Chapter 18.
Project Planning

18-1. Introduction

- Successful execution of any photogrammetric project requires that thorough planning be done prior to proceeding with the work
- Planning, more than any other area of photogrammetric practice, must be performed by knowledgeable and experienced persons who are familiar with all aspects of the subject
- The first and most important decision to be made in the planning process concerns the selection of the products that will be prepared
- In addition to selecting the products, their scales and accuracies must be fixed
- These decisions can only be made if the planner thoroughly understands what the client's needs are, so that the best overall products can be developed to meet those needs
- The client will also naturally be concerned with the anticipated costs of the items as well as the proposed schedule for their delivery
- Therefore, successful planning will probably require several meetings with the client prior to commencing the work, and depending upon the nature and magnitude of the project, continued meetings may be needed as production progresses

18-1. Introduction

- A variety of products may be developed in a given photogrammetric project, including prints of aerial photos, photo indexes, photomaps, mosaics, orthophotos, planimetric and topographic maps, digital maps for GIS databases and other purposes, cross sections, digital elevation models, cadastral maps, and others
- In addition to the wide variation in products that could be developed for a given project, there are normally other major considerations that will have definite bearing on procedures, costs, and scheduling
- These include the location of the project; its size, shape, topography, and vegetation cover; the availability of existing ground control; etc
- Thus, every project presents unique problems to be considered in the planning stages

18-1. Introduction

❖ Assuming that the photogrammetric products, and their scales and accuracies, have been agreed upon with the client, the balance of the work of project planning can generally be summarized in the following categories:

1. Planning the aerial photography
2. Planning the ground control
3. Selecting instruments and procedures necessary to achieve the desired results
4. Estimating costs and delivery schedules

❖ When planning has been completed for these categories, the photogrammetrist will normally prepare a detailed proposal which outlines plans, specifications, an estimate of costs, and delivery schedules for the project

❖ The proposal often forms the basis of an agreement or contract for the performance of the work

❖ Of the above four categories, this chapter concentrates primarily on planning of the aerial photography

18-2. Importance of Flight Planning

- Because the ultimate success of any photogrammetric project probably depends more upon good-quality photography than on any other aspect, planning the aerial photography, also called *flight planning*, is of major concern

- If the photography is to satisfactorily serve its intended purposes, the photographic mission must be carefully planned and faithfully executed according to the "flight plan."

- A flight plan generally consists of two items:
  (1) a *flight map*, which shows where the photos are to be taken
  (2) *specifications*, which outline how to take them, including specific requirements such as camera and film requirements, scale, flying height, end lap, side lap, and tilt and crab tolerances

- A flight plan which gives optimum specifications for a project can be prepared only after careful consideration of all the many variables which influence aerial photography

18-2. Importance of Flight Planning

- An aerial photographic mission is an expensive operation involving two or more crewpersons and high-priced aircraft and equipment
- Periods of time that are acceptable for aerial photography are quite limited in many areas by weather and ground cover conditions, which are related to seasons of the year
- Failure to obtain satisfactory photography on a flight mission not only necessitates costly reflights, but also in all probability will cause long and expensive delays on the project for which the photos were ordered
- For these reasons flight planning is one of the most important operations in the overall photogrammetric project

18-3. Photographic End Lap and Side Lap

- Before discussing the many aspects which enter into consideration in planning an aerial photographic mission, it will be helpful to redefine the terms *end lap* and *side lap*
- Vertical aerial photographic coverage of an area is normally taken as a series of overlapping flight strips
- As illustrated in Fig. 18-1, **end lap** is the overlapping of successive photos along a flight strip
- Figure 18-2 illustrates **side lap**, or the overlap of adjacent flight strips

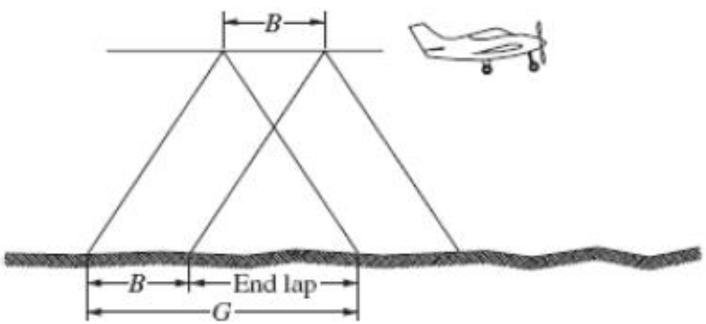

Figure 18–1. End lap, the overlapping of successive photos along a flight strip.

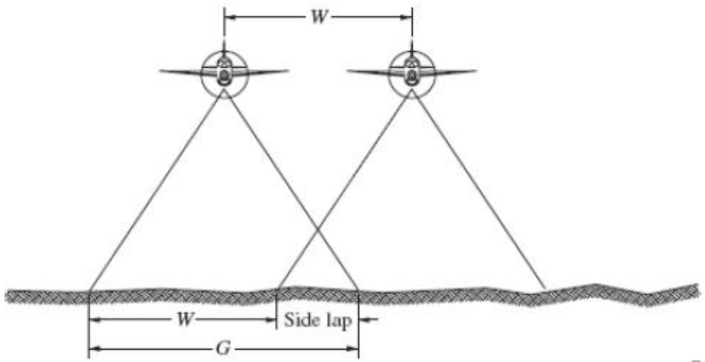

Figure 18–2. Side lap, the overlapping of adjacent flight strips.

18-3. Photographic End Lap and Side Lap

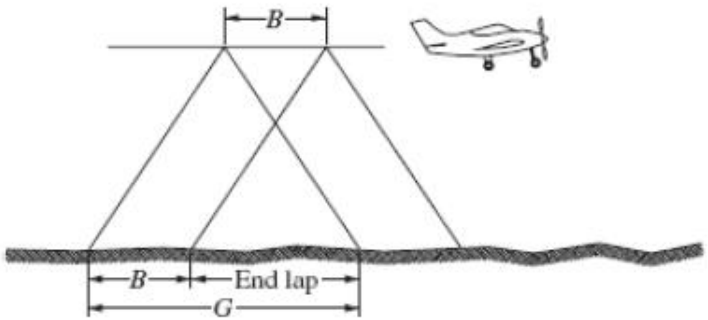

Figure 18–1. End lap, the overlapping of successive photos along a flight strip.

- In Fig. 18-1, G represents the dimension of the square of ground covered by a single vertical photograph (assuming level ground and a square camera focalplane format), and B is the air base or distance between exposure stations of a stereopair
- The amount of end lap of a stereopair is commonly given in percent
- Expressed in terms of G and B, it is $$\mathrm{PE} = \frac{G - B}{G} \times 100 \qquad (18\text{–}1)$$
- In Eq. (18-1), **PE** is percent end lap, and If stereoscopic coverage of an area is required, the absolute minimum end lap is 50 percent
- However, <u>to prevent gaps from occurring in the stereoscopic coverage due to crab, tilt, flying height variations, and terrain variations, end laps greater than 50 percent are used</u>
- If the photos are to be used for photogrammetric control extension, images of some points must appear on three successive photographs—a condition requiring greater than 50 percent end lap
- For these reasons <u>aerial photography for mapping purposes is normally taken with about 60 percent end lap</u>

18-3. Photographic End Lap and Side Lap

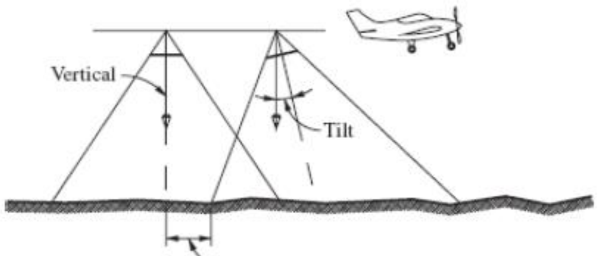

Figure 18–3. Failure to achieve stereoscopic coverage due to tilt.

