PROBLEMS OF PHOTOGRAPHIC IMAGERY ANALYSIS

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PR[illegible]LEMS OF PHOTOGRAPHIC IMAGERY A[illegible]YSIS

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FIGURES

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PROBLEMS OF PHOTOGRAPHIC IMAGERY ANALYSIS

INTRODUCTION

The purpose of aerial photography is to bring into the laboratory for study and evaluation the most revealing and informative coverage of specific locations on the earth's surface upon which nature or man has placed something of interest to the analyst. Just how revealing and informative the coverage may be, and how satisfactory the study and evaluation, depend on the capability of the series of media which comprise the photographic process to transmit the appearance of the object on the ground to the brain of the laboratory analyst. The series of transmitting services consist of light or radiant energy, the optical properties of the atmosphere, the optical system of the camera, the emulsion, and the reproductive quality of the photographic film, as well as the reproducing processing, the optical instruments used in laboratory study, and the capability of the human eye to recognize details of the object's image on the resulting photography. Each of the transmitting services has discrete characteristics. Each, in turn, degrades the image, detracting from its visual clarity, modifying its tone, masking its composition, or otherwise making the image it transmits something less true and less intelligible than the image it received. The job of the photo analyst is to read as completely as possible the nature and significance of the object. His ability to do so is largely a measure of his training and experience in his trade. The capability with which he explains to his audience what he perceives and also the reasons for limitation of his perception depend in no small fraction on the analyst's understanding of the basic physical phenomena that determine the nature of the photo image. Only by judiciously evaluating tone variations on the photography does the analyst detect an image in the first place. Only by expertly employing effective laboratory equipment can he distinguish as fully as possible the complex of these tone variations, and only by his ability to distinguish the causes and values of these variations does he create the mental image and the object description.

Photographically the object of interest is an inert and passive thing. In order to be identifiable it must exhibit material aspects such as size, shape, scalar values, and composition. An object is recognized because it has a different tone or brightness from its surroundings and because of the variations of brightness and contrast over its surface. It may be associated with other objects related to its function; its surroundings may be relevant; and the light on it may or may not be advantageous to its identification. Whatever the inherent characteristics of the object and its locale, the important aspect of the photography is the quality of the image which light,

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falling upon the object, carries skyward by means of individual reflected light rays. These in turn are transported through the atmosphere to the aerial camera, which is some distance overhead. If a desirable amount of light is reflected from the object through a clear atmosphere, it can be expected that a high quality image will reach the camera. The camera lens and body may adversely affect the image falling upon the film, which is able to capture the image only within the limits of its composition and purpose. In the process of laboratory reproduction to positive photography, certain features of the image may be ideally reproduced at the expense of other portions of the total image. In the human eye the visual process may be insufficient for detecting all the details carried thus far on the image. The final product depends on the analyst's ability to communicate what he has found on the imagery.

It is the purpose of this report to consider, in two parts, the photographic process, from the object on the earth's surface to its description in the analyst's report, with the intention of identifying the physical and optical properties of each transmitting service and the functions of each which limit the final quality of the image and its identification and evaluation. Consideration will be restricted to black-and-white, or monochromatic, duplicate positive transparency, which is the common media subject to direct laboratory study and analysis.

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SECTION I
PRACTICAL PROBLEMS OF I.A.

IMAGERY INTERPRETATION

There is an endless variety of examples to which one can turn to illustrate the business of reading, analyzing, presenting and communicating the substance that photographic imagery has to offer in support of man's world-wide endeavor to know what is there, what is happening, and what may be the next situation to be considered in any locality. The task involved is simply ability to assess the site and prepare whatever communication is expected of the analyst. Difficulties arise when coverage is poor or of small scale, for that is when almost anything becomes a small object. In other words, the mere term "small object" is a comparative concept, and the practical problems involved depend on what is expected in the way of analysis and reportage.

The imagery of small objects, in the total concept in which the term was originally expected to be handled in this project, can be separated into five classes, each of which requires a background knowledge different from that needed for the others. First, there are those which are really small on the coverage, which are near the limits of human vision. There are those whose finest detail is beyond the range of human vision but is detectible in brightness differences that can be mechanically or electronically distinguished. ~~There are those which are large enough to see~~ but which are too weak in contrasts for visibility of pertinent details. There are images with highly reflective surfaces which are lightstruck and therefore distorted. And lastly, there are the endless variations of camera angle, sun or lighting angle, and target orientation, providing an image for which the analyst must imaginatively fill in the invisible detail and reconcile its concept, sometimes in order to prove or disprove one or another of alternate choices in identity. Each of these classes of image variations will be discussed in turn to elaborate background, essential factors, and possible points of departure in acquiring solutions, or, lacking them, a limited but reasonable understanding of the insolution. Altogether they require a thorough understanding of the mechanical aspects of vision and optics, of photography and film, of imagery and analysis, and of geometrics and complexity of photography

Thus far we have followed the analyst in deriving the information from the imagery, in the acquisition of knowledge. At this point his job is only half done. His communication of that knowledge to others is still ahead.

The effectiveness with which the communication task as a whole is visualized often determines whether the new knowledge catches on. In common practice communication is a team effort, and the analyst may find that, for several reasons, his work as an analyst is communicated by others who have made the effort to develop communication as a skill. There is no objection to this type of teamwork, except that no one else can transmit the analyst's ideas as well as he might with a little more awareness and effort. Teamwork with graphic and mensuration specialists is often desirable. The real problem here is one of knowing the tools of communication, reasoned analysis, succinctly stated ideas, an apt vocabulary, and a perspective of the greater concept into which his contribution is to fit. The opportunity to improve in the role of communicator is a real live issue for the imagery analyst.

Exploitation of each of these limitations in analysis and communications must concern both practical and theoretical approaches. We will first address ourselves to the practical problems. These are briefly summarized in the first section of this report, and the broader background presented in the subsequent section. The individual who is interested only in the reasons for the difficulties need not go beyond the first section. For those who are interested in fully understanding photoanalysis it is suggested that the latter section will be the more interesting and informative.

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Small Objects Near the Limits of Imagery

The human eye is very sensitive to light. It has been said that the mechanical energy produced by a pea falling from the height of an inch would, if transformed into luminous energy, be sufficient to give a faint impression of light. Either too little or too much light can destroy an image falling upon the eye. It is only within certain visual limits, and within the visible wavelengths of light, that an image is satisfactorily registered in the retina of the eye and that real seeing occurs. But there are several other involvements in reading photography.

There is a limitation of object size, or visual acuity. Standard visual acuity is defined as the ability to see an object which subtends only one minute of arc at the eye, such objects being white on black, or black on white background. As this has been applied to photography to represent its resolving power, it has come to imply that the ground resolution figure would be a criterion of what can or cannot be seen on a photograph. But this is not the case. Imagery on photography deviates from this standard in two distinct directions. First, very few images on photography come from sharply black-and-white contrasted objects as resolution targets are. Theoretically, as such contrast is decreased the unit image loses definition, making it less clear and requiring that the size of the object be increased in order that it be visible. Secondly, the camera often registers images of objects that are nowhere near as large as the ground resolution figure indicates they must be in order to be definable unit images. For example, it has been possible, over a period of years, to distinguish on some whether or not there are rails on railroad track beds. It is often found possible to see perimeter fence rows and median strips on highways, and these dimensions have no comparison to a minute of arc at the eye. In imagery analysis visual detection reaches beyond the mechanically verifiable. In order to understand this we need to know how an image becomes visible in the first place, and how we actually see it.

The photographic system is made up of two imagery transmitting components, the lens or camera system and the film. It is evident that for whatever image is to be captured by the film the representative light rays must first pass through the lens and then affect the film, in each case with sufficient clarity to register distinguishable differences in contrast and resolution. If an inferior lens is used the imagery will be poor regardless of the quality of the film, and vice versa. If both are of high quality we get high quality imagery, and under certain circumstances we get imagery that far surpasses the expected ground resolution. Here we should say not only why, but also why not. Why not get such imagery as an expectable thing? If we can see telephone poles on the desert, cables at a power facility, and the shadows of fence posts none of these a foot in diameter, why do we not see them everywhere?

A second important question needing clarification here is the manner in which we see an image, which in essence means how the mind handles the image transmitted through the eye. Regardless of the appearance of similarity, the eye-mind system is only partly analogous to the lens-film system. The latter is purely objective. It registers whatever comes through to the film, the clear line and the blurred, making no rejection and no analysis. Not so with the eye-mind system. The mind tries to make sense of whatever it attempts to see, often rejecting and requiring a second look, and possibly misinterpreting the signal. Furthermore, in imagery analysis the mind is not dealing with a primary image, but rather the image of an image, for which it has to fill in the gaps and supply reason in order to substantiate or identify an object.

With small objects the problem is one of seeing and identifying rather than measuring. The sizes of objects on a single photography are not necessarily comparable. We may take as an example a view of wire lines beside roads in a desert area (Figure 1). The roads are for tracked vehicles, the poles the simple vertical implanted pole with cross arms and insulators. it cannot be expected that either can be used as a control for deriving the width of the other. The width of the wider line, the road, if it is clearly imaged, may be fairly well derived from the photographic scale, but not the narrower line, the pole, because it is beyond the limit of resolution. If subjective evaluation is required, reasoned dimension for such an object must suffice.

FIGURE 1

Photograph:

Roads and wireline poles and shadows.

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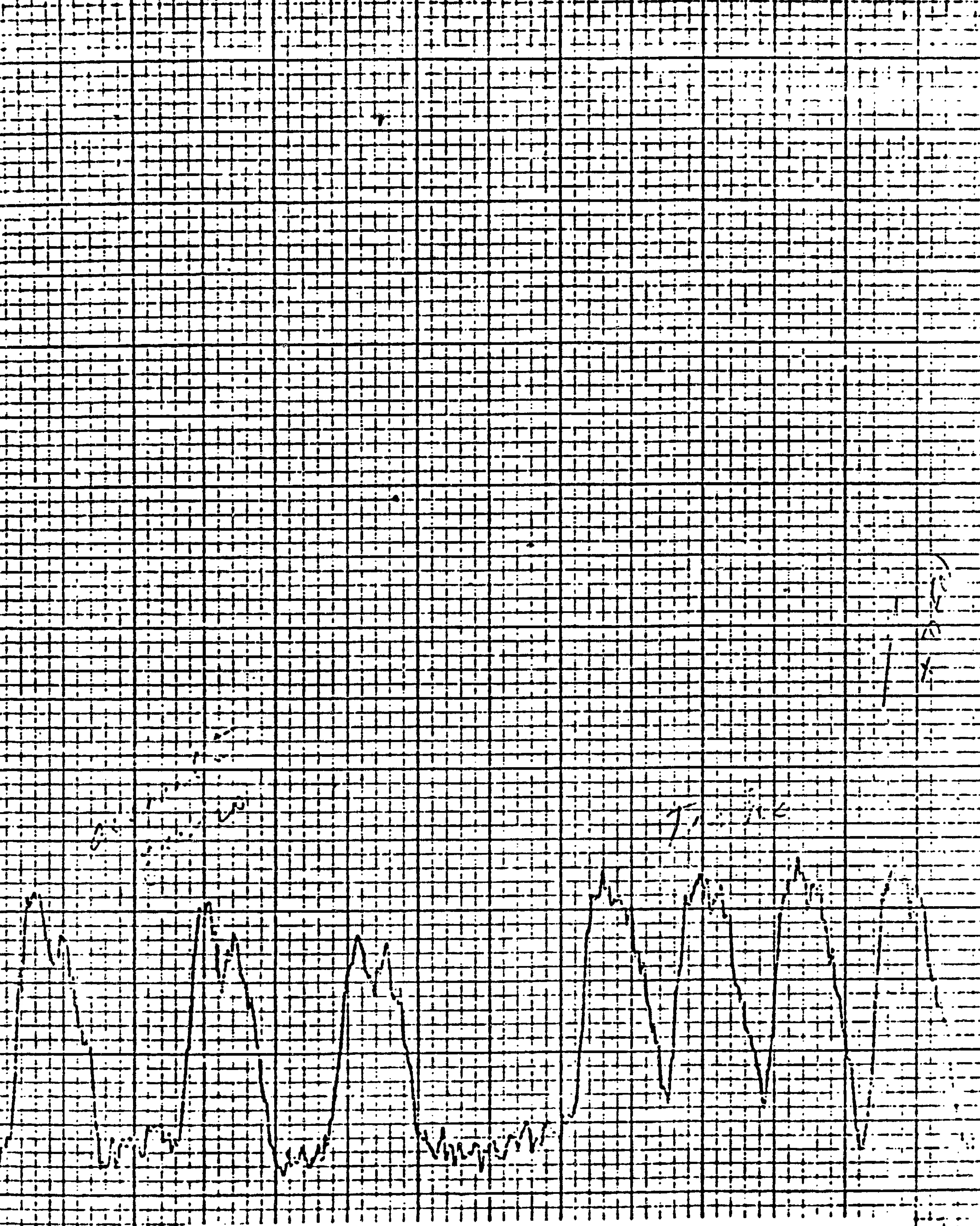

Figure 2. Microdensity trace across assault guns and tanks.

Figure 3. Isodensity tracing of [redacted]

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Fine Detail Beyond the Range of Human Vision

A critical phase of photoanalysis comes where we look for things beyond the limits of human vision, as in cases where the photoanalyst seeks to distinguish detail he knows is there. To this end there is assistance possible from mechanical and electronic analysis.

Microdensity traces (Figure 2) are derived by mechanical curvilinear mensuration, and edge gradient analysis is performed wherein, in tracing density variations, attempt is made to distinguish most precisely the configuration of an object and location of the edge or contact between the object image and its surround. Continued research by photogrammetrists with better imagery and better controls is expected to produce the methodology necessary for satisfactory determination of differences that human vision cannot resolve.

