PART IX: PHOTOGRAMMETRIC CONTROL SURVEYING

9.1.   Basic Concepts

Photogrammetry is the science of making measurements and maps from imagery. Generally this means from an aerial photograph. As it will be seen, it is essential that the imagery be tied to the datum on the ground in order to faithfully represent the reality on the ground. This means that field control is necessary to complete the photogrammetric process.

9.1.1. Camera Systems

The aerial camera is a precision image acquisition system. It is referred to as a metric camera because through the calibration process, the elements of interior orientation can be recreated. These elements include the focal length of the camera, the location of the fiducial marks and principal point, and the camera lens distortions. Modern aerial cameras have superb optical systems and are generally considered as distortion free in that the lens distortion values are generally lower than the uncertainty in the measurement of the distortion.

The camera is placed in a camera mount that is rigidly attached to the airframe of the aircraft. The mount has vibration isolators that absorb the vibration inherent of an aircraft in flight. Vibration will introduce blur on the image and reduce the interpretative qualities of the pictures. Moreover, mounts also have gimbal system that allows the photographer to accommodate for the pitch and yaw of the aircraft and compensate for the heading direction. Because of winds, the aircraft often must set the heading direction slightly into the cross-wind to maintain a constant flight direction. The difference between the heading direction and the actual flight direction is called the crab angle. The elimination of crab yields an image that is properly oriented with the direction of flight which is required for a photogrammetric mission.

Todays camera systems are highly automated and much more accurate. In addition, GPS can be tied to the camera so that the 3-dimensional coordinates of the exposure station can be measured very accurately. With the use of digital gyro mounts, the amount of crab, pitch and yaw can also be recorded. This gives the photogrammetrist all of the necessary elements of exterior orientation. Theoretically, this means that there is no further need for ground control. Despite this, control should still be used for checking purposes, as a minimum. As in all surveys, redundancy and checks need to be incorporated into a measurement system for quality control purposes.

9.1.2. Photographic Scale

Like a map, photography has scale. Unfortunately, the scale can vary over the photograph whereas the scale for a map is generally considered as constant. The camera represents a central projection in which all light rays from outside the camera come together within the lens and then are projected in focus onto the film behind the lens. The determination of the scale is based on simple geometric relationships. In figure 9.1 the ground is considered as generally level. The ground points A and B intersect the diapositive at points a and b. These lines pass through the lens and intersect the negative, again at a and b. The projection center is labeled as O which represents the exposure station in space at the instant of photography. The flying height of the camera is the distance from the ground to the exposure station, designated as H_A. The flying height above the datum is shown as H. The scale can be represented as

$$ S = \frac{ab}{AB} = \frac{f}{H - h} $$

Figure 9.1
Scale relationship over flat terrain.
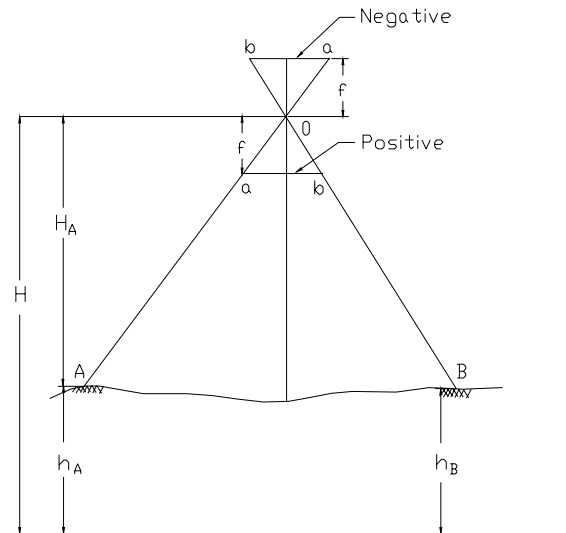
For example, if the focal length of the aerial camera is 6 inches and the flying height over flat terrain is 1640 feet, the scale becomes

$$S = \frac{6\ in}{1640\ ft} = \frac{1\ in}{273.33\ ft}$$

As a representative fraction, the scale is 1:273. Generally, this would be rounded off as 1:270.

Figure 9.2 shows the scale geometry when the terrain is not flat. Using the same relationship as above, assume that the elevation of A is 246 feet while the elevation at B is 82 feet. Then the scale for A becomes

$$S_A = \frac{6\ in}{1640\ ft\ -\ 246\ ft} = \frac{1\ in}{232\ ft} \approx \frac{1}{230}$$

Figure 9.2
Scale relationship over points at different elevations.
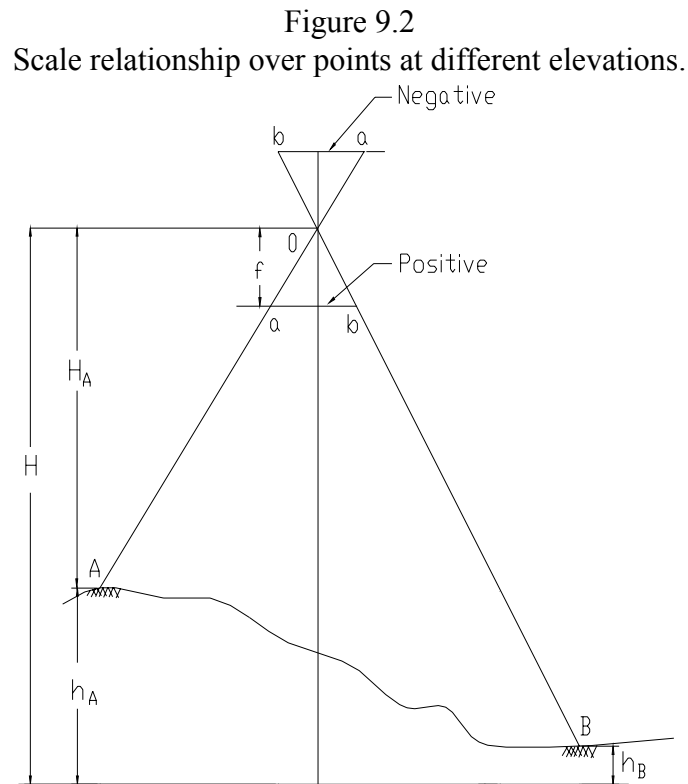
The scale at B is

$$S_B = \frac{6\ in}{1640\ ft - 82\ ft} = \frac{1\ in}{260\ ft} = \frac{1}{260}$$

This represents a difference in scale of about 10%. What this shows is that scale is dependent upon the elevation of the ground point, flying height of the aircraft, and focal length of the camera. Since the focal length and flying height are constant during an exposure, scale will change over the photograph based on the differences in elevation of the ground points. To assign a scale to a particular photograph, select an average elevation over the site that represents the terrain the best.

