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Shutter/Aperture Settings for Aerial Photography

Aerial camera shutter and aperture settings are determined based on sunlight, aircraft altitude, subject and season, film speed, and optical system.

Abstract: *Determination of aerial camera shutter and aperture settings to produce consistently high quality aerial photographs is a task complicated by numerous variables. Presented in this article are brief discussions of each variable and specific data which may be used to systematically control each. The variables discussed include sunlight, aircraft altitude, subject and season, film speed, and optical system. Data which may be used as a base reference are included and encompass two sets of sensitometric specifications for two film-chemistry processes along with camera-aircraft parameters which have been established and used to produce good exposures. Information contained here may be used to design and implement an exposure determination system for aerial photography.*

Introduction

Scientists, aerial photographers and processing laboratory personnel within the Photographic Technology Division (PTD) at NASA's Johnson Space Center (JSC) in Houston, Texas have accumulated extensive experience in the determination of camera exposure settings for aerial photography. JSC is responsible for photography on major projects including the Earth Resources Aircraft Program (ERAP) and manned space flight missions. The ERAP uses aircraft flown as low as 1000 feet and as high as 60,000 feet over thousands of subject areas both on and off the continental United States. Space flights, of course, have enabled photography of sites around the world, with the largest collection of photographs taken during the three manned Skylab missions.

Exposure determinations for these projects are made within PTD where the ERAP as well as the space flight original imagery is processed, duplicated, and distributed. Correct exposure settings must receive high priority. PTD strives to either control or compensate for the many variables which affect in-camera film exposures. Discussed here are the variables which affect film exposure and the steps taken by PTD to control those variables.

Variables Affecting Film Exposure

The variables which affect film exposures in aerial photography can create considerable confusion and poor results if each is not considered and controlled where possible. These variables include:

- Sunlight: The amount of illumination provided the ground subject, which varies with time-of-day and time-of-year.
- Altitude: The height of the aircraft or space craft above the ground.
- Subject: The reflectance or effective brightness of the ground object or objects being imaged on the film.
- Season: The time-of-year relative to the

type of ground cover to be expected. Season may be considered as part of the subject, but is a frequently overlooked exposure variable.

- Film Speed: The effective sensitivity of the film type and emulsion batch relative to the subject being photographed.
- Optical system: The transmission of the camera lenses, aircraft windows, and filters relative to the subject and film being used.

Most of the above variables can result in a minimum of 1/2 f-stop changes in exposure and some may require as much as 3 f-stops or more compensation in camera exposure to maintain correct exposure.

Correct Exposure

A brief discussion of correct aerial exposure is necessary if the best results are to be achieved from aerial photographs. It is desirable to image the subject on the photographic film such that (1) the subject reflectances have a linear relationship in the image and (2) the color balance for color films be acceptable over the entire subject reflectance/image density range. Figure 1 shows the optimum placement of imagery for a 10:1 effective brightness range scene on a typical black-and-white film, Kodak Plus-X Aerographic Film 2402. Figure 2 shows the optimum imagery placement on the characteristic curve of a typical color film, Kodak Aerial Color Film SO-242. It is obvious from these curves that only a narrow subject brightness range (10 or 20:1) may be accommodated with a linear density relationship by these film types. In most aerial photography above 10,000 feet, however, the contrast range is typically only 4 or 5:1. A goal for correct exposure, then, may be specified as placement of imagery in the optimum recording range of the film to be used. This optimum range usually means placement of maximum subject reflectances (in a positive image) at the low density end of the straight line of the film-process characteristic curve. When this is ac-

