J. Fleming
Canada Centre for Remote Sensing
Ottawa, Ontario K1A 0E4, Canada

Exploiting the Variability of Aerochrome Infrared Film

Those batches of film shown by testing to have an enhanced IR-sensitivity are reserved for high-altitude use.

Abstract: *Some non-standard descriptive parameters that have been found useful in dealing with the unique attributes of Aerochrome Infrared film are defined. One of these, designated "IR-Balance," has been employed in the compilation of a histogram illustrating the range of variability encountered in practice over a three-year period. The manner in which the variability is exploited for high-altitude use by the Airborne Operations Section of the Canada Centre for Remote Sensing is briefly discussed.*

The characteristics and applications of Aerochrome Infrared Type 2443 film have been described in the literature of remote sensing and elsewhere.[1,2] Its limitations as a high-altitude sensor have also been recognized and suggestions advanced to compensate for those limitations.[2] An alternative approach also may be available to some users of this unique remote sensing tool who have a particular interest in its high-altitude applications. Some large-volume users of color infrared film are undoubtedly aware of the possibility of exploiting its variability,[5] but occasional users without access to close sensitometric controls and statistical data may be unaware of the pitfalls of failure to compensate for the variables.

To review briefly, Aerochrome Infrared Type 2443 is a high-contrast, integral tripack reversal color film whose sensitivity to near-IR radiation is deliberately made about 1½ stops less with respect to daylight illumination than the sensitivities of the other two layers to visible red and green light, respectively. It is always used in conjunction with a sharp-cutting minus-blue filter such as the Wratten #12 in order to exclude the blue light to which all three layers are also sensitive.

The near-IR reflectivity of trees, field crops, and other vegetative cover tends to be closely correlated with plant vigor. Since the high-contrast color characteristics of the film render variations of IR-reflectivity visible to the photo interpreter long before the effects of stress become apparent to the eye of an observer on the ground, Aerochrome Infrared has become widely used by foresters, agricultural scientists, and others who wish to map the areal distribution of insect infestation, disease, moisture, or other biological stress.

The difference of sensitivity (i.e., speed) of the layers is illustrated graphically by the typical characteristic curves of Figure 1, in which it may be seen that the curve of the IR-sensitive layer lies to the right of the curves of the other two layers at a distance of approximately 0.35 on the Log E scale. A film with the characteristics illustrated by Figure 1 works well at ground level or from low altitude. In this range, the excess of reflected IR radiation from healthy deciduous foliage is sufficient to reduce the cyan dye concentration in the IR-sensitive layer below that required for neutral rendition, so that variations in the intensity of radiation reflected from objects of high IR-reflectance (e.g., deciduous foliage) become apparent as

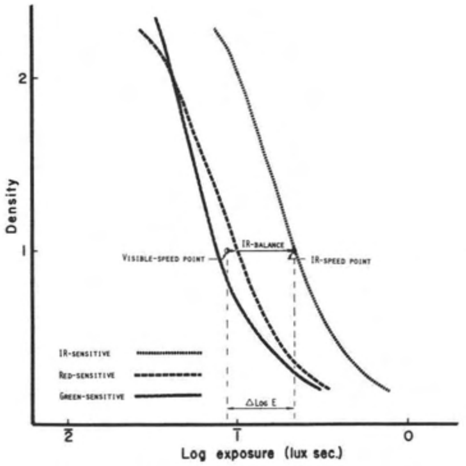

FIG. 1. Typical characteristic curves of Aerochrome Infrared Type 2443 film of "normal" IR-balance; i.e. the length of the IR-balance vector is approximately 0.35 on the Log E scale.

variations in the degree of red saturation in their images.

With increasing altitude, however, the ratio of reflected IR to visible radiation is reduced, by absorption of IR and by increased upward scattering of visible light in the longer atmospheric optical path between the aerial camera and the ground.[2] Although the rate of change of the ratio with altitude is not precisely predictable, being a function of both path length and water vapor concentration, it becomes desirable to increase the IR sensitivity of the film relative to the sensitivity to visible radiation if one wishes to achieve a high-altitude result comparable to that obtainable from low altitudes.