9.1.3. Flying Heights and Altitudes

As it has been shown, flying height is a major element in the determination of the scale of a photograph. By increasing the flying height, the picture will image more of the terrain. This makes the mapping more economical because fewer photographs mean that there is less time required to set up the stereomodels for mapping. The main drawback is that important terrain features may become so small so as not to be imaged on the photograph. This will defeat the purpose of the aerial photography. Therefore, the altitude of the camera needs to be carefully selected in order to optimize the coverage of the photography while still maintaining the image on the film. Very often, the photo scale is selected such that the smallest ground object that needs to be measured is imaged on the photograph. Another important criteria in selecting the scale will be the desired accuracy of the height measurements, if elevations are to be observed photogrammetrically.

There are three types of photo mission: High Level Aerial Photography (HLAP), Standard Aerial Photography (SAP), and Low Level Aerial Photography (LLAP). HLAP is generally flown for planning and project development with flying heights greater than 4900 feet. SAP is flown for road design with flying heights between 1400 and 3000 feet. LLAP is flown with a helicopter for very accurate mapping on busy highways with flying heights of 450 feet or less. Each of these types has different requirements for control.

9.1.4. Relief Displacement

Relief displacement is the apparent displacement of a point because of its position above or below the datum (figure 9.3). From the geometry, one can see that point A is imaged on the diapositive at "a" while the datum position, indicated as A' would be imaged at a' on the diapositive. The effect is a displacement of the image from the principal point, or center of the photograph, by an amount equal to

$$d = r - r'$$

The values for r and r' can be derived using the scale relationship. After some manipulation, the amount of relief displacement can be found to be

$$d = \frac{rh}{H}$$

where r is the radial distance from the principal point of the photograph,

h is the elevation of the point, and

H is the flying height above the datum.

This formula can also be used very effectively to determine the height of objects where both the base and top of a feature are imaged on the photograph. For example, assume that a communications tower was imaged on a photograph. The radial distance measured on the photograph to the top of the tower from the principal point was found to be 3.144 in while the radial distance to the bottom was

Figure 9.3
Relief displacement.
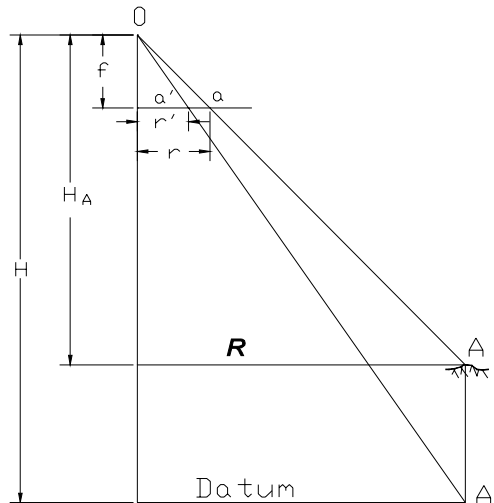
 measured as 2.824 in. The radial displacement is d = 3.144 in - 2.824 in = 0.320 in. Then the height of the tower can be found by re-arranging the formula for displacement as

$$h = \frac{dH}{r} = \frac{(0.320 \ in)(1640 \ ft)}{3.144 \ in} = 167 \ ft$$

9.5

9.1.5. Flying Lines and Photographic Overlap

When acquiring photography for a photogrammetric mission, the airplane will generally fly in a direction parallel to the side with the greatest length. Depending on the purpose of the photography, this flight line will be located such that a part of the imagery will acquire detail that is outside of the project area. This is to ensure that the whole site has been imaged completely. An example flight line with the location of the exposure stations is shown in figure 9.4. Note that exposures begin before the plane arrives on the site and continue beyond the site boundary. Again, this is to ensure that there is no area missing from the photography of the site. There is usually about a 15% overlap between imagery on adjacent flight lines.

The exposure stations are selected such that there is a minimum of 60% overlap between successive photos. The geometry of overlapping photography is shown in figure 9.5. The crosses are the principal points of each exposure. The hatched area is called the triple overlap area which results in a space where features within the image can be seen on three successive photographs. This is the area where the photogrammetrist usually picks control points for aerotriangulation. These control points, generally called pass points, are indicated by filled circles in figure 9.5. By choosing control in the triple overlap area, fewer control points are required which again reduces the cost of the mapping. The control on the edges of the strip are sometimes called wing points or tie points and they are designed to tie together adjacent strips of photography. Thus, one of the wing points could be imaged on 9 different photographs.

Figure 9.4
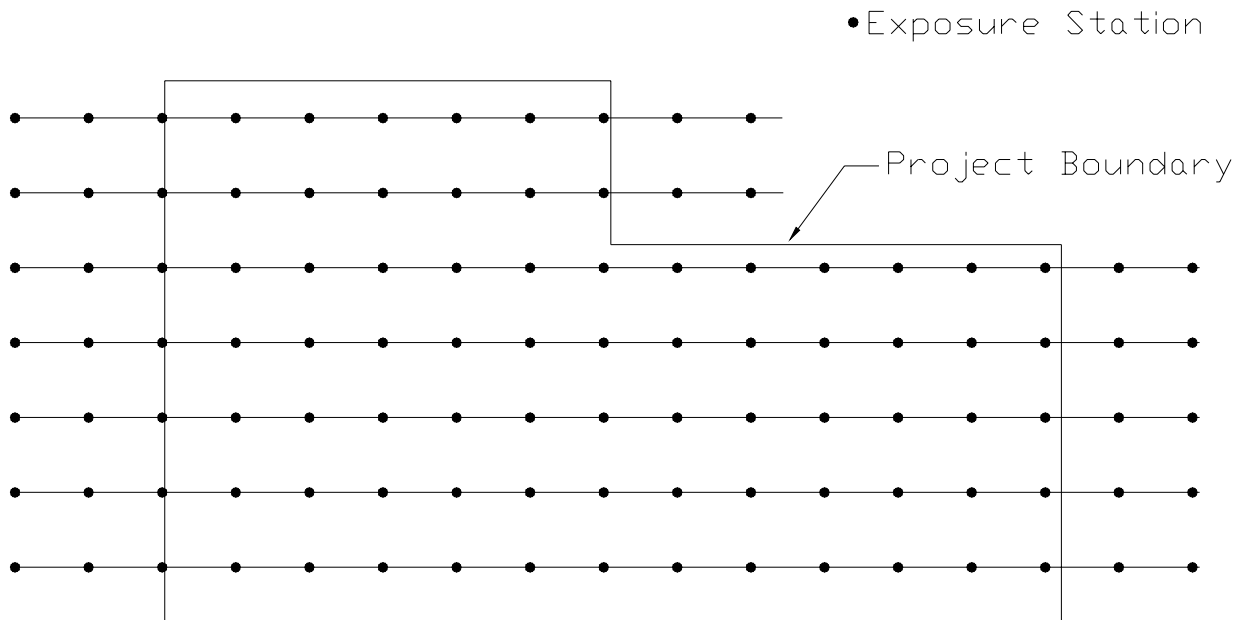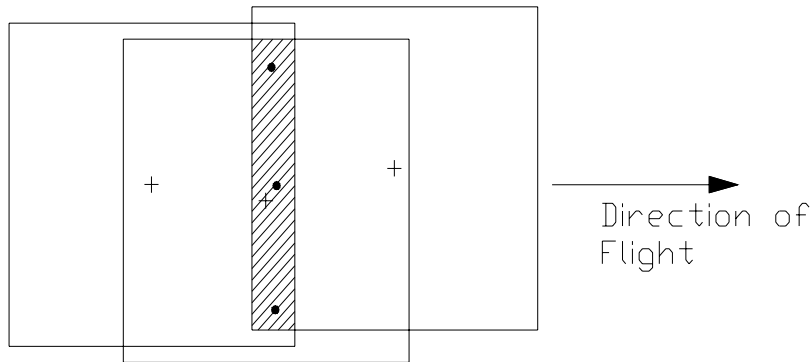Example flight plan showing exposure stations.