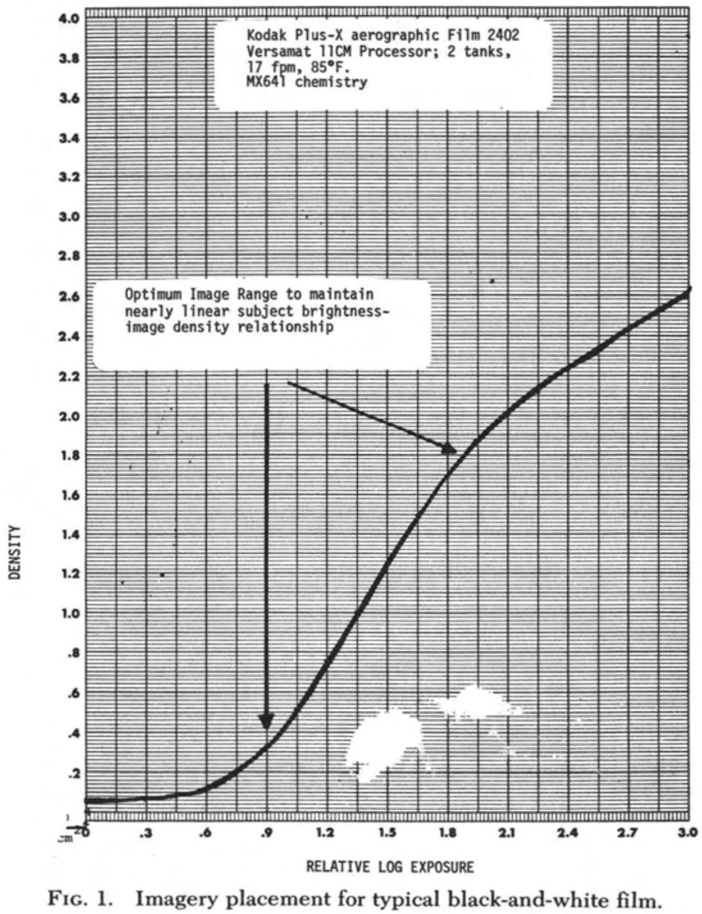

Fig. 1. Imagery placement for typical black-and-white film.

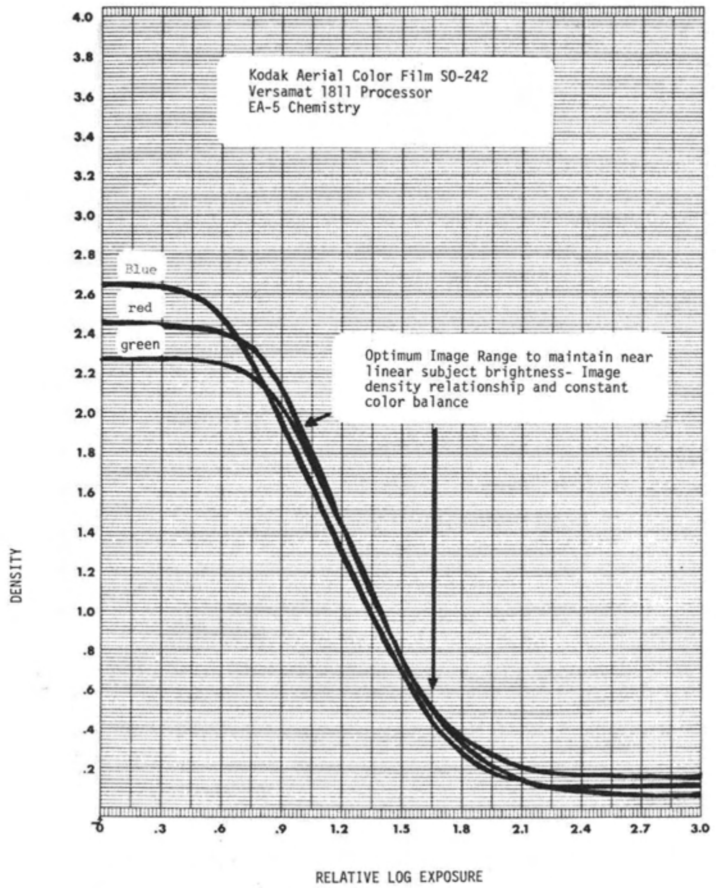

FIG. 2. Imagery placement for typical color film.

complished it will be found that mid-range densities in aerial color positive photographs taken at lower altitudes (below 10,000 feet) will frequently fall in the density range of 0.9 to 1.3 for medium contrast films and in the 1.3 to 1.6 range for higher contrast films. At higher altitudes it will be found that the density range of imagery is lower because of contrast attenuation due to the atmosphere. A typical subject frequently results in image densities at higher or lower densities than the optimum density range but exposures should be centered about the optimum area. Most subjects will be found to image in the optimum range with specular highlights and dense shadows imaged outside that range.

VARIABLE SUNLIGHT

The intensity of the illumination at the ground subject is a major factor affecting aerial film exposures. The effects of the sun elevation angle or solar altitude[1] as well as atmospheric effects [2,3] have been well documented. Sunlight relative to aerial photography includes not only the direct light from the sun but also scattered light from clouds and haze. Non-image forming light at the aerial camera reflected by the clouds and haze in the atmosphere is a definite factor in exposure determination. The effects of sun elevation angle (the angle of the sun, measured at the subject, between horizontal and a line to the sun, Figure 3) best describe the gross sunlight available for aerial photography. Sun elevation angle is also referenced as solar altitude in some publications.

