Survey Manual

Chapter 4

Aerial Surveys

Colorado Department of Transportation
December 30, 2015

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Chapter 4 – Aerial Surveys

4.1 General

4.1.1 Acronyms found in this Chapter

AGPS	Airborne Global Positioning System (See also the application of GPS in this document.)
ASCII	American Standard Code for Information Exchange
AGL	Above Ground Level
ASPRS	American Society for Photogrammetry and Remote Sensing
ATC	Air Traffic Control
CDOT	Colorado Department of Transportation
DEM	Digital Elevation Model
DGN	This is a reference to a Bentley MicroStation file format. The term is based on the file name extension used for this format.
DTM	Digital Terrain Model
FAA	Federal Aviation Administration
FMC	Forward Motion Compensation
GIS	Geographic Information System
GNSS	Global Navigation Satellite System (See also the application of GPS in this document.)
GPS	Global Positioning System (In this document it refers generically to space satellite system positioning. See Chapter 3 for application of specific space satellite systems.)
GSD	Ground Sampling Distance
Hz	hertz (frequency per second)
INS	Inertial Navigation System
IMU	Inertial Measurement Unit
LAS	This is a reference to an industry standard LiDAR point cloud file format. The term is based on the file name extension used for this format.
LiDAR	Light Detection and Ranging
MUTCD	Manual of Uniform Traffic Control Devices
NAD	North American Datum
NAVD	North American Vertical Datum
NIR	Near Infrared: Used in reference to a part of the light spectrum.
NGS	National Geodetic Survey
NSRS	National Spatial Reference System
NSSDA	National Standard for Spatial Data Accuracy
NVA	Non-vegetated Vertical Accuracy
PDOP	Positional Dilution of Position
PID	Photo ID, used in reference to aerial mapping ground control points naturally identifiable in aerial imagery without the need to target, (or panel) the control point.
PPR	Prior Permission Request
RGB	Red, Green, Blue, used in reference to parts of the visible light spectrum.
RMSE	Root Mean Square Error (may be followed by lower-case “z” as referred to elevation or an “r” if referencing a radial distance - x & y combined)
VVA	Vegetated Vertical Accuracy

4.1.2 Purpose of this Chapter

The purpose of this chapter is to define the specifications that shall be followed while performing aerial surveys, photogrammetry and geospatial data processing for CDOT.

CDOT contracts out all aerial surveys as the aerial photography and mapping equipment is not available in the department. As such CDOT relies upon the expertise and experience of the aerial mapping consultant to provide guidance and products that will meet the needs of the project. The survey fieldwork is most often performed by the aerial consultant however it may also be performed by CDOT survey crews.

The guidelines and specifications described in this chapter are geared towards development of design scale mapping that has been historically referred to as 1”=50’ scale mapping with 1’ contours. The vast majority of aerial mapping contracted by CDOT calls for mapping standards associated with this scale. Where requirements differ from this scale, the necessary equipment, ground control, flight planning and other key components of the project design may need to be modified. This may be accomplished either to ensure a higher standard is met or to realize efficiencies that may be offered to meet a lower standard. Any variation from the specifications in this chapter shall have the prior approval of the CDOT Region Survey Coordinator.

While it is recognized that technical developments, particularly in airborne LiDAR, are making wider application of aerial data possible for design scale mapping, this chapter provides specifications and guidelines for LiDAR data used alone or in conjunction with photogrammetry supplementing field survey data on the hard road surfaces. Certain circumstances may call for consideration of wider data application such as full detail extraction from a high-density LiDAR point cloud. Where accessibility, safety, economics or other concerns call for such consideration it should be done in consultation between a professional aerial surveyor, such as an ASPRS Certified Photogrammetrist, map scientist or state licensed aerial survey professional and the CDOT Region Survey Coordinator. This will facilitate development of a custom project design, specifications, and deliverables that meet unique CDOT project requirements.

Again, any variation from the specifications in this chapter shall have the prior approval of the CDOT Region Survey Coordinator.

4.1.3 Aerial Surveys

Aerial surveys utilize photographic, LiDAR, electronic, digital, or other data obtained from an airborne platform. Photographic data processed by means of photogrammetry and LiDAR processing using AGPS and IMU data represent the principal applications of aerial surveys to satisfy the needs of CDOT. Aerial survey data is combined with field survey data to produce high precision mapping and meet the accuracy standards described in this Chapter.

4.1.4 Aerial Photogrammetry

Aerial photogrammetry is the science of deducing the physical dimensions of objects on or above the surface of the Earth from measurements on aerial photographs of the objects. The end result produces the coordinate (X, Y, and Z) position of a particular point, a planimetric feature, and a graphic representation of the terrain from a DTM.

Aerial photogrammetry is often used for the following:

1. Highway reconnaissance
2. Environmental
3. Preliminary design
4. Geographic Information System (GIS)

The information produced from aerial photographs of the existing terrain allows both designers and environmental personnel to explore alternate routes without having to collect additional field information.

The photographs can be used to layout possible alignments for a more detailed study.

Photogrammetry has evolved into a limited substitution for topographic ground surveying. It can relieve survey crews of the most tedious time-consuming tasks required to produce topographic maps and DTMs. However, ground surveys will always remain an indispensable part of aerial surveys as a basis for accuracy refinement, quality control and a source of supplemental information unavailable to aerial data acquisition.

4.1.5 Photogrammetric Advantages / Disadvantages

Surveys collected by aerial photogrammetry methods have both advantages and disadvantages when compared with ground survey methods as follows:

Advantages:

1. Photos provide a permanent record of the existing terrain conditions at the time the photograph was taken.
2. Photos can be used to convey information to the general public, and other federal, state, or local agencies.
3. Photos can be used for multiple purposes within CDOT such as reconnaissance, preliminary design, environmental, and Right of Way.
4. Topographic mapping and DTMs of large areas can be accomplished relatively quickly and at a lower cost when compared to ground survey methods.
5. Photogrammetry can be used in locations that are difficult or impossible to access from the ground.

Disadvantages:

1. Seasonal conditions, including weather, vegetation, and shadows can affect both the taking of photographs and the resulting measurement quality. If the ground is not visible in the photograph it cannot be mapped.
2. Overall accuracy is relative to camera quality and flying height. Elevations derived from photogrammetry are less accurate than ground surveys (when compared to conventional or GPS ground survey methods using appropriate elevation procedures).
3. Identification of planimetric features can be difficult or impossible (*e.g.* type of curb and gutter, size of culverts, type of fences, and information on signs).
4. Underground utilities cannot be located, measured, or identified.
5. Right of Way and property boundary monuments cannot be located, measured, or identified.
6. Since photogrammetric features are compiled from a plan view, buildings are measured around overhangs and eaves rather than at building footprints, resulting in some areas of DTM occlusion under overhangs, eaves, and overhead walkways. Areas under bridges are similarly affected.

4.1.6 Aerial LiDAR

LiDAR is collected using a laser that measures distance to an object by emitting timed pulses and measuring the time between emission and reception of reflected pulses. The measured time interval is converted to a distance. Modern LiDAR sensors are capable of recording several returns per pulse. Multiple returns occur when the beam footprint strikes multiple targets before terminating. The sequence of returns from a single pulse, (For example, first, 2^{nd}, 3^{rd}, last or first and last), is also recorded along with an intensity value.

AGPS and IMU data are collected on board the aircraft during flight. Base station information must be collected on the ground during the flight mission. These data provide the input necessary to provide initial geo-referencing. Swath to swath calibration is then performed to refine the relative accuracy of the resulting point cloud. To achieve high levels of accuracy and quality control, application of ground control is applied in the data calibration process. Elevation data is converted from ellipsoid to orthometric values, completing the process.

A classification process follows which identifies the type of return, (for example bare-earth, water, vegetation, structure, etc.). The classification process typically includes automated and a final manual editing process. The automated classification routines are best accomplished with highly sophisticated software that provide for user inputs that modify algorithms for different return densities and land cover types. A final manual editing process is necessary to assure the required quality level of the data point classification. The end result produces the coordinate (X, Y, and Z) position for each return, called a point cloud. Point clouds can be used to generate a DTM, DEM, vegetation clouds or may be used as a source from which to extract planimetric map features.

Aerial LiDAR may be used for:

1. Highly detailed DTM
2. Drainage analysis
3. Preliminary design and design scale mapping
4. 3D vegetation mapping
5. Flood plain mapping
6. Planimetric feature extraction
7. In combination with photogrammetry for large scale mapping

LiDAR has quickly evolved over the last several years to become a valuable tool for 3D mapping. Similar to photogrammetry, it can relieve survey crews of the most tedious time-consuming tasks required to produce topographic maps and DTMs. It can provide detailed terrain data and additional information that would be too time consuming using photogrammetry or field surveys. However, as an aerial survey, LiDAR must be controlled by ground survey and cannot replace ground topographic survey methods where the ground is obstructed from a top view. Final “ground” class returns, often supplemented by breaklines, are quality checked by producing a TIN (Triangular Irregular Network) and validating against a set of ground surveyed checkpoints that were not used in the registration process, (also known as blind checkpoints).

4.1.7 LiDAR Advantages / Disadvantages

Surveys collected using aerial LiDAR have both advantages and disadvantages when compared with ground survey methods as follows:

<u>Advantages:</u>

1. Like aerial photography, LiDAR data sets provide a permanent record of the existing terrain conditions at the time of aerial survey.

2. The information extraction may be limited to bare-earth terrain or extend to other data on an as needed basis. It is possible to extract planimetric data from LiDAR as well. Vegetation may be extracted as 3D points, (or cloud data), defining the vegetation extents in 3d space. The vegetation classed points can also be sub-classified based on height which may be useful for identifying line of sight issues.

3. The information extracted from a LiDAR point cloud provides more detailed information to designers and environmental personnel with respect to topography. It can also offer 3D point cloud visualization opportunities that could prove useful for line of sight analysis and alignment study.

4. When collected in combination with aerial photography, the LiDAR point cloud can be colorized based on the orthophoto rectified imagery to create realistic 3D models. This is especially effective

when using high-density LiDAR data sets. The 3D models offer any number of views that might be useful for conveying information to the general public or other governmental agencies.

5. LiDAR can be used for multiple purposes within CDOT such as, preliminary design, drainage analysis, and roadway clearance for power lines and vegetation.
6. Topographic mapping and DTMs of large areas can be accomplished with more detail than using photogrammetry, relatively quickly, and may be more economical than ground survey methods depending on project size and ground conditions.
7. Data points in a LiDAR point cloud are geographically referenced by means of GPS/IMU technology. Each point is solved for in ellipsoid elevation. The most current geoid information is then applied to the elevations to arrive at orthometric values. There is no initial least squares adjustment application as required for the relative orientation of photographs. Secondly, there is no interpolation of positional values by visual means; therefore the relative accuracy is higher than that which can be achieved photogrammetrically. It should be noted that final achievable absolute accuracy is a dependent on the application of aerial project control that has been tied to the primary control network.
8. LiDAR can be used in locations that are difficult or impossible to access from the ground.
9. LiDAR is more successful than photogrammetric methods at achieving ground returns in vegetated areas. As a rule, if any sky can be seen when looking straight up from ground level, some ground returns can be expected.
10. If collected as a stand-alone data set, (without aerial photography), it can be collected at any time of day or night.

