Section VII

Photogrammetric Surveys

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VII. Photogrammetric Surveys

A. General

Photogrammetry can be defined as the science of making reliable measurements using photographs or digital photo imagery to locate features on or above the surface of the earth. The end result produces the coordinate (X, Y, and Z) position of a particular point, planimetric feature, or 3-D graphic representation of the terrain.

Photogrammetry has evolved into a reliable substitution of ground surveying activities when large area mapping is necessary. It can relieve survey crews of the most tedious, time consuming tasks required to produce topographic maps and Digital Terrain Models (DTMs). Ground survey methods will always remain an ***indispensable*** part of Photogrammetry and are not replaceable by the photogrammetric process.

WYDOT’s Photogrammetry Unit compiles or obtains terrain and planimetric data, then converts it into useful information for various WYDOT programs. That information includes but is not limited to ortho rectified imagery, topographic mapping, digital terrain models, 3-D point clouds, and various other mapping related tasks used for engineering and design purposes. The data may be obtained through ground survey methods, lidar terrestrial scanning methods, photogrammetric methods, or a combination of the three to produce a complete and accurate representation of the topography as it exists.

Increased information of existing terrain conditions allows designers the ability to explore alternative alignments without the need to collect additional field information. Surveys collected photogrammetrically, have both advantages and disadvantages when compared with ground surveys.

1. Photogrammetric Advantages

- Aerial imagery provides a permanent record of the conditions as they existed at the time the photograph was taken.
- The imagery can be used to convey information to the general public, local, state or federal agencies, and other WYDOT programs.
- Terrain data and mapping features can be extracted from stereo image models with little effort and at a low cost.
- Large area mapping and digital terrain models can be accomplished quicker and at a lower cost when compared to ground survey methods.
- Photogrammetry can be used in locations that are difficult or impossible to access from the ground.
- If information must be re-surveyed or re-evaluated, it is not necessary to perform expensive field work. The image stereo model can be re-loaded and measurements verified and/or additional information compiled in a timely manner.

2. Photogrammetric Disadvantages

- Seasonal weather patterns that produce increased wind and cloud cover may hamper the ability to perform the mission.
- Solar conditions such as sun angles less than 30° above the horizon will cast long shadows. Sun angles greater than 45° will produce sun spots on the image.
- It may be difficult or impossible to collect measurements in areas with dark shadows, dense vegetation, snow, water, or overhanging features.

B. Photography

1. General

This section discusses the equipment, materials, and methods used to obtain the imagery taken from WYDOT's Photogrammetry aircraft. It will also provide a summary review of the software used in mission planning, flight management, and image post processing to produce high resolution panchromatic, color, and color near infrared 12 bit imagery. The imagery is used to create engineering grade mapping and terrain files for planning and design activities.

2. Photograph Collection

a. Aircraft

The Department's aircraft used to flying aerial photo missions is a Cessna Caravan 208. It has an approximate maximum flying altitude of 25,000 ft. and a maximum air speed of 175 knots (200 mph). The aircraft is based out of Cheyenne and is maintained by WYDOT's Aeronautics Division. Due to the weather and ground conditions required to produce quality images, WYDOT has a pilot and digital mapping camera operator on staff to allow for the flexibility necessary in scheduling photo missions.

Image VII-1. WYDOT photography plane (208 Cessna Caravan)

The aircraft has been structurally and electrically modified to host our DMC, digital mapping camera, which is mounted on and through the belly of the aircraft. An electrically operated sliding door has been added to the exterior belly of the aircraft over the camera hole. This door was added to protect the lens from fly rock during takeoff and landings.

A heads-up display mounted to the instrument panel allows the pilot to navigate over the planned mission and communicate with the camera operator as the mission is being collected.

Image VII-2. Sliding door for lens protection

Image VII-3. Heads-up pilot display

b. Camera

In 2007, WYDOT purchased a Zeiss Digital Mapping Camera system to replace our existing film based system. The camera system is comprised of a DMC main camera assembly, gyro stabilization mount, integrated computer system, and solid state disk (SSD) for on-board data storage of images.

Image VII-4. WYDOT DMC (Digital Mapping Camera System)

The DMC also has an inertial measurement unit (IMU) to improve the onboard GPS solution and strengthen the aerial triangulation results during the bridging process. The Gyro stabilized mount removes the effects of vibration in the imagery during collection. The gyro mount also compensates for roll, pitch, and yaw of the aircraft so the principle and nadir points are relatively equal. An electronic forward motion compensator (FMC) removes blurriness resulting from the forward motion of the aircraft at the time of the exposure.

The DMC main camera has 8 individual cameras that are autonomous, 4 panchromatic, and 4 multispectral (red, green, blue, and near infrared). These cameras are able to produce images in black and white, colored, or colored near infrared with a 12 bit resolution. Each image is approximately 272 megabits and the SSD can store roughly 1000 images.

The camera focal length is 4.72” (120 mm), with a sensor dimension (also known as the negative in film cameras) of 3.63” x 6.53” (92.16 mm x 165.89 mm). A basic principle of the optics is that all light rays pass through the nodal point (center of the lens). Therefore, the center of the lens is the reference point for measuring the distance above ground. The basic geometric relationship shown in Figure VII-1 is that of similar triangles.

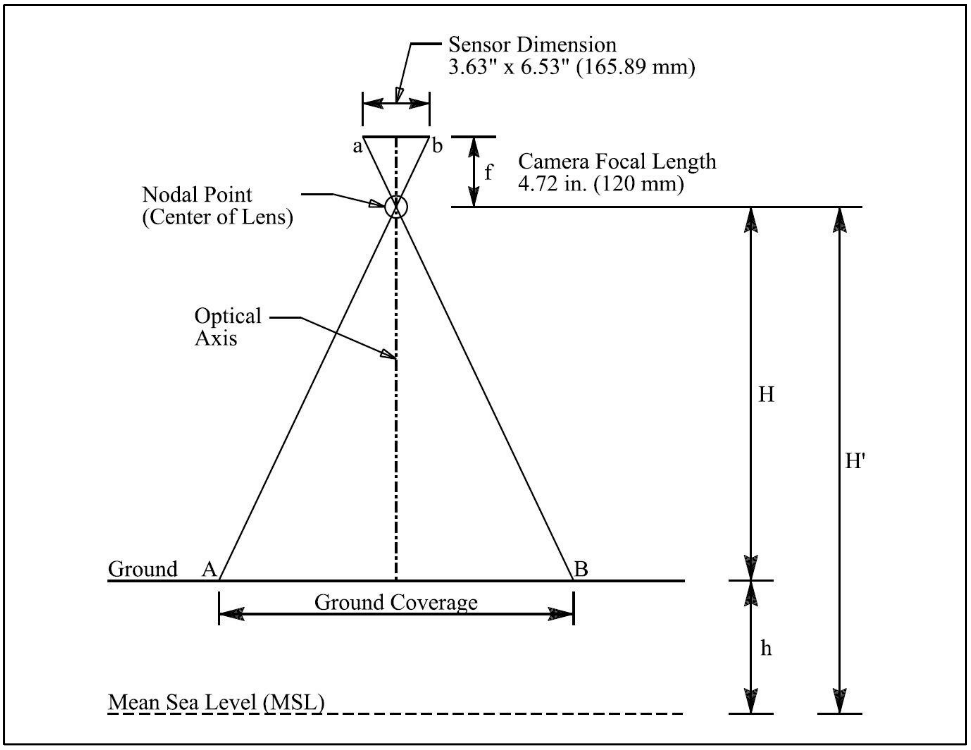


Figure VII-1. Theoretical camera exposure diagram.

Table VII-1 shows the relationship between flying heights, ground coverage, and resolution quality.

Project Type	Flight Height (ft)	Pixel Resolution (in/pixel)	Ground Coverage Along Flight Line	
			Length (ft)	Width (ft)
Urban Projects (plains)	1250	1.50	960	1728
Urban Projects (mountainous terrain)	1500	1.80	1152	2074
Suburban Projects	1800	2.16	1382	2488
Rural Projects (plains)	2000	2.40	1536	2765
Rural Projects (mountainous terrain)	2400	2.88	1843	3317
Systems	7075	8.49	5433	9779
High altitude city planning imagery	9500	11.40	7295	13131

Table VII-1. Image coverage.

