CHAPTER 9

Characteristics of Film and Camera

In Chapter 1 we have seen how the main attributes of an air photograph depend upon the resolution and distortion of both the negative and print itself. We must now consider in more detail, the factors governing these characteristics.

Resolution or definition refers to the clarity of the image and is measured in terms of resolving power, which indicates the power of an optical system to separate the images of a pair of neighbouring points or lines. A resolving power of s lines per mm means that the smallest separation of a pair of lines which can be discerned is $1/s$ mm (see Fig. 9.1).

It will usually be necessary to examine an air photograph under magnification in order to appreciate its limit of resolution.

In testing for resolving power it is usual to photograph test targets similar to the one illustrated in Fig. 9.1. One such target is photographed many times on to different portions of the negative, so that the resolving power of every part of the lens is known.

Distortion of an image indicates the amount by which that image is displaced from its true position. If measurable distortion is present, measurements from the photograph will be in error. Distortions due to tilt and height differences are inherent in an air photograph (see Chapter 2), but there are other distortions caused by defects in the photographic instruments, materials or processing. Distortion of the image due to negative or positive materials is almost confined to that due to temporary or permanent instability of the base (see Chapter 1), since expansion and contraction of the emulsion is entirely in a direction perpendicular to the surface of the negative or print.

PROCESSING THE NEGATIVE

The film in an air camera is commonly about 270 mm wide and some sixty metres long. It is most important that the processing does not subject the film to scratching or to undue stresses, particularly in the longitudinal direction. Therefore processing, which includes development, washing and fixing, takes place in specially designed tanks. Each tank is of sufficient size to take two spools side by side (see Fig. 9.2) and the film is wound alternately from one spool to the other, in such a way that each layer of film is always cushioned from the next layer by a small amount of whatever liquid it is being treated with at the time. The alternation from one spool to the other ensures that fresh liquid is continually being brought into contact with each portion of the film. However, if the length of the film being processed is long, the developer remains undisturbed on the face of

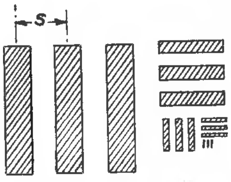


FIG. 9.1. SKETCH OF PART OF A TYPICAL TEST TARGET
s = separation of lines

FIG. 9.2. TANK DEVELOPING EQUIPMENT
(*Wild Heerbrugg Ltd.*)

the film for too long without renewal. This cannot be counteracted by increasing the speed of winding indefinitely since eventually the initial acceleration and final deceleration would be so great that it would apply undue stresses to the film. Probably about 35 m of film is the greatest length which should be treated in a tank at any one time.

Longer lengths of film are developed by the continuous process as shown in Fig. 9.3. The film is passed continuously through the series of tanks and is dried by lightly blown air. The process is only economical for bigger organizations as the tank capacities are larger than those of the individual tanks and more developer and fixer need to be made up at one time.

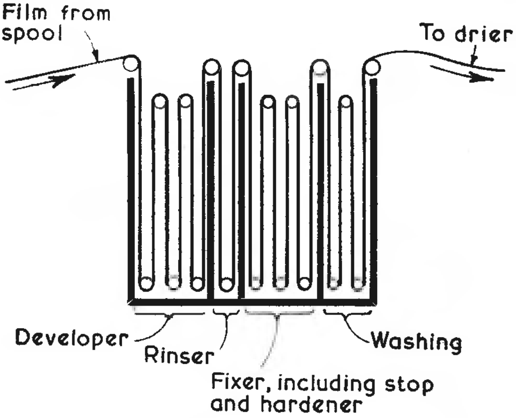


Fig. 9.3. Apparatus used in Continuous Processing
The size of each compartment depends on the time required for each process.

The drying process presents a bigger problem in that the film must be laid out to dry in such a way that its weight is supported throughout its length, without scratching taking place. A series of soft-wood slats, which are often arranged round a circular drum, usually serve this purpose (see Fig. 9.4). During this stage care must be taken to keep the air, and therefore the surface of the film, clean. The difficulties of drying are increased by the fact that during processing the film doubles its weight due to the moisture absorption.

The Developer

This is a chemical solution which actually causes the chemical changes in the sensitizer and so makes the latent image visible. All developers are reducing agents, and those normally used in air photography are benzene derivatives or aniline dyes; therefore they are nearly all by-products of coal-tar. There are many such agents, but by far the most popular are metol and hydroquinone (quinol).

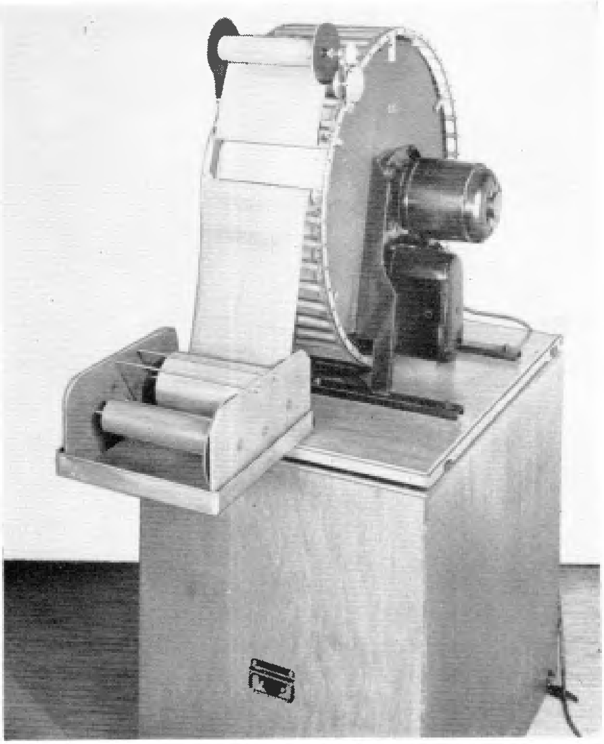


FIG. 9.4. DRYING MACHINE
(*Wild Heerbrugg Ltd.*)

Metol is more vigorous in action than quinol, but usually results in a " softer " image, in which the lights and shades do not contrast as vividly as if quinol were used. Many of the most popular developers contain a mixture of metol and hydroquinone known as M.Q. Hydroquinone alone is very suitable for developing process camera negatives.