The falloff of illumination on a horizontal subject is caused both by attenuation of sunlight by the Earth's atmosphere and by the angular relationship of the subject plane and the sun.[7] The net effect can be a large loss in illumination at the subject. When the sun elevation angle is 35° or lower, exposure compensations are necessary because the available illumination at the subject is less by

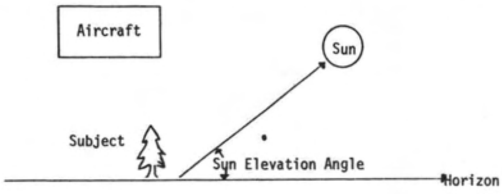

FIG. 3. Sun elevation angle (solar altitude).

1/2 f-stop or more. A compensation system used successfully at JSC is shown in Table 1. The attenuation, of course, varies continuously with Sun Elevation Angle (SEA) and compensations may be made at finer camera adjustments than 1/2 f-stop if desired. References 1 and 7 can provide data for those adjustments.

During the April to September months, five to six hours of aerial photography time are available in the forty-eight contiguous states with no exposure compensation required. The SEA during these periods remains within the 90° to 35° range. This is not the case during the remainder of the year. Table 2 shows a comparison of exposure factors necessary at 1200 hours at mid-month as time-of-year varies. Table II reflects data at latitude 40° or the approximate locations of such U. S. cities as Philadelphia, Pittsburgh, Indianapolis, Kansas City, Denver, Salt Lake City, and Reno. The SEA also varies from morning to night and typical summer and spring days at these same cities would have the variance shown in Table 3. Fortunately, SEA data tables for aerial photographers are available in the literature and are summarized in an Aerial Exposure Computer available from the Eastman Kodak Company to aid in determining the camera setting compensation.

TABLE 1. SUN ELEVATION ANGLE VS. EXPOSURE COMPENSATION.

Sun Elevation Angle	Exposure
90°–35°	Normal
35°–25°	Add ½ f-stop (1½X)
25°–15°	Add 1 f-stop (2X)
15°–10°	Add 1½ f-stop (3X)
*10°– 5°	Add 2 f-stop (4X)
* 5°– 0°	Add 2½-4 f-stop (6-16X)

* Photography at these sun elevation angles should be avoided.

TABLE 2. TIME-OF-YEAR VS. EXPOSURE COMPENSATION.

Time-of-Year (Noon, Mid-Month)	SEA*	Exposure Compensation
Dec, Jan	29°	plus ½ stop
Nov, Feb	36°	plus ½ stop
Oct, Mar	47°	Normal
Sept, Apr	58°	Normal
Aug, May	69°	Normal
July, June	72°	Normal

* Latitude = 40°.

TABLE 3. SEA VS. TIME-OF-DAY (40° LATITUDE)

Time-of-Day	Summer SEA	Spring SEA
0600, 1800	15°	7°
0700, 1700	26°	19°
0800, 1600	38°	30°
0900, 1500	49°	42°
1000, 1400	60°	51°
1100, 1300	69°	59°
1200	73°	62°

VARIABLE ALTITUDE

Atmospheric effects, principally haze, impact the camera exposures used in aerial photography. Color aerial photographs generally will have a blue color balance, increasing with increasing altitude if no corrective filtration is provided. Aerial photographs also will receive increased exposure as altitude increases as a result of sunlight scattered toward the camera lens by aerosols and particulate matter in the atmosphere.

Figure 4 is a typical curve of atmospheric transmittance by wavelength. Transmittance varies with the composition of the atmosphere and with the number of atmospheric thicknesses which the radiation must penetrate. In general, however, the atmosphere, as shown, transmits less in the shorter wavelength regions than in the longer visible wavelength regions. The major natural influencing factor on color balance in aerial photographs is scattering of light by the atmosphere. Figure 5 shows the scattering effect by the atmosphere as a function of wavelength for a minimum haze condition (Rayleigh Atmosphere). The scattering in the 450nm wavelength region (blue) is significantly greater than in the 700nm wavelength region (red). As the wavelength decreases the effect worsens. (Rayleigh scattering is proportional to the inverse of the wavelength to the fourth power). A comparison of Figures 4 and 5 clearly indicates that atmospheric scattering has more influence on color balance than atmospheric transmittance.