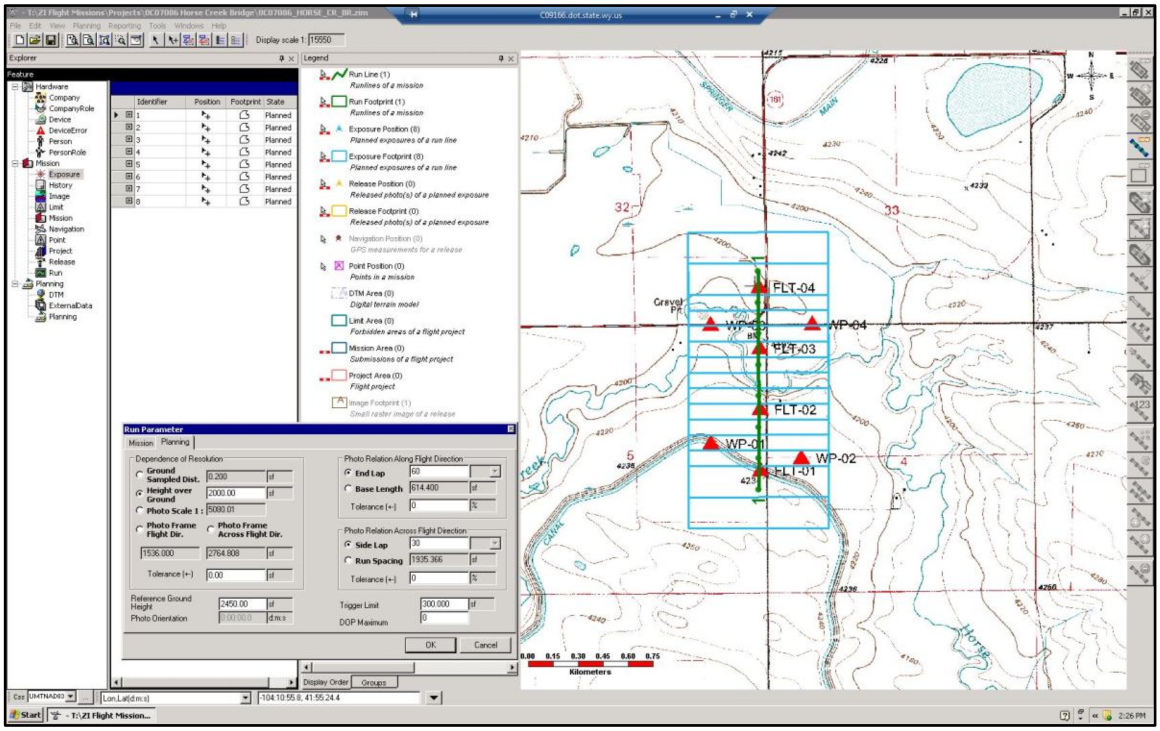
c. Mission Planning

Once the project limits and the type of project, rural or urban, have been identified, the appropriate flying height is determined to provide adequate photo coverage for mapping. The flying height determines the flight line target spacing to be physically laid out by the survey crew. Table VII-2 shows flying height, flight line and wing point target spacing and distances.

Project Type	Flight Height (ft)	Centerline Target Spacing (ft)	Approximate Wing Point Target Distance from mission flight line	
			Min. (ft)	Max. (ft)
Urban Projects (plains)	1250	770	575	650
Urban Projects (mountainous terrain)	1500	920	690	780
Suburban Projects	1800	1100	825	935
Rural Projects (plains)	2000	1230	920	1045
Rural Projects (mountainous terrain)	2400	1474	1105	1250

Table VII-2. Targeting spacing.

As the target locations are identified, geographic coordinates for each location are recorded for use in the mission planning software. Mission planning is conducted using Z/I Mission planning software. The mission example below shows some of the features of the planning software.



Identifier	Position	Footprint	State
1			Planned
2			Planned
3			Planned
4			Planned
5			Planned
6			Planned
7			Planned
8			Planned

Run Parameter

Mission | Planning

Dependence of Resolution
○ Ground Sampled Dist. 0.200 sf
● Height over Ground 2000.00 sf
○ Photo Scale 1 : 5080.01
○ Photo Frame Flight Dir. 1536.000
○ Photo Frame Across Flight Dir. 2764.808 sf
Tolerance (+-) 0.00 sf
Reference Ground Height 2450.00 sf
Photo Orientation 0:00:00.0 d:m:s

Photo Relation Along Flight Direction
● End Lap 60
○ Base Length 614.400 sf
Tolerance (+-) 0 %

Photo Relation Across Flight Direction
● Side Lap 30
○ Run Spacing 1935.366 sf
Tolerance (+-) 0 %
Trigger Limit 300.000 sf
DOP Maximum 0

Lon,Lat(d:m:s) -104:10:55.8, 41:55:24.4

Figure VII-2. Z/I Mission planning software.

The software offers the ability to import photo control onto a digital quad map of the project location. Flight run parameters such as terrain elevation, AG (above ground flying height), exposure overlap, and flight line trigger limit are then entered. The proposed beginning and end of each flight line are identified and accepted. The mission flight line exposures and exposure foot prints now appear to show coverage. At this point the flight lines and exposures can be edited if necessary.

When complete, the mission is exported to a Google Earth file for review to ensure the project limits are covered. Mission .apf or .afl output files are generated and then downloaded onto the camera flight navigation System, Z\I Inflight.

d. Flight Conditions

Obtaining imagery for mapping purposes depends on a multiple of factors that impact the quality of the image and thus the mapping compiled from it. Those factors include weather, ground, sun angle, and equipment. Fortunately, Wyoming has a long photographic season or "window of opportunity" to complete photo missions in a successful and timely manner.

(1) Weather & Ground

Weather and ground conditions in Wyoming are at times difficult to predict when coordinating targeting and photo mission activities. Prolonged mission delays require survey crews to revisit and refresh photo control targets until the mission can be completed. Ideal conditions include clear skies, no winds aloft, and dry ground.

Wind Conditions: Strong winds cause upper air turbulence that makes it difficult to maintain good direction and a stable platform for photography.

Cloud, smoke or hazy conditions: Heavy scattered cloud cover casts dark shadows while grey overcast skies create poor lighting. Both conditions degrade the imagery and the ability to collect engineering quality terrain data. Low level clouds, smoke, or haze occurring below the planned mission obstruct a clear view of the ground and prevent or severely degrade collection of data.

Ground conditions: Vegetation growth is a concern late spring through early fall. The presence of snow, ice, or flooding due to spring runoff or excessive soil moisture will obstruct collect and may produce sun hot spots from reflection.

(2) Seasons

For optimum sunlight conditions for engineering quality photography, the sun’s direction and angle above the horizon are critical. The optimum sun angle for mapping imagery is between 30° and 45° above the horizon. Angles above 30° provide enough reflective light and minimize the effects of long shadows. Sun angles below 45° eliminate shadows and hot spots created by the aircraft. During the winter months, the sun is lower, so the acceptable light angle is available only for a few hours around midday. During the summer months, there are a couple of hours in the morning and afternoon when “windows of opportunity” occur. The midday sun is unacceptable due to the presence of sun spots and aircraft shadows. These optimal photography times vary throughout the year and can be found in Table VII-3. Non-engineering quality images such as systems, reconnaissance, and snow studies can be taken with a sun angle greater than 45°.

- Early spring is the best time to take mapping images. By then, winter snows have hopefully melted and left matted down vegetation. Crops and vegetation have not begun to grow or are in the early stages of growth. This minimizes the interference in obtaining reliable vertical measurements caused by standing weeds or grasses.
- In areas of deciduous trees, early spring is best before leaves have budded out. Late autumn can be ideal as well after the leaves have fallen from the trees.
- In areas of conifer (evergreen) forests and open prairie, images can be taken almost any time between spring snow melt and autumn snowfall.
- As the name implies, snow study images have to be taken while there are sufficient accumulations of snowfall.