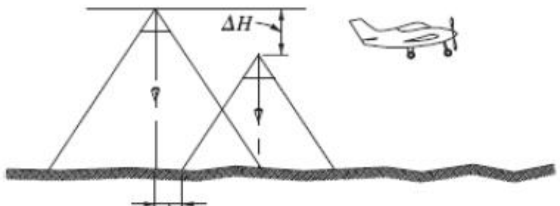

Figure 18–4. Failure to achieve stereoscopic coverage due to flying height variations

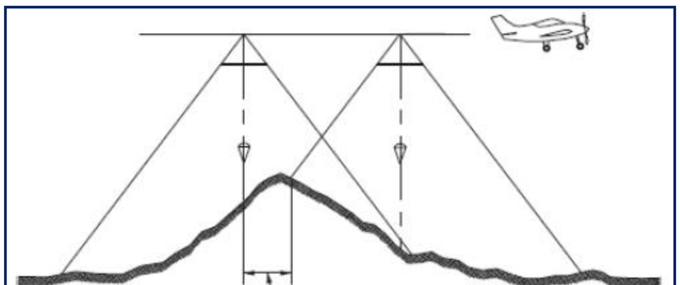

Figure 18–5. Failure to achieve stereoscopic coverage due to terrain variations.

- *Crab* exists <u>when the edges of the photos in the x direction are not parallel with the direction of flight</u>
  - ⇨ It causes a reduction in stereoscopic coverage

- Figures 18-3 through 18-5 illustrate reductions in end lap causing loss of stereoscopic coverage due to tilt, flying height variation, and relief variations, respectively

18-3. Photographic End Lap and Side Lap

❖ Side lap is required in aerial photography to prevent gaps from occurring between flight strips as a result of drift, crab, tilt, flying height variation, and terrain variations

❖ *Drift* is the term applied to a failure of the pilot to fly along planned flight lines

❖ It is often caused by strong winds, but can also result from a lack of definite features and objects shown on the flight map which can also be identified from the air to guide the pilot during photography

❖ Excessive drift is the most common cause for gaps in photo coverage; when this occurs, reflights are necessary

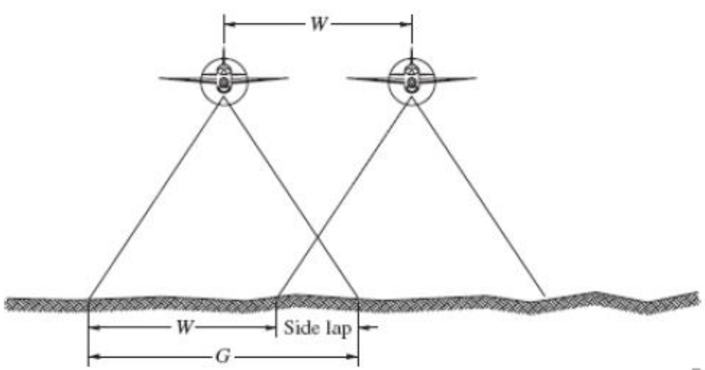

Figure 18–2. Side lap, the overlapping of adjacent flight strips.

❖ In Fig. 18-2, again G represents the dimension of the square of ground coverage of a single vertical photograph, and W is the spacing between adjacent flight lines

❖ An expression for **PS** (percent side lap) in terms of G and W

$$\mathrm{PS} = \frac{G - W}{G} \times 100 \qquad (18\text{–}2)$$

18-3. Photographic End Lap and Side Lap

- Mapping photography is normally taken with a side lap of about 30 percent
- Besides helping to prevent gaps in coverage, another advantage realized from using this large a percentage is the elimination of the need to use the extreme edges of the photography, where the imagery is of poorer quality
- Photography for orthophoto or mosaic work is sometimes taken with greater than 30 percent side lap since this reduces the sizes of the central portions of the photographs that must be used, thereby lessening distortions of images due to tilt and relief
- In certain cases, such as for very precise photogrammetric control extension, the aerial photos may be taken with 60 percent side lap as well as 60 percent end lap to increase the redundancy in the bundle adjustment

18-4. Purpose of the Photography

- In aerial photographic missions, the foremost consideration is the purpose for which the photography is being taken
- Photos having **good *metric* qualities** are needed for topographic mapping or other purposes where precise quantitative photogrammetric measurements are required
- **High pictorial qualities** are required for qualitative analysis, such as for photographic interpretation or for constructing orthophotos, photomaps, and aerial mosaics
- Photographs of good metric quality are obtained by using calibrated cameras and films having fine-grained, high-resolution emulsions or digital sensors with a high pixel count
- For topographic mapping and other quantitative operations, photography is preferably **taken with a wide- or super-wide-angle (short-focal-length) camera** so that a large *base-height* ratio (B/H') is obtained
- The B/H' ratio is the ratio of the air base of a pair of overlapping photographs to the average flying height above ground
- The larger the B/H' ratio, the greater the intersection angles (parallactic angles) between intersecting light rays to common points

18-4. Purpose of the Photography

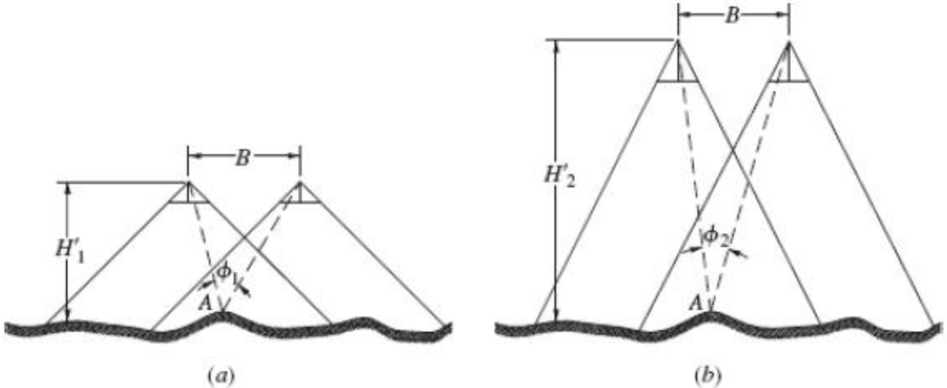

Figure 18–6. Parallactic angles increase with increasing B/H' ratios.

- In Figs. 18-6a and b, for example, the air bases are equal, but the focal length and flying height in Fig. 18-6a are one-half those in Fig. 18-6b

- The photographic scales are therefore equal for both cases, but the B/H' ratio of Fig. 18-6a is double that of Fig. 18-6b, and parallactic angle φ_1 to point A in Fig. 18-6a is nearly double the corresponding angle φ_2 in Fig. 18-6b

- It can be shown that the errors in computed positions and elevations of points in a stereopair increase with increasing flying heights, and decrease with increasing x parallax

- Large B/H' ratios denote low flying heights and large x parallaxes, conditions favorable to higher accuracy

- The photos of Fig. 18-6a are therefore superior to those of Fig. 18-6b for mapping or quantitative analyses

18-4. Purpose of the Photography

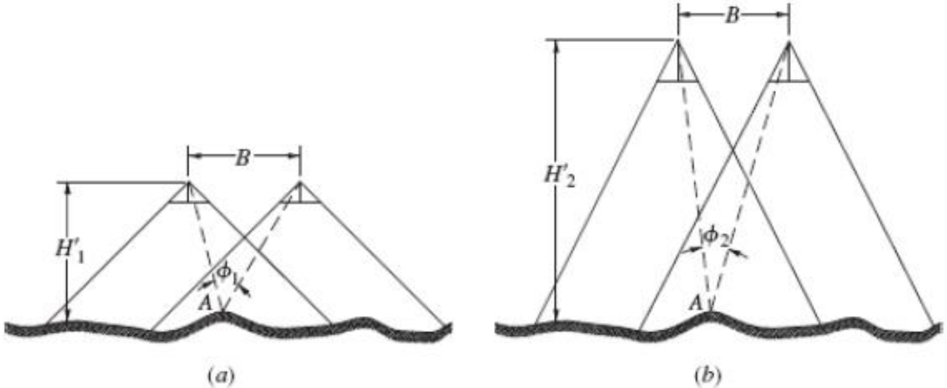

Figure 18-6. Parallactic angles increase with increasing B/H' ratios.