A typical remedy for the blue color balance is the addition of a filter which absorbs short

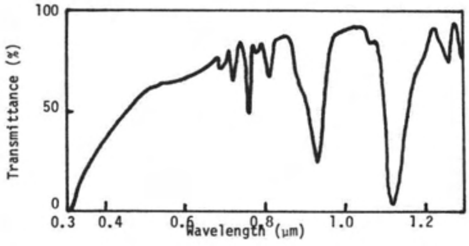

FIG. 4. Atmospheric transmittance versus wavelength[3].

wavelength light and reduces the problem. A filter equivalent to a Wratten 2A, Figure 6, will perform the task for many aerial photography applications.

Increased exposure with increased altitude is another effect resulting from scattering of light by the atmosphere. Using 5000 feet as a base altitude, an additional 1/2 stop exposure will be experienced at about 25,000 feet under normal haze conditions and 1/2 stop less exposure will be available at a 1000 foot altitude. Altitudes above 25,000 feet, including space craft altitudes, will result in 1/4 stop more exposure. Table 4 lists factors based on a typical color film. The altitude effect is greater for shorter wavelengths compared to longer wavelengths; therefore, filtration will be an additional factor with black-and-white films used in multispectral applications.

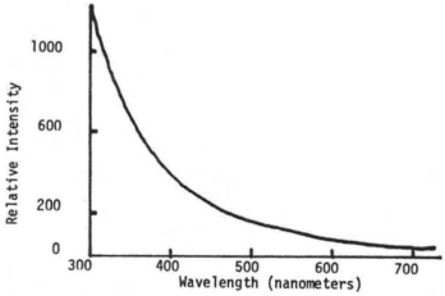

FIG. 5. Atmospheric Scattering versus wavelength[5].

FIG. 6. Wratten 2A filter for short wavelength correction[6].

VARIABLE SUBJECT AND SEASON

The reflectance properties of the ground subject or the effective brightness of the subject in the photographic spectrum are important considerations relative to correct exposure. Table 5 lists nine categories of subject matter and the exposure compensation necessary. These data have been used successfully for calculating exposures for high altitude (60,000 feet) and space craft altitude photography. The table may also be used as a starting reference for medium and low altitude photography, but a greater range of brightnesses will be apparent at these altitudes.

Seasonal variations must be expected and are of concern particularly where aircraft or space craft have global coverage as a matter of routine. The presence of snow is an obvious result of season but less obvious is the effect of plant growth. Agricultural or vegetated areas have varying brightnesses depending on plant growth. The effect is also dependent on the spectral sensitivity of the film being used. For example, during a typical growing season the ground will be covered with vegetation and trees will be covered with leaves, which have relatively high reflectivity in the near infrared and an average reflectivity in the visible spectrum. During the dormant season, when there is absence of ground cover, the same area will have low reflectivity in the near infrared and may have high reflectivity in the visible region. The effect from

TABLE 4. LIGHT VS. ALTITUDE.

Altitude	Light Factor
1000 ft	plus ½ stop
5000 ft	Normal
25000 ft	minus ½ stop
Space	minus ¾ stop

TABLE 5. SUBJECT VS. EXPOSURE COMPENSATION.

Subject Category	Exposure Compensation
A. Clouds	Minus 2 stops
B. Snow	Minus 1½ stops
C. Bright desert; e.g. Sahara	Minus 1 stop
D. City (street & building)	Minus 1 stop
E. Sandy soil; e.g. Mojave Desert	Minus ½ stop
F. Vegetation and mountains	Normal
G. Coastal and shallow water	Normal
H. Deep Ocean Water	Plus 1 stop
I. Heavy vegetation (jungle)	Plus 1 stop

season-to-season may mean as much as a 1/2 stop variance in effective exposure depending on the amount of ground cover.

Variable Film Speed

A vital part of any exposure determination is the effective sensitivity or speed of the photographic film on which the subject is to be imaged. Wide variability will be encountered not only between different film types but also sometimes between emulsion batches of the same film type. Film-processing systems also add a significant variable for consideration.

It is imperative that a close working relationship be established between the aerial photographer or person responsible for exposing the film and the processing laboratory which is responsible for processing the exposed films. Figure 7 illustrates potential variability between processes with the same SO-022, Kodak Panatomic-X Aerial Film. A variability equivalent to 1 3/4 f-stops at a density of 0.4 is apparent. Figure 8 shows the effect of process gamma on effective speed measured at a density of 0.4. A difference of 1 1/4 f-stops between the slower and faster process rate for 2402, Kodak Plus-X Aerographic Film is apparent.