30° - 45° Sun Angle Mission Windows

Month	Day	Mountain Daylight Savings Time	Remarks
March	8	10:39 AM - 4:02 PM	Range of dates for first day
	14	10:22 AM - 4:15 PM	of Daylight Savings Time
	15	10:21 AM - 1:00 AM and 1:36 PM - 4:17 PM	
	31	9:46 AM - 11:30 AM and 2:59 PM - 4:43 PM	
April	15	9:18 AM - 10:49 AM and 3:31 PM - 5:02 PM	
	30	8:56 AM - 10:22 AM and 3:52 PM - 5:18 PM	
May	15	8:41 AM - 10:05 AM and 4:08 PM - 5:32 PM	
	31	8:32 AM - 9:55 AM and 4:21 PM - 5:43 PM	
June	15	8:31 AM - 9:53 AM and 4:28 PM - 5:51 PM	
	21	8:32 AM - 9:54 AM and 4:30 PM - 5:52 PM	Summer Solstice
	30	8:34 AM - 9:57 AM and 4:31 PM - 5:53 PM	
July	15	8:42 AM - 10:05 AM and 4:27 PM - 5:49 PM	
	31	8:54 AM - 10:18 AM and 4:14 PM - 5:38 PM	
August	15	9:08 AM - 10:34 AM and 3:54 PM - 5:21 PM	
	31	9:25 AM - 10:59 AM and 3:21 PM - 4:55 PM	
September	15	9:44 AM - 11:35 AM and 2:35 PM - 4:19 PM	
	27	10:03 AM - 3:58 PM	
	30	10:09 AM - 3:50 PM	
October	15	10:42 AM - 3:09 PM	
	31	11:36 AM - 2:10 PM	
November	1	11:41 AM - 2:06 PM	Range of dates for last day
	6	12:11 PM - 1:36 PM	of Daylight Savings Time

Month	Day	Mountain Standard Time	Remarks
November	1	10:41 AM - 1:06 PM	Range of dates for first day
	7	11:19 AM - 12:28 PM	of Mtn Standard Time
	8	11:31 AM - 12:16 PM	Sun Angle concern
	9	Sun Angle below 30° horizon at sample location	
	16	Sun angle unacceptable for mapping photography	Entire state
December	15		
	21		Winter Solstice
	31		
Januray	24	Sun angle unacceptable for mapping photography	Entire state
	31	Sun Angle below 30° horizon at sample location	
February	1	12:07 PM - 12:40 PM	Sun Angle concern
	14	10:48 AM - 2:01 PM	
	28	10:01 AM - 2:44 PM	
March	8	9:39 AM - 3:03 PM	Range of dates for last day
	13	9:26 AM - 3:13 PM	of Mtn Standard Time

Table VII-3. Aerial photography windows of opportunity.

Time determinations obtained from www.susdesign.com/sunangle. These times are valid at latitude 43°N latitude and 108° W longitude, and elevation 6000'. For each longitudinal degree east, subtract 4 minutes from each end of the time interval. For each longitudinal degree west, add 4 minutes from each end of the time interval.

e. Scale Calculation

The similar triangle relationship, as shown in Figure VII-1, is the basis for calculations involving scale, ground coverage, and flying height. The relative scale of the image can be calculated in different manners depending upon the requirements. The following equations can be used for scale calculation:

Scale = D/d = H/f = (H′ - h)/f

d = distance on photograph (a-b)	f = focal length of camera lens
D = distance on ground (A-B)	H′ = flying height above mean sea level
H = flying height above average ground	h = average ground elevation

Scale Calculation Example:

H = 1800 ft. and f = 4.72 in.

1:1 Image Scale = H/f = 1800 ft./4.72 in. = 380 ft./in.

If the flight height is not known, look for objects that are identifiable on the ground and on the photo. Take a measurement between the objects on both and divide the photograph measurement into the ground measurement to get the photo scale.

Photo scale can also be expressed as a representative fraction or ratio. A ratio is without units but can be expressed in any unit of measurement. The units are the same (i.e., a ratio of 1:24000 or 1/24000 means 1 unit is the same as 24000 units). Applying this to an aerial image, 1 inch on the photo equals 24000" (or 2000') on the ground. Flying height requirements for the desired mapping scales are located in Table VII-4.

Project Type	**Flight Height (ft)**	**Photo Scale**	
		(1"=____')	**Ratio**
Urban Projects (plains)	1250	265	1:3180
Urban Projects (mountainous terrain)	1500	320	1:3840
Suburban Projects	1800	380	1:4560
Rural Projects (plains)	2000	425	1:5100
Rural Projects (mountainous terrain)	2400	510	1:6120
Systems	7075	1500	1:18000
High altitude city planning imagery	9500	2000	1:24000

Table VII-4. Aerial photography chart.

f. Scale Variation

The hypothetical situation in Figure VII-1 will result in an image that has a uniform scale. However, there are four reasons why this situation, for practical purposes, will not occur in the real world. Those situations affecting the scale of the image are shown in Figure VII-3. Due to changes in ground elevation, tilted optical axis, flying altitude, and earth's curvature the stated scale of a given image is an approximate, non-uniform scale.

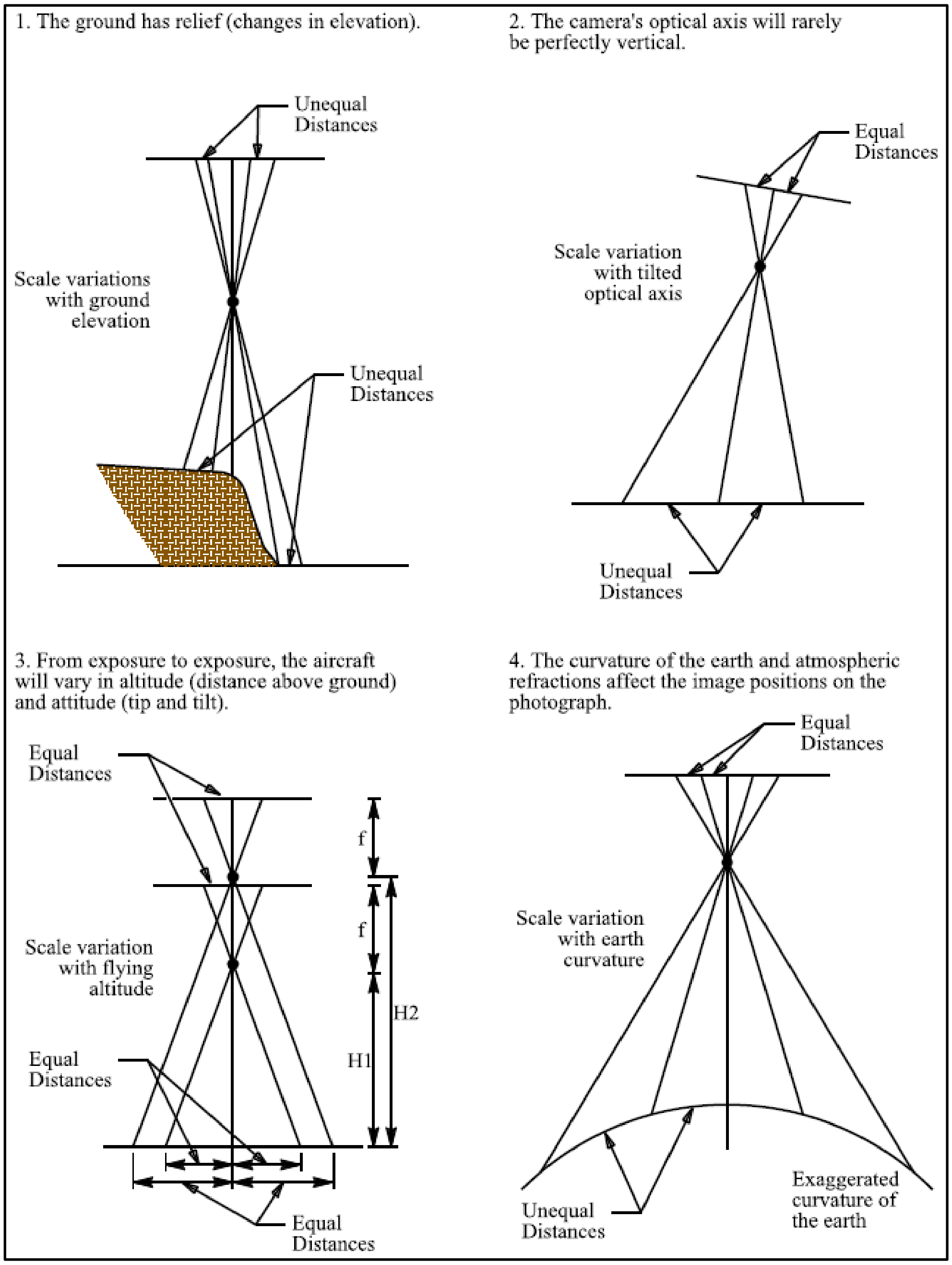


Figure VII-3. Scale variations.