<u>Disadvantages:</u>

1. LiDAR must be collected in appropriate weather conditions. While not as demanding as aerial photography, there must be no rain, snow, fog or smoke between the sensor and the ground. While LiDAR has more opportunity to provide ground data than photogrammetry in wooded areas, it doesn't penetrate full cover. Heavy vegetation canopy may completely obscure the ground.
2. Classification of LiDAR ground returns in areas of thick, low vegetation becomes less reliable. The last return from a pulse could be erroneously classified as ground when the last reflection was just short of ground. Using photogrammetry, these land cover types are subject to visual interpretation and points may be interpolated by an experienced photogrammetrist with greater success.
3. Since LiDAR data is dependent on Airborne GPS, accuracy is limited to the accuracy of the Airborne GPS solution and applied geoid model until calibrated to the project ground survey control. This makes it more dependent on low satellite PDOP (Positional Dilution of Precision) levels than aerial photography. It should be noted that conventional ground survey methods using appropriate elevation procedures, still provide the most accurate measurements.
4. Depending on the density of the data set, without the aid of photogrammetry, identification of planimetric features can be difficult, (e.g. curb and gutter, hydrants, manholes, small road signs, etc.) Since it is an aerial view, size of culverts may be difficult if not at all possible along with any other feature that cannot be seen or measured from above.
5. Processed LiDAR data sets are very large. Point clouds delivered in .LAS or ASCII format to CDOT as project source data must be tiled to manageable file sizes. (Contractors should deliver the point clouds just as they would deliver film or raw imagery to CDOT for a photogrammetry project archive.)
6. The type of material used for construction of fences, buildings, or other man-made features is not

interpretable from aerial LiDAR.

7. Underground utilities cannot be located, measured or identified.
8. Right of Way and property boundary monuments can-not be located, measured, or identified.
9. Building overhangs, overhead walkways and bridges will result in ground data occlusions.

4.1.8 Pre-survey Conference – Aerial Survey

Prior to beginning any aerial survey activities a Pre-survey Conference for Aerial Surveys shall be held. The CDOT Region Survey Coordinator or designee shall work closely with the aerial mapping consultant during the pre-survey conference to review the scope of work and ensure products will meet the needs of the project. This close working relationship shall continue through the duration of the project to ensure that CDOT receives an accurate, quality, and useable product. Any known error or oversight on the plans or specifications shall be discussed at the pre-survey conference. The project manager will communicate any modifications to the scope of work to all affected parties following the conference. The project manager shall notify all parties listed below at least two weeks prior to the conference. The following individuals should attend the Pre-survey Conference for Aerial Surveys:

1. CDOT Region Survey Coordinator or designee
2. CDOT Region Right of Way Plans Coordinator or designee
3. CDOT Design Engineer or designee
4. CDOT or Aerial Survey Consultant Survey Crew Chief
5. Aerial Survey Consultant/Photogrammetrist
6. Any appropriate subcontractor personnel

The surveyor in responsible charge for the survey fieldwork shall have the following reference materials at the pre-survey conference:

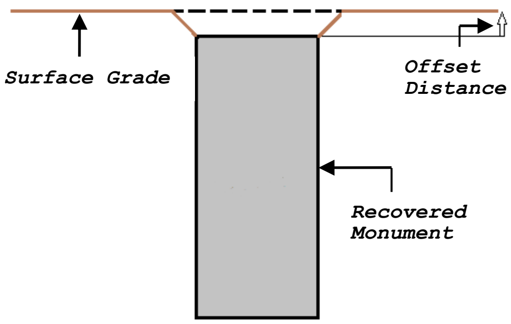
1. Project Plans if available (*e.g.* Project Control Diagram if supplied by CDOT)
2. CDOT Standard Plans (Mapping & Survey Standards)
3. CDOT Survey Manual
4. Manual of Uniform Traffic Control Devices (MUTCD)

See Appendix Pre-survey Conference – Aerial Survey Form, for additional information.

4.2 Ground Control for Aerial Surveys

4.2.1 General

Aerial survey data must be referenced to ground control points in order to maximize the absolute accuracy achievable for the aerial data. This is achieved by survey crews establishing photo ground control within the project area. Targets are placed over ground control so that the location of the point is easily identified on the imagery. The field measurement of the horizontal and vertical elevation (X, Y and Z) of the control points will be used in the downstream processes of photogrammetry and/or point cloud calibration to register the data sets to field survey values. Elevations, (Z), must be provided at surface grade. If a target is laid over a monument that is below grade, the offset elevation must be applied to the elevation since the aerial control target will be measured at surface grade. The diagram at left illustrates monument targeted below grade.



4.2.2 Ground Control Targeting Requirements

Ground control requirements for aerial mapping will be predicated upon flying height, terrain, equipment, accuracy requirements and technology applied for data acquisition. To meet the design scale accuracy requirements described in this Chapter, an aerial mapping project should be controlled by pairs of inter-visible points not more than 1,500' apart. A control point targeting plan at this density would satisfy ground control requirements for a photogrammetric approach using a mapping grade, large format film camera with FMC flying at 1,500' AGL.

By applying AGPS/IMU, INS technologies and modern digital sensors it is possible to reduce the density of targeted ground control significantly. However, multiple variables must be considered. These include specific sensor capabilities and specifications, flying height, frequency and quality of AGPS signal and distance to GPS base stations.

CDOT recommends the following when applying AGPS technologies:

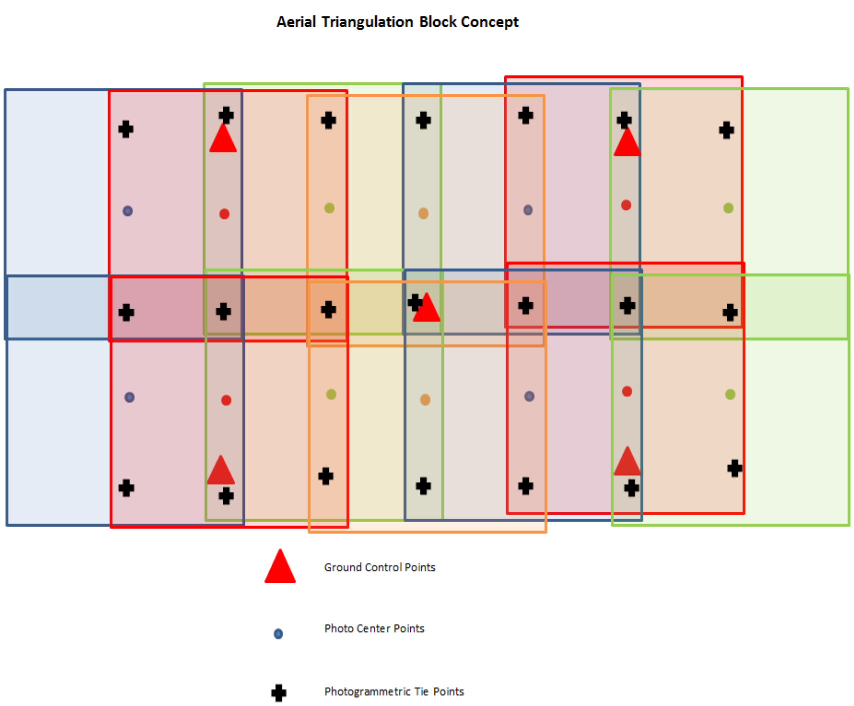
1. A minimum of five (5) targets or PID points for any aerial mapping project;
2. A maximum spacing of 1 mile between pairs of points along a mapping corridor;
3. A minimum of one control point to tie lines together where broken to accommodate a heading change along a corridor.

The aerial mapping consultant is responsible for determining and specifying all aerial control monument locations, material, spacing, and configurations for the survey. The CDOT Region Survey Coordinator or designee shall work closely with the aerial mapping consultant when determining what monumentation shall be used for control points.

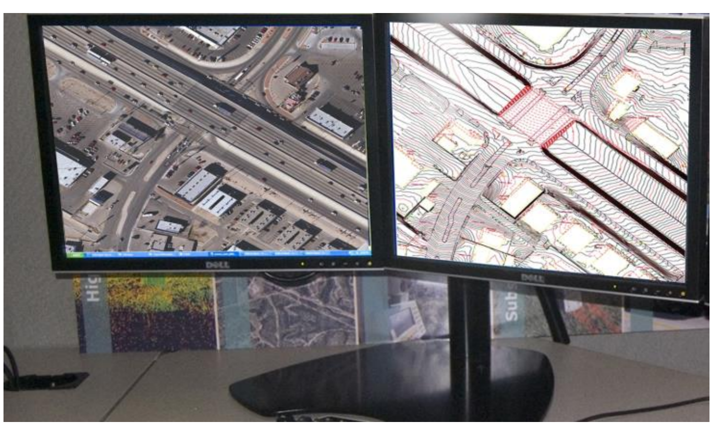
See Chapter 1 – General, Appendix Survey Monuments M-629-1, for additional information.

4.2.3 Photogrammetry

The control points must be visible from a minimum of two overlapping photographs. To apply the basic principle of photogrammetry, at least three photo ground control points are needed for any single stereo model, (one overlapping pair of photographs) or block of adjoining stereo models. This establishes the spatial relationship between the ground and the model coordinates. One or more additional points are required to determine the accuracy of the model based residual error and to identify any data entry errors. When controlling multiple models or blocks of photography, aerial triangulation is applied serving to bridge control across multiple stereo models by combining their relative orientations with the ground control measurements. The following diagram illustrates the aerial triangulation concept for a small block of photographs.



The photo coordinates of identifiable points on the ground (*i.e.* photo ground control points) are measured on multiple photographs, (at least two), along with other image locations, or tie points, common to multiple photographs to begin the aerial triangulation process. From these measurements and the camera calibration data, a trigonometric calculation determines the camera (focal point) location and sensor attitude for each exposure. Finally, a least squares adjustment is applied to the entire block, refining relative orientations of each image and registering the block to ground control for absolute orientation.



The aerial triangulation output allows analysis of stereo models using a digital softcopy workstation to produce photogrammetric mapping and terrain modeling. Digital workstations allow the operator to accurately compile and record data in 3D. The aerial triangulation data can also be used in combination with the camera calibration data and DTM to produce orthophotography.

More modern aerial survey acquisitions apply AGPS or a combination of AGPS and IMU technology. This is supported by collection of data at static ground base stations during the aerial survey. AGPS provides additional control to aerial photography by establishing a coordinate value for each photo center. In addition to AGPS, aerial imagery may be combined with IMU data to provide a more accurate photo center along with the camera attitude and heading, (tip, tilt, swing), also known as direct geo-referencing. For photogrammetry, the direct geo-referencing provides additional input to aerial triangulation process, facilitating more automation. Modern aerial triangulation software automates the selection of photogrammetry tie points. This allows a much larger number of tie points to be incorporated into the aerial triangulation solution improving overall results.

