FUNDAMENTALS OF AERIAL PHOTOGRAPHY

Introduction

Remote Sensing can be broadly defined as the collection of information about an object or physical phenomena without being in physical contact with the object or phenomenon. Aircraft and satellites are the most common platforms from which remote sensing observations are made. Aerial photography is the original form of remote sensing and has wide applications in topographical mapping, engineering, environmental studies and exploration for oil and minerals. In the early stages of development, aerial photographs were obtained from balloons and kites. Later, with the development of airplane (1903) and specifically during the World War (1914 to 1918), aerial photography received more attention in the interest of military intelligence.

In India, aerial photographs have been in use since 1920 for aerial surveys and for interpretation in specific fields such as geology. Attempts were also made to use terrestrial photographs obtained from photo-theodolites for survey purposes around 1899. Photogrammetric methods for mapping were introduced in the 1948 with the advent of multiplex stereo plotting instrument. Later, such equipment was further augmented with the acquisition of modern stereo plotting instruments during the period from 1954 to 1956. Since then, Survey of India (the national mapping agency) has kept itself abreast of the technological changes in the fields of photogrammetric mapping and aerial photography.

The present discussion confines itself to aerial remote sensing only i.e. aerial photography.

Aerial Photography

Aerial photography is defined as the science of obtaining photographs from the air using various platforms, mostly aircraft, for studying the surface of the earth. The sun provides the source of energy (electromagnetic radiation or EMR) and the photosensitive film acts as a sensor to record the images. Variations in the gray tones of the various images in a photograph indicate different amounts of energy reflected from the objects as recorded on the film.

The earth's atmosphere, which contain various particles and molecules of gases and water vapor, attenuates the incoming as well the outgoing energy/radiation (scattering) after interaction (reflectance, transmittance and absorption) with the object and thus reduces the contrast between different images formed on the photographic film. Therefore, the quality of aerial photography largely depends upon the atmospheric conditions prevailing at that time. Different filter/lens combinations can, however, be used to eliminate some of the atmospheric effects in black and white photography by making use of a yellow (minus blue) filter to reduce the effects of haze. The problem becomes more complex in the case of colour photography. Other factors that influence aerial photography are as follows.

Scale

Scale is the ratio of distances between two images on an aerial photograph and the actual distance between the same two points/objects on the ground, in other words the ratio f/H (where f is the focal length of the camera lens and H is the flying height above the mean terrain). Due to variations in flying height, the scales of different photographs may vary. Scale may also vary because of the effects of tilt and relief displacements.

Camera/Film/Filter Combinations In order to extract the maximum information from aerial photograph, the image should be of the highest quality. To ensure good image quality, modern distortion-free cameras are used. Some of the latest versions have image motion compensation devices to eliminate or reduce the effects of forward motion. Depending upon the requirements, different lens/focal length/film/filter combinations can be used.

Flight Direction

As a rule, aerial photography is flown in strips to cover the designated area. For convenience in handling, it is advisable to keep the number of strips to minimum. The flight direction of the strips is therefore kept along the length of the area. This direction may be any suitable direction along a natural or man-made feature and should be clearly specified.

Time/Season of Photography

The time of aerial photography is very important, as long, deep shadows tend to obscure details, where as small shadows tend to delineate some details effectively and are generally advantageous in improving the interpretational values of a photograph. Based on experience, aerial photography should be flown when the sun's elevation is 30 degrees above the horizon, or three hours before and after the local noontime.

The choice of the most suitable season depends on factors such as seasonal variations in light reflectance, seasonal changes in the vegetation cover and seasonal changes in climatological factors. The purpose for which aerial photography is flown also dictates the season. For example, for photogrammetric mapping, geological or soil survey purposes, the ground should be as clearly visible as possible.

Atmospheric Conditions

As mentioned before, the presence of particles (smoke or dust) and molecules of gases in the atmosphere tends to reduce contrast because of scattering, especially by the heavier particles; therefore the best time for photography is when the sky is clear, which normally in India is from November to February. The presence of dust and smoke during the pre monsoon summer months and of clouds during the monsoon months forbids aerial photography during these periods.

Stereoscopic Coverage

To examine the earth's surface in three dimensions, aerial photography is normally flown with a 60 % forward overlap and a 25 % side lap, to provide full coverage of the area. This is an essential requirement from the photogrammetric mapping point of view to obtain data both on planimetry and heights using the stereoscopic principle of observation in 3-D and measurement techniques with stereo plotting instruments. Stereoscopic viewing also helps in interpretation, as the model is viewed in three dimensions.

Applications of Aerial Photography

Mapping

The application of aerial photography in photogrammetric mapping is an established procedure all over the world. It has been found to be fast, accurate, indispensable in inaccessible areas and cost effective in the long run, as initially the establishment of a photogrammetric survey/mapping unit involves capital expenditure due to the cost of photogrammetric instruments and other ancillary equipment.

Interpretation

Photo interpretation has revolutionalised the methods of data collection in various disciplines. It greatly reduces the fieldwork and thereby the cost. The information is reliable and acceptance for most studies such as in the fields of geology, water resources, geomorphology, hydrogeology, forestry and ecology, soil surveys, and urban and regional planning.

Map Substitute

In a situation where there are no adequate large-scale maps available, aerial photographs can serve as map substitutes in the form of photomaps. In the case of relatively flat terrain, these photomaps can be produced by rectification to remove the effects of tilt distortion and scale correction. This method has been found to be three to four times faster than conventional mapping by photogrammetric methods. In the case of hilly terrain, such photomaps (orthophoto maps) can be produced by the orthophoto technique, which has also proved to be faster than conventional mapping. In some urgent situations, simple mosaics prepared from aerial photographs can substitute for maps.

Classification of Aerial Photography

There are different criteria to classify aerial photographs depending upon the scale, tilt, coverage, film and spectral coverage/response. This classification can be defined as follows:

Scale

* Large scale: between 1:5,000 and 1:20,000
* Medium scale: between 1:20,000 and 1:50,000
* Small scale: smaller than 1:50,000 (Scale classification may differ from country to Country)

Tilt

* Vertical: when the tilt is within $\pm 3^\circ$ (nearly vertical)
* Oblique : Low oblique (horizon does not appear but tilt is more than 3°)
  High oblique (horizon appears)
* Horizontal or terrestrial : camera axis is kept horizontal.

Angular Coverage

* Narrow angle : angle of coverage less than50°
* Normal angle : angle of coverage of 60°.
* Wide angle : angle of coverage of 90° .
* Super-wide angle : angle of coverage of 120°

Film

* Black and white panchromatic.
* Black and white infrared.
* Colour
* Colour infra-red/false colour

Spectral Coverage/Response

* Multispectral: Depending upon the number of spectral bands.

As indicated above, a wide variety of photographic data products are available for mapmakers, interpreters and resources scientists from which they can derive data relevant to their specific needs. A thorough knowledge of the characteristics of these data products is therefore imperative to derive the maximum benefits and to optimize the work procedures.

Photographic Products

In all aerial photographic tasks, the images are recorded on film negatives, which are seldom used for mapping or interpretation. Positive prints or transparencies/diapositives prepared from the film negatives are used for photogrammetric mapping as well as for interpretation work. The criteria for good positive prints are that the prints should represent the actual response and reproduce all the details in the negative in a manner that permits easy recognition.

