TxDOT Airborne Lidar Specifications and Workflow for Design-Grade Mapping Applications

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Contents

Manual Use

This manual serves as a comprehensive guide for airborne Lidar specifications and a general project workflow. It empowers Airborne Lidar consultants to exercise their judgment in the development of flight plans, control layouts, technology selection, and workflow optimizations while ensuring strict adherence to TxDOT accuracy and deliverable standards for transportation infrastructure design-grade mapping.

Airborne Mapping Systems

Lidar is a surveying method that measures distance to a target by illuminating the target with laser light and measuring the reflected light with a sensor. Differences in laser return times and wavelengths can then be used to make digital 3-D representations of the target. Lidar is sometimes called 3D laser scanning, a special combination of 3D scanning and laser scanning. It has terrestrial, airborne, and mobile applications. Lidar is commonly used to make high-resolution maps for transportation corridor mapping. When the sensors are docked in an aerial platform (i.e., an airplane, a helicopter, or a drone), then the entire process is called airborne Lidar.

All laser ranging, profiling, and scanning operations are based on the use of some type of laser-based ranging instrument – usually described as a laser ranger or laser rangefinder – that can measure distances to a high degree of accuracy. The distance measurement can be carried using one of the two following methods:

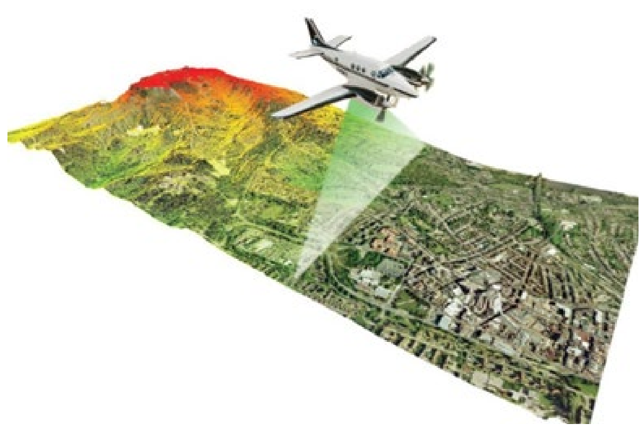
- **Accurate measurement of the TOF (Time of Flight)** uses a very short but intense pulse of the laser ranger to the object being measured and return to the instrument after having been reflected from the object. Thus, the laser ranging instrument measures the precise time interval elapsed between the pulse being emitted by the laser ranger located on point A and its return after reflection from a ground object located at point B.
- **Wave-form Lidar method** is the second (alternative) method, in which the laser transmits a continuous beam of laser radiation. In this case the range is computed by comparing the transmitted and the received version of the sinusoidal wave pattern by measuring the phase difference between them. The wavelength (λ) of the carrier signal of the emitted beam is short. A modulation signal in the form of a measuring wave pattern is superimposed to the carrier signal and its phase difference can be measured more precisely. The amplitude of the laser radiation will be modulated by a sinusoidal signal, which has a period of T_m and a wavelength of λ_m. The measurement of the slant distance R is then carried out through the accurate measurement of the phase difference (or the phase angle, φ) between the emitted signal at point A and the signal received at the instrument after reflection on the ground at point B.

Airborne Lidar Project Requirements

- RPLS, ASPRS CP, or CMS-Lidar (Precertified for TxDOT work category 15.3.6 Airborne Lidar) is required for overseeing airborne Lidar mapping projects.
- Airborne Lidar should also be performed along with aerial photogrammetry. TxDOT current point density requirements do not allow for effective 2D planimetric compilation from the Lidar point cloud. Aerial photography with a minimum 5cm ground sampling distance (GSD), as stated in the TxDOT Photogrammetry Guide, must be used for 2D planimetric feature identification and compilation.
- Prior to data acquisition, the control layout must be provided to the TxDOT PM and included with the final deliverables for each project.
- TxDOT Level 3 ground control points, as specified in the "TxDOT Survey Levels of Accuracy for GPS," should be set prior to Airborne Lidar acquisition to ensure visibility within the point cloud and generated intensity image.
- Lidar ground control points may be surveyed concurrently or following Airborne Lidar data acquisition. Correction Panel Points need to be set prior to LIDAR acquisition, panels can be seen in photography for Aero Triangulation and can be seen in the Lidar derived intensified images from the airborne Lidar point cloud.
- A Lidar ground-truthing report must be provided as part of the final deliverables.

