requires "setting-up-camp" on an airfield from which the aircraft can operate, but where living facilities are not normally available. Since all personnel on the Air Photographic Mission are volunteers, they tackle the cooperative job of improving their own accommodations with enthusiasm and imagination.

The independence from support by local facilities in working areas becomes impossible on occasions and the mission is deeply indebted to Coast Guard, Air Force, and Civil Aeronautics Administration facilities, both in the United States and Alaska, for their generous assistance.

Practical Exposure Determination for Aerial Photography

W. D. HARRIS,
Photogrammetry Division, Coast and Geodetic Survey

ABSTRACT: *The U. S. Coast and Geodetic Survey has developed a method for varying the exposure and development of the aerial photographic negative to produce a desirable and constant negative density range, regardless of the brightness range of the scene. Beginning with the desired characteristics of the photographic print, a definition of the "perfect aerial negative" is attempted and a practical method for producing this negative is presented. The method does not require special equipment for the determination of correct exposure, nor does it require an uncanny ability for evaluating the brightness range of the scene. The success of the method has been due to the control of all of the other variables through a scientific application of the sensitometric data published by the manufacturer of the negative.*

INTRODUCTION

SEVERAL years ago it became necessary for the Coast and Geodetic Survey to replace its aerial photographer. He was one of those unusual men who, through many years of experience, had developed a special ability in the evaluation of the illumination level and the brightness range of aerial scenes. Whereas he needed only to look at the scene to determine the correct exposure and development, he found it quite impossible to explain his mental processes to the new photographer. Inquiries of other organizations revealed that each had its own more-or-less empirical methods for exposure determination, and most of them were using a fixed degree of development. It was then decided that the only solution to the problem was a more scientific approach which would minimize the human element.

The manufacture of photographic emulsions has reached a stage of perfection which has changed photography from an art to an engineering science. The photographic engineer can now design a negative to fit almost any desired specification.

The most natural definition of the "perfect negative" is, "that negative which, when printed on normal contrast photographic paper, will most nearly reproduce the scene as it appeared before the camera." Although this definition is excellent for most types of documentary photography, it requires modification in one way for newsprint photography, and in the opposite way for portraiture.

Aerial photography requires still another definition for the "perfect aerial negative." With the exception of photography intended to give special pictorial effects, all aerial photography is made for the purpose of recording as much of the terrain detail as is possible regardless of the atmospheric conditions. The method of exposure and development determination which is described in this paper is designed to produce the *perfect aerial negative* defined as "that negative which, when printed on normal contrast paper, will produce a photograph using all of, and no more than, the linear density range of the paper regardless of the brightness range of the scene before the camera."

A serious study of paper prints resulted in the conclusion that the perfect aerial negative should have a density range of 0.9. A negative of this density range can be printed on normal contrast paper so that the highlights are rendered in a very light shade of gray and the shadow areas in a dark shade of gray. This assures a good tonal separation of all highlight and shadow details recorded on the negative. When a "snappy" exhibit print is needed it can be made from the same negative, by using a grade three contrast paper.

Inasmuch as the usable density range of the desired negative is less than half the total density range of the negative emulsion, a careful placement of the exposure at at the lower end of the density scale will result in several other advantages which are much needed by the photogrammetrist:

(1) The resolving power of the negative, which reaches its maximum value at a density of approximately 0.9, is highest over the entire density range when the exposure is made to place the minimum density just safely above that of the clear negative material.

(2) The effective speed rating of the emulsion is higher than its published ASA rating for all scene brightness ranges of less than ten to one. This makes possible obtaining excellent photography under high overcast skies where the shadows of elevated terrain features would normally obscure other important features.

(3) The "thinner" negatives which result from this placement of the exposure will print more rapidly. This feature is particularly valuable when printing is done with electronic printers.

What is sacrificed to obtain these advantages? It is the exposure latitude of the negative emulsion. Latitude is that wonderful characteristic of modern negative emulsions that enables the photographer to make a printable negative even though his exposure is as much as 200 per cent in error. When a photographer uses a safety factor on his exposure, he not only assures himself of always getting a picture, but also of never getting a good picture.

The development of the Coast and Geodetic Survey method was somewhat laborious due to a lack of familiarity with the scientific presentation of the sensitometric data, and method of determining the ASA index rating of the negative emulsion. However, the actual data required for the application of the method to any other aerial photographic system can be presented without the use of sensitometric terminology.

Exposure Determination

The aerial photographer's equipment for exposure determination consists of a Weston Master* exposure meter and a small card which has a list of assigned ASA indexes for the required film-filter-camera combinations on one side and the "Scene Brightness Range Evaluation Chart" (Table 1) on the other. This chart is used to calculate exposure compensation for differences in scene brightness ranges in terms of the exposure meter reading positions. The N designates the normal arrow position on the Weston Master exposure meter; the A and C positions are already marked on the meter to the left and right of the normal arrow, and the D position must be added to the meter at the same interval to the right of the C mark. Before proceeding with the application of the exposure meter, the descriptive terms of the table arguments will be explained more thoroughly.

Table 1

Scene Brightness Range Evaluation Chart

Type of Terrain	*Atmospheric Condition*		
	Clear	*Normal*	*Hazy*
Flat	N	AN	A
Normal	C	N	AN
Contrasty	D	C	N

The column headings of Table 1 are descriptions of the atmospheric haze conditions. The term "normal" is defined as the usual amount of aerial haze as it appears at altitudes of 6,000 to 15,000 feet; "clear" defines the usual aerial haze

* Any of several exposure meters would serve equally as well, but each would require small differences in the presentation of method.

as it appears from 2,000 to 6,000 feet, as well as the unusually clear day from 6,000 to 15,000 feet; "hazy" defines the usual haze as it appears from 15,000 to 25,000 feet, as well as the unusually hazy day from 6,000 to 15,000 feet.

