Photo Scale, Direction, and Distance

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Description: Up to this point we have used relatively subjective approaches to looking at and interpreting photography. This lesson will introduce the tools for making precise photo measurements and common units of measurement. Using this knowledge we can accurately determine photo scale and measure direction and distance between locations on a photograph.

Photo Scale

The scale of an aerial photograph is an important component. Knowing the scale tells you something about the size of the features visible in the photograph and the level of detail you can expect to see. With the appropriate tools, measurements from the image can be used to determine the actual size of features. Unlike the maps used in the previous lessons, photographs typically do not specify the scale. Occasionally a scale will be provided, however, these nominal scale values are not necessarily correct for the photograph, or even in all parts of an individual photograph.

Scale is expressed as a unitless ratio in which the numerator is *always* 1. The denominator, also called the **scale reciprocal** or **SR**, is the value that may vary. It should be obvious that since the scale always has a 1 as its numerator, the reciprocal of the scale is the same as the value of its denominator:

$$\frac{1}{SR} \text{ --reciprocal--> } \frac{SR}{1} = SR \qquad (1)$$

For example, if you are told that the nominal scale of a photograph is 1 to 15840, this may be expressed as:

$$1:15840 \quad \text{or} \quad \frac{1}{15840} \qquad (2)$$

And the scale reciprocal equals the denominator:

$$\frac{15840}{1} = 15840 \qquad (3)$$

Obtaining ground distance from scale:

Conversion of linear measurements from a map or a photograph to a real world distance is very simple using the scale ratio. Simply multiply the distance measured from the map or photo (**map distance, MD** or **photo distance, PD**) by the scale reciprocal (**MSR** for a map, **PSR** for a photo) to obtain the real-world **ground distance** (**GD**):

MD x MSR = GD
PD x PSR = GD (4)

For example, if we measured a length of road on our topo map (with of scale of 1:24000) and found it to be 1.65 inches, the ground distance in the real world would be:

1.65 inches x 24000 = 39600 inches (5)

Note that the real world measurement is expressed in the same units that were used to make the measurement on the map. However, since we typically do not describe large distances in inches, we should convert this to feet or miles as appropriate:

$$39600 \text{ inches x } \frac{1 \text{ ft}}{12 \text{ inches}} = 3300 \text{ ft} \qquad 3300 \text{ ft x } \frac{1 \text{ mi}}{5280 \text{ ft}} = 0.625 \text{ mi} \tag{6}$$

You may also notice that when making the above conversion calculations, it is helpful to carry the units. If your units do not properly cancel, you will see errors before you get too far into a calculation.

Obtaining scale from ground distance:

As you may have realized by this point, we can reverse this process to calculate the scale when it is unknown, but ground distances are available. So, for our map we could calculate the scale, shown here as the **representative fraction** (**RF**), by determining the ratio of the map distance to the ground distance:

$$RF = \frac{MD}{GD} = \frac{1.65 \text{ inches}}{0.625 \text{ mi}} \text{ x } \frac{\text{mile}}{5280 \text{ feet}} \text{ x } \frac{\text{ft}}{12 \text{ inches}} = \frac{1.65}{39600} \tag{7}$$

To convert the representative fraction to a conventional scale ratio with a numerator of 1, simply divide both the numerator and the denominator by the numerator:

$$\text{RF} = \frac{1.65}{39600} \div \frac{1.65}{1.65} = \frac{1}{24000} \tag{8}$$

What if we don't have either ground distance or scale?

In the above example we assume that ground distance is available. In many cases it is not practical or possible to go out into the field to obtain these measurements. Fortunately, for most parts of the United States, good topo maps are available. Using the map scale reciprocal, as in equation 4, a ground distance for a map or photo with unknown scale can typically be calculated from a map or photo of known scale of the same location.

