A SHORT CUT FOR SCALING AERIAL PHOTOS

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A Short Cut
For Scaling Aerial Photos

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Aerial photos are a handy tool for the forester. They furnish forest data quickly. But when the photo is used as a map, care is necessary--especially in rough country. In flat country photo scales are quite uniform and distances can be measured accurately But in rough country photo scale varies with changes in elevation, and it is more difficult to measure distances accurately. There are other factors that affect photo scale, but land elevation is the most important to foresters.

In flood-control survey and forest survey work at the Northeastern Forest Experiment Station thousands of aerial photos are used. Frequently we need to know the scale of an aerial photo so we can measure distances or interpret some forest condition. Computing scale and adjusting it to different elevations for each photo is a tedious job. A satisfactory short cut was needed.

To fill this need we developed a method for determining the scale for any point on any individual photo of a photo project. The scale determined by this method will usually be within 3 to 5 percent of the true scale, regardless of the amount of rough land. For most uses of aerial photos in forestry this error is acceptable. In practice this method has proved to be very efficient, reliable within the limits indicated above, and easy to apply.

THE PROBLEM

In scaling distances from aerial photographs, there are two factors to be considered: (1) the aerial photograph and (2) the ground surface it represents. Getting accurate ground measurements is not a problem; the U. S. Geological Survey's topographic maps have proved quite satisfactory. The variable factor is the photograph.

If the photographic plane could fly at a uniform elevation and perfectly level while making the photographs, the problem would be simple. If it were making photographs of level ground, every photograph would have exactly the same scale.

Unfortunately, this degree of perfection has not yet been attained. Good plane crews can fly at nearly uniform altitudes under proper weather conditions. They can keep the plane nearly level, thus keeping camera tilt to a minimum; 90 percent of the photos should be affected by tilt of less than 3 degrees. The photographic equipment--precision cameras, special high-quality films--is near perfection.

However, the imperfections in flying and equipment do result in variations in the finished aerial photographs. These variations have an effect on the scale of the photographs.

As already mentioned, the elevation of the land has the most important effect on the scale of aerial photographs (fig. 1). High land is naturally closer to the plane and camera than low land, and a photograph of high land will not have the same scale as a photograph of low land.

For these reasons, it is necessary to compute scale for the aerial photographs in order to get accurate results in measuring or studying the land surface and objects on it.

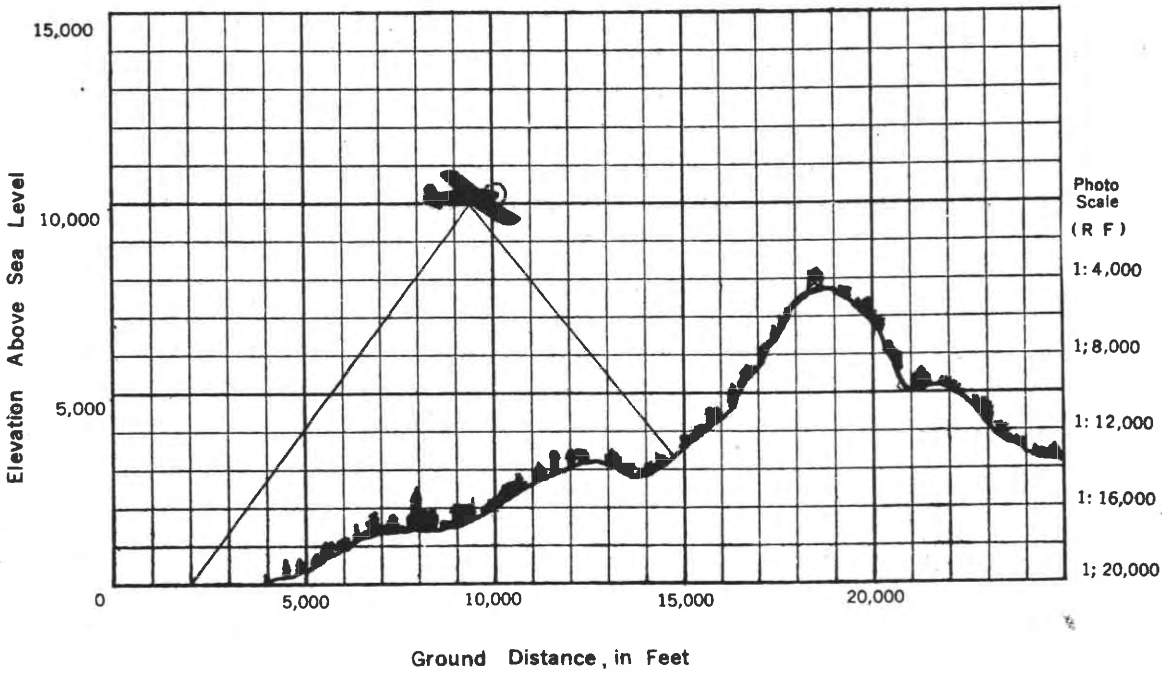


Figure 1.--The land elevation has an important effect on the scale of aerial photos. The scales in this illustration are based on the use of a camera with a 6-inch focal length.