9.6

Figure 9.5
Geometry of overlapping photography.

9.1.6. Stereoscopic Viewing and Parallax

The power of photogrammetry lies in the fact that photographs are taken of the same scene from two different locations, see figure 9.6. This results in a stereo image. The distance between the two exposure stations is called the air base (B). H' is the flying height above the ground. Then, when viewing each photo individually, with the left eye viewing the left photo and the right eye the right photo, the photogrammetrist can see the image in three dimensions. This is a critical requirement for measuring height of a desired point. The two photographs are referred to as a model or stereoscopic model.

How far should the air base be? To be able to see stereo, all of the terrain needs to be viewed stereoscopically. Therefore, al least 50% of each photo needs to image the same terrain features. But 50% would mean that there is no room for error when flying. Thus, 60% overlap is usually the minimum requirement. In figure 9.7, the effects of sloping terrain on stereoscopic imagery are shown assuming that the pilot it maintaining a constant flying height above the datum. Eventually stereoscopic viewing is lost. Moreover, the amount of detail imaged on the photo also decreases thereby requiring more flight lines closer together. While this situation is kind of unique and easily solved for by proper planning, it does show that variations in the terrain, along with fluctuations in the aircraft altitude, can affect stereoscopic coverage. While this situation is kind of unique and easily solved for by proper planning, it does show that variations in the terrain, along with fluctuations in the aircraft altitude, can affect stereoscopic coverage.

One of the unique and advantageous outcomes of stereophotogrammetry is that the vertical scale is exaggerated when viewed by the observer. This allows for accurate determination of height by the

Figure 9.6
Air base and subsequent overlapping area on photography.

B

1   2

Direction of flight
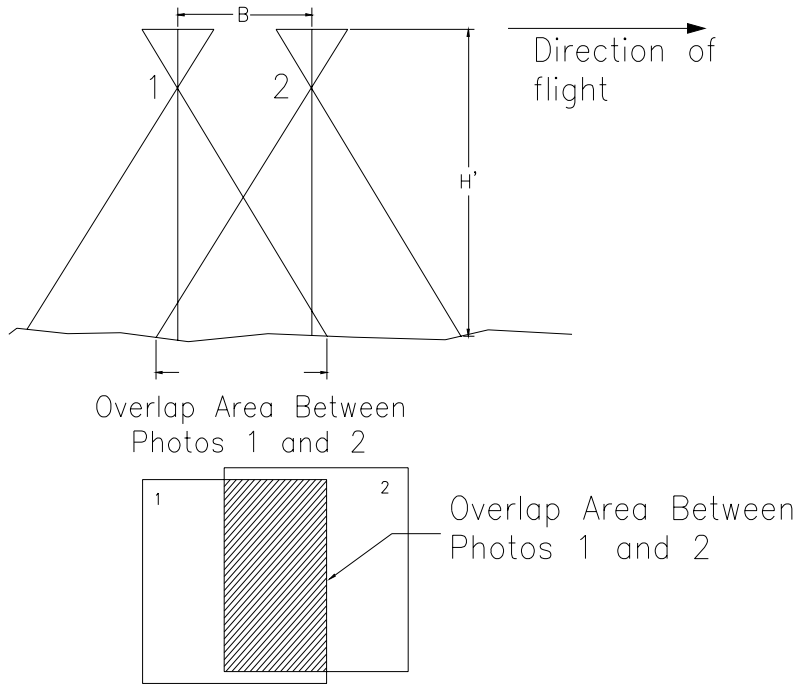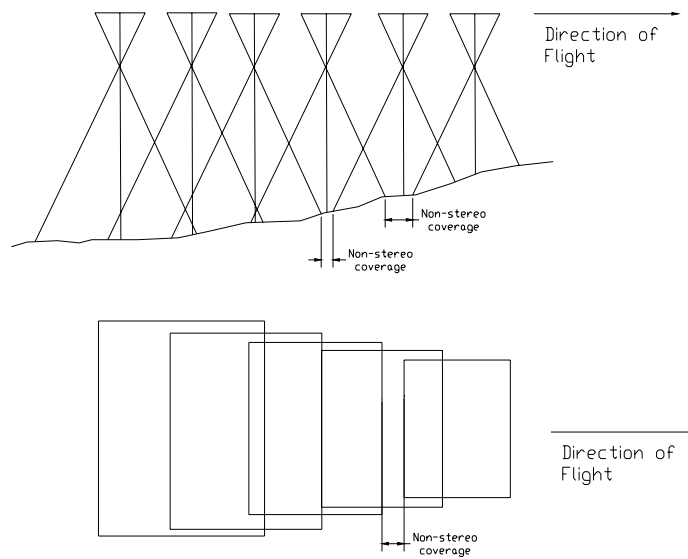
H'

Overlap Area Between
Photos 1 and 2

1   2

Overlap Area Between
Photos 1 and 2

Figure 9.7
Effect of terrain on stereoscopic imagery.

Direction of
Flight

Non-stereo
coverage

Non-stereo
coverage

Direction of
Flight

Non-stereo
coverage

photogrammetrist. Increasing the flying height will decrease the amount of vertical exaggeration. Again, if we look at our snapshots taken during our last vacation, far away objects appear flat on the image. By increasing the air base, vertical exaggeration is increased. But, there is a physical limitation here in that if the base increases too much, stereoscopic coverage is lost.