g. True Scale

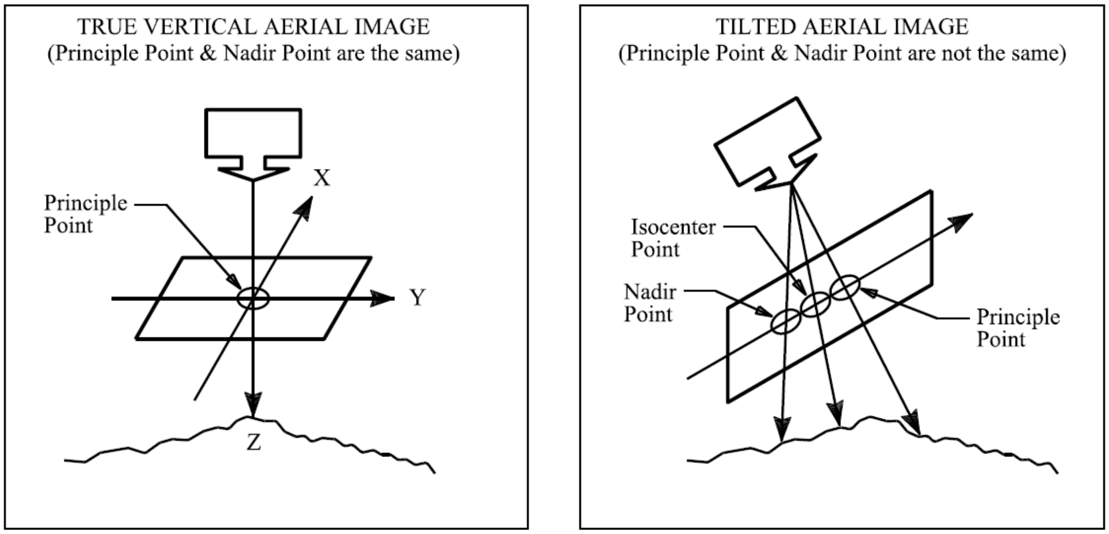
Since WYDOT's Photogrammetry & Surveys Section (P&S) uses an average ground elevation in the calculations for flying height, the true scale of a photo print cannot be determined without making ground measurements between objects that are identifiable on the image. The ground distance and the distance on the image can be used in the formula given on page VII-12 to calculate the true scale. This true scale calculation is semi-accurate only between the two points used. The image will not have a uniform scale until all the variations have been removed.

h. Uniform Scale

Orthographic projection is the only process that will create a truly uniformly scaled digital image. These projections are commonly called ortho-photos and are the only products that can be classified (by definition) as a map. They are created by matching each individual DTM ground shot with the image location the shot was collected from. The final ortho-image has been rectified using thousands of ground shots per image model. If a DTM does not exist, image rectification can be performed at a lesser quality using photo control points or a USGS Digital Elevation Model (DEM). This type of rectification process can remove the major effects of scale variations but cannot remove all the effects.

i. Vertical Digital Photography

Vertical digital photography refers to the direction of the camera's optical axis, which is in the direction of gravity. This is the position of the camera in which the image's Principle point and Nadir point are the same during the exposure process. The Principle point is the point where the perpendicular projection through the center of the lens intersects the photo image center. The Nadir point is the vertical projection from the camera center through a point on the photo image as shown in Figure VII-4.



(a) (b)

Figure VII-4. Image orientation

The truly vertical situation occurs rarely in the real world, as diagramed in Figure VII-4a, but it better reflects the situation identified in Figure VII-4b. This is why a point called the Isocenter and Nadir point play an important role in Photogrammetry. The Isocenter falls halfway between the Nadir and Principle point and is the location where all tilt displacement on the image radiates from. The Nadir point is the location where all elevation displacement radiates from.

j. Overlapping Imagery

Aerial photography taken from above is rarely a single shot event. Multiple photographs taken along a flight path are generally taken to ensure complete photo coverage of an area. To achieve this we must have overlap between photo images. The overlapping of photos end to end is termed end lap. An end lap of 30% will avoid potential missing areas of coverage due to the effects of turbulence. Imagery collected for use in stereo viewing, an end lap of 60% is considered ideal.

For block coverage of an area at a specific photo scale, it is often necessary to fly parallel strips of aerial photography. The adjacent strips also overlap each other. This overlapping area is termed side lap and is generally specified at 30% to ensure good coverage.

k. Acceptable Tolerances

The acceptable tolerance for altitude variation during image collection is plus 5% or minus 2% of the predetermined altitude. Thus, if the desired altitude is 2000’ above ground (AG), the acceptable range for altitude is between 2100’ AG and 1960’ AG. For both urban and rural projects, the trigger limit is set to 200’ either side of the flight line while the systems imagery is set to 300’. The trigger limit is the planned flight path corridor the aircraft must maintain during image collection process. If the aircraft strays beyond that corridor, the camera will disengage from image collection. The incomplete flight strip will need to be redone.

Image end lap tolerances throughout a flight strip shall average not less than 57% or more than 62%. No individual end lap within a strip shall be less than 55% or greater than 68%. Side lap may vary from 20% to 40% unless otherwise specified.

In addition to satisfying altitude, end lap, and side lap requirements, other factors contributing to the acceptance or rejection of photography are course correction, crab, tilt, and image quality. The crab and tilt can be somewhat compensated by the gyro stabilized camera mount. For crab and changes in course correction, the resultant error between images cannot exceed 3°. The tilt within a single frame may not exceed 4°, nor shall the difference in tilt between two consecutive frames exceed 4°. See Figure VII-5. The average tilt for all images of the same scale cannot exceed 1°. The combined effects of aircraft course correction, crab, and tilt must not result in an apparent crab greater than 5° on successive images. Apparent crab is defined as the angle between the intended flight path and the line between adjacent image principal points within the same flight line.

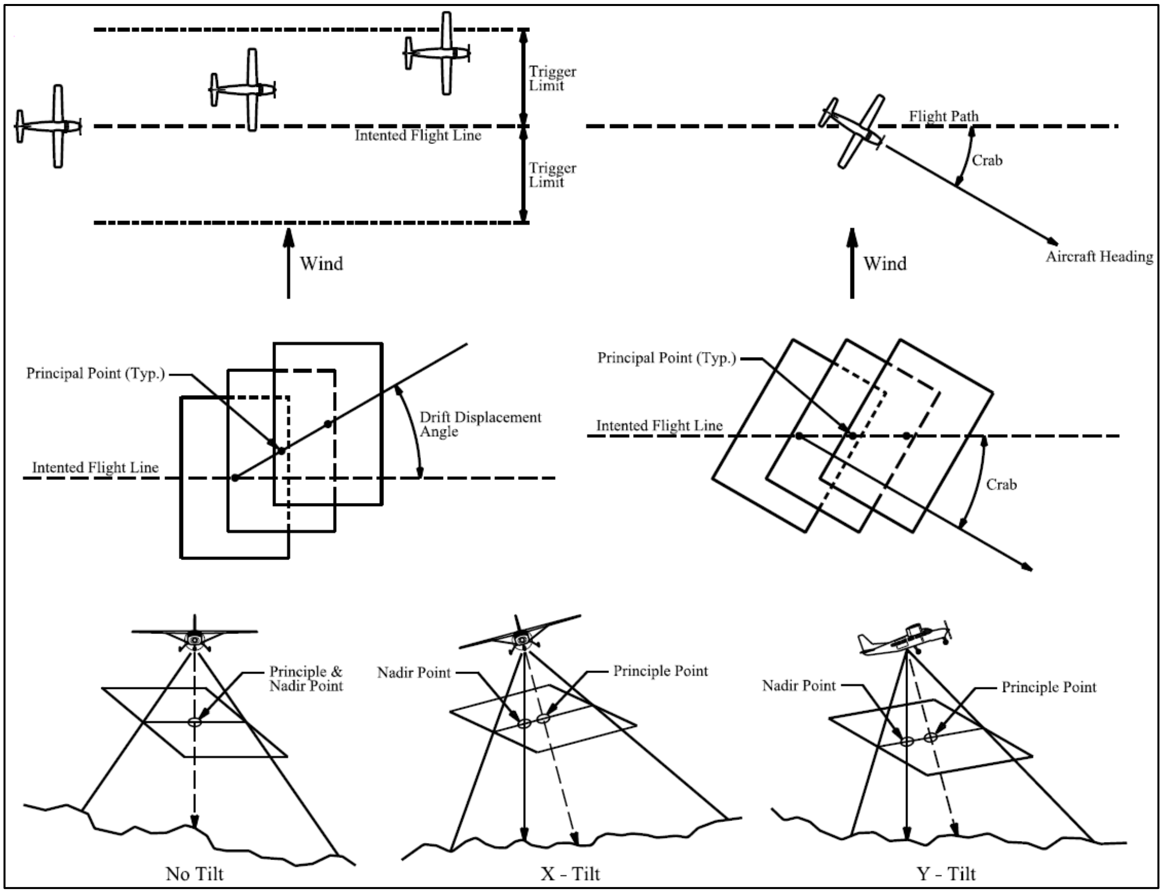


Figure VII-5. Effects of wind and turbulence on aircraft during photo collection.