4.2.4 Aerial LiDAR

LiDAR requires both AGPS and IMU data. These inputs provide a relative positioning solution. A minimum of two base stations should be used to provide a basis of comparison for the repeatability of the solution and redundancy in case of equipment failure. While not necessarily within the mapping boundaries, base stations must be tied to the ground survey network associated with the mapping project. To meet the 0.25’ class vertical accuracy described in this Chapter, CDOT recommends that base stations not be more than 25 miles from the sensor at any time during the data acquisition. Application of this technology can reduce the number of targeted control points required. This may be helpful by reducing the necessity for Wing Point Control as these points tend to fall beyond the transportation right of ways and may be difficult to place.

The aerial mapping consultant is responsible for determining control requirements for the aerial survey. Final photo control monument locations, spacing, and configurations for the survey may be influenced by conditions. It is important that the aerial mapping consultant and field survey team work in close coordination to ensure control requirements for the project are met. Additional considerations include the type of sensor employed, the technology applied, and the required positional accuracy of the data. The CDOT Region Survey Coordinator or designee shall work closely with the aerial mapping consultant when determining how many and where each photo control point shall be located.

4.2.5 Equipment Checking and Calibration

Checks and calibrations on all types of electronic survey equipment are essential to obtain and maintain the minimum tolerances required for aerial surveys. Equipment must be properly maintained, regularly checked, and calibrated for accuracy at the beginning of any aerial survey project to ensure that the equipment is operating properly in accordance with Chapter 2 – General Procedures, and Chapter 3 – GPS Surveys of this manual. It is the aerial consultant’s responsibility to ensure no errors due to poorly maintained or malfunctioning equipment will affect the project. For surveys lasting longer than six months, the checking, and calibration of equipment shall be repeated once every six months to ensure equipment will meet the needs and specifications for the project.

See Chapter 2 - General Procedures, and Chapter 3 – GPS Surveys, for additional information.

4.2.6 Permission to Enter Property Form 730a

If it becomes necessary for a survey crew to enter property outside of CDOT Right of Way the property owner or occupant shall be contacted before a survey crew enters the property. The purpose of this contact is to inform the owner or occupant that an entry is required, to explain what survey activities are to be performed, to indicate the duration of the survey and any effect it may have on the property. A permission to Enter Property Form 730a should be completed in order that survey crews will have permission, in writing, for performing their assigned functions. The owner or occupant at this time is to be advised to use section “Conditions requested by Owner” of the permission form to place certain restrictions on the activities (*i.e.* time limitations, where vehicles may drive, cutting of brush, digging holes or if notice needs be given before entering property).

See Chapter 2 – General Procedures, Appendix CDOT Permission to Enter Property Form 730a, for additional information.

4.2.7 Underground Utility Locates Prior to Installing Photo Control Monumentation

Once the aerial control survey sites are identified, and if installation of new monumentation is required, each site shall be marked with a lath with white paint and/or flagging and underground utility locates shall be called for prior to establishing the monument. Depending on specific project requirements, some control points may only require semi-permanent monumentation such as a nail in asphalt or rod iron bar and cap outside of the ROW, in which case locates will not be required.

See Chapter 2 – General Procedures, Underground Utility Locates Prior to Installing Monumentation, for additional information.

4.2.8 Aerial Ground Control Monumentation

Survey crews establish ground control points for aerial surveys. Targets are placed over the control points on the ground so that the location of the point is easily identified in the aerial survey. Depending on the contract scope of work, control survey may be performed by either the aerial mapping consultant or by CDOT survey crews. The aerial consultant will be responsible for the targeting of control points to ensure identification in the aerial imagery.

Photo control points typically consist of the following:

1. Photo Center points
2. Photo Wing points

4.2.9 Center Point Control

Center (*i.e.* flight line) point control is established as close to the center of the flight line as possible. Their location and configuration is dependent upon the flight height. For highway work the closest to the flight line center that is most often achievable on the ground is on the shoulder of the highway. Whenever possible CDOT primary control monuments that have been previously established on the ground by a primary control survey as defined in Chapter 5 – Preliminary Surveys shall be used for all photo center control monuments. This allows the aerial control survey to be horizontally and vertically referenced and tied directly to the primary control established on the ground as the framework for the survey control network without having to install additional monuments. This also greatly reduces the amount of field surveying needed to establish photo ground control since the primary control monuments need only to be targeted.

CDOT control monument caps or disk shall not be set for any photo center control point, unless the point has or will be established as part of a CDOT Class A – Primary survey as defined in Chapter 5 – Preliminary Surveys.

For projects where no CDOT primary control monuments have been previously established on the ground, the aerial center control point shall be monumented with a CDOT Type 5 or Type 6 aluminum monument and stamped with the appropriate aerial control point number or name. In areas where a Type 5 or Type 6 monument is not suitable or desired, the monument shall consist of a material that when set solidly into the ground will prove to hold the required Minimum Horizontal and Vertical Accuracy Tolerance for the aerial control survey.

Examples of these types of monuments may include the following:

1. Public Land Survey System (PLSS) monuments
2. Right of Way monuments
3. Federal, State, or local agency monuments
4. Benchmark monuments
5. Boundary monuments
6. CDOT Type 5 or Type 6 monuments
7. 5/8 inch rebar with no cap (set for temporary monuments only)
8. Nail set in asphalt (set for temporary monuments only)

CDOT Type 5 or Type 6 photo center control monument materials shall be furnished by CDOT in accordance with M & S Standards M-629-1.

See Chapter 1 – General, Appendix Survey Monuments M-629-1, for additional information.

4.2.10 Wing Point Control

Wing point control is established at the right or left outer edge of the flight lines. These points become more critical for flight plans that include multiple flight strips run parallel to one another. Their location and configuration is dependent upon the flight plan.

CDOT control monument caps or disk shall not be set for any photo wing control point, unless the point has or will be established as part of a CDOT Class A – Primary survey as defined in Chapter 5 – Preliminary Surveys.

Wing point control shall be monumented with a CDOT Type 5 or Type 6 aluminum monument and stamped with the appropriate aerial control point number or name. In areas where a Type 5 or Type 6 monument is not suitable or desired, the monument shall consist of a material that when set solidly into the ground will prove to hold the required Minimum Horizontal and Vertical Accuracy Tolerance for the photo control survey.

Examples of these types of monuments may include the following:

1. Public Land Survey System (PLSS) monuments
2. Right of Way monuments
3. Federal, State, or local agency monuments
4. Bench mark monuments
5. Boundary monuments
6. CDOT Type 5 or Type 6 monuments
7. 5/8 rebar with no cap (set for temporary monuments only)
8. 60d or larger nail set in asphalt (set for temporary monuments only)

CDOT Type 5 or Type 6 wing control monument materials shall be furnished by CDOT in accordance with M & S Standards M-629-1.

See Chapter 1 – General, Appendix Survey Monuments M-629-1, for additional information.

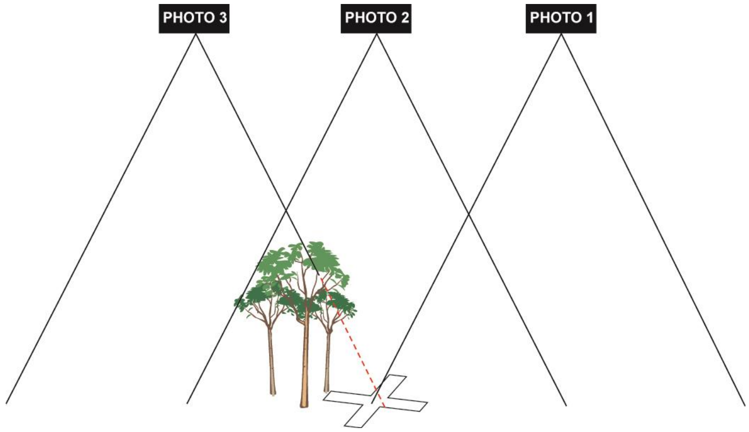
4.2.11 Aerial Control Targets (Paneling)

Targets (*i.e.* paneling) shall be placed on the ground symmetrical and centered over aerial control points in order that the location of the point is easily identified in the imagery. The paneling width and configuration is dependent upon the flight height for aerial photography. The material or biodegradable paint used to target the control should contrast surface surrounding the target. (IE: White in most instances, however, if the surface is very light colored, a black target may be preferable.)

4.2.11.1 Photogrammetry

For photogrammetric measurement made during the aerial triangulation process, the target must be clearly visible on multiple images. A minimum of two adjacent images allows measurement but accuracy increases with the number of images the target can be seen from. Ideally, targets should be visible from aerial view between 90 and 60 degrees above horizon in all directions. Trees or structures may obscure view of the target. See below.

Diagram 1: Example of a visibility problem: Target visible on only one of two possible image pairs.



Ideally, the targets should be placed on the ground just prior to the aerial survey, and should be maintained until the aerial mission has been flown and the data has been accepted. This reduces the risk of the targets being disturbed prior to the aerial survey.

4.2.11.2 LiDAR

The aerial consultant is responsible for ensuring that the aerial target design meets the identification needs for the aerial survey. The reflectivity of the surround surface must be considered. The reflective properties for various surfaces may differ slightly between LiDAR and RGB light. For example, moist grass can be highly reflective making a white target difficult to identify in LiDAR intensity imagery. The density of the LiDAR GSD must also be considered. Target legs will need to have a minimum width 2X greater that the planned GSD of the LiDAR data. Length of legs should be 4X the width. Secondly, the area around the control point should be level for a radial distance greater than the nominal spacing between LiDAR returns. Lower densities of returns may necessitate larger target dimensions. At very low density it may be necessary to validate LiDAR horizontal accuracy by using the known coordinates for large features in the imagery such as building corners or asphalt areas on the ground. If the LiDAR was flown in conjunction with aerial photography these coordinates may be obtained photogrammetrically.

4.2.12 Aerial Control Target Design & Material

The target design shall be symmetrical and centered on the aerial control point. There are three designs commonly applied for aerial surveys. These include four-legged “X” targets, three-legged “Y” targets), and two-legged “L” targets. More than one type can be used for a project if there is a need to distinguish between different types of control, such as wing and center control point targets. The length and width of the target legs will depend on the specifications of the flight mission. The principal drivers will be flying height or GSD of the resulting data.