- ❖ Photography of high pictorial quality does not necessarily require a calibrated camera, but the camera must have a good-quality lens
- ❖ In many cases, films having fast, large-grained emulsions or digital cameras with high ISO speeds produce desirable effects
- ❖ For some photo interpretation work, normal color photography is useful
- ❖ For other special applications, black-and-white infrared or color infrared photos are desirable
- ❖ Special effects can be obtained by using filters in combination with various types of films
- ❖ Timber types, for example, can be delineated quite effectively by using a red filter in combination with black-and-white infrared film
- ❖ Similarly, digital image processing techniques can be applied to enhance photos for many different interpretive applications

18-4. Purpose of the Photography

- For mosaic work, **relief displacements, tilt displacements**, and **scale variations** produce objectionable degradations of pictorial quality
- These may be minimized, however, by increasing flying height, thereby decreasing the B/H' ratio
- Increased flying height, of course, reduces photo scale; but compensation for this can be achieved by using a longer-focal-length camera

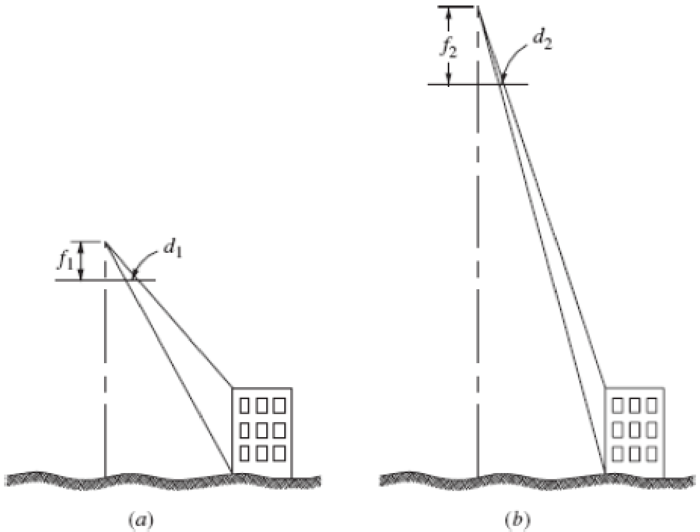

Figure 18–7. Reduction in relief displacement is achieved by increasing flying height.

- The photo of Fig. 18-7a was exposed at one-half the flying height of the photo of Fig. 18-7b
- The scales of the two photos are equal, however, because focal length f_2 of Fig. 18-7b is double f_1 of Fig. 18-7a

18-4. Purpose of the Photography

- For mosaic work, relief displacements, tilt displacements, and scale variations produce objectionable degradations of pictorial quality
- These may be minimized, however, by increasing flying height, thereby decreasing the B/H′ ratio
- Increased flying height, of course, reduces photo scale; but compensation for this can be achieved by using a longer-focal-length camera

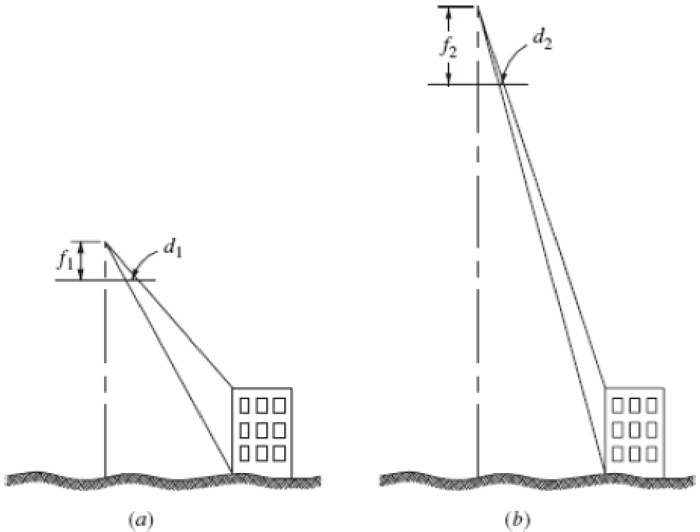

Figure 18–7. Reduction in relief displacement is achieved by increasing flying height.

- The photo of Fig. 18-7b is more desirable for mosaic construction because its scale variations and image distortions due to relief, tilt, and flying height variations are much less than those of the photo of Fig. 18-7a
- On Fig. 18-7a, for example, relief displacement d_1 is more than double the corresponding relief displacement d_2 of Fig. 18-7b

18-5. Photo Scale

- Average photographic scale is one of the most important variables that must be selected in planning aerial photography

- It is generally fixed within certain limits by specific project requirements

- For topographic mapping, photo scale is usually dictated by the map's required scale and/or horizontal and vertical accuracy

- On the other hand, in photo interpretation applications, or for orthophoto or mosaic preparation, ensuring that the smallest ground objects of importance can be resolved on the photos may be the governing consideration in selecting the photo scale

18-5. Photo Scale

- In topographic mapping, the enlargement ratio from photo scale to the scale of the plotted map must be considered
- With older direct optical projection stereoplotters, where maps were drawn in real time as the operator viewed and traced the stereomodel, the enlargement ratio was fixed within narrow limits, with 5 being most common
- Mechanical projection stereoplotters have enlargement ratio capabilities which range from less than 1 up to 10 or more, depending upon the particular instrument
- However, the number of these instruments in use today is also declining, and those being used are seldom employed for direct map compilation anymore
- Rather they are equipped with digitizers, and topographic information is digitized and stored in files
- Analytical plotters and softcopy systems account for the majority of topographic mapping, and for topographic mapping both of these systems are normally used to produce digital files

18-5. Photo Scale

- In using computers to plot map from digital file, virtually any enlargement ratio is possible
- It is important to note that the digitized information contains errors, and these errors are magnified by whatever enlargement ratio is used
- Thus to ensure the integrity and accuracy of a map compiled from digital data, the enlargement ratios that are actually utilized must be held within reasonable limits
- To ensure that their plotted maps meet required accuracy standards, many organizations will not enlarge more than five to seven times over photo scale
- Higher enlargement ratios are sometimes used but this should be done with caution, and generally only when experience with previous projects has shown through field checks that satisfactory accuracies have been obtained

18-5. Photo Scale

- Selection of optimum map scale depends upon the purpose of the map
- It should be carefully planned, because compilation at a larger scale than necessary is uneconomical, and compilation at too small a scale reduces the usefulness of the map or may even render it unsatisfactory
- The **horizontal accuracy** (accuracy to which planimetric positions of points can be measured from a map) depends directly upon the map's scale

Examples

- Assume, for example, that map positions of planimetric features can be plotted correctly to within 1/30 in, a condition necessary to meet National Map Accuracy Standards for largescale maps
- If a particular cadastral map requires that points be accurate to within ± 2.0 ft, required map scale is 1 in = 60 ft (1:720)
- Then for that situation, if an enlargement ratio of 5 is employed, photo scale is fixed at 5 × 60 = 300 ft/in (1:3600)
- In another example, if points only need to be accurate to within ± 20 ft on a topographic map for preliminary planning, and again assuming the same accuracy of 1/30 in, then a scale of 1 in = 600 ft (1:7200) is all that would be required, and minimum photo scale would be 5 × 7200, or 1:36,000

18-5. Photo Scale

- Vertical mapping accuracy is also an important factor to be considered in planning aerial photography
- In past, contours which portrayed topographic relief were compiled directly from stereomodels, and thus the guidelines and standards for specifying vertical accuracy in topographic mapping were commonly given in terms of contour interval
- However, for modern photogrammetry projects digital elevation models (DEMs) are now generally compiled rather than contours
- From the DEMs, triangulated irregular network (TIN) models are constructed using computers, and then contours, cross sections, and profiles can be generated automatically from the TIN models
- But even though different procedures are now employed to compile topographic information, contours are still the end product that is often used in representing topographic relief
  - ⇨ Thus, guidelines and standards that are based on contour interval are still appropriate for quantifying vertical mapping accuracy, and as vertical mapping accuracy requirements increase (contour interval decreases), flying height must decrease and photo scale must increase

18-5. Photo Scale

❖ As with planimetric accuracy, the contour interval to be selected for a particular mapping project depends upon the intended use of the maps

Examples

- Assume, for example, that elevations can be interpolated correctly from a map to within one-half the contour interval, a condition required for meeting National Map Accuracy Standards
- If elevations must be interpolated to within ±0.5 ft on a highway design map, then a 1-ft contour interval is necessary
- If elevations must be interpolated to ±10 ft on a map prepared for studying the volume of water impounded in the reservoir of a large dam, then a 20-ft contour interval is all that is required

18-5. Photo Scale

- The recommended contour interval depends on not only the use to be made of the map but also the type of terrain
- If the map is being prepared for planning a sewer system for a city such as Las Vegas, Nevada, which lies on relatively flat terrain, a 1-ft contour interval would be required
- On the other hand, if a topographic map of San Francisco is being prepared for the same purpose, because of the large range of relief in that city, perhaps a 5- or 10-ft contour interval would be used
- In planning a topographic mapping project, contour interval and map scale must be selected so that they are compatible
- As map scale decreases, contour interval must increase; otherwise, the contours would become too congested on the map