Changes of 1/2 stop in effective film speed have been encountered with emulsion batch changes making this an additional speed variable which must be controlled. Aerial photographs of consistently high quality are possible, therefore, only if the film speed variable is controlled. This may be accomplished by establishing two procedures:

- Evaluate all emulsion batches of every film type for effective sensitivity and make adjustments, if required, in exposure index to compensate for changes in emulsion sensitivity.
- Establish process control curves for the laboratory to use in maintaining process consistency so that there is minimal variance in effective film speed due to processing.

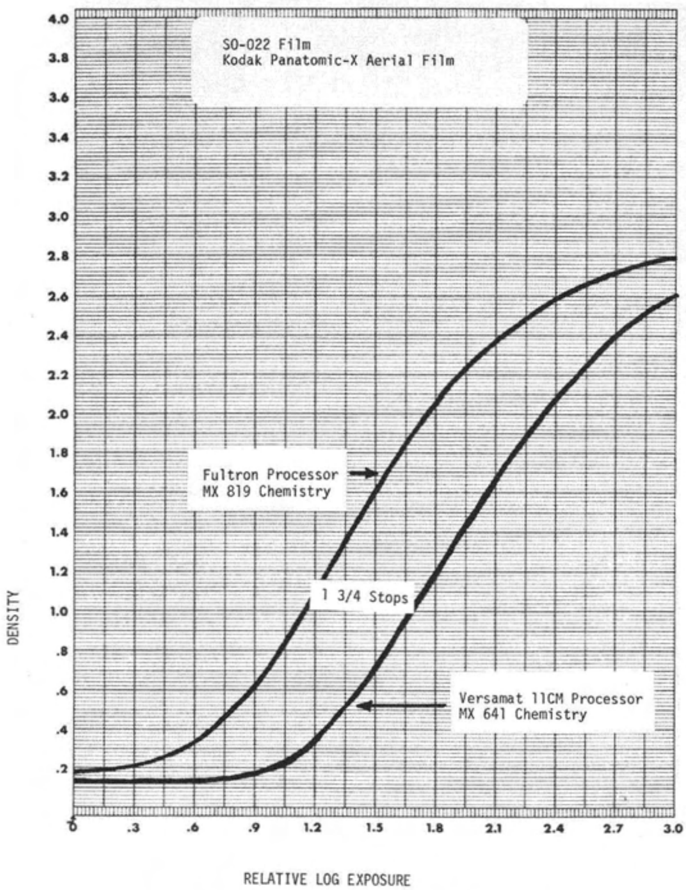

Fig. 7. Effective speed versus process.

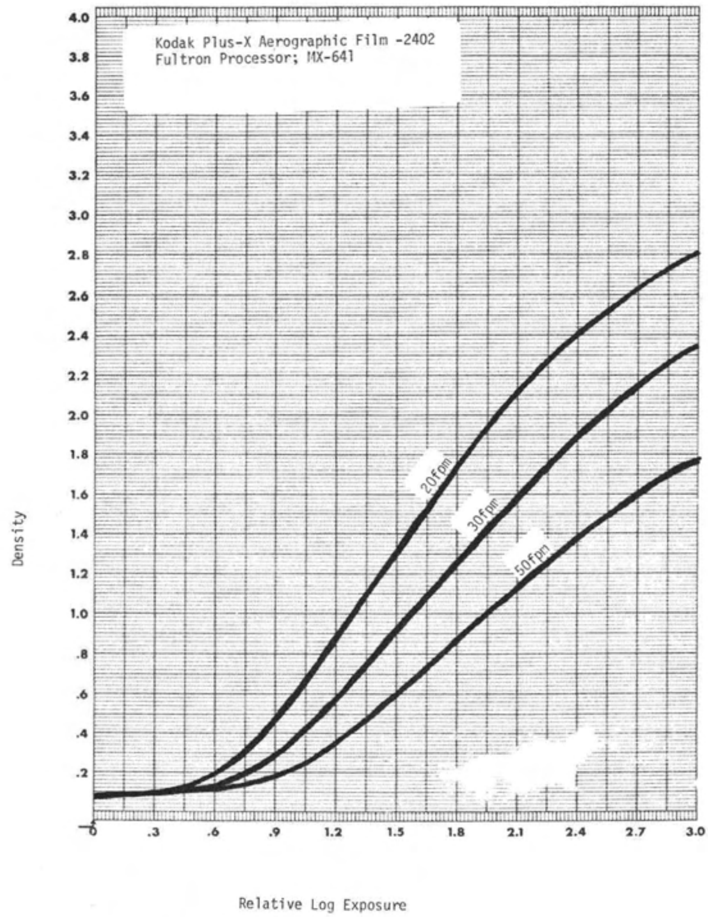

FIG. 8. Effective speed change with gamma.