The positive materials in use are paper, film, and glass plates. Positive transparencies, which are also called diapositives, are better as, they record all the details present in the negatives. Diapositives are therefore used when high precision and quality are the goals. Paper prints are, however, so much easier to handle that they are always used for photo interpretation and field checking. The different types of photographic data products are detailed below.

- Negatives on film (polyester based): previously on glass plates also.
- Diapositives/transparencies on film
- Contact prints on photographic paper of various grades and types. Such photographic papers are available in grades of soft, medium and hard, and are used to obtain contact prints of optimum contrast from the original film negative. For example, if the original negative is of high contrast, a soft paper is used to prepare the contact prints. Similarly, photographic paper is also available in various thickness and surface qualities (matte or glossy) for use in different stages of mapping and interpretation.
- Enlargements obtained on film or photographic paper for specific uses.
- Colour/false colour prints. Positive prints can also be prepared on colour films/paper/transparencies from original colour negative films for use in interpretation. Likewise, such prints/transparencies can also be obtained from colour infra-red/false
- colour films. However, the processing of such films requires special processing facilities.
- Multispectral photographs on film or photographic paper. In the case of multispectral photographs from an I^2S camera, it is possible to obtain colour composites or false colour composites by the combination/superimposition of different spectral bands: for example, the blue, green and red bands can be combined in special projection instrument to obtain true colour composites. If the idea is only to view them, colour/false colour composites can be obtained from special instruments such as Mini Addcol Viewer.

Obtaining Aerial Photography

As per the existing policy of the Government of India, all types of aerial photographs are classified documents (secret or restricted), depending upon the location and its strategic importance. The Surveyor General of India coordinates all activities relating to the execution of aerial photographic tasks for all civilian needs. The coordinating authority performs the following functions :

- Design and issue of the specifications for photographic tasks.
- Layout and priorities, clearance from various agencies and distribution of tasks among the three flying agencies.
- Flight planning and evaluation for suitability of the executed tasks.
- Distribution of photographs to the indenter.
- Accounting for the above.

Flying Agencies

As the coordinating agency does not have its own flying facilities, the flying operations for aerial photography are carried out by the Indian Air Force; the Air Survey Company, Dum Dum, Calcutta and the National Remote Sensing Agency (NRSA), Hyderabad.

Cost of Aerial Photography

The cost of aerial photography in India depends upon the flying agency carrying out the operation; the scale of the aerial photography; the area covered. Cost also depends whether the prints are supplied from fresh or existing photography.

In the case of Indian Air Force, the cost depends upon the number of actual flying hours and the type of aircraft used: as such , the cost can not be worked out in advance.

In the case of Air Survey Company, the cost is Rs. 75.20 per square mile (Rs. 29/- per square km) for 1:40,000 scale (1990 price - the cost is now under revision). For other scales, a linear conversion can be made; for example at 1:5,000 scale the cost is (40/5) X 75.2 = Rs. 601.60 per square mile and at 1:60,000 scale the cost is (40/60) X 75.20 = Rs. 50.15 per square mile.

In the case of the NRSA, the cost varies from scale to scale and by the distance of the area from their headquarters. As such, the cost must be worked out separately for each task.

Handling of Aerial Negatives

The greatest sources of dimensional change in aerial negatives are humidity and thermal expansion/contraction. Ideally, negatives should be kept at the same temperature and relative humidity that existed at the time of exposure. The recommended relative humidity is 50 to 60 per cent, and temperatures should be 70o F with +/- 3o F tolerance. In order to ensure dimensional stability, it is advisable to control the temperature of the aerial camera while in operation so as to be close to normal room temperature.

It is also recommended that negative rolls be stored for future use in controlled conditions of temperature and humidity as mentioned above. While working with negatives, their surfaces should be kept free from dust, grease, scratches and fingerprints. These precautions will help in obtaining good quality data products on reproduction as and when required.

Specifications of Aerial Photography

For planning fresh photography, the purpose of the photography and scale are the main considerations. However, while defining these specifications, the following factors should be kept in view. Unless otherwise specified, the overlaps should be kept 60 per cent in the forward direction and 25 per cent in the lateral direction. For special tasks and terrains, the overlaps can be increased to 80 percent in the forward direction and 50 to 60 per cent in the lateral direction, especially in steep hilly areas and in city centers with high-rise buildings.

- Camera lens : depending on the type of photography required.
- Film/filter combination : depending on the type of photography required.
- Shutter speed : depending on the scale, type of aircraft, its speed and film speed/aperture (between 1/100 to 1/1,000 seconds).
- Image motion : to be kept within tolerable limits (i.e. 20 um on the negative scale) by the proper combination of shutter speed/aperture and speed of aircraft
- Camera frame : stable mounts
- Platforms : ceiling height, stability in flying and speed limits.
- Auxiliary data : as required
- Processing : depending on the film type and the requirements of the data products.

AERIAL CAMERAS

Basic requirements of aerial photographs

The most important uses of aerial photographs are for production of base maps and for application of photo-interpretation techniques for natural resources survey for geology, soil survey and forestry purposes. In order to be useful for above purposes, aerial photography should fulfill the following requirements :

a) the photography should provide a faithful image of even the minute's detail,

b) the definition of photography should be clear,

c) the photography should be distortion free and continuous,

d) the tilt and crabs are within tolerable limits.

Optical aspects of aerial camera

In aerial survey owing to the movements of the camera relative to the ground, short exposure time and the necessity for bright photography, the aerial camera should fulfill the following requirements :

a) A large relative aperture of the taking lens to produce bright and clear photographs.

b) The photographs produced are geometrically accurate with a high degree of sharpness and good definition over large angular field.

c) The camera lens should be free from following lens aberrations.

I. Spherical aberration - Occurs when rays from various zones of a lens focus at different places along the axis; this results in an object point being imaged as a blurred circle. It is caused by the spherical shape of the lens surfaces. It is decreased as the lens aperture is reduced.(Fig.1).

II. Coma - is a comet-shaped blur of light formed around image points off the axis. It is partly due to spherical aberration of oblique rays.

III. Astigmatism - is an aberration, which causes a point object off the axis to be imaged as two mutually perpendicular short lines, located at different distances from the lens. One of these is radial and other tangential with respect to centre of the field.(Fig.2).

IV. Curvature of the field - The surface of the best definition is located midway between the two radial and tangential surfaces as explained in (iii) above and its departure from flatness is termed `curvature of the field.' (Fig.2).

V. Chromatic aberration - results when rays of various wavelengths of different colours focus at different distances from the lens. Lateral chromatic aberration is a difference in image magnification for various colours caused by chromatic aberration of oblique rays (Fig.3).

d) The camera lens is free from lens distortion. Radial lens distortion is the linear displacement of an image point radially to or from the centre of the image field - a positive value being considered away from the centre. Tangential lens distortion is a small displacement in the image plane perpendicular to radial lines from the centre of the field and is caused due to either lack of precision in centering of the various lens elements or to improper mounting of the lenses. A lens exhibiting distortion will image a square positioned perpendicularly and symmetrically with reference to the optical axis as a pincushion or barrel since the various zones of the image correspond to different focal length values and consequently varying image scale (Fig. 4).

e) The definition is good. Definition concerns the ability of a lens to record fine details and can be expressed as maximum number of lines pair per millimeter that can just be seen as separate lines in the image. Normally, a resolving power of 45 lines pair per mm is considered satisfactory.