Airborne Lidar System Requirements

- Airborne Lidar System Minimum Technology Specifications:
  - A minimum laser frequency and scan rate sufficient for TxDOT aerial mapping specifications.
  - A FOV of at least 75°.
  - The Airborne Lidar system must have onboard GNSS.
  - An onboard IMU.
  - To ensure accuracy, the Airborne Lidar system must undergo an annual Lidar sensor calibration performed by the manufacturer. A certificate with updated calibration values must be input into the Lidar processing software.



Airborne Lidar Data Requirements

- To be determined in scoping with TxDOT PM.
- Classified point cloud data should be provided in LAS or LAZ format, accompanied by metadata.

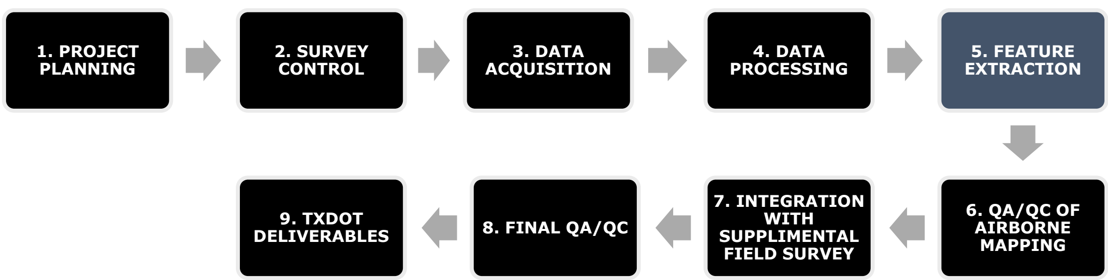
- All Lidar data must be classified to bare-earth surface and adhere to ASPRS 1.2 (or above) specifications.
- The point cloud must be appropriately tiled to facilitate end-user computing efficiency.
- Point cloud with a point density of at least 25 points per meter^2

Airborne Lidar Accuracy Requirements

Airborne Lidar accuracies are as follows:

- Hard Surfaces:
  - Vertical $RMSE_V$ accuracy of +/- 0.15-ft.
- Soft Surfaces:
  - Vertical $RMSE_V$ accuracy of +/- 0.33-ft.

Airborne Lidar Workflow



1. PROJECT PLANNING

The airborne Lidar consultant must provide the professional expertise, trained personnel, and equipment necessary to achieve the results that meet or exceed TxDOT aerial mapping standards.

Mission Planning

- **Coverage and Planning Parameters** – These are parameters that shall be taken into consideration for planning the flight lines for the project area, ensuring the complete coverage of the project area. The mission planning parameters of: point cloud post spacing, swath width, swath overlap, navigation, GPS, visibility, and tide-coordination (if project AOI is near the shore area) shall be considered in planning. TxDOT may supply recommendations and/or requirements for planning parameters in the Project Instructions. The separate Project Instructions may define the point density of the point clouds, DSM, and other requirements.
- **Collection Area –** The defined project area (DPA) shall be buffered by a minimum of 100 meters (m) (328-ft.) to create a buffered project area (BPA)
- Mapping area Buffered 50’ of established mapping limits.
- **Overlap –** Adjacent swaths shall have a minimum overlap of no less than 35% of the mean swath width, while maintaining 100% coverage.

- **Data Voids** - in Lidar are gaps in the point data coverage caused by surface absorbance, scattering, refraction in the near infrared, sensor issues, processing anomalies, improper data collection, or obstructions of the Lidar pulse. A data void is considered to be any area greater than or equal to $(4 \times \text{ANPS})^2$, which is measured using first returns only.
  Data voids within a single swath are not acceptable, except in the following circumstances:
  - where caused by waterbodies.
  - where caused by areas of low near infrared reflectivity, such as asphalt or composition roofing.
  - where caused by Lidar shadowing from buildings or other features.
  - where appropriately filled in by another swath.
- **Flight Direction** – Flight lines shall be flown in the most convenient direction, but adjacent, parallel lines should be flown in opposite directions to help identify systematic errors. Flight direction could be impacted by Federal Aviation Administration (FAA) airspace restrictions.
- **Lidar Survey Plan Report**
  - **Proposed flight lines** – Prior to data acquisition, it is important to submit digital map(s) clearly showing all proposed flight lines, and include coverage, scale, proposed ground control, and project area boundaries. Also included shall be information about scan angle, pulse repetition frequency (PRF), flight height, and aircraft speed over ground.
  - **Actual lines flown** – Similar map(s) showing the actual flight lines shall be included in the Final Report.
- **Cross lines** – At least one cross line (i.e., perpendicular to the primary flight lines) is required per survey. For longer survey areas, one cross line is required (approximately) every 25 km.
- **Flight Height** – Sensor shall not be flown at an altitude that exceeds that given in the manufacturer's specifications or that results in a significant number of "drop-outs" (i.e., pulses for which no return is received.) The altitude must be low enough that the average laser footprint (per survey block) is ≤ 10cm diameter.
- **Flight Clearances** – The survey plan shall comply with all required FAA regulations, including obtaining all required clearances.
- **Weather Conditions** – Lidar data acquisition missions shall be flown in generally favorable weather. Inclement weather conditions such as rain, snow, fog, mist, high winds, and low cloud cover shall be avoided. Such weather conditions have been known to affect or degrade the accuracy of the Lidar data. If clouds are present, data capture is only permitted if cloud coverage is above the height of the sensor and airborne platform. Lidar shall not be conducted when the ground is covered by water (flood), snow, or ice, and shall not be conducted when the land-water interface is obscured by snow, ice, etc. Storm systems and events (e.g., hurricanes, northeasters, or storm fronts) that may cause an increase in water levels, tidal heights, and wave activity shall be avoided.
- **Time of Day** – Data acquisition operations may occur during either day or night, unless specifically called out in the Project Instructions. Unlike aerial photography, sun angle is not a factor unless supplemental imagery (e.g., digital imagery) is required to be acquired