TEST EMULSION BATCH

Each emulsion batch should be tested by the laboratory prior to use. To do this, sensitometric exposures can be made both on the emulsion under test and on one in current use; then the two sample films are processed together. A density analysis of the results will show differences in speed, color balance, gamma, maximum density, and minimum density. In most instances corrective actions are possible if differences do exist. It is also a good idea to test films with commonly used camera filters to determine any gross problems with spectral sensitivity. PTD certifies every emulsion batch received using these methods and in the case of 2443, Kodak Aerochrome Infrared Film, every cut of every emulsion batch is certified. Records are maintained and the films are recertified if the emulsion remains in use for six months or if the film is subjected to any questionable environment. Stored with each emulsion are pertinent notes regarding use; e.g., "one-half stop faster than standard" or "for high altitude use only".

PROCESS CONTROL STANDARDS

Process control standards are established for each film type with aerial application compatibility being a major criterion. These standards are maintained by a laboratory process control group, and prior to processing any exposed aerial imagery the process is sampled and evaluated to meet the standards established. PTD maintains standards for each color film process and three standards for each black-and-white film process (one each for red, green, and blue filters) with the exception of 2424, Kodak Infrared Aerographic film, which has a single standard for each process (with infrared transmitting filter). Once these standards are established, the speed of the films are determined, and the film storage is adequate, a high confidence will be established that film-process variables have been minimized.

Variable Optical System

The camera-aircraft optical system is another important factor which impacts exposure determinations. Camera lenses, camera filters, and aircraft windows are the system components routinely encountered in aerial photography.

Camera lens data either may be available from the manufacturer or may be determined in the optical laboratory. Transmission should be measured at various wavelengths which cover those commonly recorded should special multispectral projects be undertaken. It is not common, for example, for lens transmission at shorter wavelengths (400nm) to be one-half of the lens transmission at longer wavelengths (700nm).

Camera filters for spectral correction or spectral isolation along with anti-vignetting filters should be calibrated or checked so that the exposure or filter factor is known. Anti-vignetting filters may be labelled as percent transmission of center versus edge, e.g., 40%, or as the exposure factor required, e.g. 2.2, to correct for the center density of the filter. Filters alone can add 3 f-stops or more to the exposure required. In the case of unknown spectral filters a sensitometric comparison with a known filter of similar wavelength may be accomplished to determine the exposure factor.

Aircraft windows are the remaining optical system variable commonly encountered. Windows are usually of high quality, high transmission glass and will present little problem. Perhaps the most severe window problems are either cleanliness or condensation caused by change in air temperature and altitude.

