Since errors introduce not only inaccuracies but also delay in the preparation of maps, the commercial firm, for economical reasons, is forced to assign values to various known errors and take these into consideration in completing the final map.

Such articles as those by Dr. Howlett, and Mr. Sewell, should be of aid along these lines to photogrammetrists in general, regardless of connection.

The chart accompanying the article on, "A Functional Comparison of Stereoscopic Plotting Instruments" is published with the hope that it will be useful, as a reference, for quickly comparing the various instruments that have been referred to many times in previous issues.

I should like to take this occasion to thank not only those who contributed material, but also those who had every intention of doing so, but did not find sufficient time prior to the deadline date.

K. E. Reynolds,
Rochester, N.Y.

PHOTOGRAPHY FOR SURVEY PURPOSES

L. E. Howlett

Head of the Optics Section, National Research Council of Canada

THERE was a time when mapping consisted of compiling data obtained directly in the field by measuring distances and angles. Many engaged in the actual compilation of maps had served in the field and through this experience had a feeling for potential errors and their relative importance from the beginning of the field measurements to the printing of the final map. Progress in survey methods has been very rapid during the last twenty years, and new branches of scientific knowledge have been introduced. Among these, photography is already of very great importance and consequently a careful study of the subject by photogrammetrists is justified. Similarly, radar will soon be widely introduced into survey operations, and will merit similar attention.

Photography introduced many physical phenomena with which map makers were not previously familiar, and even now full comprehension of these and their influence on map making is not always possessed by the personnel involved. The situation has probably been greatly aggravated by the fact that the widespread use of photography for amateur purposes has led many who should really know better to consider photography an art rather than a science. At least a general knowledge of the science of photography is essential to the photogrammetrist since so many photographic factors have a direct bearing on the accuracy of the final map. Without this knowledge it is inevitable that some potential errors are ignored, and others are put into quite the wrong perspective. Too often, discussions take place on acceptable tolerances for a certain stage in the mapping process, with apparently no thought, or even knowledge, of the fact that, in other steps of the photographic process, anything approaching the suggested tolerances is beyond present practice by reason of either inadequate developments or practical considerations of bulk, weight, convenience, and practicability. It is not uncommon to hear photogrammetrists who are content to map from paper prints urge stricter tolerances on lens distortion. Some complain of the dimensional instability of film bases and urge manufacturers to greater improvements when, at the same time, they are not insisting that all available means be taken to obtain optimum performance of present-day film bases. Such situations occur all too frequently, and there is consequently some value in a review of the photographic factors which influence the final accuracy of the map, and in placing these factors in correct relationship to each other and to the ultimate accuracy desired in the map. The intention will be to stimulate intelligent consideration of these factors rather than to provide an exhaustive discussion of them. Nevertheless an attempt will be made to draw attention at least to every important aspect of photography that concerns the photogrammetrist. Some of the points raised will be controversial, and, in such cases, conflicting issues will be delineated so that the photogrammetrist, who must always be the final judge, can base his decision on a full investigation of the facts set forth in the literature.

General Requirements of the Photographs

Photographs taken for mapping purposes must give two general kinds of information. First, there must be a sufficiency of detail so that topographic features can be identified and adequate descriptions of them obtained. Secondly, the geometrical relationships between images of details in the photograph must be such that the original geometry of the details on the ground can be deduced with minimum complexity by standard mathematical processes to the desired degree of accuracy. These two requirements will dominate the discussion of equipment, materials, and processes.

The Camera

The camera probably has the most important single influence on the quality of the photographs, in respect to both geometry and topography. It is a costly instrument, but, because the success of the whole operation depends upon its adequacy, the monetary value is of very secondary importance in comparison with the huge outlays that are involved for aircraft, crews, ground parties for establishing control points, processing operations, photographic materials, and the time expended by mapping organizations in compiling maps. Granting this rather obvious fact, it is surprising to find that many cameras lack one or more features essential to good overall performance. It is difficult to understand the reason for these deficiencies, because the really essential requirements of a good survey camera are relatively few and easy to meet. Disregard of these will do little to reduce production costs. The most likely explanation of the situation seems that the responsibility for the final design rests all too frequently upon those very competent in the design of mechanical features, but who are preoccupied by them to the detriment of the optical performance. Cameras should be designed by optical engineers, knowledgeable of the over-all requirements dictated by the camera's function, and who know how to combine optics and mechanics to serve this function successfully.

General Requirements of the Camera

No camera merits consideration as an accurate survey instrument unless the lens and focal plane, including the fiducial marks, are locked together as a rigid unit with such a degree of mechanical stability that disturbance of the geometrical relationships can be effected only by deliberate intent or physical damage.

It is not an essential feature, but for some purposes it is a very convenient one, if on this same unit there is provided a machined surface having a definite relationship to the axis of the lens and the lines joining opposing pairs of fiducial marks in the focal plane. Such provision is easily made and is of great value in certain problems of mounting the camera when its optic axis must have a definite orientation.

The Shutter

It is of fundamental importance that the negative be properly exposed, since nothing can be done later to restore information which is lost at this stage.

The only completely satisfactory sort of shutter for survey purposes is the between-the-lens type with high efficiency and capable of short exposure times. High performance aircraft are now commonly used in aerial survey operations. Unless sufficiently short exposures are available some form of image movement compensation will be necessitated for good quality photography. The shutter should be ruggedly constructed and capable of maintaining its calibration over long periods of operation. A common fault, even in otherwise good shutters, is that the leaves may bounce open slightly after closing at the end of an exposure. This is most undesirable. To permit repairs in the field, it is advantageous that it be possible to replace the shutter without disturbing the calibration of the camera.

Protection Against Veiling Glare

The inside of the camera body between the lens and the focal plane should be so designed that a minimum amount of non-image-forming light or veiling glare reaches the film plane. In a later section, it will be shown how such non-image-forming light, through reducing the contrast in the photograph, can seriously reduce resolving power. Early cameras with leather bellows were well designed for eliminating veiling glare. Unfortunately when the survey requirement of rigidity introduced metal camera bodies, many designers apparently forgot the importance of reducing veiling glare to a minimum. As a result, in some cameras the body so closely confines the image-forming light that marginal rays almost graze the walls of the body. Light from outside the field of view of the focal plane strikes the walls and is scattered or reflected to the focal plane. Specular reflections of the sun from highly reflecting surfaces beneath the aircraft can cause serious trouble. Light from clouds beneath the aircraft can be similarly scattered or reflected to the focal plane, and, although the results are less obvious, measurements show that the loss of resolving power can be serious.

A practical limit for reduction of veiling glare can be attained with little trouble by intelligent design. The interior of the camera body should be of sufficient size for the convenient introduction of baffles at appropriate positions, i.e. such that no part of the interior wall of the camera not screened by a baffle can be seen from the focal plane. The number of baffles required can be reduced to a minimum by a little consideration of the interior geometry. The edges of all the lens elements, the metal parts of the shutter, lens mount, diaphragm, and the interior of the camera body should be flat black. It should not be forgotten that the photographic emulsion in the focal plane is a reasonably good reflector. Properly designed lens hoods in front of the lens are valuable for excluding light from outside the field of view of the focal plane. It is well to have the shape of the mouth of the lens hood conform to the general shape of the picture format.

The Lens

The aberrations of the lens should be kept as low as possible. Two characteristics are of paramount importance in this connection. In combination with the negative material to be used in service, it must yield a high resolving power under conditions comparable with those to be encountered in practice. Methods of assessing this aspect of lens performance will be discussed later. Secondly, a survey lens must have very low residual distortion. The requisite degree depends upon the extent to which geometrical accuracy can be preserved in other stages of the photographic process and the mapping procedures. Very low lens distortion can, for instance, be quickly masked and rendered valueless when photographs are taken with inadequate care to preserve the dimensional stability of the film base. Too often, lens designers are urged to improve distortion by users of photographs who are wittingly or unwittingly accepting much greater distortions of geometry from other causes. This does not mean, however, that designers should not proceed with their efforts to reduce lens distortion, because in exceptionally well controlled operations, when photographic plates are used, advantage can be taken of immeasurably small lens distortion. At the same time, it is unlikely that with present-day film bases and every practical form of control for maintaining dimensional stability, full value of such freedom of distortion can be realized. The commonly used lenses in survey operations are quite sufficiently free of distortion to permit the residual aberrations being ignored in 90% of the user requirements at normal scales of mapping.