Descriptive Parameters

At this point it is necessary to define certain ad hoc descriptive parameters that the author has found helpful in dealing with the unique attributes of Aerochrome Infrared film. Because of the uniqueness of the material, there are no widely-recognized standard procedures for determination of film speed, color balance, etc. An attempt has been made to adhere reasonably closely to an ANSI standard, with the object of achieving numerical values of film speed consistent with use of exposure photometers or other auxiliary equipment calibrated in accordance with standard criteria, as well as permitting valid comparisons with more familiar materials to which existing standards are directly applicable.

Film Speed

There is available to date no standard procedure for determination of the effective speed of aerial color films in general, nor for determining the speed of color infrared film in particular. The nearest thing appears to be ANSI Standard PH.2.21-1972[4] which is applicable to reversal color films. The effective speed of Aerochrome Infrared is, therefore, determined from the characteristic curves in accordance with the criteria specified by the above standard, and is designated $EAFS$. The average value of film speed so determined for Aerochrome Infrared is about ASA50.

Visible Speed and IR Speed

Since Aerochrome IR includes one IR-sensitive layer which is deliberately made slower than the other two layers whose speeds are more nearly equal, it has been found useful to determine one speed value for the IR-sensitive layer (AFS_{ir}) and another composite speed value (AFS_{vis}) representing the mean speed of the red- and green-sensitive layers.

Film speed is usually expressed as a simple inverse function of the exposure required to produce a specified level of density under specified conditions; i.e., $S = K/E$, where S is film speed, E is exposure in lux sec, and K is a constant selected to meet some specified condition. Hence, the visible-speed and IR-speed have been defined as follows:

$AFS_{vis} = 4.72/E_{vis}$, where E_{vis} = value of E midway between the green and blue curves at $D = 1$*

and

$AFS_{ir} = 10.4/E_{ir}$, where E_{ir} = value of E where the red curve intersects $D = 1$*

(*D = Status A integral diffuse density)

IR-Balance

The horizontal separation between the two speed points referred to above has been designated "IR-balance" (See Figure 1) and appears to be a key parameter for use in categorizing Aerochrome Infrared emulsions as to their suitability for use at various altitudes. For convenience the decimal point is ignored; e.g., a separation of 0.35 log units is expressed as an IR-balance of 35.

Choice of Constants

The constants, 4.72 and 10.4 respectively, were selected so that the numerical values of $EAFS$, AFS_{vis}, and AFS_{ir} will all be equal when the IR-balance is 35. An Aerochrome Infrared emulsion which exhibits such a value of IR-balance is designated "normal" for several reasons:

(a) it conforms closely to the manufacturer's published data;
(b) it produces excellent imagery at ground level and from low altitudes, and
(c) a significant proportion of the emulsions tested to date fall in that category.

Enhancement of the IR Sensitivity

Enhancement of the *relative* IR-sensitivity may be accomplished by reducing the length of the IR-balance vector, either by shifting the IR curve to the left (IR enhancement) or by shifting the other two curves to the right (visible attenuation).

Relative IR Enhancement by Visible Attenuation

Enhancement of the relative IR sensitivity by means of "minus-visible" filtration has been advocated as a practical means of achieving high-altitude results on Aerochrome IR film that compare favorably with those obtainable from low altitudes.[2] It is an effective expedient if one can afford the concomitant loss of effective film speed from the added filters, which may be as much as two full stops at 35,000 feet; and it may be the only expedient available to those who must work with a limited supply of Type 2443 emulsion.

The set of characteristic curves designated "A" in Figure 2 illustrates the effect of exposing a normal Aerochrome Infrared emulsion through a CC 40 Blue filter in conjunction with the usual Wratten #12 "minus-blue" filter. The Wratten #12 plus CC 40B combination represents "minus-visible" filtration which attenuates the visible portion of the spectrum while allowing almost unimpeded transmission of the near infrared, since both filters have infrared windows. Note the loss of effective film speed amounting to a full stop, as a consequence of having to apply a filter factor.