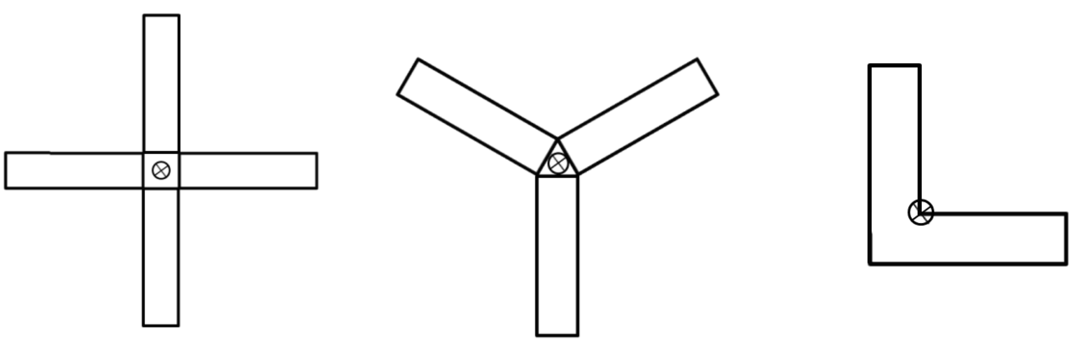


Diagram 2: “X” Type Target *Diagram 3: “Y” Type Target* *Diagram 4: “L” Type Target*

If paint is used to target aerial control point locations it must be of a type that is biodegradable and washes away within six months. Suggested materials for targeting include opaque polyethylene film (visquine of four to six mils thickness), unbleached white muslin or white cotton bunting. In flat terrain, plywood or masonite, painted flat white, may be used. When using either polyethylene film or material, it may be necessary to secure the target to the ground, either by stakes or nails. Placing rocks or dirt along the edges of the material may also help to keep it flat on the ground.

Natural target features, also known as Photo ID points or PID's may be used in lieu of artificial targets provided that a reasonably large angle of intersection exists to positively identify a point. Examples include sidewalk intersections, corner of concrete slabs, existing paint markings on asphalt, or other clearly visible feature from which a precise location can be interpreted. The illustration at right is an example of a PID control point observed at a sidewalk corner. This point would be ideal for photogrammetry or LiDAR control. The elevation should be measured at the sidewalk surface at the edge of the where it aligns with the sidewalk surface extending to the right.

The aerial mapping consultant is responsible for determining and specifying target dimensions, material, and configurations for the survey crews to layout. The CDOT Region Survey Coordinator or designee shall work closely with the aerial mapping consultant when determining how monuments are to be targeted.

4.2.13 Removal of Aerial Control Target Material

To maintain proper public relations all man made target material placed over aerial control points shall be removed and the site cleaned up within seven days of confirmation that aerial survey was successfully acquired and no re-flights are necessary.

Unless directed otherwise, all aerial control monuments on public property shall be left in place and undisturbed for future use if needed. Monuments set on private property may require removal depending on what has been agreed to by the property owner or tenant. The removal must be completed on a schedule agreed to by the owner or tenant. Aerial control monuments shall only be removed with the approval of the CDOT Region Survey Coordinator.

4.3 Aerial Control Horizontal Survey

4.3.1 Aerial Control Horizontal Survey Datum

All aerial control horizontal surveys shall be referenced and tied into the CDOT primary control survey as defined in Chapter 5 – Preliminary Surveys.

As defined in Chapter 5 – Preliminary Surveys, the purpose of a primary control survey is to establish a network of physically monumented coordinate points in and along a highway corridor that provide a common horizontal and vertical datum for the entire project. The primary control survey provides the means for tying all of the geographic features and design elements of a project to one common horizontal and vertical coordinate system. The primary control survey is performed at a higher level of accuracy than the aerial control survey, as such the aerial control survey shall be considered secondary control.

For projects where no CDOT primary control survey has been completed, the CDOT Region Survey Coordinator shall be contacted and a determination made if a primary control survey is to be completed prior to the aerial control survey. CDOT discourages the practice of performing any aerial control survey without a previously established primary control survey already in place, as this causes accuracy and coordinate conversion problems at a later date.

If a primary control survey will not be performed, all aerial control horizontal surveys shall be referenced to and tied into the National Spatial Reference System (NSRS) as defined by the National Geodetic Survey (NGS)

As stated in Chapter 5 – Preliminary Surveys, NGS defines and manages the NSRS, the framework for Latitude, Longitude, height, scale, gravity, and orientation throughout the United States. The NSRS provides the foundation for transportation, communication, and defense systems, boundary and property surveys, land records systems, mapping and charting, and a multitude of scientific and engineering applications. NGS also conducts research to improve the collection, distribution, and use of spatial data.

The National Geodetic Survey defines and manages the National Spatial Reference System (NSRS). The NSRS is a consistent coordinate system that defines latitude, longitude, height, scale, gravity, and orientation throughout the United States and is designed to meet the nation's economic, social, and environmental needs. The NSRS has traditionally been defined by survey marks in the ground. More recently, the horizontal datum is defined by the continuously operating reference stations (CORS).

The current datums are the North American Datum of 1983 (NAD 83) and the North American Vertical Datum of 1988 (NAVD 88). NAD 83 (2011) epoch 2010.0 is the latest realization of the horizontal datum. Both the horizontal and vertical datums will be replaced around 2022.

See Chapter 5 – Preliminary Survey, and Chapter 3 - GPS Surveys, for additional information.

4.3.2 Minimum Aerial Control Horizontal Survey Accuracy Tolerance

All aerial control horizontal surveys shall meet the Minimum Horizontal Accuracy Tolerance for a CDOT Class B – Secondary survey as required in Chapter 5 – Preliminary Surveys.

4.3.3 GPS Photo Control Horizontal Survey Methods

All aerial control horizontal surveys performed by GPS methods shall be performed in accordance with Chapter 3 – GPS Surveys, and shall meet the Minimum Horizontal Accuracy Tolerance for a CDOT Class B – Secondary survey as required in Chapter 5 – Preliminary surveys.

Unless field conditions do not permit, (*e.g.* obstructions of the sky by trees, buildings, etc.) only Global Positioning System (GPS) survey methods shall be performed for all aerial control horizontal surveys.

Those aerial control horizontal surveys performed by survey methods other than GPS shall be approved in advance by the CDOT Region Survey Coordinator.

Unless approved otherwise by the CDOT Region Survey Coordinator, all GPS aerial control monuments (center and wing points) shall be observed by Static or Fast Static GPS survey methods and procedures in accordance with Chapter 3 – GPS Surveys. RTN data may be acceptable for supplemental ground truth purposes or other applications upon approval. Any type of RTK survey used must be post-processed and its application approved by the CDOT Region Survey Coordinator.

4.3.4 Conventional Aerial Control Horizontal Survey Methods

All aerial control horizontal surveys performed by conventional survey methods shall consist of a closed traverse or closed loop survey in accordance with Chapter 5 – Preliminary Surveys, and shall meet the Minimum Horizontal Accuracy Tolerance for a CDOT Class B – Secondary survey as required in Chapter 5 – Preliminary Surveys.

4.4 Aerial Control Vertical Survey

4.4.1 Photo Control Vertical Survey Datum (NAVD 88)

All aerial control vertical surveys shall be referenced and tied to the North American Vertical Datum of 1988 (NAVD 88) or the latest vertical datum produced by NGS. This is typically accomplished when referencing and tying the aerial control vertical survey to a CDOT primary control survey that has been previously referenced and tied to NAVD 88 datum in accordance with Chapter 5 – Preliminary Surveys.

For projects where no CDOT primary control survey has been completed, elevations for any aerial control vertical survey shall be established from existing national bench marks and referenced and tied to the North American Vertical Datum of 1988 (NAVD 88) in accordance with the methods and procedures as defined in Chapter 5 – Preliminary Surveys.

4.4.2 Minimum Aerial Control Vertical Accuracy Tolerance

All aerial control vertical surveys shall meet the Minimum Vertical Accuracy Tolerance for a CDOT Class B – Secondary survey as required in Chapter 5 – Preliminary Surveys.

As required in Chapter 5 – Preliminary Surveys, the following Minimum Vertical Accuracy Tolerance shall apply to all CDOT Class B – Secondary surveys including photo aerial surveys (center and wing points):

The square root of the total horizontal distance of the differential level loop in miles multiplied by 0.035 feet.

$$0.035\,ft\sqrt{d}$$

4.4.3 GPS Aerial Control Vertical Survey Methods

All aerial control vertical surveys performed by GPS methods shall be performed in accordance with Chapter 3 – GPS Surveys, and shall meet the Minimum Vertical Accuracy Tolerance for a CDOT Class B – Secondary survey as required in Chapter 5 – Preliminary Surveys.

As required in Chapter 3 – All GPS derived elevations shall be verified or supplemented with elevations by a more accurate survey method as follows:

1. Differential leveled elevations in accordance with the methods and procedures as stated in Chapter 5 – Preliminary Surveys.
2. Trigonometric elevations by conventional survey methods such as a total station in accordance with the methods and procedures as stated in Chapter 5 – Preliminary Surveys.

4.4.4 Conventional Aerial Control Vertical Survey Methods

All aerial control vertical surveys performed by conventional survey methods shall consist of a closed loop survey in accordance with Chapter 5 – Preliminary Surveys, shall meet the Minimum Vertical Accuracy Tolerance for a CDOT Class B – Secondary survey as required in Chapter 5 – Preliminary Surveys.

4.5 Aerial Control Survey Report

4.5.1 General

Upon completion of the aerial control survey, whether performed by the consultant or CDOT survey crews, an Aerial Survey Report shall be completed and filed with the CDOT Region Survey Coordinator. The project shall not be accepted as final without the Aerial Control Survey Report.

4.5.2 Aerial Control Survey Report

The Aerial Survey Report shall include the following information:

1. CDOT Project name
2. CDOT Project number
3. CDOT Project Code number
4. Highway number
5. Beginning and ending mile post
6. Sections, Townships, and Ranges
7. Permission to Enter Property Forms
8. Survey Equipment Checking and Calibration Report
9. Date of survey
10. Date of targeting
11. Date to be photographed
12. Survey crew names, titles and duties
13. Surveyor's seal and signature
14. Description of all found or set photo control monuments (center and wing points)
15. Underground Utility Locates
16. Description of targeting design and material (center and wing points)
17. Basis of Bearing
18. Basis of Elevation
19. Coordinate Datum
    a. Horizontal Datum
    b. Vertical Datum
    c. Project Elevation
    d. State Plane Coordinate Zone
    e. Project Combined Factor
    f. Meters to Feet Conversion (U.S. Survey Foot = 3937/1200)
    g. Northing Reduction (truncated)
    h. Easting Reduction (truncated)
    i. For local low-distortion coordinate systems: A detailed statement of how to convert from the primary system, (such as State Plane), to project coordinates.
20. Geodetic Coordinate listing
    a. Point's number or name
    b. Latitude
    c. Longitude
    d. State Plane coordinate North
    e. State Plane coordinate East
    f. Ellipsoid height (if GPS used)
    g. Orthometric height (elevation)
    h. Geoid model (if applied)
    i. Mapping angle
    j. Scale
    k. Point description (including, highway, milepost, and monument type, *e.g*. Type 2)

21. Project Coordinate listing
    a. Point’s four digit number
    b. Northing
    c. Easting
    d. Elevation (orthometric)
    e. Point description (including, highway, milepost, and monument type, *e.g*. Type 2)

4.6 Aerial Topo Mapping Standards

4.6.1 CDOT CADD Standards

Topographic aerial survey data features and contours shall be output to MicroStation/InRoads DGN, DTM, and TIN format applying CDOT's current configuration files.