The line headings of Table 1 are descriptions of the type of terrain regardless of the atmospheric conditions. The term "flat" denotes all mono-toned areas whether dark wooded areas or vast areas of white sand. The term "normal" indicates areas having moderate ranges of reflectivity, such as intermingled woodlands and farmlands. The term "contrasty" denotes areas having high reflectivity ranges, such as snow-capped mountains and shaded lower slopes with dark trees, or white sand beaches with woodlands.

The evaluation of the haze condition and the type of terrain are the only subjective elements of the exposure determination. Although they should be made with care, any shift in the right direction from the *N* position will be an improvement over the best results that can be obtained with a method which uses a fixed degree of development for the negative. If the photographer feels that the evaluation of a particular scene falls midway between the steps of the chart, he can assign a meter position accordingly and record both meter position letters in the flight data record. For example, an *AC* position can be used to interpolate between the *A* and *C* positions.

Following the meter position determination, a light meter measurement is made by pointing the exposure meter straight downward. At the same time, it should be noted whether more than 75 per cent of the area beneath the plane is either very light, as white sand, or very dark, as woodland. By setting the light meter reading opposite the previously selected meter position letter *A, N, C, D* on the exposure calculator of the meter, the proper aperture setting can be read opposite the shutter speed of the camera. After the aperture setting has been obtained from the meter, it must be increased (opened up) one-half stop if the meter reading was made over an area that was more than 75 per cent light sand or it must be decreased (stopped down) one-half stop if the meter reading was made over an area that was more than 75 per cent woodland. The adjusted value is the correct aperture setting for the camera.

Flight Data Record

The flight data record should be arranged to contain the light meter reading, atmospheric condition, terrain contrast, meter position designation and the one-half stop compensation for an unbalanced meter reading, if necessary. These data will accompany the film to the processing laboratory where they will be used to determine the degree of development that the film will require. Where it is necessary to use different meter position designations on the same roll of film, a few blank exposures should be left between the projects so the roll can be cut, if necessary, during development.

Film Development

The choice of developer and approximate developing time are determined by entering the meter position designation and the length of the roll of film as arguments in the "film development table" (Table 2).

Table 2

Film Development Table

Meter Position Designation	*Developer Formula*	*Length of Film in Feet*			
		75	*125*	*175*	*200*
A	D-19	12	14½	17½	19½
AN	DK-60b	17	20½	25	27½
N	D-76	29	35	42½	47
NC	D-76	25	29	35	39
C	D-76	22	26½	32	36
CD	D-76	19	23	28	30½
D	D-76	16	19½	23½	26

It should be noted that Table 2 gives the developing time in minutes at 68°F. when development is carried out according to the methods specified for Super XX film in the Kodak handbook "Materials for Aerial Photography."

The flight data are useful to the laboratory technician for forming a mental picture of the negative image regarding the distribution of densities. That is, he will know whether the negative will have an equal amount of dense and thin areas, or whether he must expect a negative which has large dense of thin areas. This information is very helpful to him when he makes safelight inspections of the negative image during development.

The first inspection is made when 60 per cent of the developing time has elapsed. The final decision on the proper developing time is made by inspection but not without the knowledge that the ideal negative density range will be attained only if the time is nearly the same as that given by Table 2. As a result, the negative may be allowed to develop to a greater density, if necessary, to make the developing time agree more closely with the table.

This method of exposure and development determination has resulted in the use of D-76 developer on more than 75 per cent of all aerial photography made by the Coast and Geodetic Survey. The finer grain structure which results from the use of this soft working formula is appreciated by the operators of first-order plotting instruments which have a high optical magnification.

Exposure Index

The use of the meter position designations *A*, *N*, *C*, *D* makes it possible to vary the exposure without changing the exposure index setting on the meter. The filter factor is included in the exposure index which is assigned for each camera-film combination. The Coast and Geodetic Survey uses an exposure index of 64 for the 6 inch metrogon lens with the "star" filter for Super XX film, and an exposure index of 125 for all normal angle lenses as well as the 6 inch Wild aviogon lens with the minus-blue filter.

Equipment Calibration Test

Although the emulsion manufacturer's sensitometric data is designed for use with ordinary production equipment, it seemed advisable to test the method with our own camera and developing machine on the ground before using it for aerial photography.

The test was made on a street scene with the camera supported on its side. Light meter readings were made on several large uniform objects for comparison with densitometer readings of their images on the negative. Two of these objects were selected to represent the full brightness range of the scene. The darkest object read 100 and the lightest read 1000 candles per square foot, thus giving a brightness range of 10 to 1 for the scene. Since this brightness range corresponds to the *D* meter position designation, the meter reading of the whole scene (325 candles per square foot) from the camera position was set opposite the *D* position on the exposure meter. The exposure index for the film-filter-camera combination was 64. It is of interest to note that the *D* position used with an exposure index of 64 is the equivalent of using the normal arrow position with an index of 16, which agrees well with the manufacturer's ASA rating of 100 for Super XX film before the filter factor is applied.

The test negatives were developed without inspection according to the film development chart. The negative densities were then measured and found to almost exactly equal those of the theoretically perfect serial negative for which the system was designed.

The confidence which this test created in the method has not diminished during the six years that the method has been in operation. Furthermore, three aerial photographers and three cameras have been added to our photographic system without additional tests.