18-5. Photo Scale

❖ In large-scale mapping of average types of terrain, the scale and contour interval relationships shown in Table 18-1 generally provide satisfactory compatibility

Table 18–1. Compatible Map Scale and Contour Intervals for Average Terrain

(English System) Map Scale	(English System) Contour Interval	(Metric System) Map Scale	(Metric System) Contour Interval
1 in/50 ft	1 ft	1:500	0.5 m
1 in/100 ft	2 ft	1:1000	1 m
1 in/200 ft	5 ft	1:2000	2 m
1 in/500 ft	10 ft	1:5000	5 m
1 in/1000 ft	20 ft	1:10,000	10 m

18-5. Photo Scale

- Relative accuracy capabilities in photogrammetric mapping, whether planimetric or vertical, depend upon many variables, but the most important is flying height above ground

- Others include the quality of the stereoplotting instrument that is used and the experience and ability of its operator, the camera and its calibration, the quality of the photography, the density and accuracy of the ground control, and the nature of the terrain and its ground cover

- A rule of thumb for quantifying vertical accuracy capability, based on contour interval, employs a term called the **Cfactor**

- The **Cfactor** is the ratio of the flying height above ground of the photography (H') to the contour interval that can be reliably plotted using that photography, or in equation form

$$\text{Cfactor} = \frac{H'}{\text{CI}} \qquad (18\text{–}3)$$

18-5. Photo Scale

$$\text{Cfactor} = \frac{H'}{\text{CI}} \qquad (18\text{–}3)$$

- The units of H' and $\mathbf{CI}$ (contour interval) of Eq. (18-3) are the same
- The **Cfactors** that are employed by photogrammetric mapping organizations are based upon their experiences, and this experience will include field checks of map accuracies achieved on a variety of previous projects
- To ensure that their maps meet required accuracy standards, many organizations use a **Cfactor** of from about 1200 to 1500
- Other organizations may push the value somewhat higher, but this must be done with extreme caution

18-5. Photo Scale

- In some topographic mapping projects, particularly where there is little relief, it is impractical to show elevations using contours
- In these situations, a grid of spot elevations can be read throughout the area to depict the relief
- A rule of thumb relating accuracy of spot elevations and flying height is that the ratio of flying height above ground to the accuracy with which spot elevations can be reliably read is approximately 5000
- Thus, if spot elevations are needed to an accuracy of ±1/2 m, then the flying height above ground necessary to achieve those results would be in the range of about 1/2 (5000), or roughly 2500 m
- Again, in addition to flying height, the actual accuracies that can be achieved also relate to the stereoplotting instrument, the operator's ability, the quality of the aerial photography, the density and accuracy of the ground control, and other factors

18-6. Flying Height

- Once the camera focal length and required average photo scale have been selected, required flying height above average ground is automatically fixed in accordance with scale [see Eq. (6-3)]

$$S_{avg} = \frac{f}{H - h_{avg}} \qquad (6\text{-}3)$$

- Flying heights above average ground may vary from a hundred meters or so in the case of large-scale helicopter photography, to several hundred kilometers if satellites are used to carry the camera

- Flying heights used in taking photos for topographic mapping normally vary between about 500 and 10,000 m

- If one portion of the project area lies at a substantially higher or lower elevation than another part, two different flying heights may be necessary to maintain uniform photo scale

18-6. Flying Height

- Ground coverage per photo for high-altitude photography is greater than that for low-altitude photography
- Very **high-altitude coverage** is more **expensive** to obtain than low-altitude photography because of the special equipment required
- Some of the problems encountered at high flying heights are the decreasing available oxygen, decreasing pressure, and extreme cold
- Most aerial photography is taken by using single- or twin-engine aircraft
- Supercharged single-engine aircraft can reach altitudes of about 6 km, and supercharged twin-engine aircraft are capable of approaching 10 km
- Higher altitudes require turbocharged or jet aircraft

18-6. Flying Height

- During photography the pilot maintains proper flying height by means of an altimeter or GPS receiver
- Since altimeters give elevations above mean sea level, the proper reading is the sum of average ground elevation and required flying height above ground necessary to achieve proper photo scale
- Altimeters are barometric instruments, and consequently their readings are affected by varying atmospheric pressure
  - ➪ They must be checked daily and adjusted to base airport air pressure
- GPS receivers, while essentially unaffected by barometric pressure, give elevations relative to the ellipsoid
  - ➪ Therefore a geoid model is required to relate these elevations to mean sea level

18-7. Ground Coverage

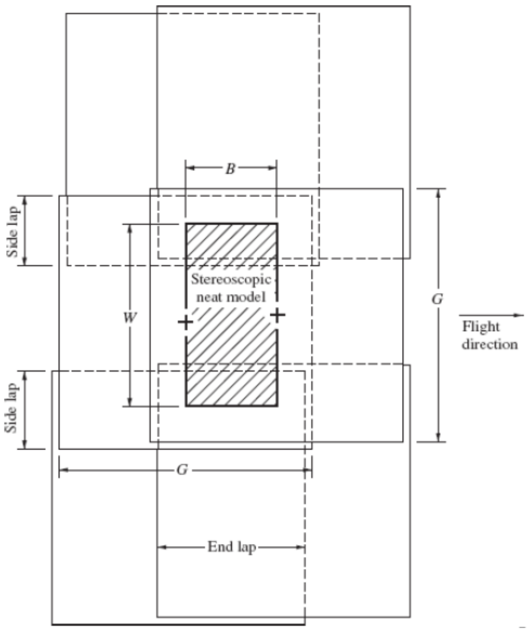

Figure 18-8. The area covered by a stereoscopic neat model.

- Once average photographic scale and camera format dimensions have been selected, the ground surface area covered by a single photograph may be readily calculated
- In addition, if end lap and side lap are known, the ground area covered by the stereoscopic *neat model* can be determined
- The **neat model**, as illustrated in Fig. 18-8, is the stereoscopic area between adjacent principal points and extending out sideways in both directions to the middle of the side lap
- The neat model has a width of B and a breadth of W
- Its coverage is important since it represents the approximate mapping area of each stereopair

18-7. Ground Coverage

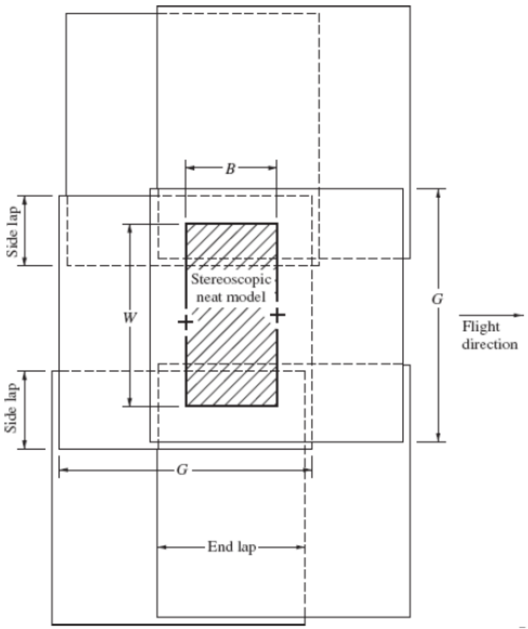

Figure 18–8. The area covered by a stereoscopic neat model.

