85° field previously used. In addition, the tolerance for distortion is 8 microns as compared with previous specifications of 10 microns for the smaller field (Frontispiece).

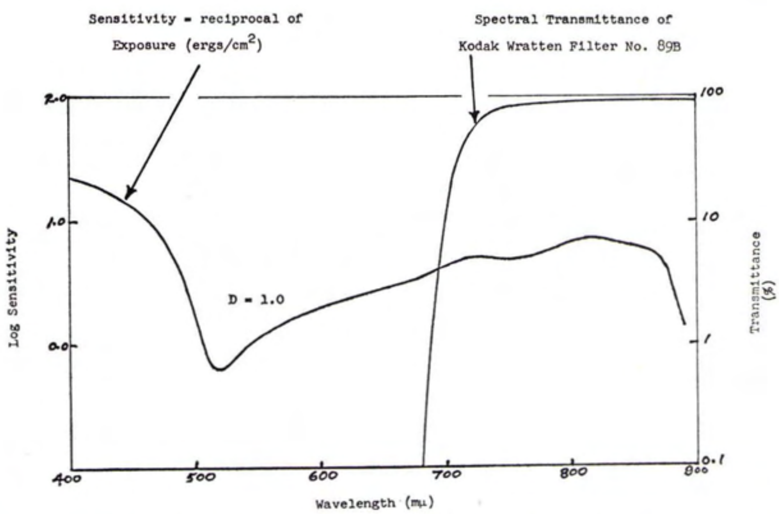

FIG. 1D. Spectral sensitivity of Kodak Infrared Aerographic Film, Type 5424, together with the transmittance of the Wratten 89B Filter. (Reprinted with permission of Eastman Kodak Co.)

The KC-6A is an advanced design having certain advantages over the KC-4. It has image motion compensation which not only reduces loss of resolution due to forward image motion, but allows slower and finer grain film to be used. This should greatly increase the quality of color photography. It also has an automatic exposure control which adjusts the lens apertures and shutter speed in accordance with the intensity of light reflected from the scenes being photographed. As mentioned previously, the camera is equipped with the Geocon IV lens in which the computed color correction is superior to the Geocon I. The design of the Geocon IV is such that Dr. Baker believes it is capable of producing 55 lines/mm AWAR, high contrast, on Plus X Aerographic film when the lens is fully optimized. Both lenses correct the light distribution with anti-vignetting filters.

Exposure tests, made with the KC-4 camera prior to the photogrammetric survey runs over the Phoenix test area, provide an example of the increase in resolution (and image quality) that can be gained with forward image-motion compensation. At slow shutter speeds, as can be seen from Figure 2, the resolution increases with altitude because the image motion during the fixed exposure time decreases with increased altitude. Although the results are easily computed, it is interesting to observe the correlation of the data with theory. It is proof of the need for image-motion compensation in mapping cameras on low and medium altitude surveys, a condition which is emphasized when slow shutter speeds are used for color film.

Aerial Reconnaissance Cameras

Image quality and color correction are exceedingly important to reconnaissance cameras using color, infrared, and false-color films. The more sophisticated, modern panoramic cameras are equipped with lenses which, in some cases, approach the ultimate quality termed *diffraction limited.* This is possible because the very wide-field coverage—usually in the direction perpendicular to flight direction—is achieved by either an optical or mechanical scanning technique in conjunction with a narrow-field lens. Even for these lenses, however, the high performance is difficult to achieve if color correction is requisite over the full visual spectrum and into the photographic infrared.

One such Fairchild camera, which is ca-

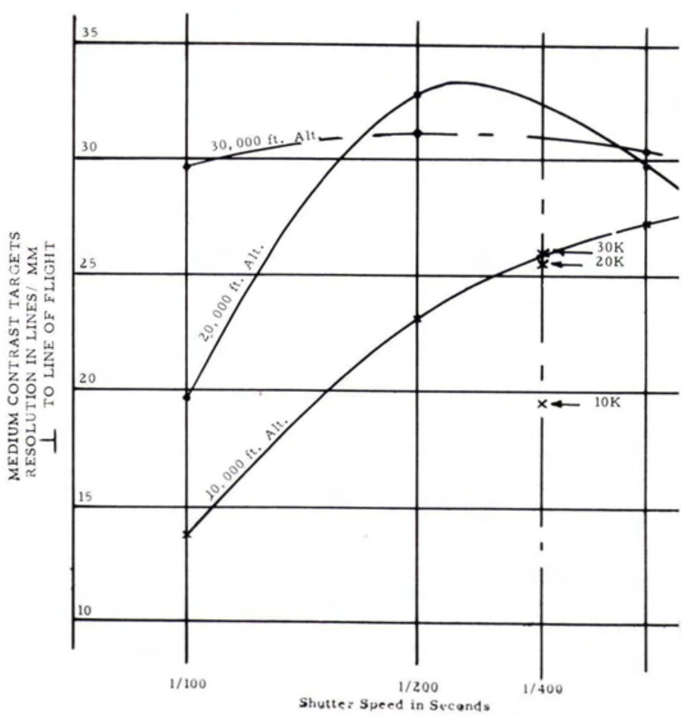

FIG. 2. Variation of image resolution with shutter speed and camera altitude illustrating the effect of image motion. (Fairchild KC-4 Camera, ASP Phoenix Flight Test, June 1966.)