Isodensity traces are offered as photogrammetric support to photo analysis for the purpose of distinguishing differences in density too weak for detection by the human eye to be apparent. They are electronically derived plots of differences in density and represent brightness differences of the imagery (Figure 3). The patterns they form, generally highly magnified, commonly show the invisible details of the film areas under investigation. Only the trained isodensity analyst can interpret a trace, which may be said to have the characteristics of a topographic map, with like densities instead of like elevations being represented by the patterns derived from electronic scanning of photographic area. Because their differences vary with actual contrasts in the photography they have a coincident relationship to the imagery which the photoanalyst seeks to interpret. The two analysts work as a team, each seeking to derive information not available to the other, each depending on the other to recognize in his own medium its peculiar variations, and each offering for consideration points which may add up to significant conclusions. The isodensity study is not a substitute or a verification of the photoanalyst's subjective interpretation, but rather serves as an independent analysis of objective variations beyond the visual realm of the photoanalyst.

Isodensity analysis, as a support function, is not requested for the majority of photoanalysis problems. It is specifically desirable in the detection of minutiae which are beyond the limits of resolution of the imagery of slight differences in scale or detail that make possible the more accurate descriptions vital to distinguishing critical features or capabilities beyond visual recognition. As one result of this role the isodensity analyst is most often called upon to aid in analysis of poor imagery. He rarely sees the best coverage because there the photoanalyst has become accustomed to depending on his own visual acuity to reveal all the necessary imagery details. Oftentimes he is unaware that in the imagery there is still a certain reserve that is visually indetectable but nevertheless there in infinitesimal changes in character pattern of film. It has probably been too little understood that isodensity support in the study of good coverage could probably add to many requirements where derivation of small detail might provide useful information.

Another use of density analysis in preference to high magnification imagery studies is related to grain noise in the imagery. In high optical magnification the grain noise is magnified along with imagery detail, finally destroying the latter. In isodensity derivations it is possible to detect density differences first and then enlarge the pattern with the result that grain noise falls somewhat behind.

In the increased quality of film that has come because of improvement, [redacted] there has come opportunity to settle some of the recent problems in interpretation of small objects.

[redacted] But this does not mean that the small objects' problem will go away. For every step in improvement of information derivation there will come, as better imagery is produced, an increased demand for more fine detail.

[redacted]

Occasionally unexpectedly small objects are readily discerned on imagery for which ground resolution does not approach anywhere near so small an object. One of the interesting examples here is the set of cables or power lines between two buildings at an electric installation (Figure 4). [redacted] they have been alternately seen and unseen without the irradiation effect, both as light lines on dark background and as dark lines on lighter ground. The exact reason for their visibility lies in the quality of the emulsion, but the exact physical reason for their discernibility does not reconcile itself with inability to see such fine detail elsewhere.

No device has been produced which can either verify or refute the interpretation given by a photoanalyst or by analysts who may not agree on a specific interpretation. In visual mensuration cooperation is achieved between the two analytical skills. Where the machine operator is unsure of the limits of the object being measured by such instruments the analyst is often called upon to verify the points for point-to-point mensuration. This he is happy to do in order to forego the time consuming operation of the machine itself. There is convincing evidence that the two skills are mutually beneficial. Perhaps at this point it is also quite obvious that the two should be kept separate rather than that the photoanalyst should be expected to do the most exacting types of mensuration. The field of knowledge required is too extensive for analysts in general to be content with attempting to perform with maximum quality in both fields.

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[redacted]

[redacted]

FIGURE 4

Photograph revealing power cables.

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Imagery with Weak Photo Contrasts

Much of the problem of object identification or visualization is not a matter of size but of image clarity. If all photography were distinctly black and white, such as ground resolution targets are, this would be a standard problem with standard expectabilities, but most imagery consists of gradations of gray tones that seem to merge imperceptibly. To some degree this is inherent in the use of granular emulsion.

Field conditions are a major cause of such poor contrasts. Light reaching the camera lens is attenuated by atmospheric humidity, haze, or overcast; the image may be blurred because of lack of perfect coordination between film and vehicle motion; or visibility may be poor because of poor lighting and lighting angles at inappropriate times of day or season. Snow cover often masks ground surface details, but it may be revealing because it sharpens contrast and can date activity. Obliquity of coverage may be a problem because of poor viewing angle but it too is advantageous in many instances. In cases where one or more of these conditions is dominant, an object, even one that is large, may be imperceptible, or if identifiable may still be too poorly imaged for full and satisfactory description. These are the usual conditions under which imagery is acquired.

The real problem of identifying the fine detail of photographed objects is generally one of distinguishing between closely related tones produced in the relatively clear images of objects whose overall appearance is not black and white but the in-between shades or colors that come out gray on so-called black and white photography. The large difficult objects fall into two categories: (1) those which occur in shadow of a nearby object; and (2) those whose gray tones closely match the surround. If the gray tones were effectively contrasted resolution could be good ~~even~~ and objects of low scalar size distinguished but if the tones are closely alike or merge imperceptibly object definition is apt to be poor. There has not been reported any coherent body of research into the expectable relationships between vision, visual acuity, and identification and description of objects only faintly contrasted in their included detail or in association with surrounds, at least no research that is of direct application to the photoanalyst. In this phase of his work he is operating in an area for which no physical parameters have been developed as guidelines or goals, with the result that whatever he accomplishes is open to criticism and greater expectations.

The photoanalyst, personally, either sees an image well enough to recognize and describe it, or he does not, in which case he may be able to get help from available technical services. The image contrast can sometimes be increased by developing techniques that enhance film density differences. It is worth while for the analyst to discuss such contrast problems with the skilled staff of the photo reproduction laboratory, or with the photogrammetrist in case an exact edge presents the problem. These techniques are most valuable in object mensuration, and they sometimes also lead to corroboration of identity.

[redacted] [redacted]

Imagery of Highly Reflective Surfaces

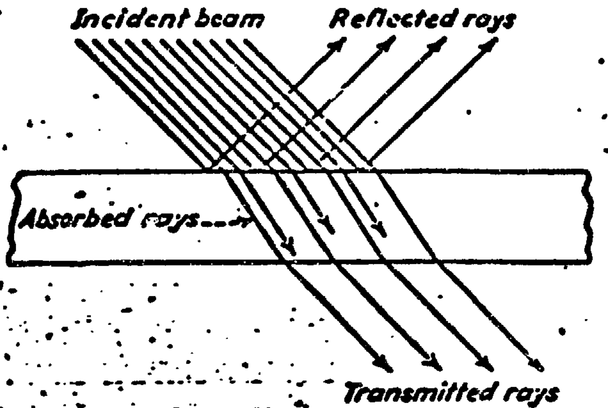
Metal objects, such as aircraft and unpainted oil or chemical tanks, are generally as readily seen and measured as other types of construction, but occasionally, and often then in critical situations, the amount of light reflected from such objects into the aerial camera is so bright as to partly efface object outline and detail. The analyst can most often distinguish the nature of such large objects by distinct outlines of portions of the image, or by conclusions derived from the surround. Exact measurement or description of small detail, especially that required to distinguish between similar appearing aircraft, for instance, may be impossible, although this bit of information may be one of the most important goals of an aerial mission.

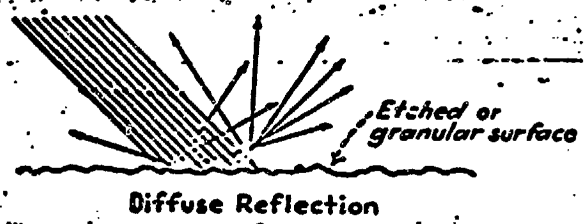
The majority of statements on such overbright light effects attribute the cause to glare, which in conversation is frequently, though mistakenly, referred to as halation. The real cause of overbrightness therefore needs discussion and clarification. Three questions invaribly express the problems of those concerned with such identification assignments. They are: (1) under what circumstances does such overbrightness affect imagery?; (2) what is the amount, percentage, or factor of error in mensuration of such image distortion?; and (3) what can be done to avoid its occurrence?

The first of these questions is fairly easy to answer although it requires detailed objective explanation. Overbrightness is almost wholly caused by natural and normal concentration of light reflection from the metallic surface itself. To understand this we need to review basic explanations of the behavior of light, its distribution, scatter, or concentration, depending upon the media through which it passes, the surfaces through which it cannot go, and the manner in which it is directed away from those surfaces.

It is theorized that light travelling from the sun toward the earth is propagated in direct rays until it hits the earth's atmosphere, whereupon 18
some of it is diffused or scattered by minute particles contained therein. Much of the sunlight falling through haze, overcast, and smog strikes the surface of the earth or the objects thereon, whence it can proceed no farther. Some of the light is absorbed and turns into heat energy. If the surface is translucent some of the light will be transmitted through it (Figure 5a), as through a window, but that which is reflected (turned back by the object) carries an image to whatever optical system is within viewing position. If the surface is rough, either coarse or fine (Figure 5b), the reflected light is diffused or scattered in all directions, and the object is generally easy to see and easy to look at, although excessive diffuse light produces a washed-out appearance which is readily apparent.

[redacted] [redacted]





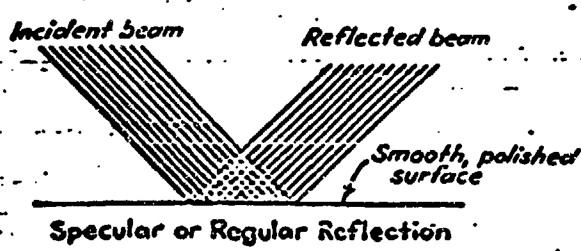


Figure 5. a- Absorption, transmission, and reflection of light rays striking a transparent surface.
b- Diffuse reflection from surface which is irregular compared with dimensions of light waves.
c- Specular or regular reflection.

The smoother the surface may be the greater the proportion of reflected light that is oriented in a particular direction (Figure 5c). That direction is determined by the direction from which the light comes and the orientation of the bit of surface from which each light ray is reflected. This relationship is clearly explained in the physical law which states that the angle of incidence of the light is equal to the angle of reflection, these angles being measured from a line normal, or vertically projected, to the reflecting surface. The law is well illustrated in the brightness of sunlight reflected into the eyes of a westbound driver in the evening when the sun is low, or in the brightness of a smooth water surface as one looks into or out over it while facing the sun on a bright day. If one faces away from the sun the water appears dark, not because the sun is not shining upon it also but because the viewer is in the same direction as the sun, in the diagrammatic direction of the angle of incidence, while the concentrated reflection is directed into the air out beyond the viewer in the opposite direction.

For smooth surfaces this light concentration is called specular reflection. A mirror is such a surface. Any smooth metal surface, such as the body of a car or the curve of an aircraft wing has such a reflective capability. The brightness of the specularly reflected light, and the image it may carry, is said to be equal to the brightness of the source of light, viewed on a line through the point of incidence, times the reflecting power of the surface, which may be less than 0.1 for water or glass, but as much as 0.98 for some metals. Thus it is that polished metals are used for mirror surfaces, and that the brightness of reflection from metal equipment, such as tanks and aircraft bodies, sometimes appears too bright for comfortable visual observation. The brightness from such an object may be too great for the camera film to capture a good clear image; this is the reason why these items often appear as overbright blobs of light or only partially discernible images on aerial film.

The second question, concerning the amount, percentage, or factor of error in the mensuration of light distorted images, has no single or specific answer. Each item is a case by itself. The amount of distortion registered on the film, for example, will depend not only upon the nature, curvature, and angle of the reflecting surface, but also upon redirection and control of the light. For each object there is not necessarily a unit reflection. This is well illustrated in the photography of an airfield at Dallas where several aircraft were parked (Figure 6). Of these only one was subject to overbrightness, but for it the forward part of the fuselage between wing and nose was distorted beyond definition, while the rear of the same aircraft was clearly outlined. [
~~problems~~, and some means have been achieved in avoiding undesirable light

[redacted]

[redacted]

FIGURE 6

Photograph:

Love Field, Dallas, Texas,

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[redacted]

effects. First among these may be mentioned the use of polarizing filters to help reduce excessive diffuse light and to minimize reflectivity while otherwise producing good quality film. In the photogrammetric and reproduction laboratories, too, microdensity and film reproduction research is underway to help solve such problems. But this laboratory work cannot erase from the negative the overbrightness already registered there nor restore an image that never reached the film.

We now come to the question of what can be done to avoid the occurrence of specular reflection. Let us look at this in two parts, the general and the particular. As a general subject in photography we need concern ourselves very little about its occurrence. All of us as experienced ground photographers know that, except for special lighting effects and with great discretion, in order to get good photographs we turn our backs toward the sun and by observation guard against including overbright objects. By this same deduction we could also conclude that aerial photography taken with the same caution could equally well avoid specular reflection. But aerial photography is not quite so simple.

In order that a photographic mission be most successful, it is carefully programmed before the mission is flown, [redacted] And because there are no possible means of knowing all the reflecting surfaces in the path of the mission, the laws of chance practically guarantee that for a long mission some smooth-surfaced object will be imaged in the very angle that will produce specular reflection. However, if the object is known to exist, and an image of such an object is a purpose of the mission, there should be no reason why the photography could not be secured from a satisfactory angle.

It could be possible that, [redacted] there is only a single chance to acquire a photograph of a desired object, and that, regardless of the uncertainty as to the sun, object, and camera, it is deemed best to take that chance. In this case an exceedingly small variation in the relative position of the three could insure a good view or an unsatisfactory one. It is worth the try. But if the object in question, an airfield for example, is one of the prime targets [redacted] and the presence or probable presence of highly reflective objects (in this case either oil tanks or aircraft) is expectable, the programming should take account of possible specular reflection to the point of guaranteeing against it by careful placement [redacted] a position which not necessarily approaches the angle of incidence of light on the object but which is in the same azimuthal orientation. This would minimize the probability of good

[redacted]

[redacted]

shadows. It is in sharp contrast to the long-standing belief that objects are most clearly seen when the shadow falls toward the observer. The really analytical photoanalyst finds that a good look at the sunny side of an object provides details usually associated with obliquity, and often revealing of image details not captured on the shadowy side. No matter how carefully such programming is established there may still be times when an aircraft, oriented at an arbitrary angle and with a curved surface reflecting sunlight from a fortuitous portion of its complex exterior, will direct a bright enough amount of specularly reflected light to cause poor lineation over a fraction of the image. If such overbrightness destroys a critical detail of the image it may be impossible to distinguish that aircraft as being one or the other of two closely like models, or to identify a known model from a possible closely resembling prototype that has not been previously observed. Although such an instance seems wholly unlikely, the possibility should not be overlooked, and cannot be completely avoided.