Parallax is a geometric property that affects stereoscopic viewing. Parallax is basically the difference in the location of a point on two subsequent photographs. In other words, the object will not appear in the exact same location on the two photos. This makes a lot of sense when we consider that the aircraft has moved during the two exposures. There are two components of parallax. x-parallax is the difference in the position in the x-direction or direction of flight. This component is critical in the determination of height. In fact, there is a direct correlation between the amount of x-parallax in two images and the elevation of a point. The second component is y-parallax and this is in a direction perpendicular to the flight direction. If y-parallax exists, stereoscopic viewing is not possible. Tilt in the photography is the biggest culprit in introducing y-parallax. Therefore, a critical function of the photogrammetrist is to eliminate the y-parallax within the model.

9.1.7. Photogrammetric Mapping

The creation of a line map requires sophisticated, specialized instruments called stereo plotters. It is within these plotters that three dimensional models are formed and then measurements made in that model. Throughout history, many different approaches have been used to accomplish this task, from optical projection of the film diapositive to mechanical reconstruction of the model to the numeric solution of the orientation task. This latter approach is the predominant form used today.

The process of setting up a stereoplotter for mapping requires three steps. The first is called interior orientation. The purpose of interior orientation is to recreate the geometry of the taking camera. Think of the process this way. Take two cameras out in the field and take a picture of the same area with both separated by a defined distance (air base). The axes of both cameras are parallel to one another. Lets further assume that a slide is taken much like a Polaroid picture (in other words, the film does not have to be removed for processing). Then, take the two cameras and mount them onto a stereoplotter. When the light hits the film and is projected through the lens, it would negate the distortion of the image that comes when the light travels from the terrain through the lens and onto the film. But it is impractical to have a bunch of cameras like this. Therefore, the projectors where we will place our film need to be adjusted so that they mimic the distortion of the taking camera. This process can be performed numerically on analytical and digital or softcopy plotters

Once the interior orientation is performed, the stereoplotter operator needs to complete relative orientation. Here, the same relative angular relationship that existed between the two successive exposures are recreated within the stereoplotter. This is done by methodically eliminating the y-parallax that is present within the stereomodel. This can also be described as determining the

differences in the pitch, yaw and crab between successive exposures and putting these differences in the stereoplotter. Once the relative orientation is completed, the operator is able to view the model in stereo. Again, with modern plotters, this orientation can be performed numerically since there exists a mathematical relationship between y-parallax and these orientation angles.

The stereoscopic model created after relative orientation is not referenced to any survey system. In other words, the model is created in space. Our map, on the other hand, requires fitting the orientation to the ground. In photogrammetry, this process is called absolute orientation because it brings the model datum parallel to the ground datum. This is also the place where scale is applied to the mapping process by assigning the proper coordinates to the control for the photogrammetric process. Figure 9.8 shows the model that needs to be fitted to the datum defined by the table surface of the stereoplotter (only the view from the side showing the model to be too high in front. The table is where the map is made. Thus, absolute orientation involves rotating the model so that the model datum coincides with the map datum defined by the table surface.

There are a wide array of stereoplotters available to the photogrammetrist. A simple approach is by optical projection (this is shown in figure 9.8). This is similar to the situation when viewing a slide show. The diapositive are illuminated and the latent images are directed to a surface for viewing. The only difference, though, is that two images are projected instead of one in a slide show. To separate the images such that only one eye sees the appropriate image, some sort of viewing device is required. A simple method is anaglyphic viewing that operates like some of the older 3-D movies where red and blue lenses are used in a pair of glasses. More advanced systems use polaroid filters to achieve the same effect. This approach is used with many of the softcopy plotters except that the polarization is performed electronically.

Figure 9.8
Leveling of a projection plotter. This represents the side view (Ω rotation).

Before   After
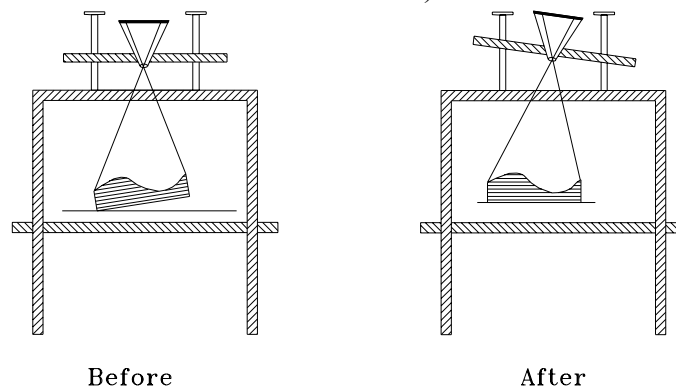
Mechanical stereoplotters perform in a similar manner except that the model is constructed using mechanics instead of projection of the image onto a surface. Here the viewing system is performed through an optical train. Both mechanical and optical projection plotters are referred to as analog plotters. These instruments require the operator to introduce angular changes to the projectors for the relative and absolute orientation. Analog plotters are still occasionally used but are now interfaced with computers to help expedite the orientation process. The orientation, though, is still done manually.

Analytical and digital stereoplotters are the most common types of instruments used today. They depend upon a numerical solution to the orientation processes. The difference between these two types of plotters is digital plotters utilize digital images instead of diapositives. They are also capable of performing extended operations that are not available to analytical plotters, namely the creation of digital orthophotos, automatic aerotriangulation, and image correlation. While digital plotters offer more flexibility, they do have some loss in resolution of the imagery because they are scanned.

The newest technology used in photogrammetry is softcopy photogrammetry (referred to as digital photogrammetry in Europe). It involves using digital imagery with digital viewing systems, such as a digital stereoplotter. Softcopy is changing the world of mapping. The production of orthophotography, aerial triangulation, and DEM (digital elevation model) extraction are being used in the production environment by some companies.

Taken to its theoretical limit, softcopy photogrammetry will automate the mapping process. This should significantly increase productivity and reliability. But, since this is a technology at its infancy, there is still a lot of development necessary before the full benefits of softcopy are realized. One of the reasons is that the process mimics the conventional process currently being used in mapping. For example the images, for the most part, still have to be obtained using conventional photography.

Being a digital mapping system, one of the first tasks of the photogrammetrist is to create the digital data. As of now, digital cameras for aerial photography have not met the expectations of the industry. From satellite imagery, we know they work but the resolution is such that film is still the perferred method of data collection. Once the film has been processed, it needs to be scanned. This can be done using two different types of scanners: flat-bed or drum scanners (see figure 9.9). Generally, the flat-bed scanner offers higher accuracy and stability in the scanning process.

