aeronautical charts from radar scope photography are under way. The Laboratory's cartographic section has conducted investigations of new methods for representing relief and terrain cover on aeronautical charts. Some results of these studies are displayed in the Congress Exhibition. Another very interesting study of techniques for obtaining a wide variety of color gradations with only three press runs has just been completed.

The staffs of the Mapping and Charting Research Laboratory and the Institute of Geodesy, Photogrammetry, and Cartography are proud of the contributions which The Ohio State University is making to research and education in the mapping sciences. Much remains to be done, but it is felt that these two organizations are beginning to fill an important void in the American technological development.

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# *Atmospheric Haze in Aerial Photography**

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"THE quality of the atmosphere known as haze often prevents a cloudless day from being suitable for aerial photography. . . . [The] picture will be flat because of lack of sufficient contrast, and will appear veiled or milky."[1] In this brief manner many of the textbooks and publications currently being used in conjunction with basic photogrammetry courses pass over the subject of atmospheric haze. Admittedly the subject is a minor one in a course (or courses) which must range from optics to map compilation and reproduction. However, this state of affairs leads many students, particularly those with little background in photography, to dismiss haze as an indefinite and unimportant factor. In consideration of this, and in view of the paucity of information on haze and haze factors available to the student who does seek it, this paper is presented in the hope that its compilation and organization of various material will prove of value.

Photogrammetry, as the science of obtaining measurements from photographs, is directly dependent upon the photographs from which the information is being taken, and the success of its application may be considered as in part proportional to the quality of these photos. Unfortunately this quality is a highly variable item. It is desired that the photographic prints (in the usual case aerial) be of exacting definition and accurate featural reproduction. These factors are not consistently available without careful consideration and treatment of the light reflected from the terrain being photographed. Even under apparently perfect weather conditions, a lack of definition and contrast may result in one instance and not in another, even though the same equipment (camera, film, developer, etc.) is employed in each case. This is basically due to the large distances that separate the camera and the object being photographed.

* This paper was submitted in competition for the Bausch & Lomb Photogrammetric Award. It was given Second Prize.

[1] Harman, William E., Jr., "Aerial Photography," in the MANUAL OF PHOTOGRAMMETRY, 2d ed. Washington, D. C.: American Society of Photogrammetry, 1952.

These distances between the high flying photo airplane and the ground are not across a void but rather through a region of air in which particles of dust, moisture, organic material, and to a certain extent the molecules of the air itself exist as refracting and reflecting mediums. These particles reflect and otherwise scatter the various light rays such as to superimpose a uniform illumination over all parts of the subject being photographed (i.e. producing flatness or lack of contrast for the viewer). Furthermore these particles interfere with some of the light traveling on its reflected path from the subject to the camera negative so as to cause indistinct images (the lack of definition aforementioned). This optical turbidity of the air is generally termed "haze."

The turbidity of the atmosphere is a variable thing. It varies with the weather, the time of day, the altitude, and with the nature of the suspended particles, but it is accepted that haze is present in the atmosphere to some extent all over the world. In general haze may be attributed to two components. The lesser in importance of the two is the concentration of molecules of the various gases of the air; this accounts for some one-fifth of the over-all haze. These molecules vary little in concentration from day to day, and the concentration depends mostly upon the effects of temperature and pressure in a manner commensurate with the molecular theory of gases. Thus a high altitude is clearer than a low one where the pressure is greater, and a cold day will find a lesser concentration of molecules than a hot day. The other component of atmospheric turbidity is the suspended matter of all forms. This aerial colloid or aerosol results from contamination of the air with smoke, dust, etc. and is widely variable in extent and concentration. However, the air will tend to contain less such suspended material at the higher altitudes, on windless days, and after rainstorms which serve to "wash" the air. Droplets of water in the atmosphere do not fit readily into either of these component classifications, but may be considered in the former if small and sparse in number or in the latter in an area such as near Niagara Falls where the amount of suspended water runs high due to the mechanical action of the falls.

