New York LiDAR Acquisition and Calibration Report

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SUBMITTED BY:

L3Harris Corporation
1395 Troutman Blvd.
Palm Bay, FL 32905
321.984.6110

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Overview

The USGS New York LiDAR acquisition and calibration activities were completed by L3Harris Corporation (L3Harris) of Melbourne, Florida. This document outlines the steps that were taken to perform quality control (QC) on the elevation data for the USGS.

Two pilot projects were completed and submitted to USGS in the Fall of 2020 (Saratoga and Corinth counties). These pilot projects were approved but included a few requests from USGS to be addressed in the full delivery. The first request was to classify buckshot as “unclassified” points. The second request was to apply version 2.4 of gdal translate to the DEM data which outputs the DEM’s spatial reference in a format consistent with other USGS datasets. The third request was to ensure the X,Y and Z locational references in point cloud headers are consistent within each LAS file.

Additionally, a TEM was held on October 8th 2020, with the USGS and L3Harris representatives to discuss the pilot projects. The primary issue discussed was related to sparse terrain (ground point) density. L3Harris explained, that these LiDAR data were collected during “full leaf out” environmental conditions, which prevented the LiDAR system from fully detecting the ground. The USGS decided to move forward, with the full project, with the recommendation to “avoid making this a habit for future off-the-shelf data purchases”, and the mutual understanding that the products were expected to satisfy USGS specifications with some variances.

PROJECT AREA

The project area addressed by this report is within the following New York counties which were collected as part a larger project; Jefferson, Lewis, Columbia, Rensselaer, Saratoga, Warren and Washington. The total size of this project is approximately 3,174 square miles.