When the photo is scanned the resultant image is composed of an array or raster of picture elements called pixels or cells. The size of these cells gives us the resolution of the image. Figure 9.10 shows

Figure 9.9
Methods of scanning.
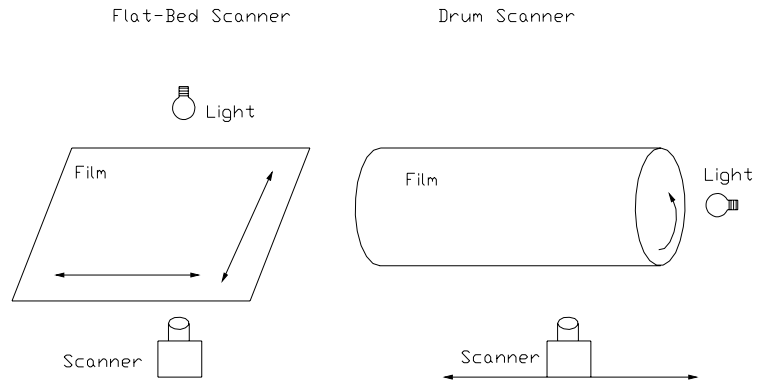
the effects of creating a raster image containing a straight line such as a road. On the left size, the cells

Figure 9.10
Creating a raster image from vectorized data.
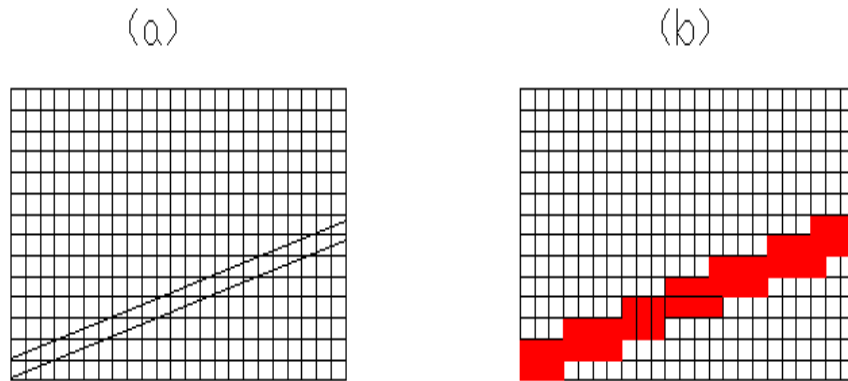
are overlaid the straight line. Then, let each pixel containing the line be classified as a road. The right hand side depicts the result of this process. You will note that the road has a step-like structure. If the pixels are smaller then the effects are lessened, but the storage of the data increases.

How the pixels are created depends on the scanner being used. With the flat-bed scanner, the photo is placed in a plate carrier and a light is illuminated from above. Below is the actual scanner which measures the amount of energy received after the light has passed through the film. A digital number (DN) is then assigned that pixel. With the flat-bed scanners, the film moves first along a row before moving to the next row. The drum scanner operates in a similar fashion, except that the drum rotates. Once the sensor has captures a line of data, it moves longitudinally to the next line.

Increasing the resolution of a digital image results in a corresponding increase in the file size. Table 9.1 shows the size of a neat model for different scan rates. A neat model is a part of the overlap area between two successive photos that are usable for mapping. The edges of the photo are usually not usable because distortions can become larger the farther away from the center of the photo. In this case, a model of 7.2 inches by 6.3 inches is used. The latter value is in the direction of flight while the 7.2 inches is the width of the coverage. The values in table 9.1 are valid for uncompressed black and white imagery. Color photography would be three times larger. Table 9.2 shows the pixel size in ground units for different photo scales and the same scan sample rates. Note that the pixel sizes are in inches except for the last photo scale of 1": 1 mile which is in feet.

Table 9.1
Neat model size for different scan rates.

Scan Sample Rate								
micrometers	7.5	15	22.5	30	45	60	90	120
dots per inch	3386	1693	1128	846	564	423	282	211
File Size in megabytes	496	124	55	31	14	7.7	3.4	1.9

Table 9.2
Scan sample rates for different photo scales.

	Scan Sample Rate in micrometers							
Photo Scale	7.5	15	22.5	30	45	60	90	120
1" = 200'	0.7"	1.4"	2.1"	2.8"	4.2"	5.7"	8.5"	11.3"
1" = 300'	1.1"	2.1"	3.2"	4.3"	6.4"	8.5"	12.7"	17.0"
1" = 400'	1.4"	2.8"	4.3"	5.7"	8.5"	11.3"	17.0"	22.7"
1" = 500'	1.8"	3.5"	5.3"	7.1"	10.6"	19.2"	21.2"	28.3
1" = 800'	2.8"	5.7"	8.5"	11.3"	17.0"	22.7"	34.0"	45.3"
1" = 1000'	3.5"	7.1"	10.6"	14.2"	21.3"	28.4"	42.5"	56.7"
1" = 4000'	14.2"	28.3"	42.5"	56.7"	85.0"	113.4"	170.1"	226.8"
1" = 63360 (1" = 1 mile)	1.6'	3.1'	4.7'	6.2'	9.4'	12.5'	18.7'	24.9'

9.1.8. Orthophotos

The effect of relief displacement on a photograph is to tilt features away from the principal point or center of the photo. This problem makes the photograph inappropriate for use as a map, except under very special conditions. But many people cannot read maps and more are slow at assimilating the information displayed on them. The reason is simple: maps use symbols to identify features and they are difficult to differentiate. Therefore, photography offers a lot in interpretative value for many users.

Tilt in the photography has been something that can be easily taken out of a photograph using a rectifier. Unfortunately, relief displacement will still be present.

Recall that relief displacement is an error due to the point being above or below the datum. Therefore, if the elevation can be corrected, relief displacement can be eliminated. From this idea, the concept of differential rectification, or orthophotography, was born. Very simply, the orthoprojector would rectify small segments of the photograph, something like tens of micrometers at a time. To accommodate the elevation error, the projector, as an example, would move up or down to account for the changes in the elevation of the ground point. In the past, this was done by running a series of profiles on the model within a stereoplotter. Once the profiles were recorded, the orthophoto would be produced in an orthoprojector. As the exposure of the orthophoto was made, strip by strip, the profile reader would read the profile and adjust the distance between the projector and the film.

With softcopy photogrammetry, this process is much simpler. With the digital image and file of elevations for the sites, such as a DEM, the production of a digital orthophoto can be made without the need of a highly skilled photogrammetric technician. The downside to this though is the heavy reliance on third-party DEM data. This is a problem primarily because of how the DEM was captured. For example, if elevation data is found for nodes on a grid pattern, important elevation changes between the nodes may leave out significant geomorphological data.

