LiDAR PROJECT REPORT

Utah 2018 LiDAR – Brian Head Addition QL1

Contract # AV2406

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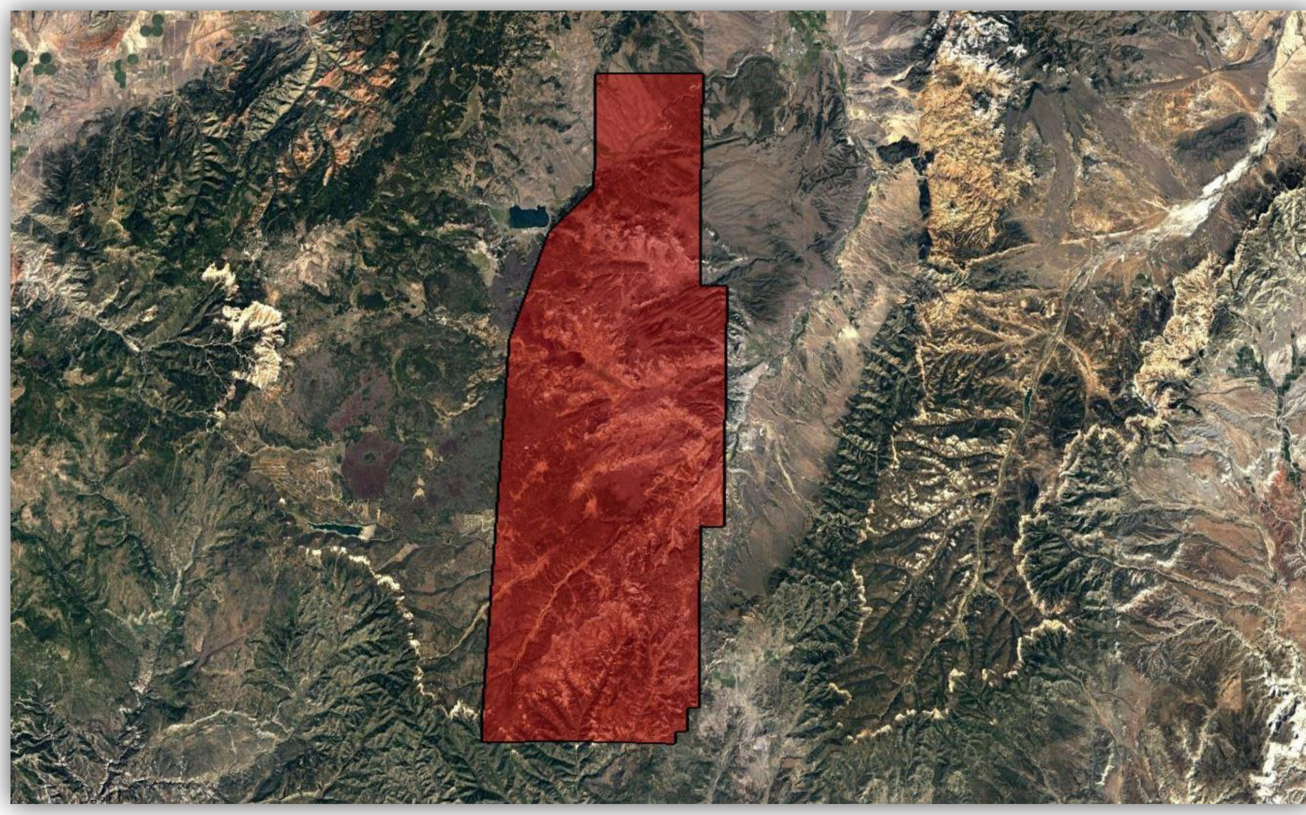

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TABLE OF CONTENTS

1. Introduction 2
   1.1 Project Overview 2
2. LiDAR Acquisition 3
   2.1 Flight Planning 3
   2.2 LiDAR Sensors 4
   2.3 Flight Logs 4
3. LiDAR Processing Workflow 5
4. Ground Control and Check Point Survey 7
5. Accuracy Testing and Results 9
   5.1 Relative Calibration Accuracy Results 9
   5.2 Calibration Control Point Testing 9
   5.3 Point Cloud Testing 9
   5.4 DEM Testing 10
   5.5 Data Accuracy Summary 10
6. Project Coordinate System 11
7. Project Deliverables 11