There is one additional method for determining the scale of a photograph that relies solely on flight and camera system parameters. If the height of the aircraft above ground level (**H**) and the **focal length** (**f**) of the camera are known, scale can be calculated this way:

$$\text{RF} = \frac{\text{f}}{\text{H}} \tag{9}$$

Since aircraft instruments typically provide an altitude above sea level (ASL), as opposed to the height above ground level (H) it is often necessary to calculate the value for H. One additional piece of information needed for this calculation is the elevation (E) of the local terrain. Of course, when a topo map of the area is available, this is a simple value to obtain. The resulting value for H is then:

$$H = ASL - E \tag{10}$$

Summary of photo scale determination methods:

Having discussed a number of scale equations, we can consolidate scale determination into two common approaches:

1) Field method: A precisely known (measured) ground distance is obtained in the field and clearly visible within the effective area of the photograph. Although running out into the field every time you require a GD is not practical, collecting your own measurements is always an option when a map is unavailable or unreliable.

2) Office method: More often we are able to relate a measurement of a feature on a *reliable* map to its conjugate distance on the photograph of the area. When going into the field is not possible, good quality maps are equally useful for computing the needed values.

Calculating scale using a known focal length is a less common approach, but one could similarly obtain the value for H by going to the field to measure the elevation, or by using a reliable topo map or Digital Elevation Model (DEM).

You will notice that a number of the parameters used in the above equations appear more than once. By using sets of equations it becomes possible to solve other problems not specifically described above. For example, using a topo map of known scale, and knowing a desired photo scale, one could determine the altitude that the aircraft for a particular photo mission would need to fly at when using a lens of any particular focal length. This type of calculation is not uncommon for mission planning or other work with aerial photography. Becoming comfortable with the various formulas and learning how to manipulate them algebraically to solve for a parameter of interest is a valuable skill.

Measuring Scale on Aerial Photos

A number of complicating factors can occur in photography due to factors such as camera tilt or changes in terrain relief across a photo area. The result of these problems is a variation in scale as one examines different portions of a single photograph. This variation in scale is a primary reason for working within the effective area, where these scale differences are less severe. It follows that when making measurements from photography, for scale, or anything else, it is preferable to work within the effective area.

Some other things the interpreter can do to minimize errors in the scale calculation include:

1) Choosing easily identified features as the endpoints of the baseline selected for the scale measurement (road intersections, stream junctions, fence corners, trees, etc.).

2) Selecting the longest reasonable baseline (given the constraints of the effective area). Longer

measurements are subject to less error (by percent) than shorter ones.

3) As much as possible, the ends of the baseline should lie close to, and equidistant from, the PP of the photo.

4) As much as possible, the ends of the baseline should lie at the same elevation in the terrain and at the mean elevation of the terrain included in the effective area of the photo. Avoid measuring at the extremes (mountain tops and valley bottoms).

Land Survey Dimensions

There are a number of measurement systems common in land measurement, both for distances and areas. Since most measurements in the original land survey were made using English units, they will often be used in natural resource work. However, metric units may also be encountered and you should feel equally comfortable working with, and converting between the various units of any system.

Some of the more common (and perhaps less familiar) units are summarized below.

Units of Length/Distance	Units of Area
1 chain = 100 links	1 acre = 43,560 feet^2
1 chain = 66 feet	½×½ mile = quarter section = 160 acres
¼ mile = 20 chains = 1,320 ft	¼×¼ mile = quarter quarter section = 40 acres
1 mile = 80 chains = 5,280 ft	1×1 mile = 1 section = 640 acres

Units of Measurement and Expression

Measurements made during the aerial photo interpretation process must be as accurate as possible. What may seem a very small measurement error on a map or photograph actually translates to large errors on the ground. Typically, we will use engineering rulers interpretable to 0.0005 (five ten-thousandths) of a foot. While this may seem excessively precise, consider that for typical 1:15840 resource photography this still translates to nearly eight feet. Even a small measurement error can lead to extremely large errors on the ground!

Direction and Distance

Aerial photos can often provide an easy means for location of features in the field. They have visual information not included on most maps and can often provide more detailed information, such as distinguishing a specific stand of trees, that may not be possible with a map. In areas where a map does not exist, aerial photographs are a common means for beginning the mapping process. For these reasons, having experience in measuring directions and distances from aerial photographs can be crucial to completing a wide range of resource mapping and management tasks.