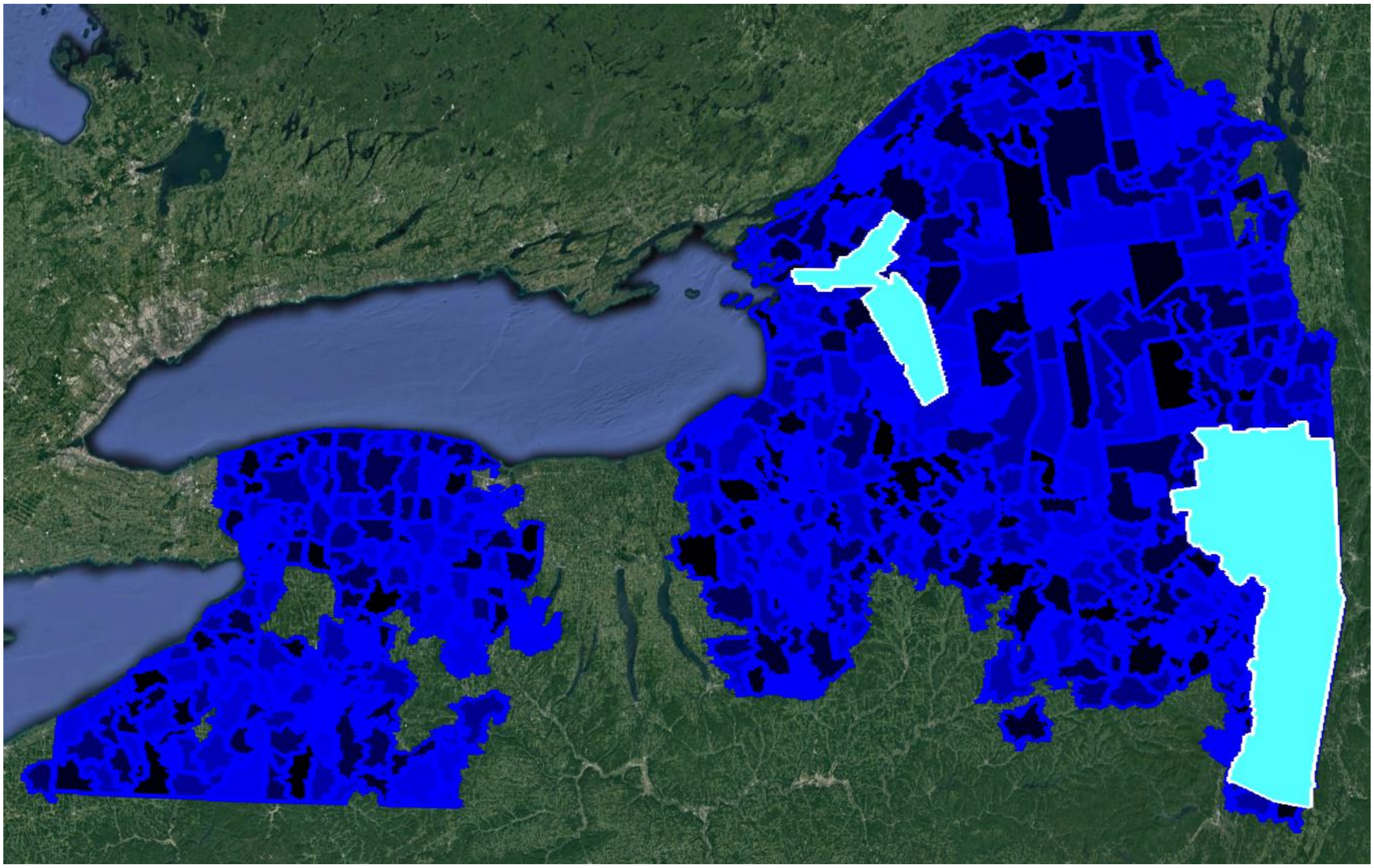

Figure 1 – Area of Interest: The area of interest consists of two AOIs, one called the East AOI and the other the West AOI. These are subsets of data collected for the original NGUS contract performed by L3Harris from 2018 and 2019.

ACQUISITION DATES

The LiDAR survey was conducted between August 10, 2018 and October 24, 2019.

DATUM REFERENCE

Data produced for the project were delivered in the following reference system:

Datum: North American Datum of 1983 (NAD 83)
Coordinate System: UTM Zone 18N
Units: Horizontal units are in meters; Vertical units are in meters.
Geoid Model: Geoid12B

LiDAR Acquisition Details

L3Harris planned collections (i.e., bricks) for the entire New York project area as a series of parallel East to West flight lines. The flight plan included zigzag flight line collection of less than 53 nautical miles in length limited by the inherent IMU drift associated with all IMU systems. To reduce margin for error in the flight plan, L3Harris followed FEMA's Appendix A "guidelines" for flight planning which at a minimum, includes the following criteria:

- A digital flight line layout using L3Harris' custom Mission Planner flight design software for direct integration into the aircraft flight navigation system.
- Planned flight lines; flight line numbers; and coverage area.
- LiDAR coverage extended by a predetermined margin beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables.
- Local restrictions related to air space and any controlled areas have been investigated so that required permissions can be obtained in a timely manner with respect to schedule. Additionally, L3Harris will file flight plans as required by local Air Traffic Control (ATC) prior to each mission.

L3Harris monitored weather and atmospheric conditions and conducted LiDAR missions only when no conditions exist below the flight altitude that would affect the collection of data. These conditions include no snow, rain, fog, smoke, mist and low clouds. LiDAR systems are active sensors, and do not require ambient light, thus missions may be conducted during night hours when weather restrictions do not prevent collection. L3Harris accesses reliable weather sites and indicators (webcams) to establish the highest probability for successful collection to position our sensor to maximize successful data acquisition.

Within 72-hours prior of the planned day(s) of acquisition, L3Harris closely monitored the weather, checking all sources for forecasts at least twice daily. When weather conditions were acceptable for collection, the aircraft was mobilized to the project site to begin data collection. Once on site, the acquisition team took responsibility for weather analysis.

L3Harris' GmAPD LiDAR sensors are calibrated at one of our designated sites located within the United States after each system integration effort. Calibration sites include Bridgewater Air Park (Bridgewater, VA), Concord Regional Airport (Concord, NC), Gatlinburg-Pigeon Forge Regional Airport (Sevierville, TN), L3Harris Corporation ((2) Melbourne & Palm Bay, Florida), Kenosha Regional Airport (Kenosha, WI), Montgomery Field Airport (San Diego, CA), and Westside Elementary School (Thermal, CA). These calibration sites have been professionally surveyed and adjusted to minimize corrections at project sites.

LIDAR SYSTEM PARAMETERS

L3Harris operated a Beechcraft King Air 200 outfitted with the L3Harris GmAPD LiDAR system during the collection of the NGUS collection area. In addition, L3Harris conducted the survey with three sensors. To comply with air traffic control safety measures, Sensor 1 was flown at 13800', Sensor 2 was flown at 16300' and Sensor 3 was flown 14000'. Table 1-3 below, illustrate the L3Harris GmAPD system parameters for LiDAR acquisition on this project.