In most instances where clear photography is vital it is possible to arrange for more than a single frame of coverage of the vital object.

the chances are very good that at least one frame if not both will have the object clearly imaged. If neither image is clear or only a single poor image is acquired, there is some value in knowing that an interesting object is at least poorly imaged and that its identity may be clarified when another mission is flown.

Problems of Orientation and Viewing Angle

Overhead photography provides the analyst with imagery that varies with lighting angle, viewing angle, and target orientation. First of all the geographic location of an object determines whether, on a particular date, there can be sufficient light at a site to allow clear photography.

Exceptions made to this condition are included in missions with the full knowledge that certain targets are better viewed under poor light than not at all. In cases where obscurity occurs the reasons are generally other atmospheric conditions or terrain or structure shadows.

The matter of sun angle should not be left without pointing out the seasonally greater quantity of light in the sky in summer than in winter. If the sun's course were related to a cylinder instead of to the spherical shape of Earth there would be no differences in this respect. But anyone reflecting on the subject recognizes that the immediately pre-sunrise and post-sunset light in summer is far greater than in mid-winter.

In lower latitudes it can happen that with high seasonal sun mid-day photo-coverage yields imagery that is almost shadowless, generally an undesirable feature. On the other hand, in the latitudes between the Tropics (Cancer and Capricorn), coverage can be secured seasonally with shadows falling either north or south as well as daily either east or west. This allows unshaded views of all sides of an object of interest and provides guidelines for targeting in order to acquire the desired look.

A full discussion of these properties of the imagery should also include unit target shape and complexity, and the nature of its surface. But these are so intimately related to the basic aspects of vision and imagery that, if discussion is deemed desirable, it should follow after a full reading of the second section of this report.

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A photoanalyst has mixed feelings about shadows. He learns early that photography is easier to look at if oriented so that shadows fall toward him. For vertical photography this is simply done, but for oblique photography, where obliquity should also be slanted in the direction of the viewer, there are times when a choice has to be made between the two. And then there is no single answer or simple rule to follow. The situation varies not only with the obliquity and shadow angles but with image quality and even the nature of the image itself. The analyst in such cases may find it useful to look at the photography, the site location, from several angles, and often finds something revealing in viewing the imagery from different angles. The angle permitting the most penetrating analysis is often found to depend on target orientation, or on whether or not the object to be identified is a single unit or a small factor in a more detailed and complex site.

Target orientation is also a dual or triple concept. In the first place it may make a difference in judgment whether one views a 30-foot missile or a freight car from the end, the side, or some point in between. It may or may not be important whether it is seen from the direction in which the shadows fall or in the direction of obliquity. If the target has a highly reflective surface the light return from it will depend on the relationships of the camera's look angle to the angles of incidence and reflection (Figure 7). These are all orientation factors that aid or hamper the look at the imagery. But target orientation with respect to acquisition of the imagery is also important. This is immediately obvious in consideration of ground resolution targets, where tests show that the target oriented parallel to the flight path of the vehicle has a lesser resolution than the target oriented perpendicularly, the reason being that there is a slightly greater sensitizing of the emulsion in the direction of flight, with the film traversing that flight path. In some instances the difference may be important.

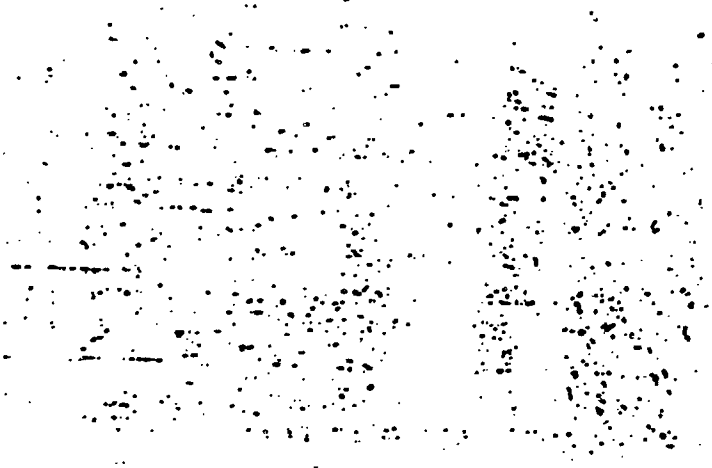

FIGURE 7

Photograph:-

Misshaped images of missiles

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[redacted] [redacted]

PERFORMANCE SKILL

Imagery analysis is not just a matter of object definition. As much as its concern over objects may be emphasized, the imagery analyst is responsible also for recognizing action or the immediate condition of a capability that is being developed. He is most often expected to be able to draw on an intensive background knowledge of some one or several diverse and technically complex fields of man's industrial, political, economic and military capabilities. To the degree that it is pertinent, he acquires a wide acquaintance with the geographic assets and limitations of a site, and the history of the activity there. It is expected that he keep himself informed of whatever may transpire there, or elsewhere, that may be related to the function in question.

In the process he becomes skilled in the techniques he finds most productive of satisfaction in his work. Such skills may take the form of illustration of a single site or feature, of photographic comparisons between similar but unrelated sites. Or he may have a special interest in verbal communication, in which case his word pictures become increasingly apt and meaningful. But in all probability he will not be highly skilled in all collateral techniques.

Most particularly he will probably ~~not be~~ Lack extremely interested ~~nor ever~~ and ~~highly~~ competent in the mechanical aspects of imagery derivation and presentation. ~~He may do it and~~ Many analysts are graphic artists, but the average analyst will neither enjoy nor perform well at graphic support or the mensuration of his own small objects' analysis problems. This is not because he lacks interest in the data such manipulation can provide for him but because he is then moving from the subjective analysis, which he enjoys and therefore does well, to objective skill that by comparison is a subdominant accomplishment and therefore not able to command the place in his interest which is necessary for real skill. In the process of becoming self-sufficient he becomes isolated, a hermit if you will, lacking the support of discussion and differences of opinion and purpose which in photoanalysis are highly productive.

The techniques of subjective and objective analysis of photography are distinctly separate concepts, both as to philosophy and practice. The individual who is concerned with the objective techniques will become a photographer, a photo-lab technician, a photogrammetrist, or an optical specialist perhaps, but he will not be interested in verbally describing the leg of an electronics site or the chemical output of a railside installation. His interest is in the mechanical perfection of the photographic product, and having achieved the highest quality under a given set of mechanical conditions, he then attempts to improve some small component of these conditions for another go-around. The imagery analyst, on the other hand, is interested in the game of deriving expertise from the visual potentials. His skill differs from the mechanical or mensurable, and when he is asked to do both he is in a position analogous to that of a test pilot being asked to take a place in the assembly line of an aircraft factory. When ~~If~~ there is a critical ~~real~~ need for objective analysis of small object photography, it should not be expected that this be done by the subjective analyst. True, he will, or should, understand the objective background, but he needs the support of the skilled and knowledgeable objective analyst to produce the best products.

In addition, it will probably be discovered that the objective work can be done better by the objective specialists, that they will do it faster and less expensively than the subjective analyst can, that he thereby will be free to accomplish a greater amount of the work he does best, and that as a total result more work will be done more economically and more people will be happier.

[redacted] [redacted]

COMMUNICATION

Communication of ideas is mainly a language skill. Our words must be well chosen to say exactly what we think if we are to convey to others precisely what we mean. The phrase, "be specific," rings in our ears. This does not mean that graphics, either annotated photographs or objective illustrations, do not have a place in putting across salient points in presentation, or that numbers are not highly effective in conveying magnitudes. These are useful after the fact, The concepts they convey must first have had to be verbally defined. In company with visual acuity and analytical skill in studying the imagery, idea formulation and vocality are the means by which the analyst communicates. To do this well he must know the nature of the media with which he works, and the descriptive terms which effectively carry his message to others. The first of these is covered in the second section of this report. Here we will concern ourselves with introducing the analyst's practical problem of communicating what he knows.

As in any profession, the body of photoanalysis terminology has been accumulated slowly as the science has grown. Certain terms that have been well chosen stand the test of time. Others, less apt, may be carried in active use because of priority, because their real meaning is overlooked, because their use is expected and even required, or because more adequate terms have not been introduced. The photoanalyst, as a vocalizer, might sharply increase his ability to handle words if this phase of his activity were brought to attention as a whole field of habit that needs evaluation. Unless a good look and an open mind are brought to focus on the problem it might better be disregarded.

The prime weakness, poor word handling (which here also includes phraseology), resolves itself into two parts, words poorly used and words poorly understood. Words poorly used are most commonly the general or non-professional terminology that has been incorporated and thereby endowed with pseudo-scientific status. "Poor image quality" is such a term. Many of these terms are ambiguous and misleading. They include terms which mean one thing to one group of analysts, but something else to others.
Terms which connote different things in several aspects of image production, such as speed or flare, most commonly are used precisely in one sense, which should be the only usage, and in all other cases should be replaced by terms which really mean what is implied. In a few cases, as contrast and exposure used by photogrammetrists in one sense and photoanalysts in another, two different usages are justifiable.

[redacted]

Among words poorly understood we find most commonly the borrowed scientific terms, which in the borrowing have been poorly chosen, and in the retention have come to denote something outside the original meaning which may be a valid term within the bounds of the profession. Halation fits into this group. We find a simple term, defined precisely in physical science, used loosely and conveying no useful impression when substituted into the position of a related, significant idea. There is, for instance, a custom of using "resolving power" as a criterion in imagery when "ground resolution" is the important value. On the other hand, we may find ourselves poorly understood because our audience or readership fails to catch the full significance of terms we choose. In this case we, however, have the choice of using simple vocabulary so carefully presented as to convey the more complex meaning, or of explaining exactly what an unfamiliar term means.

The photoanalyst should be aware of these weaknesses in verbal communication. He may find value in this amount of definition. To go beyond this point is not within the scope of an introduction to the problem.

[redacted] [redacted]

Conclusion

~~SUMMARY~~

Given two reels of photography from film with equal resolving power, used in two different but supposedly equal cameras, exposed under two different (supposedly equal) sets of atmospheric conditions, photographing two actual (and supposedly equal) sets of scenes, developed under supposedly equal conditions, and viewed by two different (supposedly equally capable) imagery analysts, it is difficult to conceive that definition and description of identical small objects would be equal. There are too many variables for full equality. [redacted] The point here is that if everyone concerned with photoanalysis, and with its products [redacted] comprehended that imagery analysis is not an exact science, and the reasons therefore, our effort could be better concentrated into doing what we can instead of being too concerned with what we cannot. In the following section are analytical data on which such comprehension must be based.

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SECTION II
BASIC IMAGERY RESEARCH

In the transmission of an object's appearance on the ground to its description in a photo analyst's report, the descriptive data are forwarded through a series of media, none of which functions perfectly and each of which degrades the image or robs it of certain detail which is not recoverable. The media in turn are the reflected light carrying the image details, the atmosphere which attenuates the light rays enroute to the camera, the lens which focuses light on the film, the roll of film on which the latent image is recorded, the negative or processed film and the duplicate positive or reproduced positive image, the mechanical equipment used to light, magnify, and measure the image, the human eye, and the analyst's mind wherein the imagery is translated to a facsimile of the object on the earth's surface.

Between the object and the report the image can be said to have one stable or real stage and one instable or imaginative stage. The stable stage is that recorded on the original negative which, once processed, remains the same until or unless emulsion deterioration sets in for organic reasons. Reproductions from that negative are essentially also parts of the stable stage although one may differ in quality from another. The instable stage is that recapitulated in the mind of the analyst; it occurs fleetingly in single recognition fragments the total and composition of which becomes not so much an image as a reasoned conclusion, whose recording depends on pre-knowledge and descriptive ability. It is assumed that we are sufficiently versed in the art and purpose of understanding to seek explanation for whatever knowledge is necessary for insight to occur. The physical media and means which control the transmission and reproduction are discussed as they pertain to the present state-of-the-art of imagery analysis.

THE FILM

Composition and Characteristics

The requirements specified for films to be used in the procurement of aerial photography are necessarily very stringent. The reliability of information extracted from the photography is dependent upon the film meeting these requirements.

A film is composed of two basic parts--the film base and the photographic emulsion. There are other components required but they are directly related to one of the above or to their combination.

The film bases used predominantly are polyesters, or "safety" film, so called because they do not support combustion. The two most important characteristics, other than stability, are greater tear strength These films are much more expensive than the cellulose acetates available, but are necessary for cartographic purposes because of their high dimensional stability.

The emulsion is a suspension of silver halide crystals within a gelatin mass. The gelatin serves as a protective colloid. Without this protective colloid, the developing of an image would be impossible because the silver halide, whether it is exposed or not, would be reduced to silver on contact with the developer. The gelatin is also essential for uniform dispersal of the crystals of silver halide. Strict quality controls must be exercised when the emulsion is applied to the film base. It must be smoothly and uniformly distributed over the base; otherwise a lens effect will probably result. A lens effect produces a spreading of light within the image, solely as a result of a non-uniformity of emulsion application.

The emulsion and the film base are joined by an adhesive. Additionally an anti-halation coating is most often applied to the non-emulsion side of the film base. This coating is water-soluble and is removed during processing of the film. Some film bases because of their color qualities, do not require anti-halation coatings.

There are many factors which must be considered in the ultimate selection of a particular film type in order to obtain the most desirable image for maximum interpretability. These include film speed, granularity, contrast and definition characteristics, spectral response, etc.

[redacted] [redacted]

Speed, as used when speaking of film, is merely an expression of the sensitivity of the emulsion. This must not be confused with spectral response which indicates the range of the visible portion of the electromagnetic spectrum that a film emulsion will record. Although commonly referred to as film speed, it might more likely be called emulsion speed. It is a relative quantity, used to indicate emulsion sensitivity to light. The speed depends in part upon the size, quantity, and dispersal of the silver halide crystals in the colloidal suspension. These factors equate to the granularity and graininess of the film. Film speed may be thought of more simply as the time required for incident light to produce the desired chemical reaction within the emulsion, thus creating a condition of exposure. Speeds are expressed in general terms; i.e. fast, medium, slow, however they do have definite numerical values which are more often used by the photogrammetrist.

The granularity of an emulsion is an expression of the grain size and the density of their dispersal throughout the solution. Graininess is a psychophysical quantity referring to the visual appearance of the granular structure in a developed photographic image. Graininess is evident as a result of an agglomeration of developed grains or an overlapping pattern of grains.