- While neat models guide the planning process for projects intended for stereoplotter mapping, other applications may call for different ground coverage parameters
- For example, if orthophotos are the intended final product, it is beneficial to plan flights with equal end lap and side lap
- The advantage of **increasing the side lap** is that more ground is covered near the center of photos
- This reduces the amount of relief displacement and occlusion by buildings, and is therefore more useful in urban areas than rural

18-8. Weather Conditions

- The **weather**, which in most locations is uncertain for any given day, is a very important consideration in aerial photography
- In most cases, an ideal day for aerial photography is one that is free from clouds, although if the sky is less than 10 percent cloud-covered, the day may be considered satisfactory
- If clouds of greater than 10 percent coverage are present but are so high that they are above the planned flying height, this may still be objectionable since large cloud shadows will be cast on the ground, obscuring features
- The number of satisfactory cloudless days varies with time of year and locality
- There are certain situations in which overcast weather can be favorable for aerial photography
- For example, when large-scale photos are being taken for topographic mapping over built-up areas, forests, steep canyons, or other features which would cast troublesome shadows on clear, sunny days

18-8. Weather Conditions

- A particular day can be cloudless and still be unsuitable for aerial photography due to atmospheric haze, smog, dust, smoke, high winds, or air turbulence
- Atmospheric haze scatters almost entirely in the blue portion of the spectrum, and it can therefore be effectively eliminated from the photographs by using a yellow filter in front of the camera lens
- Best days for photographing over industrial areas which are susceptible to smog, dust, and smoke occur after heavy rains or during moving cold fronts which clear the air
- Windy, turbulent days can create excessive image motion and cause difficulties in keeping the camera oriented for vertical photography, in staying on planned flight lines, and in maintaining constant flying heights
- The decision to fly or not to fly is one that must be made daily
- The flight crew should be capable of interpreting weather conditions and of making sound decisions as to when satisfactory photography can be obtained
- If possible, the flight crew should be based near the project so that they can observe the weather firsthand and quickly take advantage of satisfactory conditions

18-9. Season of the Year

- The **season** of the year is a limiting factor in aerial photography because it affects ground cover conditions and the sun's altitude

- If photography is being taken for topographic mapping, the photos should be taken when the deciduous trees are bare, so that the ground is not obscured by leaves
  - This occurs twice a year for short periods in the late fall and in early spring

- Oak trees tend to hold many of their leaves until spring, when the buds swell and cause the leaves to fall

- In areas with heavy oak cover, therefore, the most satisfactory period for aerial photography is that very short period in the spring between budding and leafing out

- Sometimes aerial photography is taken for special forestry interpretation purposes, in which case it may be desirable for the trees to be in full leaf

- Normally, aerial photography is not taken when the ground is snow-covered
  - Heavy snow not only obscures the ground but also causes difficulties in interpretation and in stereoviewing
  - Occasionally, however, a light snow cover can be helpful by making the ground surface more readily identifiable in tree-covered areas

18-9. Season of the Year

- Another factor to be considered in planning aerial photography is the sun's altitude
- Low sun angles produce long shadows, which can be objectionable because they obscure detail
- Generally a sun angle of about 30° is the minimum acceptable for aerial photography
- During the winter months of November through February, the sun never reaches a 30° altitude in some northern parts of the United States due to the sun's southerly declination
  - ➪ Aerial photography should therefore be avoided in those areas during these months
- Snow cover will prevent photography during these periods anyway
- For the other months, photography should be exposed during the middle portion of the day after the sun rises above 30° and before it falls below that altitude
- For certain purposes, shadows may be desirable, since they aid in identifying objects
  - ➪ Shadows of trees, for example, help to identify the species
- Shadows may also be helpful in locating photo-identifiable features such as fenceposts and power poles to serve as photo control points

18-10. Flight Map

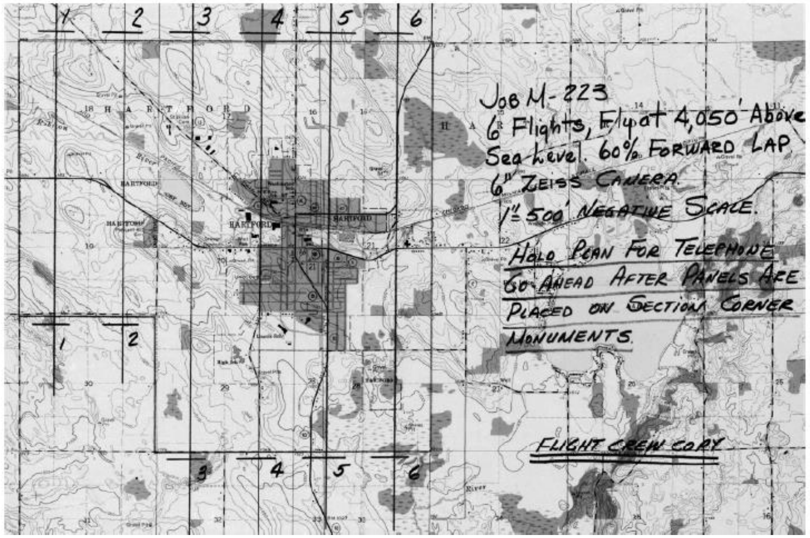

Figure 18–9. Example of a flight plan. (Courtesy Ayres Associates, Inc.)

- A **flight map**, as shown in Fig. 18-9, gives the project boundaries and flight lines the pilot must fly to obtain the desired coverage
- The flight map is prepared on some existing map which shows the project area
- United States Geological Survey quadrangle maps are frequently used
- The flight map may also be prepared on small-scale photographs of the area, if they are available
- In executing the planned photographic mission, the pilot finds two or more features on each flight line which can be identified both on the flight map and on the ground
- The aircraft is flown so that lines of flight pass over the ground points
- Alternatively, an **airborne GPS receiver** can be employed to guide the aircraft along predefined flight lines

18-10. Flight Map

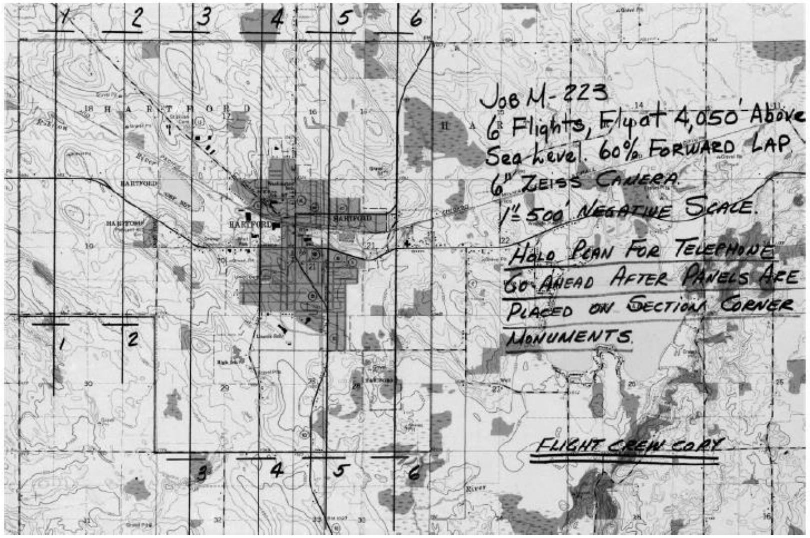

Figure 18–9. Example of a flight plan.
(Courtesy Ayres Associates, Inc.)

- A flight map, as shown in Fig. 18-9, gives the project boundaries and flight lines the pilot must fly to obtain the desired coverage
- The flight map is prepared on some existing map which shows the project area
- United States Geological Survey quadrangle maps are frequently used
- The flight map may also be prepared on small-scale photographs of the area, if they are available
- Rectangular project areas are most conveniently covered with flight lines oriented north and south or east and west
- As illustrated in Fig. 18-9, this is desirable because the pilot can take advantage of section lines and roads running in the cardinal directions and fly parallel to them

18-10. Flight Map

- If the project area is irregular in shape or if it is long and narrow and skewed to cardinal directions, it may not be economical to fly north and south or east and west
- In planning coverage for such irregular areas, it may be most economical to align flight lines parallel to project boundaries as nearly as possible
- **Flight planning templates** are useful for determining the best and most economical photographic coverage for mapping, especially for small areas
- These templates, which show blocks of neat models, are prepared on transparent plastic sheets at scales that correspond to the scales of the base maps upon which the flight plan is prepared
- The **templates** are then simply superimposed on the map over the project area and oriented in the position which yields best coverage with the fewest neat models
- Such a template is shown in Fig. 18-10

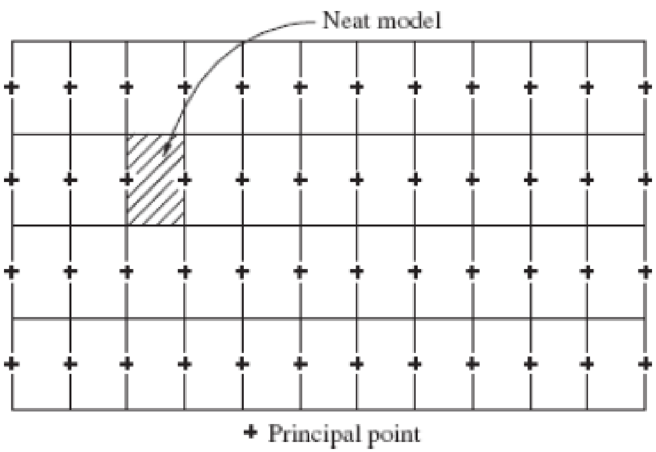

Figure 18-10. Transparent template of neat models used for planning aerial photography.

