

Surveyor Reference Manual

Fifth Edition

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35 Aerial Mapping

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Nomenclature¹

<i>d</i>	photo displacement	in	mm
<i>D</i>	ground displacement or length of ground shadow	ft	m
<i>f</i>	focal length	in	mm
<i>h</i>	object height	ft	m
<i>H</i>	mean flying height AGL (above ground level)	ft	m
<i>R</i>	radial distance from isocenter	ft	m
<i>S</i>	photo scale	ft/ft	m/m
<i>t</i>	tilt angle	deg	deg
<i>y</i>	separation of image point and isocenter	in	mm

Subscripts

<i>t</i>	tilt
<i>p</i>	principal

1. INTRODUCTION TO AERIAL MAPPING

Aerial mapping is the process of creating maps from measurements made with photography or other types of remote sensing from an airborne platform. While it is usually considered a recent surveying and mapping innovation, aerial mapping has been used for almost two centuries. Today, it is widely used for topographic surveys since it is generally more economical than ground surveys except for relatively small projects.

The first aerial mapping photographs were taken from hot-air balloons in the late nineteenth century. Kites were also used as platforms for aerial photography during this period. For example, after San Francisco's destruction in the 1906 earthquake, the city was mapped

¹Generally, upper case letters are used to represent locations and distance on the earth, while lower case letters are used to represent points and distances on the photograph or within the camera.

with a camera suspended from seven kites. Fortunately today, more controllable aerial platforms are available, including both aircraft and satellites.

Data acquisition has also evolved, advancing from relatively crude cameras to photographic systems with advanced optics as well as digital cameras, airborne LiDAR (see Sec. 9), and other remote sensing systems. Although some aerial mapping still uses traditional photographic film technology for data acquisition, the use of digital cameras and airborne LiDAR sensors is becoming more and more prevalent. The processing of aerial mapping data today, whether acquired on film or as digital data, is generally performed using digital methods. Typically, when film is used, it is scanned to allow digital processing. This trend to digital processing avoids the costly optical-mechanical components previously associated with aerial mapping and allows maximum use of modern computers. In addition, having both the original data and resulting map data in digital format allows more efficient use of GIS and other computer applications.

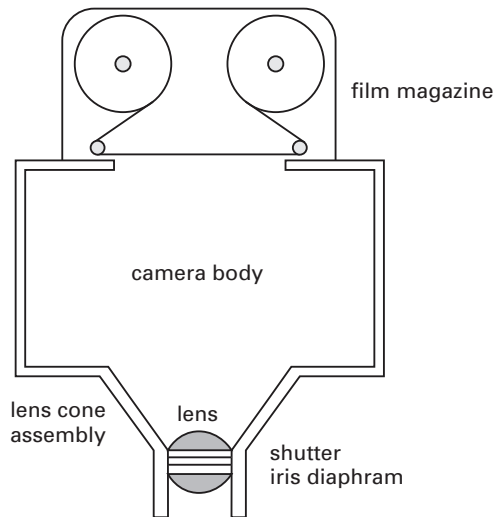
2. PHOTOGRAPHIC OPTICS

Photographic optics are based on the *refraction of light*, an optical effect used since the Middle Ages to project images. When light rays pass from one medium into another, they change speed and bend, or refract. Light rays will bend toward the normal if the speed of light is less in the second medium (such as when passing from air into a camera's glass lens). This refraction produces a reduced-scale copy of the image as it passes through the lens, which can be projected onto a plane at a focal length dependant on the lens' characteristics.

3. AERIAL CAMERAS

Aerial cameras are normally mounted on a stabilized platform using gimbals, or pivoted supports, to maintain a vertical orientation. The stabilized platform is attached to the aircraft by isolators. Most modern aerial film-type cameras are composed of three main parts: the lens cone, the camera body, and the film magazine. (See Fig. 35.1.)

Figure 35.1 Typical Configuration of a Film-Type Aerial Camera



The lens cone assembly (*lens cone*) is the camera's most critical component. Cameras used specifically for aerial mapping have lens cones with alignment tabs embedded around the perimeter. These cause fiducial marks to be imprinted onto each image, which are used to determine the principal (or center) point of the photograph. The lens cone is also important because it restricts the light striking the focal plane so that it passes through the camera lens. The lens itself typically consists of two parts, one on either side of the shutter. The *iris diaphragm* is used to regulate the amount of light admitted to the lens.

