CHAPTER 9

Photo Scale Selection

9.1 CONTOUR FACTOR

Traditionally, American mappers have subscribed to a concept of a contour factor, which describes the geometric relationship between aircraft height (above mean ground level) and the smallest accurate contour interval that can be generated at a specific flight height. This correlation is referred to as the C-factor.

9.1.1 Application of the C-Factor

The C-factor is empirical rather than statistical. Hence its application is flexible, and professional acumen must be exercised in selecting the contour factor. The C-factor, as it is applied today in the United States, can be expressed by Equation 9.1.

$$c_f = H/c_i \tag{9.1}$$

where:

c_f = C-factor
c_i = contour interval (feet)
H = flight height (feet) above mean ground level

After choosing an appropriate contour interval (Table 9.1) and judging an equitable C-factor (Table 9.2), Equation 9.2 may be utilized to determine the flight height above mean ground level.

$$H = c_f * c_i \tag{9.2}$$

9.1.2 Influences upon C-Factor

Acceptable C-factors vary from one stereocompilation machine manufacturer and model to another. Actually, the C-factor for various mapping instrumentation is

Table 9.1 Recommended C-Factors to Achieve Specific Map Accuracy Standards

Contour Interval (ft)	Photogrammetric Mapping Purpose
1.0	Final design, earthwork computations, volumes
2.0	Route locations, preliminary design
4.0–5.0	Preliminary project planning
10.0	Steep terrain, general planning

Note: These C-Factors also apply to FGDC NSSDA.

Table 9.2 Maximum ASPRS and Interpolated NMAS C-Factors

	Stereomapping System	
Map Accuracy Standard	Softcopy Workstation	Analytical Stereoplotter
ASPRS Class 1	1600	2000
NMAS	1700	2100
ASPRS Class 2	1800	2200
ASPRS Class 3	2000	2500

considered as a range rather than a discrete integer. This range is influenced by many factors. The actual C-factor is project- and equipment-specific and can only be known after the project is completed and the mapping data are assessed for accuracy. Degradation of any, or the cumulative effect of several, of these elements will alter the precision of the C-factor. Refer to Chapter 9 in *Aerial Mapping: Methods and Applications* (Lewis Publishers, Boca Raton, FL, 1995) for an in-depth presentation of the specific production-oriented variables which influence its selection. Current technology advances such as digital cameras, softcopy workstations, and airborne GPS (ABGPS) also may affect the C-factor for a specific mapping project.

9.2 PHOTO SCALE/MAP SCALE/CONTOUR INTERVAL

Definitive geometrical relationships exist between map scale and contour interval, which determine the photo scale. Judicious implementation of these geometrical considerations greatly influences mapping integrity.

Selection of a reliable photograph scale is of major importance, because the quality of the final digital mapping product hinges primarily upon it. Three fundamental factors influence the selection of a photo scale for digital mapping:

- Equipment and system used in production
- Accuracy of the horizontal map scale
- Accuracy of the contour interval

It is mandatory that map scale and contour interval be considered separately prior to selecting a photo scale. Equipment and production systems hardware and software may affect both horizontal map scale and contour interval, as well as the overall selected photo scale.

9.2.1 Planimetric Features

On large-scale mapping projects, a great number of finite cultural features are compiled. These include, but are not limited to, poles, street signs, inlets, traffic signs, sidewalks, and manholes. As the map scale gets smaller, the end user may choose to omit some of the finite detail. The reason for this is that the features may not be visible and/or identifiable on the photos or that their exclusion would reduce map clutter and digital file size and performance. Some of the smaller features may be symbolized due to minimum size limitations. This dictates that large-scale planimetric mapping requires large-scale photos.

Current emphasis on GIS applications of spatial data may dictate that a high level of detail be captured and stored in a spatial data set. Detailed GIS query demands may become the driving force for final map scale and contour interval. An engineering design-based mapping project may have multiple uses to include incorporation into a facilities management GIS. The GIS may demand utility locations at a horizontal accuracy that would be greater than that required for general engineering purposes. In these situations it may be prudent to design the photo scale for a compilation level that will accommodate both engineering and GIS demands.

Past practice would discourage these GIS demands, but technology advancements are helping to accommodate them. Computer hardware (data storage devices and processors) is constantly getting faster and more capable of handling larger amounts of data reliably at relatively lower cost. Data compression routines and software are available that allow for reliable file size compression to 20 times reduction. Data storage media such as CDs and removable hard drives are increasing storage capability at reduced cost.

9.2.2 Photo Scale/Map Scale

To preserve horizontal validity of planimetric detail, the enlargement from the photographic image to the map should not exceed those factors listed in Table 9.3, which also apply to the Federal Geographic Data Committee (FGDC) National Standard for Spatial Data Accuracy (NSSDA) specifications.