I. Image Post-Processing

The task of processing the 4 panchromatic and 4 multispectral raw images captured by the DMC's 8 individual cameras is performed by Z/I's Post Processing software (PPS). The process converts the 8 individual images into a standard central-perspective image. These images have to be processed to compensate for numerous radiometric factors. Radiometric correction is a process of assigning pixels a value from 0 to 256 on the monochromatic scale and up to 16,384 shades of color. The pixel resolution can either be 8 or 12-bit, with 12-bit being the highest quality image. This will produce an image that is distinguishable from different light intensities and allows the photogrammetrist to adjust the image contrast to improve data collection. Generally, hundreds of images are collected during each photo mission. To increase our image processing capability, Z/I's distributive software allows PPS the ability to function on multiple computers.

Scale distortion is another issue to address with aerial imagery as it increases the farther we move away from the image principle point. To resolve this problem, Z/I's ImageStation Aerial Triangulation (ISAT) software matches multi-ray tie points between adjacent images using a robust built-in bundle adjustment that removes distortions to produce an image with spatial intelligence.

After all these steps, the end result is a geo-referenced colored panchromatic sharpened image with a size of 13,824 x 7,680 pixels, or a 106 mega-pixel image.

m. Image Storage

In the past P&S was required to store all aerial film photography in a physical location for future retrieval by the Department or other outside entities. Even though we are now a fully digital shop, we still must store those images as a record of historical value and future retrieval. However, they are not kept in a physical location, rather than are stored on a dedicated server. All newly acquired DMC processed imagery and scanned historical aerial film photography, are placed on that server. To manage this enormous amount of data, WYDOT has purchased a 36 TB (terra byte) Dell Power Vault Server for storage of all imagery.

C. Photographic Ground Control

1. General

To make precise and meaningful measurements from aerial photographs, it is essential to relate the photo images to the actual ground surface. This is achieved by physically tying horizontal and vertical positions of various photo identifiable points or pre-flight targeting placed within the project photo limits.

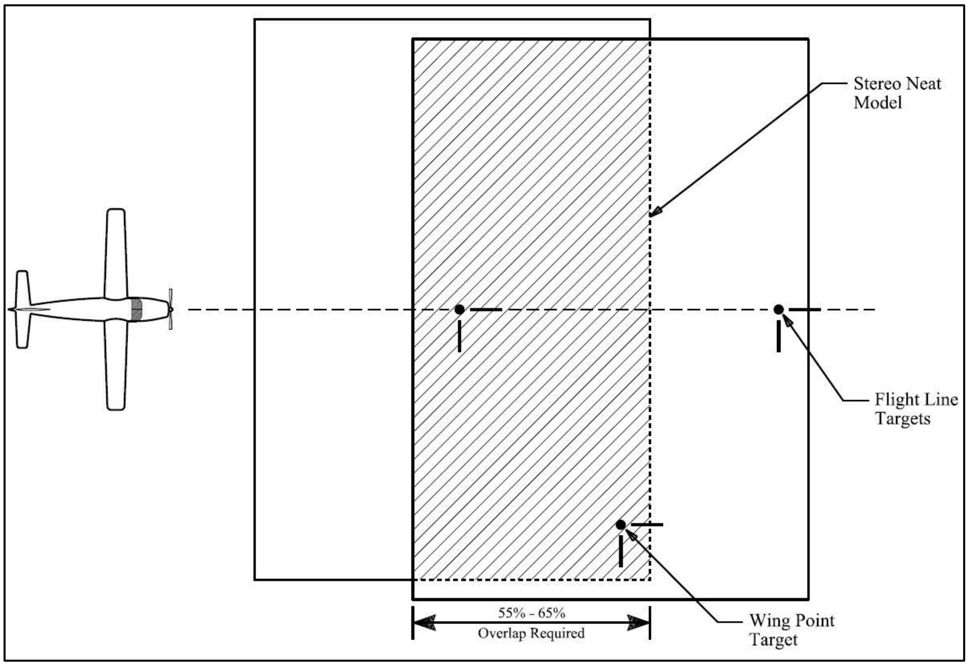


Figure VII-6. Two photo stereo model.

Three photo control points are required at the beginning and end of each planned flight strip. The flight line target spacing is a factor of the flight altitude to insure at least one photo control target falls within each digital image. Wing points are typically placed on either side of the flight path, every other flight interval space, at a preferred distance of 75% - 85% of the target interval spacing. Figure VII-7 is an example of the targeting layout for a typical WYDOT project.

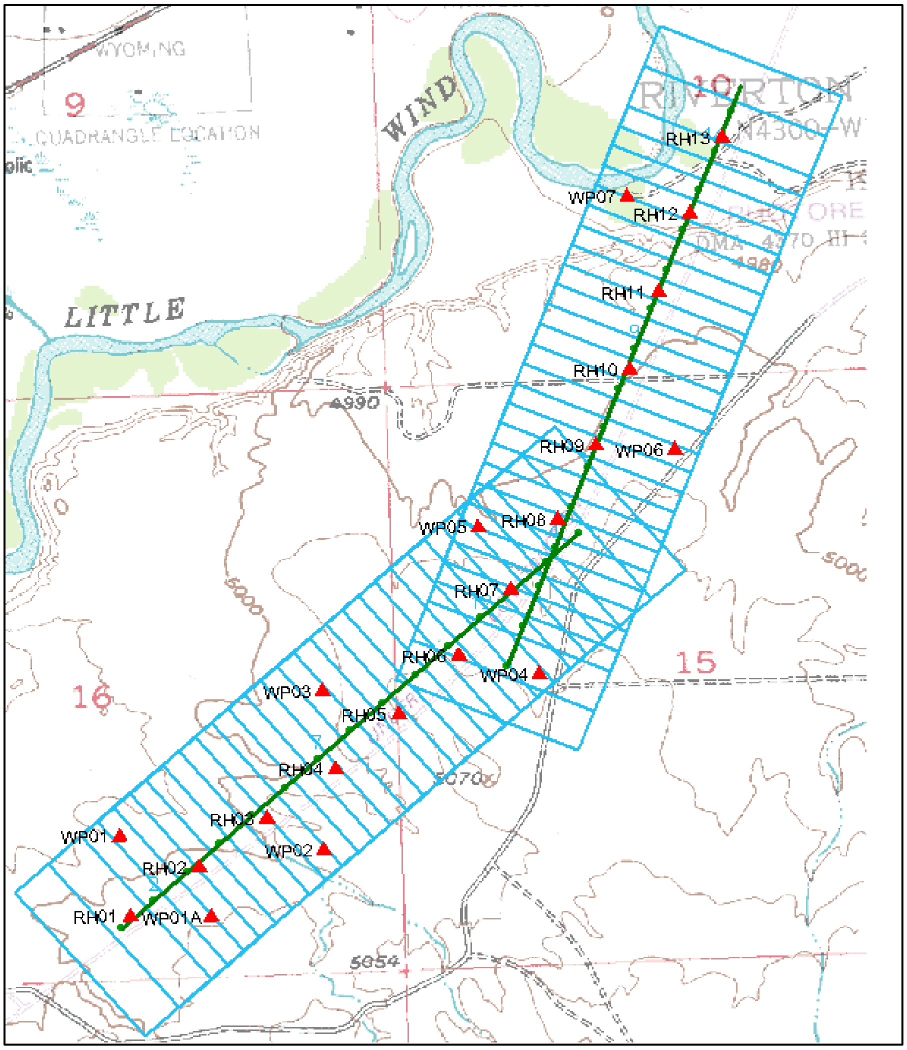


Figure VII-7. Photo targeting and flight line diagram example.

With the advancements in GPS and digital camera technology mission planning and in-flight guidance software have greatly reduced flight time, collection problems, and errors due to misplaced targeting. It has allowed the pilot the ability to concentrate on flying the aircraft rather than searching for and staying on the correct flight path. Flight line and altitude, image overlap, and collection locations are all predetermined in the office using Z/I Mission or Lieca MissionPro planning software. Z/I in-flight reads the mission files to guide the pilot over the project flight line. The camera will automatically cycle over each preset exposure location along the flight path. Because of the onboard GPS and internal camera IMU, each image has spatial intelligence at the time of collection. When combined with the ground control, a stronger bridging solution is achieved during the auto triangulation process.

Images with spatial intelligence reduce the amount of targets required for aerial triangulation by tying each image together. Aerial triangulation (sometimes referred to as bridging) is similar in theory to the field survey process of triangulation. It establishes a coordinate relationship between the project control points and the supplemental bridging points.

Because of the time and labor savings, all photogrammetrically collected projects are bridged. Bridging also allows for a check of the field measurements and the elimination of some field work in inhospitable areas (e.g. adverse terrain and areas without permission to survey).

For some projects only requiring imagery for GIS purposes, it is possible to not have any established photo control to create this product. A set of GPS base stations, collecting at half second intervals, positioned over known monuments within in the area are more than adequate. The rectification process is then accomplished using USGS DEM's, and the GPS solution created from the on board GPS/IMU and ground base stations. With the limitations of signal strength and terrain conditions, this process works best on projects located in areas with open terrain. The advantage of this procedure is to eliminate the man-hours required for targeting activities.