concurrently with the capture of Lidar data to help assist in identifying features in post-processing production.

- **Safety Planning** – Because Lidar systems typically employ Class 4 lasers, safety is a paramount concern. ANSI standards for safety shall be followed. A safety plan is prepared by adherence and enforcing to all TxDOT safety regulations and shall implement necessary internal controls to ensure the safety of all persons in the aircraft and in the survey area below.
- **Preliminary Plan for Scan Locations and Number of Scans/Site Terrain Research** – The preparation of the preliminary plan in the AOI will be done by placing the location of scan-lines according to the scan angle of the TXDOT-approved scan instrument and corresponding overlap between contiguous strips. For the preparation of this preliminary plan, it is important also to research the terrain site in terms of prevalent slopes and terrain use/terrain coverage in the AOI to see if they are of enough relevance to change the parameters of the flightlines.
- **GPS Data Acquisition** – The consultant shall propose a GPS data acquisition frequency that shall never be greater than 1Hz, utilizing dual frequency receivers in the platform and in the base stations. This shall be materialized by two points of known coordinates (expressed in the same cartographic system of the project) and the distance between them shall not be more than 45 Km. GPS Manufacturer, receivers name, serial number and accuracy characteristics shall be included also (both for the instrumentation in the acquisition platform and on the base stations).

Airborne Lidar necessitates meticulous planning to establish a comprehensive flight plan capable of covering the entire project area. The flight plan must be formulated in a KMZ format and should be included with the control layout. Additionally, mapping limits for 2D/3D aerial mapping extraction will also be included and must be approved by the TxDOT PM. Any changes to the mapping limits could change the overall flight plan.

2. SURVEY CONTROL

Control Network Layout

An appropriate number of Lidar ground control points will be strategically positioned in flat (no slopes) and open areas. Aerial ground control points will adhere to TxDOT Level 3 accuracy specifications. Each airborne LIDAR consultant will have the latitude for aerial panel placement and frequency. Each TxDOT project is unique and will require a custom ground control network layout that will ensure TxDOT required accuracies are met or exceeded.

With the current TxDOT specification (in most scoping) for an airborne Lidar point cloud at a minimum of 20-25 points per meter2, Airborne Lidar is sufficient for DTM development, however, aerial photogrammetry will be required for compiling 2D planimetrics, necessitating the need for 2.5 – 5.0 cm ground sampling distance (GSD) aerial photography. Airborne Lidar will utilize the aerial photography control network.

Airborne LIDAR Ground Control Points

Airborne Lidar targets are established prior to data acquisition to ensure visibility within the Lidar point cloud.

- Airborne Lidar will utilize the same control network required for photogrammetry.
- Airborne Lidar control points will not exceed 4,500-ft. spacing but will typically utilize an aerial photography control network.
- Airborne Lidar can be acquired prior to ground control being set due to limited visibility within the point cloud with a nominal post spacing of 25 points per square meter.
- Aerial panel points must be set prior to airborne Lidar data acquisition.
- Final survey control must be received prior to trajectory alignment and processing of the Lidar point cloud.