The creation of a digital orthophoto brings with it competing issues. These include accuracy, quality, cost, and the hardware/software display and manipulation capabilities. Image quality is dependent upon a number of production components such as:

- camera quality
- photo to orthophoto map scale magnification
- orthophoto diapositive density range or bits in the scanner scan pixel
- sample scan rate in micrometers or dots per inch (dpi) and the photo scale
- rectification procedures
- final pixel size in ground units

- electronic auto-dodging or radiometric image smoothing after the rectification process
- selection of control points
- DEM data density

The accuracy of the digital orthophoto is a function of:

- magnification
- geometric accuracy of the scanner
- quality of the DEM
- control
- focal length of the taking camera

One of the most abused aspects of digital data on the computer is the use of scale or magnification. Computers have the ability to zoom in or out very simply. This may give the user a false sense of the accuracy of the map product. As an example, field measurements may be taken of features with one meter positioning capabilities, such as with "resource-grade" global positioning system (GPS) receivers. But in the computer, these positions could be displayed at the millimeter level, as an example. Clearly, displaying data at this range is inappropriate for data collected at the "coarse" meter range. The same applies to orthophoto imagery. Remember that the farther the camera is away from the ground, there is a loss of detail in the features imaged on the photo. For example, a manhole might not be imaged on the photo because it is too small at the scale in which the photography was taken.

Magnification also affects the image quality. The recommended magnification range is 8 or 9 times enlargement. Magnification of ten times or more will degrade the image quality because the distance between the silver crystals on the film become noticeable. Below five times enlargement does not noticeably improve the image quality. Therefore, a range of 5-9 times enlargement is the optimum range, depending upon the area being mapped. This means that if the desired final ortho scale is 1" = 100' then the photo scale should not be less than 1" = 900'. Note that this would be for optimum terrain. Larger photo scales, such as 1" = 700', may be required to meet the needs of the client.

Image quality is also affected by the resolution of the scanner. Earlier the concept of the pixel was introduced and it was shown that the coarser the resolution (larger the pixel size), the more "step-like" lines and features become. The important issue is the relationship between the size of the scan pixel to the scale of the photography and the desired output ortho scale. One suggestion is to scan the photo at about 240 dpi for each magnification range. This means that if the desired photo to final orthophoto magnification range is 5 times, then the photo should be scanned at 5 x 240 = 1200 dpi as a minimum. This represents a pixel size of approximately 20 micrometers at the photo scale. Taking the magnification recommendation to its limit of 9 times yields a sampling rate of 2160 dpi with a pixel

size of roughly 12 micrometers.

Another issue affecting image quality is the pixel size expressed in ground units. This is frequently performed by resampling the pixel values to create a smoother image in terms of it tone. When this is done, the preference will be to sample to a coarser resolution, such as sampling at half a foot and resample to the foot level. As a rule of thumb, a 1.2 times or larger factor should be applied to the scanned pixel. For example, using this factor to a one-foot scan, the final orthophoto would have at least a 1.2' pixel size.

The accuracy of the orthophoto is dependent upon two primary factors: control and DEM accuracy. Survey control is required to fix the map to the ground. As it will be discussed later, photogrammetrist use aerotriangulation to provide control between the primary ground control on a project. In some instances, control for the orthophoto is derived from existing maps of the area. Significant errors can be introduced into the process thereby degrading the orthophoto. For large scale mapping, ground targets that will be imaged on the photo should be used. The control needs to meet the specifications for the mapping.

DEM accuracy is also critical to the final quality of the orthophoto. The appropriate DEM must be selected to match the scale of the orthophoto, terrain conditions, focal length of the camera used to acquire the photography, and the magnification. The sampling interval for collecting the elevation data depends upon the terrain conditions. Where the ground is relatively flat, a coarser DEM can be used. On the other hand, if there is a lot of elevation changes in the area, a denser sampling rate is required. For large scale mapping, it is important to also include break lines in the data collection. A break line is where the terrain changes direction in slope, such as the bottom or toe of a hill. These break lines control the modeling of the terrain and fixes the placement of contour lines on the site.

The effect of a DEM on the accuracy of the orthophoto can be shown by the following example. Assume that the map is to meet National Map Accuracy Standards. Then, the shift in the placement of well defined points should not exceed 1/50" at the map scale. Therefore, for a map at a scale of 1" = 100' (1:1200), the maximum shift that should occur is 2' at the ground scale. This is found from the formula (1/50" x 100'/1") = 2'. Then, if the aerial camera has a 6" focal length lens, using basic trigonometry, a 22.5" error in the DEM would bring about a 2' error in the extreme edge of a 9" x 9" format aerial photo. Since only the neat model area is used in mapping, and using the dimension of 6.3" x 7.2" for the neat model, then the DEM can be in error by 30" at the extremity of the neat model and still fall within the 1/50" criteria. It can be seen that the closer to the center, the greater the tolerance. The formula for computing the errors in digital orthophotos can be expressed as:

$$e_{Ortho} = e_{DEM} \times \tan A$$

9.16

where: e_{Ortho} = error in digital orthophoto,

e_{DEM} = error in the digital elevation model, and

A = viewing angle in degrees outward from the center of the photo.

Another factor to consider in DEM accuracy is the magnification ratio and the density of the DEM. Generally, the density of the DEM needs to be denser with smaller magnification ratios. As a rule of thumb, if the magnification is less than 3 times then the spacing for the DEM needs to be $\frac{3}{16}$ - $\frac{5}{16}$ in at the final map scale. If the magnification is 3-8 times, then the spacing at the final map scale should be $\frac{5}{16}$ - $\frac{5}{8}$ in. Over 8 times magnification allows a grid spacing of $\frac{1}{2}$ -1 in at the final map scale. The operator needs to be aware that the density is greater when the terrain changes rapidly on the site and can be relaxed or spread farther when the terrain is flat.

Problems with digital orthophotos that need to be looked at include:

- *Image Completeness* - The image area is not adequately covered by DEM resulting in an inaccurate orthophoto

- *Image Stretch (Blurring)* - This is typically caused by anomalies within the DEM data resulting in a spike or large error. Excessive relief on the edge of the photography can also be the cause of this problem.

- *Double Image* - This is when the adjacent orthophotos are compared and the same feature is mapped on both photos when this should not occur. In other words, the maps should be mutually exclusive. The problem may be either improper orientation in the control or less accuracy in the DEM where ground elevations are given that are larger than the reality.

- *Missing Image* - The causes of this error are the same as the double image except that the DEM gives elevations lower than the real ground values. This error is hard to detect but is clearly evident when looking at linear features where sections may be missing.

- *Inaccurate Planimetry* - If the planimetric position of the pixels are in error, look at the control by comparing the visible control on the orthophoto and the photogrammetric control used to control the project.

9.2.   Ground Control

Ground control is necessary to fix the photography to the ground. It not only fixes the scale for the photogrammetric mapping, it also is necessary to ensure that the model formed in the stereoplotter and the subsequent mapped data are references to the datum for that particular site. Ground control surveys can be done using either conventional ground techniques or using GPS. For large sites, GPS is the more economical and accurate method. While it is true that theoretically it is possible to perform photogrammetric mapping without any field control, this practice should not be used except with the support of the Photogrammetry Unit. The lack of control removes the independent check that is essential for quality control and quality assurance purposes.

