Chapter 10 - Airborne LiDAR

10.1 AIRBORNE LiDAR

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

NJDOT contracts out all aerial surveys as the Airborne LiDAR 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 however it may also be performed by NJDOT survey staff.

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.

With the rapidly occurring technology developments in Airborne LiDAR, the applications are becoming more widely used for design scale mapping. This chapter provides specifications and guidelines for Airborne LiDAR to be used alone or in conjunction with Aerial Photogrammetry for highway design scale mapping as well as other uses.

Lidar is a Light Detection and Ranging System. It is analogous to radar except that light waves (lasers) are used instead of radio waves. These systems consist of Airborne GPS (AGPS), an Inertial Measurement Unit (IMU), and a laser measurement device mounted in either a fixed-wing aircraft, helicopter, or a drone. 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. Phase Shift/Phase Based measure the wavelength of a continuous beam to calculate the distance the laser traveled. The Time of Flight (TOF) measures the time it takes for the laser to return to the sensor. 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, 2nd, 3rd, last or first and last), is also recorded along with an intensity value.

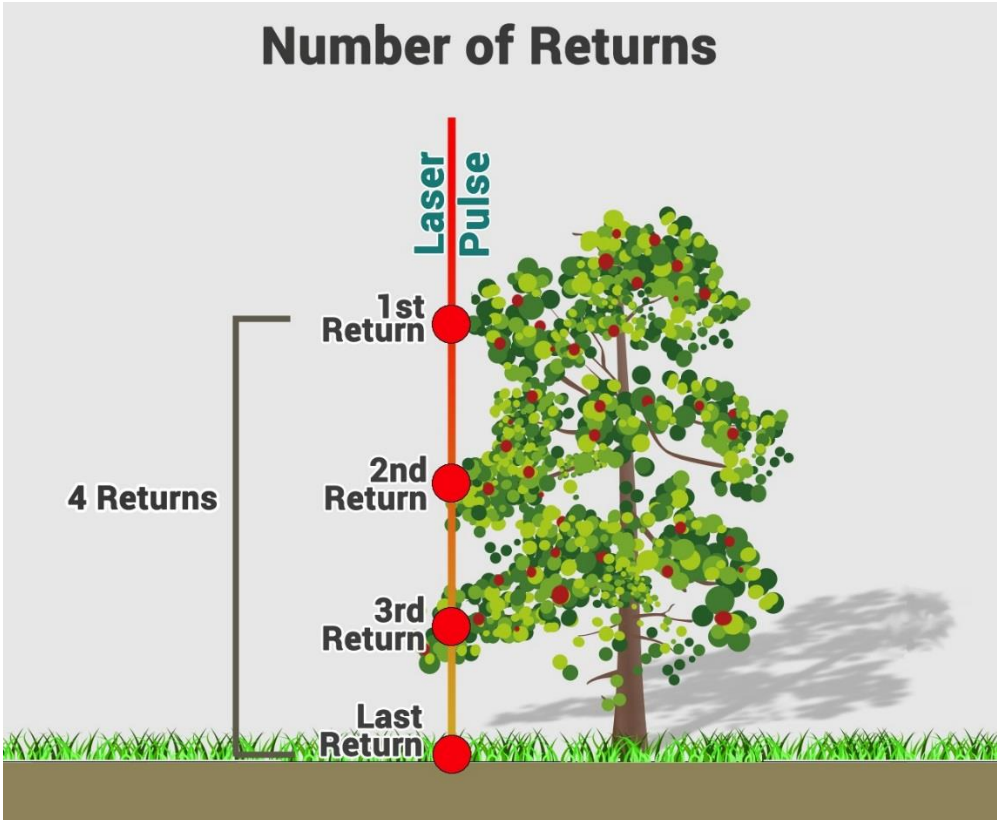


Image Courtesy of GISGeography.com

AGPS and IMU data are collected on board the aircraft during the flight. Base station information must be collected on the ground during the flight. It is recommended that the Base Station not be more than 25 miles from the sensor at any time. These data sets 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 (see note 1).