Aerial cameras

The aerial cameras should be of a good quality. Its optical unit holding the lens, fiducial marks and edges, which define the focal plane, should be of a rigid mechanical structure. The main types of aerial cameras are given in Table 1.

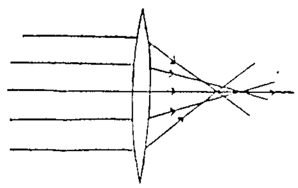
Components of Aerial Cameras

The major components of an aerial camera are : Lens, lens cone, shutter and diaphragm, camera body, drive mechanism, film magazine, focal plane and film flattening device (Fig.5.).

The lens should be distortion-free and of high resolution. The lens surfaces should have anti-reflection coatings.

The lens cone support the lens and retain it at a predetermined distance and position from the film or plate negative, and serves to include direct light from striking the film or plate. The interior of the lens cone should be black and fitted with baffles so as to reduce the reflection of flare light.

The shutter and diaphragm of an aerial camera functions as a light value and regulates the amount and period of time that light is permitted to pass through the lens and expose the film or plate. The shutter should be of the between the lens type.



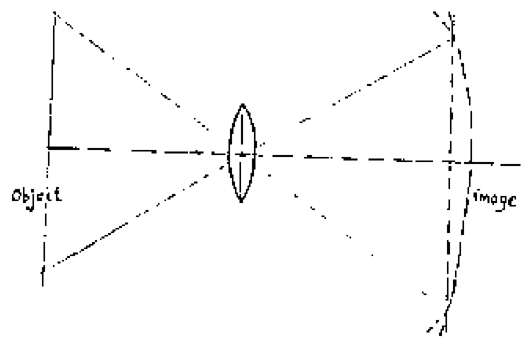
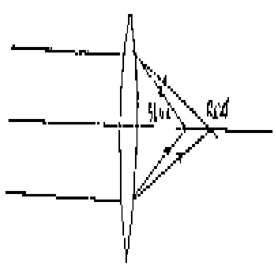


Fig. 1 Spherical aberration and curvature curve)

Fig. 2 Astigmation (Dotted curves) of field (solid



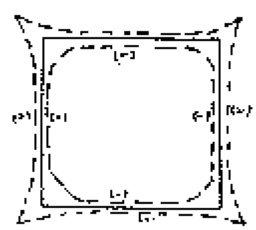


Fig. 3 Chromatic aberration distortion

Fig. 4 Effect of lens

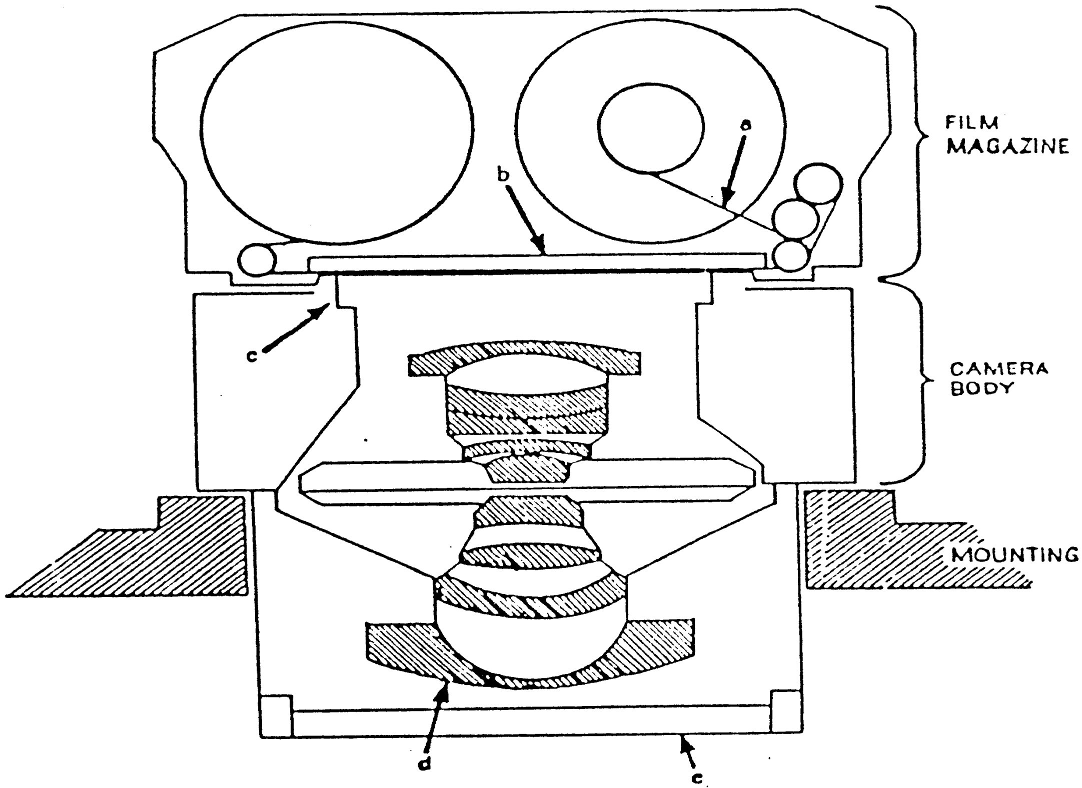


Fig. 5 An aerial camera
(a= film, b= pressure plate, c= focal plane frame, d= lens, e= filter)

The camera body houses the camera drive mechanism, driving motor, operating handles and levers, electrical connections and switches and other accessories which may be necessiciated by specified requirements.

The camera derive mechanism is the power unit and power distributor for the entire camera. The electric motor causes the many cams gear and shafts of the camera to move. By means of rods and couplings, the power is routed to the shutter and the film magazines. When a cycle is completed, the camera drive receives and electrical or mechanical impulse, operates the shutter, and thus exposes the sensitized material.

The film magazine is first of all a container of film. Besides this it contains a driving mechanism, which receives power from the camera drive mechanism and thereby shifts the film after each exposure has been made. In addition, the magazine contains a means of holding the film flat in the focal plane while the exposure is being made.

The focal plane of an aerial camera is the plane in which all light rays through the lens cone come to a focus. A frame bound the focal plane, which determine the size of the negative. In order to provide a means for placing the emulsion of the film in the exact focal plane, a metal plate known as locating back is used in modern aerial cameras.

The film flattening is usually accomplished in modern aerial cameras by a vacuum system. The locating back has grooves in which there are small holes which leads to a central vacuum connections and hold the film firmly against the focal plane frame.

Camera mounting

It is advisable to keep the maximum relative motions between image and film, arising from angular vibrations during the longest exposure, below a value of 0.002 mm. For a good camera mounting, the centre of support should be near the centre of gravity, the mount should be near the centre of gravity, the mount should feel soft and yield easily to hand pressure, with its natural frequency not higher than 5 cycles per second, and damping should be somewhat under damped.

Intervalometer

The use of an intervalometer, which controls the automatic exposure of the camera at, specified distance intervals, along the flight line result in correct forward overlap. The determined exposure interval is set on the intervalometer, which is then regulated by electric or mechanical impulses with varying flying speeds and flying heights.

Crab compensation

Another important requirement is that the camera must be able to be turned into its mount to compensate for crab. The crab is determined through simple sighting devices and is eliminated by turning the camera ;through the `angle of crab' and thus uniform overlap over the entire breadth of the photograph is ensured.