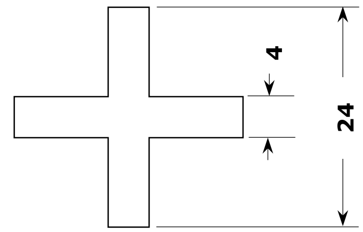


Figure 1: Airborne Ground Control Lidar Panel Dimensions

3. DATA ACQUISITION

Airborne Lidar can be acquired in daytime or nighttime conditions. Lidar data will be acquired at an altitude of 1,000 – 3000-ft. above ground level, dependent on the mission requirements. Flight height, aircraft speed, flight overlap, and laser field-of-view (FOV) all impact airborne Lidar point density. It will be up to the airborne Lidar consultant to determine the appropriate flight parameters to meet TxDOT Lidar point density requirements, while acquiring the data in the most efficient manner.

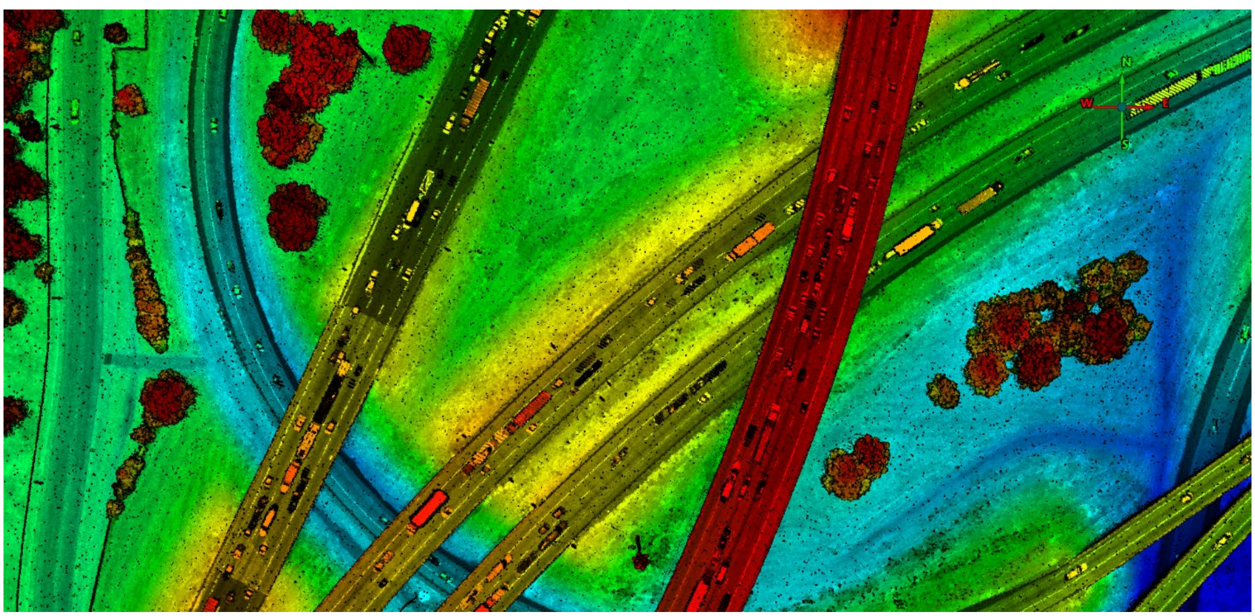


Figure 2: Airborne Lidar pointcloud colorized by elevation

Point Density

Refers to the number of points per meter^2. TxDOT specifies 25 points per meter^2 on most projects. If greater point density is requested by TxDOT, multiple flight lines and overlap will be required by the consultant.

Flight Height

Flight height for fixed-wing airborne Lidar missions range from 1,500-ft AGL and 4,000-ft. Flight height planning and considerations include airspace restrictions, cloud cover, and variation in terrain elevation. Flight height will be determined by the airborne Lidar consultant. The flight height will impact FOV, flightline overlap, accuracy, and the point density.

Field-of-View

The field-of-view (FOV) is defined as the angle which is covered by an airborne Lidar sensor. For Lidar applications this is equal to the angle in which Lidar signals are emitted. Reducing the FOV angle will result in a denser point pattern while increasing the FOV is going to spread the Lidar returns farther apart.

Flightline Overlap

For typical transportation corridors, 20% overlap is good flightline overlap practice. For increased point density from the TxDOT required 25 to 50 points per meter^2, flightlines would require up to 50% overlap for the increased point density requirement.

Equipment Maintenance and Boresight Calibration

Lidar equipment requires maintenance and repair. The sensor comes with a comprehensive manual of installation and maintenance. All aerial Lidar consultants must follow the manufacturer's suggested maintenance schedule. The scanner's observation precision can be improved by the manufacturer's instrument calibration. Any repairs outside of normal maintenance and end-user serviced items should be sent to the manufacturer.