Table 1 – LiDAR Sensor 1 System Parameters

MISSION OPERATIONAL DETAILS

Recommended Collection Parameters	Value
Platform Altitude (MSL)	13,800 ft
Platform Speed	220 knots
Camera Sensitivity	79
Filter Position	1
Filter Transmissivity	25%
Scanner Speed	14.2 Hz
Scanner Overlap	50%
Swath Overlap	50%
Range Bias Adjustment	0.00 m
Period of Operation	Night

Link Budget Analysis	Value
Expected Mean Reflectivity	40%
Expected Minimum Reflectivity	10%
Single Photon Pde (QE)	27.8%
Mean Np per Detector	19.1
Filtered Mean Np per Detector	4.8
Mean PEs per Detector	1.33
Maximum Allowable BRDF	7426
Mean PuPde	73.5%
Min PuPde	28.3%
Mean Number of Signal Detects	3268
Expected Range of Signal Detects	3268 - 3665
Probability of Time Out (Mean)	20.1%
Mean Number of Time Outs	823
Expected Range of Timeouts	426 - 1318
Probability of Noise Detection	0.1%
Expected Number of Noise Detections	5
Expected Atmospheric Tranmissivity	52%

Sensor Geometry Data	Value
Min Platform Altitude (AGL)	11,244 ft
Min Slant Range	11,641 ft
Max PlatformAltitude (AGL)	13,663 ft
Max Slant Range	14,145 ft
Swath Width	1.65 km
Planned Product GSD	18.3 cm
Planned Product Point Density	30 m^{-2}
Detector IFOV (Max)	15.1 cm

Estimated Actual Point Densities	Value
Mean Reflector Aggregate	79 m^{-2}
Mean Reflector Single	39 m^{-2}
Minimum Reflector Aggregate	30 m^{-2}
Minimum Reflector Single	15 m^{-2}

Expected Noise Characteristics	Value
Dark Count Frequency	0.51 kHz
Solar PEs/detector/bin	7.29E-14
Dark Count PEs/detector/bin	2.57E-07
Total Noise PEs/detector/bin	2.57E-07
Total Noise PEs/detector/gate	0.0

Sensor Data	Value
Planned Sensor	ISU - 0002
Current GmAPD Camera	1506A2012 10um R5

Collection Constraints	Setting
Collection Type	General WAM
Day or Night	Night
Desired Point Density	30.00 m^2
AOI Maximum Height (MSL)	2,556 ft
AOI Minimum Height (MSL)	137 ft
AOI Width	[redacted]
AOI Length	[redacted]
Distance to AOI	70.0 miles
Human Activity Layer Height	300 ft
AOI Mean Reflectance	High
AOI Minimum Reflectance	Moderate
Flight Restrictions - Deck	12,000 ft
Flight Restrictions - Ceiling	13,800 ft
Expected Visibility	Clear - Humid
Collection Constraints	Constraints - Standard

Advanced Flight Tuning	Setting
Point Density Target	Aggregate Min
AOI Auto Calculate?	Yes
Limit Performance by IFOV Resolution?	No
Swath Overlap %	50%
Clip Angle	0°
Scanner Overlap	50%
Maximize Scanner Speed ?	Yes
Mean Looks per Element Scaling Factor	1.00
Required PSF Detects (Tuned Reflector)	10
Required Detects/m2 Selection	Point Density
Enable Range Based Multi-Look?	No
Maximum Detector IFOV	30 cm
Additional Aircraft Roll Allowance?	Yes
Aircraft ID	Platform - DA N49R NationalGrid
Sensor ID	ISU - 0002

Display Units	Setting
Altitude	Feet
Swath Width	Kilometers
Collection Area	Square Miles
Aircraft Speed	Knots
Scanner Speed	Hz
AOI Distance	Miles

Table 2 – LiDAR Sensor 2 System Parameters

MISSION OPERATIONAL DETAILS

Recommended Collection Parameters	Value
Platform Altitude (MSL)	16,300 ft
Platform Speed	180 knots
Camera Sensitivity	85
Filter Position	1
Filter Transmissivity	25%
Scanner Speed	17.4 Hz
Scanner Overlap	67%
Swath Overlap	50%
Range Bias Adjustment	0.00 m
Period of Operation	Night