When one attempts to use Aerochrome Infrared film in a wide-angle or super-wide-angle aerial survey camera in which lens speed and uniformity of focal plane illumination have had to be sacrificed in favor of minimum geometric distortion and maximum resolution, the loss of effective film speed as a consequence of IR-balancing filtration presents a serious limitation.

The best modern super-wide-angle lenses limit the maximum radial distortion to less

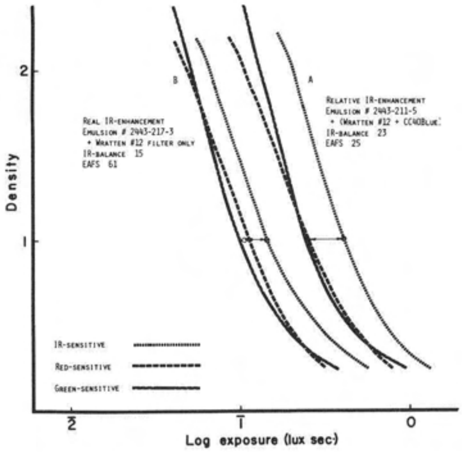

FIG. 2. (a) Curves of a "normal" emulsion whose relative IR-sensitivity has been enhanced by "minus-visible" filtration for use at about 10,000 feet, at a considerable penalty in effective film speed. (b) Curves of a selected "IR-enhanced" emulsion considered suitable for use at about 20,000 feet without additional filtration and with no loss of effective film speed.

than 10 μm across a field of view of up to 125°, but this is accompanied by severe vignetting at the maximum aperture of *f*/5.6, which reduces illumination of images in the corners of the format to about 20 percent of that available at the principal point. In order to counteract the effects of the severe off-axis illumination fall-off, a heavy anti-vignetting filter is employed having an axial attenuation factor of 4.4×, i.e., at a penalty of more than two stops in effective speed of the central portion of the field. The further loss of up to two more stops due to use of "minus-visible" filtration leaves one with a rather slow-speed aerial photographic system that is seriously limited with respect to season and time of day when acceptable photography may be secured from high altitudes on Aerochrome Infrared film with a super-wide-angle camera.

Real IR Enhancement by Selection

A more attractive approach to IR-enhancement for high-altitude use lies in the possibility of improving the IR-balance by a genuine increase in the speed of the IR-sensitive layer, i.e., by moving the IR curve to the left, rather than by moving the other curves to the right by using absorption filters involving a filter factor (e.g., see characteristic curves designated "B" in Figure 2).

There is no magic formula for increasing at will the sensitivity of any given layer of a multi-layer film. However, analysis of many rolls of Aerochrome Infrared Type 2443 film has indicated that in many cases the IR-sensitive layer is significantly faster than in the case of "normal" film. Using the descriptive parameters defined earlier, the sensitometric data from several hundred rolls of Aerochrome IR film, representing many different emulsion batches, have been analyzed and the emulsions categorized according to IR-balance. A rather surprising range of IR-balance has been encountered, from a minimum value of 10 to a maximum greater than 50. The frequency distribution of IR-balance among rolls exposed by the Canada Centre for Remote Sensing over the past three operating seasons is illustrated by the histogram of Figure 3. Fortunately, most of the departures from "normal" are in the direction of enhanced IR-sensitivity which can be exploited for high-altitude use.

Application to CCRS Operations

Stocks of Aerochrome Infrared Type 2443 held in cold storage by CCRS are subjected to periodic testing and categorization on the basis of IR-balance, by sensitometric analysis of representative samples of all emulsion numbers on hand, and occasionally on specific rolls for specific purposes. Those emulsions categorized as "IR-enhanced" are reserved for high-altitude use, or for other applications requiring more nearly equalized layer sensitivities. Emulsions in the "normal" category are used at low altitudes—i.e., up to 3,000 feet—without modification, or at higher altitudes only with appropriate "minus-visible" filtration.