Pyrogallol is also used for developing negatives, but it has a tendency to leave a yellowish stain which makes it unsuitable for use with positives.

These three developers are the only ones in general use for air photography.

Temperature has a direct and marked effect on the speed of development and must be kept at between 18° and 21°C. Lower temperatures will give slower reactions and loss of contrast; and higher temperatures may cause too rapid a reaction, blistering of the emulsion and decomposition of the developer.

The developer itself is readily oxidized, i.e. it will reduce the silver halides to metallic silver, and thus develop the image. However, action is accelerated by the addition of an alkali; sodium carbonate is the commonest accelerator, but there are many alternatives, and it is the degree of alkalinity which determines the rate of development. Degree of alkalinity or acidity of a solution is known as its pH value. A pH value of 7 is neither acid nor alkaline; as the alkalinity increases so the pH value increases from this number and a pH value of 9 is ten times as alkaline as one of 8; pH values of less than 7 indicate acidity.

The developer and accelerator together would result in the immediate oxidation of the developer, which would then have lost its power for developing the image. To prevent this, a preservative (usually sodium sulphite) must be added. The preservative prevents oxidation until the developer comes in contact with the sensitized emulsion.

With these three constituents only, the development would be very rapid and would tend also to blacken the areas of emulsion which had not been exposed to the light, so causing " fogging " of the negative. Fogging is reduced because the developer absorbs some of the potassium bromide from the emulsion, but to offset completely the objectionable effects of fogging, potassium or sodium bromide must also be added to the developer. The bromide is known as a *retarding agent*. The additional potassium bromide absorbed from the emulsion will further slow down the reaction—thus speed of development rapidly decreases, especially as the oxidation process set up on first use of the developer may continue after the removal of the negative.

Development begins at the surface of the emulsion and gradually penetrates to the deeper parts so that the developer in the vicinity of the emulsion becomes exhausted before the lower part of the emulsion has been developed. To offset this, the developer must be agitated continuously to replenish the liquid on the emulsion surface. The emulsion film should be as thin as possible consistent with full and even coverage, as the silver image should penetrate the full depth of the emulsion and because a thick emulsion is more prone to *halation.* The latter is a phenomenon due to reflection of bright light from the base of the plate or film causing blurring of the image (see Fig. 9.5). It can be reduced by applying an anti-halation coat to the film base, before spreading the sensitized emulsion.

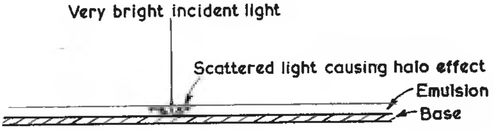


FIG. 9.5. HALATION
(Greatly enlarged section through negative)

Fixing

When development is complete, the film should be rinsed and then subjected to a stop bath in the form of a solution of sodium bisulphate and chrome alum. The sodium bisulphate has the effect of stopping development by neutralizing the alkali of the developer and the chrome alum hardens the emulsion.

This is normally followed by the fixing process proper, using a solution of sodium thiosulphate (hypo), but for air photographs, fixing, stopping and hardening are usually included in one process.

The purpose of fixing is to remove the unused parts of the sensitizing chemicals. Hypo dissolves silver chloride very readily and silver bromide readily, but silver iodide is dissolved only slowly. Since the anti-halation layer often contains silver iodide and must be completely removed during fixation, ample time must be given for the hypo to do its work.

When air film is processed, both the stopper and the hardener are usually included in the fixing solution, as it is considered that this reduces the tendency for the chemical stopping reaction to damage the emulsion film by blistering.

Washing

The negative must be washed absolutely free of all processing chemicals. Thorough washing entails running clean water over the negatives for at least twenty minutes and preferably for half an hour. If hypo is left on the face of the negative it tends to turn the image areas brown; other salts cause staining of the clear areas.

Drying

Only after washing has been completed is the processed film removed from the tank. It is then dried by blowing slightly warmed air over it. The atmosphere must be kept scrupulously clean and the air introduced must be filtered.

Summarizing, it can be said that, after exposure to the light when the latent image has been formed, the film is removed from the camera and placed in the developing tank where it is subjected to—

1. *Development* by chemical reduction of the light-affected part of the silver halides to form a metallic silver image.
2. *Rinsing* to remove surplus developer.
3. (*a*) *Stopping* to neutralize any remaining alkali.
    (*b*) *Fixing* to remove the unused sensitizing halides by solution.
    (*c*) *Hardening* the gelatine to render it more stable. Sometimes hardening is carried out after washing.
4. *Washing.*
5. *Drying.*

CHARACTERISTICS OF AN EMULSION

On a black and white photograph detail can only be recognized by a difference in grey tone values. Thus in spite of its distinctive shape a church spire could not be distinguished from its background if the latter consisted of cloud represented on the print by exactly the same tone value as the spire. No outline could be distinguished unless its background had a different tone value. The greater the difference in tone between object and background, the more readily can the object be distinguished. The depth of tone of any part of a print depends upon the opacity of the corresponding portion of the negative.

The emulsion is composed of a large number of very small crystals suspended in gelatine. The largest of these grains is of the order of one micron in diameter.