Link Budget Analysis	Value
Expected Mean Reflectivity	40%
Expected Minimum Reflectivity	10%
Single Photon Pde (QE)	27.8%
Mean Np per Detector	16.5
Filtered Mean Np per Detector	4.1
Mean PEs per Detector	1.14
Maximum Allowable BRDF	6222
Mean PuPde	68.1%
Min PuPde	24.9%
Mean Number of Signal Detects	3260
Expected Range of Signal Detects	3260 - 3823
Probability of Time Out (Mean)	20.3%
Mean Number of Time Outs	831
Expected Range of Timeouts	268 - 1545
Probability of Noise Detection	0.1%
Expected Number of Noise Detections	6
Expected Atmospheric Tranmissivity	52%

Sensor Geometry Data	Value
Min Platform Altitude (AGL)	10,962 ft
Min Slant Range	11,349 ft
Max PlatformAltitude (AGL)	15,774 ft
Max Slant Range	16,330 ft
Swath Width	1.60 km
Planned Product GSD	18.9 cm
Planned Product Point Density	28 m^{-2}
Detector IFOV (Max)	17.9 cm

Estimated Actual Point Densities	Value
Mean Reflector Aggregate	77 m^{-2}
Mean Reflector Single	39 m^{-2}
Minimum Reflector Aggregate	28 m^{-2}
Minimum Reflector Single	14 m^{-2}

Expected Noise Characteristics	Value
Dark Count Frequency	0.55 kHz
Solar PEs/detector/bin	1.05E-13
Dark Count PEs/detector/bin	2.77E-07
Total Noise PEs/detector/bin	2.77E-07
Total Noise PEs/detector/gate	0.0

Sensor Data	Value
Planned Sensor	ISU - 0003
Current GmAPD Camera	PLI 1507A2013 R3

Collection Constraints	Setting
Collection Type	General WAM
Day or Night	Night
Desired Point Density	28.00 m^2
AOI Maximum Height (MSL)	5,338 ft
AOI Minimum Height (MSL)	526 ft
AOI Width	[redacted]
AOI Length	[redacted]
Distance to AOI	70.0 miles
Human Activity Layer Height	300 ft
AOI Mean Reflectance	High
AOI Minimum Reflectance	Moderate
Flight Restrictions - Deck	14,000 ft
Flight Restrictions - Ceiling	16,300 ft
Expected Visibility	Clear - Humid
Collection Constraints	Constraints - Standard

Advanced Flight Tuning	Setting
Point Density Target	Aggregate Min
AOI Auto Calculate?	Yes
Limit Performance by IFOV Resolution?	No
Swath Overlap %	50%
Clip Angle	0°
Scanner Overlap	50%
Maximize Scanner Speed ?	Yes
Mean Looks per Element Scaling Factor	1.00
Required PSF Detects (Tuned Reflector)	10
Required Detects/m2 Selection	Point Density
Enable Range Based Multi-Look?	No
Maximum Detector IFOV	30 cm
Additional Aircraft Roll Allowance?	Yes
Aircraft ID	Platform - DA N49R NationalGrid
Sensor ID	ISU - 0003

Display Units	Setting
Altitude	Feet
Swath Width	Kilometers
Collection Area	Square Miles
Aircraft Speed	Knots
Scanner Speed	Hz
AOI Distance	Miles

Table 3 – LiDAR Sensor 3 System Parameters

MISSION OPERATIONAL DETAILS

Recommended Collection Parameters	Value
Platform Altitude (MSL)	14,000 ft
Platform Speed	220 knots
Camera Sensitivity	61
Filter Position	1
Filter Transmissivity	25%
Scanner Speed	18.9 Hz
Scanner Overlap	67%
Swath Overlap	50%
Range Bias Adjustment	0.00 m
Period of Operation	Night

Link Budget Analysis	Value
Expected Mean Reflectivity	40%
Expected Minimum Reflectivity	10%
Single Photon Pde	14.6%
Mean Np per Detector	39.7
Filtered Mean Np per Detector	9.9
Mean PEs per Detector	1.45
Maximum Allowable BRDF	4186
Mean PuPde	76.4%
Min PuPde	30.3%
Mean Number of Signal Detects	3240
Expected Range of Signal Detects	3240 - 3518
Probability of Time Out (Mean)	20.6%
Mean Number of Time Outs	846
Expected Range of Timeouts	569 - 1189
Probability of Noise Detection	0.2%
Expected Number of Noise Detections	10
Expected Atmospheric Tranmissivity	52%