Focal Plane Registry

The film must be held flat in the focal plane of the camera during exposure. There are two common methods of doing this; a register glass against which the film is pressed, and a suction back in which air suction forces the film tightly into contact with a flat metal plate. It is doubtful whether a decisive case can be made for one at the expense of the other. Each has its peculiar advantages and disadvantages, but with proper service maintenance both give satisfactory results. A lens designed for a register glass must always be so used or an increase of distortion will result, although resolution would not in general be seriously affected if due allowance were made in focussing for the lack of the path in glass. A parallel condition obtains with lenses designed for suction backs. Sometimes exaggerated ideas are held as to the quality required in register glasses. Selected white plate is in general quite adequate if it conforms to the thickness required by the lens design.

Anti-Vignetting Filters

Nearly all aerial survey operations employ wide angle lenses. Unfortunately such lenses show a large fall-off in illumination from the centre of the field to the margins. This has a deleterious effect on the resolving power that will be obtained since the intrinsic resolving power of all photographic emulsions is a function of density. It is desirable to expose so that the optimum density range of the emulsion for resolving power is obtained over as large an area of the picture as possible. With wide angle lenses, unless corrective steps are taken, there is a loss of detail at the centre of the picture due to over-exposure, or at the margins due to under-exposure, depending upon which region of the field of view is exposed to the optimum density. The resulting negative will also be inconvenient to print. Dodging will be required and printing exposures will be unnecessarily long. It is therefore expedient to find a means of making the illumination reasonably uniform over the whole focal plane. This can be done in at least two ways. The filter in front of the lens can be given a properly graded density, or the register glass can be correspondingly treated. In both cases the graded density can be obtained by the vacuum evaporation of a suitable material such as chromel. If the treatment is applied to the filter in front of the lens, care must be exercised in service handling, particularly during cleaning. Such filters have, however, been successfully employed for long periods under service conditions without the need for recoating. The coating techniques should be such as lead to the hardest possible layer. The treatment of the register glass has the advantage that the graded density is well protected. Technically, there is little to choose between the two methods of compensation. Neither should be designed to correct the condition in the extreme corners, or unreasonably long exposures are necessitated. In practice it is acceptable to apply the correction so that the graded density causes no diminution of the original illumination beyond 35° in the case of lenses having a half angle of approximately 45°. This leads to sufficiently uniform negatives.

It is of interest to note in this connection that the relative aperture marked on wide angle lenses is misleading for selecting the proper photographic exposure. Conventionally the relative aperture is measured on the axis of the lens. With the fall-off of illumination in wide angle lenses, the effective relative aperture for exposing purposes is one that corresponds to an off-axis position, which is more representative of the average relative aperture over the picture area. This is only one of the unfortunate aspects of conventionally defined relative apertures for determining exposures. The general situation has recently been discussed by Gardner (1).

Magazines

The usefulness of large magazines in survey operations needs no justification. Provision of suitable means for movement of the film during exposure to compensate image movement will become of increasing importance.

Convenience of Calibration

Too many camera designs give no consideration to the convenience of those who will adjust and calibrate the cameras as survey instruments. Convenient fine controls are required. These involve little extra trouble or expense to the manufacturer. They must permit adjustment of the lens position in its own plane, or the fiducial marks in the focal plane. Since all users do not accept the same criterion for the photographic focal plane, a means of focussing the camera to meet individual preferences must be provided. This should be in the form of a spacer or spacers. Screw motions for this are not in general acceptable, because of the risks of accidental or careless derangement of the adjustment.

Provision for Mounting

Allowance must be made for some method of attaching the camera to its support in the aircraft. Trunnions are commonly used. It is important that the plane containing the trunnions or other means of attachment pass through the centre of gravity of the loaded cameras. This simple precaution greatly reduces rotational vibrations of the camera during exposure. This is obvious and is mentioned only because cameras are still available in which it is ignored.

In an earlier section, attention was called to the fact that for certain operations, such as trimetrogon photography, it is advantageous to have on the camera a machined surface which has a definite relationship to the optic axis and the fiducial marks. One method of so doing can be indicated. Rugged trunnions with holes can, after adjustment, be rigidly fixed to the camera. The trunnions are joined by means of accurately machined pins to their mating parts on the mount itself, the latter parts having been adjusted with respect to the mount. When the camera is thus attached to the mount it is held in the correct relationship to the other two cameras similarly attached for trimetrogon photography, or to some other definite direction for other special purposes. It is important to have sturdy pins, fitting accurately reamed holes, and of adequate length so that the preservation of accuracy with repeated camera interchanges is favoured. Crews must be familiarized with the precautions needed to prevent damage to the alignment when replacing cameras.

Camera Operation

Hand operated cameras are still used to some extent but automatic electrical operation is considered desirable for most aerial surveys. It permits the spacing of the exposures to be regulated by an intervalometer. It avoids the necessity of a camera operator in many cases and, where one is provided, he has more time and opportunity to make sure of the over-all success of the photography.

Recording Instruments

For many types of survey, it is advantageous to record on each negative at the time of exposure the readings of certain instruments. The selection of these will rest with the photogrammetrist.

Mounting the Camera in the Aircraft

The performance of a first-class survey camera can be very adversely affected by engine vibrations unless it is properly installed in the aircraft. The principal requirement of the mount is that it have a long period and be adequately damped. Friction is a convenient method of doing this. Very effective yet simple mounts were developed in England during the war in which the long period and damping was introduced by 1″ or 2″ thicknesses of sponge rubber having for the desired period an area appropriate to the weight of the loaded camera. Such mountings are superior to many more elaborate and costly types.

With sponge rubber the period is controlled and the damping supplied by the one means, and the constants are a complex function of a construction of the sponge rubber. The fact that the number of types of sponge rubber is limited no doubt encouraged mounting experiments in which the aim was to control the period by springs and to provide the damping by mechanical friction in the hope that such mountings would offer greater flexibility to the designer. The difference between kinetic and static friction is however a real difficulty in this type of design. At least one friction damped mount was developed in the United States during the war. Whether the added complexity and cost of such mounts can be justified has not yet been clearly shown because, although the range of sponge rubbers is limited, it must be emphasized that those presently available permit construction of very cheap, simple mounts, which actual trials have shown to be quite adequate for most purposes in aerial photography.

There is a simple qualitative way of judging the effectiveness of aircraft camera mounts. It is a necessary although not a sufficient condition that on pressing the camera in its mount there should be a feeling of softness and not rigidity.

For accurate mapping, the advantage is obvious of providing some form of stabilization for maintaining the camera vertical in order to avoid need for rectification.

The Camera Compartment

Mechanical and optical parts do not function well at low temperatures unless special rather complex provisions are made. The usefulness in military operations of cameras which will operate satisfactorily at extremely low temperatures may be very great. On the other hand, it should not be forgotten that it is relatively simple to supply hot air from the engine to an enclosure containing the camera. Only a careful operational analysis would determine whether the number of times such an arrangement is likely to break down in service justifies solving the many difficult problems which are introduced by the requirement that the camera function as efficiently at very low temperatures as it does at normal temperatures.

Not only do moving mechanical parts present problems at very low temperatures, but with long focal length lenses some automatic compensation must be made for changes in focal length with temperature. Even if this be done, there is still the risk that the glass elements of the lens have not had time to come to equilibrium at the ambient temperature before a photographic operation must commence. There are also the hazards associated with condensation on optical components when sudden changes in temperature occur. All these difficulties are avoided by keeping the temperature of the camera compartment reasonably close to normal room temperatures. In this connection one cannot help but view with astonishment the fact that camera filters are still being produced with heater wires to keep the filter warm and so avoid condensation. It was clearly shown as long ago as 1941 that this practice leads to serious loss in resolving power.