At exposure, light makes a certain proportion of these grains developable (the latent image) and during development each light-affected grain is made to deposit its load of silver. The quantity of silver deposited at any particular point governs the opacity of the negative at that point.

Opacity is a measure of the proportion of incident light which is prevented from passing through the negative. An opacity of 10 denotes that $\frac{1}{10}$th of the incident light will pass through, whereas an opacity of 100 indicates that only $\frac{1}{100}$th of the light will pass. Density is the logarithm of the opacity and is the term usually applied when discussing the tone value of the silver image. Thus tone varies over the face of the negative according to the amount of light which came to a focus at that point.

Exposure is the unit of measurement for the amount of light admitted to the sensitized film and is the product of the intensity of illumination and the time for which that illumination is admitted to the film.

For any particular emulsion the final negative density will be increased by increasing the exposure, and it is instructive to examine this relationship. Consider a series of experiments in each of which the camera is focused on to a constant light source, and different parts of the same film are exposed for varying lengths of time. For each of these experiments the resulting density is measured and plotted on a graph against the logarithm of the exposure (log *E*, on Fig. 9.6). Numerous such points are plotted, and then a smooth curve is drawn through the mean positions. The resulting graph is known as the *characteristic curve* for that particular emulsion, and will be of the form shown in Fig. 9.6.

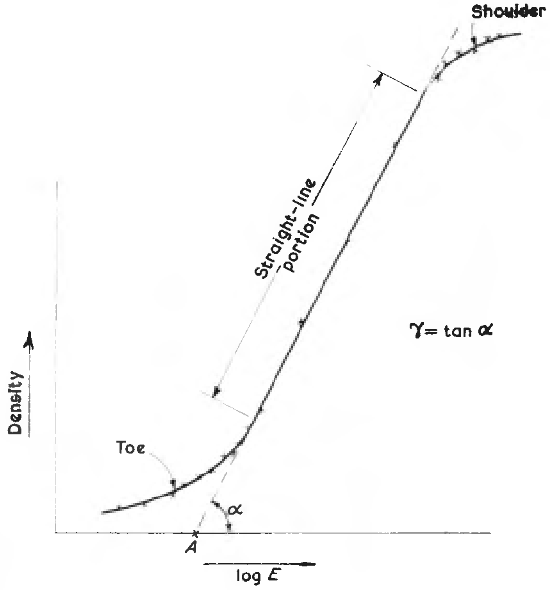


FIG. 9.6. THE CHARACTERISTIC CURVE OF AN EMULSION
Graph is interpolated between results of separate experiments plotted thus ×.

It will be noted that as log *E* increases, so the density increases, slowly at first, but at an increasing speed until it reaches the foot of the straight-line portion of the graph. Within this portion the increase of density with increase in log E remains constant. Finally as the density begins to reach its maximum values so the increase in its value relative to log E slows down.

That part of the curve below the straight-line portion is known as the toe and that above as the shoulder.

In the above experiments we were concerned with a series of photographs each of which consisted of only one tone value. In an air photograph we have seen that the tone value varies continuously over the face of the negative. This is due to the varying intensity of light received from each of the objects within the field of view. Thus for any one photograph the time of exposure applies to the whole of the negative but variations in exposure (and therefore in log E) occur because of the differences of illumination by the individual objects whose images are reproduced.

If the time of exposure in the air camera had been very short, then only for the brightest objects would log E be sufficiently great for the density to register on the characteristic curve at all. If a somewhat longer time of exposure had been given, the brightest objects might have achieved sufficient density for log E of their image to be carried to the foot of the straight-line portion of the graph whilst the dullest objects might be registering at the lower end of the toe. In this case the density range is seen to be small, i.e. there is little difference in tone between the densest part of the negative, which represents the highlights, and the most transparent parts representing the shadows. The ratio between the density of the highlight and that of the shadow parts is known as the *contrast*: the greater the contrast, the greater the range of tone. A negative exposed so that even the highlights are represented on the toe of the characteristic curve is said to " lack contrast " due to under-exposure.

As more time is given to the exposure so log E increases, bringing more and more of the image on to the straight-line portion of the graph and increasing the contrast. When the time of exposure is long enough for the whole of the view to register on the straight-line portion, then the contrast will be at its maximum. The aim is to expose so that log E for every part of the negative image falls within the log E range of the straight-line portion of the characteristic curve.

It is apparent, therefore, that the slope of the straight-line portion of the graph is a measure of the potential contrast of an emulsion, and this slope is known as the *gradation gamma* (or just γ) of the emulsion, where $\gamma = \tan \alpha$ as in Fig. 9.6.

So far in our discussion of the characteristic curve we have assumed that development was carried to completion. Now we must consider the effect of changes in time of development.

As development proceeds so each of the light-affected grains gradually deposits its silver. In the highlight areas there is a greater proportion of grains which have been light-affected so the image builds up more quickly in these areas. Thus as time of development increases so gradation increases. Figure 9.7 represents the stages through which the overall density of the image passes in terms of the characteristic curve. The curve on the right represents the density built up over the full range of tone values for only a short development time. The middle curve represents the position after a longer period of development and the left-hand curve illustrates complete development and is a repetition of the characteristic curve of the emulsion. Thus contrast increases with the time of development until the full potential contrast for the emulsion and exposure is achieved. If development were continued appreciably beyond this point there would be a tendency for the developer to attack the non-affected grains, with a consequent fogging effect and loss of contrast.

