Chapter 7 - Aerial Photogrammetry

7.1 Purpose of this Chapter

The purpose of this chapter is to identify and define the specifications that shall be followed while performing Aerial Photogrammetry for NJDOT.

NJDOT contracts out all aerial surveys as the aerial photography and mapping equipment is not available in the Department. As such, NJDOT 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 or survey subconsultant.

The guidelines and specifications described in this chapter are geared towards development of design scale mapping that has been historically referred to as 1”=30’ scale mapping with 1’ contours. The vast majority of aerial mapping contracted by NJDOT 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 NJDOT Survey SME and Project Manager.

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 Aerial Photogrammetry. Airborne LiDAR is addressed in a subsequent chapter. 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 NJDOT Survey SME. This will facilitate development of a custom project design, specifications, and deliverables that meet unique NJDOT project requirements.

Any variation from the specifications in this chapter shall have the prior approval of the NJDOT Survey SME and Project Manager.

7.2 Aerial Surveys

Aerial Photogrammetric surveys utilize photographic, digital, or other data obtained from an airborne platform (e.g. airplane, helicopter, drone). Photographic data processed by means of photogrammetry is combined with field survey data to produce high precision mapping and meet the accuracy standards described in this Chapter.

7.3 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 plans
3. Preliminary design
4. Geographic Information System (GIS)

The information produced from aerial imagery of the existing terrain allows both designers, planners, and environmental personnel to explore alternate routes without having to collect additional field information. The imagery can be used to layout possible alignments for a more detailed study.

Photogrammetry 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 (i.e. obscured areas).

7.4 Project Location and Limits

The location and limits of the aerial survey project is indicated in the initial request for mapping (usually as beginning and ending MP). The NJDOT Survey SME or designee is responsible for determining the aerial survey location and limits. The aerial mapping consultant shall work closely with the NJDOT Survey SME 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 mileposts
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 a minimum of 1000 feet of the crossroad on each side of the existing transportation corridor centerline and shall usually include any ramps within the interchange limits and 300 feet beyond the end of the ramp on the crossroad.
2. For at-grade intersections (signalized or unsignalized), the aerial survey shall also include 750 feet of the crossroad on each side of the existing transportation corridor centerline and shall include all turning movements such as jughandles, turning lanes, etc.
3. When requested the aerial survey shall also include the area necessary for a complete hydraulic design and/or wetland mitigation site as required in the project specifications.
4. Aerial Photography and Aerial LiDAR shall extend ½ mile beyond the end of the aerial survey location and limits of the highway corridor.

7.5 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 is used.

The aerial mapping consultant shall work closely with the NJDOT Survey SME when determining the aerial mapping specifications.

7.6 Aircraft and Crews

All aerial surveys will be conducted in full compliance with Federal Aviation Administration and Civil Aeronautics Board 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.

Crews having a minimum of 200 hours experience in flying precise photographic missions for aerial surveys shall be used. In addition, each crew shall have prior experience (50 hours minimum) with the same type of aircraft to which the crew is assigned.

The use of any UAV shall be discussed with the Survey SME and be in accordance with Chapter 10, Section 10 of the NJDOT Survey Manual.

7.7 Aerial Survey

Prior to beginning any aerial survey activities, the surveyor shall contact NJDOT Geodetic Survey Unit to determine if any new control has been established in the area. The NJDOT Survey SME or designee shall work closely with the aerial mapping consultant to review the scope of work and ensure the project needs are being met. This close working relationship shall continue through the duration of the project to ensure that NJDOT receives an accurate, quality, and useable product. Any known error or oversight on the plans or specifications shall be discussed prior to commencing any work. The NJDOT Project Manager will communicate any modifications to the scope of work to all affected parties. If determined by the NJDOT Survey SME a meeting shall be held to discuss the project and the desired results as soon as possible. The following individuals should attend the meeting:

1. NJDOT Survey SME or designee
2. NJDOT Project Manager
3. Aerial Survey Consultant/Photogrammetrist
4. Any appropriate subcontractor personnel

Any project specific information should be provided by the NJDOT at the meeting.