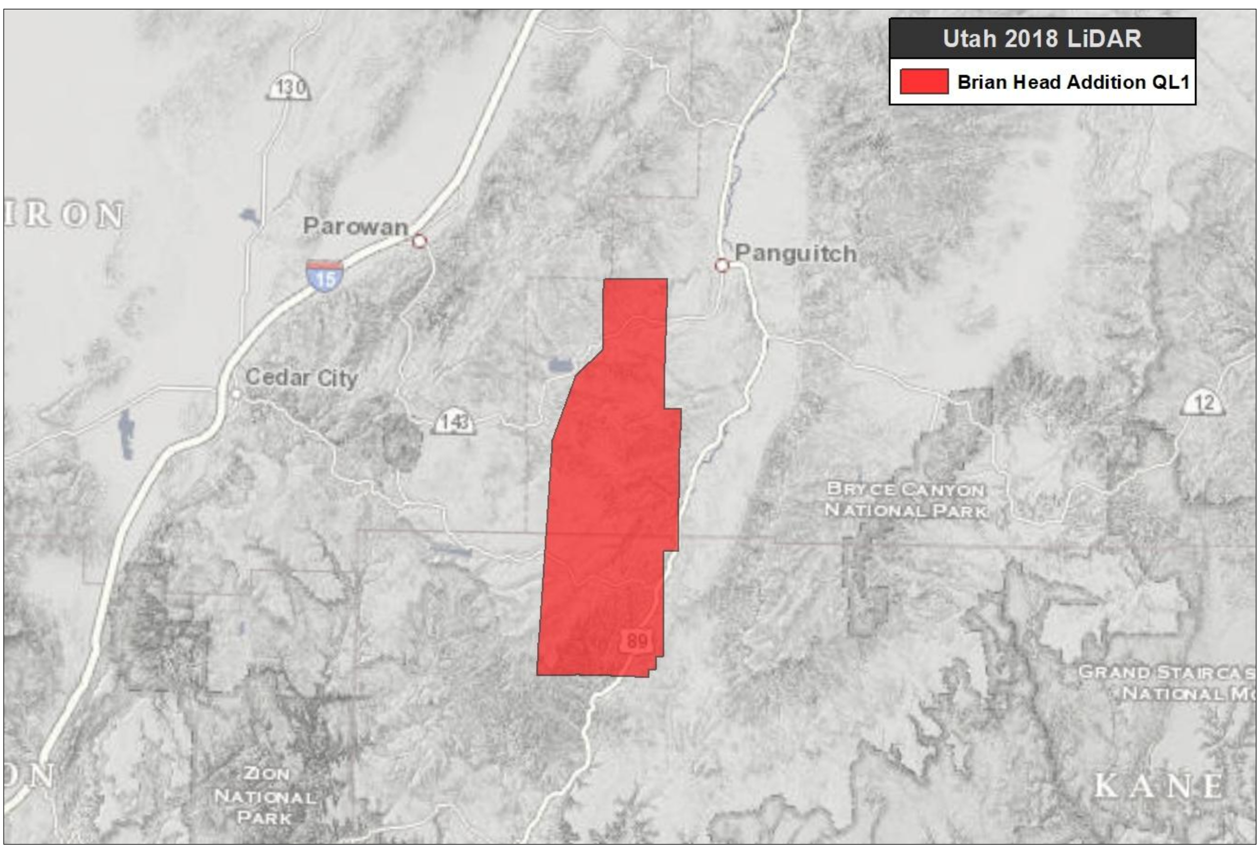
Appendix A – Base Station Coordinates 12

1. Introduction

1.1 Project Overview

Aero-Graphics, Inc., a full-service geospatial firm located in Salt Lake City, Utah, was contracted by the State of Utah, Department of Technology Services, Division of Integrated Technology, Automated Geographic Reference Center (AGRC) and partners to acquire, process, and deliver aerial Lidar data and derivative products that adhere to U.S. Geological Survey (USGS) National Geospatial Program (NGP) Lidar Base Specification Version 1.2 (2014). As described in the Scope of Work (SOW), the Utah 2018 LiDAR project was separated into three (3) delivery areas: Northern Utah, Central Utah, and Southern Utah. This report focuses on the Brian Head Addition QL1 AOI, which is a 216 mi^2 addition to the Southern Utah Project.