TABLE I
DETAILS ABOUT CAMERAS

SL. NO.	CAMERA TYPE & MAKE	TYPE OF LENS	ANGU-LAR COVE-RAGE	FOCAL LENGTH	PIC-TURE SIZE	SHUTTER TYPE & SPEED	FILM LENGTH USED PER ROLL (m)	NO. OF EXPO-SURE PER LENGTH	OVER-LAPS IN FLIGHT DIREC-TION POSSIBLE	SHORT-EST SEQUE-NCE OF PICTURE	REMARKS
1.	Wild RC 5 (a)	a)Normal angle b)Wide angle	60° 90°	210 115	18x18 18x18	Spring type 1/100 1/200	60 60	280 280	20,60,70,80 -do-	3..5 -do-	Lens fully corrected for visible spectrum (400 nm to 750 nm) -do-
2.	Wild RC 8	Wide angle	90°	115	18x18	1/300	60	280	-do-		-do-
3.	Wild RC9	Universal wide angle	90°	115	23x23	Rotary shutter with continuous setting from 1/100 to 1/00	60	235	-do-		-do-
4.	Wild RC 10	Wide angle F/5.6	90°	152	23x23	Rotary shutter 1/100 to 1/1000	60 or 120	230 or 460	20,25,30 50,55,60 65,70,75 80,85,90	1.6	Lens corrected for the visible and infrared sectors of spectral range (500 nm to 900 nm) and with appropriate light filters
5,	Zeiss RMK'A	Wide angle	93°	153	23x23	Rotating disc type from 1/100 to 1000 continuously	120	470	20 to 90 continuously	2.0	
6.	Multiband I^2S		76°	153	8.9x8.9	Focal plane (2 type A, B) 1/140 to 1/350-A 1/350 to 1/980-B	76	-	-	2.0	Can be used for photography on Panchromatic, infrared, colour and false colour infrared films.

The older types of cameras of Eagle IX type of British make, which have been used largely in the past, are also available. These cameras have lenses, which show distortions, which are appreciable, and the image quality is also not good as with modern cameras. The focal length available is 6", 10", 12" and 20".

PROCESSING OF BLACK AND WHITE, COLOUR, BLACK AND WHITE INFRARED AND COLOUR INFRARED FILMS, FILM DENSITY AND CHARACTERISTICS CURVES

A real image formed by an optical system, may be recorded permanently by situating a photographic film in the image plane. After the appropriate processing and printing, a two dimensional impression of the scene is obtain.

BASIC BLACK & WHITE PHOTOGRAPHY

A light sensitive emulsion consisting of a suspension of microscopic silver halides crystals in a gelatin binder is coated on a piece of flexible polyester to produce a black and white film.

How a picture is formed

1. Light reaching the sensitive layer through the camera lens during the exposure causes an invisible change in the silver halides.

2. When the emulsion is treated with a developer those grains of silver halides, which have been affected by light, are reduced to black metallic silver. The developer has no effect on the grains in areas that have received no light during the exposure.

3. The grains that are not affected by the developer would blacken if exposed to light and so a fixing solution is used to dissolve these unexposed, undeveloped grains without effecting the permanent image in black silver.

4. The film is then washed to remove all unwanted chemicals. And so a negative is made in which the various brightness of the original are recorded as corresponding degrees of blackness.

5. To obtain a picture in which the various brightness correspond to those of the original scene, this negative is printed by passing light through it onto a paper coated with a silver halides emulsion.

6. The paper is then developed, fixed and washed as in the case of the negative.

Physical properties of the developed image

The degree of darkening of the film on development is expressed by a logarithm number, which is called Density. The higher the density, the darker is the film. In case of film, we are only interested in transmission density. Following relation is used for defining photographic density.

$$\text{Transmittance} = \frac{\text{Illumination (OUT)}}{\text{Illumination (IN)}} \times 100 \text{ percent}$$

$$\text{Opacity} = \frac{\text{Illumination (IN)}}{\text{Illumination (OUT)}}$$

Density = Logarithm of Opacity

Characteristic Curve

The relation between exposure, development and the density of corresponding negative is represented by a characteristic curve. It is also known as H and D curve, D log E curve or response curve.

In the characteristic curve, densities are plotted against the logarithm of the exposure to which they correspond. The characteristic curve of all photographic films or papers has general S shape as shown in the figure 6. The shape of the curve will vary on the following conditions.

a) Type of emulsion (speed, contrast, B&W or colour etc.)
b) Type of developer (contrast, chemical constitution etc.)
c) Time of development
d) Temperature of developer
e) Dilution of the developer
f) Method of agitation (manual or automatic processing)

The lower part of the curve AB is known as the Toe region and the upper part CD is known as the shoulder region. The central part BC is known as straight-line region and tangent of its angle with the log. Exposure axis is known as Gamma or contrast of the emulsion. Straight-line region is the best region of the film response. The aim of correct exposure is to utilize the straight-line region of the characteristic curve.

Speed/Sensitivity

Speed is one of the most important sensitometric properties of photographic material intended for aerial photography and also for general-purpose photography. Knowledge of speed value permits the proper settings of shutter speed and aperture number for correct exposure of a film. The general sensitivity of a film describes its ability to produce a density change on exposure to light. The less light required to produce a certain measurable density response, the higher is the sensitivity/speed of the emulsion. Speed of the film is directly proportional to the size of the silver halides grains.

Speed of a film is specified by arithmetical numbers in American and British standards (ASA/BS) and by logarithmic numbers in German Standard (DIN). The formula to compute these speed number is :-

$$ASA/BS = \frac{0.8}{Em}$$

$$DIN = 10 \log (1/Em)$$

Here Em is the exposure in Lux seconds corresponding to the point M obtained on the characteristic curve for a density value of 0.1 above base plus fog density.

In case of under exposure, we have loss of information in the lowlight areas we have loss of information in highlight areas for over exposure.

Printing from negatives

There are two methods of photo printing.

a) **Contact printing** : The negative film and the positive printing paper is kept in perfect contact and exposed to light without a lens. Size of the positive print is of the same size of original negative.

b) **Projection printing** : The negative image is projected through a lens on the positive paper and the size of the positive print is of the desired magnification.

For preparing good quality positive prints from B&W negatives of varying density range or contrast we use positive papers of different grade such as hard, medium, soft etc.

BASIC COLOUR PHOTOGRAPHY

In the spectrum of light (see fig.7), the most obvious colours are blue, green, red and spectral yellow. For convenience, in colour photography, the spectral yellow is ignored (it is a very narrow band of wavelengths) and it is said that the spectrum is divided into three major bands, each being one third of the total :

BLUE (400 to 500 nm)
GREEN (500 to 600 nm) and
RED (600 to 700 nm)

and that WHITE LIGHT contains equal quantities of these three. All systems of 'true' colour photography in use today are based on three facts. They are

1) All the colours and wavelengths of light that the human eye can see can be matched by mixtures of only three suitably choosen colours called YELLOW, MAGENTA & CYAN. Each of these absorbs one third of all the wavelengths in white light while transmitting the other two thirds. See figure 7.