It is the responsibility of the NJDOT PM to ensure that the scope of work for the project is provided to the aerial mapping consultant and surveyor so that they can ensure that the project needs are being met. If there are any questions or concerns, they should be addressed prior to the commencement of any survey work.

7.8 Ground Control for Aerial Surveys

7.8.1 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 measurements of the horizontal and vertical elevation (X, Y and Z) of the control points will be used to process the final mapping product. Elevations, (Z), must be provided at ground elevations (modified NJSPCS). 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 use of commercial RTK and RTNs based on the latest realizations of NAD83 and NAVD88 using the proper techniques can also be utilized.

7.8.2 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 of 1″=30′ plans a photo control point should be established at a maximum approximately every 300′ apart staggered along the edge of the pavement (i.e. shoulder) for the length of the project. A control point targeting plan at this density would satisfy ground control requirements for a photogrammetric approach. The wing targets shall be established in accordance with the flight diagram established by the aerial consultant. In addition, the surveyor shall also establish control pairs at each end of the project and every 1.5 - 2 miles along the project length.

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.

The aerial mapping consultant is responsible for determining and specifying all aerial control point locations, material, spacing, and configurations for the survey. The NJDOT Survey SME or designee shall work closely with the aerial mapping consultant when determining what monumentation shall be used for control points. All project control will be established on the ground (modified NJSPCS) by applying the appropriate combined grid scale factor.

Final coordinate values for control points shall be produced and tabulated in four formats to satisfy NJDOT requirements. All coordinates are based on the latest realization of NAD83 adjustment datum. Currently: NAD83 (2011).

https://www.ngs.noaa.gov/datums/horizontal/north-american-datum-1983.shtml

- GEOGRAPHIC POSITIONS *(Latitude, Longitude and Ellipsoidal Heights in meters).*
- NJSPC (METRIC) *(State Plane Coordinates in meters).*
- NJSPC (U.S. SURVEY FEET) *(State Plane Coordinates in U.S. Survey Feet).*
- GROUND/MODIFIED *(Ground Coordinates in U.S. Survey Feet)*.

All orthometric heights will be based on the NAVD88 adjustment datum using the latest geoid model, currently GEOID18.