4.6.2 MicroStation/InRoads Configurations for Consultants

CDOT provides MicroStation configuration files and instructions for installation on-line at the CDOT Business Center website. Downloads to configure for a number of MicroStation V8 versions are available here: https://www.codot.gov/business/designsupport/cadd/microstation-inroads-configuration

The configuration will provide seed files, cell libraries and set-up MicroStation Level menus.

4.6.3 MicroStation Level Structure

CDOT's MicroStation/InRoads configuration provides the graphic attributions for all features identified and collected for mapping purposes. The MicroStation configuration provides MicroStation "Level" names beginning with a category, followed by feature name, and finally a feature descriptor. (E.g. TOPO_BUILDING_Garage) Many Levels include a feature descriptor that is beyond the degree of interpretation that can be accomplished successfully from aerial surveys. For these features there will be Levels with "Miscellaneous", "Other" or "Unknown" descriptors that shall be used for photogrammetric feature compilation. Where the feature can be identified to the full degree provided by the descriptor, it should be assigned the correct MicroStation Level.

4.6.4 Aerial Survey – Photogrammetric Feature Identification

Required features that cannot be identified by aerial survey methods will be field collected by means of a post-aerial or pre-aerial ground survey. Likewise, required features mapped within the aerial project scope that could not be positively or fully identified by the photogrammetrist shall be field identified in a Post-Aerial survey. The map compilation process shall use MicroStation Levels with feature descriptors as indicated in 4.6.3 to ensure their identification for the post-aerial ground survey. It should be anticipated that completion of the feature identification will require ground surveys.

The aerial mapping consultant is responsible for determining which features can be identified. The CDOT Region Survey Coordinator or designee shall work closely with the aerial mapping consultant when determining which features require further identification.

4.6.5 Post Aerial or Pre-Aerial TMOSS Supplemental Surveys

TMOSS Supplemental surveys shall be performed on the ground to compliment the aerial survey within the existing constructed transportation corridor template, and shall be performed in accordance with the methods, procedures, horizontal and vertical accuracies tolerances as required in Chapter 5 – Preliminary Surveys. The supplemental survey fieldwork may be performed by the consultant or by CDOT survey crews as required in the project scope and shall utilize CDOT Level Structure.

The purpose of the supplemental survey is to locate those features that require a higher level of accuracy than that of the aerial survey, to locate those features that cannot be located by the aerial survey, and to collect information not apparent to the photogrammetrist from the aerial survey.

The aerial mapping consultant is responsible for determining which aerial survey features may need supplemental identification, the CDOT Region Survey Coordinator or designee shall work closely with the aerial mapping consultant when determining which features require supplemental surveying.

4.6.6 Minimum Horizontal and Vertical Accuracy Tolerance for TMOSS Supplemental Survey

All supplemental surveys performed on the ground to complete the aerial survey shall be performed in accordance with the methods, procedures, and the Minimum Horizontal and Vertical Accuracy Tolerance as required in Chapter 5 – Preliminary Surveys.

No payment will be made for supplemental survey data conducted by the consultant until the data has been verified (See Method of Verifying Accuracy Tolerance 4.7.4, for additional information) to be within the required topographic survey Minimum Horizontal and Vertical Accuracy Tolerance as required in Chapter 5 – Preliminary Surveys . Any data not within the required tolerances will be rejected, reworked by the consultant, re-verified to be within required tolerances, and re-submitted at no additional cost to CDOT.

4.7 Aerial Mapping Tolerances

The American Society for Photogrammetry and Remote Sensing (ASPRS) has published aerial map accuracy standards titled ASPRS Positional Accuracy Standards for Digital Geospatial Data. The first edition was published in 2014, (Edition 1, Version 1.0 – November, 2014). The intention is to conform to universally accepted standards by adopting these expressions to state project accuracy requirements. ASPRS Accuracy Classes are expressed in terms of Root Mean Square Error (RMSE). The tables below provide ASPRS Accuracy Classes for horizontal and vertical accuracy, along with the corresponding expression of accuracy at 95% confidence. The tables are modeled after those provided by ASPRS. The ASPRS Accuracy Class in the tables below represents the typical project accuracy tolerance for CDOT Aerial Mapping. The accuracy tolerance is stated in relation to the project primary control monuments.

NOTE: The project scope of work may indicate different accuracy tolerances as appropriate to the individual project and approved by the CDOT Region Survey Coordinator.

4.7.1 Aerial Mapping Horizontal Accuracy Tolerance

Horizontal Accuracy Class: 0.25'

For ASPRS 0.25' Horizontal Accuracy Class the corresponding NSSDA expression at 95% confidence is 0.61'. This represents an increase in accuracy compared to the CDOT historical requirement of 1' at 95% confidence. The new requirement acknowledges the benefits offered by digital mapping production processes that have eliminated many sources of horizontal error propagation between source data and final map products. The stated Horizontal Accuracy Class requirement should apply to well-defined planimetric features compiled from any aerial source.

Horizontal Accuracy Class	RMSEx or y	RMSEr	Horizontal Accuracy at the 95% Confidence Level
0.25'	0.25'	0.35'	0.61'

See ASPRS Positional Accuracy Standards for Geospatial Data, Table 7.1 Horizontal Accuracy Standards for Geospatial Data, page A7.

RMSEr represents the RMSE in radial terms by combining X and Y distances.

4.7.1.1 Orthophotography

Horizontal Accuracy Class: 0.5'

The ASPRS Classes for orthophotography are expressed in RMSEx or y. This standard does not associate product accuracy with the GSD of the source imagery, pixel size of the orthoimagery, or map scale for scaled maps. Orthophotography is output as a fixed resolution raster data product. The resolution precision of the data output limits achievable horizontal accuracy compared to data compiled directly from 3D models. For CDOT purposes, orthophotography for standard mapping and GIS work will meet requirements Orthophoto pixels shall represent 0.25' on the ground. The table below represents the expected Horizontal Accuracy Tolerance associated with the orthophotography output at 0.25' resolution.

Horizontal Accuracy Class	RMSEx or y	RMSEr	Orthoimage Mosaic Seamline Maximum Mismatch	Horizontal Accuracy at the 95% Confidence Level	Nominal GSD of Source Imagery
0.5'*	0.5'	0.71'	1.00'	1.22'	0.13 to 0.25'

*for 0.25' foot pixels

See ASPRS Positional Accuracy Standards for Geospatial Data, Table B.3 Common Horizontal Accuracy Classes According to the new Standard, page A13 and Table B.5 Digital Orthoimagery Accuracy Examples for Current Large and Medium Format Metric Cameras, page A13.

Nominal GSD column represents the maximum acceptable GSD for source imagery. No up-sampling of imagery from a GSD lower than the intended output resolution of the orthophotography is acceptable.

4.7.2 Aerial Mapping Vertical Accuracy Tolerance

<u>Vertical Accuracy Class: 0.25’</u>

Aerial mapping minimum vertical accuracy tolerance applies to areas outside of the existing constructed transportation corridor template. The ASPRS Class that corresponds most closely with a tolerance for +/- 1/2 foot at 95% is represented in the table below. The ASPRS Class provides corresponding accuracy tolerances for open areas and hard surfaces as “Non-Vegetated Vertical Accuracy” (NVA) and for vegetated areas, as “Vegetated Vertical Accuracy” (VVA), each in 95% confidence expressions. The stated Vertical Accuracy Class requirement should apply to elevation data compiled from any aerial source.

ASPRS - Vertical Accuracy Class RMSE	Vertical Accuracy at the 95% Confidence Level	
	NVA - Non-Vegetated Vertical Accuracy	VVA - Vegetated Vertical Accuracy
0.25’	0.49’	0.74’

See ASPRS Positional Accuracy Standards for Geospatial Data, Table B.7 Vertical Accuracy/Quality Examples for Digital Elevation Data, page A15 regarding Absolute Accuracy.

4.7.3 Existing Constructed Transportation Corridor Template

The existing constructed transportation corridor template is defined as the area between the points of slope selection. Typically for a two lane highway, this area includes the transportation corridor Z distance, the transportation corridor shoulder, and the transportation corridor traveled way on both sides of the centerline. For an interstate highway, this area includes all of the median as well as the area described above. In urban areas, this includes all the area between the backsides of the sidewalks on both sides of the street.

4.7.4 Obscured Areas

Obscured areas are defined as areas within the aerial mapping project limits where vegetation or tree canopy, dense smoke features are obscuring the aerial perspective. These areas will be identified in such cases where planimetric feature compilation cannot be completed or where there is insufficient elevation data to meet the specified vertical accuracy tolerance for vegetated areas. The areas will be identified with a MicroStation polygon feature and provided to the CDOT Region Survey Coordinator to consider for supplemental ground survey.

4.7.5 Vertical Accuracy Testing - Method of Verifying Accuracy Tolerance

4.7.5.1 Photogrammetry

Accuracy tolerance requirements are evaluated by comparing a cross section string, or a series of random checkpoints taken in the field with the same cross section location, or series of random point locations, extracted from a terrain TIN model produced from the original aerial survey data. The field cross section string is collected by conventional topographic survey methods and is held as the true representation of what exists in the field in relation to the primary control monuments. The interval between observations on the cross section shall be taken at a minimum of 30 feet, include all changes of slope, and shall not exceed the interval of the aerial mapping at the particular cross section.

The field cross section string or random checkpoints are then processed and compared to the TIN model aerial survey cross section or random points. The difference between the sections is evaluated to determine if the delivered product is within the minimum horizontal and vertical aerial mapping tolerances.

The number and location of random checkpoints or cross section strings will vary according to project size, field conditions and specific project requirements. The scope of work shall include a description of the verification requirements on a project by project basis.

4.7.5.2 Aerial LiDAR

Accuracy testing of LiDAR TIN models will be accomplished in the same manner as above. TIN models produced from Aerial LiDAR shall be produced using only breaklines and “Key Points”, a DTM representation of the “Ground” class data returns that has been thinned based on a mathematical algorithm that eliminates redundant points without compromising the intended vertical accuracy requirement. This process significantly reduces file size. Aerial LiDAR TIN models will be produced from DTM data that may contain much fewer breaklines since point density is higher and intelligently concentrated to the key points necessary to accurately portray the terrain surface.