Note 1: In NJ the CORS Network consists of 15 CORS Units, 12 of which have established orthometric heights on the CORS ARP. This can be a significant time saver when establishing vertical control for Airborne LiDAR and Aerial Photogrammetry mapping projects and could minimize if not eliminate the need to perform leveling across the mapping control targets.

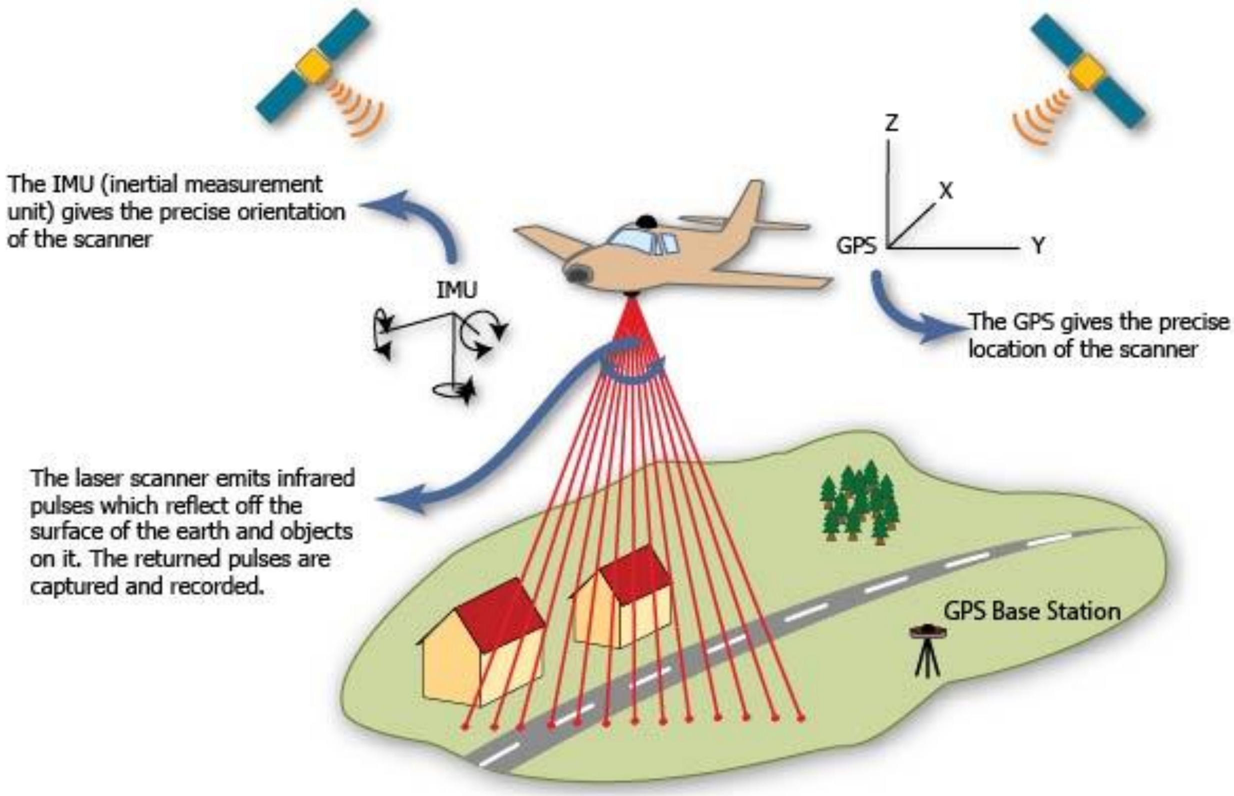


Image Courtesy of Modeling & Visualization, University of Arkansas

The raw data points then undergo a classification process which identifies the type of return (structure, vegetation, pavement, bare earth, water, etc.). The final product is a point cloud which has an X, Y, Z position for each return. Post-processing of the points is required to reduce the point data to final output and to filter the data to bare earth (last return) or first return (or both) data points. In addition to bare earth, terrain data also can extract elevation data for above-ground features such as vegetation heights, building heights, and transmission towers/lines.

This technology has the potential of greatly decreasing the turnaround time for the production of digital orthophoto base mapping and digital terrain model creation for preliminary highway design and study purposes. Its speed of acquisition and processing to usable terrain data surfaces is an order-of-magnitude faster than currently available by field surveys or photogrammetric mapping methods.