Brian Head QL1 Project Area			
AOI Name	Quality Level	Area (mi^2)	Acquisition Spec
Brian Head Addition	QL1	216	Leaf On



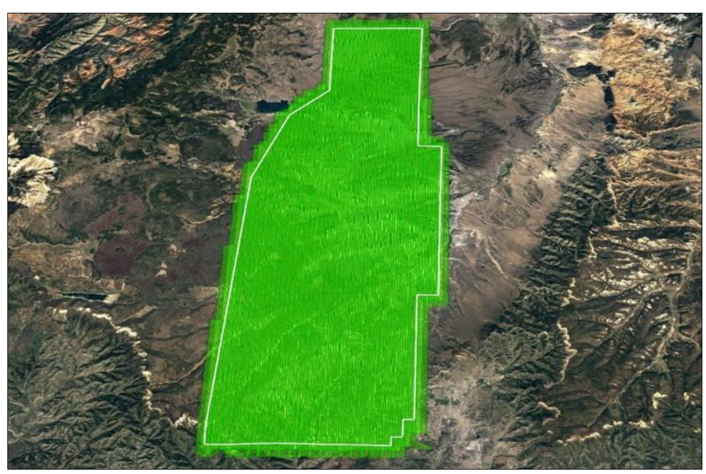
2. LiDAR Acquisition

2.1 Flight Planning

A specialized flight plan for each area was developed by Aero-Graphics' Aerial Department Manager to ensure complete coverage and that all contract specifications were met. Prior to mobilizing to the acquisition sites, Aero-Graphics' staff monitored all site conditions and potential weather hazards including wind, rain, snow, and blowing dust. In addition, Aero-Graphics ensured that all airspace clearances were secured by the proper officials before acquisition occurred.

The table below contains the planned settings for the Brian Head Addition QL1 AOI. Additional flight information including area coverage and sensor settings can be found in the individual lift metadata files.

Planned Specs	Brian Head Addition QL1
	Optech Galaxy PRIME
Altitude (m)	1450
Speed (kts)	120
PRF (kHz)	550
Scan Freq (Hz)	74.1
Scan Angle (°)	34
Swath Width (m)	887
NPS (m)	0.35
Point Density (ppm^2)	8.0
Overlap (%)	60



2.2 LiDAR Sensor

Optech Galaxy PRIME

The Optech Galaxy PRIME is currently the most productive sensor available in the industry. This sensor features SwathTRAK technology, which dynamically adjusts the scan FOV in real time during data acquisition. It also features a 1MHz effective pulse rate, providing on-the-ground point density and efficiency formerly reserved for dual-beam sensors. Up to 8 returns per pulse are possible for increased vertical resolution of complex targets without the need for full waveform recording and processing. Industry-leading data precision and accuracy (<5cm $RMSE_z$) results in the highest-quality datasets possible.

2.3 Flight Logs

Acquisition for the Brian Head Addition QL1 AOI occurred on September 8 and 9, 2018, when ground conditions were free of snow, ice, and standing water; rivers were at a stage of low flow; and lakes and reservoirs were close to the lowest levels of the year. The specified leaf-off/leaf-on requirements were accounted for during acquisition.

A total of 3 lifts were required to complete lidar acquisition for the assigned Brian Head Addition QL1 AOI. Flight dates are listed in the tables below along with the AOI, sensor name, sensor number, and aircraft tail number for each lift. Additional flight details including sensor settings and lift extent coordinates can be found in the individual lift metadata files.

Brian Head Addition QL1 Flight Logs				
Flight Date	**AOI Covered**	**Sensor Name**	**Sensor Number**	**Aircraft Tail Number**
20180908	Brian Head Addition	Optech Galaxy PRIME	SN5060410	N7269T
20180909-A	Brian Head Addition	Optech Galaxy PRIME	SN5060410	N7269T
20180909-B	Brian Head Addition	Optech Galaxy PRIME	SN5060410	N7269T

3. LiDAR Processing Workflow

a. **Absolute Sensor Calibration.** Our absolute sensor calibration adjusted for the difference in roll, pitch, heading, and scale between the raw laser point cloud from the sensor and surveyed control points on the ground.

b. **Kinematic Air Point Processing.** Differentially corrected the 1-second airborne GPS positions with ground base station; combined and refined the GPS positions with 1/200-second IMU (roll-pitch-yaw) data through development of a smoothed best estimate of trajectory (SBET).