You already have the knowledge to measure distances in aerial photographs. Using the photo scale, a distance measured from the image can be converted into an actual ground distance as demonstrated in equation 4.

Determining direction is equally straightforward given that you have a known baseline. As was the case for scale, the known can be determined either in the office or in the field. Measurements taken on a photograph with a protractor can be easily translated to the field using a standard magnetic compass. Using such measurements it becomes easy to locate points in the field such as plot centers, section corners or other features that may be difficult to locate on the ground.

Aerial photography is typically flown in one of the **cardinal directions**. However, directions are not indicated on the individual photographs. Since we know there can be significant variations in flight path the only reliable method for properly orienting a photo is to work from an established base line of known direction. The known base line can be established in the field using a compass, or in the office with a reliable map.

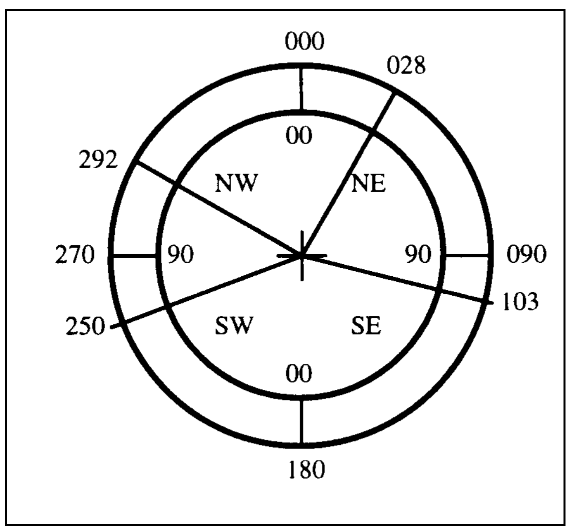
There are two methods for describing direction, **bearings** and **azimuths**. Of these, azimuths are most commonly used. Bearings are a historical remnant of much of the early survey data. An archaic version of azimuth also exists and, and may occasionally be encountered when working with historical data. Each of these approaches to describing directions is discussed below and several examples are included in figure 12-1.

Bearings are always expressed in angle measurements of less than 90˚. Since we must be able to describe directions in a full circle from a given point, and a circle is 360°, bearings require us to subdivide the circle into four quadrants. Directions are then described according to relation to north or south. Starting with the nearer direction, N or S, we then describe the desired direction in degrees east or west. For example, a proper bearing might be N35°E or S67°W. Bearings *always* start with N or S as the reference direction, starting with E or W is incorrect.

Azimuth is now in common use and avoids much of the confusion associated with bearings. Directions are simply expressed as an angular measurement between 0 and 360°. In this approach each angle is used to describe one, and only one direction. One measure, that for north can be described as either 0 or 360° since these are the same point on a circle. Angles are typically measured in a clockwise direction, however in some old survey data the azimuths were measured in the opposite direction and you should be aware of this possibility. Any time you are using data from an outside source you should be sure to determine the conventions that were used.

Bearing	Azimuth
N28°E	28°
S77°E	103°
S70°W	250°
N68°W	292°

Figure 12-1. Comparisons of bearing and Azimuth readings. (Olson, 1994)



Factors Affecting Accuracy of Measurements

When working with photographs containing substantial changes in relief, it is important to be aware of some additional issues. The geometry of a photograph is altered by the position of particular objects in the terrain. Features that lie in high or low regions will be radially displaced relative to the PP of the photograph. The level of the terrain which the camera focuses upon is called **scale datum**.

The scale datum, as its name suggests, is the elevation at which the scale is calculated based on the mean elevation for an area and the height of the plane. Points in the terrain that lie above scale datum lie closer to the camera. When you consider the effect of this in the context of the scale (equation 9) it becomes clear that the height of the camera, relative to the terrain, will decrease and the resulting scale will be larger. The opposite will be true for objects that lie below scale datum. Furthermore, objects above scale datum will appear to radiate (lean) *away* from the PP and those below will radiate towards the PP (figure 12-2).