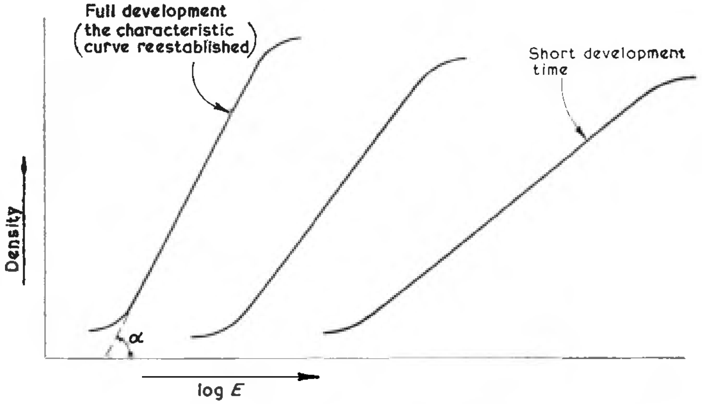


Fig. 9.7. Changes in Development Time in Terms of the Characteristic Curve

Some emulsions require more exposure than others for a latent image to be formed. Those requiring less light are said to be more sensitive or faster than the others. The faster the emulsion, the further to the left will its characteristic curve appear—in fact the point *A* in Fig. 9.6 has sometimes been used to denote the speed of the film. Various units are used to denote speed, among them Din, Weston and ASA.

Since the same amount of light is required to affect a grain whatever its size, the fast emulsions will usually comprise a comparatively large proportion of bigger grains. On the other hand, a contrasty emulsion is usually composed of smaller and more evenly graded grains; this is unfortunate since both qualities are needed in an air film.

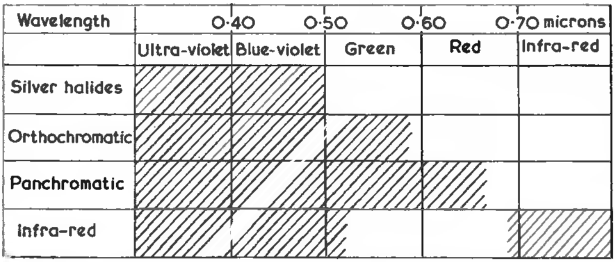
The characteristic curve of an emulsion can be amended by changing the composition of the developer, or altering the development technique, e.g. hydroquinone is included in the normal developer because it gives greater contrast than metol.

The quality of the positive print depends on that of the negative but the contrast may be increased by using a printing paper having a " hard " or contrasty emulsion and reduced by the use of a " soft " paper. In addition, there are now electronic dodging contact printers available, which automatically correct for unevenness of illumination in the negative.

Sensitivity to Different Wavelengths

Ordinary silver halides sensitizer is sensitive only to the ultraviolet and blue rays (see Fig. 9.8). The resulting negative would record only those objects which reflect light of lower wavelength. The result is that many of the objects which we normally see would be represented by a very faint image, quite out of keeping with their normal tone values—in fact, reds and greens would be represented by transparent parts of the negative. The first improvement to this ordinary silver halides film, was known as *orthochromatic*, in which the addition of certain dyes to the sensitizer increased the range of sensitivity to include most of the green division of the spectrum. Nowadays, nearly all film is panchromatic, which by incorporating additional dyes, even further rectifies the silver halides in respect of their sensitivity to different ranges of the spectrum. From Fig. 9.8 it will be seen that this type of film can be processed only in the dark, as it is sensitive to all colours of the spectrum, but even panchromatic film is not fully sensitive to red light.

A special *infra-red film* is also produced; this is especially useful for piercing haze since the longer infra-red waves are not so easily deflected from their course. Haze conditions are caused by light being deflected from its course on meeting minute dust particles. The more such particles there are the more scattered the rays become, so that the view becomes blurred and obscured. Infra-red film is sometimes used in aerial photography since it allows photographs to be taken in otherwise unsuitable conditions. The tone contrasts of infra-red film are very different from those of pan but the result is not so bad as a glance at Fig. 9.8 might suggest, since green vegetation usually reflects a lot of infra-red light as well.



Wavelength	0·40	0·50	0·60	0·70 microns	
	Ultra-violet	Blue-violet	Green	Red	Infra-red
Silver halides	▨	▨			
Orthochromatic	▨	▨	▨		
Panchromatic	▨	▨	▨	▨	
Infra-red	▨	▨	▨		▨

FIG. 9.8. SENSITIVITY OF EMULSIONS
Hatching indicates the range of sensitivity.

FILTERS

The most serious drawback of panchromatic film is that it is oversensitive to blue light and it becomes necessary to hold back some of the blue light before it enters the camera. This is done by placing a *minus-blue filter* in front of the camera lens. Filters generally transmit light of their own colour and hold back or absorb the other colours. There are three main types: those consisting of a thin coloured gelatine film which is very fragile; those consisting of a gelatine film between two plates of optical glass; and coloured optical glass. The last type is the only one suitable for use with an air camera and the filter must have an optical quality not inferior to that of the lens. Green, yellow-green and yellow filters are often used in cameras but with pan film in an air camera a deep-yellow filter is always used. The latter is a minus-blue filter and it reduces the quantity of blue and violet light admitted to the emulsion and so helps to correct the oversensitivity of pan film to light of the lower wavelengths; this in turn reduces the effect of haze. However, the best penetration of haze is achieved by using infra-red film with a deep red filter.

CHARACTERISTICS OF A CAMERA LENS

In Chapters 1 and 2 we considered that the objects being photographed were sufficiently far away from the camera for the beam of light rays from them to be considered as consisting of parallel rays. In air photography for topographic surveying purposes this will always be so and the camera can be set for infinite focus. In a process camera, however, the objects may be very near and the incident rays will be convergent. As the constant of refraction will remain the same, the tendency will be for the rays to be brought into focus at a greater distance behind the lens. Figure 9.9 shows light from objects O_1, O_2 and O_3 on the optical axis brought to focus at I_1, I_2 and I_3 respectively. Thus if O_2 were brought into clear focus, O_1 and O_3 would have slightly fuzzy images. If the three objects were considered as point sources of light, I_2 would be a point but I_1 and I_3 would appear as discs having a definite magnitude. These are known as discs (or disks) of confusion, and if they are 0·25 mm or less in diameter they will appear to the human eye as dots. If an enlarged print is to be made at say twice the scale, then a disc of more than 0·125 mm on the negative will be visible in the enlargement.