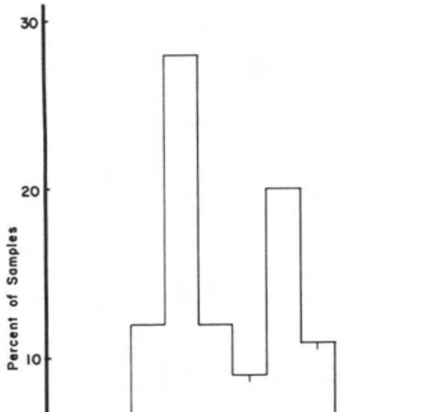

FIG. 3. Histogram illustrating the range of IR-balance encountered by C.C.R.S./Air Ops over the 1974-75-76 operating seasons. More than 200 rolls of 9½ inch Aerochrome infrared and more than 20 different emulsion numbers are represented (70 mm film not included).

The very small number of the "IR-degraded" category must be brought into normal balance, usually requiring CC Magenta filters, before use at any altitude. Altitude-compensating filtration is then added as necessary, but the overall filter factor which results generally rules out the use of "IR-degraded" emulsions in super-wide-angle cameras.

The roll-to-roll variability of IR-balance of a given emulsion number has been found to be gratifyingly small. In the case of fresh film, stored at −18°C and handled with all reasonable care, it is likely that the IR-balance can be maintained within ±3 units of the mean value for that emulsion throughout an entire operating season.

In the case of emulsions that have been held in storage for up to three years, the range of variability is greater and a slow drift in the direction of degraded IR-sensitivity is detectable in the sensitometric data from periodic re-checks. However, these data enable us to specify compensating filtration if necessary to ensure a greater degree of consistency in the output of Aerochrome Infrared imagery at all altitudes.

Instrumentation

All sensitometric data are based on measurement of step-wedges exposed in a sensitometer designed and calibrated by the National Research Council of Canada, meeting the requirements of the ICAS Specification for Aerial Survey Photography, 1973.[6] The illuminant is standard air photo daylight[7] and the effective exposure time is 1/118 second.

Densities are measured on a controlled photo-electric densitometer, fitted with a Status A filter turret.

All films are processed under close control by the Reproduction Centre of the National Air Photo Library in a Kodak RT 1811 continuous processor using EA5 chemistry. Process control is independent of the sensitometric wedges printed on all operational rolls of film.

REFERENCES

1. Fritz, N. L. Optimum methods for using infrared sensitive color film, *Photogrammetric Engineering* 33(10)1128–1138 (1967)
2. Pease, R. W., and L. W. Bowden. Making color infrared film a more effective high-altitude remote sensor. *Remote Sensing of Environment*, Volume 1 (1969) 23–30
3. Pease, R. W. More information relating to the high-altitude use of color infrared film, *Remote Sensing of Environment*, Volume 1 (1969-70) 123–126
4. Sensitometric exposure and evaluation method for determining speed of color reversal film for still photography ANSI PH2.21 (1972)
5. Sauer, G. E., and H. E. Lockwood. Skylab photography—A study in zero-error film handling, processing and duplication. *Journal of Applied Photographic Engineering*, Volume 1, Fall (1975) 18–24
6. Interdepartmental Committee on Air Surveys, Canada Department of Energy, Mines and Resources Specification for Aerial Survey Photography (1973)
7. Canadian Standards Association. CSA Standard Z7.3.2.1 (1969) Sensitometry of Monochrome Aerial Films

Notice to Contributors

1. Manuscripts should be typed, double-spaced on $8\frac{1}{2} \times 11$ or $8 \times 10\frac{1}{2}$ white bond, on *one* side only. References, footnotes, captions—everything should be double-spaced. Margins should be $1\frac{1}{2}$ inches.
2. Ordinarily *two* copies of the manuscript and two sets of illustrations should be submitted where the second set of illustrations need not be prime quality; EXCEPT that *five* copies of papers on Remote Sensing and Photointerpretation are needed, all with prime quality illustrations to facilitate the review process.
3. Each article should include an abstract, which is a *digest* of the article. An abstract should be 100 to 150 words in length.
4. Tables should be designed to fit into a width no more than five inches.
5. Illustrations should not be more than twice the final print size: *glossy* prints of photos should be submitted. Lettering should be neat, and designed for the reduction anticipated. Please include a separate list of captions.
6. Formulas should be expressed as simply as possible, keeping in mind the difficulties and limitations encountered in setting type.