Sensor Geometry Data	Value
Min Platform Altitude (AGL)	12,719 ft
Min Slant Range	13,168 ft
Max PlatformAltitude (AGL)	13,826 ft
Max Slant Range	14,314 ft
Swath Width	6,107 ft
Planned Product GSD	17.7 cm
Planned Product Point Density	32 m^{-2}
Detector IFOV (Max)	15.3 cm

Estimated Actual Point Densities	Value
Mean Reflector Aggregate	81 m^{-2}
Mean Reflector Single	40 m^{-2}
Minimum Reflector Aggregate	32 m^{-2}
Minimum Reflector Single	16 m^{-2}

Expected Noise Characteristics	Value
Dark Count Frequency	0.99 kHz
Solar PEs/detector/bin	2.16E-14
Dark Count PEs/detector/bin	4.95E-07
Total Noise PEs/detector/bin	4.95E-07
Total Noise PEs/detector/gate	0.0

Sensor Data	Value
Planned Sensor	ISU - 0004
Current GmAPD Camera	1411A2007 10um R4 0217

Collection Constraints	Setting
Collection Type	General WAM
Day or Night	Night
Desired Point Density	32 m^{-2}
AOI Maximum Height (MSL)	1,281 ft
AOI Minimum Height (MSL)	174 ft
AOI Width	
AOI Length	
Distance to AOI	70.0 miles
Human Activity Layer Height	300 ft
AOI Mean Reflectance	High
AOI Minimum Reflectance	Moderate
Flight Restrictions - Deck	11,000 ft
Flight Restrictions - Ceiling	14,000 ft
Expected Visibility	Clear - Humid
Collection Constraints	Constraints - Standard

Advanced Flight Tuning	Setting
Point Density Target	Aggregate Min
AOI Auto Calculate?	Yes
Limit Performance by IFOV Resolution?	No
Swath Overlap %	50%
Clip Angle	0°
Scanner Overlap	50%
Maximize Scanner Speed ?	Yes
Mean Looks per Element Scaling Factor	1.00
Required PSF Detects (Tuned Reflector)	10
Required Detects/m2 Selection	Point Density
Enable Range Based Multi-Look?	No
Maximum Detector IFOV	30 cm
Additional Aircraft Roll Allowance?	Yes
Aircraft ID	Platform - NationalGrid
Sensor ID	ISU - 0004

Display Units	Setting
Altitude	Feet
Swath Width	Feet
Collection Area	Square Miles
Aircraft Speed	Knots
Scanner Speed	Hz
AOI Distance	Miles

ACQUISITION STATUS REPORT AND FLIGHTLINES

Upon notification to proceed with LiDAR data acquisition, the flight crew loaded the flight plans and validated the flight parameters. The Acquisition Manager contacted air traffic control and coordinated flight pattern requirements. LiDAR acquisition began immediately upon notification that control base stations were in place. During flight operations, the flight crew monitored weather and atmospheric conditions. LiDAR missions were flown only when no conditions existed below the flight altitude that would affect the collection of data. The pilot continuously monitored the aircraft course, position, pitch, roll, and yaw of the aircraft to ensure successful collections. The sensor operator monitored the sensor, the status of GPS position dilution of precisions (PDOP) and performed the first QC review during acquisition. The flight crew constantly reviewed weather and cloud locations. Any flight lines impacted by unfavorable conditions were marked as invalid and re-flown immediately or at a future opportunity. Figure 2 shows the combined bricks and flight lines.