pable of over 100 lines/mm AWAR resolution on Plus X Film in dynamic laboratory tests, is the F-638 panoramic camera equipped with a Fairchild 12-inch f/3.8 lens. Although not yet proved in flight test, photography taken with this new camera using any of the spectral sensors should provide increased scientific and military information at a high acuity level.

The Fairchild KA-56 panoramic camera containing the Zeiss 3-inch f/4.5 Biogon has produced excellent color on many missions. Photographs taken with this military camera over Miami Beach from an altitude of 800 feet as shown in *Life Magazine*'s 30th anniversary issue on "Photography" are examples of the greater information which is available.

Exposure Control

The limited but well defined latitude of color as compared with black and white makes it imperative that, after the processing controls have been selected, the film be correctly and uniformly exposed over the full format of the reconnaissance or survey camera. First, the illumination characteristics of the lens must be known and, if not uniform, compensated by some technique. As previously noted, this is usually accomplished in photogrammetric cameras with an anti-vignetting filter. Similar methods may be necessary for reconnaissance cameras where differences in illumination across the field will significantly affect color balance.

Secondly, the total exposure must be optimum so that color film, the most critical sensor, is well balanced. This can best be accomplished with automatic exposure control using a photo cell whose response covers the full spectral range of the film. The lens aperture and shutter speed are then varied to provide the correct quantities of light and time for each exposure in accordance with AEC directions as controlled by the voltage output from the photo cell.

Laboratory tests of the exposure control system (AEC) usually begin with an exposure of the photo cell to a source of known, variable brightness while obtaining simultaneous measurements of the cell's voltage outputs. The camera response to the range of potentials is then determined. If it is assumed that the accuracy required must be at least $\frac{1}{4}$ stop, whereas the variation in illumination as represented by a low-slope, non-undulating, continuous curve over the format must be no greater than half that tolerance, these quantities can be evaluated from measurements of aperture dimensions and shutter speeds; or preferably, from photographic tests where processing is rigidly controlled, so that the indicated film speed rating is obtained.

This latter method which is now being used at Fairchild for black-and-white film on panoramic camera tests has proved to be a successful quality control testing technique and evidently no difficulty is encountered in employing it for the more rigid requirements of an AEC color system.

Much work remains to be done before practical specifications can be written and testing techniques fully defined, but for wide-angle cameras, particularly mapping cameras, our present knowledge shows that inspection of color cameras must include total exposure with all its contributing components.

Additional Camera Problems

Other camera functions will need investigation and, perhaps, modification. In camera calibration, we may be faced with questions as to the mechanical characteristics such as thickness of the color emulsion coated on spectroscopic plates as compared with color on film base. If differences are found to exist with respect to distortion, solutions must be found.

The light source illuminating the collimators must be more carefully selected and the spectrum well controlled when color is used in laboratory testing. This is not too difficult if a single collimator is employed or if large ranges in exposure time are not required for different cameras. If a number of collimators are used, as occurs in a calibration array, the task of maintaining equal spectral and timing characteristics can become quite complex and must be constantly monitored.

Methods of exposing film or glass plate emulsions will also be more critical for color than for black and white. When a lens undergoes a through-focus test to select its optimum focal position, it is not always possible to use a between-the-lens shutter to expose the film. In some laboratories the exposure is controlled by turning the lights on and off for a certain interval of time. In others, exposure is with flash. Tests of the camera, on the other hand, would obviously be made with a camera shutter defining the exposure interval. Again, the difference between the two tests in the case of color must be proved to be equivalent in our investigations.

Eyes Forward

The problems that have been noted are only a few of many which must be solved before the bulk of aerial photography can be done with mapping and reconnaissance cameras that are designed to make full use of our many spectrally selective films. Plans are being set up to investigate all links in the photogrammetric equipment and techniques chain which contribute to the quality and reliability of aerial color photography. These investigations may lead to improvements in equipment and refinements in testing techniques. The latter, supplying detailed information on image characteristics will no doubt spur our design engineers to greater achievements.

If we continue to look forward, taking definite steps to consolidate each technical gain, there is no doubt that color will be a major contribution to the constantly enlarging field of photogrammetry.

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