Whatever the merits may be from the military point of view of requiring that cameras function equally well at very low temperatures as at normal ones, there certainly seems to be no reason in ordinary peace-time survey operations to invite avoidable complexities with all the attendant possibilities of breakdown, when the difficulties can be completely cured by providing a heated camera compartment with a window of optical quality compatible with the resolution and distortion of the camera-film combination. Selected white plate is quite adequate for this purpose. It should be obvious that, in providing heat to the camera compartment, care should be taken to prevent a hot blast from striking locally any part of the equipment. However, since there currently exist installations in which this does occur, it seems worthwhile to mention the point.

Once the camera and perhaps the operator have been relegated to a separate temperature controlled compartment, it should only be a short step to provide some measure of humidity control. This will have a beneficial effect on the stability of the film base. The compartment can be maintained at approximately the condition of the air with which the film was in equilibrium at the time of spooling. Magazines can be loaded within the compartment, and assurance given that the exposing was done under known constant conditions of temperature and humidity. The dimensions of the film can be restored to those obtaining at the time of exposure on any later occasion by proper conditioning. Experiments to determine the advantage to photogrammetrists of such a procedure are now being carried out by the Royal Canadian Air Force.

Filters

A great deal of interest exists in the possibility of using filters to change the tone rendering of an emulsion with a view to increasing the amount of a certain kind of information that can be obtained from the photographs. The distinction between deciduous and evergreen trees by infra-red photography has no doubt had a great deal to do with the continual breaking out of this interest over a long period of time. Probably there are few other fields of photographic science in which so much effort has so frequently been expended on fruitless efforts to attain the impossible. Efforts to distinguish between various types of evergreens or various types of deciduous trees is a perennial sample of this. It is most unlikely that general success can be won by such means. The tone distinctions between the leaves of types within the two groups as observed from altitudes that make aerial surveys economically practicable are largely masked by a number of variable conditions which at present are certainly beyond control. Each of these conditions causes wider tone variations at the film plane than the tonal differences between tree types under the most auspicious conditions. It can be safely stated that, barring some radical new development, success with filters can only be expected when such strong reflective differences exist as for deciduous and evergreens in the infra-red. This tonal difference cannot be readily masked by the angle of lighting, the amount of haze, the altitude, the disposition of leaf surfaces with respect to the camera, etc.

During the war, a large number of very complete experiments were conducted to assess for reconnaissance purposes the relative value of panchromatic emulsions used either with a Wratten 12 or a Wratten 25 filter, and infra-red emulsions with an infra-red filter. The results showed that there were occasions when detail of a certain type would be revealed by only one of the combinations, but with none did this happen more frequently than with the others. In general, the same detail was recorded by all the combinations, but with different tonal values. Successful interpretation of any one combination depended only upon the experience of the interpreter with it. These experiments did much to justify, on experimental grounds, the previous widespread acceptance of the combination of a panchromatic emulsion with a minus blue filter for general purpose aerial photography. The experiment also showed that for general aerial photography other factors tend to neutralize the haze penetrating characteristics of the infra-red which might have been expected to give a considerable advantage.

Color photography under appropriate conditions gives more general promise of increasing information in aerial photographs than the selection of special filter-emulsion combinations for black and white photography.

Where detailed information is of the highest importance, such as in forestry and in geological investigations, the use of positive transparencies instead of positive opaques also has much greater potentiality of increasing available information than by varying filters. Again, it is strange to find those who are seeking detailed information from photographs using semi-matte positive opaques because of the ease of writing on them. With such positives, nearly half the information that could be obtained with glossy prints is lost.

From the results of a number of investigations, and from consideration of practical trends, it is suspected that the dominant factor affecting the amount of information obtainable from a photograph is scale, even when strong tonal differences exist. If true, this suggests that continuous strip photography at relatively low altitudes would be useful for detailed sampling of large forest areas already covered by normal vertical or oblique photography under standard conditions at higher altitudes. This photographic technique should also have value when standard photographic cover has suggested interesting possibilities of one sort or another in a local area.

Exposure

The plates or films for survey purposes must be properly exposed in order to obtain the greatest amount of information from the final photographs. The practical requirement of maximum information is not taken into account by the usual methods of assessing the speed of photographic emulsions. It is therefore of considerable interest to find the variation of information with exposure. The characteristic of the photographic emulsion which most directly affects the volume of information is its intrinsic resolving power.

The usual method of determining intrinsic resolving power has been to print on the emulsion, by projection or contact, a series of progressively smaller targets. A number of different exposures of the target should be given. This can be conveniently done by placing targets on each step of a typical step-tablet such as is used for obtaining characteristic curves. The density of each step forms the uniform background for the lines. This resolving power step-tablet can be printed with the ordinary sensitometric controls of exposure and processing. The illumination should be mean-noon sunlight modified by the operational filter. The exposure should be similar in length to the practical one. After processing under standard conditions, the maximum resolving power can be read for each step and a curve plotted which relates resolving power to the logarithm of the exposure.

The target used for the results presented here consists of three lines equal in width to the space between them and with a length-space ratio of eight. The results might have been more logically secured with the annulus target discussed later since they are to be used in determining exposures for lens-film combinations. However, the ones used were available and it was felt they would illustrate the argument sufficiently well.

The resolving power measured will depend on the contrast of the test target used. Figure 1 presents some resolving power-log exposure curves for Aero Super XX with targets of different log brightness ratio. The ordinate is the logarithm of the resolving power. The abscissa represents negative logarithms of exposures. It will be noted that in every case the resolving power rises rapidly from the threshold value to a maximum and then falls off somewhat more slowly at greater exposures. It is obvious from these curves that, if information is of prime importance, the widespread notion that any exposure on the relatively straight portion of a characteristic curve is a good one, is by no means correct. The proper region of exposure for aerial photographs is the one over which the maximum intrinsic resolving power of the emulsion can be attained.

It has been pointed out elsewhere (2) that it is logical to select as a reciprocal measure of the speed of an emulsion for aerial purposes, the minimum exposure necessary to obtain 90% of the maximum resolving power of the emulsion.

The contrast of the target materially affects the maximum resolving power and the resolving power speed. In aerial photography, there is generally greater interest in low contrast detail than in high contrast detail, and consequently it seems reasonable to accept a test target having a log brightness ratio of .2. When high contrast detail is of prime importance, slight modifications in the speed value of emulsions can be made if the circumstances justify this refinement. These will be rare since the exposure as determined for low contrast will be satisfactory generally for high contrast targets. Figure 2 shows the variation of log exposure for 90% resolving power with contrast for Aero Super XX developed to a gamma of 1.34 in D19b.

Slight under-exposure is a far worse error than a considerable amount of over-exposure. Over-exposures up to four times do not result in an extremely serious loss of resolving power over the range of brightnesses commonly encountered in aerial photography. Every effort, however, should be made to place the exposure in the optimum range. Figure 1 also shows the characteristic curve of the emulsion. The right-hand density ordinate applies only to this curve. It will be noted that the density range over which 90% resolving power can be obtained is from .4 to 1.2. This represents a log exposure range of .75. The latter circumstance is a happy one since this is fairly representative of the brightness range encountered in high altitude photography.

It has been shown that emulsion speed as determined on a resolving power basis can be measured with good accuracy by different observers on different occasions.