4.8 Aerial Surveys and Photogrammetry Specifications

4.8.1 General

The aerial mapping consultant shall provide specifications meeting the project needs for the following:

1. Camera/Sensor(s)
2. Film or digital imaging requirements, for example: 3-band (RGB), 4-band (RGB&NIR)
3. Scanner type and resolution if film used.
4. Aircraft *
5. Crew *
6. Photogrammetry/geospatial data processing equipment and software

** Only required for flights below 1,000' Above Ground Level (AGL) and flights in FAA designated "Special Use Airspace" or those requiring a written Prior Permission Request (PPR) to land at a military airport.*

All aerial surveys will be conducted in full compliance with FAA rules and regulations. It is the aerial mapping consultant's responsibility to obtain necessary FAA or military authorizations to fly in Special Use Airspace as defined by the FAA's aeronautical charts. The CDOT Region Survey Coordinator may provide assistance as necessary in the form of a letter supporting the request as being in the public interest.

The aerial mapping consultant shall work closely with the CDOT Region Survey Coordinator when determining the aerial mapping specifications.

4.8.2 American Society for Photogrammetry & Remote Sensing (ASPRS)

Personnel qualifications must be appropriate to the planned technical approach. A Certified Photogrammetrist having experience with the planned approach should oversee project design and quality control. Approach and resulting products shall follow relevant guidelines and meet or exceed the current standards set forth by the American Society for Photogrammetry & Remote Sensing (ASPRS) for use in aerial surveys.

See Appendix "ASPRS Positional Accuracy Standards for Geospatial Data", for additional information.

It is the aerial mapping consultant's responsibility to ensure that aerial surveys are conducted in accordance with equipment manufacturers recommendation's and stated limitations in terms of accuracy. The aerial mapping consultant will be ultimately responsible for the aerial system's output suitability in terms of compatibility with downstream processes and final product specifications.

4.8.3 Project Location and Limits

The location and limits of the aerial survey project is indicated in the project provisions. The CDOT Region Survey Coordinator or designee is responsible for determining the aerial survey location and limits. The aerial mapping consultant shall work closely with the CDOT Region Survey Coordinator when determining the aerial survey location and limits.

Location and limits of the aerial survey project need to be clearly defined to ensure complete coverage is acquired. There are several alternative methods to define the location and limits such as on hard copy maps or electronic maps such as GoogleEarth or Bing Maps. (Please note that web-based maps should only be used for planning and general illustration purposes since their spatial accuracy is limited and inconsistent.) Further clarification of the aerial survey location and limits may be provided with some text descriptions. The location and limits of the aerial survey should specify the following:

1. Beginning and end sections
2. Required width
3. Minimum distance on either side of the existing transportation corridor

The aerial survey location and limits shall include the following in addition to the project provisions:

1. For crossroad interchanges with grade separations, the aerial survey shall also include 1,000 feet of the crossroad on each side of the existing transportation corridor centerline.
2. For at-grade intersections, the aerial survey shall also include 500 feet of the crossroad on each side of the existing transportation corridor centerline.
3. The aerial survey shall also include the area necessary for a complete hydraulic design as required in the project provisions and in Chapter 5 – Preliminary Surveys.
4. Aerial Photography shall extend one full photograph beyond the end of the aerial survey location and limits.
5. Aerial LiDAR data shall extend a minimum 300’ beyond all project limits and 900’ past corridor end limits.

4.8.4 Aerial Survey Field Conditions

Field conditions during aerial surveys shall be conducive to the preparation of the final aerial survey products within the required tolerances.

Aerial surveys shall not be conducted when the ground is obscured by clouds, haze, fog, dust, snow, or vegetation, when streams are not within their normal banks, or when flooding conditions exist unless specific waiver is given by the CDOT Region Survey Coordinator.

Aerial survey approach using AGPS must also consider Positional Dilution of Precision (PDOP) during the flight mission. PDOP should be lower than 3.0 and at least six (6) GPS satellites must be available at 10 degrees or more above the horizon at all times throughout the mission. Space weather in the form of excess charged ions entering the earth’s magnetic fields can also present an issue. This condition is caused by solar storms that are also responsible for the “Northern” or “Southern” Light phenomenon. While this condition is rarely at a level that causes significant disruption to signal accuracy, it should be checked before flight. The National Oceanic and Atmospheric Agency’s website, http://www.swpc.noaa.gov/, provides forecasts of for this condition. In Colorado, flights shall *not* be conducted when the predicted K-index exceeds four (4.0).

As a guideline, aerial surveys will be accomplished during the period when deciduous trees are barren, and between 10 A.M. and 2 P.M. (when the sun angle is not less than 30 degrees). The same rule applies to aerial LiDAR systems collecting imagery in conjunction with the LiDAR.

Note: If a project plan calls for a LiDAR-only flight, sun angle becomes irrelevant.

4.8.5 Flight Plan

Prior to any aerial survey the mapping consultant shall submit a flight plan showing the proposed flight lines on a topographic map of the project area or in a digital file that can be geo-referenced with existing mapping or a web-based GIS application. The aerial mapping consultant is responsible for the flight plan and shall work closely with the CDOT Region Survey Coordinator when establishing the flight plan. CDOT reserves the right to comment on the elements of the flight plan, but is not responsible for approval. The consultant is responsible for ensuring that the aerial survey coverage will be adequate to produce the final results required for all the deliverable products.

The flight plan shall at a minimum include the following:

1. Flight lines labeled to show flight height and negative scale or nominal Ground Sample Distance (GSD).
2. CDOT primary control monument locations labeled by number or name.
3. Photo control monuments to be targeted, labeled by number or name

4. The flight plan should be accompanied by a statement describing the intended data acquisition and map production approach to be applied, i.e. AGPS data acquisition, conventional film approach and optical analytical plotter, scanned film and softcopy photogrammetry, fully digital softcopy photogrammetry, or any other aerial survey sensor & approach.
5. Camera calibration report and calibration file as appropriate to sensor(s) planned.
6. Manufacturer's Specification sheets for digital cameras or LiDAR systems planned.

4.8.6 Aircraft

Aircraft maintenance and operation shall be in accordance with Federal Aviation Administration (FAA) and Civil Aeronautics Board (CAB) regulations.

4.8.7 Aerial Data Acquisition

The planning and aerial data acquisition will follow relevant guidelines and shall meet or exceed all of the current American Society for Photogrammetry & Remote Sensing (ASPRS) standards for the following:

1. Flight height (determined by the desired mapping scale and contour interval)
2. Forward and side overlap (typically 60% forward and 30% side for photography)
3. Side overlap for LiDAR (typically 30% but may require increase for urban areas)
4. Aircraft motion; crab, tip and tilt and acceptable departures for each parameter (photography)
5. Nominal Ground Sampling Distance GSD (digital photography)
6. Density of returns; point per unit area (LiDAR)
7. Estimated pulse footprint size (LiDAR)
8. Sensor manufacturer's estimate of accuracy at planned flying height (digital cameras and LiDAR)
9. PDOP – Shall be below 3.0 for the entire flight mission (LiDAR and any photo acquisitions using AGPS data to reduce ground control targeting requirements.)
10. On-board AGPS shall collect data at 1 Hz or more with a constellation of at least 6 GPS satellites at all times during flight.
11. For aerial LiDAR data acquisitions and any photo acquisitions using AGPS data to reduce ground control targeting requirements, CDOT recommends that the Aerial Survey Consultants use minimum of two (2) ground base stations collecting data at 1 Hz or more within 25 miles of the data acquisition platform at all times during flight. Continuous Operating Reference Stations (CORS) may be acceptable as ground base stations assuming they meet the data collection and distance criteria above during the mission.

NOTE: Any aerial data acquisition system employing AGPS shall follow the relevant items 9 through 11 above.

4.8.8 Raw Data

These subsections define the requirements for raw data including digital imagery and LiDAR data.

4.8.8.1 Imagery Quality

The film original negatives or original imagery produced shall meet the current American Society for Photogrammetry & Remote Sensing (ASPRS) standards for clarity and contrast and shall meet or exceed all project needs for the following:

The film original negatives or original imagery produced shall meet the current American Society for Photogrammetry & Remote Sensing (ASPRS) standards for clarity and contrast and shall meet or exceed all project needs for the following:

1. Color (negatives, or RGB imagery)
2. Black and white or monochromatic imagery
3. Infrared (negatives or multispectral imagery)
    a. Color or RGB, IR
    b. Monochromatic imagery

If film is used it shall be exposed in accordance with the manufacturer's recommendations.

The film shall be scanned to digital imagery using a high precision film scanner at a resolution of 15 microns or finer. All digital imagery shall be delivered in a universal digital format so it can be used in a softcopy photogrammetry workflow.

Imagery shall become the property of CDOT. Once the aerial survey has been submitted and accepted all imagery files shall be sent to the CDOT Region Survey Coordinator or designee for inclusion in the project archive.

The required horizontal and vertical accuracy will determine the flight height and photo scale or image GSD of the original photography. (See Section 4.8.5 item 1.)

4.8.8.2 Film Labeling

If film is used it must be labeled prior to scanning. Each negative shall be marked clearly with the following:

1. Numerical abbreviation of the month, day, and year of exposure (*e.g.* 4/19/82)
2. CDOT Project Code (five digits)
3. Flight line number
4. Frame number (e.g. XXXXX 5-15)

The exposures shall run in a series of numbers beginning with the number 1 for each flight line.

The first and last negatives of each flight strip shall carry the approximate time of day of the exposure, the approximate scale, and the nominal focal length of the lens used. This information shall be suitably spaced between the date and the project number (e.g. 4/19/82 11:30 1:12000 6" XXXXX 5 of 15). All lettering and numbering on the negative shall be approximately ¼ inch high and shall result in easily read, sharp and uniform letter and numbers on all photographs (both contact prints and enlargements) printed from the negatives.

4.8.8.3 Aerial Triangulation

Aerial triangulation shall be done under the direction of an ASPRS Certified Photogrammetrist or state licensed aerial survey professional. The process will be conducted in accordance with guidelines set forth for aerial triangulation in the current ASPRS Positional Accuracy Standards for Digital Geospatial Data manual.

The following table provides an example of the accuracy guidelines to output data 0.25 foot in RMSE (0.5 foot at 95% confidence.)

Product Accuracy (RMSEx, RMSEy, RMSEz)	AT Accuracy	
	RMSEx and RMSEy	*RMSEz
0.25'	0.13'	0.13'

See ASPRS Positional Accuracy Standards for Geospatial Data, Table B.2 Aerial Triangulation and Ground Control Accuracy Requirements, Orthophotography and/or Planimetric Data and Elevation Data, page A12.

**If products are for planimetric data or orthophotography only, the RMSEz may be relaxed to 0.25 feet. (See Table B.1 Aerial Triangulation and Ground Control Accuracy Requirements, Orthophotography and/or Planimetric Data Only.)*

Aerial triangulation best practices should include a validation run of the block adjustment with up to 20% of the ground control withheld from the solution. This provides a quantitative quality control step revealing accuracy at known points not incorporated as control in the aerial triangulation. The final block adjustment should include all control points in the solution for application in subsequent geospatial data processing and production.