Lidar Data Collection and Monitoring

During the airborne Lidar survey mission, laser pulses and POS data are stored in on-board hard drives or memory cards in the airplane and the GPS reference stations save their data locally. The pilot is guided by guidance software which uses data from the flight planning program. The pilot must pay attention to circumvent roll angles of more than ± 20°, because otherwise it could happen that the carrier phase of the Kinematic or Differential GPS cannot be resolved continuously in post processing.

The pilot also must monitor the effect of cross-flight winds that can provoke a deviation from the planned trajectory. In large airborne Lidar missions, the amount of data being stored and the capacity of the storage devices in the airplane should also be monitored.

It is advisable to scan a "calibration control area" (a runway with markings) with airborne Lidar at the beginning and at the end of a flight. This is to help to identify system drifts. In fact, it is a must if the Lidar and POS system are newly assembled or re-assembled and mounted the first time or mounted again in the airplane. As mentioned before, the area should exhibit special features which can identify system drifts and assure calibration precision.

Environmental Factors

Environmental considerations play a pivotal role in the planning phase of Airborne Lidar projects. The following is a list of common environmental factors that can significantly impact Lidar quality:

- Temperature: The Lidar sensor operates within a temperature range of 14°F to 104°F. Data collection outside this range may result in poor-quality data.
- Precipitation: All scanning activities must occur in dry conditions. Standing water on the ground or morning dew can create void areas within the Lidar point cloud. Water or frozen precipitation has limited reflectivity, making it crucial to ensure dry ground at the time of data collection through thorough planning and forecasting.
- Sun Angle: Rising or setting sun angles can lead to lens flare, degrading the quality of images captured by the Airborne Lidar system.
- Dust: Airborne dust or debris, whether caused by wind or traffic, can introduce noise within the Lidar point cloud.

4. DATA PROCESSING

Lidar Strip and Block Adjustment

Airborne Lidar data processing should be performed using professional Lidar processing software, i.e., TerraSolid or similar. Adjust Lidar point cloud data to project control points. One of the main characteristics of Lidar data is that each point of the cloud has its own EO parameters and have no relationships with one another. Moreover, each flown Lidar strip has its own instantaneous yaw, pitch, and roll as well as corresponding 3-dimensional shifts (i.e., ΔX, ΔY, ΔZ), that are the same as the platform during its flight. Each consultant may use their best judgement for airborne Lidar processing software techniques, if the calibrated and classified pointcloud meets TxDOT accuracy specifications. Figure 3 below illustrates Lidar strip matching.