Most aerial cameras also have a "leaf-type" shutter located between the two lenses that opens during each exposure. The focal length of the camera, as established by the lens, varies with different camera models. A 6 in (155 mm) focal length lens is the most common, although lenses with 3.5 in (88 mm), 8.25 in (210 mm), and 12 in (305 mm) focal lengths are commonly available.

The *camera body* contains the drive motor and mechanisms that operate the shutter, advance the film, and perform other camera operations. The camera body also typically contains a recording chamber that prints pertinent information on each exposure such as the photo number, date, time, altitude, level bubble, and so on.

The *film magazine* holds the unexposed and exposed film. Most aerial cameras use a detachable magazine that can be changed or removed as needed. Typically, the magazine contains a vacuum system that flattens the film against the focal plane. Many cameras are also equipped with a *forward motion compensation* system that, during the exposure, moves the film backward at the same rate as the aircraft's forward motion to prevent blurring caused by the aircraft's movements.

All aerial mapping camera systems need to be periodically calibrated in order to precisely determine the

processing parameters of the camera's photographs. In the United States, the U.S. Geological Survey provides camera calibration services.

Film-Type Cameras

Most film-type aerial photography is taken on film with a 9 in by 9 in (23 cm by 23 cm) square format. 5 in by 5 in (13 cm by 13 cm) is also used. The light-sensitive emulsion is coated on a flexible transparent polyester film base. Then the emulsion is coated with a thin protective layer of clear gelatin to shield the emulsion from scratches.

There are four general types of film emulsions used in film-type aerial photography. These include panchromatic black and white, natural color, black and white infrared, and false color infrared. *Panchromatic black and white film* detects a wide spectrum of light and is widely used for aerial mapping and interpretation. The emulsion on *natural color film* is composed of three primary color layers to cover the full color spectrum. *Black and white infrared film* is sensitive to longer light wavelengths and is capable of penetrating haze. It is used to delineate water bodies, as well as for military and intelligence photographs because it can detect camouflage. With *false color infrared film*, different colors are arbitrarily used to represent different portions of the light spectrum. It is often used to detect agricultural crop diseases and to monitor pollution.

Digital Aerial Cameras

Digital aerial cameras replace the focal plane's film with an array of light-sensitive detectors that record images in digital form. Data can be directly transferred to, and used in, digital processing systems. Some digital cameras have the ability to capture black and white, natural color, and infrared data simultaneously to significantly increase efficiency. Aerial digital imaging cameras generally use one of two technologies to capture data: frame imaging or "push-broom sensing." *Frame imaging* uses a shutter device similar to that used with film-type cameras that allows light to strike sensors at a predetermined interval and duration to achieve the desired overlap. *Push-broom sensing* uses three sets of sensors orientated forward, down, and back. These are generally fixed to provide a 67% overlap so that one third of the image is viewed simultaneously by all three sensors. Ground sample dimensions are defined by the flying velocity and altitude, and instead of using shutters, a continuous "carpet," or rows, of pixels are captured by each set of sensors. The rows are then combined to form a long image of the aircraft's entire flight path.

Image Centers

Three "center" points are used when correcting aerial photographs for tilt and displacement. These three points coincide in untilted photographs, but they diverge in tilted photographs. The *principal point* is the geometric center of the photograph. It is located at the

intersection of lines connecting the fiducial side (or, in some cases, corner) marks. The *nadir point* (also known as the *vertical point* and *plumb point*), N, is directly below the camera. There are no indications on the photograph where the nadir point is located, although it can be located optically by extending lines from perfectly vertical objects in the photograph toward a common intersection point. The nadir is always located on the downward side of a tilted photograph. Relief displacement is radial from the nadir point and is proportional to the distance from it. The *isocenter*, I, is located on a line connecting the nadir and principal points, midway between them.