Aerial triangulation digital output will be delivered along with raw TIF imagery in a universal format approved by the CDOT Region Survey Coordinator. The intent is to ensure that project raw data is available to CDOT should there be a requirement to re-visit or extend the project at a later date. Industry standard output formats from software such as Hexagon (Intergraph) ISAT, Trimble Inpho, Bingo, or any PAT-B output may be acceptable. The provided digital output should provide the following at a minimum:

1. Summary of Aerial Triangulation adjustment results (Including RMSE at Ground Control)
2. Ground control
3. Camera file (calibration data)
4. Photo files
5. Photo measurements
6. Adjusted coordinates
7. Photo centers
8. Exterior orientations

Aerial triangulation digital output will be delivered on portable USB hard drive. (See: 4.9.11 Raw Data Files.)

4.8.8.4 Digital Image Naming Convention

Original digital imagery or scanned film images will be delivered in a TIF format, 8 bit per band. (i.e.: RGB imagery will be delivered in 24-bit TIF format.)

Each TIF image shall be named as followings:

1. CDOT Project Code
2. Flight line number
3. Frame number (For example: 00300-03005)

The first five digits shall be the CDOT Project Code, dash, two digits for flight line number and three for the frame number.

Information such as date & time of exposure, width or number of pixel columns, height or number of pixel rows, and other attribute information shall be available by right clicking on an image in a Windows environment.

Raw digital imagery will be delivered on portable USB hard drive. (See: 4.9.11 Raw Data Files.)

4.8.8.5 Aerial LiDAR - General

Aerial LiDAR may present opportunities to benefit an aerial survey based on advantages described under section 4.1.6. If approved, the consultant will apply industry standard tools and established best practices to ensure source data meets the quality standards required for the map accuracy specification. Data shall be processed to minimize noise, calibrated internally, swath to swath, and finally calibrated to the ground control points. The **ASPRS Positional Accuracy Standards for Geospatial Data** will be the reference document governing accuracy requirements. This includes relative accuracy within a swath as well as swath-to- swath accuracy requirements for internal data calibration. Tables are metric and not all vertical accuracy examples are provided, however, units can be converted and interpolations can be accomplished for any accuracy requirement. An example of vertical accuracy/quality requirements for CDOT 1' contours is as follows:

Vertical Accuracy Class	Absolute Accuracy		Relative Accuracy		
	RMSEz Non-Vegetated	NVA at 95th Percentile	Within Swath Hard Surface Repeatability (Max. Diff.)	Swath-to-Swath Non-Veg. Terrain (RMSEz)	Swath-to-Swath Non-Veg. Terrain (Max. Diff.)
0.25'	0.25'	0.75'	0.15'	0.2'	0.4'

See ASPRS Positional Accuracy Standards for Geospatial Data, Table 7.2 Vertical Accuracy Standards for Digital Elevation Data, page A7.

4.8.8.6 Aerial LiDAR Data Application

Any proposed application of aerial LiDAR approved to support topographic mapping will be planned such that a minimum of eight (8) pulses per square meter (ppm) are collected over the project area during flight. Systems collecting photography and LiDAR data simultaneously must be planned with consideration for limitations of both sensors. *(For example, camera specifications call for a flying height of no more than 1500' to meet the vertical accuracy requirement, the flying height shall not exceed that altitude regardless of whether the LiDAR can meet the requirement at higher altitude.)*

Topographic break lines, as well as planimetric features will be compiled by photogrammetric means. LiDAR ground returns at positions less than 1' distance from photogrammetrically compiled break lines shall be filtered out of the DTM to avoid any adverse effect of horizontal relative accuracy between data sets.

For any approach that combines photography and LiDAR flown separately, the consultant will describe the measures taken to ensure relative accuracy, or registration, between the two data-sets.

While broader applications, such as break line and planimetric data extraction from aerial LiDAR may be tested and considered by CDOT in the future, the guidelines and limitations for such applications have not yet been determined and therefore not included in this chapter.

4.8.8.7 LiDAR Data Calibration Results

A digital record of the LiDAR data calibration accomplished to arrive at final relative and absolute accuracy will be delivered along with the point cloud data in a universal industry standard format. The intent is to ensure that project raw data is available to CDOT should there be a requirement to re-visit the data calibration at a later date. At a minimum, the calibration record should show adjustments made to register to ground control and any internal swath to swath calibration test results demonstrating that specified relative accuracy requirements were met. LiDAR data calibration digital output will be delivered on portable USB hard drive along with the LiDAR Point Cloud. (See: 4.9.11 Raw Data Files.)

4.8.8.8 LiDAR Point Cloud

If LiDAR is flown to support production of topographic mapping the calibrated point cloud will be delivered to CDOT in ASPRS LAS 1.2 (or later) format unless otherwise specified in the scope of work. The data, at a minimum, will be "Ground" classified (see "2" below) and "Model Key Point" following the ASPRS numerical coding for LAS files.

Basic ASPRS LAS numerical coding for LiDAR Data Classes and their definitions are:
0 = Created, never classified
1 = Unclassified
2 = Ground
3 = Low Vegetation
4 = Medium Vegetation
5 = High Vegetation
6 = Building
7 = Low Point ("low noise")
8 = Key Point (Note - For LAS format 1.2 or 1.3 – model key points or subset of ground classified points used for DTM products.)
8 = High Point (For LAS 1.4 or later typically "high noise") - Note that this value was previously used for Model Key Points. *Bit 1* of the Classification Flag must now be used to indicate Model Key Points. This allows the Model Key Point Class to be preserved.
9 = Water
10 = Rail
11 = Road Surface
12 = Overlap points (Note – For LAS format 1.2 or 1.3 Overlap Points are those points that were immediately culled during the merging of overlapping flight lines. For LAS format 1.4, the *Withheld* bit should be set since these points are not subsequently classified.)
12 = Bridge Deck (Note – for LAS format 1.4)
13 = Wire - Guard
14 = Wire – Conductor (Phase)
15 = Transmission Tower
16 = Wire-structure Connector (e.g. Insulator)
17 = Reserved
18-63 = Reserved
64-255 = User definable – The specific use of these classes should be encoded in the Classification lookup Variable Length Record (VLR).
*(Minimum requirements are in **bold**.)*

If required, ASCII files should be in a six (6) column, comma delimited format as follows:
X,Y,Z, Class, Intensity, Echo
Where;
X = easting value in State Plane coordinates in US Survey Feet to 2 places of decimal
Y = northing value in State Plane coordinates in US Survey Feet to 2 places of decimal
Z = orthometric elevation in US Survey Feet to 2 places of decimal
Class = LAS point classification
Intensity = reflectance value of return expressed as an integer
Echo=sequence of return and total number of returns from the associated pulse *(e.g. 1/3, meaning 1st of 3 returns from a LiDAR pulse.)*

LiDAR Point Cloud data shall be delivered on portable USB hard drive. (See: 4.9.11 Raw Data Files.)

4.8.8.9 LiDAR Tile Layout, File Naming

LiDAR LAS files will be delivered in a rectangular tile format. Files should not exceed 2,000 feet by

2,000 feet, assuming data acquisition density of 8 ppm. For projects requiring a higher density of returns, it may be necessary to limit tile sizes to as small as 1,000’ by 1,000’. An intuitive approach to file naming such as truncated lower left coordinate pairs or sequential numbering west to east or south to north is recommended. For projects that include orthophoto deliverables it is recommended that LiDAR tile layouts and naming coincide with the orthophotos. File naming should be pre-determined and approved by the CDOT Region Survey Coordinator or designee in the project planning stage. Any raw LiDAR (.LAS or ASCII) shall be accompanied by a tile index in the CDOT MicroStation configuration format. (See: 4.6.3 MicroStation Level Structure and 4.9.11 Raw Data Files)

4.8.8.10 Re-flights

Unacceptable photography / aerial data coverage shall be corrected at the consultant's expense. Re-flights shall be flown parallel to the original flight line. Re-flight aerial photography coverage shall overlap accepted coverage by two stereo models and shall meet the end and side lap requirements specified. The same camera used on the original flights shall be used on re-flight. Aerial LiDAR re-flights may be flown at right angles or parallel to the original flight lines in the opposing direction to ensure best mission to mission calibration. Overlap distance shall be adequate for line to line and/or mission to mission data calibration.

4.9 Deliverables

4.9.1 General

The following is a list of potential deliverables. Some or all of these may be requested based on project needs. Specific file formats and detailed specifications for all deliverables should be clearly specified in the project scope and reviewed at the Pre-survey Conference – Aerial Surveys.

The aerial mapping consultant and the CDOT Region Survey Coordinator or designee shall work closely together to determine what deliverables, hard prints, and electronic file formats shall be submitted. The due dates for all deliverables should be clearly specified in the contract scope of work.

1. Pre-survey Conference – Aerial Survey Form - (See Section 4.1.8)
2. Photo Control Survey Report - (See Section 4.5.2 and 4.9.9)
3. Flight Plan - (See Section 4.8.5 and 4.9.9)
4. Camera Calibration Report - (See Section 4.8.5 and 4.9.9)
5. Camera Calibration File - (See Section 4.8.5 and 4.9.11)
6. Original Images - (See Section 4.8.8 and 4.9.11)
7. Aerial Triangulation Data (See Section 4.8.8.3 and 4.9.11)
8. Photo Index - (See Section 4.9.2 and 4.9.10)
9. Analytical Aerial Triangulation Report - (See Section 4.9.9 and 4.9.10)
10. LiDAR Data Calibration (See Section 4.8.8.7 and 4.9.10)
11. LiDAR Point Cloud – (See Section 4.8.8.8, 4.8.8.9 and 4.9.10)
12. LiDAR Tile Index – (See Section 4.8.8.9 and 4.9.11)
13. Planimetric Features - (See Section 4.6.4, 4.9.3, 4.9.4 and 4.9.10)
14. TMOSS Supplemental Survey - (See Section 4.6.5)
15. Triangulation Irregular Network (TIN) - (See Section 4.9.6 and 4.9.10)
16. Digital Terrain Model (DTM) - (See Section 4.9.5 and 4.9.10)
17. Contours - (See Section 4.9.7 and 4.9.10)
18. Orthophotography - (See Section 4.9.8 and 4.9.10)
19. Orthophotography Tile Index – (See Section 4.9.8 and 4.9.10)
20. Vertical Accuracy Report (See Section 4.7.5 and 4.9.9)
21. Aerial Survey Report (See Section 4.9.9 and 4.9.10)
22. Any other mapping or aerial survey products defined in the project scope of work

4.9.2 Photo Index

The aerial mapping consultant shall prepare a photo index that references the images captured against the overall project area. It should be possible to identify specific photos or image files at their geospatial locations relative to the project area and other photos. The index should be delivered in a PDF file that can be plotted out on paper at a scale of 2,000' to the inch (1:24,000) on sheets not larger than 22" x 34".