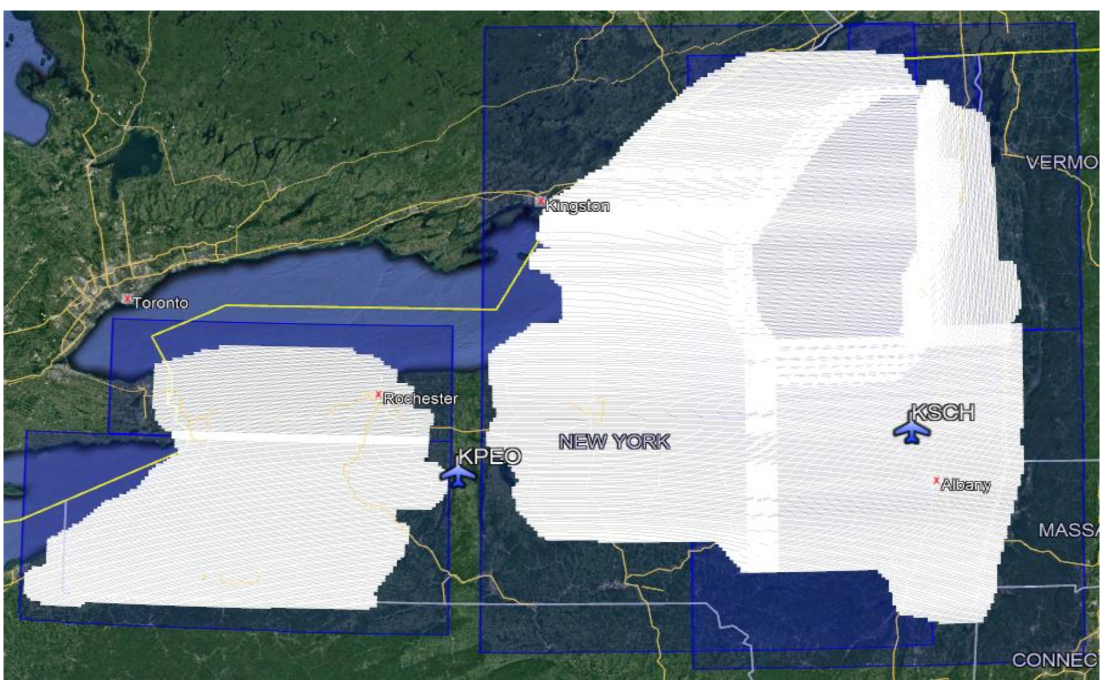

Figure 2: Bricks and flight lines as flown by L3Harris

AIRBORNE GPS KINEMATIC

Airborne GPS data were processed using the Applanix PosPac kinematic Mobile Mapping Suite 8.0 software. Most flights were flown with a minimum of 6 satellites in view (10° above the horizon) and with a PDOP 3 or less. Distances from base station to aircraft were kept to a maximum of 40 km.

For all flights, the GPS data was classified as good to excellent, with recorded GPS residuals of less than 3 cm and no larger than 10 cm.

GENERATION AND CALIBRATION OF LASER POINTS (RAW DATA)

The initial step of calibration is to verify availability and status of all needed GPS and GmAPD sensor laser data.

Swath footprints are generated and displayed to confirm complete two swath minimum coverage. Associated waterfall displays are reviewed to confirm that there are no cloud obscurations.

Data collected were reviewed for completeness, acceptable coverage and to make sure all data is captured without errors or corrupted values. In addition, all GPS, aircraft trajectory, mission information logs, and ground control files are reviewed.

After product generation, a supplementary coverage check was completed to ensure no data voids unreported by Field Operations are present.

CAMERA CALIBRATION, RELATIVE AND ABSOLUTE ACCURACY

Camera boresight angles are calibrated using surveyed calibration sites prior to collection. Orthogonal swaths at multiple altitudes are flown, smooth best fit telemetry (sbet) data are generated and resulting point cloud data registered to find the swath-to-swath correspondences. The correspondences are used in a bundle adjustment minimization process to determine x, y and z boresight angles for the specific sensor. Swaths are then viewed and measured for relative offsets and compared to the calibration site ground control. The relative calibration is then adjusted to ground control to achieve a final camera calibration solution.

For the project flights, sbets are generated using Applanix recommended best practices, and in conjunction with the camera calibration, an initial transformation is performed for each swath, forward and aft looks, to generate initial point clouds.

The project is subdivided into blocks, with blocks grouped into ten (10) separate registration sections.

For each registration section, point clouds from each swath are matched to other swaths using every fourth processing tile (5x5 arc second tiles). Correspondences are used to perform a bundle adjustment on the trajectory positions and attitudes to generate adjusted trajectories that best align the datasets covering the area.

Using these adjusted trajectories, the final product is generated and evaluated against the ground control for the brick. The process of measuring offsets of point cloud features to LiDAR identifiable ground control with a subsequent translation of the project to the ground control was performed. An analysis of the fit to ground control was performed, along with an analysis of the fit of a registration section with the neighboring sections. The final adjusted product was then verified using independent ground check points to establish the final accuracy for the product. Overall, the calibrated LiDAR data products collected by the L3Harris product meets or exceed the requirements defined in the Statement of Work and established with the pilot product results demonstrated for the LiDAR data collection environmental conditions. The quality control requirements of L3Harris quality management program were adhered to throughout the acquisition stage for this project to ensure product quality.