4. PLANNING FOR DATA ACQUISITION

To obtain good data, it is important to consider exactly when and where aerial photography will take place. When mapping bare-earth elevations in temperate zones with deciduous trees, aerial photography should be scheduled during the winter months when there is better visibility because trees have fewer leaves, and there are smoother flying conditions and clearer air because cooler, dryer air prevails. In tropical zones, aerial photography is typically scheduled during the dry season, generally January through March in the northern hemisphere, so that photographs are not obstructed by rain.

In addition to the time of year, time of day must also be considered for aerial photography. A relatively high sun angle minimizes large shadows, though small shadows help delineate detail and generally increase the photograph's quality. A 45° sun angle is generally considered most desirable. Solar angular altitude diagrams and several computer programs are available to assist in selecting the most appropriate schedule for mapping a given location. Time of day is not a concern with active remote sensors such as LiDAR since sunlight and shadows are not factors with those systems.

It is also necessary to plan the route of the mapping aircraft. Aerial photography is generally taken along a series of preplanned flight lines where successive photographs are exposed such that a predetermined amount of overlap occurs. Generally, 60% forward overlap and 20–40% (30% nominal average) side lap is used.

5. SCALE

The *scale* of a photograph is typically expressed as the ratio of the dimension of the image of an object on the photograph to the dimension of that object on the ground. As an example, the scale of 1:24,000 indicates that an object measuring one inch in length on a photograph would measure 24,000 inches or 2000 feet on the ground. If the focal length, *f*, of the camera and the flying height, *H*, is known, the scale of a photograph may be calculated as the ratio of those parameters.

$$S = \frac{f}{H} \tag{35.1}$$

When the desired scale of the photography and the focal length of the camera are known, the required *flying height* can be calculated by rearranging Eq. 35.1.

$$H = \frac{f}{S} \tag{35.2}$$

Example 35.1

What is the required flying height necessary to produce a 1:24,000 negative scale if a land surveyor is using a camera with a 6 in focal length?

Solution

Using Eq. 35.2,

$$H = \frac{f}{S} = \frac{(6 \text{ in}) \left(\frac{1 \text{ ft}}{12 \text{ in}} \right)}{\frac{1}{24,000}} = 12,000 \text{ ft}$$

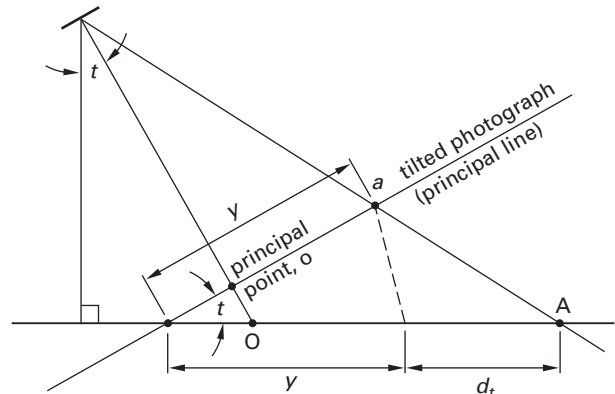
6. TILT AND RELIEF DISPLACEMENT

When photogrammetric measurements are made from an aerial photograph, not all images will have the correct spatial relationship to each other. Tilt in the photograph, as well as variation in terrain elevation, will cause image displacement as well as scale variation. Figure 35.2 shows *tilt displacement*, *d_t*, of a point A, which causes points downslope of the isocenter to be displaced radially away from the isocenter, while points upslope would be displaced towards the isocenter. The tilt displacement for a specific point is calculated as

$$d_t = \frac{y^2}{\left(\frac{f}{\sin t} \right) - y} \tag{35.3}$$

t is the tilt angle, *f* is camera lens focal length, and *y* is the distance between the image point and the isocenter. The *principal line* is the line of intersection between the plane in which the tilt angle is measured and the plane of the tilted photograph.