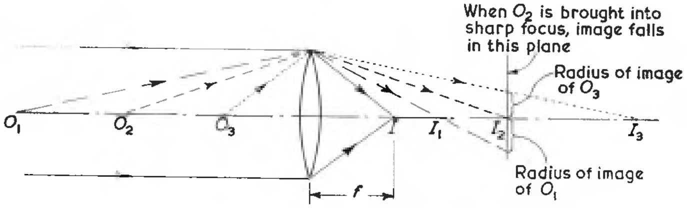


FIG. 9.9. DEPTH OF FOCUS

I = sharp image of object at " infinite " distance
I_1 = sharp image of object at O_1
I_2 = sharp image of object at O_2
I_3 = sharp image of object at O_3

In process work the objects usually lie in one plane surface so that with a theoretically perfect lens there will be zero depth of focus. However, the halo-forming aberrations or lens faults which are considered later in this chapter will all be accompanied by discs of confusion not all of which will be circular in shape.

The Angle of View

The angle of view or width of angle of a lens is the angle subtended at the rear node by the diameter of the circle defining the limit of satisfactory image. Since the whole of an air photograph is required to be satisfactory it follows that the diameter of such a circle cannot be less than the diagonal of the format. A normal angle lens has a width of angle up to 75°. If the angle lies between 75° and 95° the lens is usually described as *wide-angle*, but an angle of over 95° would be described as *ultra-wide-angle* or *super-wide-angle*. With a given focal length lens and flying at a fixed height, the wider the angle of view the larger the area of ground covered with one exposure and the fewer exposures required for a given area of ground. The most common types of air camera have lenses 152·4 mm focal length and a 230 mm × 230 mm format size. Thus the diagonal of the format is $230\sqrt{2}$ mm long, and this can be regarded as the diameter of the circle defining the limit of satisfactory image. From Fig. 9.10 it will be seen that the angle of view of such a lens is approximately 93½°. This is by no means the widest angle lens in use: lenses with angles of up to at least 120° can be made today but unfortunately both definition and illumination tend to fall away from the axis. Improvements in the manufacture of lenses have largely overcome this defect but the wider-angle lenses are more expensive.

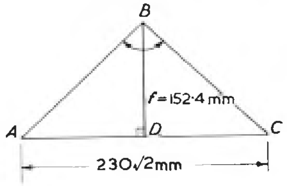


FIG. 9.10. ANGLE OF VIEW (152·4 MM LENS AND 230 MM × 230 MM FORMAT)

B = back node
AC = diagonal of format
BD = principal distance
$\angle ABC$ = angle of view

$$\tan \angle ABD = \frac{\frac{1}{2}\times 230\sqrt{2}}{152{\cdot}4}$$

$$\therefore \angle ABD = 46^\circ 52'$$

$$\text{i.e. angle of view} \simeq 93\tfrac{1}{2}^\circ$$

Relative Aperture

The diaphragm consists of a set of thin metal plates arranged in the form of an adjustable iris as in Fig. 9.11. At the time of exposure, the hole or aperture in the centre of the diaphragm forms the only access for light into the camera.

The leaves can be turned on pivots to vary the size of the central hole although there are definite upper and lower limits to the size of this aperture. The action of reducing the size of the aperture is known as *stopping down*. The stop is the method of controlling the amount of light entering the camera—the wider the aperture the greater the illumination of the image, but opening up the stop increases the depth of focus. If you were to point a hand camera at three persons A, B and C such that A was nearer to the camera than B who was in turn nearer than C, then focusing on B with the lens stopped right down you might find that A and C were also in focus (compare O_1, O_2 and O_3 in Fig. 9.9). If we now increase the aperture size, at the same time keeping B in focus, we find that A and C gradually lose definition by going out of focus. In an air camera the depth of focus is of little importance as the distance of the camera from the ground objects is very great compared both with the equivalent focal length and with the differences in ground heights.

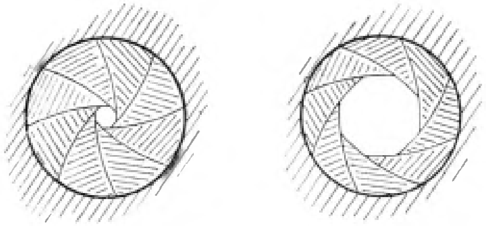

(i) (ii)

FIG. 9.11. AN IRIS DIAPHRAGM
(i) SMALL APERTURE
(ii) OPEN APERTURE

Relative aperture is usually denoted as the ratio of the focal length to the diameter of the stop. That is, relative aperture $= f/D$ where D is the diameter of the stop. A relative aperture of 8 is expressed as $f/8$ and this is sometimes called the f number. For example, if the focal length of a lens were 152 mm and the diameter of the aperture 19 mm, then the relative aperture $= 152 \div 19 = 8$, i.e. relative aperture of $f/8$.

In British practice, camera stop adjustments are usually marked with the following f numbers: 2, 2·8, 4, 5·6, 8, 11, 16, 22, etc.—each higher number is $\sqrt{2}$ times the number next preceding it.