Slow emulsions in general have finer granularity and better resolution than the faster types, but they are not necessarily the best for aerial photography on that account. In past years fine-grained emulsions were excluded from use in aerial photography by the need for high contrast and full emulsion speed.

of a film for certain contrast ~~characteristics~~ does relate directly to granularity and film speed. Contrast of images is a function of maximum and minimum density levels of granularity and exposure.

Definition may be stated as the degree of clarity and sharpness apparent in a photographic image. Restricting discussion of this subject to film characteristics only, definition is more dependent upon granularity of the emulsion than any other factor. Although a certain level of sharpness is necessary, it should never be forgotten that sharpness, as such, without any specification of focal length, conveys no guarantee of good resolution of ground details.

Spectral response indicates the range and peak of that portion of the visible spectrum to which a given emulsion is sensitive.

Many other experimental film types are available and being tested.

But first, reference to the characteristic curve must precede detailed discussion of variable factors in development. It is the most common reference point utilized in describing variations in density scale (or contrast), and gamma rating (or relative contrast). The characteristic curve (Figure 8) is used in this text merely as a graphic reference for clarification of statements written in the following paragraphs.

Density, by definition in the photogrammetric sense, is a measure of the degree of blackening of an exposed film or of the direct image in a positive print-out material. Density scale indicates the range between the highest and lowest densities in negative images. The term density scale or range is often referred to as the contrast capability of the negative or positive material. This must not be confused with the usage of contrast as it is applied to imagery analysis. In this latter instance, contrast is intended to indicate the relative physical appearance of an object against its background. There the term has a subjective application.

A graphic representation of density range as applied to the characteristic curve is shown in Figure 9. It is shown here as a function of the relationship between exposure and the gamma value of a given emulsion.

The density scale of the negative is most influenced by three variable conditions: the brightness scale of the imaged object, the exposure level of the camera, and the degree of development. After the imagery has been obtained, only one of the three variable conditions listed can be altered--the degree of development. It also is probably the most important single factor which can affect the density scale.

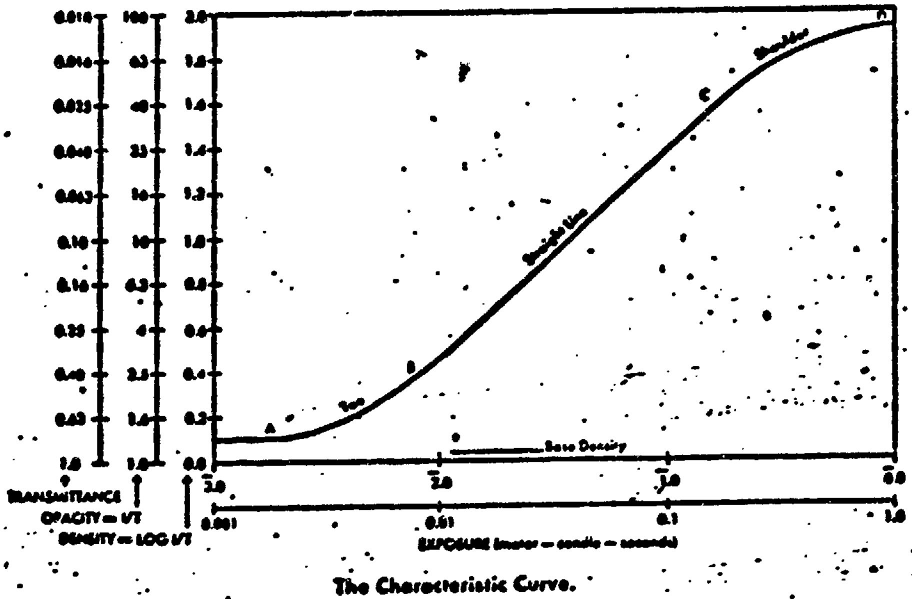

Figure 8. Typical characteristic curve.

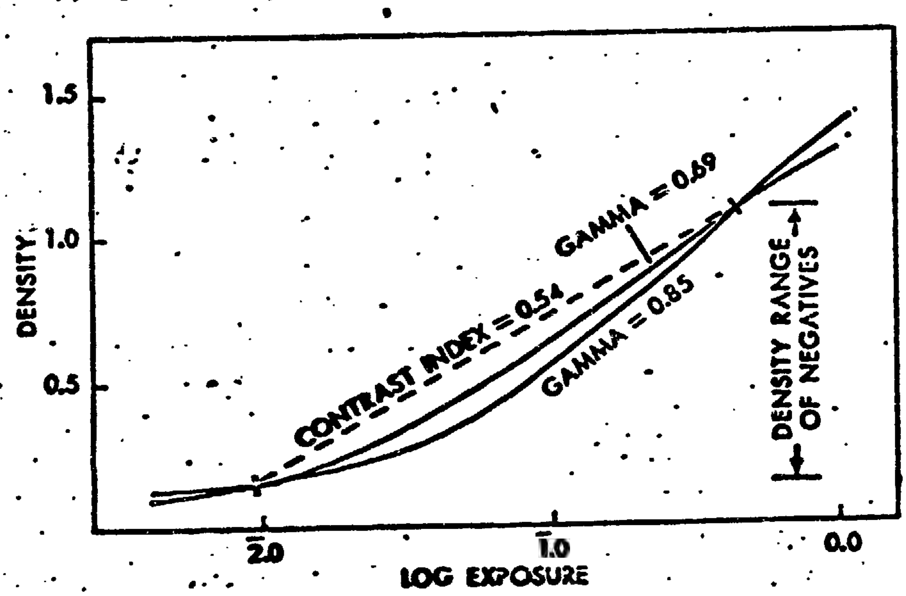

Figure 9. Gamma-density relationship.

Of the many development changes possible, variations in development <u>time</u> apparently offers the most satisfactory method of controlling the negative density scale. The range may be regulated toward either maximum or minimum density as shown on Figure 9.

Gamma is a term used to denote inherent relative contrast of a given emulsion and also the degree of development. It may be expressed more clearly as the relation of a negative contrast (or density scale) to subject contrast or brightness range. Gamma is synonymous with the angular measurement formed by the slope of the straight line portion of the characteristic curve (B-C, Figure 8). As long as most of the negative density range falls within the bounds of this straight line, gamma can be a reliable guide to contrast. If most of the density range registers on the curved toe portion of the curve (A-B, Figure 8) it then becomes an unreliable guide to contrast.

The preceding description of density, density scale, and gamma is, by necessity, an oversimplification of each. In reality, the terms are interrelated to such an extent that each is dependent upon the variable conditions created by the others.

[redacted] [redacted]

Resolving Power and Ground Resolution

There is a general consensus that the primary limiting factor in identification and mensuration of small objects is resolution. This being the case, it is well to take a critical look at resolution, for the photoanalyst is concerned with photography mainly as a working tool in order to identify, describe, and measure an object through the medium of the photographic image. Again, as in the problem of optical acuity, we have to consider the camera, the film, and the eye. For any optical instrument a theoretical limit of resolution may be calculated on the basis of the wavelength of light and the diameter of the lens. It is said that, for the eye, the image of an object must have a diameter of at least 0.002 mm on the retina (46). A circle 0.1 mm in diameter at a distance of 12 inches from the eye should be distinguishable. For the eye we have, whenever necessary, additional magnifying devices beyond the present capability of any film.

If we are to work up to that limit we should have a clear understanding of what is meant by resolution on photography, how resolving power is derived and measured, and just what values and problems it contributes and leaves unsolved in the analyst's quest for knowing what he sees and his attempt to mean what he says. How is a certain resolving power applied to a particular film, and of what practical use is such knowledge to the analyst? Is there possibly a better or simpler way to define that quality of the film which is paramount in its use?

Photographic resolving power, as an industrial concept, is the capability of the camera system, lens plus emulsion, to resolve and reproduce fine black and white lines. The finer the lines resolved the higher the resolving power of the photographic system in use. Resolving power is expressed in lines per millimeter.

These three statements generally constitute a photoanalyst's introduction to the capability of the photographic materials which are to be the tools of his trade. If he is inquisitive he may attempt to learn more, and what he usually finds out before ceasing to be concerned is that the lines/mm is convertible to the ability of the photography to reveal the image of an object of certain dimensions at a certain scale. He discovers that, when working with a certain photographic system, he should be able to see, under magnification, objects that are, say, ten or five feet in width, whereas with another system he should see something only one foot wide. As he becomes familiar with more and more photography he realizes that in many instances he sees perimeter fences around secured sites, that such small-scaled objects as electric power lines and guy wires of towers are clearly discernible on coverage which is not black and white but actually a motley assortment of grays. He discovers that, stereoscopically, he may see through haze or overcast sky, and that lines/mm is most often a completely disregarded term. He is not necessarily disturbed by the increase of knowledge, but he is by the lack of any clear explanation of why and how there seem to be only vague connections between theory and practice. Let us investigate the former and attempt to put the latter on a reliable base of reasonable terminology.

The concept of resolving power and the tests devised to determine the resolving power of an optical system originated in astronomy. There, where the photographic telescope is turned to the night sky, it is always impossible to see the individual smaller stars, although it can be known beforehand that a certain instrument is capable of detecting stars of certain magnitude. It is sometimes difficult to separate the images of two distant points of light, such as double stars. A standard test for determining the qualities of a lens capable of resolving such stars was developed by G. B. Airy in the 19th century.

A lens, whether single or complex, does not produce a perfect image. This means that a point object will not produce a point image but a central prominence surrounded by a blur or diffraction pattern. A single point image, if large enough, is distinguishable as a blurred entity. In his studies of the size and relative luminance of the image center and the surrounding zones formed at a focal point by a beam of light passing through a lens, Airy proved that the pattern was the function of the wavelength of light and properties of the lens in use. Because the central point in such a pattern is so great in comparison to the diffraction pattern surrounding it, the latter was disregarded and the central disk is said to constitute the image of a point object. This is known as the Airy disc (Figure 10a). Unless centers of two such points are separated by a distance equal to the radius of a single point image the two points are not separately distinguishable by that particular lens system, in which case they are said to be not resolved (Figure 10b). When a series of discs of known size is rated against a certain lens the resolving power of that lens or its amplitude reduction curve is determined along with its optimum focal length.

As the science of photography developed, involving lens capabilities and object sizes, the concept of resolving power was applied to it and a similar test was devised that is used to measure the resolving power of

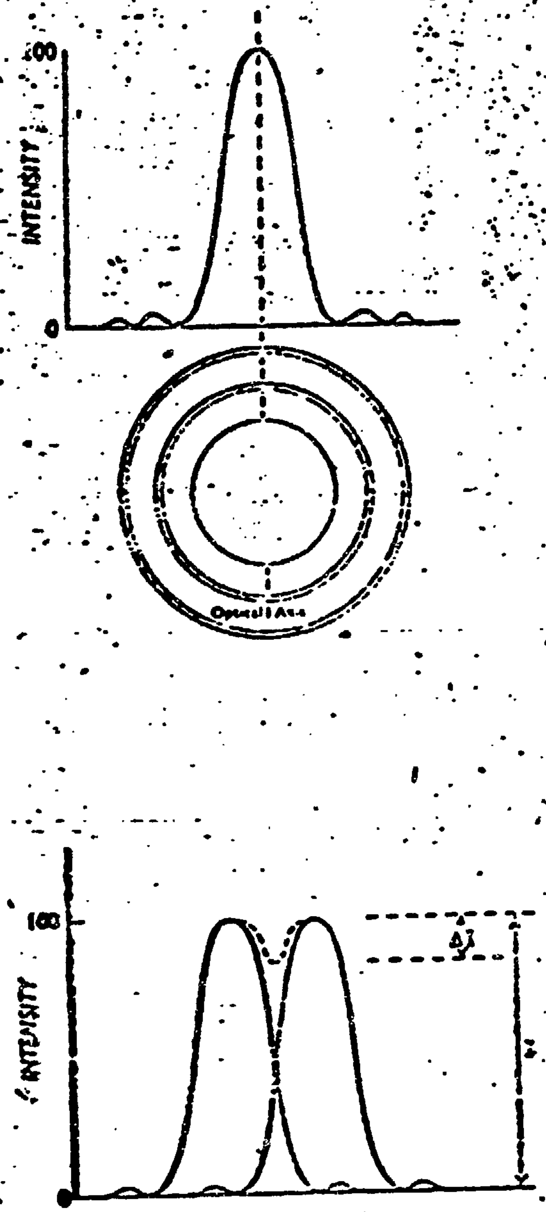

Figure 10. a- Diffraction pattern produced by perfect lens.
b- Resolution between two close images.

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the system used for aerial photography. Lenses used for aerial photography are subject to tests, both visual and photographic. The test with which we are concerned here is the resolution test, in which standardized charts are photographed at different focal settings for the lens. When images on the finished negative are found to have the best overall definition of the smallest possible test pattern, the equivalent focal length of the lens is determined.

The resolving power of the lens is determined by the rating of lines per millimeter of the finest line pattern which is fully resolved into separate lines on the negative. The exposure and development of the film must be adequately controlled to conform to the test situation. If the width of a line plus an adjoining space in the pattern is 0.5 mm wide, and the rate of reduction from the photographed chart to its image is 40 to one, the actual width of the finest line and space on the chart is an eightieth of a millimeter, and the lens is said to be capable of resolving 80 lines/mm. This is lens resolving power rather than photographic resolving power which has a test of its own. For resolution of two image points from a good camera lens, the necessary separation is such a small quantity that it causes little difficulty in the production of good aerial photography. This is because the size of silver halide grains, the active ingredient in the photographic emulsion, is so much larger that granularity of the emulsion is the present limiting factor.

By its very nature, camera film, which is made up of a more or less thin coating of emulsion on a fixed base, cannot capture the full integrity of an image which comes to it from the camera lens. When the image falls on the photographic emulsion it suffers a certain diffusion which is relatively more serious the smaller the detail.

In order that an image be visible when a photograph is enlarged or magnified there must be a higher potential of visibility than that limited by the scale of the original negative. For the film, the upper limit of effective magnification usually occurs at the point when the diffraction blurring of the image on the film becomes a distraction sufficient to offset the gain in visual acuity. In other words, the photoanalyst is accustomed to using film under higher and higher magnification until it "falls apart," which is when the graininess of the photograph interferes with further analysis of the image. The present limit of visibility under magnification is thus seen to be set by the grain structure, or granularity, of the emulsion, the individual silver halide grains. The film therefore has limited resolving power which is a limiting factor in photoanalysis. Typical values of film resolving power are supplied by the manufacturer.