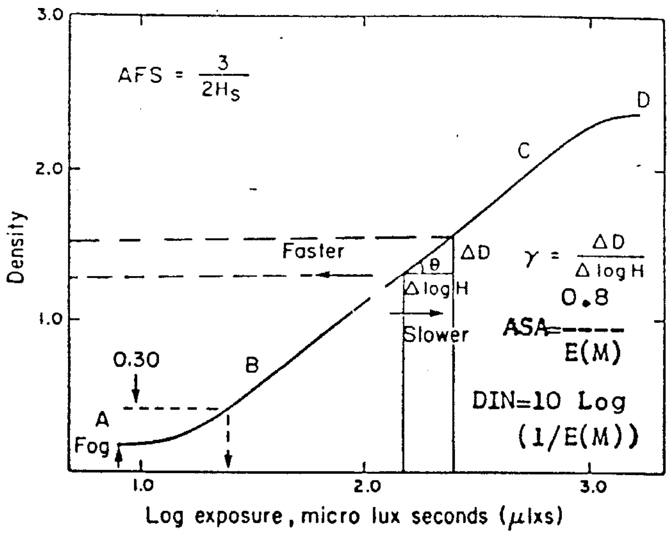


Fig. 6 Characteristic curve and aerial film speed

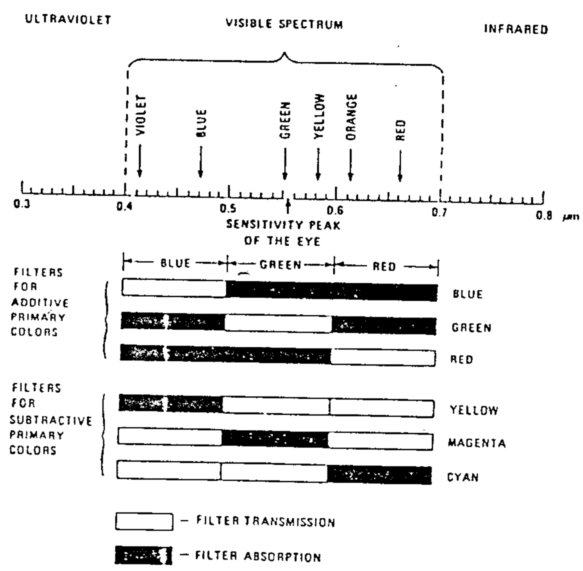


Fig. 7 Visible spectrum with transmission and absorption characteristics of filters

for additive and subtractive colors.

Because each colour absorbs the one third of the spectrum that it does not transmit, each is sometimes called a MINUS COLOUR. That is

YELLOW is called MINUS BLUE because it absorbs Blue

MAGENTA is called MINUS GREEN because it absorbs Green

CYAN is called MINUS RED because it absorbs Red.

The three colours BLUE, GREEN & RED, each being one third of the total spectrum are called PRIMARY COLOURS whilst each of the other colours, YELLOW, MAGENTA & CYAN are called secondary or COMPLEMENTARY COLOURS.

YELLOW is complementary to BLUE (Yellow absorbs blue)

MAGENTA is complementary to GREEN (Magenta absorbs green)

CYAN is complementary to RED (Cyan absorbs red)

The three complementary colours are used to match all of those in nature, obviously anything, which was yellow, magenta or cyan is easy to match and (figure 8) shows how blue, green and red are made. White is the absence of any colour whilst black is a mixture of the maximum possible quantity of all three, grays are matched by mixtures of equal quantities of yellow, magenta and cyan but not at the maximum possible strength. The correct proportions of each of the complementary colours can match any other colour that occurs in nature.

The other two important facts, which are used in colour photography, are :

2) It is possible, in effect, to make three different emulsions, each sensitive to one third of the spectrum and to use then all at the same time, that is one emulsion is sensitive to blue light (400 - 500 nm) another is sensitive to Green light (500 to 600 nm) whilst the last is sensitive to Red light (600 to 700 nm).

3) In the processing of the colour film or paper, it is possible to produce a different dye in each emulsion layer and each dye may be in the form of an image complementary in colour to the sensitivity of the emulsion layer in which it is formed.

That is, the Blue sensitive layer gives a Yellow dye image.

the Green sensitive layer gives a Magenta dye image.

the Red sensitive layer gives a Cyan dye image.

This system is called CHROMOGENIC development. In respect of point 3 above, the three layers will only be sensitive to Blue, Green and Red, and the dye images produced will only be Yellow, Magenta and Cyan respectively in a 'true' colour film. In a 'false' colour film, there will not necessarily be three emulsion layers, the emulsion layers may not be sensitive to Blue, Green and Red but possibly to other bands of the visible spectrum or even to invisible radiations such as infrared, nor will the dye images produced necessarily be complementary to the sensitivities of the emulsion layers in which they are formed.

Construction of a colour film

The sources of all contemporary colour photographic systems depends not only on the facts that various emulsions can be made sensitive to well defined spectral bands and that dye images can be produced later in those emulsion layers by chromogenic development, but also on the facts that all the emulsion layers are exposed at the same time and that the images formed in them are exactly registered. In other words, the image of a point in one layer will be exact coincidence with the image of the same point in all the other layers. The three (usually) emulsion layers and the three images formed cannot be physically separated from each other.

A `true' colour film consists, then, of three light-sensitive emulsion layers coated upon a film base, each emulsion being sensitized to one of the primary colours and capable of producing the corresponding complementary colour during processing, the dye image which is produced by chromogenic development in each of the three emulsion layer will absorb the primary colour to which that layer was originally sensitive.

This system is used for both types of film, negative and reversal, giving respectively, negative and positive images, figure 9 shows the cross-section of the true colour film.

BLUE SENSITIVE EMULSION *gives* YELLOW DYE IMAGE

yellow layer

GREEN SENSITIVE EMULSION *gives* MAGENTA DYE IMAGE

RED SENSITIVE EMULSION *gives* CYAN DYE IMAGE

FILM BASE FILM BASE

Figure 9 - Cross-section of a true colour film

In figure 9, the layer between the Blue and Green sensitive emulsion layers was not explained. It is a yellow layer which is necessary to absorb blue light and prevent it from reaching the lower two emulsions because they are also sensitive to blue light. As was stated earlier, all photographic emulsions are inherently sensitive to blue and in a colour film, this sensitivity is suppressed by making sure that no blue light reaches the Green and Red sensitive emulsion layers. The yellow filter layer is destroyed during processing.

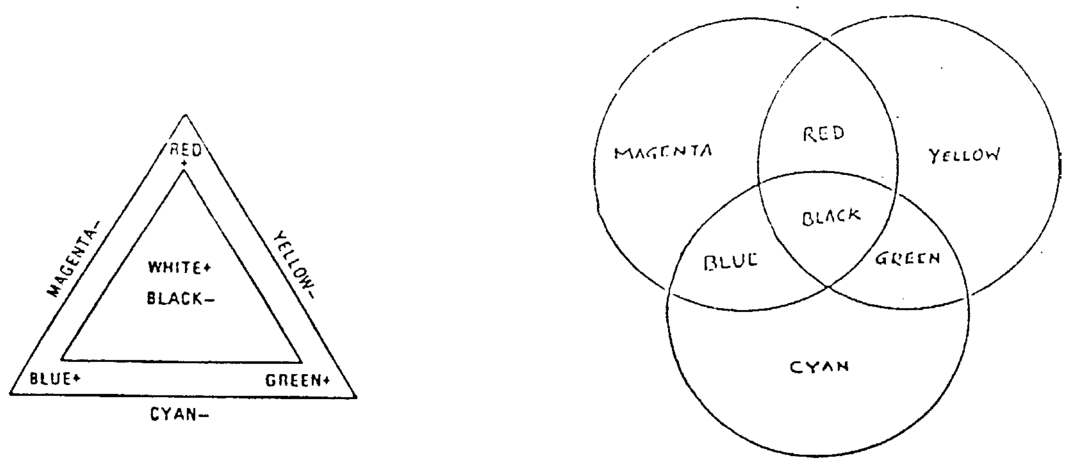


Fig. 8: Color triangle showing the relationship among additive (+) and subtractive (-) primary colors.