Altogether too much attention has been devoted to tone rendering in aerial photography. Tone rendering is a factor in resolution which in turn controls information, but it is an indirect one and the direct approach is much more satisfactory. It is too often forgotten that conclusions drawn with respect to tone

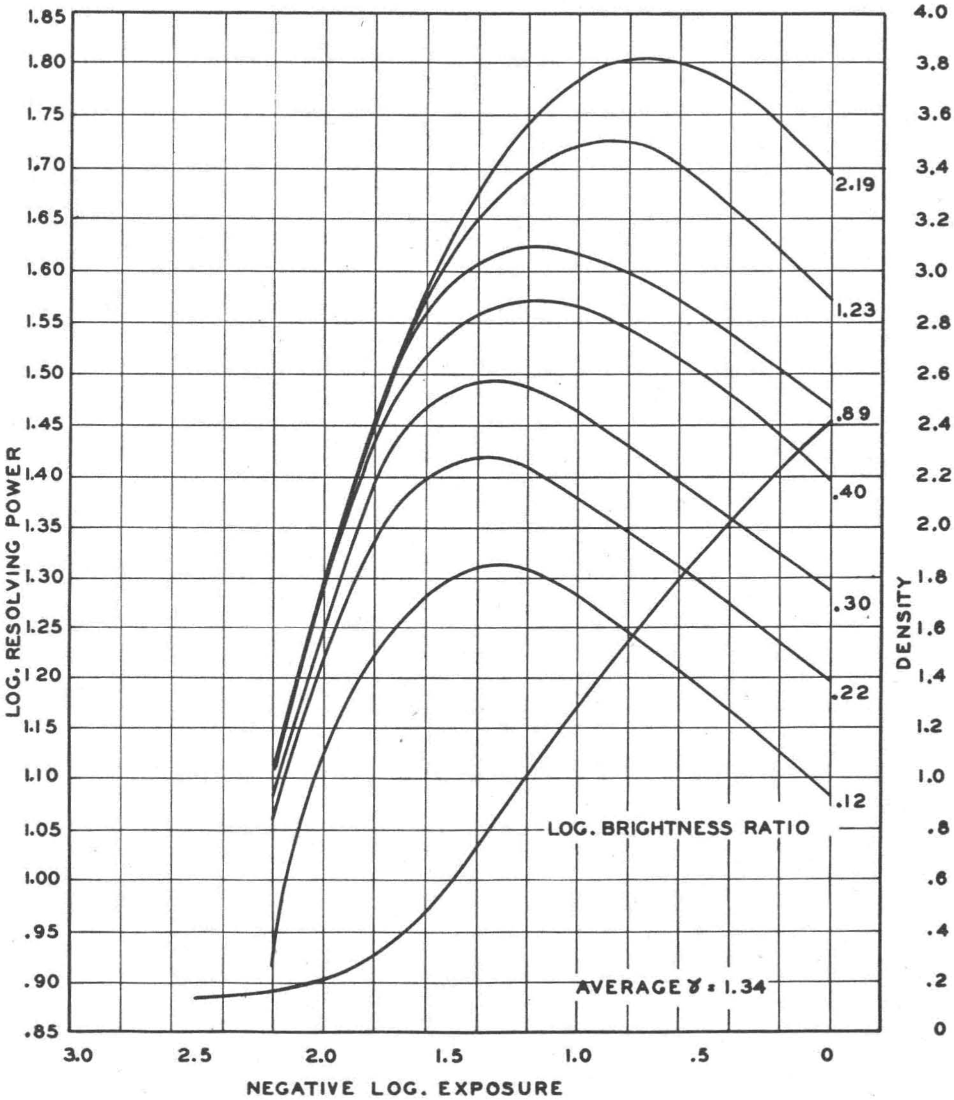

FIG. 1. The family of seven curves shows the relationship between resolving power and exposure for different log brightness ratios of the target. The characteristic curve of the emulsion is also shown. The density values of the right-hand ordinate apply only to the characteristic curve.

rendering from relatively large areas of density become increasingly inaccurate as the areas involved become smaller and approach the limit of resolving power of the lens-film combination. In aerial photography, most of the details are suggested by very small areas of density. In general, they are too small for the application of conventional tone rendering procedures.

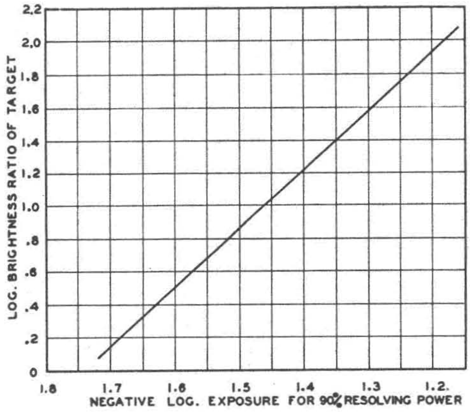

FIG. 2. This curve shows the relationship between the log brightness ratio of the target and the negative log exposure for 90% resolving power.

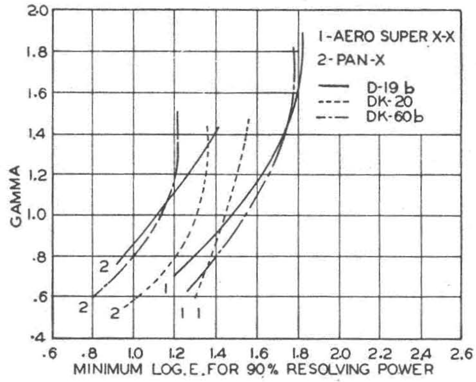

FIG. 3. These curves show the relationship between gamma and negative log exposure for 90% resolving power for Aero Super XX and Panatomic X with three developers.

Methods of development affect the resolving power speed, the maximum resolving power, and the exposure range over which 90% resolving power can be obtained. Consequently it is necessary to select a processing method which leads to the best compromise of these factors for practical purposes. Figures 3, 4, and 5, show the relationships between these quantities for Aero Super XX and Panchromatic X. A full discussion of the use of these is given elsewhere (3). Consideration, however, can be briefly given to some of the facts and the conclusions to be drawn from them. With Aero Super XX, speed increases quite rapidly with increasing gamma. The maximum resolving power of the emulsion is not seriously affected by high gammas. Development with D19b gives the highest speed, without serious loss of resolving power. This is an important factor in practice. The resolving power of the ordinary lens-film combination reaches a maximum for apertures between f/11 and f/16 (6). Consequently an emulsion speed which permits use of such apertures may lead to better results

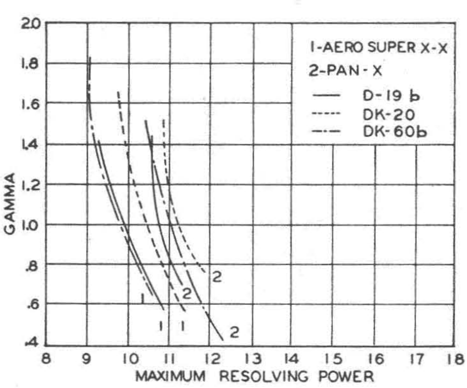

FIG. 4. These curves show the relationship between gamma and maximum resolving power for Aero Super XX and Panatomic X with three developers.

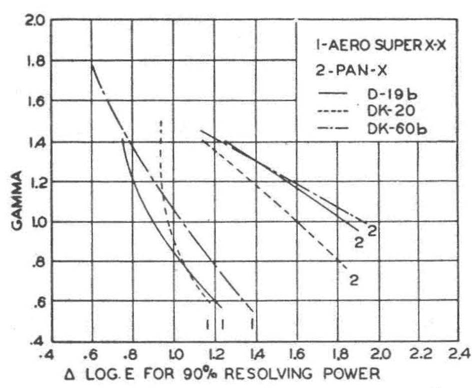

FIG. 5. These curves show the relationship between gamma and Δ log E for 90% resolving power for Aero Super XX and Panatomic X with three different developers.

than an emulsion with a somewhat higher resolving power but lower speed. This is generally the case for existing lens-film combinations. The characteristics of lenses and emulsions must be better harmonized before full advantage can be taken of increase in the intrinsic resolving power of the emulsion, unless the speed of the latter can be maintained. Even then, lack of harmony between the characteristics of the lens and the emulsion will be a limiting factor.