[redacted] [redacted]

For typical aerial camera film there are two defined sets of resolving power presented in the lines/mm framework. One is the total overall resolution and the other a contrast factor relating to brightness and tone. These lines/mm limits are innate to the film emulsion, [redacted] and mean simply that a standard processed negative image can be magnified only within the limits set by the resolving power before undue deterioration of image quality sets in. It is not essential to think of the two emulsion factors, gamma and contrast, separately in order to see the relation between lens and film in resolving power. There are extractable qualities of the film emulsion that can be evaluated against the focal length-resolving power capability of a camera lens which permit most effective combinations of the two.

The terms resolving power and ground resolution differ in meaning but in discussion of photo interpretation analysts, often unknowingly, use the former when they should be using the latter. The resolving power of a system, or any of its component parts, is known or can be determined before the system is activated in-flight. Its meaning is of real significance to photogrammetric and optical design engineers because it relates to the objective capabilities of the overall photographic system. On the other hand, ground resolution is a measure of the capability of the system as expressed by results obtained on the imagery, which are affected both by in-flight conditions such as light attenuation, contrast ratio, and image motion compensation, and by the reproduction and processing of the film in the laboratory.

The photo analyst is most concerned with the ground resolution of a system and what its implications are in regard to fulfilling his specific [redacted] requirements. For this reason it is felt that ground resolution, [redacted] warrants more detailed discussion.

When the photo analyst is informed that the ground resolution obtained, [redacted] is one foot, it is generally his conclusion that one-foot objects, observed on the imagery, are identifiable and measurable. In practice however, this does not hold true for many of the [redacted] items observed. One must understand the precise meaning of the statement [redacted] This is a measure of the ability to resolve a resolution target of uniform size and separation with an object-to-background contrast ratio of five-to-one (Figure 6). Most [redacted] items in a natural setting have, at best, a two-to-one contrast ratio. This would reduce one's ability to resolve a target within the stated one-foot figure. This does not mean, however, that one cannot detect and identify objects much smaller than [redacted] but only that they cannot be measured to a meaningful degree of accuracy. A perfect example of this is the ability to see and identify power lines when the object-to-background contrast is favorable and/or light is reflected from the object in a specular manner (Figure 4).

Resolution, by definition, indicates the ability of a system to render a sharply defined image. Many items, smaller than the stated ground resolution, are detected and identified even though they are definitely not sharply imaged. The reason for this is most often the result of identification by association; aided by an analyst's skill and experience in a particular specialty. Object pattern and the knowledge that, in a given set of circumstances, a particular item could be present, is also an immeasurable aid in detection and identification.

In further assigning the proper perspective to a statement of ground resolution it must be understood that two adjacent targets, one oriented in an X-direction, the other in a Y-direction, will have different resolution values. This occurs because all image motion is not compensated [redacted] This is not necessarily a detrimental factor in detection and identification, but it must be considered in mensuration. Rather than applying a resolution value to an entire mission, it should be used as a comparative figure, indicative of relative resolution between two or more missions.

It may eventually be possible to derive factors that can be applied to aerial image characteristics to determine photographic resolution of chosen emulsions. But because resolving power depends on contrast the resolving power is lowered under field conditions such as haze and other factors that lower the tone of an object. Resolving power actually performs no function in definition of an object by virtue of distinguishing its contrasting parts. Higher resolving power in a system is a laboratory or comparative factor only.

In review, it should be emphasized that ground resolution in aerial photography is not to be regarded as a characteristic of the system itself. It is a threefold combination depending on the light source and its energy; the instrument and its capabilities; and the receiver and its sensitivity. It becomes rather meaningless to speak of resolving power under these circumstances, but the practice is continued. Conventional resolving power concerns only calculated images and has very little meaning compared with the ground resolution to be applied to detected images, which is the value of practical interest for those who work with aerial photography.

Photoanalysts are really interested in a scalar value that can be applied directly to the film and used to derive actual dimensions of the object image. At present this value is best expressed in terms of ground resolution, which is minimum object size measurable, [redacted] But even ground resolution is not constant because landscapes are not plane surfaces, photography is most often not vertical, and the image may not be at the nadir of the photograph.

FIELD CONDITIONS

The Nature of Light

Light is radiant energy evaluated in proportion to its ability to stimulate our sense of sight. Through space it travels in straight lines, commonly referred to as rays. There is a repeated pattern of electric and magnetic forces along the path of such a ray. The unit of the pattern in this repeated sequence is the wavelength of light. Light waves approximately 400 to 700 Millimicrons long are normally sensed by the human eye (Figure 11), and are said to be the link between the object which is seen and the viewing eye which sees the object. For a given amount of light intensity the eye is relatively insensitive to the red end of the spectrum. Sensitivity increases through the spectrum from red to yellow-green (about 554 millimicrons) and beyond that point diminishes to reach insensitivity in the violet region (Figure 12). The exact wavelength of light which is most readily visible changes with the intensity of light as is shown in Figure 13. Light perception and color sensitivity vary from one person to another; the variations in these, however, are due to human factors and are not physical attributes of the light, as such.

The scattering of sunlight in the atmosphere results in the phenomenon we know as daylight. When the air is sufficiently clear we recognize direct sunlight and extended visibility. When air contains appreciable amount of water vapor, dust, smog, or other particles, differentiated as Rayleigh or Mees atmospheres depending on elevation, known collectively as haze, there is weakening of sunlight as a result of loss of light scattered skyward again, as well as limitation of distant visibility which results from actual interference of particles and from diffusion of light in the surface atmosphere. Light rays that undergo either refraction or reflection in the course of passing through the atmosphere experience some polarization before reaching an object on the earth's surface. Because blue light survives the journey better than the other wavelengths we have the impression that the sky is blue. The depth of blueness is a measure of the amount of light broken up chromatically. In the various shades of blue the discerning individual recognizes certain meteorological or atmospheric conditions. To such an individual even the elevation of the sky is not a constant. "How high is the sky?" is not an idle question.

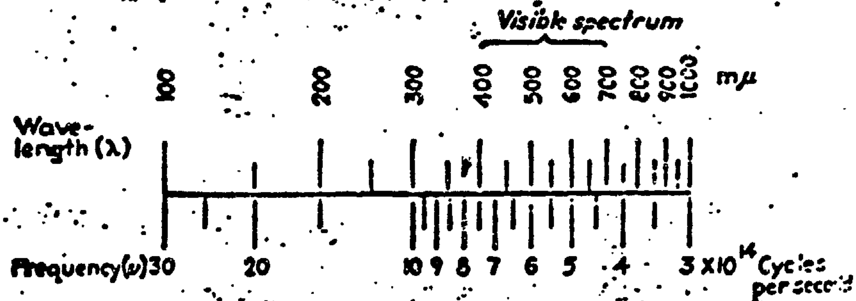

Figure 11. Wavelength-frequency relationship for the visible and adjacent spectrums for light traveling in free space.

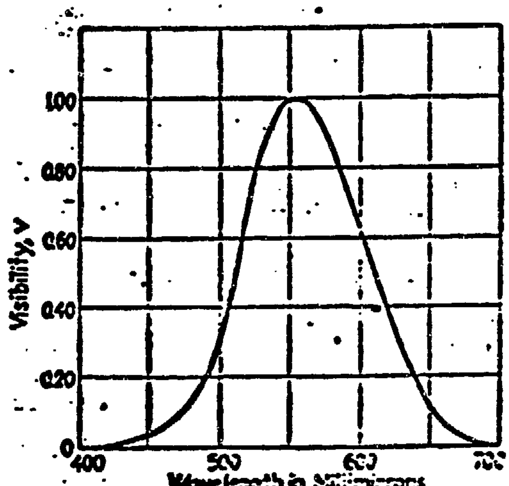

Figure 12. Spectral sensitivity of the normal human eye.

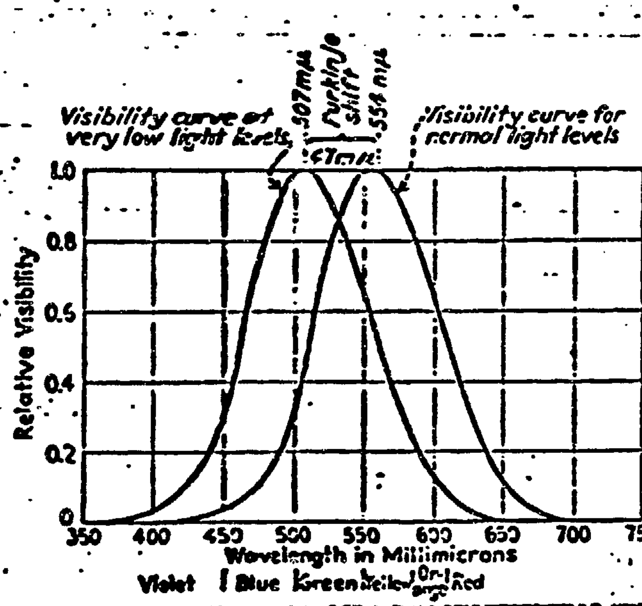

Figure 13. Relative visibility of the normal human eye at normal and greatly reduced light levels, showing the Purkinje shift.

Light in the Atmosphere

The usefulness of aerial photography always depends on atmospheric and lighting conditions at the time and place. [redacted]

[redacted] the state of the atmosphere may allow photography of great clarity, of complete lack of any imagery from the earth's surface, or of some intermediate state. To the photoanalyst the exact cause of the obscuration is of interest mainly as he seeks to fully understand the whole condition under which the achieving of photography is limited.

In photographing the light reaching the camera from the ground through clean air is appreciably attenuated. The long paths of light waves suffer more from attenuation. Obviously, the greater the distance the light must travel through the atmosphere, the greater the variety and amount of attenuation produced.

All particles in the atmosphere contribute to some degree to the scattering of light. Scattering occurs as either reflection or refraction and is one of the major processes involved in the attenuation of light waves, and, consequently, in the procurement of aerial photography. It is manifested by the scattering of different wavelengths of light in direct proportion to the size of the atmospheric particles which they may strike. Therefore, the denser the atmosphere and the more diverse its molecular composition, the smaller the number of light waves properly reaching the desired object on the ground.

Playing a less dominant role in the attenuation of light waves is absorption. In absorption, light waves are completely assimilated by atmospheric particles equal to or greater in size than the wavelengths of light attempting to penetrate. A high content of moisture in the atmosphere is the most absorptive condition usually encountered and the most damaging in the procurement of usable photographic images. The common relegation of absorption to a less dominant role in attenuation is due to the fact that it is significantly minimized on a seemingly clear day, whereas scattering always occurs, regardless of atmospheric conditions.

The majority of the light waves which ultimately reach the object on the ground is reflected back into the atmosphere, either in a diffuse or specular manner, and is subject to further atmospheric attenuation along its path to the camera. In addition, the effect of light radiated upward from the atmospheric impurities may be even more important. This light plays no part in the image formation but, falling upon the camera lens

[redacted] [redacted]

along with the image-forming light, it weakens the image and further lowers the contrast of the scene. The term haze is used for both the minute particles in the atmosphere which impede light and vision and for the lack of transparency of the atmosphere. Its effects are important. Haze modifies imagery both before and after the image-creating light falls on the object of interest. As light is filtered earthward through haze it becomes diffused and scattered instead of direct, with an apparent tendency toward scatter in a forward direction. Fully diffused light is incapable of creating shadows; it limits variations in reflectivity from unlike surfaces, and is devoid of strong contrasts.

The scatter of blue light by thin mist or haze is sixteen times the scatter of infrared light. By applying an infrared filter to screen out the scattered blue and other visible light waves, a clear picture may be obtained through mist or haze. However, the desirability of this procedure is dependent upon the sensitivity of the recording film to insure that there is no appreciable loss of resolution. Ultra-violet light, which is said to be scattered by haze in the atmosphere to a much greater extent than is light in the visible spectrum, is particularly effective in causing deterioration of the photo negative, which degrades the picture contrast.

There appears to be no way to measure the amount of atmospheric attenuation encountered on photo imagery. At present the only way to quantify atmospheric conditions is to use verbal description. Such terms as clouds, haze, fog, and poor image quality are the most commonly used. If it has been impossible to circumvent undesirable atmospheric effects in the camera and film systems, there is nothing the analyst can do to increase the information transmission capacity of the imagery.

Reflection and Imagery

Light reaching through the atmosphere to an object is absorbed, transmitted, or reflected according to physical laws governing light propagation (Figure 5). The absorbed portion turns into heat energy which may be detected by special non-visual sensors. If some of the light is transmitted it passes through the object in obeyance with laws concerning the density of the materials through which it passes. The reflected light, the portion in which we are interested in aerial photography, is reflected into the atmosphere, carrying potential images of the objects from which it is reflected.

Only by being reflected from the object does light convey the image to the camera where it is captured by the film, or to the eye whence it is conveyed to the brain and translated to a mental image. As the amount of light or energy increases, the ability to capture an image or stimulate the sense of sight varies from zero to a certain maximum and back to zero again. With complete lack of radiant energy, image projection is impossible. Optimum light falling in clean straight lines on common surfaces creates sharp contrasts, strong shadows, and clear visual images. Greater absorption of light by an object results in darker imagery; greater reflection causes lighter values. Overabundance of light reflected from a surface, whether diffuse or specular reflection, obstructs the image and produces in its place a formless blob of light (Figure 7). Within the image producing range the actual amount of light reaching the camera film or the retina of the eye is less important than the clarity of the image which it transmits, the sharpness of the image boundaries, the strength of its contrasts, the perfection of image transmission.

The reflecting capability of an object or surface varies with the nature of the material from which the object is made, with its surface, and with the angles that its various portions, large and small, subtend to the direction of the sun, the eye and camera. Where the surface of an object absorbs and transmits much of the incident light a lesser amount of light will be reflected (Figure 5a). If the object surface is rough in comparison to the wavelength of light, its elementary sections lie at various angles to the direction of incident light, and the reflected rays are scattered in many directions. If the surface is minutely rough so light is uniformly scattered in all directions the reflection is said to be diffuse (Figure 5b). A matte surface is diffusely reflective. Diffuse scattering of light seriously affects object definition on a photograph. On the other hand, a smooth metal object or water surface reflects light from a single plane, the surface, and mainly in a single direction. This is called specular or regular reflection (Figure 5c).