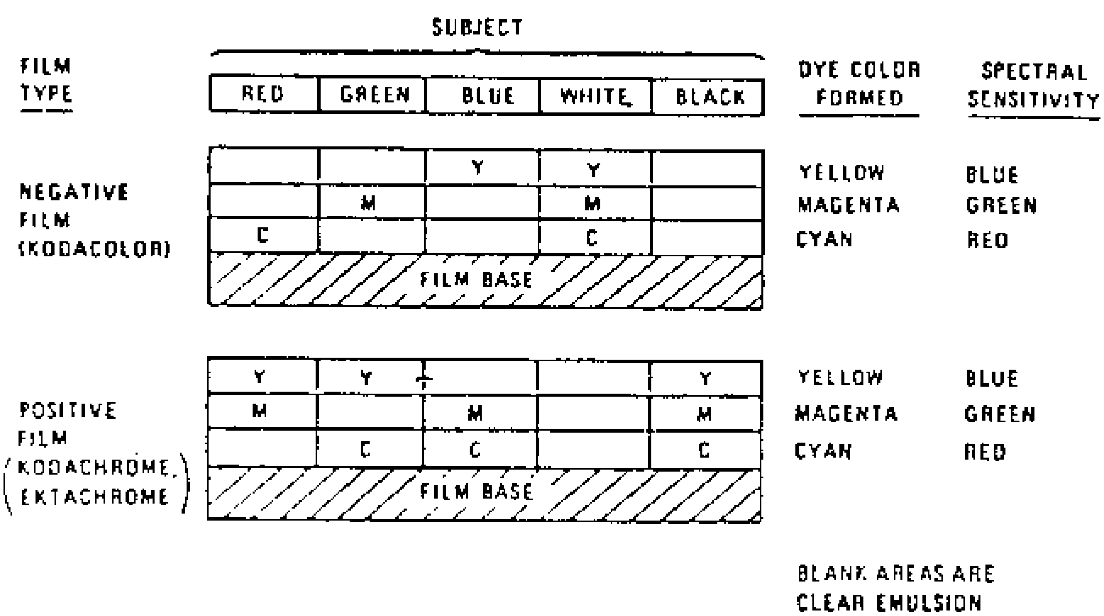


Fig. 9: Cross sections of positive and negative color films showing how images are formed on the three emulsion layers.

Colour film type

It has already been mentioned that there are two types of colour film, negative and reversal, giving negative and positive image respectively. The two types of film are constructed in an identical way but their emulsions are slightly different, it is the processing of the film, which controls the final image depending upon whether it is negative or positive. The best images can only be produced however, if a film is made to be processed only to a negative or is made to be processed only to a positive, it is not possible to make just one film that can be processed successfully to either a negative or a positive. This has been attempted in the past (Kodak `Ek-tachrome `MS' `Aerographic' film) but by the most modern standards, the quality achieved was inadequate.

In other words, manufacturers make and sell two different types of colour films for negative or positive images, they are known as negative or reversal films. It is possible to buy `true' colour films as either negative or reversal material but the most widely used `false' colour (Kodak `Aerochrome' Infrared) is available only for reversal processing to give positive images. Of the other `false' colour films, Kodak Water Penetration Colour films is a reversal film, the G.A.F. Blue-sensitive Colour Film is also for reversal processing whilst the Russian films which are quite well known but no longer available (Spectrozonal) were made in two types, one to give negatives, the other to give positives by reversal processing.

Colour reproduction

The next four diagrams show

fig.10 the reproduction of colour by an aerial colour negative film

fig.11 the reproduction of colour by a 'true' colour reversal film

fig.12 the reproduction of colour by Kodak 'Aerochrome' Infrared 'false' colour film

fig.13 the reproduction of colour negative by colour printing paper.

Choice of film type

Colour photographs made with reversal film are usually sharper, contain more detail and have better colour reproduction, (in true colour photography). BUT, the film actually used in the aerial camera is the same film that is processed to give the final diapositive, it is the same film that is exposed in the air, which is finally used, by the interpreter or the photogrammetrist. This is a poor situation because if a diapositive is damaged or destroyed, it can only be replaced by re-flying the photographic mission. It is possible to make paper prints or duplicate diapositives from original transparencies but the techniques, which must be used, are difficult and the material is expensive as