2. Photo Control Points

Photo pick points can be used, but the potential for error increases. Confusion may occur on which point for the field to tie or which point P&S should use. It is generally preferred to set photo control targets for mapping projects prior to image collection. Photo pick points are sometimes used if a target has been lost.

Photo mission targets are placed with an 8" plastic or painted disk centered over a control point (1" hub or PK nail). Plastic or painted target legs 6' in length are placed to help locate the control point on the imagery. WYDOT now uses two basic target configurations, the 2-legged "photo control" target and on occasion the 3-legged "wye/project control" target. See Figures VII-8 and VII-9, for target configuration.

a. 2-legged "photo control" Targets

Photo control targets identify both flight line and wing point target locations used for aerial triangulation.

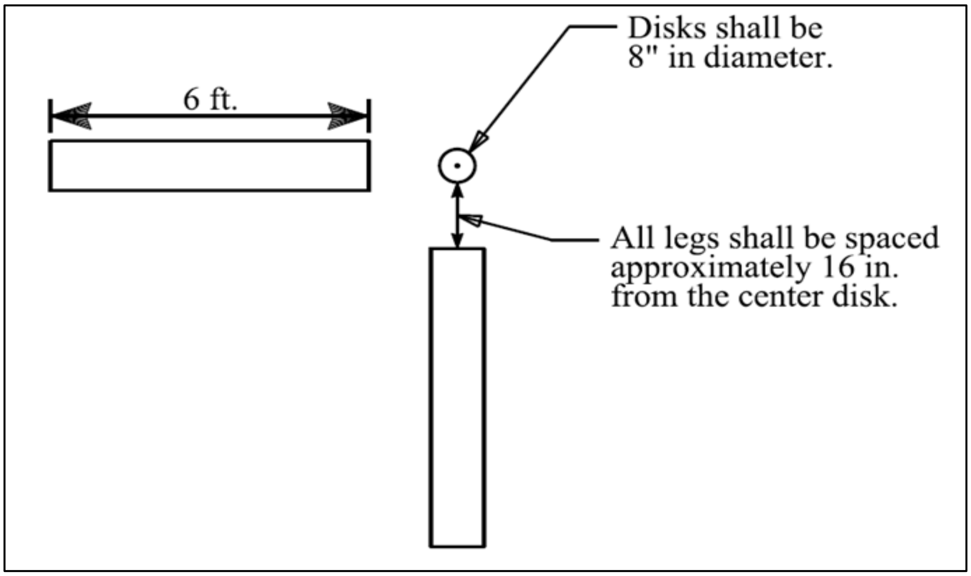


Figure VII-8. Photo control target.

They are tied vertically and horizontally by conventional survey methods. As the project photo mission is laid out, photo control targeting locations are identified to optimize the image triangulation process for use in stereo compilation. They may be placed on the roadway surface, right-of-way, median, or adjacent permitted property. When placed on a roadway surface, targets may be painted on the shoulder or in one lane of traffic to reduce the amount of traffic control required during placement and control activities. When painted on a roadway surface it is acceptable to use only one targeting leg.

b. 3-legged “wye/project control” Targets

On occasion it is useful to photo identify the locations of project control monuments. They are generally not used for stereo compilation.

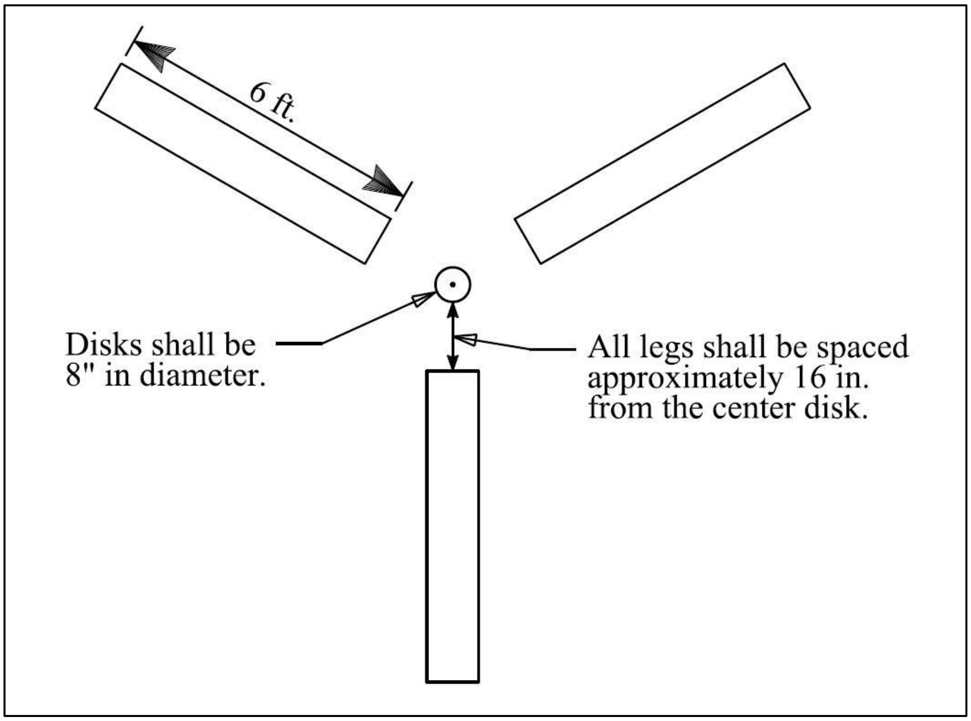
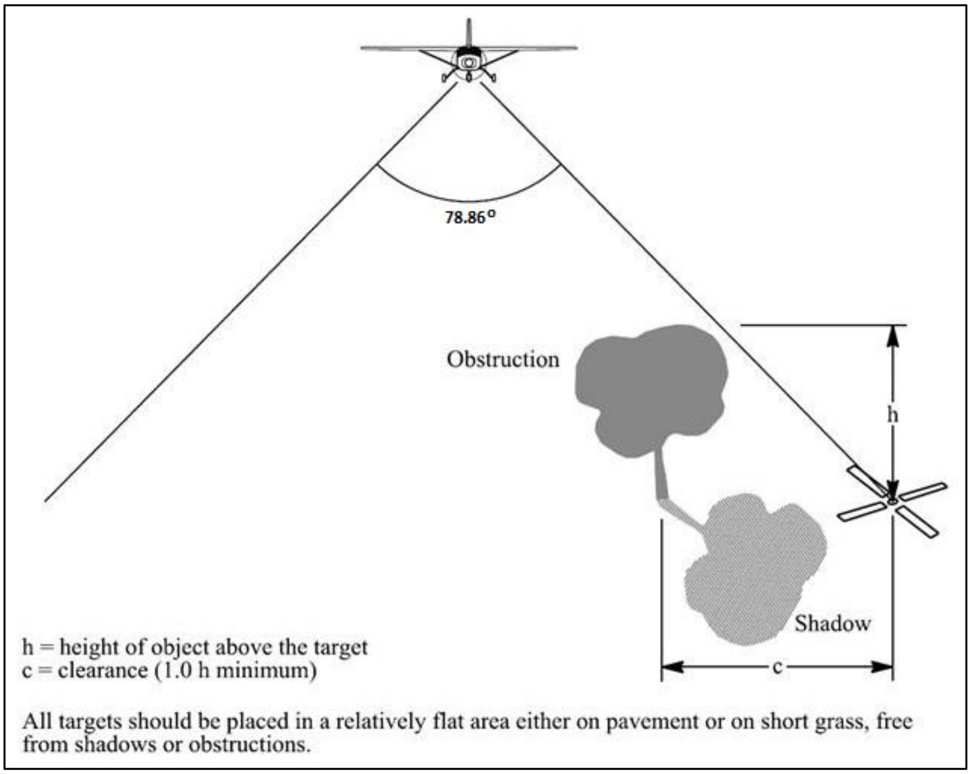


Figure VII-9. Project control target.

c. Obstructions

All targets should be place on a relatively flat area or surface, either on pavement or short grass. Potential shadows that may be cast at the time of the planned mission must be avoided as well as overhead obstructions such as trees or manmade structures. See Figure VII-10.



h = height of object above the target
c = clearance (1.0 h minimum)

All targets should be placed in a relatively flat area either on pavement or on short grass, free from shadows or obstructions.

Figure VII-10. Shadow and overhead obstruction example.