It is important to note that for each ray of light the angle at which it strikes the surface, the incident angle, determines the angle at which it is reflected (Figure 14). If the sun is high in the sky it will be necessary to be closely above an object to catch strongly reflected light. We earth-bound creatures have more occasion to experience light reflected from low objects, such as house windows facing a sunset, or headlights from oncoming cars shining on rainy pavements.

Very little effort has been made to clarify what actually happens when specular reflection strikes camera film. To fill the photoanalyst's needs the explanation is simple. In aerial photography of highly polished or smooth surfaces, the amount of direct reflection may be so great as to completely destroy the image of the area from which the reflection comes. Destruction of such an image results not from the actual failure of the light to carry details or outline of the image, but from the incapability of the film coating to absorb immediately the overabundant light. The resulting irradiation within the emulsion has the same net effect as the inability of the human eye to see through a blinding light.

The quality of an image is determined by what happens to the light reflected from an object as a whole and from its component parts. Image sharpness and object definition on a single photographic mission with a given quality of film may vary from excellent to useless, depending upon the clarity of the light which reaches the object, the reflecting capability of its surface, and the perfection with which the image is transmitted through the atmosphere to the camera and film. If the surface which faces the camera has variable light absorbing capacity, this should be revealed by variations in gray shades, from black to white. The shades and variable qualities of images are referred to as tone. Distinction between tonal values, their contrast, is as essential to photographic imagery analysis as light is to vision.

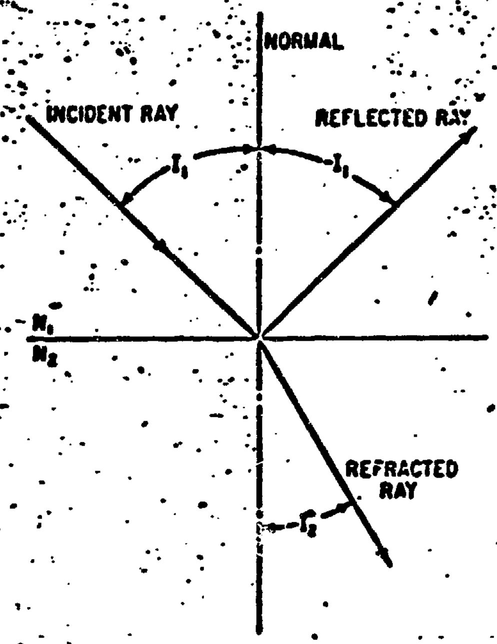

Figure 14. Relationship between a ray incident on a plane surface and the reflected and refracted rays which result.

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VISION

Its Relation to Light

Astronomers have found that if an observer is placed in a dark room having only a very small opening towards the night sky, he can see stars of magnitude 7, 8, and even 8.5. This is so because the stars are then seen against a dark background. It is the brightness of the sky on which the stars appear which prevents us from seeing these dim stars under ordinary conditions of observation. The illumination produced by the faintest star we can see with the naked eye is about 10^{-14} times that produced by the sun. This means that the earth receives from the faintest star, per unit area, an amount of light which is one hundred million million times less than that received from the sun. In tests determining the threshold of vision the amount of radiant energy or light required is taken as the energy content of the flashes which are seen in a proportion of the trials equal to 55 percent frequency of seeing range from two to 5.6 times 10^{-10} erg. The mechanical energy of a pea falling from a height of one inch would, if transformed into luminous energy, be sufficient to give a faint impression of light. These figures tell us something of the high quality of our visual sensitivity.

The deciding factor in vision is not the amount of light but the wavelength. The magnitude of the energy quantum is inversely proportional to the wavelength of the radiation, as is shown in the following example. The energy of a quantum of violet light of 400-millimicron wavelength is twice as large as that of a quantum of red light of 800-millimicron wavelength. A flux of light does not behave as a stream of individual quantum particles, like a series of bullets. It is only when light interacts with matter, for instance when it is absorbed by the retina, that its quantum properties come into evidence.

In the case of a human eye, vision is achieved by its refractive system. Light coming from all parts of an object falls on all the external parts of the eye. As a result of the passage of light through the transparent media of the eye, the rays originating from the same point of the object are, ideally, reunited at one point of the retina so that to each point of the object which emits light there corresponds a point on the retina which receives some of this light. These corresponding points are arranged in the same order on the object and on the retina. But no optical image is ever completely sharp and clear. Because of light diffraction and optical aberration the average eye does not reach the theoretical limit in its functional activity. In

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seeing, the sharpness of the image is determined to some degree by the accuracy with which convergence of light onto the retina takes place. Normal visual acuity approaches the limit imposed by size and spacing of receptors in the fovea. The sensitivity of the eye is so high that it comes very close to the absolute limit set by the quantum properties of light. Its maximum accuracy in the discrimination of form is high enough for the wave properties of light to have a strong bearing on the subject. It is expectable therefore that the theory of the natural limit of sensitivity and accuracy of physical instruments be applied to the study of the physiology of vision. But it is equally expectable that not all attributes of vision are directly comparable to those derived as either attributes or limitations of such physical instruments.

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Visual Acuity

Acuity, a dictionary synonym of sharpness, is also defined as the ability to see fine details of an object, or as keenness of sense perception. To the degree that it is mechanical, visual acuity is comparable to the resolving power of a camera lens. As a physical phenomenon, visual acuity is measured in terms of a critical dimension (diameter, width, or other scalar value) of a black test object just barely detected on a white background. It is defined as the reciprocal of the visual angle subtended by the smallest details which the eye can distinguish, in this case the thickness of the black bars, similar to those in the camera and film tests. This angle is expressed in minutes of arc, so that if the thickness of the bars which are distinguished corresponds to an angle of one minute, the visual acuity is unity; if it corresponds to 60 minutes, the visual acuity is 1/60. Standard visual acuity is defined as the ability to see an object so small that its image subtends an angle of only one minute of arc at the eye. This one-minute standard is said to be used in optometric tests involving letters on wall charts.

Tests of visual acuity are commonly made with black or colored test forms on a white or luminous background. Recognition of such objects depends on other variables besides size and shape, and on the whole is thought to depend on distinction between object and background over a sufficient distance to permit discrimination. When black test objects are used with a sufficiently wide, luminous background or surround, it is found that visual acuity increases with increasing background luminance until it reaches a maximum value after which it rises no farther. This is in keeping with the everyday observation that in dim light we are unable to read fine print which is easily legible at higher illuminations, while on the other hand there is a limit to the fineness of detail which can be seen with the naked eye even in sunlight. Objects of lower contrast need to be larger than a black-and-white test object in order to be detected.

In one field experiment it was found that a wire was seen against a sky of high brightness when its diameter subtended only half a second of visual angle. For this it was found that the wire had to be at least one degree long. Shorter wires had to be thicker. Silhouetted squares were seen at angles of only 18 seconds. Considering length and width, squares were more efficient visual targets than fine lines by about a factor of three. In another test it was demonstrated that the seeing of fine wires in horizontal or vertical meridians was superior to such seeing in oblique orientations. This may be of interest to anyone concerned with imagery because there are, apparently, no dioptric factors to account for such selectivity. In another study of visual texture discrimination and depth perception, results are believed to

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show that connectivity detection is basic to both of these visual tasks and that it is a more primitive process than form recognition. From such tests as these one may anticipate further understanding of the visual process which may be of service to the imagery analyst.

In actual practice, the ability to see and the objects that one sees do not necessarily conform to theoretical findings. This is particularly evident in photoanalysis where much of what is written on the subject is reported as the results of tests involving either purely mechanical bases or human vision under prescribed conditions. There is no doubt that much of the testing and reporting is both valid and valuable, and that the better read analyst is the most versatile in appreciation of his own visual processes. However, it must be realized that the experience of photoanalysts does not occur under controlled conditions but rather over the full range of light, contrast, object variety, and scale of necessary definition. The purpose in cartography is to reproduce as faithfully as possible exactly what is seen on the photography used for that purpose. That cartography and imagery analysis are two different fields of competence is strongly avowed by anyone who has changed from the former to the latter. There seems to have been little investigation of what an analyst really sees on photo imagery and the mental comparisons and processes by which he produces his findings. It is not surprising that the mature analyst has developed reflective and reasoning abilities that are not verified.

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Stereoscopic Vision

There appears to be some confusion as to just how stereoscopic vision takes place, both as a visual activity and with respect to the attributes of the two images that enable it to result in three-dimensional perception. The exact nature of the seeing process is obscure and is not a part of the current discussion. But the attributes of the two images that are detected and analyzed in the visual process which results in stereoscopy are the subject of some concern and difference of opinion. On the one hand it is said that stereopsis will occur when correlatable stimuli are out of phase with respect to some reference system such as another set of correlated objects. Any mechanism which can detect the correlation between the binocular stimuli and also detect a difference in their phases can yield representation of depth. Fusion is not necessary. A slightly different dimension is given to the problem in considering disparity, probably the most responsible factor in stereo acuity. It is said that disparity exists between two points when they occupy different visual direction. Disparity is an adequate stimulus for stereopsis when there are other points of different disparities in the field; only similar objects can fuse and therefore only similar objects can be seen in depth when they are disparate. The fusion concept fails to predict outcome where depth occurs without disparity except on the outer edge of the patterns. Elsewhere it has been said that monocular acuity depends on a process of boundary recognition, whilst stereoscopic acuity relies on pattern recognition over large areas. It is not expected here to explore the subject further except to observe that the exact nature of the process is important to the photoanalyst because of its bearing on the processing of film to be used in stereoscopic study. If it is not known whether the effect of fusion or disparity, or the recognition of edges of areas, is the more important, there is a question as to the desired processing of an individual negative or positive for special study purposes. Solution of such problems as these should be sought from actual operational material and varied processing rather than from laboratory test objects because the latter do not include the natural variables which are found in the former.

A clearer, more meaningful concept of stereoscopy as the photoanalyst makes use of it is contained in recognition that the absolute convergence of a single point never determines its apparent depth in a stereoscopic image. Its relative convergence with other points is used by the brain to locate it with regard to those other points after the general position of the image is fixed. In binocular vision there is a fixed tie between accommodation and convergence. Thus in looking at a point two feet away the eyes are focused for a two-foot distance and the axes of the eyeballs intersect at two feet.

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Regardless of the distance of the fixation point, nearly the same angle of convergence always goes with a given focus, only varying slightly for objects not directly in front of the observer. Both change together as objects of different depth are viewed. In stereoscopic vision this established tie is broken. The two views of the point on the stereograph determine the convergence. This convergence changes with changes of separation between different points on the two views. However, the accommodation remains constant, i.e., the focus of the eyes is either fixed for the distance from the eyes to the stereograph or by a distance dictated by the lenses of the stereoscope--usually infinity. This split of the accommodation-convergence habit is the outstanding difference between binocular and stereoscopic vision. Since the eyes are presented with a situation foreign to binocular vision, the psychological interpretation tends to differ from that of binocular vision.

In very simple stereographs containing only separate points and lines and viewed without a stereoscope, the resultant interpretation tends to place one prominent point or plane of the picture--called the "fixation" point or plane--in or near the plane of the plate. Thus one point is approximately determined from the accommodation. The depth of the rest of the points of the picture are interpreted from this point in accordance with both the relative convergence with this point and the other depth factors relating the points and objects to each other.

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CHARACTERISTICS OF THE IMAGERY

Tone

The total image on overhead photography exhibits a variety of related conditions: tone, brightness, surrounds, sharpness, and contrast; whose effects must be evaluated in order that object recognition and description may be accomplished. Of these, tone and brightness are direct aspects of object appearance and result from light modifications as the object modulates or attenuates the incident radiation both in intensity and color. The quantitative relationship between the light or photometric input to a photographic system and the output of that system is expressed in terms of tone of the developed photograph image.

Tone, generally defined as color quality or value, or a distinguishable shade variation, is detectible as visible differences or textural values in the gray scale or density level on black-and-white photography. It is the overall tonal quality that makes one photograph immediately more attractive than another, and the textural quality of individual portions of the photograph that give it character. A very small inequality in the tonal level of a positive may play a significant part in the information quality of an image reproduction, and careful control in the photographic laboratory is essential to first class imagery. For specific purposes, such as image enhancement, the tone quality of adjacent portions of the film may be varied by controls in the reproduction process.

Tone reproduction is concerned with the relationship that exists between the object and its image. There are two distinct phases in the conventional approach to the solution of tone reproduction problems. The first phase deals specifically with the objective or physical relationships of the tone reproduction cycle. The second deals with the subjective or psychophysical factors which relate to the human observer. It is in connection with the first, or objective, phase that analytical methods of particular interest to engineers have been developed. For the photoanalyst the main concern is the relationships between tone differences on the photographic copy in use and the assurance with which he can derive the image they represent in order to identify and describe the original represented by that image. By tonal and textural evaluation he distinguishes between a flat, smooth, hard surface and one with notable depth or minor irregularities. A functioning railway (Figure 15) appears different from a rail line under construction where the rails are lacking. Hard topped roads differ from dirt surfaces, grasslands from shrubbery as a ground cover, a corn field from a meadow.

FIGURE 15

Photograph showing rails and ties on railroad bed.

Brightness

As changes in wavelength of light cause changes in tone, so changes in its amplitude result in luminosity or brightness changes. Brightness of individual colors increases with intensity or amplitude of light and is highest in yellow light. But in this sense it must be distinguished from the curve of energy of the spectrum which rises, with wavelength, from the violet to the red end. Brightness is the attribute of a light source by which it appears to emit light from a minimum for very dim to a maximum for very bright, the measurement being in lamberts or candle power per square centimeter. With the use of a photometer it is possible to measure differences in brightness varying on the order of one to several million. Vision is said to be at its best when brightness contrasts are about 1:20, and without visible discomfort if less than 1:100. Much lower contrasts are discernible. Flash glare or spot glare causes strained brightness accommodation. The optimum level of brightness varies with the image.