9.2.1.   Control Point Identification

Occasionally a project is flown before targeting can take place. In this case, photo identifiable points are used to control the photography. Photo identifiable points often called "pick points" are images on the photographs that are used in place of targets such as sidewalk corners, intersections of painted parking lot lines, and paved drive corners. Prior to establishing control on these points a Photogrammetry Unit representative will meet with the survey crew to identify each pick point on the ground. This insures that the point is acceptable for photogrammetric control and suitable for occupation by the survey crew.

For horizontal control, these control points should be clearly identifiable both on the photograph and on the ground. The point should be well-defined with sharp contrast between the feature and the surrounding area. A good quality vertical control point is one whose elevation is higher than the surrounding area. Again, it needs to be identifiable on both the terrain and photography.

9.2.2.   Target Configuration

Targeting before a project is flown is the preferred method of establishing photo control points. The survey crew will be supplied with a targeting diagram showing the locations of the desired targets. The paneling diagram will also indicate the maximum distance a target can be moved from its desired location. Targets located on pavement shall be painted using yellow traffic marking paint and outlined with black driveway sealer or black paint. The dimensions and configurations for targets shown in figures **9.11**, **9.12**, and **9.13** will be used unless otherwise specified in the project scope. For targets in non-paved areas, cloth panels shall be used (contact the Photogrammetry Unit for information on where to obtain said material). Painted targets should have mag-nails places at the proper locations indicated in figures 9.11 - 9.13. For paneled targets, a #4 or larger 18 inch long reinforcing rod should be placed at the center of the target set flush with the target material. The paneled target shall be witnessed as an intermediate control point so that if the panel is removed the point can be easily recovered. No witnesses are required for painted targets.

When determining where to place a target the following guidelines shall be followed:

- Place targets as close to the position indicted on the targeting diagram as possible. Follow the diagrams instructions on the maximum distance a point can be moved from its desired location.

- Place targets in the safest position possible away from traffic. The point will have to be occupied later to obtain the coordinates and elevation. On limited access highways, keep the targets in the paved shoulder of the roadway with the chevron painted to the outside edge. This is primarily a tripod placement issue for subsequent occupations. If the chevron is pointed towards the traveled portion of the road then tripod legs may be in the roadway creating a safety issue for the control surveyors.

- Place the target where there are not obstructions (trees and buildings) to the sky. This insures that the target will be visible on the photograph and that GPS can be observed at that point. A rule of thumb is that if a point is unacceptable for GPS observations then it will be unacceptable for photogrammetry.

- Place targets outside of shadows. Targets inside shadows generally do not show up on a photograph.

- Targets must be placed in flat areas. If a target is placed on sloping terrain then it may be either partially or totally obscured in photography that is not perpendicular to the sloping terrain.

- Try to place painted targets where they will not be an eyesore to the public.

- Contact land owners before placing targets on their property.

- Do not place targets where they will inconvenience the land owner; for example, in the middle of a plowed field.

- Place targets in areas where they will not be disturbed.

Once targets are in place, contact the Design Survey Office so that the area can be flown. A new targeting diagram should be returned to the Design Survey Office showing the actual target locations.

9.2.3. Target Replacement and Use of Substitute Points

If a target has been destroyed, replace the target at the desired location identified in the targeting diagram. If the survey crew sees that this location is not suited for target placement and if the offset distance to an acceptable location exceeds the specifications in the targeting diagram, contact the Photogrammetry Unit for possible alternative locations of that control point.

9.2.4. Specifications for Vertical and Horizontal Accuracy

The control required for photogrammetry will be marked on the even numbered photos. The points indicated by 600 series numbers are full control (xyz) and those indicated by 500 series numbers are vertical control (z). Coordinates shall be obtained using the standards identified for Intermediate Control with the following additions:

1. Leveling for Standard Aerial Photography (SAP) is considered intermediate control and shall meet unadjusted closures of 0.06 feet times the square root of the distance leveled in miles between known bench marks.

2. Leveling for Low Level Aerial Photography (LLAP) shall meet unadjusted closures of 0.04 feet times the square root of the distance leveled in miles between known bench marks. At a minimum, LLAP leveling shall use as control two published second order bench marks, which are on the same datum.

3. Targets will be occupied and be part of a closed level loop.

4. GPS elevations can be used for High Level Aerial Photography (HLAP) if the standards for intermediate control by GPS are followed and the resulting elevations are better than +/- 0.26 foot from actual.

5. All aerial targets that lie within 300 feet of the intermediate vertical control level run shall be leveled to and included in the adjustment.

6. Elevations can be transferred to targets on SAP and LLAP projects by GPS if the following procedure is followed:

9.20

a. Level to at least 40 percent of the targets throughout the project.

b. Hold 10 percent of the leveled points, distributed evenly throughout the project, fixed in a least squares adjustment.

c. Compare the GPS elevations and the remaining leveled elevations. If the two elevations for each point agree within 0.07 feet, then GPS elevations can be used. If the difference is greater than this, then all targets must be leveled too. This comparison must be shown in the Photo Control Notes.

d. Hold fixed all leveled elevations in the final least squares adjustment.

7. Elevations on cloth panel targets should be taken to the surface of the target, not on the point (which could be centimeters below the target material.)

8. When using GPS to obtain horizontal coordinates, neighboring targets (targets on the same photograph) shall be occupied simultaneously.

9. If occupation of the point is impractical for safety reasons or "pick points" are involved, such as poles or trees, the point must be tied from two or more control points.

9.3.   Deliverables

Data Required to be Submitted for Photo Control:

Hard copy format data:

*   Everything required for Intermediate Control as previously stated in the standards.
*   ASCII file listing of target coordinates in the following format:

| 501 | 0 | 0 | z.coordinate | **xy** std. dev. | **z** std. dev. |
| 601 | x.coordinate | y.coordinate | z.coordinate | **xy** std. dev. | **z** std. dev. |

Digital format data:

*   Everything required for Intermediate Control as previously stated in the standards.