https://www.ngs.noaa.gov/GEOID/

7.8.3 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

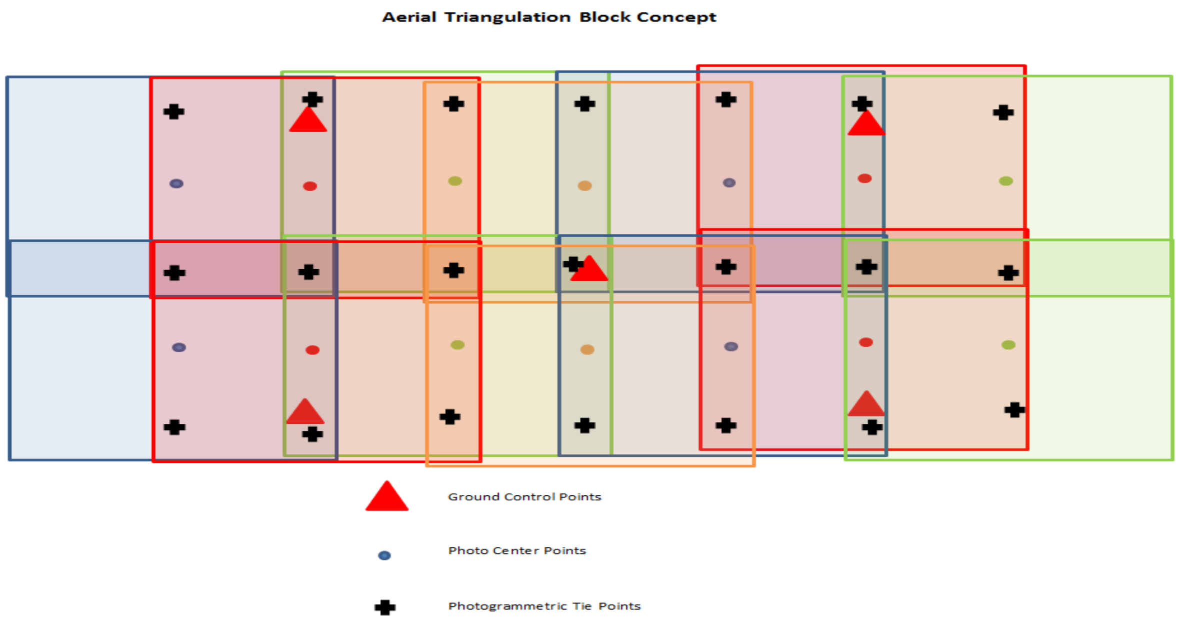

Image Courtesy of Colorado Department of Transportation

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.

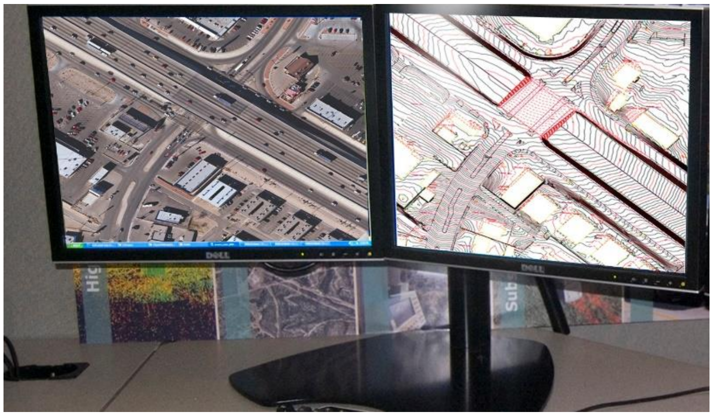
Image Courtesy of Colorado Department of Transportation

The aerial triangulation output allows analysis of stereo models using a digital 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.

7.8.4 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 5 – Surveying Equipment, and Chapter 4 – 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.

7.8.5 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 NJDOT survey staff. In addition, the aerial consultant or NJDOT survey staff 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

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 NJDOT existing control monuments that have been previously established on the ground by a control survey shall be used for project 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 can also greatly reduce the amount of field surveying needed to establish photo ground control since the primary control monuments need only to be targeted. The surveyor shall contact the NJDOT Geodetic Survey Unit for any new control established in the project area before commencing any field work. The surveyor shall also request copies of the existing plans covering the project limits from the NJDOT Engineering Documents Unit. Depending on the project scope the following is a list of the information that may be requested from the EDU:Key Sheet

- Tie and Alignment Sheets
- Construction Plans
- Profiles
- Drainage Plans
- Grading Plans
- ROW Plans

Whenever possible the surveyor shall research and use existing monuments within the project limits to establish project control.

Examples of these types of monuments may include the following:

1. Existing Baseline monuments
2. Right of Way monuments
3. Federal, State, or local agency monuments
4. Benchmark monuments

Photo control points shall be set flush with the pavement using a PK nail (or other type) with a distinguishable center point, or a Photo ID (PID) point. The NJDOT strongly discourages the use of drill holes, “X” cuts, or “Box” cuts as survey control points. Project Control pairs shall be of a semi-permanent nature such as a rebar and cap.

Examples of these types of monuments may include the following:

1. Types of monuments listed above
2. 5/8 inch diameter rebar with cap (set for temporary monuments only)
3. Nail set in asphalt (set for temporary photo control points only)

7.8.6 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.

7.8.7 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. (White in most instances, however, if the surface is very light colored, a black target may be preferable.)

7.8.8 Photogrammetry

For photogrammetric measurements 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:

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

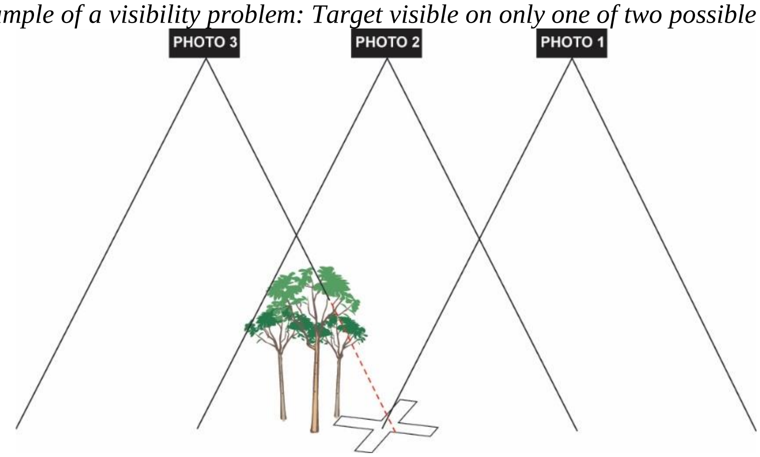

Image Courtesy of Colorado Department of Transportation

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.

7.8.9 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.

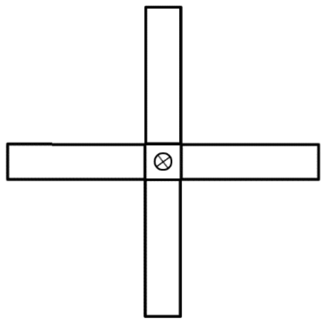

Diagram 1: "X" Type Target

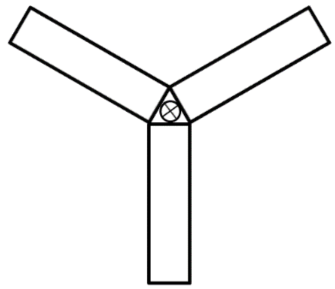

Diagram 2: "Y" Type Target

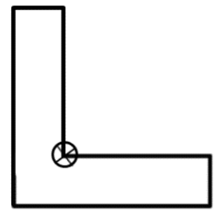

Diagram 3: "L" Type Target

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, 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, corners of inlets, existing paint markings on asphalt, or other clearly visible features from which a precise location can be interpreted. Examples of a painted target and a PID are shown below. The nailhead should be flush with the pavement and the horizontal and vertical position should be taken at the center of the nail. The PID 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 NJDOT Survey SME or designee shall work closely with the aerial mapping consultant when determining how monuments are to be targeted.

Example of Painted Target

Example of Photo Identifiable Point (PID)

Images Courtesy of Colorado Department of Transportation

7.8.10 Removal of Aerial Control Target Material

To maintain proper public relations all manmade 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 NJDOT Survey SME or designee.

7.8.11 Aerial Control Horizontal Survey Datum

All aerial control horizontal surveys shall be referenced to the National Spatial Reference System (NSRS) and the NJSPCS and tied into the NJDOT primary control survey. Any supplemental or additional project surveys shall also be tied to the primary project control survey.

As defined in NJDOT Survey Manual, Chapter 2 – Control 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 all projects an NJDOT primary control survey will be required and shall be established as part of the survey effort for the aerial photogrammetric control. The NJDOT Survey SME shall be contacted if there are any questions regarding the primary control survey prior to commencing any field survey effort. NJDOT discourages the practice of performing any aerial control survey without establishing a primary control survey as well. Any consideration for not providing a primary control survey shall be reviewed by the NJDOT Survey SME and approved by the Manager Roadway Design Group 2.

All control horizontal and vertical surveys shall be referenced to and tied into the National Spatial Reference System (NSRS) as defined by the National Geodetic Survey (NGS).

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 latest realization of the horizontal datum (NAD83 (2011) and the North American Vertical Datum of 1988 (NAVD 88).

To improve the NSRS, NGS will replace all three North American Datum of 1983 (NAD 83) frames and all vertical datums, including the North American Vertical Datum of 1988 (NAVD 88), with four new terrestrial reference frames and a geopotential datum.

The new reference frames will rely primarily on Global Navigation Satellite Systems (GNSS), such as the Global Positioning System (GPS), as well as on a gravimetric geoid model resulting from our Gravity for the Redefinition of the American Vertical Datum (GRAV-D) Project.

Refer to the NGS link for additional datum information.

https://geodesy.noaa.gov/datums/newdatums/index.shtml

See NJDOT Survey Manual Chapter 4 - GPS Surveys, for additional information.