Actual levels of brightness vary with clarity of the atmosphere, the time of day, angle of the sun, and the season. Variation with clarity of the atmosphere is well illustrated in differences in photography on clear and hazy days. Objects of different brightness in clear light are said to suffer the same proportional reduction in brightness by haze. With increasing light scatter the difference tends toward unity of brightness, and thereby to decreased contrast.

Differences resulting from time of day are well recognized by aircraft crews who fly mapping coverage, their flights generally being restricted to the time of day in a desert region when the air is calm, or in a humid region before air humidity reaches undesirable concentration later in the day. The relation of photographic brightness to angle of the sun is illustrated by the desirability of shadows sufficient to show some detail but not to obscure brightness and outline of related images. Seasonal differences cut across all of these. One investigator found, for example, that in Washington June morning light is brighter and June afternoon light is duller than December's. Strictly seasonal differences include the dark quality of burgeoning vegetation or the albedo of snow cover.

The range of brightness which can be acceptably recorded represents the useful range of a photographic material. Invisibility is experienced when emulsion sensitivity is insufficient to record an overweak light source. Irradiation results when the upper limit of brightness is overreached. When specular reflection or overbrightness occurs the emulsion suffers excessive particle activation and the resulting image is only a nominal representation of the object. There are instances when specular reflection from small objects such as wires or other smooth metal objects thus bring into the range of detection images that could not otherwise register within the limits of the resolving power of the film. The useful range of negative film is greater than the range of brightness in the vast majority of subjects photographed. The exposure scale of positive materials is much less, and in general the higher the gamma to which it is developed the lower is the material's latitude of capability.

Ideally, a photographic objective should be capable of reproducing accurately the full range of brightness in the object photographed. In order to do so, it is necessary that each area in the image receive light only from the corresponding area in the object. When other than true image-forming light falls upon the image area, an adulteration of brightness occurs and the photographic reproduction lacks the brightness quality possessed by the original subject. If the negative image were perfect, and the brightness of the photo copy, translucent or opaque, varied exactly with the brightness of the negative, the photographic image brightness should be comparable to that of the object as seen by the human eye. Because exact rendition of brightness fails to occur at each stage in the process, the ideal image is never fully realized.

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Surround

The surroundings, generally called the surround, of an object are influential in its detection, enhancing the possibility when differences are notable, minimizing it when they are minimal. Probably the most notable difference, and one often overlooked, is the general site location. A man-made site is most apparent in an otherwise natural setting (Figure 16). A missile or industrial site in the wilderness, a frequented waterhole; [redacted], a trail across the desert: these are most obvious not because of size, luminance, or tone, but because of differences in context. While it is true that what the analyst sees depends on the perception of differences in luminance and tone, and that these are used to distinguish an object from its surround, it is important to bear in mind that the term surround encompasses an overall view of the site in which an object occurs. In this respect we distinguish between surround and contrast.

An object anywhere is recognized because it has different tone or brightness from its surroundings. Brightness difference allows a distinction of the border between an object and its background, which, according to tests, can be rated as a product of the area and the luminance, one decreasing as the other increases. With low contrast object and background the size of the object must be greater in order that the brightness differences can be detected. It has been said that larger targets require less contrast but more total flux as the area increases until a certain stage is passed when the required contrast becomes independent of area. Although it is also reported that the greater the ratio of length to width the greater contrast required, it must be realized that under field conditions this is not necessarily true. The relationship also varies notably with shape and fine detail of a complex object.

It is difficult to compare profitably actual photographic analysis problems with such laboratory test series on object and surround. In test studies the objects are most often simple geometric shapes of different shades from black to white viewed under different brightness conditions. Under field conditions it is only rarely that the analyst seeks a simple geometric object or a uniform tone. The surround of an object is stable on any single or stereo view, but the contrast between the two parts of a stereo pair may be revealing. This is mainly as a result of the luminance and tone and not because of the change in the surround as such. The effects of variations in luminance on recognition of an object on a dark or light ground is difficult to equate with the effect of object size, shape, and composition as it actually occurs on one set of coverage in comparison to another. It is the analyst's feeling that there needs to be a clarification between the objective concept of surround and the analyst's interpretation of the word.

FIGURE 16

Photograph:

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Sharpness of Definition

Sharpness of definition relates to image clarity rather than to contrast as a term denoting differences in either brightness or tone. Thus it is not precisely synonymous with contrast, although the two are known to act together to enhance or degrade the value of the photo coverage. For example, a hazy atmosphere degrades the definition of the object by diffusing the light before it strikes the object, as is exemplified by lack of shadows. At the same time the atmosphere lowers the photographic contrast, reducing both brightness and tone. But the two differ in their effects on image clarity. Although the general effect of flare (non-image-forming light) is to increase illuminance of every point of the camera image and to reduce the contrast, it is said that over a limited range of exposure a certain amount of flare, or for that matter haze, can actually increase contrast in the negative. It is possible for the overlay which affects image quality to be either lighter or darker than the object of attention.

In addition to brightness contrast and tone contrast, image clarity is affected by the depth of focus of the lens, by the position of the object image on the film frame, and by the relation between sun angle and camera. In optical terminology the term depth of focus means the total allowable variation of the sensitive surface, from the position of best focus, within which the image is tolerably sharp, according to a given standard of performance. In aerial photography the range is understandably wide and the image clarity variable.

Object distortion can be thought of as variation of magnification with field angle. All other things being equal, an object is most perfectly defined at the nadir of the frame. It tends to be degraded with position elsewhere by imperfection of the camera lens (no lens is perfect), by the increasing distance of the object, by attenuation of the image, and by the look angle of the object. The desirable look angle of an object is not necessarily the same as the desirable mensuration angle. The look angle on vertical photography has been said to be best if shadows fall toward the observer.

But the presence of shadow often obscures details which are more important than comfortable viewing.

Clarity, a

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subjective sensation, refers to the quality aspects of photographs associated with which ease of visibility occurs, while sharpness of an object image refers to the degree of resolution of element detail as is determined by granularity and resolving power of the film.

Mechanically, the outline of a black object on a white background is a sharp line, and the object's dimensions can be precisely determined. Theoretically, the contrast in photography of a black and white test object should be equally distinct. But, because the photographic emulsion is made up of myriads of miniscule irregular particles, the line is not a sharp cut between the white area from which all color has been removed and the black area which has suffered no effect from exposure. Instead, there is a zone, however narrow, of gradual change between the black and white. The quality of a picture is closely related to the shape of the curve which describes the brightness transition from a light to a dark area, the edge gradient.

The character of that zone, the steepness gradient of the curve revealing the remaining emulsion density contrast, or the sharpness of the image outline, is referred to in photogrammetry as the edge gradient or the spatial induction, depending upon whether the investigator is concerned with the steepness or declivity of the most nearly vertical portion, the edge gradient, or the width of the zone, measured horizontally, between the density plateaus of the pure white and pure black, which is referred to as spatial induction. In the mechanical derivation of an object image on photography the edge gradient may be employed to distinguish the most probable locations of object perimeters, from which mensuration is possible; or the width of the zone of gradual change, by means of which a longest or shortest distance between object perimeters permits a greatest or least size to be attributed to the object as a whole. The procedure, however, is not altogether that simple because data for the photographic mission, as well as object position on the frame, are entered into the machine calculation to account for additional mechanical variations in image response. And, just as the visual analyst's photographic image clarity or sharpness of definition is subject to environmental conditions and optical limitations in determining the object's absolute position and size, so the photogrammetrist has problems of equal complexity in his determinations made from mechanical response to the photography.

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Contrast

Contrast is the expression of difference in brightness, color, or tone, and in aerial photography analysis it is used to denote recognizable differences in both mechanical and visual stimulation. In mechanical considerations, negative contrast is defined as the difference between maximum and minimum densities of the image. In this context the contrast of a duplicate positive may depend on the brightness range of the subject, the degree of exposure of the film, or the degree of development, often confused with gamma which is relative contrast. The terms contour, border, and outline are equated to contrast location in that they are used to indicate the narrow region that separates something from something else on a photographic image or other two-dimensional representation. In photogrammetry contrast differences are measured in a variety of concepts such as spatial induction, edge gradient, object modulation, modulation transfer function, and others. Each of these is basically an analysis of the horizontal or spatial difference between two adjacent, measurably or visibly different fractions of the image, or between two recognizable differences in density of the emulsion. Unfortunately, in the emphasis on mensuration it is frequently the deriving of the exact location of a boundary line that appears to be the most important contribution expected of the photo analyst. That analyst makes a distinction between a target which can be discriminated and described because of contrast and the evaluation of a minute area which outlines differences of brightness or tone, such as are the subject of laboratory studies of contrast.

Contrast has been equated with brightness range of a subject, completely disregarding tone. But contrast may also vary from weak to strong according to the degree of differentiation between tones of a photo image. Pattern recognition by the visual analyst depends as often as not on non-adjacent variations in contrast, either luminance or tone. In this context contrast has long been used in a descriptive sense rather than as a mensural quality. And, as the imagery analyst uses it, contrast can mean the comparison of relative luminance and tone differences between two or more sequential images of an object.

Visually, though not for mensuration purposes, the exact edge of a contrast need not be precisely located, but the concept is confused by statements which make distinctions between surface contrasts on opposite sides of a line of separation, and the implication that contrast occurs directly at the border. It is true, photogrammetrically, that a contrast effect takes place at a line of separation, but in imagery analysis the actual contrast between two things involves two areas rather than limitations of the edge or space separating

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the two. When sharply outlined edges or contrast borders occur in photo imagery there is no detectible increase in contrast across the borderline as distinct from the contrast of adjacent areas. As a matter of fact, in analysis experience on aerial photography there is, probably more often than not, a natural decrease of contrast near the edge. A few examples will serve to illustrate. A concrete highway does not immediately abut the grass or forest cover of the area it transits. Invariably there are shoulders or disturbed areas with intermediate tone. A slanted or rounded roof loses contrast near the edge, due either to differential reflection of light or to diffraction. A pond of water is almost invariably surrounded by a moist but not surficially wet shore zone which is frequently undiscernible on black-and-white coverage but nicely detectible in certain chromatic photography.

The behavior of object contrast, both as to brightness and tone, must be considered in the recognition or detection performance of a photographic system and the resolution of a standard film type. According to a report on tests on object recognition it has been found that if a lens is found to have an angular resolving power of, say, 1:2,000 for detail of contrast 0.2, it will resolve from 20,000 feet details ten feet apart on the ground if their contrast with their surroundings is 0.2, but much smaller objects will be seen in the negative if their contrast is high enough. White objects on a black background, for example, will be resolved if they are about five feet apart. Conversely, objects of lower contrast than 0.2 will be seen in the imagery only if they are larger and more widely separated than ten feet. In this case the contrast differences are due to object and background tone and not to changes in luminous flux or brightness from test to test.

It should also be remembered that single objects will often be recorded at sizes smaller than the limit of resolution for two adjacent objects. As the camera gets farther away from an object, its image at first gets smaller in accordance with the laws of geometrical optics, but eventually a stage is reached at which the patch of light is the smallest that the lens will give. If the camera continues to recede the size of the image remains about the same, but its contrast with the background diminishes, since less flux enters the lens to be concentrated in the luminous patch. The distance at which the object finally vanishes in the negative depends mainly on its contrast with the background, though the contrast of the emulsion also has some influence. The shape of the image at this stage is mainly determined by the characteristics of the lens and bears little relation to the shape of the object, but it will be recorded in some fashion from much greater distances than might be expected from the resolving power as determined by standard tests. As an example of this kind of effect, negatives taken from 10,000 feet with an eight-inch lens will often show the white broken lines painted on roads for traffic control at corners; the individual white patches are of the order of three inches wide, while the ground resolution from that distance with that length lens is approximately two feet for black-and-white-line test. The nominal resolving power of a lens-film combination has therefore to be used with care in attempting to predict the size of objects which can be recorded from a given height; some thought has first to be given to their nature and the contrast with their background.

One of the greatest problems in photo reconnaissance is caused by low levels of contrast. After identifying the existence of a contrast there is concern, photogrammetrically speaking, with the linear shape of the line of differentiation, or its acuity. In much of the test work reported on photogrammetric studies, emphasis has been put on the premise that visual acuity depends in large measure on the ability to perceive contrast at the border of the object. It has been suggested that the critical region of a target is a ribbon just inside its perimeter.

When mensuration is attempted the sharpness of a contrast becomes objectively important, as does the abruptness with which the variation takes place. Attempts made to correlate sharpness ratings with physical measurements of some aspect of the developed image have not been entirely successful. Neither resolving power nor simple density relationships across an abrupt boundary between light and dark areas result in satisfactory correlations with sharpness ratings. Because the existence of contrast is the more clearly discernible and the less adapted to determination of its origin, the greater emphasis in photoanalysis has been placed on its quantification and, as a result, the term contrast is now most commonly used to indicate the density difference or edge gradient. Whether, photogrammetrically, a contrast is a contour to be perceived, a spatial deviation to be resolved, or an edge gradient, there is more to the concept of visual analysis than a mere dimensional value, and more to interpretation of photo imagery than definition of perimeters.

The details of an object, as they appear in duplicate positive-transparencies, are often incapable of definition. They may have suffered reduction of contrast which always obscures some of the smallest details of any object. In visual analysis that obscuring is not necessarily synonymous with lack of object identification. Mensuration of the minute detail would truly depend on sharpness of contrast between its area and its surround. But this mensuration activity should occur only after recognition has taken place; and, from the photoanalyst's point of view, the need for mensuration must depend on determination, by other aspects of the imagery, otherwise derived, that the minute detail is worthy of mensuration.

Lighting Defects

Other than poor contrast, lighting defects are usually referred to as flare, light scatter, poor image quality, or halation, which plays little, if any, part in modern photography. Any report, written or verbal, which fails to use these or other terms adequately also fails to convey to its recipient actual conditions which may be of significance. Any explanatory term should convey a message. Transmission of ideas can be notably improved, and even reasonable understanding of the imagery may benefit, by knowing and using each term to mean what others expect it to signify. Poor image quality, a catch-all phrase, if used only for the briefest reporting, may suffice as a general excuse for limited review. Light scatter, used to indicate diffusely reflected light, actually says nothing about an image nor its quality. Light scatter and flare should be distinguished from both diffuse and specular reflection. The latter is also sometimes referred to as glare, because it comes from particularly highly reflective surfaces and results in excessive irradiation. Much of what is commonly referred to as either flare or halation is also irradiation.