Haze may be practically invisible in a region where rainfall is sparse and the humidity is low (e.g. Western Plateau and desert country in the U. S.) whereas a heavy haze is visible practically all the time on the eastern seaboard. However, its visibility to the observer is no criterion since the haze causes to be preferentially scattered a large proportion of actinic (shorter wave-length) light, while it is transparent, to the longer wave-lengths. Therefore its effect is much greater photographically than visually because the human eye is not as sensitive to the shorter wave-length light rays (particularly ultraviolet) as are the modern film emulsions. It may be noted that the characteristic bluish cast of visible haze is due to this preferential scattering of the shorter wave-length blue light of the visible spectrum. The transparency of haze to certain colors but its opaqueness or translucence to others introduces the idea of color mechanics being used to remove its effects.

It is known that a "red" object appears red because it absorbs the other colors of light incident upon it and reflects only red. Thus a red filter will absorb (to an extent dependent on its shade or depth of hue) various colors such as green, blue, and some of the ultraviolet, allowing only red light to pass through it. Similarly, an infrared filter will permit the passage of only infrared rays, and a yellow filter such as is commonly used for haze penetration will absorb the blue, violet, and some of the ultraviolet rays (the light rays predominantly interrupted by haze), allowing transmission of red and green rays only. Also our modern film emulsions are made sensitive to practically all light rays (panchromatic film) as differing from the older photographic materials which were more sensitive to the shorter light waves and less sensitive to the longer (and relatively non-scattered by haze) light waves. Therefore a suitable combination of filters and panchromatic or other universally sensitive photographic emulsions will allow the recording of the desired terrain detail with much less of the flatness which results from non-filtered light.

The percentage or degree of the absorption of the undesirable light depends on the shade of the filter used. Since a filter absorbs some of the total light, it will require a longer exposure for a given set of light conditions and film than if the filter were not used. This is denoted by the "filter factor" which is the number of times by which the exposure must be increased for a given filter used with a given photographic material. These multiplying factors or filter factors are usually available for various combinations in a tabular form prepared by the manufacturer and may vary from 1.0 to 25 and upwards. However, in actual use the filters must be so selected that the factors do not increase the exposure time of the film to an extent that the effects of ground motion or lens aberrations destroy the ground detail. It should be noted that at the best the tabular filter factors are only an indication of the true value for any field situation since they were arrived at under controlled laboratory conditions not likely to be matched in the field.

Some sort of filter is used with the camera for all aerial photography. These may be made of colored glass plates, dyed gelatin (usually between glass plates), or colored liquid between glass plates. The expense of making and calibrating the first type and the relative fragility of the last often preclude their general use leaving the dyed gelatin types as the popularly accepted kind. A good example of this sort of filter is the Kodak Wratten Filter which comes in a variety of hues and shades, and is prepared through the use of organic dyes. They may be in the form of lacquered gelatin film for insertion into the camera elements or, as commonly used, in the form of a gelatin film cemented between two pieces of optical glass of the same quality as that used in lenses and polished into optical flats. In the latter case the filter is mounted as an easily changeable unit over the lens barrel in front of the lens. Recently, colored glass filters of a high precision that have been produced in Japan and imported into this country have been offered for sale at very reasonable prices.

The filters as used do not absorb all objectionable light, nor are they intended to do so. They merely absorb a sufficient percentage to permit clear photography under normal conditions in line with the other limitations of the camera system, such as graininess of emulsion, lens distortion, etc. If a filter is used that is darker than necessary for penetration of the haze present, the photo will be overcorrected for color and excessive contrast will result. Infrared filters and special infrared film as a combination seem to offer the best haze penetration and find much application in oblique photographs. However, even infrared light is interrupted in fog or other dense atmospheric murks. And, due to the overcorrection for color with infrared filters, blue as in bodies of water photographs as black (absence of infrared) and leaves of trees, grass, and other vegetation photograph almost white due to the high reflective ability that chlorophyll exhibits for infrared. This makes necessary the use of specially skilled interpreters on the photos. Also there are many different effects that may be attained with the use of filters that have no bearing on haze and haze penetration, but these will not be discussed here.

In addition to the adverse effect upon photography that atmospheric haze may have under certain conditions, backscatter from haze may be sufficient to destroy the survey value of photographs due to increased negative densities even when visibility in the forward looking view is judged to be acceptable or correctable within desired limits. In such a case yellow, red, or infrared filters and panchromatic or infrared material are not generally accepted as being sufficiently corrective in nature. Stated simply, this condition results when the solar rays are inclined to the vertical at angles less than the lens field semi-angle when appreciable haze is present.