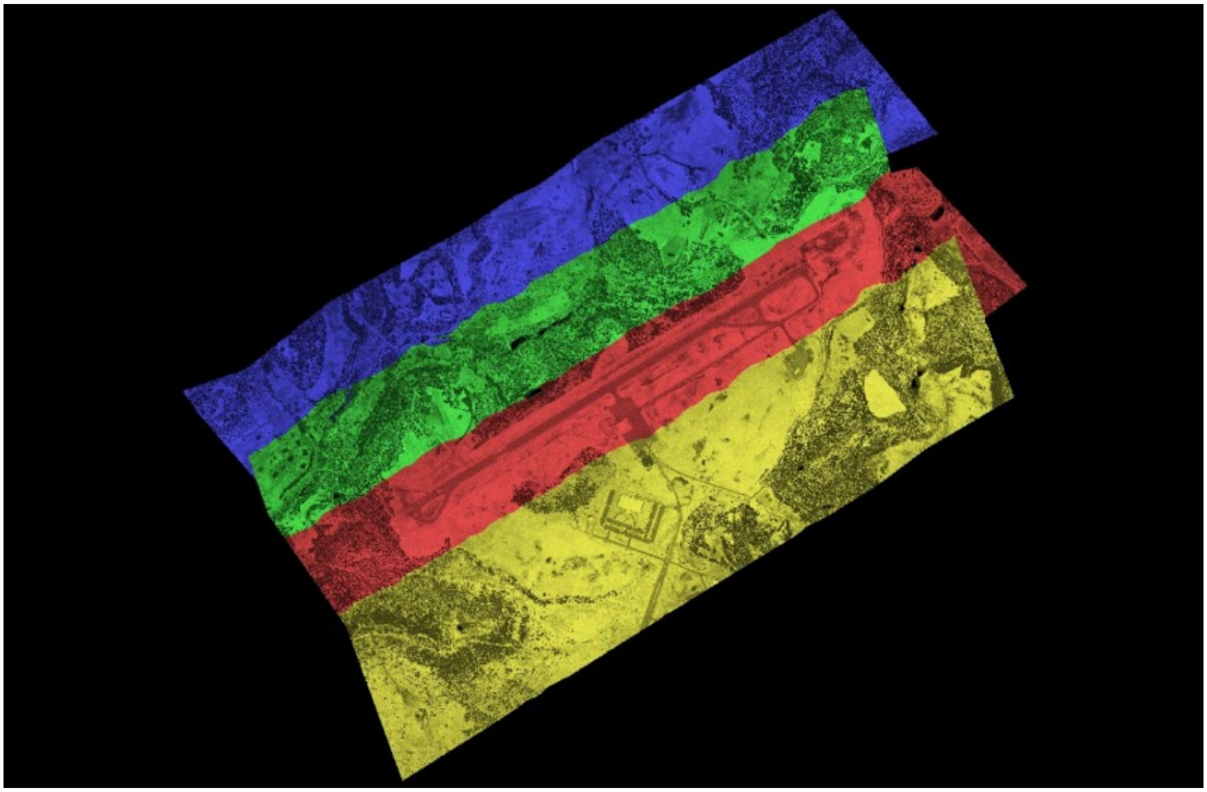


Figure 3: Lidar Post Processing Strip Matching

LIDAR Classification

Terrasolid or similar software must be utilized for classifying Airborne Lidar data for feature extraction purposes. The Airborne Lidar data will be classified according to the standard ASPRS 1.2 (or above) specifications, shown below in Figure 4:

Classification Value	Classification Type
0	Never Classified
1	Unassigned
2	Ground
3	Low Vegetation
4	Medium Vegetation
5	High Vegetation
6	Building

Figure 4: ASPRS LAS 1.4 Classifications

Lidar Ground-Truthing Requirements

Airborne Lidar projects are expected to include a minimum of 30 Lidar ground-truthing checkshots per project area as described in Edition 2 of the ASPRS Positional Accuracy Standards for Digital Geospatial Data, August 23, 2023. The determination of the ground-truthing check shot count for a project will be undertaken by an RPLS, ASPRS CP, or CMS in Lidar, considering factors such as urban/rural environments, tree cover/ground vegetation, GPS quality, and other relevant considerations. Each airborne Lidar consultant will have the latitude for check shot placement and frequency. Each TxDOT project is unique and will require a custom ground-truthing checkshots layout that will ensure TxDOT required accuracies are met or exceeded.

Reporting

The airborne Lidar consultant will provide TxDOT with a complete Survey Narrative report including but not limited to all the procedures carried out: From mission/flight planning through the deliverables. The narrative should include, at a minimum, the following topics:

- Description, topographic characteristics as well as the land cover/land use of the AOI.
- Area of the AOI (expressed in square miles or square Km) or swath width.
- Details regarding the planning of the Mission/Flights, including the flight parameters (e.g., flying height, scan angle, scan field of view, instantaneous field of view, scan width, average point spacing (along and across flight path), point density, overlapping factor, flight line separation on the field, number of flight lines (including transversal lines), etc.).
- Established Control. To include the base station(s) in relation to its (their) location (s) within the AOI, its (their) coordinates (in the Geodetic / Cartographic system of the project), number of base stations within the AOI, the characteristics of the base station(s) - meaning if they are field surveyed or are CORS stations. Their positional accuracy, etc. Among the control, the consultant will deliver a map at a convenient scale, showing the position of the Base Station Points, the GCPs and Check/Blind points and corresponding flight lines coverage. Regarding the GCPs, their field survey coordinates and corresponding accuracy per point expressed according to their individual standard deviation and in accordance with the NSSDA for a 90% and 95% confidence level. The same regarding the Check/Blind points. A close-range digital image of the points will be included (formats such as bmp, jpeg, tiff, etc., are acceptable).
- Calibration detail narrative regarding the entire procedure. This shall include, but not is necessarily limited to, the boresight field characteristics (e.g., total area, topographic characteristics of the area, land use/land cover), number and characteristics of the used GCPs and/or natural or manmade objects, geographic and cartographic coordinates systems used, number of flight lines covering the boresight, flying height (s), transversal flights, calibration parameters and their arrived accuracy, angle scan error due to zero angle reading, angle showing the lack of perpendicularity between the scan plane and the vector of the flight direction, scale factor, components (ΔX, ΔY, ΔZ) and total distance between the INS/IMU axis and the emitter/receiver, setting errors of the roll, pitch and yaw angles, total calibrated distance (and ΔX, ΔY, ΔZ components) between the center axis of the INS/IMU and the GPS

central phase antenna, Δt value or time correction for the clock measuring the pulse travel (emitting and receiving).