c. **Raw LiDAR Point Processing (Calibration).** Combined SBET with raw LiDAR range data; solved real-world position for each laser point; produced point cloud data by flight strip in ASPRS v1.4 .LAS format; output in NAD83 (2011) UTM Zone 12, meters.

d. **Relative Calibration.** Performed relative calibration by correcting for roll, pitch, heading, and scale discrepancies between adjacent flightlines; tested resulting relative accuracy.

e. **Vertical Accuracy Assessment.** Performed comparative tests that showed Z-differences between surveyed points and the laser point surface.

f. **Tiling & Long/Short Filtering.** Cut data into project-specified tiles and filtered out grossly long and short returns.

g. **Classified LAS Processing.** The point classification is performed as described below. The bare earth surface is then manually reviewed to ensure correct classification on the Class 2 (Ground) points. After the bare-earth surface is finalized, it is then used to generate all hydro-breaklines through heads-up digitization.

   All ground (ASPRS Class 2) LiDAR data inside of the Lake Pond and Double Line Drain hydro-flattened breaklines were then classified to Water (ASPRS Class 9) using TerraScan macro functionality. A buffer of 1 meter was also used around each hydro-flattened feature to classify these ground (ASPRS Class 2) points to Ignored ground (ASPRS Class 10). All Lake Pond Island and Double Line Drain Island features were checked to ensure that the ground (ASPRS Class 2) points were reclassified to the correct classification after the automated classification was completed. All bridge decks were classified to Class 17. All overlap data was processed through automated functionality provided by TerraScan to classify the overlapping flight line data to approved classes by USGS. The overlap data was classified using standard LAS overlap bit. These classes were created through automated processes only and were not verified for classification accuracy.

   All data was manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler. LP360 was used as a final check of the bare earth dataset. LP360 was then used to create the deliverable industry-standard LAS files for both the All Point Cloud Data and the Bare Earth. Aero-Graphics, Inc. proprietary software was used to perform final statistical analysis of the classes in the LAS files, on a per tile level to verify final classification metrics and full LAS header information.

USGS Version 1.2 minimum point cloud classification scheme		
CLASS #	CLASS NAME	DESCRIPTION
1	Processed, but unclassified	Points that do not fit any other classes
2	Bare earth	Bare earth surface
7	Low noise	Low points identified below surface
9	Water	Points inside of lakes/ponds
10	Ignored ground	Points near breakline features; ignored in DEM creation process
17	Bridge decks	Points on bridge decks
18	High noise	High points identified above surface

h. **Hydro-Flattened Breakline Creation.** Class 2 (ground) LiDAR points were used to create a bare earth surface model. The surface model was then used to heads-up digitize 2D breaklines of inland streams and rivers with a 100-foot nominal width and inland ponds and lakes of 2 acres or greater surface area. Elevation values were assigned to all Inland Ponds and Lakes, Inland Pond and Lake Islands, Inland Stream and River Islands, using LP360 functionality. Elevation values were assigned to all inland streams and rivers using Aero-Graphics, Inc. proprietary software. All Ground (ASPRS Class 2) LiDAR data inside of the collected inland breaklines were then classified to Water (ASPRS Class 9) using TerraScan macro functionality. A buffer of 1 meter was also used around each hydro-flattened feature. These points were moved from ground (ASPRS Class 2) to Ignored Ground (ASPRS Class 10).

   The breakline files were then translated to ESRI shapefile format using ESRI conversion tools. Breaklines are reviewed against LiDAR intensity imagery to verify completeness of capture. All breaklines are then compared to TINs (triangular irregular networks) created from ground only points prior to water classification. The horizontal placement of breaklines is compared to terrain features and the breakline elevations are compared to LiDAR elevations to ensure all breaklines match the LiDAR within acceptable tolerances. Some deviation is expected between breakline and LiDAR elevations due to monotonicity, connectivity, and flattening rules that are enforced on the breaklines. Once horizontal placement, vertical variance is reviewed, all breaklines are reviewed for topological consistency and data integrity using a combination of ESRI ArcMap tools and proprietary tools.

i. **Hydro-Flattened Raster DEM Creation.** Class 2 (Ground) LiDAR points in conjunction with the hydro breaklines were used to create a 0.5 meter (QL1) and 1 meter (QL2) hydro-flattened raster DEMs. Using LP360 along with automated scripting routines within ArcMap, a GeoTIFF was created for each tile. Each surface is reviewed using ESRI ArcMap and ArcScene to check for any surface anomalies or incorrect elevations found within the surface.