As can be seen from Figure 1, backscatter of sunlight when the solar rays are inclined to the vertical at an angle ($\alpha_2$) which is less than the lens field semi-angle ($\beta$) will produce a "hot spot" of high density on the negative upon exposure, whereas when the angle ($\alpha_1$) between the solar rays and the vertical is greater than the lens field semi-angle the "hot spot" does not fall on the negative. However, increased density of a non-serious nature may be observed on one side of the negative. When the solar ray angle ($\alpha$) equals the lens field semiangle ($\beta$) the effect may or may not be appreciable depending upon the atmospheric haze conditions, but it will occur. In any case the "hot spot" of high negative density can be seen to occur in the neighborhood of the image of the point on the ground collinear with the lens and the sun. Field experience has shown this haze back-scatter to be sufficient to negate many exposures. It may be best avoided by undertaking flights at times when the solar rays make angles with the zenith less than the semi-field angle of the lens. Such suitable times may be easily computed with the aid of a solar ephemeris, and they will ordinarily be circa the morning and afternoon times usually desired for improved contrast and resolution provided by shadow effects. Also flying at lower altitudes might be an alternative solution if the haze can be shown to be stratified at higher altitudes.

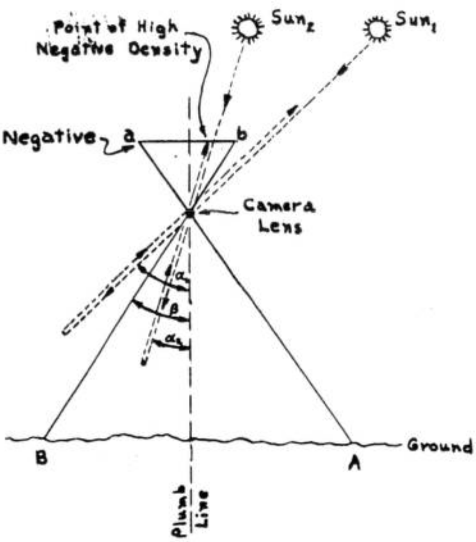


FIG. 1. Schematic diagram for haze backscatter. $2\beta$ = lens field angle; $\beta$ = lens field semiangle; $\alpha_1$ = angle between solar rays and vertical for $Sun_1$; $\alpha_2$ = angle between solar rays and vertical for $Sun_2$; $\alpha_1 > \beta > \alpha_2$.

It is often of interest to investigate more specifically the effect of haze in aerial photography. This may be done as follows.[1] Envision a surface on the ground of area $2A$ which has diffuse reflecting properties. Divide this surface into two equal parts, each with area $A$. One portion of this surface is to be prepared so as to give the greatest brightness attainable (i.e. a white surface) and this brightness will be designated as $B_G{}^W$. Similarly the other portion is to be prepared so as to give the least brightness possible (i.e. a black surface) and let this brightness be designated as $B_G{}^B$. Then define the contrast $K_G$ between the white and black surfaces when viewed from the ground to be the ratio of their brightness values (measured in any standard fashion).

Then

$$K_G = \frac{B_G{}^W}{B_G{}^B}$$

[1] The succeeding derivation is original with this paper but neither the approach nor the result are necessarily so.

This is the maximum contrast available on the ground.

(Note the superscripts are referring to the surface in question and the subscripts to the place where the brightness is measured. Thus $B_G{}^W$ denotes the brightness $B$ of the white surface $W$ measured at the ground $G$.)

Now assume a camera station at altitude $h$ above the chosen ground area. A cone with its vertex at the camera station and its base of area $A$ on the ground in the vicinity of the chosen white and black surfaces, will have a haze brightness value when viewed from the camera station which shall be designated as $B_{\theta_v}{}^H$ where $\theta_v$ indicates the variable angle $\theta$ between the vertical and the axis of the cone. This haze brightness is due to light passing down through the atmosphere and being reflected back to the camera station. Due to the aforementioned backscatter in haze this brightness $B_{\theta_v}{}^H$ will be a maximum value $[B_{\theta_v}{}^H]_{\text{max.}}$ when $\theta_v$ equals the angle the solar rays make with the vertical, and the axis of the conical element is collinear with the solar rays passing through the camera station. Another amount of light reflected up from the ground objects will be deflected away from the camera station. This will be equal to $[B_{\theta_v}{}^H]_{\text{max.}}$ at all times. It is evident then that the light from the white surface arriving at the camera station will be diminished by a quantity $[B_{\theta_v}{}^H]_{\text{max.}}$ but will be viewed by an observer at the camera station in conjunction with the haze brightness $B_{\theta_v}{}^H$ and therefore will be equal to