LiDAR has rapidly 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 other information that would be too time-consuming using photogrammetry or field surveys. Just as aerial photogrammetry, 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, are quality checked against a set of ground surveyed checkpoints that were not used in the registration process, (also known as blind checkpoints).

The LiDAR technology has few constraints compared to conventional topographic survey methods. It can survey day and night, at altitudes between 300 and 900 m (1,000 to 3,000 ft) above ground, over any terrain, and through most vegetation and canopy. Most of the highway application surveys are conducted at a height of 300 m (1,000 ft) above ground level to develop 1″=30′ scale mapping. The flexibility of day and night missions is subjected to usual constraints of flying aircraft at relatively low altitudes due to applicable aviation rules. An airborne platform provides non-intrusive operation and no interference with highway traffic. Flight planning determines optimal LiDAR settings and aircraft parameters.

From an aircraft flying a pattern over the survey area, a high-accuracy scanner sweeps the laser pulses across the flight path and collects the reflected light. By varying the aircraft altitude, the aircraft speed, the scanner angle, and the scanner frequency, the operator is able to program ground point spacing to fit the particular survey for the mapping project.

10.2 Project Requirements

Prior to the commencement of any field work the consultant shall contact the Geodetic Survey Unit to determine if there is any new control available and to discuss the control to be used for the project. If necessary, a meeting should be held with the NJDOT PM, NJDOT Survey SME, and the consultant to discuss and review the project mapping requirements and final deliverables. In addition, a tentative delivery date shall be established for all deliverables. Given that the weather can play a significant role in the final delivery it is the responsibility of the consultant to update the NJDOT PM and SME of the progress during the data capture and establishment of the survey control for the project and to inform them of any delays that have occurred that will affect the final delivery date.

10.2.1 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.

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

10.2.2 Project Location and Limits

The location and limits of the aerial survey project is indicated in the initial request for mapping. 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 (i.e. 15’-20’ beyond edge of pavement)

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.
2. For at-grade intersections, 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. The aerial survey shall also include the area necessary for a complete hydraulic design 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.

10.3 Project Control

The aerial mapping consultant is responsible for determining control requirements for the aerial survey. Final 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 teamwork 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.

Airborne LiDAR must be controlled with ground survey similar to Aerial Photogrammetry. Although the number of ground survey control points for Airborne LiDAR can be significantly less than what is required for Aerial Photogrammetry, control points and check points are required. Airborne LiDAR can be collected practically anytime during the year, day or night, unlike Aerial Photogrammetry. The weather still will have an impact as to when the LiDAR data can be collected (i.e. rain, fog, wind, snow cover, etc.) When collected alone there are few if any seasonal restrictions for highway projects. Also, Airborne LiDAR collected in conjunction with

Aerial Photogrammetry must be flown during daylight hours to accommodate the photography.

In order to provide the required accuracies for the mapping project it is recommended that a pair of control points be established not more than 1000 feet apart along the highway corridor edge of pavement (i.e. shoulders), in addition to all control points required to control the entire imagery to develop 1”=30’ scale mapping. The number of control points and their locations will be determined by the aerial consultant.

All control shall be tied to the NAD83 Horizontal and NAVD88 Vertical control networks latest NGS adjustments. In New Jersey, the use of the Mid-Atlantic SMARTNET Network can be a significant time saver in establishing horizontal and vertical control for a project provided proper GPS techniques are followed (see NJDOT Survey Manual Chapter 4). When establishing control using GPS for Airborne LiDAR the surveyor should follow the same general procedures as Aerial Photogrammetry.

10.3.1 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.

Airborne LiDAR control points typically consist of the following:

1. Aerial Center control points
2. Aerial Wing control 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 aerial 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)

10.3.2 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.

10.3.3 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 the LiDAR sensor. 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.)

10.3.4 Global Navigation Satellite System 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 website (https://www.ngs.noaa.gov/) must be used for procedures for RTK/RTN projects.

Current 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 Field Procedures and Best Practices:

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

10.3.5 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 NJDOT Survey SME.