Table 9.3 Maximum Recommended Enlargement Factors from Photo Scale to Map Scale

	Stereomapping System	
Map Accuracy Standard	Softcopy Workstation	Analytical Stereoplotter
ASPRS Class 1	6.0	7.0
NMAS	6.5	7.5
ASPRS Class 2	7.0	8.0
ASPRS Class 3	8.0	9.0

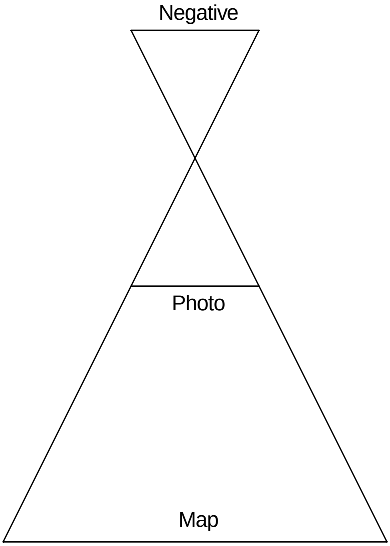

Figure 9.1 Map scale/photo scale relationship.

Calculation of photo scale is based upon horizontal accuracy objectives, and Equation 9.3 should be employed.

$$s_p = s_m * f_x \tag{9.3}$$

where:

s_p = photo scale denominator (feet)
s_m = map scale denominator (feet)
f_x = enlargement factor from photo to map scale

The relationship of photo scale and map scale is visually demonstrated in Figure 9.1.

9.2.3 Topographic Features

A given photo scale must maintain accuracy of the selected contour interval by reference to the C-factor. Although the credence of a C-factor is debated in some quarters, it is universally accepted within the American mapping community. Planners should be judicious in selecting a C-factor that will maintain map accuracy.

9.2.3.1 Flexible C-Factor

Currently in the United States, the flexible C-factor may diverge significantly from one production system to another (i.e., analytical stereoplotter vs. softcopy workstation). The selected factor may be subject to qualitative analysis and be

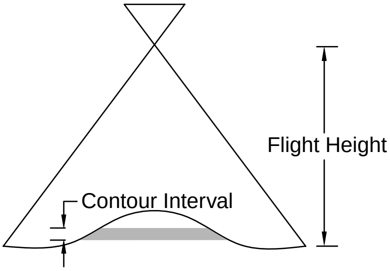

Figure 9.2 Relationship of the contour interval to flight height.

influenced by available equipment, compiler, or the philosophy of the organization providing the mapping product. It is better to be conservative in the application of the C-factor, since the production cost differential may be of less consequence than potential future liability which may be incurred from “stretching” the accuracy limits of the imagery.

The drawing in Figure 9.2 graphically illustrates the relationship between the contour interval and flight height. Once the flight height has been determined, the resultant negative scale can be reckoned by entering the appropriate variables into Equation 6.3 (Chapter 6).

9.2.3.2 Photo Scale/Contour Interval

Calculation of the photo scale based upon the vertical accuracy is premised on the interaction of the C-factor and contour interval.

Purpose of Mapping

The appropriate contour interval is dependent upon the purpose of the mapping. Refer to Table 9.1 to determine which contour interval meets the criteria for the topographic mapping.

Accuracy

The accuracy of the selected contour interval relies upon the C-factor, which is dependent upon the mapping class and production system. ASPRS map classes and interpolated NMAS accuracy standards limit C-factors to those found in Table 9.2 for analytical stereoplotters. The references to softcopy workstation C-factors in Table 9.2 are based upon the author’s current experiences and discussions with various photogrammetric mapping firms in the United States. FGDC NSSDA C-factor recommendations mirror either ASPRS standards or NMAS.

Flight Height

Once the contour interval/C-factor combination has been selected, the height of the aircraft can be calculated by Equation 9.2.

Photo Scale

The proper photo scale to maintain vertical accuracy can be computed using Equation 6.3 (Chapter 6).

9.2.3.3 Contours from Existing Photos

If the user has access to existing photographs, the appropriate contour interval associated with those photos can be determined. With the aid of a map measurement between two solid features and the corresponding ground distance between those same image features, the photo scale can be determined. Then, based upon a suitable C-factor for the stereomapping system utilized, the smallest contour interval would be determined by Equation 9.4.

$$c_i = H/c_f \tag{9.4}$$

where:

c_i = contour interval (feet)
H = flight height (feet) above mean ground level
c_f = selected C-factor

9.2.4 Photo Scale Selection

The desired map scale/contour interval may or may not be compatible. This is precisely the reason that photo scale must be computed for both the map scale and contour interval.