Illumination of Image

In theory we may consider a particular field object to be self-illuminated and to lie in a plane perpendicular to the optical axis of the lens. Let us assume too that this object is very small, having an area of A, and that it lies on the optical axis of the lens. Let the light per unit area of the source be I. Then the total light emanating from the source is $I \times A$, and the total amount of light passing through the stop is proportional to $\frac{I \times A \times d^2}{l^2}$ (see Fig. 9.12).

If now we consider a second similar source of light in the same

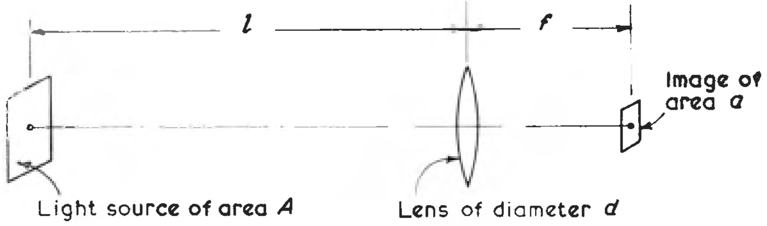


FIG. 9.12. ILLUMINATION OF AXIAL IMAGE

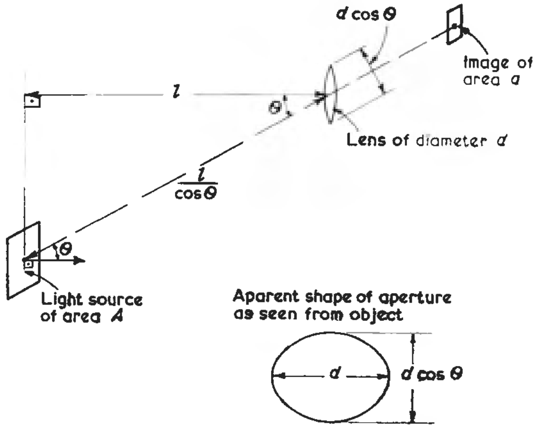


FIG. 9.13. ILLUMINATION OF NON-AXIAL IMAGE

plane as the first but situated off the lens axis in such a position that the angle of incidence for the light rays at the lens is θ, then the rays of light from the object leave the surface of the object at an angle of θ with the normal, and the intensity of illumination will fall to $I \cos \theta$. The apparent area of the lens aperture as viewed from the object will be reduced to an ellipse whose major axis is still d but whose minor axis is reduced to $d \cos \theta$. The distance of the object from the lens is now increased to $l/\cos\theta$ (see Fig. 9.13). Thus the amount of light passing the stop is now proportional to

$$\frac{I \times \cos\theta \times A \times d^2 \times \cos\theta}{\left(\dfrac{l}{\cos\theta}\right)^2} = \frac{I \times A \times d^2}{l^2} \times \cos^4\theta$$

The illumination has then decreased from that of the axial image proportionally with $\cos^4\theta$. This is known as the $\cos^4$ law, and it represents a decrease in illumination per unit area since the area of the image remains the same.

Illumination from all sources is subjected to further losses of light when the light rays pass from one medium to another. Loss of illumination when the rays pass from air to glass or from glass to air is approximately four per cent. Thus the transmission of light through a single lens is not greater than $(0{\cdot}96)^2$, and through a lens with eight air-glass intersurfaces it is not greater than $(0{\cdot}96)^8$. These losses may be reduced by coating the lens surfaces with a very thin anti-reflecting film. The latter helps by reducing flare-light (see the section on lens mount and cone, page 16).

In addition to the above losses, the glass itself will absorb some of the light.

Thus from the point of view of illumination, the thickness of the lens should be reduced as far as possible, and the number of air-glass interfaces should be kept to a minimum.

Chromatic Aberration

In focusing a particular object a lens acts similarly to a prism in that it brings different wavelengths of light impulses to focus at different distances from the lens. A simple lens, as illustrated in Fig. 9.14 (i), refracts the blue-violet rays more strongly than the red rays. Thus if the focal plane is taken to be the plane through V, the image point would appear to be of blue-violet light with a halo of green and red. The photograph would be such that the whole image of the point would be replaced by a blurred disc, since all light would be represented by tones of black and white.

Chromatic aberration can occur with oblique rays of light, when it is known as *lateral chromatic aberration.* In such a case the true position of the point is no longer central within the blur (see Fig. 9.14(ii)).

By stopping down the aperture the rays of light passing through the outer areas of the lens can be eliminated and chromatic aberration can be virtually cured if this stopping-down is carried to extremes. However, stopping-down cannot be used to any great extent in an air camera because the resulting loss of illumination would increase the necessary time of exposure. Until recent years there were only two main types of optical glass: *crown* and *flint* which have different refractive effects on the spectrum. By using a combination of one of each of these types of glass the lens can be made to focus two parts of the spectrum in the same plane: thus either the green and red rays or the green and blue-violet rays will be brought to the same focus. Such a combined lens is called *achromatic.*

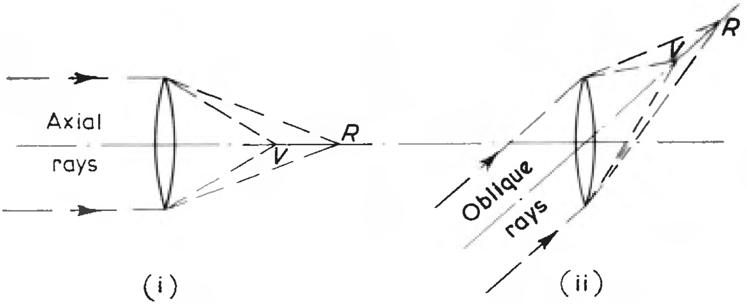


FIG. 9.14. CHROMATIC ABERRATION
(i) AXIAL
(ii) LATERAL
V = violet image R = red image

An *apochromatic* lens consists of three separate lenses combining to bring three parts of the visible spectrum to the same focus.