A SHORT-CUT SOLUTION

One way to solve the problem would be to determine the scale for each individual photograph. However, in an aerial photo project--such as the photographing of half a dozen large counties in New York--there may be 10,000 photos, or more. Scaling each one would give complete accuracy, but it would be a long and tedious job.

Such a tedious job is not necessary. By scaling about 10 photos, selected at random, you can compute the average scale at sea level for the entire project. From this average scale you can make adjustments for different elevations.

The steps in this short-cut method are as follows:

1. Select about 10 photos at random from the photo project.

2. On each photo select two points that can be located on a base map. (Frequently, in forest areas, there is little choice in selecting these points simply because good points are hard to find on the photo. If there is a choice, look for points about the same distance from the center of the photo, about 3 to 5 inches apart, and located so that a line drawn between them would pass near the photo center.)

3. Measure the distance between these two points on both the photo and the base map.

4. Convert the base map distance to actual ground distance

5. From the base map, determine the average elevation of the two points.

6. Compute the flying height (above sea level) of the plane for each photo. (Use Formula II, p. 9)

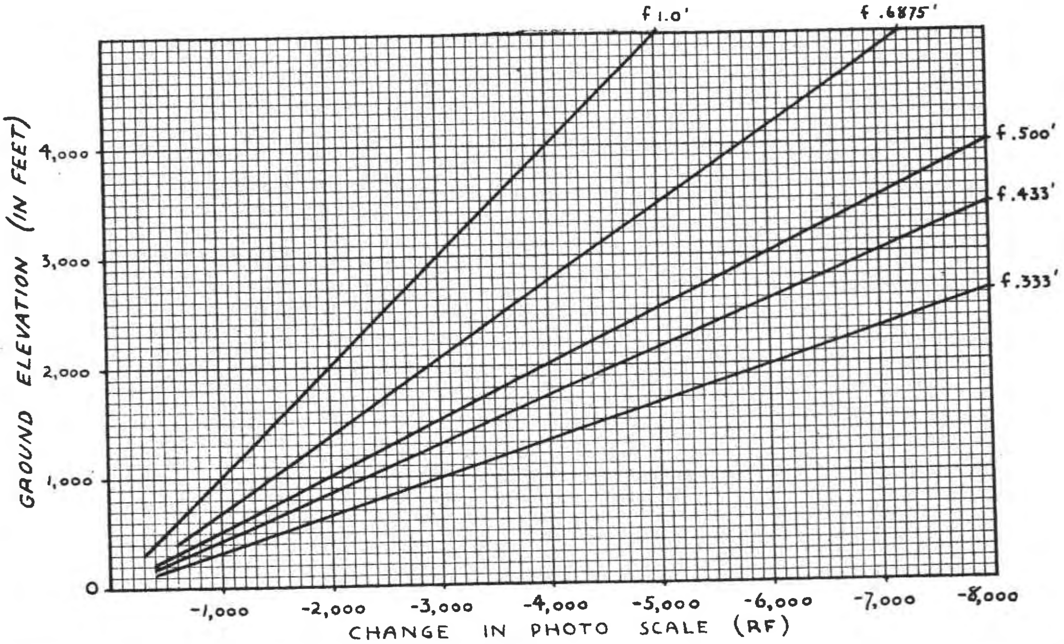
7. Compute the scale at sea level datum for each photo. (Use Formula I, p. 8)

8. Compute the average scale at sea level for the 10 photos.

Use this average for all the photos of the photo project. This average scale is for sea level. For other elevations you must make adjustments. This can be done simply and quickly by means of a graph (fig. 2).

An example of the data used in computing the average scale for a photo project is given in table 1. The nine sample photos used in this computation yielded a satisfactory average scale.

GRAPH FOR ADJUSTING PHOTO SCALE
FROM SEA LEVEL TO GROUND ELEVATION



INSTRUCTIONS

1. Obtain the average photo scale (RF) at sea level and the focal length of the camera lens (f).
2. Find the known ground elevation on the left-hand vertical axis and read across to the applicable sloping f line.
3. From this intersection read down to the bottom horizontal axis and find the amount of change to make in the RF.

Example: With an average photo scale at sea level of 1:21,915 and a focal length of 0.6875 feet, adjust the RF for a ground elevation of 1,350 feet.

Reading across from 1,350 to the f .6875 line, and then down to the bottom horizontal axis, you find that the change in RF for this elevation is -1,950. Therefore, the RF for a photo of land at 1,350 feet elevation will be 1:21,915 - 1,950, or 1:19,965.

Figure 2.--Graph used to adjust photo scale to different elevation.