18-10. Flight Map

- The crosses represent exposure stations, and these may be individually marked on the flight map
- This template method of flight planning is exceptionally useful in planning exposure station locations when artificial targets are used
- Once the camera focal length, photo scale, end lap, and side lap have been selected, the flight map can be prepared
- The following example illustrates flight map preparation for a rectangular project area

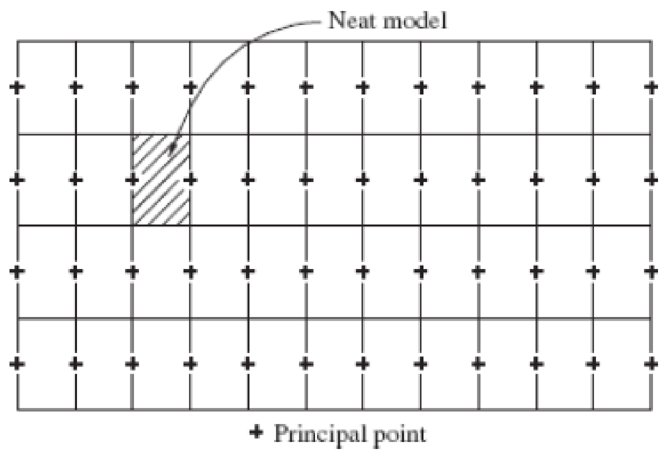

Figure 18–10. Transparent template of neat models used for planning aerial photography.

18-10. Flight Map

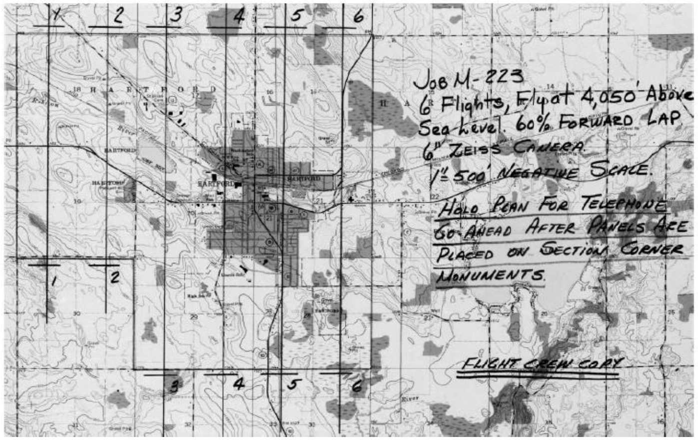

Figure 18–9. Example of a flight plan.
(Courtesy Ayres Associates, Inc.)

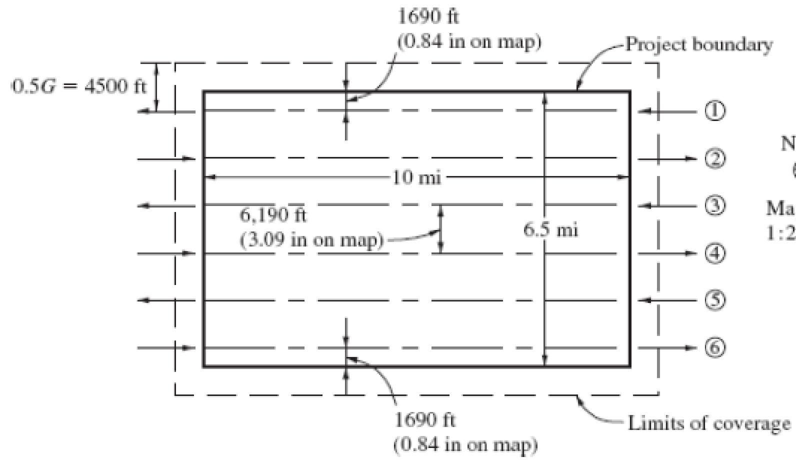

Figure 18–11. Project area for Example 18–9.

Examples 18-8

- A project area is 10 mi (16 km) long in the east-west direction and 6.5 mi (10.5 km) wide in the north-south direction (see Fig. 18-11)
- It is to be covered with vertical aerial photography having a scale of 1:12,000
- End lap and side lap are to be 60 and 30 percent, respectively
- A 6-in- (152.4-mm-) focal-length camera with a 9-in- (23-cm-) square format is to be used
- Prepare the flight map on a base map whose scale is 1:24,000, and compute the total number of photographs necessary for the project

18-10. Flight Map

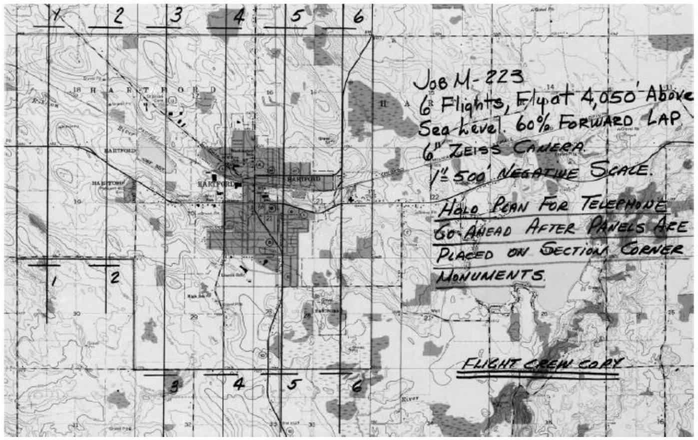

Figure 18–9. Example of a flight plan. (Courtesy Ayres Associates, Inc.)

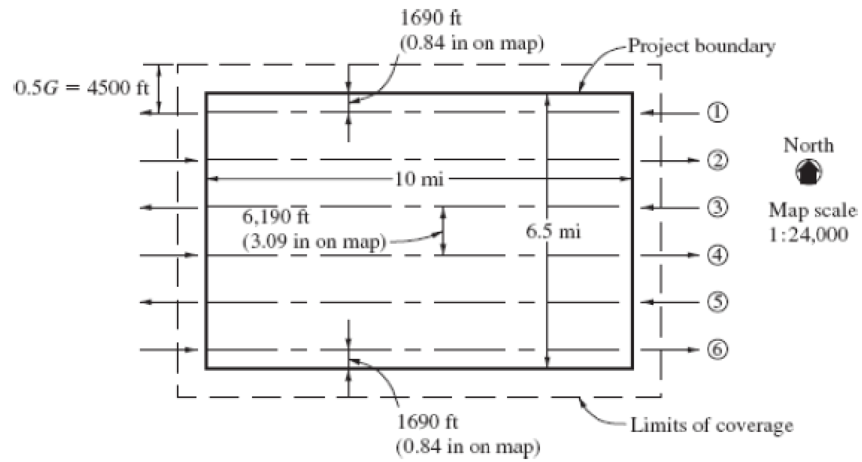

Figure 18–11. Project area for Example 18–9.

Solution

1. Fly east-west to reduce the number of flight lines.
2. Dimension of square ground coverage per photograph [photo scale = 1:12,000 (1 in/1000 ft)] is
   - $G = 9\ in \times 1000 ft/in = 9000 ft\ (2800 m)$
3. Lateral advance per strip (at 30 percent side lap) is
   - $W = 0.7G = (0.7)(9000 ft) = 6300 ft\ (1900 m)$
4. Number of flight lines. (Align the first and last lines with 0.3G (side-lap dimension) coverage outside the north and south project boundary lines, as shown in Fig. 18-11. This ensures lateral coverage outside of the project area.) Distance of first and last flight lines inside their respective north and south project boundaries (see Fig. 18-11) is
   - $0.5G - 0.3G = 0.2G = 0.2(9000) = 1800 ft\ (550 m)$

18-10. Flight Map

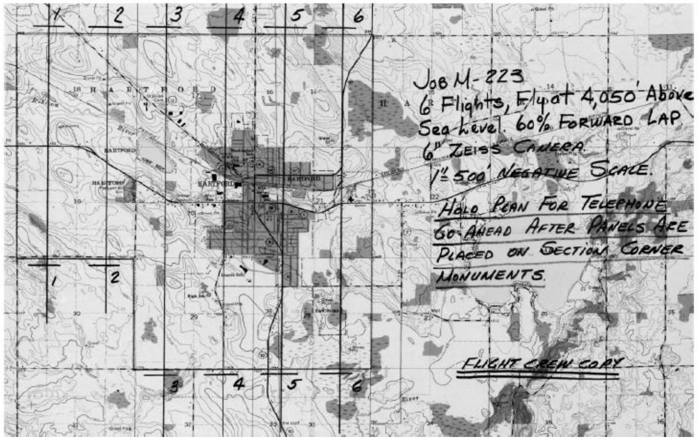

Figure 18–9. Example of a flight plan.
(Courtesy Ayres Associates, Inc.)