Veiling Glare

Veiling glare is non-image-forming light which reaches the focal plane. The effect of such light is to reduce the contrast of images in the focal plane. This resulting reduction of contrast leads to a loss of resolving power in the lens-film combination. Figure 6 shows the resolving power-log exposure curves for a number of different log brightness ratios of the target. These curves are similar to those in Figure 1 except that the abscissa has been expanded to show only the more interesting range of exposures. The dotted lines indicate the degeneration in resolving power which occurs when 10% veiling glare is present. Ten per cent veiling glare is defined as the veiling glare existing when the image of a black hole in the centre of a uniformly illuminated area of infinite extent is 10% the brightness of the image of the infinite area less the veiling glare. Calculations similar to those illustrated in Figure 6 can be made for 20%, 30%, or more veiling glare, and it will be found that the deterioration of resolving power for 20% to 30% is very serious. Cameras should not have more than 10–15% veiling glare. The fact that some well-known commercial air cameras have as much as 25% shows that the matter warrants careful attention. It will be noted that veiling glare tends to reduce the emulsion speed for a particular log brightness ratio at the ground.

An interesting study has been made of the effect of veiling glare in the Optics Laboratory of the National Research Council, and a full report of this will be published shortly by K. M. Baird.

Veiling glare comes from two distinct sources. The first of these is light scattered from haze beneath the aircraft. This is beyond the control of the operator and the only remedy is to postpone the operation when the degree of veiling glare is such that it causes an unacceptable reduction in resolving power. The other source of veiling glare is controllable. It is light scattered or reflected from the internal parts of the camera and the light from out-of-focus images formed by certain of the surfaces of the lens elements acting as reflectors. The first condition can be almost completely controlled by making the surfaces flat black and by providing adequate baffle systems. The second source can be improved very considerably by anti-reflection coatings.

Processing

Even with properly exposed negatives, incorrect processing can cause a serious loss of information. The controls essential to good processing are not difficult to apply in practice, and it is surprising that so often one or more of them are omitted from the routines of processing establishments.

The need for obtaining pure chemicals and for care in their mixing is obvious. So is the maintenance of temperature and correct time of development. A constant and reproducible agitation of the developing solution is a requisite for uniform development. Sensitometric control of the development process is as important as any control mentioned, but it is the one which in practice is the least frequently applied to aerial negatives. On every roll of negative material, a sensitometric step-tablet should be printed so that after processing the characteristic curve of the roll can be drawn. In case of photographic failures, it is then easy to determine whether the fault lies with the exposing or the processing. The knowledge that there exists an internal telltale has a very beneficial effect on both the efficiency of the staff of the processing establishment and the care taken by the camera operator in setting the proper exposure.

With the long rolls of film that are now in standard use for aerial photography, two types of processing equipment have found wide acceptance.

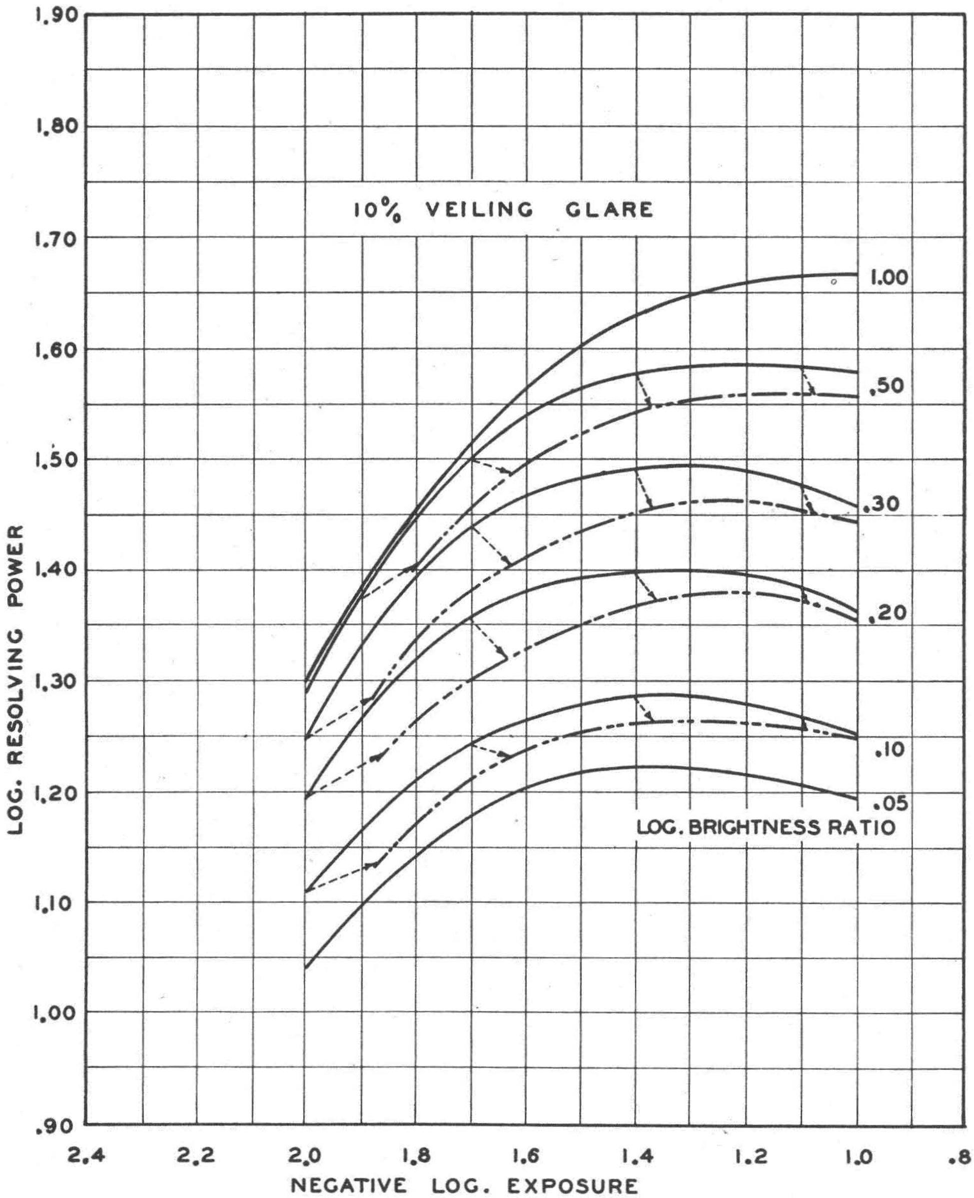

FIG. 6. The full curves in the above show the relationship between resolving power and exposure for a number of log brightness ratios of the target. The broken curves show the condition which occurs when 10% veiling glare is present.

The first type consists of a tank in which the roll of film can be transferred rapidly from one spool to another in the processing solutions. Such tanks can be operated manually or electrically. These equipments serve a very useful purpose in many operations, but they are by no means an ideal solution to the processing problem. The principal objection is that development is not uniform throughout the roll. This makes accurate sensitometric control difficult, since it would be necessary to print quite a large number of step-tablets along the roll between exposures. It is possible to do this, but the complexity of the operation is hardly likely to commend itself to practice.

The second type of processing involves an equipment in which the processing is done as one continuous operation. The negative passes through the various solutions and finally to a drying machine at the end of which it is spooled for storing. The time of development, fixing, and washing, is controlled by the rate at which the negative goes through the machine and the length of negative in each solution at a given time. Temperature control of the developing solution is made easy by a thermostatically controlled double tank. Reproducible and uniform agitation is obtained by pumping the developing solution in and out of its tank by means of a non-corrosive pump. A properly constructed machine of this sort becomes an almost ideal solution for large scale processing. Obviously to justify its expense, a reasonably large number of rolls must be processed per year. Due to the uniformity of development, only one step-tablet need be placed on each roll, although there is merit in having two, one at each end. The characteristic curves from roll to roll can be studied and the time for replenishing the developer determined.

Concern is sometimes expressed that continuous processing machines may cause distortion of the film base as a result of the force which is required to pull it through the solutions. The concern is quite unfounded, since the forces required are far less than the minimum necessary to produce distortion in wet films. It may be possible that improper tracking of the film over the rollers in some continuous processing machines may lead to local forces that are dangerous. However, proper design of the transport system removes this hazard.