D. Photograph Annotation

1. Annotated Photo Enlargements

A black and white photo mosaic is also created for the purpose of map feature identification and annotation. This mosaic is created at a large enough scale to provide room for annotation of all utilities and photo identifiable objects within the project limits. This activity is conducted by P&S Surveys, resident crew, or survey consultant. Ideally, this should be completed before map compilation activities begin to aid the plotter operator during collection. If these annotations are not complete by the time the mapping is complete, paper prints of the mapping can be used for review and annotation of missing utilities and features. If care is taken, objects can be measured from identifiable points on the photos or mapping prints and drawn at their approximate location. Color coding is helpful for locations with a large number of features requiring identification. Depending on the scope of the project, some features may require survey collection. As a general rule, utility information or features that are underground should be located by their owner and then surveyed for accuracy. The feature code list in Chapter 4 of the Data Collection Manual has all codes and symbols to be used for feature identification. Symbology for utility and various features can be found on the plan set title sheet for reference during annotation. Ownership and type of utility should be included on the annotated photos. Examples of features that may be annotated are:

- Buried pipelines (type and size)
- Gas lines (type and size)
- Buried or overhead power lines (type and number of lines)
- Buried or overhead television cables (type and number of lines)
- Buried and overhead telephone cables (type and number of lines)
- Water lines, buried (type and size)
- Well (type)
- Sanitary and storm sewers and storm sewer inlets (type and size)
- Water valves
- Gas and water hook-ups to buildings
- Any utilities that are in the right-of-way or cross it
- Fences (type and size)
- Culverts (type and size)
- Drain pipes (type and size)
- Irrigation ditches and structures, include direction of flow
- Street and traffic lights
- Signs (type)
- Mines
- Graves
- Underground tanks either in-use or abandoned

Annotations to be completed by the field, survey consultant or WYDOT Surveys, should complete the annotation form, Form VII-1, and return to P&S. Care must be taken to insure all annotations are easily interpretable.

Annotated Photos or Prints

Job #	**Alignment**	**Number of Photos or Pages**

Colors: DO NOT USE: BLACK, YELLOW, WHITE, OR GRAY (they do not show up well).

USE: photo color pencils that show up and are sharp.

Text: See top or bottom indications on photo. Text to be annotated in the direction of the proposed station alignment.

Utilities: **Fiber Optic, Gas, Oil, Power, Sewer, Telephone, TV, Water**

1. Show where utilities cross the road or right-of-way above or below ground.
2. Use the survey code or line style (See Legend).
3. Above Ground Utilities:
   Only draw overhead lines across the road (labeled with # of wires).
   When not crossing the road, show the pole w/ tics indicating the direction of the line.
   Labeling in between poles as needed, especially when # of wires changes.
   Connect the poles when there are too many to tell direction from the tic marks.
4. Under Ground Utilities: Show complete line.
5. Label utilities with company or owners name as needed at least once per photo.

Fences:

1. Write out description of fence, or use an understandable abbreviation.
   (3’ woven wire w/ 3 barb) (3’ WW/3 BW) (3’ barbed wire) (3 BW).
2. Show sizes and types of gates and cattle guards. (25’ steel gate) (15’ cattle guard).
3. Show where fence types change.

Hydrology:

1. Label drainage culverts with size and type (24” CMP) (15” x 30’ x 35’ ARCH CMP).
2. Show and label flared ends on pipes (24” CMP W/ FLARED ENDS).

Roadway:

1. Label guardrail with the type (Box Beam Guardrail) (W-Beam Guardrail).
2. Show Railroad and ownership.

Size:

1. Show if it is: Billboard, Major, Small, or Structural sign (use feature code or symbol from legend).
2. The information that is on the sign is NOT needed.

Name	Photos or Pages Annotated

NOTE: Have someone review your annotations. If they can’t read and understand them, we can’t either.

Please fill out and return this sheet with the completed annotations.

Form VII-1. Annotation form.

E. Terrain, Planimetric, and Digital Image Collection

1. General

Photogrammetry currently has four Image Station stereo plotter workstations for mapping/terrain photogrammetric and LiDAR compilation. Each machine is loaded with Cardinal Systems Vr Mapping software products.

2. Collection Format

All plotter compiled, LiDAR point cloud extract data, field surveyed, annotated mapping, and digital terrain data are placed and edited in the latest version of MicroStation. These files contain both 2-D planimetric and 3-D terrain data.

When the mapping file is created, 2-D planimetric details are separated from the 3-D terrain data and placed into their separate models within the project MicroStation file. The 2-D planimetric data can be found in the mapping model, with elevations set to zero. Three dimensional terrain data can be found in the DTM model.

All data is compiled with coordinate values to the nearest 1/1000 of a foot.

The working units are set at:		The Global Origin is set to:
Master Units	= ft	X = 0
Sub Units	= th	Y = 0
Positional Units	= 1	Z = 2,147,483.6470

To better inform users of the quality of the mapping and terrain they are using, P&S has created four separate MicroStation levels to help identify the collection type. They are from highest quality to lowest:

- Field surveyed “S” feature level	(PS_X_**S**_XXXX)
- LiDAR point cloud extracted data “L” feature level	(PS_X_L_XXXX)
- Stereo plotter compiled “P” feature level	(PS_X_**P**_XXXX)
- Annotated “A” feature level	(PS_X_**A**_XXXX)

3. Planimetric Mapping

All map features are collected as outlined in the WYDOT Feature Code List located in WYDOT’s Data Collection Manual, Chapter 4. Each feature has a corresponding level, color, line code, line weight, font, symbol, and character assigned to it. Features not specifically included in the Feature Code List are identified using the most equivalent symbol and descriptor from the list.

All planimetric features that are visible, identifiable, or interpretable on the aerial photograph are collected. Particular attention is given to all transportation related features, such as roads, railroads, bridges, canals, streams, dams, utilities, and drainage ditches, as well as other features along the roadway corridor. Compiled road edges consist of curves and tangent line segments. The widths of roads and streets are shown as the separation between curb faces, hard surface edges, or stabilized shoulder lines, as appropriate.

4. Digital Terrain Model (DTM)

The data collected to build a DTM consists of break lines, mass ground shot data, and obscure areas.

Breaklines identify terrain discontinuities, such as drainage ditch bottoms, ridges, toe of slopes, roadway berms, or any other sharp change in the existing surface. Breaklines are essential in the building of the terrain Triangle Irregular Network (.tin), used in the creation of the topographic map and design. They force the triangle legs to tie into the breakline of the discontinuity. A ditch bottom or terrain irregularity left undefined by a breakline will triangulate across the discontinuity and show the terrain as flat in those areas as shown in Figure VII-11.

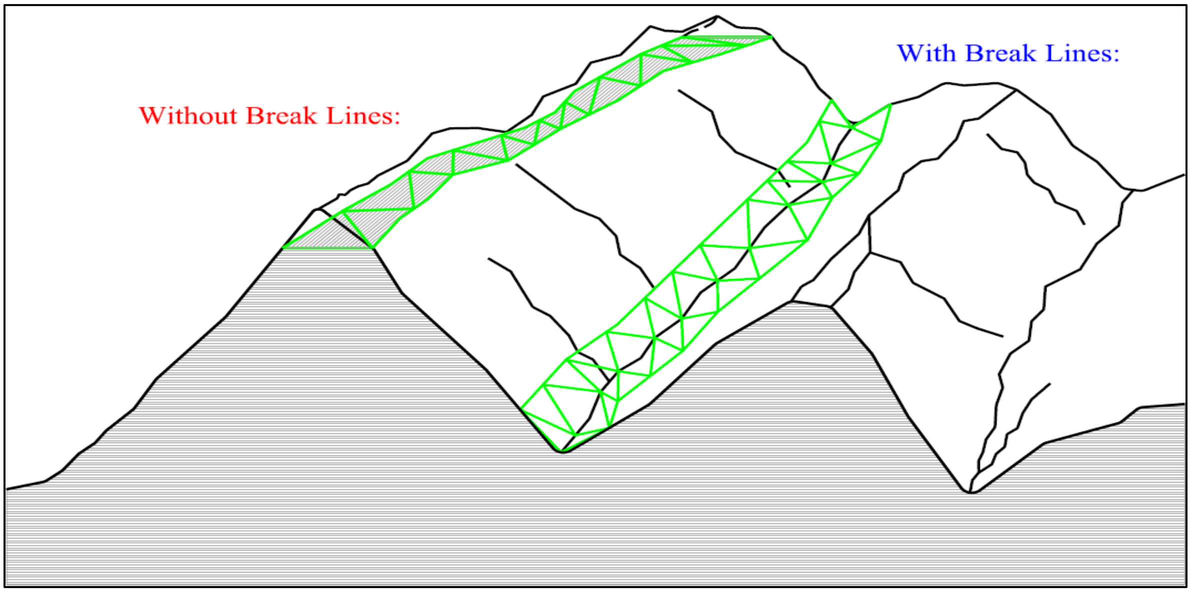


Figure VII-11. Breakline example.