Large-scale maps are usually discussed in engineers' scale rather than representative fraction (1 in. = 50 ft vs. 1:600). This is due to the use of large-scale maps by professional engineers, who prefer working with engineers' scale. Planners, cartographers, geographers, and other GIS users generally prefer horizontal scales stated in representative fraction.

9.2.4.1 Compatible Parameters

To illustrate the selection of photo scale, assume the scenario requiring a map scale of 1 in. = 50 ft (1:600) with contours at 1-ft intervals compiled on an analytical stereoplotter.

Horizontal

To satisfy the horizontal (planimetric) accuracy prescribed by NMAS, the enlargement factor for employing an analytical stereoplotter is 7.5 times (see Table 9.3). Inserting the map scale and enlargement factor into Equation 9.3 yields:

$$s_p = s_m * f_x = 50 \times 7.5 = 375, \text{ or } 1 \text{ in.} = 375 \text{ ft}$$

Vertical

Table 9.2 indicates that the maximum C-factor for satisfying NMAS when using an analytical stereoplotter is 2100.

To satisfy the vertical (topographic) accuracy, the flight height above mean ground level would be derived by Equation 9.2.

$$H = c_f * c_i = 2100 \times 1 = 2100 \text{ ft}$$

Solving Chapter 6, Equation 6.3, the resultant negative scale would be:

$$s_p = H/f = 2100/6 = 350, \text{ or } 1 \text{ in.} = 350 \text{ ft}$$

Selected Scale

When selecting the photo scale, it should be the larger of the two calculated scales so that accuracy can be assured for both horizontal and vertical features. In this example the selected photo scale would be 1 in. = 350 ft, although any scale between 1 in. = 350 ft and 1 in. = 375 ft should maintain both horizontal and vertical accuracy.

The horizontal and vertical scales are compatible because they are near to each other in absolute value.

9.2.4.2 Incompatible Parameters

There are situations where the map scale and contour interval are not directly compatible. This situation of incompatibility does not preclude mapping. Rather, it forces the planner to choose the photo scale wisely.

Horizontal

Consider a project which specifies NMAS mapping to scale 1 in. = 200 ft (1:2400) with 2 ft contours on an analytical stereoplotter. To satisfy the horizontal (planimetric) accuracy prescribed by NMAS, the enlargement factor for employing an analytical stereoplotter is 7.5 times (see Table 9.3). Inserting map scale and enlargement factor into Equation 9.3 yields:

$$s_p = s_m * f_x = 200 \times 7.5 = 1500, \text{ or } 1 \text{ in.} = 1500 \text{ ft}$$

Vertical

Table 9.2 indicates that the maximum NMAS C-factor for an analytical stereoplotter is 2100. To satisfy the vertical (topographic) accuracy, the flight height above mean ground level would be derived with Equation 9.2.

$$H = c_f * c_i = 2100 \times 2 = 4200 \text{ ft}$$

Solving Equation 6.3 (Chapter 6), the resultant negative scale would be:

$$s_p = H/f = 4200/6 = 700, \text{ or } 1 \text{ in.} = 700 \text{ ft}$$

Considering these parameters, the choice of photo scale for compiling contours would be 1 in. = 700 ft, and the photo scale for compiling cultural features would be 1 in. = 1500 ft.

In this instance, the vertical aspect becomes of prime importance, since utilizing the smaller scale (1 in. = 1500 ft) photographs would not permit the collected digital topographic information to meet vertical accuracy requirements stipulated by NMAS.

In the same project suppose that the map scale is changed to 1 in. = 50 ft and all other parameters remain the same as above.

To satisfy the horizontal (planimetric) accuracy prescribed by NMAS, the enlargement factor for employing an analytical stereoplotter is 7.5 times (see Table 9.3). Inserting map scale and enlargement factor into Equation 9.3 yields:

$$s_p = s_m * f_x = 50 \times 7.5 = 375, \text{ or } 1 \text{ in.} = 375 \text{ ft}$$

Table 9.2 indicates that the maximum NMAS C-factor for an analytical stereoplotter is 2100. To satisfy the vertical (topographic) accuracy, the flight height above mean ground level would be derived with Equation 9.2.

$$H = c_f * c_i = 2100 \times 2 = 4200 \text{ ft}$$

Solving Equation 6.3 (Chapter 6), the resultant negative scale would be:

$$s_p = H/f = 4200/6 = 700, \text{ or } 1 \text{ in.} = 700 \text{ ft}$$

Using these parameters, the photo scale for compiling contours would be 1 in. = 700 ft, and the photo scale for compiling cultural features would be 1 in. = 375 ft.

In this instance, the horizontal aspect becomes of prime importance, since utilizing the smaller scale (1 in. = 375 ft) photographs would not permit the collected digital planimetric information to meet horizontal accuracy requirements stipulated by NMAS.