These **displacements** are geometrically consistent and when understood, they can prove a useful tool in interpreting photography. Displacement of an object in an aerial photograph does not actually alter the position or perspective characteristics of the object. In effect displacement simply provides the interpreter a different point-of-view. For this reason displacement can be a valuable characteristic of aerial photography.

When an image suffers from **distortion**, the characteristics of the features in the photograph are altered in some unexpected way. Therefore distortion is something we wish to avoid since it can never provide us with useful information (beyond making us aware that something went wrong during the collection or processing of the images). Typical sources of distortion include: dimensional changes in the film or paper used in processing, optical distortions in the lens, filter or other components of the camera system or aircraft window (when a window is present), malfunctions of the camera shutter, film advance or vacuum system, and image motion caused by unexpected movements of the aircraft, or misadjustment of motion compensation systems built into the camera.

It is important to make note of the difference between these two terms. Often students will confuse their use and accidentally say an image is distorted when, in fact, what is being encountered is displacement.

Displacement can also be removed from an image, a process called **rectification**, which eliminates the changes in scale and the displacement of objects relative to the PP of the photograph. Thus displacement should be distinguished from **distortion** in the photograph. Distortion is an uncontrolled or random error in the photograph caused by equipment failure, error introduced in film processing or other factors causing unknown errors in the image.

Being aware of these displacements in images over terrain with significant relief, it is important to avoid introducing errors into measurements made from unrectified imagery. Several simple precautions can help you to avoid such errors:

1) When making measurements of distances on the photo, attempt to select endpoints that lie at the same elevation, and when possible, at or near scale datum.

2) When selecting photographs for making measurements, always choose the one on which the baseline or other distance for measurement lies closest to the PP of the photograph. Points nearer the PP are less affected by displacement compared to those points that lie further away from the PP.

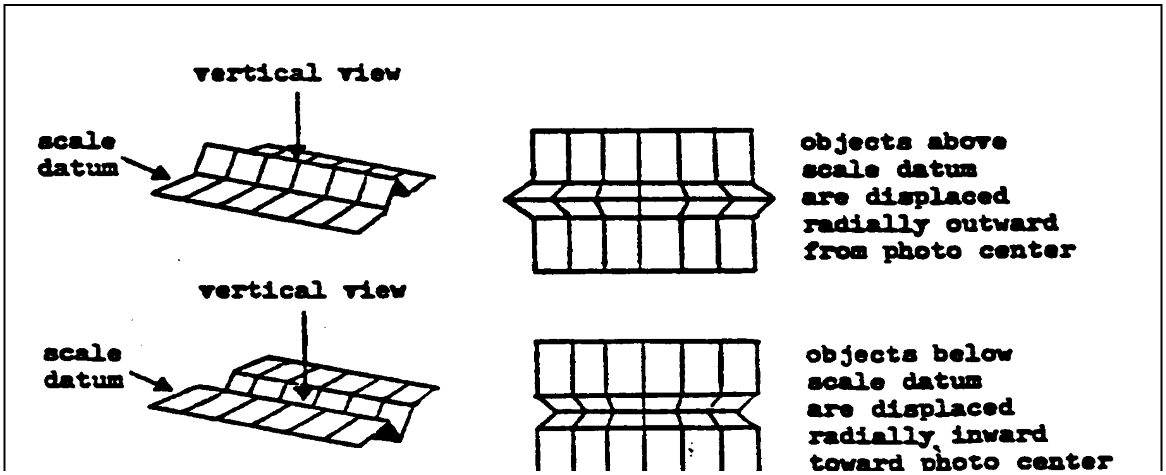


Figure 13-2. In aerial photography of mountainous country, the accuracy of direction and distance calculations tends to vary indirectly with the distance from the photo center and the degree of topographic relief. (Meyer)

Lesson Outcomes

At this point you should:

1) Know the common units of measure used for distance and direction and how to convert between them.

2) Be familiar with the PI tools necessary to measure distance and direction from maps and aerial photographs.

3) Understand the variables and approaches to calculation of scale.

4) Understand how scale may vary across an aerial photograph and approaches to minimizing errors when making measurements.

5) Be comfortable with the determination of scale, distance and direction.