Mass data points identify the XYZ coordinates of a location and are collected in profile or grid mode. Random mass points may be used when necessary to identify unique terrain situations, such as a steep irregular hill side with varied vegetation. They are obtained at locations of significant grade change. The Photogrammetry Unit has established that mass data points may not be greater than an interval spacing of 15’ inside the corridor width of a project. Typically the corridor is defined as 150’ either side of centerline of the road. The corridor may be increased and should be decided during the Surveying Meeting prior to the collection process. Beyond the corridor limit, terrain data is extracted using Z/I’s ImageStation Automatic Elevation (ISAE) collection software. ISAE is performed for the full extent of each model, at a grid spacing of 25’. Although this data is not as reliable as the physically collected data, it does provide design and the Hydraulics’ group with information for potential borrow or drainage flow patterns. If it is determined an area is critical and in need of more accurate data, P&S can load the imagery back onto a plotter for collection.

During the photogrammetric collection, it may be difficult or impossible for the stereo plotter operator to accurately collect the terrain data. This may be caused by dark shadows, buildings, heavy brush, bodies of water, or anything that may be obstructing the ground significantly. These areas are known as void or obscure areas, and are usually filled by field supplementation.

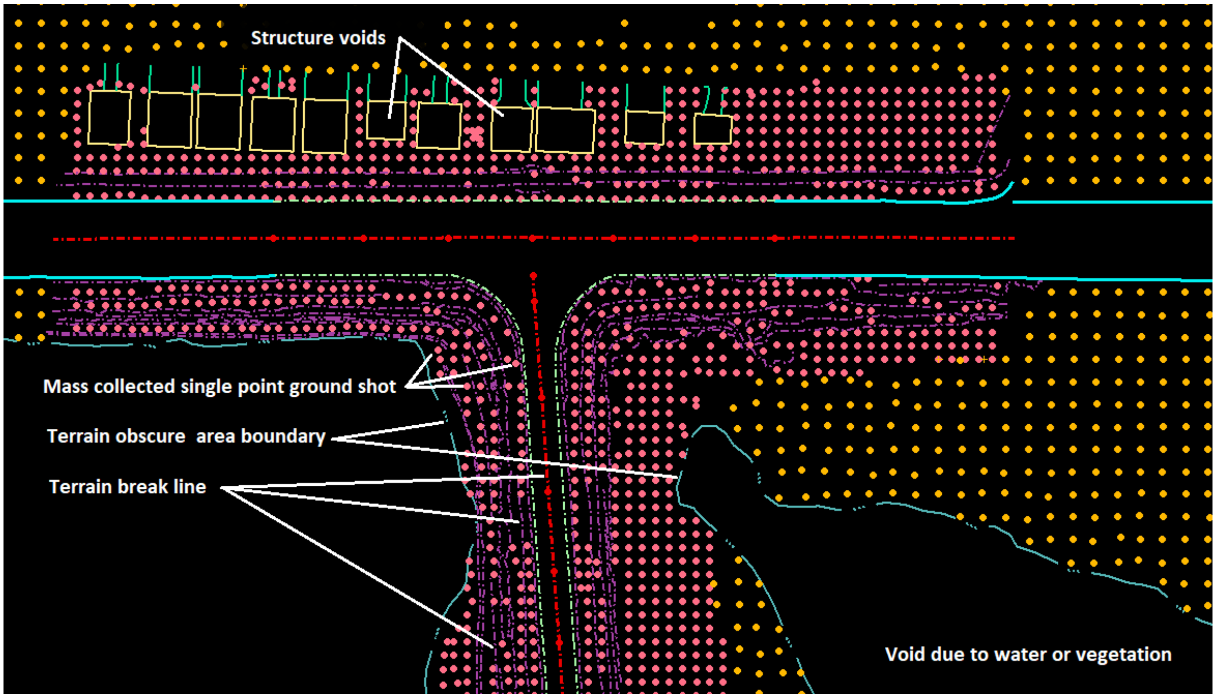


Figure VII-12. Typical DTM feature collection.

5. Accuracy Standards

Ninety percent of all planimetric map features are to be plotted so that their horizontal positions at the designated map scale are accurate to within 1/40” of their true coordinate positions. All features cannot be misplaced by more than 1/20” from their true coordinate positions.

The Digital Terrain Model “Z” coordinate or elevation is governed by the Root-Mean-Square-Error (RMSE) for all tested points and must not exceed the following ratios for each terrain condition:

- 1/6000 of the flight height—for open ground (no interfering ground cover) with uniform slope.
- 1/5000 of the flight height—for open ground (no interfering ground cover) with irregular slopes.
- 1/3000 of the flight height—for ground with interfering ground cover and irregular slopes.

No individual error may exceed three times the specified RMSE. For the purpose of this specification, the RMSE is defined as the square root of the quotient of the sum of the squares of the errors divided by the number of measurements, or

$$\mathbf{RMSE = (e^2/n)^{1/2}}$$

Where **e** is the error at each point (the difference between the value used as a standard and the value being tested) and **n** is the total number of points tested.

Table VII-5 relates the different flying heights and terrain conditions to our achievable error tolerances.

Project Type	**Flight Height (ft)**	**Root Mean Square Error**		
		Open Ground w/uniform slopes (ft)	**Open ground w/irregular slopes (ft)**	**Interfering ground w/irregular slopes (ft)**
Urban Projects (plains)	1250	0.208	0.250	0.417
Urban Projects (mountainous terrain)	1500	0.250	0.300	0.500
Suburban Projects	1800	0.300	0.360	0.600
Rural Projects (plains)	2000	0.333	0.400	0.667
Rural Projects (mountainous terrain)	2400	0.400	0.480	0.800
Systems	7075	1.179	1.415	2.358
High altitude city planning imagery	9500	1.583	1.900	3.167

Table VII-5. Accuracy for various flight heights.

Contour intervals are derived from these accuracies. At least 90% of the elevations shall be in error by no more than ½ of the contour interval. None shall be in error by more than a full contour. Table VII-6 shows the contour intervals our maps will have based on flight height.

Project Type	Flight Height (ft)	Minimum Contour	
		Use Min. contour intervals (ft)	Use Max. contour intervals (ft)
Urban Projects (plains)	1250	1	5
Urban Projects (mountainous terrain)	1500	1	5
Suburban Projects	1800	2	10
Rural Projects (plains)	2000	2	10
Rural Projects (mountainous terrain)	2400	2	10
Systems	7075	5	25
High altitude city planning imagery	9500	10	50

Table VII-6. Mapping contour intervals.

6. Accuracy Testing

After the mapping has been collected, paper prints of the mapping are forwarded to P&S Surveys, the field, or consultant for review. Any corrections are annotated on the mapping and returned to Photogrammetry for update. Horizontal accuracy of plotted planimetric features is checked using field survey supplements and/or a stereo plotter.

Vertical accuracies of the DTM may be checked using a field survey and/or a stereo plotter. Occasionally a random list of photogrammetrically collected spot locations is provided for survey crews to physically locate and verify vertical accuracy. That accuracy must meet the RMSE standards as previously described.

7. Digital Imagery

Technological improvements to computer processing speeds, storage, and software has provided the Department with an additional avenue for improving the quality of design plans through coordinately captured Google Earth imagery, control or feature rectified digital photo imagery, and DTM ortho-rectified imagery.

MicroStation offers the capability to synchronize with Google Earth and capture the image for use as a back drop to a field collected survey. There is a degree of distortion when using this method, but Google image captures have been a very useful source to supplement the field survey.

Image rectification using photo control or photo identifiable features should not be considered engineering map quality. This method, termed “rubber sheeting”, stretches the image to the photo control points and orients the image to its relative position to the ground. It removes some image distortion but is not sufficient enough to extract reliable measurements. It is, however, very useful for projects that do not require typical accuracy requirements such as overlays, guardrail improvement, slab replacement, and roadway enhancements. This type of image rectification is fairly inexpensive to create and can be produced in a fraction of the time required to collect mapping and DTM.

Unlike image rectification, ortho-rectification requires an existing DTM generated from the imagery the ortho will be created from. It is a little more time consuming to produce, but the final product is equivalent to planimetric mapping typically used in design. Ortho-rectification is created by matching each individual DTM ground shot with the image location that the shot was generated from. The final ortho-image is rectified using thousands of shots per image. Reliable measurements can be extracted, but the accuracy of those measurements is dependent on the scale of photography and the image resolution they are obtained from.

Each of these image supplements have become useful substitutes or backdrops to mapping. They help the public understand the intent of the proposed project and may help avoid confusion or conflict between all parties involved on the project from design through construction.