Continuous processing machines have come into disrepute in some quarters as a result of the necessity, in military operations, of using methyl alcohol after the last washing tank for quick drying. Methyl alcohol causes a marked distortion of topographic base and it must never be used with survey negatives.

Reasonable temperatures can be used in the drier to expedite the operation, providing they are not in excess of 100 to 125°F.

The acceptability of infra-red lamps for drying survey negatives has not been completely demonstrated. Before using them, it would be well to show that the unequal absorption of radiant energy by dense or less dense portions of the negative does not lead to local distortion of the base or movements of the emulsion on the base.

Suggestions have been made that high frequency electric power be used for drying negative materials. This method may, however, be open to the same criticism as infra-red lamps.

There are indications that residual water droplets passing into the drier cause very severe local distortions. A wetting agent in the last washing tank reduces the probability of this trouble, but it is not yet proven that local distortions do not occur from other causes. The overall distortion of film base does not necessarily give a complete picture of the distortion that may confront the photogrammetrist. Air squeegees should lessen the possibility of residual water droplets as compared with roller squeegees.

Most survey processes require the preparation of positives before the photographs are useable for mapping purposes. If the maximum dimensional stability of the film base is to be retained, it is essential that the film be in the same equilibrium condition as at the time of exposure. This necessitates conditioning the film and controlling the temperature and relative humidity of the printing room. "Cold" light printing boxes or projection systems have an obvious advantage over incandescent tungsten unless a heat absorbing filter is used.

Resolution

Resolution tests have come to be generally accepted as a measure of the amount of information that can be obtained from a photographic system. Unfortunately there is no general agreement as to the correct method of making resolution tests. One of the main reasons for this circumstance is the widespread misconception as to the meaning of the term resolution.

Papers (4, 5, 6) have been published in the last few years which exhibit a real understanding of resolution, but these are so far in the minority that further discussion of the subject is well justified.

It is often inferred or stated that resolution is an intrinsic property of the lens alone. The incorrectness of this view cannot be overemphasized. Resolution is very definitely not a function of the lens design alone. No resolution figures will permit prediction of lens performance under all circumstances. It is therefore very disturbing to hear the statement so often made that a certain lens has a resolving power of so many lines per millimeter. The intrinsic property of the lens which is associated with resolution is the distribution of the energy in the image space, but this is only one of a number of equally important factors which affect resolution. Resolution is the ability of a lens in combination with a particular kind of device for detecting energy, to distinguish detail under certain specific conditions among which are the shape and contrast of the test target and the quality of the illumination.

The manner of distribution of energy in the image space with photographic lenses is principally a function of the residual aberrations at the conjugate distances used. The residual aberrations determine the distribution of energy in the image space, both as to intensity and frequency. Resolution involves the interpretation of this distribution by a particular device sensitive to energy when certain other conditions are clearly defined.

There are many types of devices for detecting energy—photocells, photographic emulsions, the human eye, thermocouples, bolometers, etc. All have different responses to energy and with certain of them there are even different responses within the same general type.

With very little thought, it becomes apparent that a resolution measurement has no meaning whatsoever unless at least the following are accurately defined: 1. The form of the target. 2. The contrast of the target. 3. The distance of the target from the lens. 4. The spectral distribution of the illumination of the target. 5. The response of the energy receiver which is used to interpret the energy. In addition, with certain types of receivers, it will be necessary to define other conditions. With photographic emulsions, the processing procedure will have to be specified.

On account of these circumstances, there is little purpose in measuring resolution of a lens-receiver combination under conditions which differ in any avoidable way from those associated with the practical use. If the lens is tested in combination with a photoelectric cell, a thermocouple, or a high contrast fine grain emulsion, no useful information is obtained on the resolution of the same lens in combination with a fast low contrast emulsion. It is illogical to use orthochromatic emulsions if performance of the lens with a panchromatic emulsion is the point of interest. The tests will lead to a higher figure for resolution, but it is no measure of the usefulness under the desired circumstances. Similarly, if the lens was to be used with mean noon sunlight it would be unreasonable to test the lens receiver system with a sodium lamp.

Extreme samples of useless figures of resolution have been quoted, but since it is relatively simple to employ procedures in which the conditions of use are closely approximated under standardized laboratory conditions, no greater justification can be made for any type of resolution tests which are to any extent ill-founded in this way.

Sometimes those opposed to the point of view outlined state that they are not interested in practical performance tests, but in the intrinsic properties of the lens. If this is the case, they should not be studying resolution tests under specific sets of conditions, but should be investigating the distribution of energy effected by the lens in the image space. With these intrinsic lens data, and a knowledge of the relevant characteristics of the receiver used to detect the energy, the resolution of the combination can be defined for any specified circumstances.

Having established the general philosophy which should guide the establishment of procedures for resolutions tests, it is of interest to outline briefly the proper conditions for making resolution measurements in connection with aerial photography.

Consideration must first be given to the form of the target. Detail of interest is distributed in random directions throughout the field of view. Recording these items depends on the ability of the lens to form edges in any direction of the field of view. In this connection, it must be remembered that any edge in a photograph is likely to have its formation impaired by the energy distribution at nearby edges in any other direction. This immediately places a limit on the usefulness of using targets consisting of lines in the radial and tangential directions. Only two of many directions are involved and the form of the target is such that it is a measure of the resolving power in a given direction when only two parallel edges are involved. It ignores the fact that, in practical circumstances, the rendering of an edge will be limited by a number of nearby edges in other directions. The same condition limits the usefulness of averaging measurements on parallel lines in a large number of directions.

With the foregoing in mind, we have suggested that an annulus type of target is more satisfactory. The disappearance of the central edge is affected by infinitely small nearby edges in every other direction. It can consequently be considered as a convenient and simple conventionalization of the practical task set the lens-film combination in aerial photography. More complete justification of its use has been given previously (6). Aside from the logical philosophy of this form of target, there is another very definite practical advantage in that only one set of resolution curves is needed instead of two. It further permits the selection of the focal plane unambiguously. With radial and tangential lines, excepting for the very rare case when no astigmatism is present, the focal plane for photographic purposes can only be located by either some purely artificial method of averaging or making an intuitive guess as a compromise.

The contrast of most aerial photographic detail is low. Consequently English workers (5) have very properly suggested that the contrast of targets for resolution tests should be low, and have proposed that they have a log brightness ratio of .2. The value is a reasonable one and has some subjective justification. Until the statistical observations now being made from the air are complete, it is a satisfactory value to accept. It has been sometimes suggested that there exists a universal ratio for reducing high contrast lens-film resolving power tests to low contrast ones. This is not at all justified and a very brief consideration of possible energy distributions resulting from residual aberrations will show that it is quite conceivable for high and low contrast resolution tests to put two-lens-film combinations in reverse order. The condition has been shown experimentally.

The resolution target should be placed at infinity. Either a collimator or a sufficient distance is acceptable for this purpose.

The illumination should be mean noon sunlight modified by the operational filter. If a filter is employed to correct variation of illumination in the focal plane, it is advantageous to carry out tests with and without it. These will reveal whether the resolution in the outer part of the field is limited by either insufficient density or inadequacy of the lens-film combination.

The resolution of the combination should be tested at all marked apertures in the neighbourhood of the visual focus across the whole field of view in planes parallel with the machined surface of the mounting flange of the lens. The operational emulsion should be used for the tests and should be processed by a standardized version of the operational processing.

The time of exposure for the target at various positions in the field should be the same since this is the condition in the camera. The exposure should be so chosen that as much of the picture area as possible exhibits a density which favours maximum resolution of the emulsion itself.

The resolution should be read under conditions of illumination and magnification that favour reading maximum values. Smooth through-the-focus curves should be plotted for each angular position of observation. Off-axis resolution curves for the various planes studied can then be drawn more accurately as a result of smoothing out the experimental through-the-focus values. Average resolving power values on an area basis for the particular picture size can be determined for each of the planes studied. The curve relating average photographic resolving power to axial position can then be drawn, and the plane of best average photographic resolving power selected as the focal plane. The average is taken on an area basis on the assumption that detail anywhere in the field is of equal value.