- Detail narrative of the flight mission. This shall include (but not limited to) weather conditions during the flight mission (sunny, cloudy, relative humidity, etc.), temperature at the instance of flight beginning and end, number of sorties to cover the area (all above mentioned weather parameters shall be recorded and reported for each sortie), continuous flight length and loops for removing the inertia gained by the INS/IMU system, etc.
- Detail regarding the scanner being used. Manufacturer, make, model, main characteristics, serial number, and time/date of its last field calibration. The same detail regarding the INS/IMU, Kalman Filter and GPS antenna are also required.
- Report any loss in satellite coverage.
- Airplane characteristics. Manufacturer, make, model, serial number, date of last certification, copy of the certification document, etc.
- Details regarding the computation of the SBET, (i.e., mathematical, and Statistical model, software name and characteristics, etc.)
- Narrative regarding Lidar strip/block adjustment. How and how many GCPs were used. Details regarding the software being used, mathematical and Statistical model on which it is based on (e.g., polynomial interpolation, moving average, least squares linear prediction, simple 3D-shifts, or only one-dimensional shift (ΔZ), etc.)
- Arrived RMSE from the GCPs and expressed according to NSSDA for accuracies at 90% and 95% confidence level. Detail description of how the segmentation and classification of the point cloud was done to arrive to the ASPRS Lidar point cloud classification.
- Arrived RMSE of the Lidar Coordinates of the Check/Blind Points.

5. FEATURE EXTRACTION

2D planimetric/3D DTM feature extraction is performed using professional extraction software, i.e., Datum International, TopoDOT, or Cardinal Systems, or similar. Feature extraction is carried out by utilizing both the Lidar and calibrated, georeferenced images. All Airborne Lidar feature extraction will adhere to the TxDOT Photogrammetry Feature Collection Standards, provided in the TxDOT Surveyors' Toolkit.

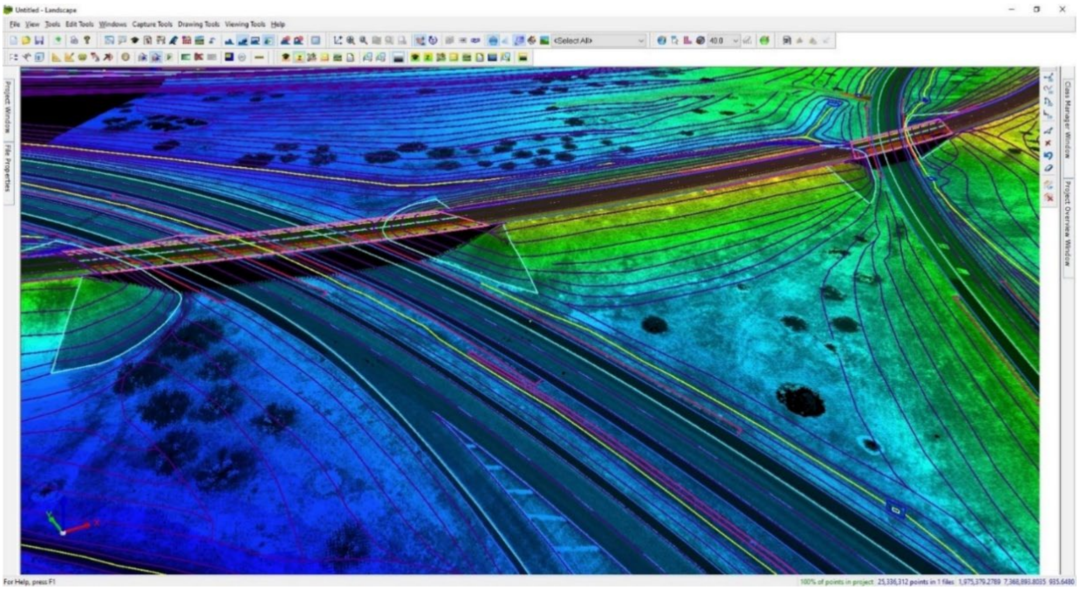


Figure 5: Breakline extraction within airborne Lidar pointcloud environment

2D planimetric feature extraction should be collected from the aerial photography following aerial triangulation is performed. 2D planimetrics can also be extracted from intensity images after the Lidar flight has been processed.