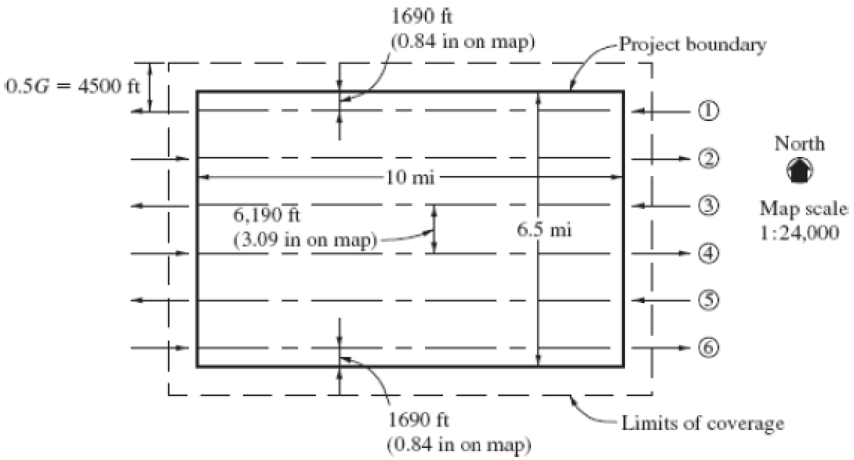

Figure 18–11. Project area for Example 18–9.

Solution

4. Number of spaces between flight lines: $\frac{6.5mi \times 5280ft/mi - 2 \times 1800ft}{6300ft} = 4.9(round\ up\ to\ 5)$

   Number of flight lines = number of spaces + 1 = 6

5. Adjust the percent side lap and flight line spacing. Adjusted percent side lap for integral number of flight lines (include portion extended outside north and south boundaries):

   - $2\left(0.5 - \frac{PS}{100}\right)G + (no.space)\left(1 - \frac{PS}{100}\right)G = total\ width$
   - $2\left(0.5 - \frac{PS}{100}\right)9000ft + 5\left(1 - \frac{PS}{100}\right)9000ft = 6.5mi \times 5280ft/mi$
   - $2\left(0.5 - \frac{PS}{100}\right) + 5\left(1 - \frac{PS}{100}\right) = 3.813$
   - $PS = 31.2\%$ (Note slight increase.)

18-10. Flight Map

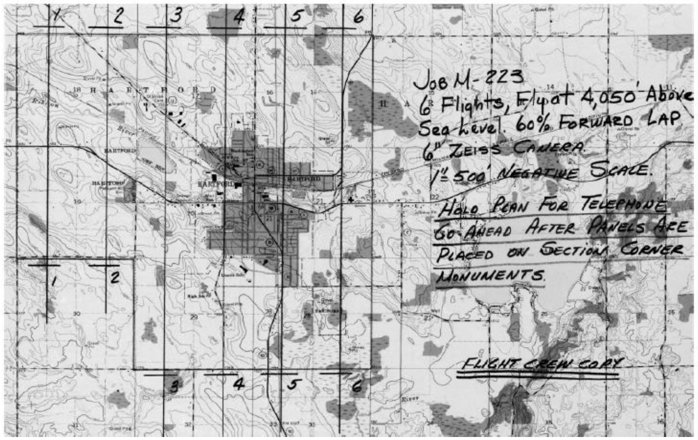

Figure 18–9. Example of a flight plan.
(Courtesy Ayres Associates, Inc.)

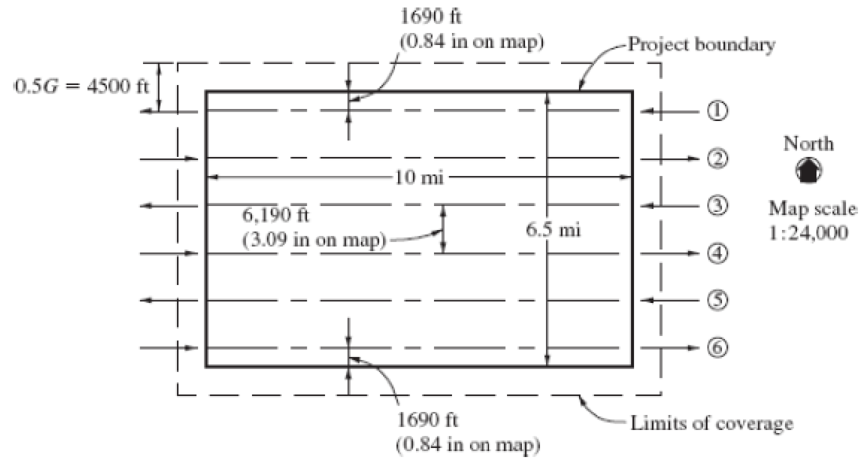

Figure 18–11. Project area for Example 18–9.

Solution

5. Adjusted spacing W_a between flight lines for integral number of flight lines:
   - $W_a = \left(1 - \frac{31.2}{100}\right) G = 6190ft\ (1890m)$
6. Linear advance per photo (air base at 60 percent end lap):
   - $B = 0.4G = (0.4)(9000ft) = 3600ft(1100m)$
7. Number of photos per strip (take two extra photos beyond the project boundary at both ends of each strip to ensure complete stereoscopic coverage):
   - $No.photos\ per\ strip = \frac{10mi \times 5280ft/mi}{3600ft} + 1 + 2 + 2 = 19.7\ (use\ 20)$
8. Total number of photos: $20\ photos/strip \times 6\ strips = 120$

18-10. Flight Map

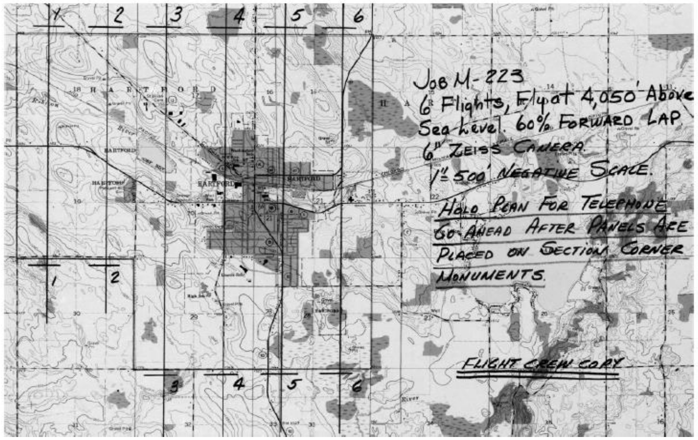

Figure 18–9. Example of a flight plan.
(Courtesy Ayres Associates, Inc.)

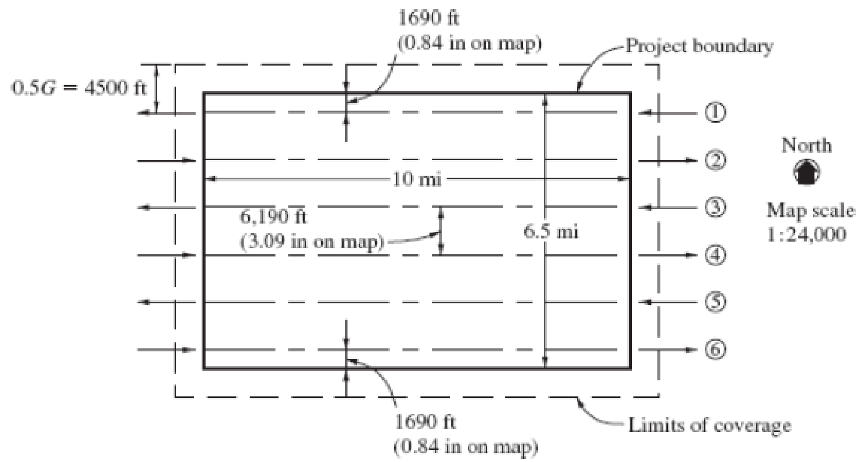

Figure 18–11. Project area for Example 18–9.