To determine the photographic focal plane by the method outlined for every survey camera would be far too laborious. Fortunately it is not necessary to do this for lenses of the same type once the full investigation has been made. The photographic characteristics of lens types so far studied have been found sufficiently uniform for the correlation of the position of the plane of best average photographic resolving power with the position of best visual focus on the axis. Reference can be made to the Bausch & Lomb 6″ Metrogon as an example. The plane of the best average photographic resolving power over a 9″×9″ picture area for this lens has been found to be .008″ further from the lens than the axial position for best visual focus on the minimum fringe criterion. The position of minimum fringe is where there is maximum contrast at an edge. Depending upon the lens type, it may or it may not coincide with the position of best visual resolving power. In practice it has been found that the former position can be selected with somewhat greater precision than the latter.

Figure 7 shows representative curves plotted from data obtained in the way just described for the Bausch & Lomb 6″ f/6.3 Metrogon lens at full aperture. R stands for resolution and F for focal length expressed in millimeters. $\bar{R}$ refers to average resolution over a 9″×9″ picture area. Similar data for a number of other lenses are given elsewhere (6). In the same place a method is given for comparing the quality of lens-Aero Super XX combinations for 9″×9″ photographs.

It has been pointed out elsewhere (6), but is worth pointing out again, that the characteristics of the best quality photographic objectives available commercially at the present time do not harmonize with the physical characteristics of the available emulsions in so far as energy sensitivity of the latter is concerned. As a consequence, no lens-film combination yields a resolving power equivalent to the intrinsic resolving power of the emulsion as normally determined. It is unlikely that emulsion characteristics will be seriously modified in the near future because their sensitivity characteristics meet very well the other requirements of aerial photography. It therefore would seem that lens designers

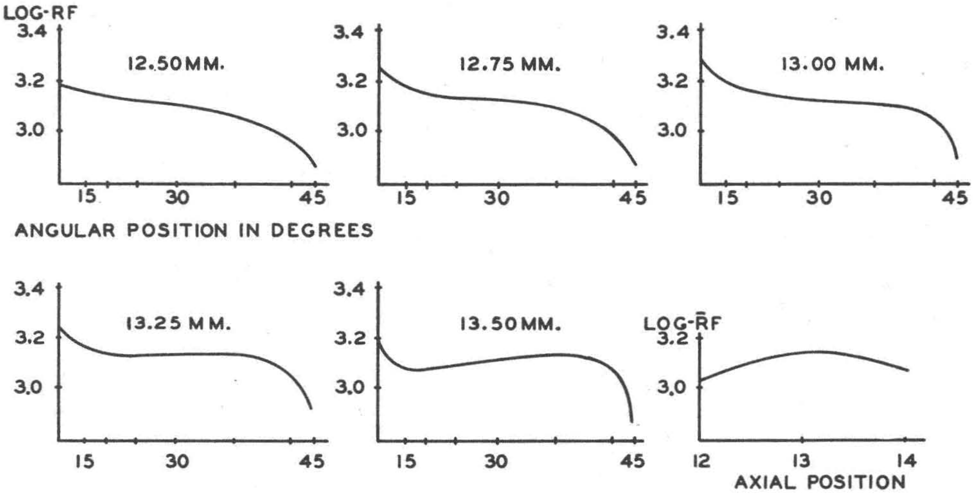

FIG. 7. The above curves represent off-axis resolving power curves for a series of planes perpendicular to the optic axis of a Bausch & Lomb 6″ f/6.3 Metrogon lens and the average resolving power over a 9″×9″ picture area plotted against axial position. The numbers indicating the positions of the various planes are arbitrary and increase for positions further away from the lens. The average resolving power graph shows how unambiguously the focal plane can be selected.

should do something about making residual aberrations such that the intrinsic resolution of the emulsion can be attained when the lens is used in combination with it. They should cease judging photographic objectives by visual performance.

CALIBRATION

The calibration of survey cameras involves a number of important measurements and adjustments.

The photographic focal plane must be determined. It is preferably determined on the basis of the procedure described in the previous section.

The principal point must be located. This is defined as the point of intersection of the focal plane and the perpendicular to it from the rear node of the lens. The distortion of the lens should be measured and the focal length for mapping purposes determined. This is often called the calibrated focal length, and is the one which gives for mapping purposes an acceptable numerical indication of the distribution of distortion in the focal plane. It is usually and most logically understood to be the focal length which makes the maximum positive distortion equal to the maximum negative distortion.

Two distances which will be printed on every negative at the time of exposure must be measured. One distance should be along the length of the film and the other across it. These will be used as a permanent record of the distortion and scale changes occurring in actual operations.

The camera shutter should be adjusted to give the exposures indicated by its scale.

Filters should be tested for freedom from distortion and prism.

It is also the function of the calibrating authority to certify that the construction of the camera as a whole conforms to survey requirements.

In the light of remarks which have already been made in the previous section, it is apparent that in undertaking calibration a problem is immediately raised as to whether visual methods are adequate for the purpose. Attention has been drawn to the fact that the image of a point source as formed by a photographic lens is in the main a function of the residual aberrations. We can expect in a well centred system that the distribution of the energy within the image on the axis will be symmetrical, and that positional measurements made visually will coincide with positional measurements made photographically, or, for that matter, by any other form of energy receiver. No such assumption can be made about the off-axis image which is unlikely to be symmetrical about the tangential direction. Consequently, it is to be expected that the locations of the centre of gravity of the energy in the image of a point source by receivers of different colour sensitivity will not of necessity coincide. Variation of gamma with wavelength can also affect the position. Therefore, as in the establishment of the photographic plane, any operation relating to the geometry of the photograph must be performed by photographic methods with the particular operational emulsion, unless it has been previously shown that visual observations lead to identical results. The only time that this assumption can be accepted without proof is in the case of a perfect lens.

Gardner (7) has long been the principal proponent of the desirability of photographic calibration. His elegant methods need no review here. In connection with them, however, it should be pointed out that he uses for both calibrating and establishing the focal plane, an emulsion differing from the operational one without showing that both lead to the same results.

Without detracting in any way from the correctness of photographic calibration or the desirability of doing so, the usefulness of visual means (8), because of their simplicity, must not be disregarded. For many and perhaps most survey operations, the distinction between the photographic geometry and the visual geometry of the commonly used lenses will be quite insignificant when other sources of error are considered.

Case (9) has given an interesting discussion on locating the principal point, when due to bad centering, the objective can be considered as a combination of a perfectly centred lens and a thin prism. Again, without questioning the inherent soundness of the procedure, it is suggested that there are a great many aerial survey operations in which the improvement in the location of the principal point is not worth the very considerable increase in complexity of the calibration procedure. The reduction in the average error of the geometry is less than one-half that of the geometry based on the principal point established by simple autocollimation methods which disregard the existence of the thin prism.

In general, the preferable way to meet the difficulty to which Case has drawn attention would be to insist on a better standard of centering so that any small residual prism can be ignored. From the recent excellent paper by Ingalls and Pestrecov (10), it would appear that serious attention is being given by optical manufacturers to the important subject of improving the centering of photographic objectives.

In considering the tolerances of calibration, it must always be remembered that the degree of accuracy required must be set with a full knowledge of the errors introduced into the geometry by other causes. For instance, it is rather unreasonable to require the highest refinement in calibration and then proceed to expose films and print them later without any regard to humidity or temperature control.

DIMENSIONAL STABILITY OF MATERIALS

The dimensional stability of the supports used for the photographic emulsions at various stages of the process and the handling of these materials have a fundamental importance in so far as the accuracy of the final map is concerned.

Three materials are in common use for this purpose. Glass plates, topographic film base, and paper. To a very limited extent, metal foil has been used in place of paper as a support for positive opaques.

Glass plates are the most satisfactory means of support for photographic emulsions. It is true that some very small distortions occur in the position of points recorded on photographic emulsions coated on glass, but these are of such negligible proportion that they concern no present day application of photography to photogrammetry. The use of glass plates is a great inconvenience throughout the whole operation because of their bulk and fragility. Rather special mechanisms are required in the magazine to change plates between exposures. Nevertheless for highest accuracy, plates must be used.