The first step in the feature extraction phase is to identify obscured areas so that survey field crews can collect supplemental data concurrently with the Airborne Lidar mapping.

- Lidar technicians will collect all 2D planimetric (aerial photogrammetry techniques) and 3D DTM features (airborne Lidar dataset) typically shown at a 1″ = 50′ map scale, as standard in MicroStation Open Roads Designer (ORD) and will comply with TxDOT CADD Standards.

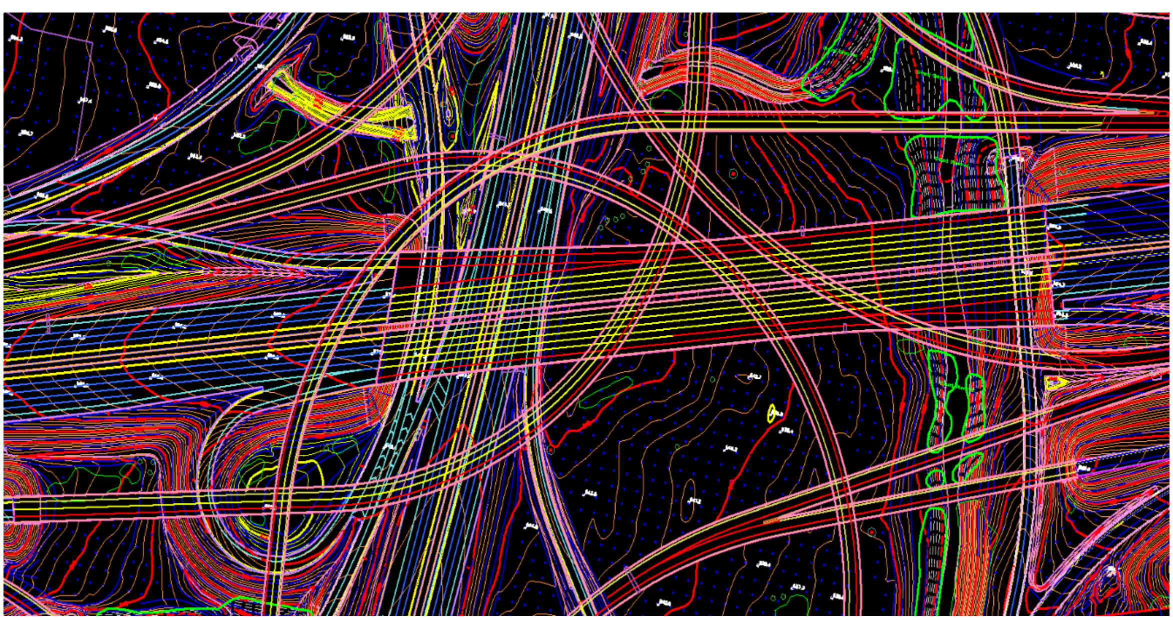


Figure 6 : TxDOT Airborne Lidar Extraction

6. QA/QC OF AIRBORNE MAPPING:

All feature-extracted 2D planimetrics (aerial photogrammetry) /3D DTM (Airborne LIDAR dataset) information will be initially edited by the Airborne Lidar Manager. Lidar ground-truthing checkshots will be compared with TIN. A preliminary TIN will be created and used as part of the initial review process before sending the final Lidar data to the RPLS for integration with conventional survey data.

7. INTEGRATION WITH SUPPLEMENTAL SURVEY:

Integration of Airborne Lidar Mapping with Conventional Survey will be performed and reviewed by an RPLS. Any QC markups will be sent back to the Airborne Lidar Manager and the extraction team to perform any revisions and fixes. Any changes in the final data will require a TIN file to be re-generated and reviewed. All labeling, QC markups, and integration of aerial mapping with survey must be performed by an RPLS.

8. FINAL QA/QC:

Final QA/QC of merged Airborne Lidar and Conventional Survey data will be performed by an RPLS, and all mapping data will be prepared for final deliverables to the State.

9. TXDOT AIRBORNE LIDAR DELIVERABLES:

- KMZ containing flight plan and control layout.
- Lidar acquisition certification containing date, time, and weather conditions observed during data collection.
- Processed and classified point cloud in LAS format with metadata.
- Georeferenced images in JPEG format.
- 2D/3D Planimetrics, 3D DTM, and TIN in MicroStation Open Roads Designer (ORD).
- ASCII point file containing Mobile Lidar ground control point locations.
- Completed Aerial Ground Control Submission (Form ROW-S-GrndCntrl).
- RMSE report with statement of accuracy from Lidar ground-truthing checkshots.