In professional usage flare refers only to the non-image-forming light coming to the film from light reflection within the camera. Non-image-forming light from extraneous sources has identifiable characteristics and should be identified by other terms. Light scatter results from atmospheric conditions and manifests itself in the reduction of contrasts in the image because of excessive amounts of light being reflected from the atmosphere into the camera. These two effects are clarified in the following explanation. Although the non-image-forming light must be considered as part of the image which acts upon the negative material, it is convenient in the treatment of the tone reproduction cycle to refer to the camera image as distinct from the flare image. In this sense the camera image may be attributed only to the light coming directly from the object by virtue of the refractive characteristics of the lens system. The flare image is not an image in the conventional sense, since it conforms to no geometrical pattern, but a veil over the entire image plane. Its effect is to increase the illuminance of every point of the camera image and to reduce the contrast.

One of the simplest explanations of irradiation is given in a dictionary definition, which states that it is the spreading of light by the grains of a photographic emulsion causing the developed image to be larger and more diffuse at the edges than the optical image. It is differentiated from halation in Figure 17. To a normal degree irradiation is caused whenever a beam of light enters an emulsion because the light is always scattered or diffused to some extent by successive reflections from the silver halide

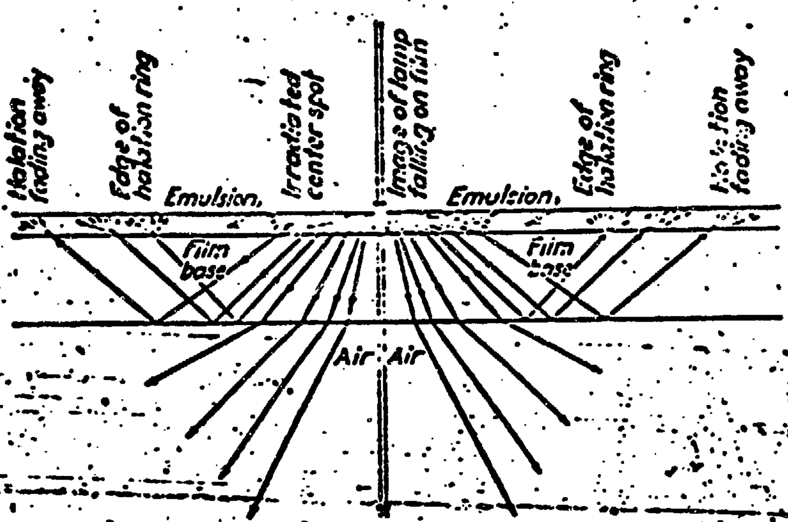

Figure 17. Diagram illustrating the difference between irradiation and halation.

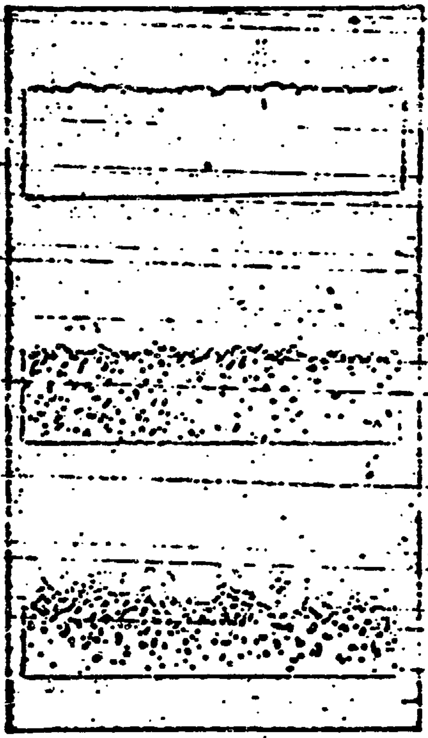

Figure 18. Imagery of the edge of a razor blade from fine and coarse grained emulsions.

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grains in the emulsion. The greater the exposure the more pronounced the spreading of the image beyond the boundary of the exposure on the surface. Irradiation is the term which fully covers both the cause and effect of such diffusion of light.

The amount, character, and dispersion of light are not alone responsible for irradiation effects in photography. Layer thickness of the emulsion and its grain size also affect light distribution at the time of exposure. Results of one study, investigating these factors in connection with image definition, indicate that the exposing light diffuses more the longer it travels through the emulsion layer, i.e., the thicker the layer. It appears that definition decreases with increasing emulsion-thickness, possibly because of increasing light diffusion for thicker layers where the total amount of scattered light is the same. The heavier scattering in high silver halide coating weights offsets the advantages of increased contrast. Really fine grain emulsions show little irradiation (Figure 18). The process of light attenuation in the development of duplicate positives from original negatives is ordinarily explained by absorption and scattering of the light by the substance of the image.

A phenomenon that must be understood if analysis of lighting defects are to be meaningful is halation. It was coined in the early days of photography when glass plates were used as backing for emulsion. It was shown to arise from light being reflected from the far side of the glass plate, or the standard film backing, and thus affecting the emulsion beyond what should have been the normal boundary of the image (Figure 17). It occurs when image forming light passes through the film. Some of the light is reflected back into the emulsion and, because of light diffusion, this light spreads sidewise beyond the boundaries of the image and thus reduces the sharpness of the latter. If a small, strong source of light is in the field, and an especially large proportion of light is reflected at an appropriate angle the image of the point of light is surrounded by a circle or halo--whence the name. Halation is comparatively small when the thickness of the emulsion is so great that the emulsion absorbs most of the image-forming light, or when the emulsion contains the diffused light so well that little passes through the film. In current practice an opaque backing is used for both glass plates and camera film. In aerial photography nonhalative film is now used exclusively and with such success that film experts report that halation is no longer a problem. However, those who have not investigated its meaning persist in using halation as an expression for light defects of all sorts, of which irradiation, flare, light scatter, and specular reflection are important in present photographic practices. Each of these has a particular meaning which is as important to the photographic analyst as are the exact meanings of tone, contrast, and other terms which give his work a scientific base.

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OBJECT RECOGNITION AND IDENTIFICATION

A principal conclusion of objective interest is the observation that under uniform illumination, such as found under cloudless daylight conditions in aerial photography, the luminances of a group of subjects will be directly proportional to their reflectances. A principal aim of the several technical, photogrammetric and photographic skills is to provide aerial coverage in which the reflectances will be proportionately imaged. This is a point of contact in imagery between the objective or engineering aspects and the subjective role and operations of the imagery analyst.

3 - The recording or definition of an object on photography is obviously not the same as object recognition as a visual performance. It has been said that the most urgent task in the general problem of qualitative evaluation of a photographic system or of its separate elements--photographic material, lens, etc.--is the establishment of a clear relationship between the results of objective measurements and the visual perception of the image. In photography the capability of defining the object depends on the sufficiency of film quality and processing for adequately registering the object. Visual recognition requires an object size and clarity that are within the range at which the eye, with or without supporting optical lens, can detect the image because it exhibits a sufficient lateral size. The object must be above the limit of registration of the photographic system currently in operation. Recognition of small objects is enhanced by sharpness of outlines, closely related to graininess of the film, and by the clarity of detail, a subjective term that signifies overall appearance or good seeing quality of a piece of film, which is quite often related to contrast. The objective basis of small detail readibility is in the photographic capability of the combined film and camera system. The problem has been separated into its component parts in the observation that, with highest, black-and-white contrast, the smallness of detectible objects is a measure of the capability of the photographic system or the absolute or differential sensitivity of the eye. These conditions are readily differentiated in photographic analysis.

7 - For the imagery analyst the main concern is the assurance with which he distinguishes character differences of the photographic copy in use and with which he recognizes the details of the image in order to identify the object represented by that image. For him imagery analysis consists of two different processes, image detection and recognition and object identification and description. As the new analyst familiarizes himself with imagery he draws on several unrelated experiences. He has looked at ground photography and so is acquainted with landscape imagery as such. He has looked down on landscapes

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either from a hill or mountain or from an aircraft and thus recognizes layouts and tonal differences. He realizes that many elements of a landscape may be perfectly familiar and identifiable, but, if put to a test, he knows that in no view will he be able to identify everything. Some of the elements will be as unfamiliar to him as a word on paper is to the illiterate. And some of the elements will be too small scale for seeing.

2 - His greatest help in early stages of training comes from looking at imagery and having pointed out to him the images of things with which he is familiar, roads, buildings, aircraft, trucks, and representative patterns. This makes him a photo reader. But he becomes an independent analyst only when he studies the unverified coverage and discerns something for which he has had no previous evaluation. Only experience, a conditioning process, can make a dependable analyst of a photo reader, but he can be amazingly assisted along the way if he knows why he discerns only so much at any stage in his training. An analyst acquiring skill in identifying and describing specialty objects, industrial sites, military installations, [illegible] or whatever, will learn more slowly than the analyst who already has competence in another specialty field because the latter will know from experience what specialty competence involves. Detection requires only the recognition that there may be something of interest at a particular spot on a photograph. Recognition requires areal limitation; identification means establishing the essential character; and description involves recounting or classifying critical features. In reflection, it seems rather incongruous that such competence stems from such a simple thing as the appreciation of tonal variations.

A wide variety of tests has been made to measure an individual's ability to see as a physical performance and as a mental perception. When this ability is applied to skill in reading photography the question becomes terrifically involved because very little serious attempt has been made to distinguish just what the analyst can be expected to see physically from what he may be able to interpret and rationalize because of special knowledge or skill in a certain field which may be of photographic concern. It is doubtful that the quantities derived from any number of relatively simple vision, detection, perception and recognition tests can add up to an adequate conclusion of the total quality of an analyst's performance. His recognition or detection performance may rate higher or lower than his ability to identify a site.

Let us take, as an example, the recognition of an installation made up of six or eight component parts in more or less well defined arrangement. If photo scan reveals most of them, the expert analyst will know where to

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search for the missing bits and recognize ill-defined but nevertheless detectible indicators near the threshold of vision. Failing this he may know whether there is enough assurance in the parts he sees, and the condition of the photograph, to postulate that the installation can be verified without them. At this point the seeing, or visual acuity, must be distinguished from the mental, or subjective, activity.

Throughout reports on vision the term threshold is used in irreconcilable connotations. It is commonly used in a step-sequence sense such as brightness difference or contrast thresholds, which are only detectible variations of a quality rather than the introduction of a new effect. The simplest use of threshold, in its unique meaning as a point of beginning, is the threshold of vision, which has been defined as the minimum perceptible luminance after adaptation to utter darkness in test situations has become complete. Such a test involves a person sitting in a dark room, knowing that, after his eyes have become accommodated to the dark, a faint light will come on in small step increments and that he is to indicate immediately his awareness of the light at whatever stage he first detects it. This is a measure of a person's brightness perception, but as it is neither detection nor recognition of an object image, this threshold has no real place in photo analysis.

Another use to which threshold has been put is the threshold of recognition, or of recognition or detection, as if the two were identical. Here threshold is used in a meaning of significance to the photo analyst. Image detection involves simply the awareness of a presence, such as is indicated in the statement that objects in tests be large enough so that the detection threshold is not a limiting factor. In other tests where form thresholds are to be compared there is not a real threshold but a requirement of recognition, or identification, which are goals of the photo analyst. In the form test cited it was found that the form threshold varied directly with the ratio of perimeter to area and inversely with the magnitude of critical detail. Put in practical terms this means that with a given area a circular form is more easily distinguished than a square, rectangle, triangle, or irregular form, and an intricate design would be most difficult. This does not mean that a photographic image of one form could be detected more readily than that of another but, rather, that in real life simple forms are resolved and recognized more readily than complex ones.

as we see them

Image outlines in a camera film are dependent on what has been called the cumulative effect of everything affecting light from the object to the psychological system of the observer. The ability to see or to distinguish small details of an image always remains a goal of the photo analyst because

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the more he can extract from a photo image the more refined his interpretation can become. The photo analyst recognizes the small details both objectively and subjectively. If a simple image is large enough to be reproduced the task is a matter of observing shape, area, and other attributes that can also be measured and described equally well by another photo analyst or a photogrammetrist working from the same piece of film. However, the imagery analyst is rarely concerned with identifying a simple shape or image. He is generally concerned in what may be called installation analysis to differentiate it from component analysis or area analysis. True, he must evaluate the area or site location, and also the minor components or small items that are defined by contrast perimeters. But his most important function is the knowledge or judgment he uses in evaluating the imagery to compare such attributes as site size, location, and layout or pattern with the various components whose relative arrangement and proportions are collectively indicative of the installation purpose and capacity. The evidence of construction or operational activity at the site or in proximal or like locations is also important. Only the well qualified analyst can fully equate these attributes with the performance such an object would have. And if the outline and detail are vague he may discern sufficient detail to deduce whether what he is viewing has in fact certain features that he knows should or should not be there.

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SUMMARY

In this study attempt has been made to discuss photo analysis in general and its problem areas in particular from the viewpoint of the visual analyst, and to include basic factual or experimental data on which that analyst can draw to understand why and how problems and limitations in analysis occur. The scope, depth, and treatment of the material is expected to serve three distinct purposes. First, as a link between the active analysts and the non-imagery analysts [redacted]. It is necessary that certain ground rules, so to speak, be recognized in order that both groups know why sometimes the impossible is faced and why it is unattainable. Second, as a link between the imagery analysts and the photogrammetric, photographic and engineering professions, it has been suggested that such a discussion of visual analysis problems may be useful in directing improvement in both the imagery and its content and in the objective support provided to the visual analyst.

Last but not least, as a fairly complete coverage of analysts' problems and activities, it should serve as a useful reference. It may be read simply for informational purposes. It presents summary ideas and a wide variety of topics that are open to elaboration, discussion, and probably to disagreement. It may serve as an invitation and a starting point for airing and exchanging ideas. It should evoke suggestions and means for improvements in what the analyst does as well as what he produces. It should prove useful in helping anyone involved in imagery analysis or its benefits to face problems more realistically. It is meant to explain the basic difference and resulting conflict between visual analysis and the subsidiary activities that go into the analysis as such and into its exploitation and results. Most of all, it is meant as a catalyst to clear up static concepts in order that the dynamic functions of the art may be used as a basis for valid procedures.