Spherical Aberration

Because of the shape of the simple lens, parallel rays of light are refracted more at the outer areas of the lens than at the centre, so that the image cannot be brought to focus in one plane, and a point will appear as a disc (see Fig. 9.15(i)).

If we use a combination of two lenses in such a way that the thickness of the lens is the same throughout (see Fig. 9.15(ii)), then theoretically we shall remove the cause of spherical aberration. Unfortunately such a lens would cease to refract at all and there would be no focused image. If one lens is of crown and the other of flint glass the ability to focus is restored but so also is some aberration. A lens of this type is known as aplanar.

Spherical aberration can also be reduced by stopping down the aperture, or by using *aspheric* lenses, i.e. lenses with a surface which is other than spherical. They are more difficult to grind to shape and therefore more expensive than the more usual spherical lenses.

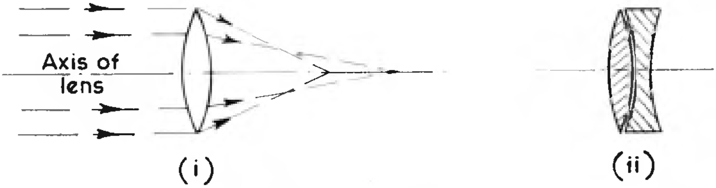


FIG. 9.15. SPHERICAL ABERRATION
(i) AXIAL RAYS
(ii) COMPOUND LENS OF UNIFORM THICKNESS

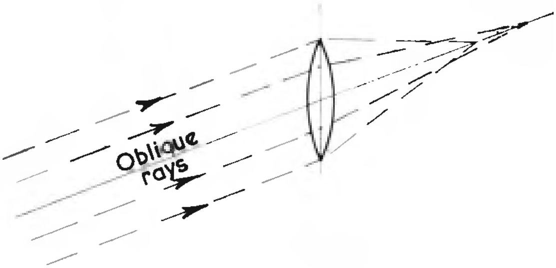


FIG. 9.16. COMA

Coma

Coma is spherical aberration of oblique rays (see Fig. 9.16), and results in a blurred image which takes on a comet-like shape—hence the term coma.

Astigmatism

This is an aberration of rays oblique to the axis of the lens. A point appears in the image as two mutually perpendicular straight lines at different distances from the lens: one of these lines will be radial from the centre of symmetry which should lie at the principal point.

Curvature of the Field

Curvature of the field indicates that the focal " plane " is no longer planar, but a curved surface. Curvature concave towards the lens is known as positive curvature. Where curvature exists the plane of the negative at the time of exposure must be adjusted so that it takes up a mean position relative to the curve of correct focus (see Fig. 9.17).

Where astigmatism exists, the radial line images form in a different curved surface from the tangential line images. The curvature of field is then said to be the mean of these two curved surfaces.

An *anastigmat* is a lens so compounded as to eliminate both astigmatism and curvature of field over a large part of the photograph.

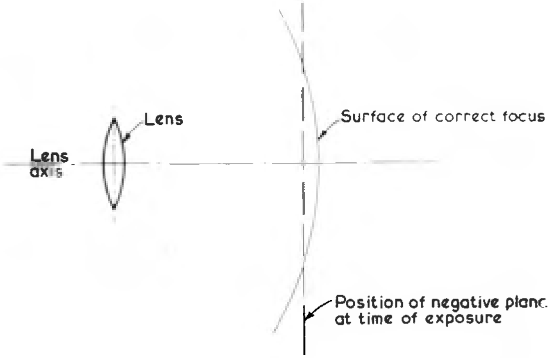


FIG. 9.17. CURVATURE OF FIELD—LONGITUDINAL SECTION THROUGH THE OPTICAL AXIS

Distortion

This implies a displacement of an image point from its true geometrical position; it therefore directly affects the accuracy of measurements made on the face of a photograph. It is the oblique rays of light which will give rise to distortion, so that the point at which the optical axis meets the plane of the negative should be free from distortion. Distortions at other points can be thought of as radial from or tangential to this point which is known as the *centre of symmetry* or *conformal point.* The lens is symmetrically constructed about its optical axis and distortions will therefore tend to vary with the distance of the image from the centre of symmetry.

If the centre of symmetry lies at the principal point, then linear distortion will be radial from the principal point and will not invalidate the radial-line assumption. It becomes important therefore to ensure that principal point and centre of symmetry coincide. Tangential distortion is measured on the face of the photograph in a direction perpendicular to the radials from the principal point, which for the present purpose is assumed to fall at the centre of symmetry. This displacement of the image is small and will cause a slight curving of straight lines. The effect of tangential distortion will be at a maximum along one radial and it will be almost non-existent along another radial perpendicular to the first.

Where distortion is such that it causes the sides of a square symmetrical about the principal point to become concave outwards, it is known as *positive* or *pincushion distortion.* Where these lines become convex outwards, this is evidence of *negative* or *barrel distortion* (see Fig. 9.18).

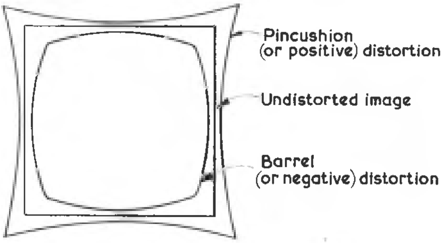


FIG. 9.18. PINCUSHION AND BARREL DISTORTION

Variation in the resolving power of a lens causes a variation in the ease with which a particular point can be accurately located, and in this way it affects indirectly the accuracy of measurements made on the face of the photograph.