Miscellaneous

There are added variables or considera-

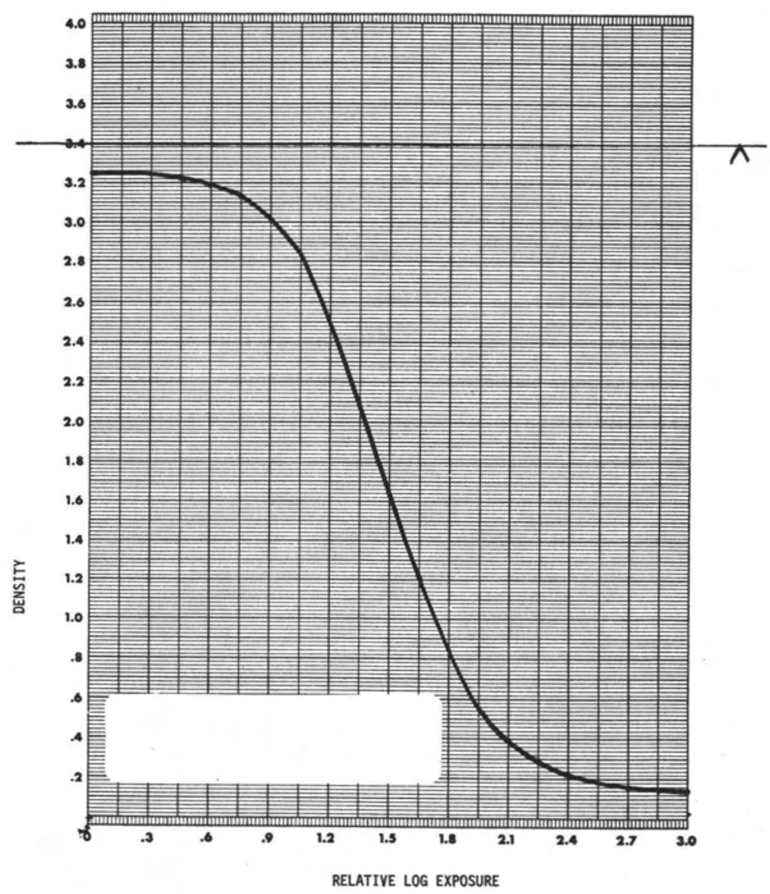

Fig. 9. Kodak Aerochrome infrared film Type 2443, visual densities.

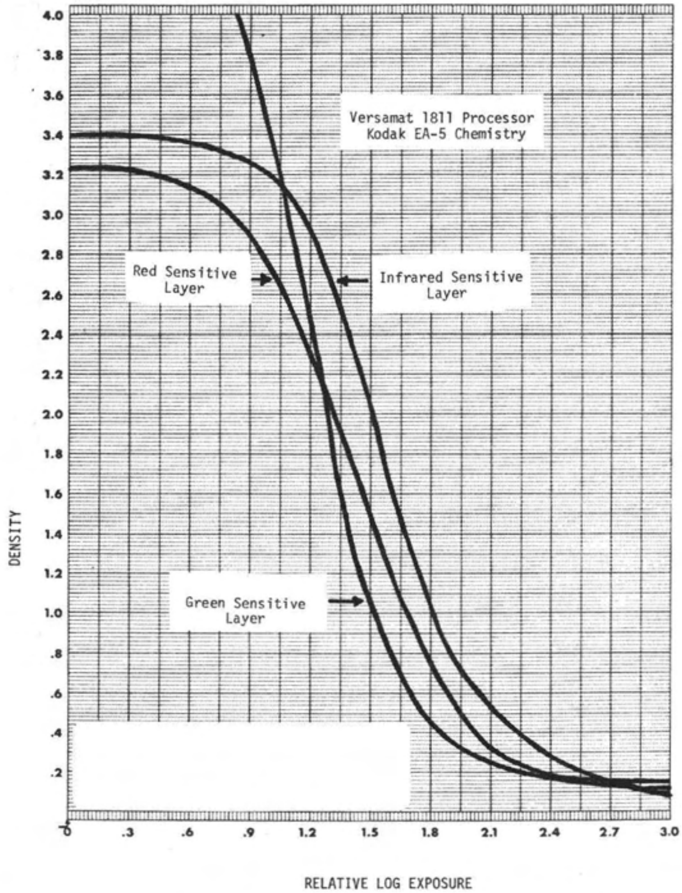

FIG. 10. Kodak Aerochrome infrared film Type 2443, tri-color densities.

tions which may affect exposure and are only mentioned here so that they are not ignored when a photographic mission is planned. For example:

- Non-vertical photography from airborne platforms requires special consideration because of the increased atmospheric path length influence. In general, the available light will increase and contrast will be reduced, appearing much the same as an increase in aircraft altitude.
- Aircraft speed versus altitude, *V/H*, will impact exposure because image motion is affected by *V/H* and the camera shutter speed versus film speed ratio may be limited by aircraft operating parameters.

A Starting Place

What is a basic exposure for a normal scene? A starting place is essential for exposure determination; therefore, basic data for two films are included here.

EXAMPLE A

Film: Kodak Aerochrome Infrared Film 2443
Camera: Wild RC-8 with 150mm lens
Filter: Wratten 12 equivalent plus 2.2 Anti-vignetting filter
Altitude: 10,000 feet
Exposure: 1/225 second at f5.6
Absolute Log Exposure for visual density of 1.2: 8.9-10 m.c.s.
Curves: Visual and tricolor density versus log E data in Figures 9 and 10.
Sun angle: 40°-60°

EXAMPLE B

Film: Kodak Plus-X Aerographic Film 2402
Camera: Hasselblad with 80mm lens
Filter: Wratten 25 equivalent