$$B_G{}^W - [B_{\theta_v}{}^H]_{\text{max.}} + B_{\theta_v}{}^H$$

which shall be designated as $B_h{}^W$. On the other hand $B_G{}^B$ the light being reflected from the black surface was originally very nearly zero and so will not be diminished any by haze interruptions, and the brightness value of the black surface when viewed from the camera station will be

$$B_G{}^B + B_{\theta_v}{}^H$$

or for all practical purposes $B_{\theta_v}{}^H$.

By the use of these terms it is possible to define a haze factor $f_H$, which is the ratio of the haze brightness for the angle $\theta_v$ to the brightness of a white surface on the ground when viewed through the haze from the camera station, as

$$f_H = \left[\frac{B_{\theta_v}{}^H}{B_h{}^W} \times 100\right] \text{per cent}$$

Since $B_G{}^W \geqq [B_{\theta_v}{}^H]_{\text{max.}}$ the numerator is always $\leqq$ the denominator $B_h{}^W$ and the maximum haze factor $f_{H\text{max.}}$ is 100%, whereas the minimum $f_{H\text{min.}}$ is 0% when $[B_{\theta_v}{}^H]_{\text{max.}}$ is zero (i.e. no haze present).

Also the contrast $K_h$ between the black and white surfaces on the ground when viewed from the camera station through the haze is

$$K_h = \frac{B_h{}^W}{B_h{}^B} = \frac{B_h{}^W}{B_{\theta_v}{}^H}$$

Here the minimum contrast $K_{h\text{min.}}$ (i.e. no contrast) is assigned the value of unity although this theoretically can occur only when $[B_{\theta_v}{}^H]_{\text{max.}} = B_G{}^W$ causing $B_h{}^W$ to equal $B_{\theta_v}{}^H$. The maximum value $K_{h\text{max.}}$ is obtained as follows. For the maximum attainable contrast at the camera station $B_{\theta_v}{}^H = [B_{\theta_v}{}^H]_{\text{max.}}$ and

$$B_h{}^W = B_G{}^W - [B_{\theta_v}{}^H]_{\text{max.}} + [B_{\theta_v}{}^H]_{\text{max.}} = B_G{}^W$$

Then

$$K_{h\ \mathrm{max.}} = \frac{B_G^W}{[B_{\theta_v}^H]_{\mathrm{max.}}}$$

which may be a very large number equal to the contrast attainable on the ground when $[B_{\theta_v}^H]_{\mathrm{max.}}$ is very small or zero.

From this rudimentary derivation it can be seen that the photographic contrast at a camera station is directly tied into the haze factor which is itself a function of the haze brightness, and this haze brightness is of course the undesirable light that the various filter-film combinations are intended to reduce. When the contrast or luminance ratio, $K_h$ above, is 1.04 or greater for a dark surface lying alongside a light surface (i.e. a 4 per cent difference in brightness between $B_h^W$ and $B_{\theta_v}^W$) the average observer can distinguish objects under normal conditions. However, since a certain amount of contrast is lost in the camera system and in the production of prints, it is certainly desirable to have a ratio somewhat higher.

Another approach to problems of atmospheric haze effects in aerial photography is to treat the effects as a problem in tone reproduction. Current research on this aspect indicates that, by deliberately introducing certain non-linearities in the photographic phase of the reproduction cycle, an improvement in the tone reproduction qualities of aerial photographs may be achieved in addition to that realized from the use of the optimum spectral sensitivity of the film and the optimum color filter. This idea is deemed practical since the use of filters gives only partial compensation for photographic flatness resulting from haze effects, and further enhancement of contrast, particularly in the shadow region, is desirable. However, practical results of this research is not yet available to the consumer in the form of print paper, etc.

This paper began with the statement that too many students tend to look upon atmospheric haze as an indefinable and unimportant factor. Perhaps haze is not yet adequately defined, but it is hoped that the foregoing pages have served to show some of its importance. With the rapid advances in techniques of photogrammetry and photo interpretation, the limiting factor has largely become the mechanics of making the photographs. Pertinent factors here include camera motion and orientation, lens definition, granularity, and many others, and haze problems are probably as troublesome as any of them.

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