Figure 35.2 Image Displacement due to Tilt in Aerial Photograph



Mapping

In Fig. 35.3, the principal point, O, is the only point in a truly vertical photograph where there is no relief displacement. Relief displacement is especially visible when tall buildings or towers are visible in aerial photographs. When viewing those images, the radial displacement from the photo center of the tops may be readily seen. Relief displacement, d , is calculated as

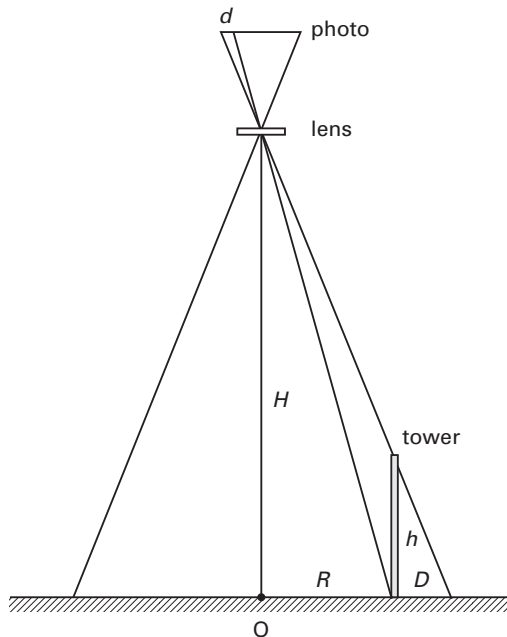
$$d = \frac{Df}{H} \tag{35.4}$$

Similarly, Eq. 35.4 can be used to calculate the actual height, D , of a vertical object from its measured (on the photograph) distance (displacement) from its top and bottom, d . f is the focal length of the camera, H is the elevation of the camera, and D is the length of the ground image's shadow. D can be calculated by

$$D = \frac{hR}{H - h} \tag{35.5}$$

H is the camera elevation above mean terrain, h is the object's ground elevation above mean terrain, and R is the radial distance on the ground from the principal point to the object.

Figure 35.3 Image Displacement due to Relief



Example 35.2

A tower's height is 300 ft above mean terrain. It has a 1000 ft radial distance from the center of a vertical aerial photograph. The photograph was taken 2000 ft above mean terrain using a camera with a 6 in focal length. What is the relief displacement for the top of the tower?

Solution

Use Eq. 35.5 to calculate the length of the tower's shadow on the ground.

$$\begin{aligned} D &= \frac{hR}{H - h} \\ &= \frac{(300 \text{ ft})(1000 \text{ ft})}{2000 \text{ ft} - 300 \text{ ft}} \\ &= 176.47 \text{ ft} \end{aligned}$$

Use Eq. 35.4 to find the relief displacement.

$$\begin{aligned} d &= \frac{Df}{H} \\ &= \frac{(176.47 \text{ ft})(6 \text{ in}) \left(\frac{1 \text{ ft}}{12 \text{ in}} \right)}{2000 \text{ ft}} \\ &= 0.441 \text{ ft} \end{aligned}$$

7. MAP COMPILATION

Photogrammetric mapping is traditionally performed using a *stereoplotter*, which is an optical-mechanical instrument that reconstructs the depicted terrain's spatial geometry in overlapping aerial photographs. It allows the measurement of a terrain's planimetric and topographic attributes by correcting for tilt and relief displacement.

Stereoplotters use the concept of *stereoscopy*, which is the ability to perceive a photographic image in three dimensions. The process involves using overlapping photographs that depict an area as viewed from two different locations in the air. As each eye sees a different photograph (binocular viewing), the two images merge into a central image that has depth. This is because the closer a point is to the eye, the larger the convergence angle is between the eyes and the point. Thus, when looking at the same feature on two photographs taken from two aerial locations, the highest point would have a larger convergence angle and appear taller.

In the past, the most commonly used stereoplotter was the *direct-projection plotter*. This plotter uses diapositive photographs (i.e., prints on glass or mylar) the same size as the original photographs to project enlarged images of the two overlapping photographs onto a tracing table. The two projected images are distinguished from each other by projecting one image through a red filter and the other image through a blue-green filter. The operator then views the images using a pair of glasses with separate red and blue-green lenses, thus allowing each image to be viewed by one eye. The direct-projection plotter has been superseded by the analytical plotter and softcopy processing and is rarely used today. The *analytical stereoplotter* uses a computer to mathematically align images so they line up correctly. It also