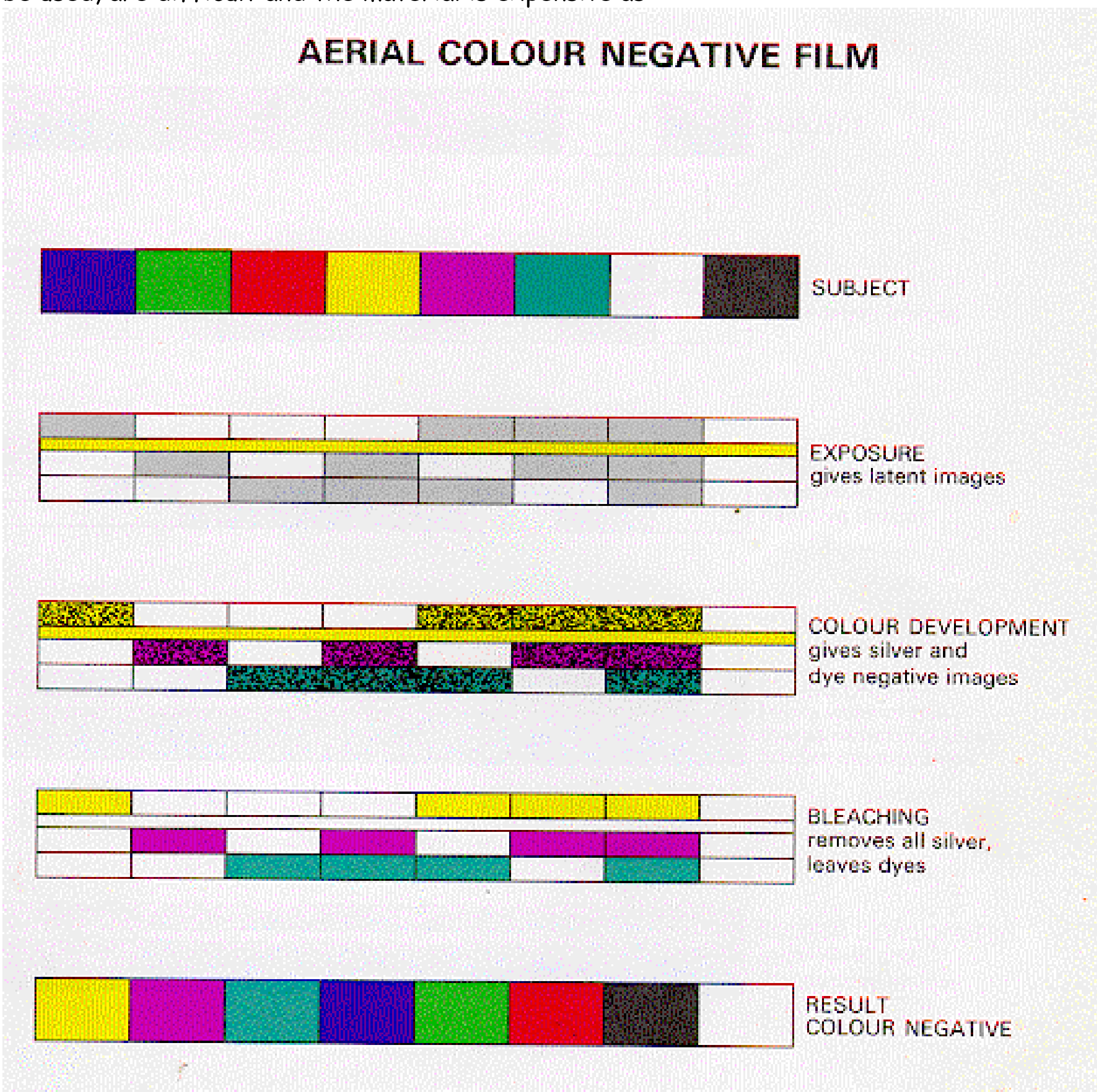


Fig. 10: The colour negative - positive process

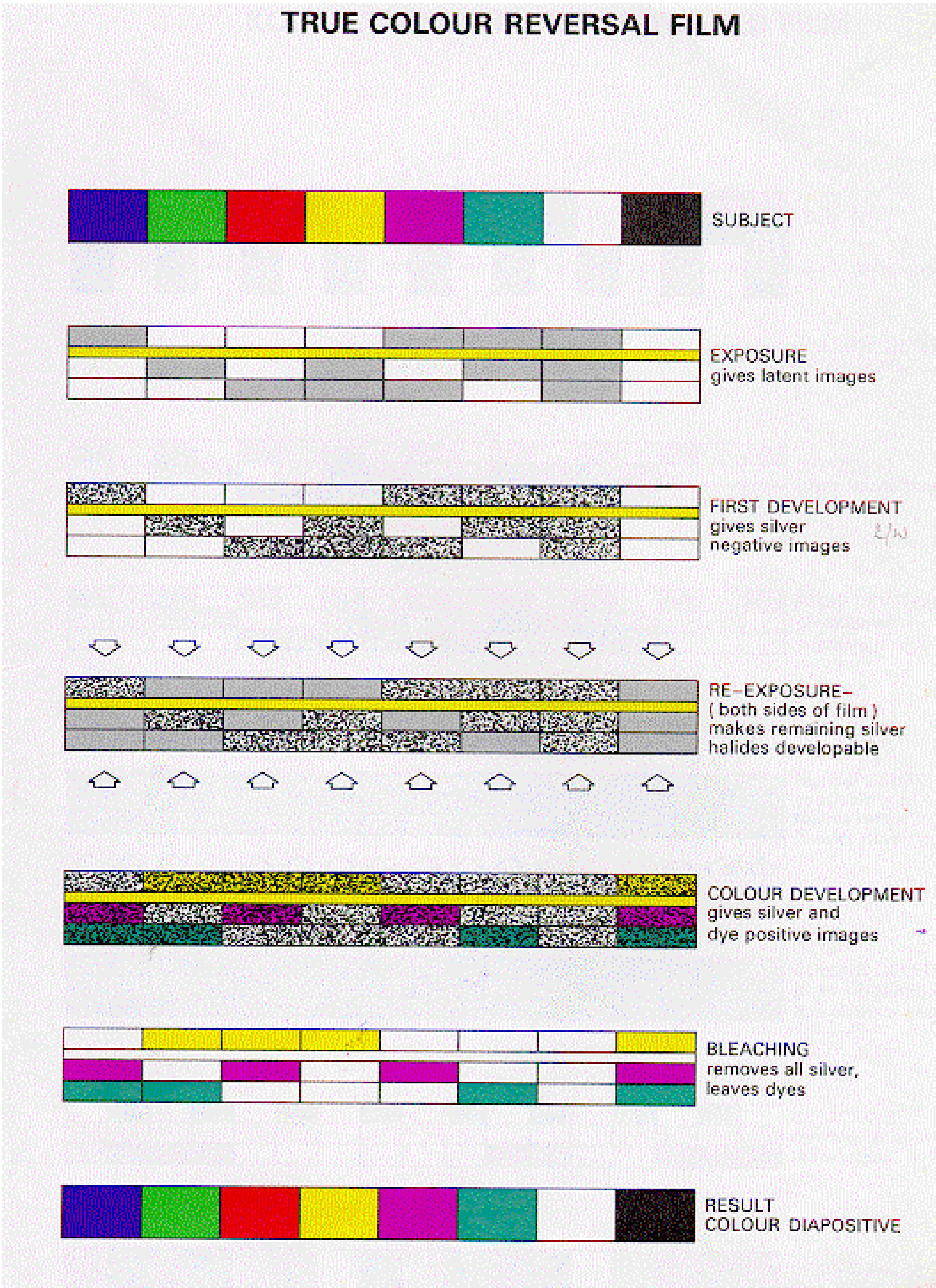

TRUE COLOUR REVERSAL FILM
SUBJECT
EXPOSURE
gives latent images
FIRST DEVELOPMENT
gives silver
negative images
RE-EXPOSURE-
(both sides of film)
makes remaining silver
halides developable
COLOUR DEVELOPMENT
gives silver and
dye positive images
BLEACHING
removes all silver,
leaves dyes
RESULT
COLOUR DIAPOSITIVE