Because of the disadvantages which plates involve, by far the greater amount of aerial mapping is done with photographic emulsions on film supports. Such supports have an intrinsic dimensional instability, even though great progress has been made in reducing this disagreeable feature by modern manufacturers. The film material specially treated for mapping, is designated topographic base. Its dimensions are a function of the ambient temperature and relative humidity. To ensure that the base is in equilibrium with the atmosphere under specified constant conditions, it should be unrolled and exposed for about twenty-four hours in a room where these conditions obtain.

The physical characteristics of topographic base have been extensively discussed by J. M. Calhoun (11). The results which he presents represent percentage dimensional changes obtained under controlled laboratory conditions. They do not necessarily tell the complete story of the dimensional conditions that may confront the photogrammetrist in practice.

Some initial work has been done and reported by P. D. Carman (12) on the dimensional instability which occurs in practical survey operations when no particular care is taken to control the atmospheric conditions to which the film is subjected at the time of exposure in the aircraft. He will shortly report further results of this sort.

In investigating the performance of a tri-metrogon mount, R. A. Nodwell and R. C. Burstow (13) encountered local distortions which in absolute magnitude were comparable to the change which might have been expected over a very considerable length of film on the basis of the accepted constants. There seems some suggestion that these local distortions are associated with residual droplets that escaped the squeegee and entered the drier on the film. However, it is by no means certain that even if such droplets were completely eliminated, local distortions would disappear. Some were still present when films were hand processed with residual water droplets in mind. Further experiments are in progress to settle the point.

The way to get the best out of modern topographic bases is to make provision for the control of temperature and relative humidity at the time of exposure, and at the time of printing. These conditions should be those with which the film was in equilibrium at the time of its original spooling. It has been established that the standard tin container provides quite an adequate vapour barrier during storage and between stages of the photographic operation.

When there is an almost continuous clamour urging the lens designer to improve the distortional characteristics of the lens, and for the film maker to improve the dimensional stability of his support, it is extraordinary that proper precautions are not taken in a routine way to obtain the maximum performance of the very excellent material that is currently available. Perhaps one of the most significant results of Carman's work (12) was that quite a variation in scale takes place in the first dozen or so photographs at the beginning of a flight line.

Care must be taken at the time of printing to see that a series of negatives do not get variably and unevenly exposed to a heat source such as incandescent lamps. Marked scale changes were observed by Nodwell and Burstow (13) as a result of heat from the source used for illumination during measurement.

Multiplex mapping is done from small glass plates. The advantages of these will be to a large extent lost if the printing is done from film negatives in an unknown and perhaps variable state of moisture and temperature equilibrium. To supplement his previous work on the distortion which arises under service conditions as they commonly exist, Carman is currently studying similar errors in diapositives intended for multiplex work where no particular precautions are taken in the conditioning of the film previous to and during printing.

Paper has been very extensively used when positive opaques are required for the mapping process. More often than not the prints are used under unknown conditions of temperature and humidity. So unstable is paper that it should be used for nothing but the crudest work. Attempts to use it for more accurate work will inevitably lead to the wasteful expenditure of time in pushing and pulling the map into shape. Positive opaques in which aluminum foil serves as the base have very desirable dimensional characteristics, but their general acceptance would depend on overcoming certain serious objections. The emulsion is apt to fray around the edges with repeated handling, and the foil is rather subject to kinking and bending.

In concluding reference to this important subject, it should be emphasized that the photogrammetrist cannot expect negatives having the dimensional correctness suggested by Calhoun's laboratory experiments unless he knows that, at the time of exposing and at the time of printing, the film was in equilibrium with the same conditions of temperature and relative humidity. Until advantage is thus taken of every possibility for making the geometry of the photographs correct, the photogrammetrist is not justified in urging further refinements on the lens designer, the film base manufacturer, and the calibration authority, since such refinements are lost by careless manipulation.

REFERENCES

1. Gardner, I. C., Compensation of Aperture Ratio Markings of a Photographic Lens for Absorption, Reflection, and Vignetting Losses. Journal of the Optical Society of America, Volume 37, Number 6, Page 524, 1947.
2. Howlett, L. E., A New Criterion for Measuring the Speed of Aerial Photographic Emulsions. C. J. R. A, 24: 1–7, January, March and May, 1946.
3. Howlett, L. E., Choosing an Emulsion and Processing Technique for Daylight Aerial Photography. C. J. R. A, 26: 60–64, March, 1948.

4. Pestrecov, Dr. Konstantin, Resolving Power of Photographic Lenses. PHOTOGRAMMETRIC ENGINEERING, Volume 13, Number 1, Pages 64 to 85, March, 1947.
5. Selwyn, E. W. H. and Tearle, J. L., The Performance of Aircraft Lenses. The Proceedings of the Physical Society, Volume 58, Part 5, Number 329, Pages 493–525, September, 1946.
6. Howlett, L. E., Photographic Resolving Power. C. J. R. A, 24: 15–40, July, 1946.
7. Gardner, Irvine C. and Case, Frank A., Precision Camera for Testing Lenses. Journal of Research of the National Bureau of Standards, Volume 18, Pages 449–460, April, 1937.
8. Field, R. H., A Determination of the Distortion in a Number of Air Camera Lenses, C. J. R., Volume 10: 239–243, February, 1934.
9. Washer, Francis E., Locating the Principal Point of Precision Aeroplane Mapping. Journal of Research of the National Bureau of Standards, Volume 27, Number 4, Pages 405–412, 1941.
10. Ingalls, A. L. and Pestrecov, K., Centering of Optical Systems. Journal of the Optical Society of America, Volume 38, Number 4, Pages 343–349, 1948.
11. Calhoun, J. M., The Physical Properties and Dimensional Stability of Safety Aerographic Film. Photogrammetric Engineering, Volume XIII, Number 2, Pages 163–221, June, 1947.
12. Carman, P. D., Dimensional Changes in Safety Topographic Aero Film Under Service Conditions. C. J. R. F, 24: 509–517, 1946.
13. Nodwell, R. A., and Burstow, R. C., An Accurate Mount for Tri Metrogon Photography. C. J. R. F, 24: 501–508, 1946.

FILM PROCESSING UNIT

New Zealand Aerial Mapping Ltd., Hastings, New Zealand

MENTION the words "film differential" to the photogrammetrist and he will immediately take up the subject with eloquence in pointing out the evils of films being stretched and distorted during development.

Uneven development and pressure bands associated with the manual development, causing poor matching of prints, particularly in mosaic work, caused us in New Zealand to design our own processor.

Essentially, with minimum tension on the film (not more than 10 ft. between driving points) the unit develops, fixes, washes and dries the entire length of film in one continuous mechanical operation.

On reference to the sketch, you will observe how we have constructed our unit. On the left, a rheostatically-controlled motor is mounted vertically onto a reduction drive, the final shaft from which protrudes through the rear to drive all the many rollers by sprocket and chain at the same speed. Actually, we used a separator crank case for it contained the large initial reduction gears and oil bath.

Seven stainless steel troughs, welded together, make up the central portion. The first three, containing the wetting agent, the developer and the first fixer respectively, are lagged and are kept at constant temperature by immersion heaters and separate thermostatic controls. Then follows the second fixer, two running washers and the final wetting agent. Each trough has an overflow, a bleeder waste and H. P. inlet at the bottom.

Rubber rollers, carefully cut to the same diameter, slip into key sprockets at the rear, each time, to carry the film from one trough to the next at the same rate. Similar rollers, mounted on stainless steel rods but not driven, guide the film near the bottom of each trough.

On the right, a tall drying cupboard containing numerous reels, accommodates approximately 80 ft. of film which is dried by air passing through an element at the top of the cupboard and drawn off by a fan at the bottom. A slipping clutch on the large take-up reel and a cord passing over a groove in most of the smaller guiding reels within the drying cupboard, satisfactorily take care of the film tension during the last stages of processing.