7.8.12 Global Navigation Satellite System (GNSS) Photo Control Horizontal Survey Methods

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

Those aerial control horizontal surveys performed by survey methods other than GNSS shall be approved in advance by the NJDOT Survey SME.

All aerial control horizontal surveys performed by GPS methods shall be performed in accordance with Chapter 4 – GPS Surveys, and shall meet the Minimum Horizontal Accuracy Tolerances as indicated in the NJ DOT Survey Manual in chapters 4.4.3.2.1 through 4.4.3.2.2.2.3.

Unless approved otherwise by the NJDOT Survey SME, all GNSS aerial control monuments (center and wing points) shall be observed by survey methods and procedures in accordance with Chapter 4 - GPS Surveys.

Real Time Kinematic (RTK) or Real Time Network (RTN) GNSS techniques, based on the National Spatial Reference System (NSRS) may be utilized for aerial projects. The latest National Geodetic Survey (NGS) guidelines as found on their homepage website: (https://www.ngs.noaa.gov/) must be used for procedures for RTK/RTN projects.

Current resource guidelines (6/2019) are as follows:

- User Guidelines For Single Base Real Time GNSS Positioning:

  www.ngs.noaa.gov/PUBS_LIB/UserGuidelinesForSingleBaseRealTimeGNSSPositioningv.3.1APR2014-1.pdf

- National Geodetic Survey Guidelines for Real Time GNSS Surveys:

  www.ngs.noaa.gov/PUBS_LIB/NGS.RTN.Public.v2.0.pdf

RTN precision expectations as noted in above referenced publication:

Since RTN positioning is a differential solution from a base station to a point of interest, the results are displayed in the data collector as measures of the precision, or repeatability, of the solution. On the other hand, the alignment of the base station to the user-selected datum (as part of the NSRS or otherwise) can be considered the level of accuracy. Many data collectors will show a position precision from the base station (whether non-physical or master) at the 68% confidence level (or "1 sigma" statistically), although some actually do show a 95% or even 99% confidence level. Typically, this is shown as horizontal, vertical (orthometric), and root-mean-square (RMS) values resulting from the baseline solution. It would be wise for the user to ascertain which confidence level is indeed displayed to have a realistic sense of the precision. Current empirical results suggest: Typical RTN precisions at the 95% confidence level are: horizontal 2-3 cm, vertical (ellipsoid) 3-5 cm, orthometric heights 5-7 cm (typical using the NGS hybrid geoid model). Exceptional RTN derived precisions are at the current limit of the RT technology: horizontal: ≤ 1 cm, vertical (ellipsoid) ≤ 1 cm, possible orthometric height ≤ 2 cm. This is a direct citation (William Henning, team leader, editor, and others (March 2011, p. 54).

- RTN Field Procedures and Best Practices:

  www.ngs.noaa.gov/web/science_edu/presentations_library/files/rtn_field_procedures.pptx

7.8.13 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 2 Control Surveys and State Ground Coordinate Systems.

7.9 Aerial Control Vertical Survey

7.9.1 Photo Control Vertical Survey Datum (NAVD 88) (Second Order Class II)

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 NJDOT primary control survey that has been previously referenced and tied to NAVD 88 datum in accordance with Chapter 3.

For projects where no NJDOT primary control survey has been completed, elevations for any aerial control vertical survey shall be established from existing national benchmarks 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 3.

7.9.2 Minimum Aerial Control Vertical Accuracy Tolerance

All aerial control vertical surveys shall meet the Minimum Vertical Accuracy Tolerance for a NJDOT Second Order Class 2 in accordance with Chapter 3.7. All photo control points shall meet Third Order Vertical Control.

7.9.3 GPS Aerial Control Vertical Survey Methods

All aerial control vertical surveys performed by GPS methods shall be performed in accordance with Chapter 4 – GPS Surveys, and shall meet the Minimum Vertical Accuracy Tolerance for a NJDOT Second Order Class 2 in accordance with Chapter 3.7. As required in NJDOT Survey Manual Chapter 4 – GPS Surveys. 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 NJDOT Survey Manual Chapter 3.
2. The use of commercial RTK and RTN networks based on NAD83 and NAVD88 with proper techniques can also be utilized.
3. Trigonometric elevations by conventional survey methods such as a total station in accordance with the methods and procedures as stated in NJDOT Survey Manual Chapter 3.