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. While this condition is rarely at a level that causes significant disruption to signal accuracy, it should be checked before the flight. The National Oceanic and Atmospheric Agency's website, http://www.swpc.noaa.gov/, provides forecasts for this condition. 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).

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

10.3.6 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 NJDOT Survey SME when establishing the flight plan. NJDOT 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), resolution (point spacing).
2. NJDOT primary control monument locations labeled by number or name.
3. Airborne LiDAR 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).
5. LiDAR sensor calibration report and calibration file as appropriate to sensor(s) planned.
6. Manufacturer’s Specification sheets for LiDAR systems planned.

10.3.7 Aircraft

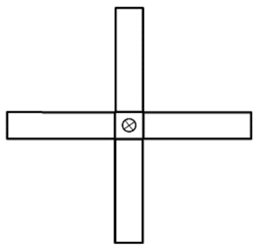
Aircraft maintenance and operation shall be in accordance with Federal Aviation Administration (FAA) and Civil Aeronautics Board (CAB) regulations. This includes UAV (see Section 10.10).

10.3.8 Aerial Data Acquisition

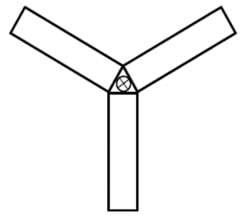
The planning and aerial data acquisition will follow relevant guidelines and shall meet or exceed all of the current American Society for Photogrammetry & Remote Sensing (ASPRS) standards.

10.4 Aerial Control Targets

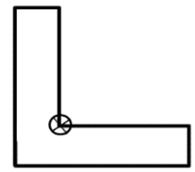
The target design shall be symmetrical and centered on the aerial control point. There are three designs commonly applied for aerial surveys. These include four-legged “X” targets, three-legged “Y” targets), and two-legged “L” targets. The targets should be easily visible in the imagery, such as black/white. 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, and type of targets and color will depend on the specifications of the flight mission as determined by the aerial consultant. The principal drivers will be flying height or the GSD of the resulting data.



"X" Type Target



"Y" Type Target



"L" Type Target

Painted Control Point Target

Photo Identifiable Point Target

Images Courtesy of Colorado Department of Transportation

As reasonably as possible the targets should be placed just prior to the flight taking place and should be maintained until the flight has occurred and the imagery accepted. LiDAR Identifiable Points (targets) should be clearly identifiable in the scans and have a large angle of intersection to positively identify the points. Some examples are corners of concrete slabs, sidewalk intersections (as shown above), existing paint markings on asphalt pavement or other clearly identifiable features which can provide a precise location. The surveyor should confer with the aerial consultant before moving any targets due to obstructions in the field (i.e. tree canopy, on street parking, etc.). Care should be taken when setting control points on private property. In the event that a material target (vinyl, wood, etc.) is required the target should be placed as close to the scheduled flight date as possible to avoid any possible damage or vandalism to them. Also, they should be removed as soon as possible after the flight has occurred. Any material targets set should be surveyed immediately to establish their X, Y, Z coordinates.

Prior to the commencement of any field survey work to be performed the surveyor shall:

- Contact the Geodetic Survey Unit for any new control within the project area.
- Request any available plans from the NJDOT Engineering Document Unit (EDU) for any existing monument locations. These monuments can be a significant time savings for establishing the project control within the project limits.

10.5 Airborne LiDAR Advantages/Disadvantages

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

Advantages:

1. Like aerial photography, LiDAR data sets provide a permanent record of the existing terrain conditions and topographic features 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 NJDOT such as, preliminary design, drainage analysis, and roadway clearance for power lines, vegetation, and environmental concerns.
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 (see note 1). 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. LiDAR can be used in locations that are difficult or impossible to access from the ground.

8. 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.
9. If collected as a stand-alone data set, (without aerial photography), it can be collected at any time of day or night.

Disadvantages:

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 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 NJDOT as project source data must be tiled to manageable file sizes. Consultants should deliver the point clouds just as they would deliver film or raw imagery to NJDOT for a photogrammetry project archive. The consultant should contact the NJDOT CADD Manager if they have any questions regarding the deliverables.
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 cannot be located, measured, or identified.
9. Building overhangs, overhead walkways and bridges will result in ground data occlusions.
10. Any feature or object not visible from the air must be surveyed by other methods such as STLS, MTLS or conventional survey methods and must utilize the same project control.