Table 1.--Data for computing average photo scale (at sea level) for project 283-A, Herkimer County, N. Y. 1/

Photo number	Photo distance (d)	Ground distance (D)	Average elevation (h)	Flying height above sea level (H)	Photo scale at sea level
	Feet	Feet	Feet	Feet	RF
133-1-2V	0.264	4,774	2,016	14,448	1:21,015
31-1-3V	.325	6,597	1,847	15,802	1:22,985
31-1-3V	.632	12,413	2,037	15,540	1:22,604
62-1-3V	.392	7,378	1,785	14,725	1:21,418
62-1-3V	.464	8,594	1,832	14,566	1:21,186
127-1-3V	.297	5,729	1,962	15,224	1:22,143
127-1-3V	.283	5,555	1,953	15,448	1:22,470
92-1-4	.342	6,510	1,621	14,708	1:21,393
92-1-4	.514	10,069	1,650	15,118	1:21,990
				Average scale	1:22,023

1/ Focal length of camera lens: 0.6875 feet

ACCURACY OF METHOD

By taking 9 or 10 samples, you get an average scale that is merely an estimate of what the real average is. The more samples you take, the more accurate your estimate will be. For the example given in table 1, a statistical analysis shows that the "standard error" for the average scale based on nine samples is 1.03 percent. In other words, average scales computed from nine samples are within 1.03 percent of being accurate, two times out of three--and they may be much closer to accuracy than 1.03 percent.

The average scale found for the nine sample photos in the sample was 1:22,023. The average scale for all the photos in the project is somewhere between 1:21,342 and 1:22,704.

For other photo projects the average scales determined had standard errors ranging from 0.49 to 2.45 percent (table 2). The amounts of scale variation by photo projects are shown in table 2 in the column titled "coefficient of variation". Small coefficients reflect low variation. Low variation reflects better photography. Therefore, it seems that of the projects listed in table 2, the best photography was in the GSM project, and the poorest was in the Cooperstown Area project.

Table 2.--Amount of error in scaling photos by short-cut method, for different projects

Project	Photos scaled	Average scale at sea level	Standard error of average scale	Coefficient of variation	Probable error per 1,000 feet
	Number	RF	Percent	Percent	Feet
GSM	8	1:45,500	0.52	1.51	2.7
MB	10	1:24,020	.68	2.1	4.2
CIW - SCS	10	1:34,680	.90	2.8	7.3
M46	40	1:23,500	.49	3.1	9.1
Cooperstown area	6	1:23,100	2.45	5.8	19.6
283-A	9	1:22,023	1.03	3.10	7.5
Franconia	9	1:28,921	1.50	4.60	12.4
CXG	9	1:22,500	1.60	4.45	15.3

The last column in table 2 shows the probable error of scaling ground distances on aerial photographs. For example, project 283-A has an error of 7.5 feet per 1,000. Thus you can expect that any 1,000-foot distance you measure on the photo will be within 7.5 feet of being accurate, two times out of three.

From these and other projects on which this short cut method of computing average scale was used, it was found that the standard error was about 1 percent when 9 or 10 sample photos were used. Therefore, 9 or 10 samples will usually provide a reliable average scale for any photo project.

HOW TO COMPUTE SCALE

Although computing scale is basic in map and aerial photograph reading, we feel it is advisable to include a brief description of the methods of computing scale as applied in this type of work.

Scale is usually expressed as a representative fraction (RF), which is the ratio of a distance on the map or photo to the same distance on the ground. A scale of 1:20,000 means a distance that is 1 inch on the map will be 20,000 inches on the ground.

<u>Formula I</u>

The formula for computing scale is:

$$RF = \frac{f}{H-h}$$

in which f = focal length of camera lens, in feet

H = flying height of plane above sea level, in feet

h = elevation of land above sea level, in feet

The focal length of the camera (f) is obtained from the agency making photographs. The elevation of the land above sea level (h) is obtained from ground control or from U. S. Geological Survey topographic maps.

Formula II

The flying height of the plane above sea level (H) is computed from the following formula:

$$H = \frac{fD}{d} + \frac{h_{G_1} + h_{G_2}}{2}$$

in which H = approximate flying height of plane above sea level, in feet

D = ground distance between points G_1 and G_2, in feet

d = photo distance between points G_1 and G_2, in feet

h_{G_1} = elevation of point G_1 in feet

h_{G_2} = elevation of point G_2, in feet

The flying height (H) obtained is not true flying height, but it is sufficiently close for our purposes. Photo scale for other elevations is computed from Formula I.

Example

Suppose you want the scale for a point whose elevation is 2,200 feet above sea level. The distance between two points on the photo (d) is 0.525 feet and the corresponding ground distance (D) scaled from U. S. G. S. maps is 10,800 feet. The average elevation of the two points (h), from U. S. G. S. maps, is 675 feet and the focal length of the camera lens (f) is 0.6875 feet.

$$H = \frac{fD}{d} + \frac{h_{G_1} + h_{G_2}}{2}$$

$$H = \frac{(.6875)(10,800)}{.525} + 675$$

$$H = 14,818 \text{ feet}$$

Scale for the point whose elevation is 2,200 feet is computed from Formula I:

$$RF = \frac{f}{H-h}$$

$$RF = \frac{.6875}{14{,}818-2{,}200} = \frac{.6875}{12{,}618} = \frac{1}{18{,}353}$$

$$RF = 1:18{,}353$$