- ASCII file listing of target coordinates in the following format:

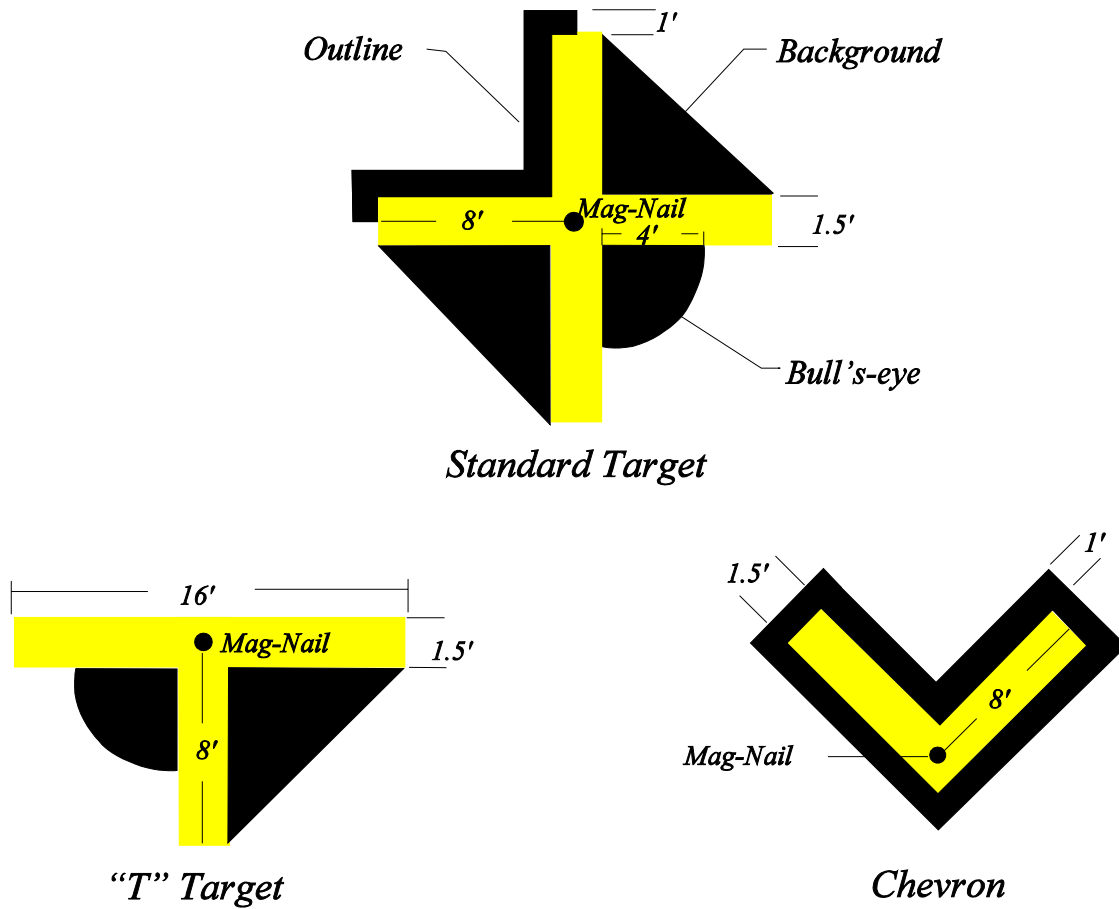| 501 | 0 | 0 | z.coordinate | **xy** std. dev. | **z** std. dev. |
| 601 | x.coordinate | y.coordinate | z.coordinate | **xy** std. dev. | **z** std. dev. |

Figure 9.11

Standard Aerial Photography Targets

Standard Target

"T" Target

Chevron
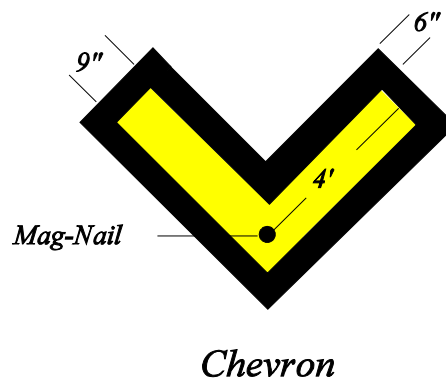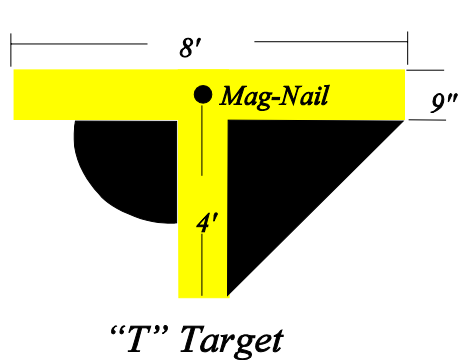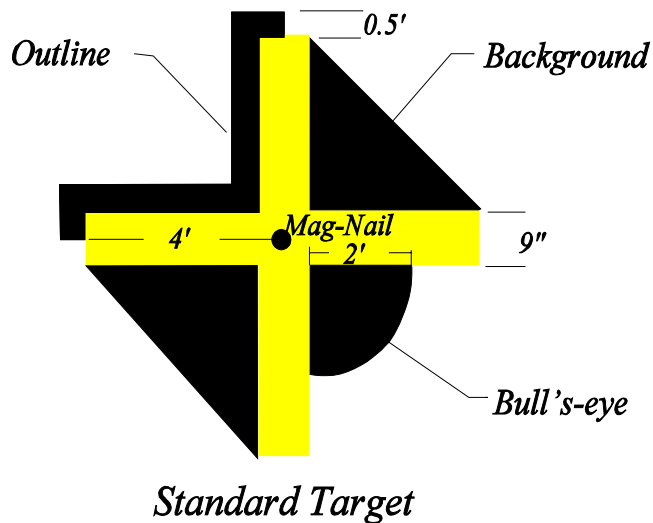
All painted targets must be highlighted in black by one of the following methods:
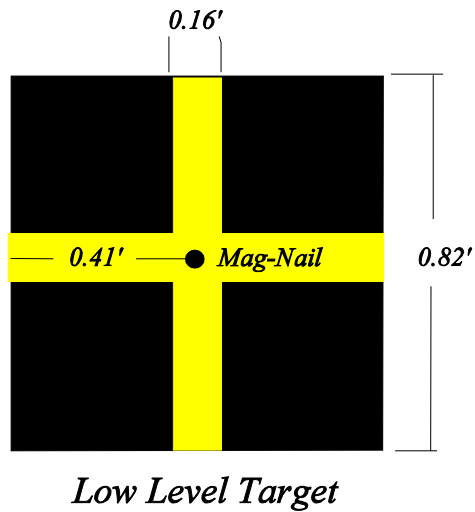
- Background
- Outline
- Bull's-eye

9.23

Figure 9.12

High Level Aerial Photography Targets

Outline

Background

1'

Mag-Nail

8'

1.5'

4'

Bull's-eye

Standard Target

16'

Mag-Nail

1.5'

8'

"T" Target

1.5'

1'

Mag-Nail

8'

Chevron

All painted targets must be highlighted in black by one of the following methods:

1.Background

2.Outline

3.Bull's-eye

Figure 9.13

Low Level Aerial Photography Targets

Low Level Target

Low Level target must have the square black outline shown.