9.3 PLANNING AN AERIAL PHOTO MISSION

Now that the elementary geometric principles of aerial photography have been explored, this knowledge can be used in planning a photo mission. The intent is to plan a photo mission to cover the area delineated in Figure 11.4 (Chapter 11) with photos to scale 1 in. = 500 ft, assuming sidelap to be 30%, forward overlap to be 60%, and the camera focal length to be 6 in.

9.3.1 Laying Out Flight Lines

Initially, it is necessary to calculate the distance between flight strips.

9.3.1.1 Sidelap Gain

If the photos are to have a sidelap of 30%, the sidelap gain is calculated by Equation 6.7 (Chapter 6).

$$g_{side} = s_p * w * \left[\left(100 - percent_{side}\right)/100\right]$$

$$g_{side} = 500\ \text{ft} * 9\ \text{in.} * \left[(100 - 30\%)/100\right] = 3150\ \text{ft}$$

As an example of flight line layout, assume that the total width of the project is 10,500 ft as measured from an adequate map source. If strips are 3150 ft apart, this project will need 3.33 flight strips (10,500/3150 ft). It is impossible to have a fractional strip, so this project will require four photo lines. Flight lines are laid out leaving an equal distance along the east and west edges as noted in Figure 11.4 (Chapter 11).

9.3.1.2 Flight Line Orientation

In this situation, since the area is almost square, lines will be flown in the north/south direction to take advantage of the road system for accessing field control layout.

If possible, flight strips are usually oriented in a cardinal direction. However, this is not always practical because sometimes the project area may be skewed. Flight lines should be oriented parallel to the long dimension of the project if possible, since it will probably require fewer flight lines. It may be desirable to position flight lines relative to easiest access (roads, transmission lines, and cleared strips in woods) for field control routing. Ease of placement of field control should not be the overriding consideration for flight planning; however, field control can be a significant cost factor in a mapping project. Accessibility for ground survey crews can affect the time and cost associated with any mapping project. In states which employ the land subdivision system discussed in Chapter 10, flight lines may possibly be oriented so that the pilot can take advantage of sectionalized lines for guiding the flight course. However, this was of more consequence when flights were controlled visually, where pilots could make use of obvious land subdivision lines as reference guides. This is of less importance when ABGPS systems are utilized, since the aircraft can more easily maintain course through electronic piloting.

9.3.1.3 Airborne Global Positioning System (ABGPS) Navigation

ABGPS navigation of aerial photography missions is the current standard practice for all but very small projects. Software and hardware systems are available that fully automate the flight planning steps and processes and maximize the efficiency of aerial photo missions. Hardware and software requirements include CADD workstations, GPS antennas, and processing units. These systems require the mission planning team to develop the coordinates of the beginning and ending points for each flight line and to plot them on a digital reference map. The reference map is stored in an on-board computer navigation system tied to a GPS antenna and positioning system. The pilot uses the GPS to navigate the aircraft and activate the camera at the proper time and intervals. These systems allow for efficient mission planning. Utilizing these ABGPS navigation systems also provides a limited amount of quality control by requiring that the pilot use the mission planning data to guide the craft and the photography collection.

9.3.2 Determining Number of Photos

After the lines are laid out on the flight map as shown in Chapter 11, Figure 11.4, it is necessary to calculate the number of exposures required to provide stereophoto coverage.

If the photos are to have a forward overlap of 60%, the endlap gain is calculated by Equation 6.5 (Chapter 6).

$$g_{end} = s_p * w * \left[\left(100 - \text{percent}_{end}\right) / 100\right]$$

$$g_{end} = 500\text{ ft} * 9\text{ in.} * \left[(100 - 60\%)/100\right] = 1800\text{ ft}$$

To compute the number of photos on each line, divide the length of line by the net gain (17,000/1800), which equates to 9.4 photos per flight line. Since there are no fractional photos, each line will contain ten photos. At least one additional photo for each flight line is necessary to assure stereoscopic coverage on the total area. This means that the project will require a total of at least 44 exposures.

9.3.3 Calculating Flight Height

Finally, flight height above mean ground level of the aircraft to maintain the desired photo scale should be determined from Equation 6.4 (Chapter 6).

$$H = s_p * f = 500\text{ ft} * 6\text{ in.} = 3000\text{ ft}$$

Referring to the project map in Figure 11.4 (Chapter 11) it appears that the terrain elevation varies between 550 ft and 650 ft for an average ground level of about 600 ft. Then:

$$\begin{aligned}\text{flying altitude} &= \text{flight height} + \text{average ground}\\ &= 3000\ \text{ft} + 600\ \text{ft} = 3600\ \text{ft above mean sea level}\end{aligned}$$

Knowing the flying altitude and the location of individual flight lines, the crew can fly this project.