Solution

9. Spacing of flight lines on the map:
   - $Map\ scale = 1{:}\,24{,}000\ (1in = 2000ft)$
   - $W_M = \frac{6190\ ft\ per\ strip}{2000ft/in} = 3.09\ in\ (78.6mm)$

Draw the flight lines at 3.09-in spacing on the map, with the first and last lines $[(0.5 - 31.2/100)9000\ ft]/2000\ ft/in\ =\ 0.84$ in inside the project boundaries

18-10. Flight Map

Figure 18-12. Flight plan prepared on a computer. (Courtesy University of Florida)

- Computer programs are now available for preparing flight plans
- Figure 18-12 illustrates a flight plan for a highway corridor being prepared with the aid of a computer
- Design variables including camera focal length, photo scale, end lap, and side lap are input to the computer
- Base maps upon which the flight maps will be prepared can either be scanned into the computer from existing hard copies, or they can be downloaded from existing databases of topographic maps

18-10. Flight Map

Figure 18–12. Flight plan prepared on a computer. (Courtesy University of Florida)

- ❖ Coordinates of points that delineate the boundaries of the area to be photographed must be input, and the coordinates of at least two control points must also be entered and their locations identified within the map area
- ❖ The computer can then make all the same calculations that were demonstrated in Example 18-8 and prepare flight maps with superimposed flight lines

- ❖ In addition to software devoted soley to preparing flight plans, there are various kinds of **mapping software** that allows users <u>to easily develop their own flight plans by superimposing lines and points over existing imagery</u>
- ❖ In the most modern aerial photography and navigation systems, after designing the flight map, the computer determines the coordinates of the ends of the flight lines
- ❖ Then the aircraft's navigation system, aided by an onboard GPS receiver, automatically guides the aircraft along the desired flight lines at the required altitude and exposes the photographs according to the given percent end lap

18-11. Specifications

- Most flight plans include a set of detailed specifications which outline the materials, equipment, and procedures to be used on the project
- These specifications include requirements and tolerances pertaining to photographic scale (including camera focal length and flying height), end lap, side lap, tilt, crab, and photographic quality
- The following is a sample set of detailed specifications for aerial photography (courtesy Ayres Associates, Inc.).

1) *General.*
   - The engineer shall perform the necessary flying and photography to provide photographic coverage of an area approximately 8 square miles in extent shown on the sketch map attached hereto as exhibit A
   - The engineer may sublet this phase of the work to a qualified and experienced aerial photographic firm
   - The city, however, retains the right to approve or reject any or all such firms which the engineer may wish to engage

18-11. Specifications

❖ The following is a sample set of detailed specifications for aerial photography (courtesy Ayres Associates, Inc.)

2) Scale.

- Flight height above average ground shall be such that the negatives will have an average scale of 1 in = 500 ft (1:6000)
- Negatives having a departure from the specified scale by more than 5 percent because of tilt or abrupt changes in flying altitude must be corrected
- The photographs shall be suitable for the compilation of the topographic maps specified herein, and the mapping flight height shall not vary from 3000 ft above mean terrain by more than 5 percent

18-11. Specifications

- The following is a sample set of detailed specifications for aerial photography (courtesy Ayres Associates, Inc.)

3) End lap and side lap.

- End lap shall be sufficient to provide full stereoscopic coverage of the area to be mapped
- End lap shall average 63 percent, plus or minus 5 percent. End lap of less than 58 percent or more than 68 percent in one or more negatives shall be cause for rejection of the negatives in which such deficiency or excess occurs
- Unless within a stereoscopic pair, end lap exceeding 68 percent is necessary in areas of low elevation to attain the minimum 58 percent end lap in adjacent areas of high elevation
- Wherever there is a change in direction of the flight lines, vertical photography on the beginning of a forward section shall end-lap the photography of a back section by 100 percent
- Any negatives having side lap of less than 20 percent or more than 55 percent may be rejected

18-11. Specifications

❖ The following is a sample set of detailed specifications for aerial photography (courtesy Ayres Associates, Inc.).

4) Tilt.

- Negatives made with the optical axis of the aerial camera in a vertical position are desired
- Tilt of any negative by more than 5°, an average tilt of more than 1° for the entire project, or tilt between any two successive negatives exceeding 4° may be cause of rejection

5) Crab.

- Crab in excess of 3° may be cause of rejection of the flight line of negatives or portions thereof in which such crab occurs

18-11. Specifications

❖ The following is a sample set of detailed specifications for aerial photography (courtesy Ayres Associates, Inc.).

6) Quality.

- The photographs shall be clear and sharp in detail and of uniform average density
- They shall be free from clouds, cloud shadows, light streaks, static marks, or other blemishes which would interfere with their intended use
- All photography shall be taken when the area to be mapped is free of snow, before foliation, and at such time as to ensure a minimum solar angle of 30°, except upon written authorization to the contrary by the city

7) Camera.

- For topographic and contour mapping, photographs shall be exposed with a distortion-free 6-in- (152-mm-) focal-length precision aerial mapping camera equipped with a between-the-lens element shutter to produce negatives 9 in × 9 in (23 cm × 23 cm)
- The engineer shall furnish the city with a precision camera calibration report for the camera to be used

18-11. Specifications

❖ The following is a sample set of detailed specifications for aerial photography (courtesy Ayres Associates, Inc.).

8) Contact prints.

- The contact prints from the vertical negatives shall be printed on double-weight semimatte paper of suitable contrast

9) Photo index.

- Photo indices shall be prepared by directly photographing, on safety base film at a convenient scale, the assembly of contact prints from all indexed and evaluated prints used
- The photo index shall carry a suitable title, scale, and north point

10) Ownership of negatives.

- All negatives shall become the property of the city and shall be delivered to the city upon completion of this contract, or may be stored indefinitely in the film library of the engineer at no added charge

18-12. Cost Estimating and Scheduling

- Cost estimating is an area of critical concern in the operation of any photogrammetric business, because if projects are let to contract that are underestimated, devastating financial results can ensue
- Material costs are directly related to the quantity of each photogrammetric product to be prepared, and the procedures for calculating these quantities are quite straightforward
- Similar procedures are used to estimate other materials, and thus these costs can usually be estimated with fair accuracy
- Overhead costs, which consist of salaries of administrative personnel, office and laboratory rental, electricity, water, heat, telephone, miscellaneous office supplies, etc., are also rather straightforward to determine
- Labor costs, which generally constitute the major expense on photogrammetric projects, are considerably more difficult to estimate accurately, and this presents the greatest challenge to the estimator

18-12. Cost Estimating and Scheduling

- Although estimates can be made of the number of hours needed to perform each task involved in photogrammetric procedures, there are many unforeseen circumstances that can cause the actual time expended to deviate significantly from the estimates
- The most realistic approach to estimating labor, therefore, is to rely on past experiences with projects of a similar nature
- Obviously, it then becomes very important to keep detailed records of the actual costs incurred on the individual items of all projects
- Because of significant variations of project complexities and rapidly changing cost factors, past records alone cannot be relied upon completely, and a good deal of intuition and subjective judgment is also necessary
  - ⇨ This can normally be obtained only through years of experience
- In estimating, it is easy to omit small items, but enough of these over time can accumulate to cause a significant loss of revenue
  - ⇨ Therefore, care must be exercised to prevent these omissions, and the use of checklists is a good way to handle this problem

18-12. Cost Estimating and Scheduling

- Once the total number of labor hours has been estimated for each phase of a project, schedules for completion of the various operations can be planned on the basis of the number of instruments and personnel available to do the work
- In addition to these factors, however, another important consideration is the amount of other work in progress and its status in relation to required completion dates
- To arrive at realistic schedules, additional time in excess of that actually needed to perform the work must be added to account for uncontrollable circumstances
- Every reasonable attempt should be made to accommodate clients with stringent scheduling needs
- In some cases, to meet critical new scheduling requirements and still adhere to delivery dates already agreed upon, it may be necessary to consider hiring additional staff and running more than one work shift
- Of course, the possibility of purchasing additional equipment also exists, but this should be done with caution and only when anticipated quantities of continued future work can justify the expenditures