7.9.4 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 3 and shall meet Third Order Tolerance.

7.9.5 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 NJDOT 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, ground control, 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.

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.

7.10 Equipment Maintenance

Checks and calibrations on all types of electronic survey equipment are essential to obtain and maintain the minimum tolerances required for aerial surveys. In accordance with the manufacturers' specifications 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. This includes but not limited to GPS units (airborne and ground), IMU, and aircraft. It is the aerial consultant's responsibility to ensure no errors due to poorly maintained or malfunctioning equipment will affect the project.

7.11 Deliverables and Documentation

The desired deliverables from an Aerial Photogrammetry project should be identified in the planning stage. The mapping consultant should refer to the NJDOT CADD Standards available online at the NJDOT website:

(https://www.state.nj.us/transportation/eng/CADD/v8/)

Contact the CADD Manager if they have any questions regarding the CADD Standards and CADD deliverables.

Any use of the data other than its intended use should be approved by the NJDOT CADD Manager and NJDOT PM before any other use of the data.

7.12 Deliverables

Different projects and customers require different types of deliverables, which can range from a standard CADD product to a physical three-dimensional (3D) scale model of the actual subject.

Deliverables for Aerial Photogrammetric surveys may include, but are not limited to:

- Mapping in current NJDOT CADD Standards for Roadway, Bridge, Electrical
- Digital photo mosaic files
- Survey narrative report (refer to Chapter 11 of the NJDOT Survey Manual)
- Aerial Triangulation Report
- QA/QC Files

7.13 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 latest NJDOT MicroStation Levels with feature descriptors 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 NJDOT Survey SME or designee shall work closely with the aerial mapping consultant when determining which features require further identification.

7.14 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 by the Aerial Photogrammetrist and provided to the surveyor for field survey data collection.

7.15 Supplemental Surveys

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. The supplemental survey fieldwork may be performed by the consultant or by NJDOT survey crews as required in the project scope and shall utilize NJDOT 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 NJDOT Survey SME or designee shall work closely with the aerial mapping consultant when determining which features require supplemental surveying.

7.16 Minimum Horizontal and Vertical Accuracy Tolerance for 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 3 – Surveying Measurements 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). Below is a link to the ASPRS standards:

http://www.asprs.org/a/society/committees/standards/Positional_Accuracy_Standards.pdf

7.17 Vertical Accuracy Testing - Method of Verifying Accuracy Tolerance

7.17.1 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.

7.18 Documentation: Aerial Control Survey Report

7.18.1 General

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

Documentation of surveys is an essential part of surveying work. Survey data not properly documented could result in additional field and office time to redo or correct what was not performed or documented properly.

The survey narrative report (refer to Chapter 11 of the NJDOT Survey Manual), completed by the PLS in responsible charge of the survey, shall contain the following general information, the specific information required by each survey method, and any appropriate supplemental information.

- Project Name and UPC Number: Route, Beginning and Ending Milepost, Project UPC Identification, Municipality, County, etc.
- Survey date, limits, and purpose
- Datum, epoch, and units

  Final coordinate values for control points shall be produced and tabulated in four formats to satisfy NJDOT requirements. All coordinates are based on the latest realization of NAD83 adjustment datum. Currently: NAD83 (2011).
  - GEOGRAPHIC POSITIONS *(Latitude, Longitude and Ellipsoidal Heights in meters).*
  - NJSPC (METRIC) *(State Plane Coordinates in meters).*
  - NJSPC (U.S. SURVEY FEET) *(State Plane Coordinates in U.S. Survey Feet).*
  - GROUND/MODIFIED *(Ground Coordinates in U.S. Survey Feet).*

- Control found, held, and set for the survey.
- Personnel, equipment, and surveying methods used.
- Field notes including scan diagrams, control geometry, instrument and target heights, atmospheric conditions, etc.
- Problems encountered.
- Any other pertinent information

- QA/QC reports
- Dated signature and seal of the Professional Land Surveyor in responsible charge.