Below is a list of items that Airborne 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

10.6 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 manufacturer's 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.

10.7 Deliverables and Documentation

The desired deliverables from an Airborne LiDAR 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/) and 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.

10.8 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 Airborne LiDAR surveys may include, but are not limited to:

- Mapping in current NJDOT CADD Standards for Roadway, Bridge, Electrical

- Digital photo mosaic files (if requested)
- Survey narrative report (refer to Chapter 11 of the NJDOT Survey Manual)
- Aerial Triangulation Report
- Point Cloud Files
- QA/QC Files

10.8.1 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 mapping professional and provided to the surveyor for field survey data collection.

10.8.2 Aerial Survey – 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 aerial mapping professional 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.

10.8.3 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.

10.8.4 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

10.8.5 Vertical Accuracy Testing - Method of Verifying Accuracy Tolerance

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.

10.9 Documentation

10.9.1 Project 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
- Control found, held, and set for the survey

- Personnel, equipment, and surveying methods used
- Field notes including target 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

10.10 UNMANNED AERIAL VEHICLES MAPPING For LiDAR IMAGERY

The use of Unmanned Aerial Vehicles (UAV) or Drones is becoming more prevalent for certain types of projects. The use of UAV's is governed by the Federal Aviation Administration (FAA) Code of Federal Regulations (CFR) Part 107. The use of an UAV for any NJDOT project shall be coordinated with the NJDOT Survey SME and follow all of these regulations. The following is a link to the regulations:

https://www.ecfr.gov/cgi-bin/text-idx?SID=dc908fb739912b0e6dcb7d7d88cfe6a7&mc=true&node=pt14.2.107&rgn=div5

10.10.1 Lidar Uses

Through the use UAV lidar mapping, there is a large range of products, which can be extracted from the aerial imagery. These products include;

- DEM/ DTM / DSM (surface models).
- 3D bridge and building models.
- Contour maps.
- Planimetric features (road edges, heights, signs, building footprints, etc).
- Volumetric Surveys

Here are some of the best uses of lidar. All of these sectors benefit for having precision 3D images of their projects. They also benefit with increased efficiency and reduced costs than using traditional aircraft.

- Forestry management and planning.
- Bridge and Structural Inspections.
- GIS Applications.
- Flood modelling.
- Pollution modelling.
- Mapping and cartography.
- Urban planning.
- Coastline management.
- Transport planning.
- Oil and gas exploration.
- Quarries and minerals (Volumetrics and Exploration).
- Archaeology.
- Cellular network planning.

Some of the restrictions are:

- Must be operated within line of sight of the operator.
- Cannot operate over any pedestrians or highways unless the pedestrians/motorists are active participants in the operation.
- Cannot operate in a manner that interferes with operations and traffic patterns at any airport, heliport, or seaplane base.

Image of a UAV (Drone) for Mapping

(Image courtesy of POB Magazine, POB.com)

When preparing to utilize a UAV for mapping purposes the Aerial Mapping consultant and the Survey SME will determine:

- the limits of the mapping
- flight elevation
- amount of ground control and check points required
- scale of mapping required for project
- size and shape of grid patterns
- point cloud density
- determine lateral and forward overlap

Any Aerial Mapping utilizing UAV's should follow the requirements Airborne LiDAR.

10.10.2 Drone Mapping and Lidar Explained

UAV lidar involves mounting a laser scanner on a UAV to measure the height of points in the landscape below the UAV. Lidar actually means (Light Detection and Ranging). Lidar scanners can capture hundreds of square kilometers in a single day.

By measuring 10 to 80 points per square meter, a very detailed digital model of a landscape can be created.

The accuracy of the measurements allows the 3D models created using the lidar drone to be used in planning, design and decision-making processes across various sectors.

Lidar sensors can also pierce dense canopy and vegetation, making it possible to capture bare earth structure which satellites cannot see, as well as ground cover in enough detail to allow vegetation categorization and change monitoring. It is essential to have a UAV which has a navigation technology.