The index shall include the following information:

1. CDOT Project Number
2. CDOT Project Code
3. State highway number
4. Mile post number to mile post number
5. County
6. Consultant name
7. Photographic scale
8. Index scale
9. Camera focal length
10. Flight height
11. Date of photography

12. North arrow
13. Bar scale,
14. Names of principal planimetric features.

4.9.3 Planimetric Features

The aerial mapping consultant will survey all planimetric features identifiable by means of the aerial survey conducted unless limited under contract scope of work. The CDOT MicroStation configuration provides a full list of MicroStation features. Compilation of the identified features should follow the outline provided in 4.6.3. Any further feature identification requirement shall be conducted as described under 4.6.4. Digital products shall be delivered in the CDOT MicroStation configuration format. (See 4.9.10 Deliverable File Naming and Directory Structure)

4.9.4 Planimetric Maps - Nomenclature

The following major planimetric features shall be labeled:

1. Cities
2. Towns
3. Villages
4. Street
5. Roads
6. Rivers
7. Streams
8. Railroads
9. Other features of importance
10. State and federal numbered highways
11. Primary control monuments

All names and numbers shall be legible, not smaller than 1/8 inch in height at intended output scale, clear in meaning and shall not interfere with map features.

4.9.5 Digital Terrain Models (DTM)

The data compiled from the aerial survey to create an InRoads <u>Digital Terrain Model (DTM)</u> consists of <u>3D break lines and mass elevations point</u> locations. Break lines are lines that can be defined on the surface of the Earth along which changes in topographic character can be observed (e.g. ditch bottoms and top of banks, top and toe of embankments, edge of asphalt or concrete, edge of water features, bottom and top of retaining walls; any 3D object that creates a change in the Earth's surface). Random mass points may be used to identify unique or undulating terrain. Digital mapping products shall be delivered in the CDOT MicroStation configuration format. (See 4.9.10 and 4.9.11 for File Naming and Directory Structure)

4.9.5.1 Digital Terrain Models from LiDAR

When using LiDAR to supply mass points, the "ground" class LiDAR should be thinned using an intelligent algorithm that removes redundant data to output a "Key Point" class. The Key Point data, as a subset of the ground class, must meet any maximum spacing requirements for mass points in the DTM. Fewer break lines are expected when developing a DTM from LiDAR. Digital mapping products shall be delivered in the CDOT MicroStation configuration format. (See 4.9.10 and 4.9.11 for File Naming and Directory Structure)

4.9.6 Triangular Irregular Network (TIN)

The consultant will generate and deliver a TIN using the DTM. This will serve as quality control evidence for the DTM since duplicate points or crossing break lines will require correction to successfully generate a TIN. The current CDOT InRoads Configuration will be applied to output the TIN to InRoads format. The TIN shall be delivered using the CDOT InRoads configuration format. (See 4.9.10 and 4.9.11 for File Naming and Directory Structure)

4.9.7 Contours

The CDOT Region Survey Coordinator shall specify the contour interval required. Every fifth contour interval will be on the major (index) contour level. Contours will be generated from mass points and breaklines using the current CDOT MicroStation/InRoads configuration. All contours shall be delivered as continuous 3D lines. The aerial mapping consultant shall work closely with the CDOT Region Survey Coordinator for contour specifications.

In areas where the terrain is relatively flat, the contours shall be supplemented by spot elevations. Spot elevations shall not be abbreviated. A grid pattern is the most effective means for labeling spot elevations. In urban built-up areas the grid pattern may need to be varied in order not to interfere with map features.

Digital mapping products shall be delivered in the CDOT MicroStation configuration format. (See 4.9.10 and 4.9.11 for File Naming and Directory Structure)

4.9.8 Orthophotography (Orthophoto)

Orthophotography, (also called orthophotos or orthophotomaps), are generated through a process of image rectification that re-projects a photographic image on a geo-referenced plane on the z axis. It has all the characteristics of a 2D map. Distances and areas can be measured in the same way as on a 2D map. Process inputs include known camera characteristics such as lens properties, focal length, CCD array, (or precise negative dimensions in an analog camera), along with the refined exterior orientation angles output from the Aerial Triangulation process and the Digital Terrain Model for the area imaged. The resulting orthophoto is output with a fixed pixel resolution. (e.g. 0.25' or 0.5') Orthophoto maps can then be produced by mosaicking individual image rectifications together into one large image covering a project area or subset thereof and then clipping the orthophoto imagery out into predetermined rectangular tiles. The nominal GSD of input imagery should always be finer than that of the intended output orthophoto resolution. No "up-sampling" of imagery to produce orthophotos is acceptable. Consultants are expected to utilize modern industry standard software applications to generate orthophotos that accomplish rectification on a pixel-by-pixel basis. Like any 2D aerial map, accuracy is dependent on camera, flying height, output resolution, aerial triangulation solution and ground control basis.

Some characteristics and limitations of orthophotos include:

1. Orthophotos are typically rectified using ground elevations, therefore any elevated features, such as tops of buildings, towers, power lines, etc. will not be located in their true positions. Only features at the ground elevation will be correctly positioned.
2. Elevated features, as identified above, will appear to lean in one direction. This affect is called radial displacement. Its effect is zero at a point directly beneath the lens and increases radially with distance from the photo-center.
3. Continuously elevated features such as utility lines will not match up along photo mosaic lines. Again, an effect of radial displacement that can't be avoided.
4. In almost all cases, the consultant should be expected to take care in choosing the mosaic lines between images such that they are more or less disguised along linear features wherever possible and ensure that they don't pass through buildings or cut through towers.

The CDOT Region Survey Coordinator shall specify the output pixel size (ground resolution) of orthophotography if required in the scope of work. Unless otherwise specified, orthophotos shall meet the following minimum standards based on the specified pixel size:

1. Horizontal Accuracy: RMSE +/- 2 pixel in X or Y
2. Maximum mismatch at image seam lines: 4 pixels
3. Horizontal Accuracy of source Aerial Triangulation: RMSE 1.0 pixels in X, Y, Z

Since orthophotos have map properties they can be imported into Bentley MicroStation or AutoCAD drawings providing a useful imagery backdrop that may provide more information than that which can be gathered from the map features alone. Orthophotography can be created relatively inexpensively and quickly and may be helpful to use in public meetings to provide a clearer picture to the public than that of traditional engineering mapping.

Digital imagery products shall be delivered in JPEG compressed TIF/TFW format. (Orthophoto TIF files will be accompanied by a corresponding TFW world file for geo-referencing.) An orthophoto tile index shall accompany orthophotography and be delivered in the CDOT MicroStation configuration format. (See 4.9.10 and 4.9.11 for File Naming and Directory Structure)

4.9.9 Aerial Survey Report

Following the aerial survey flights and aerial triangulation and/or LiDAR data calibration an Aerial Survey Report shall be produced by the aerial consultant and delivered to the CDOT Region Survey Coordinator. The project will not be considered final until the Aerial Survey Report is filed and accepted by the CDOT Region Survey Coordinator.

The Aerial Survey Report is intended to summarize the key elements of the aerial mission and should include the following details at a minimum:

1. CDOT Project name
2. CDOT Project number
3. CDOT Project Code number
4. Highway number
5. Beginning and ending mile post
6. Consultant name and contact information
7. Report date
8. Executive Summary
9. Table of Contents
10. Project Area illustration/description
11. Scope of Work Summary
12. Spatial Reference System
    a. Vertical and Horizontal Datum
    b. Units
    c. Coordinate system
    d. Geoid applied to ellipsoid elevations
13. Project Accuracy Specifications
14. Reference to Aerial Control Survey Report
15. List of Aerial Ground Control points and their coordinates
16. Flight Plan – Flight line diagram and description of aircraft & aerial system deployed
    a. Flying height
    b. If aerial photography: Nominal GSD
    c. If LiDAR flown: Point density and applied system parameters
17. Aerial Triangulation (AT) Summary Report
    a. Narrative
    b. Control diagram – referenced to project boundary and imaged area
    c. Summary of final adjustment results
    d. List of X, Y and Z control point coordinates and AT adjustment X, Y, Z residuals at each
    e. List of X,Y and Z checkpoint coordinates and AT adjustment X, Y, Z residuals at each

f. Index of final photo-centers and/or flight trajectories (Graphic and digital formats.)
g. Copies of flight logs
h. Camera and/or sensor Calibration Reports

18. DTM verification test results for random checkpoints or cross sections (Vertical Accuracy Report)
19. Certification or statement of accuracy by ASPRS Certified Photogrammetrist or state licensed aerial survey professional.

Digital documents shall be delivered Adobe PDF format. (See 4.9.10 and 4.9.11 for File Naming and Directory Structure)

4.9.10 Deliverable File Naming

Digital Product	File Type	File Name	Explanation
Photo Control Survey Report	PDF	XXXXXAS_Control.pdf	*Project codeAS_control.pdf*
Aerial Survey Planimetrics	MicroStation	XXXXXAS_50.dgn	*Project code*AS_*scale denominator*.dgn
Aerial Survey Contours	MicroStation	XXXXXAS_50_con.dgn	*Project code*AS_*scale denominator*_con.dgn
Aerial Survey DTM	InRoads	XXXXXAS_50.dtm	*Project code*AS_*scale denominator*.dtm
Aerial Survey TIN	InRoads	XXXXXAS_50.tin	*Project code*AS_*scale denominator*.tin
Ortho Tile Index	MicroStation	XXXXXASortho_index.dgn	*Project code*ASortho_index.dgn
Orthophotography	JPG compressed TIF/TFW	XXXXXASortho_.5.tif/tfw	*Project code*ASortho_*pixel resolution in feet*.tif/tfw
Aerial Survey Report	PDF	XXXXXASreport.pdf	*Project code*_surv_aerial_report.tin

Digital Product Directory Structure:

All aerial survey file names and directory structures for all files and related documents shall follow that which is setup in CDOT's ProjectWise system. At the time this chapter was written the complete file names and directory structure has not been fully setup or integrated in ProjectWise, therefore close coordination with the CDOT Region Survey Coordinator is needed to ensure the appropriate files names and directory structures are properly setup to allow easy integration with ProjectWise.

4.9.11 Raw Data Files

Upon completion of aerial survey projects the aerial consultant will deliver raw data collected under the consultant's scope of work. This may include field survey data, aerial imagery, GPS data, IMU data, aerial triangulation data, LiDAR calibration data and LiDAR Point Cloud data. Raw data will be delivered on USB portable hard drives. (See Section: 4.8.8 Raw Data).

Raw Data Directory Structure:

All aerial survey file names and directory structures for all files and related documents shall follow that which is setup in CDOT's ProjectWise system. At the time of writing this chapter the complete file names and directory structure has not been fully setup or integrated in ProjectWise, therefore close coordination with the CDOT Region Survey Coordinator is needed to ensure the appropriate files names and directory structures are properly setup to allow easy integration with ProjectWise.

4.9.12 References

CDOT Survey Manual – CDOT, 1992

American Society for Photogrammetry & Remote Sensing (ASPRS) - Digital Positional Accuracy Standards for Digital Geospatial Data – 2014 http://www.asprs.org/resources.html

National Spatial Data Infrastructure (NSDI) - Geospatial Positioning Accuracy Standards Part 3: National Standard for Spatial Data Accuracy- FGDC-STD-007.3-1998