Resolving power of the emulsion has been considered earlier, but the resolving power of the lens and the separately determined resolving power of the emulsion will be no guide to their combined resolving power. Thus an emulsion should be tested with the lens with which it will be used.

CAMERA CALIBRATION

Calibration is required to determine not only the camera constants (i.e. focal length, width of angle of lens, principal distance, format size, and location of principal point in the camera), but also the quality and efficiency of all parts of the camera.

The lens is usually tested for distortion and resolution in the laboratory although it is now realized that this will give very different results from those applying in practice, and more realistic field tests are being applied.

Such calibration is the responsibility of an expert, but the surveyor himself might need to check the camera in the field to determine whether it has retained its principal distance and whether the collimating marks still indicate correctly the principal point. If an appreciable discrepancy is found, the camera should be returned to the maker.

These field checks are similar to the full outdoor calibration, and they will be described because it will help with the theory of the camera.

Set up the camera on its side on a firm stand such that the optical axis is truly horizontal and two sides of the format are also horizontal. Choose three field points within the field of view of the camera and at a distance of five hundred metres or more. The points chosen should be in approximately the same horizontal plane as the optical axis, and one should be in a fairly central position and the others at between a quarter and a third of the format width from either edge of the format.

In the case of full calibration at least five points will be required; the extra ones will be used as checks and also for the determination of the centre of symmetry.

After the field points have been adequately marked, an exposure is made. Such an exposure is best made on a glass plate. The camera is now rotated about its optical axis through 90° and set up again in exactly the same position as before but with the other two sides of the format horizontal. A second plate is now exposed.

A theodolite is set up in the place of the camera. It does not affect the test if the theodolite is slightly displaced in the vertical direction, but the plan position of the theodolite must exactly duplicate the plan position of the lens. The theodolite is required to measure the angles between the rays from the three field objects. The plates are now developed. Let the field points be A, B and C and their image positions a, b and c. Then if m and n are collimating marks in the middle of the vertical sides of the first plate, the line mn will pass through a, b and c, and the distances ma, mb and mc are measured in millimetres. The true principal distance pO in Fig. 9.19 can now be computed, as we shall see in the next chapter, and the length mp can also be found.

The same procedure and computations are carried out for the second plate so that the true position of p, the principal point, is now known and can be checked against the marked position.

Lens calibration is a subject for the expert, but a word must be said concerning the measurement of lens distortions. The distortion of any point is usually considered as the error in its positional displacement from the principal point as measured on the face of the photograph. The principal point is here considered as the centre of symmetry. The correct position of an image point *a* is at a distance of $f \tan \theta$ from the principal point, where f is the principal distance

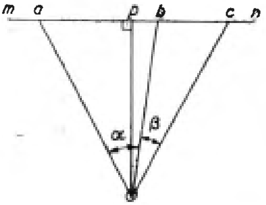


FIG. 9.19. CALIBRATION DIAGRAM
mn is a line joining a pair of collimating marks.
O represents the perspective centre or rear node and therefore in the field diagram *O* is the camera station.
a, *b* and *c* are the images of the targets.
p is the principal point.

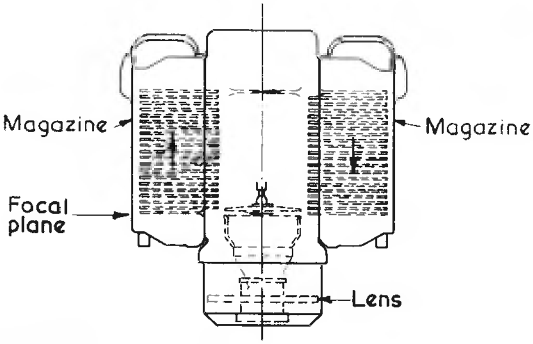


FIG. 9.20. SECTION THROUGH A WILD PLATE CAMERA SHOWING THE PLATE TRANSPORT SYSTEM

of the camera and θ is the angle of incidence of the appropriate ray. If the measured distance from the principal point is x, then the distortion is $\frac{x - f \tan \theta.}{x}$ There are practical difficulties in using this formula and it is becoming more usual to express distortion as a variation in focal length by putting $f = \frac{x}{\tan \theta}$ when f will vary according to the distortion element in the measured distance x.

Modern air camera lenses are often described as distortion free, e.g. the Wild range which includes the normal-angle Aviotar, the wide-angle Aviogon, and the Infragon (for use in infra-red work) lenses, each of which have distortions within ± 0·01 mm.

PLATE CAMERAS

A corresponding improvement in base stability of the negative is achieved by the use of glass plates. The Wild RC 7 plate camera (see Figs. 4.10(i) and (ii)) is fully automatic; the plates are loaded into the camera in two detachable magazines. The plate transfer system is illustrated in Fig. 9.20.

FURTHER READING

BROCK, G. C., *Physical Aspects of Air Photography*, 2nd ed. (Longmans).

(i) Schwidefsky, pages 34–54 (lens), pages 74–90 (photography).
(ii) *Manual of Photogrammetry*, Vol. I, Chapter 6.
(iii) Moffitt, Chapter 2 (cameras).
(iv) Hallert, pages 28–52.
(v) Lyon, Chapter 14.
(vi) Zeller, pages 105–14 (cameras).
BROCK, G. C., *Image Evaluation for Aerial Photography* (Focal Press).

Further information concerning PHOTOGRAPHIC PROCESSES can be found in the recognized books on that subject, e.g.—

CLERC, L. P., *Photography—Theory and Practice* (Focal Press).
Ilford Manual of Photography.

A good guide to PHOTOGRAPHIC TERMS is the *Dictionary of Photography* published by The Fountain Press.

(See Bibliography (page 346) for the full titles.)