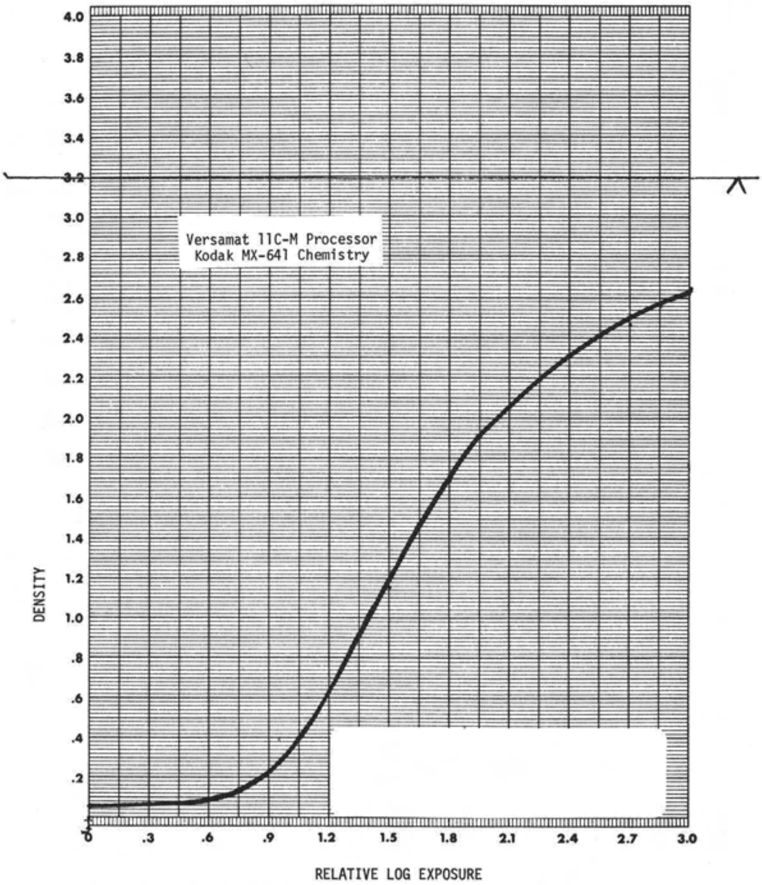

FIG. 11. Kodak Plus-X Aerographic film Type 2402.

Altitude: 8,000 feet
Exposure: 1/250 second at f8.0
Absolute log exposure for visual density of 1.2; 9.06-10 m.c.s.
Curve: Density versus log exposure curve as Figure 11.
Sun angle: 40°-60°

SUMMARY

Determination of camera exposure settings, i.e., shutter speeds and lens apertures for aerial photographs, is influenced by the numerous variables described above. Control of the variables may be accomplished if it is approached systematically. Table 6 lists a summary of steps which should be taken.

ACKNOWLEDGMENTS

The work and experience of Pete Stanley (NASA) and the Aerial Photographers from ERAP along with Noel Lamar (NASA), significant contributors to the background of exposure calculations, are gratefully acknowledged. This work was performed at the NASA Johnson Space Center under Technicolor Graphic Services, Inc., NASA Contract NAS-9-11500.

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4. Niels Jensen, *Optical and Photographic Reconnaissance Systems*, John Wiley and Sons, New York, 1968.

TABLE 6. STEPS IN THE DETERMINATION OF EXPOSURE SETTINGS.

° Basic Exposure (a known starting place)
—Reference* film/process (film calibration, certification)
—Reference camera/lens
—Reference shutter/aperture
—Reference aircraft altitude
—Reference sum elevation angle
* Reference = a starting point parameter; e.g. those listed above

° New Parameters
—Film/process effective recording speed.
—Camera/lens transmission

° Sunlight Factor

SEA	Factor
90°–35°	Normal
35°–25°	Plus ½ stop
25°–15°	Plus 1 stop
15°–10°	Plus 1½ stops
10°– 5°	Plus 2 stops

° Altitude Factor

1000 ft.	Plus ½ stop
5000 ft.	Normal
25000 ft.	Minus ½ stop
Space	Minus ¾ stop

° Subject Factor

Subject	Factor
Vegetation, mts	Normal
Sandy soil; e.g. Mojave	Minus ½ stop
Bright desert; e.g. Sahara	Minus 1 stop
Snow	Minus 1½ stop
Clouds	Minus 2 stops
Deep ocean	Plus 1 stop
Coastal ocean, shallow water	Normal
Heavy vegetation	Plus 1 stop
City (streets, buildings)	Minus 1 stop

Result
° New Camera Settings

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