Fig. 11: The substantive reversal process

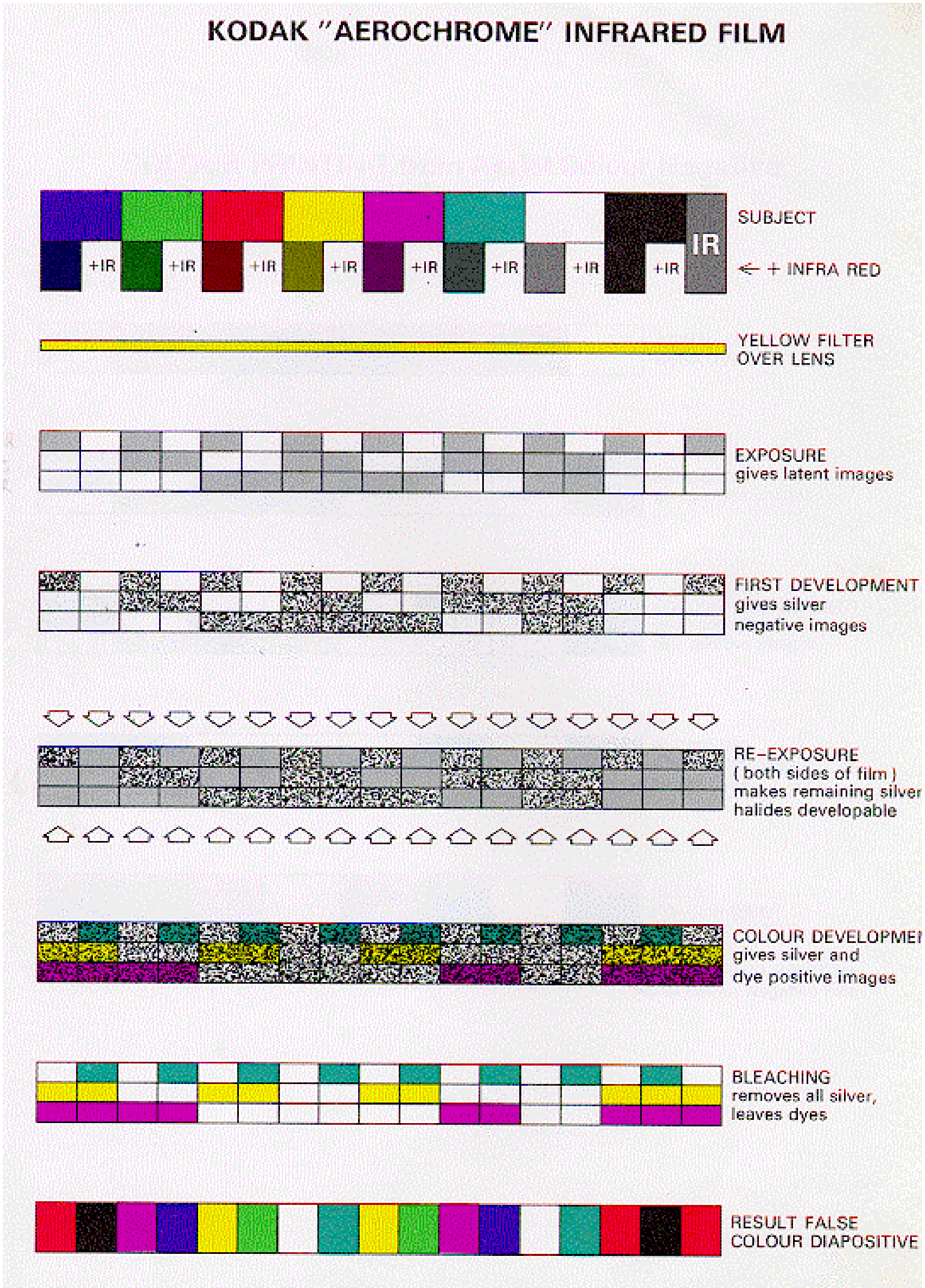


Fig. 12: Reproduction of colours by Kodak Aero chrome Infrared False colour film

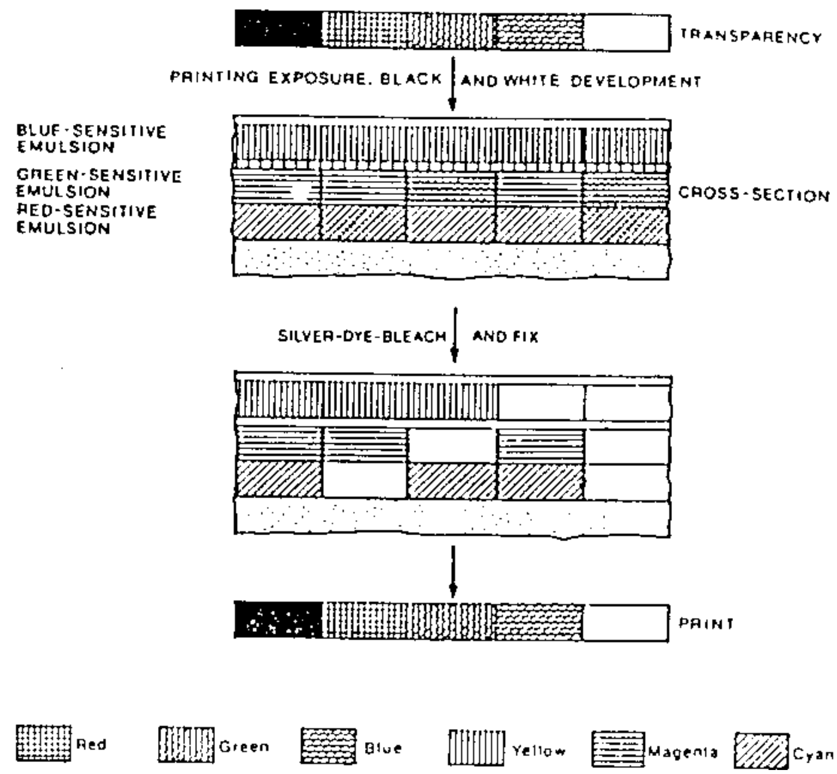


Fig. 13: The silver - dye - bleach process

compared with the costs of making similar products from colour negatives - and in some areas of the world, the adequate materials may not be available. It is therefore better to take the original aerial photographs on colour negative film. Although a diapositive made from a negative will not be as good as an original diapositive but will be very similar to a duplicate diapositive. The reasons for the changes in quality are that, as with black and white techniques, there is always a slight loss of resolution and detail each time the photographic process is used but, in colour photography, each time the process is used, the colour itself also becomes worse. It is obvious, then that the user of colour aerial photography has some difficult choices to make. It is better to use colour negative film for large-scale aerial photography to avoid the overall blue cast due to effect of scattering of lower wavelengths. And for small scale aerial photography IR colour aerial films are suitable. If all photography is carried out with reversal films, both true and false colour, then the optimum quality will not be achieved and some production will be very slow or even impossible. There are no straightforward solutions to these problems. Aerial photography should be based on utilization to fulfill the desired results of mapping/interpretation.

Equipment for colour aerial photography

So far, nothing has been written in these notes about the characteristics of the cameras and accessories, which should be used for colour aerial photography. The reasons for this is that there are no differences in the cameras required - any modern aerial camera with lenses suitable for both panchromatic and infrared black and white photography will also be suitable for colour work. The one big difference in the taking of colour photographs is that in true colour work, it is not permissible to use a yellow filter to reduce the effects of haze. But, because much of the haze radiation is short wavelength, it is both possible and desirable to fit the camera with an `ultraviolet absorbing' filter which transmits virtually all visible light but absorbs the unwanted ultraviolet radiation. Figure 14 shows the transmission curve of a typical filter that might be used. Another aspect of importance, in any use of colour film, for any purpose, is that the exposure of the film must be correct, it is not possible to compensate for under - or over-exposure during the processing of the film. Correct exposure is absolutely essential for colour reversal films.

Should colour photography be used?

If the use of colour film is considered, it is unlikely to totally replace black and white film but may be in addition. The image quality is still not quite as good as that of black and white photography and this is one reason why it is sometimes said to be desirable to take colour photographs at a larger scale. Haze also has a detrimental effect on `true' colour photography that cannot be minimized by the use of a `minus-blue' filter. These facts make it desirable to produce colour photography at the largest possible scale for optimum quality and information content.

For reasons of cost, economy and time consumption, it may be advisable therefore, to cover the total survey area by black and white photography and then to add colour photography for those parts where this might have particular advantages. Colour is especially useful when results in black and white do not show sufficient differentiation between important details and where colour differences are clear and relevant to the investigation being carried out.

The much higher costs of aerial photography are not caused just by the higher prices of colour film, these are only a very small fraction of the total expenditure on a photographic mission, they are caused much more by organizational and time consumption problems, not the least of which is the necessity of waiting for really clear atmospheric conditions. The instances in which colour aerial photography can be the best means of solving particular survey problems are limited but are becoming decreasingly so as new and better materials and methods become available. If colour photography gives better information, then the time and the money spent to produce it can be well justified.