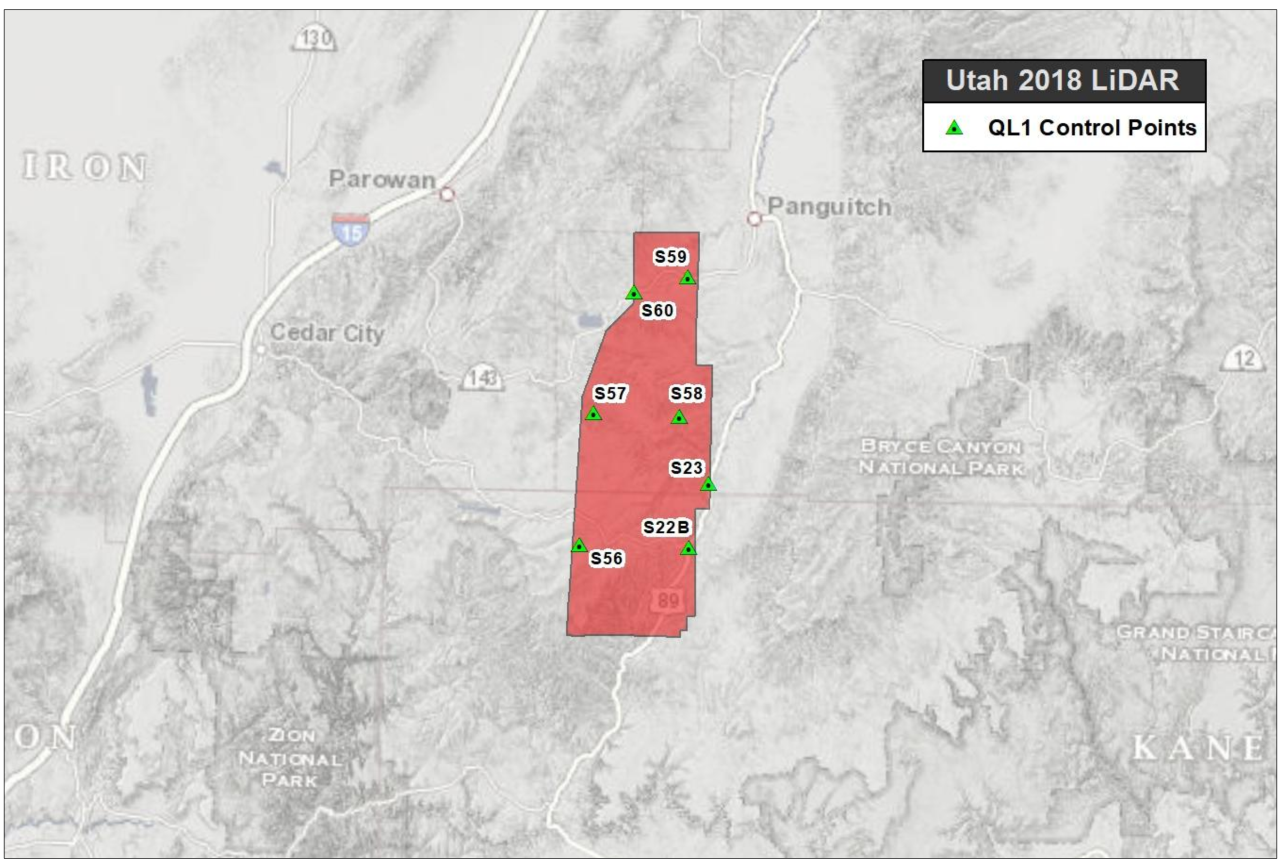
j. **First Return Raster DSM Creation.** First return LiDAR points were used to create a 0.5 meter (QL1) and 1 meter (QL2) first-return raster DEMs. Using LP360 along with automated scripting routines within ArcMap, a GeoTIFF file was created for each tile. Each surface is reviewed using ESRI ArcMap and ArcScene to check for any surface anomalies or incorrect elevations found within the surface.

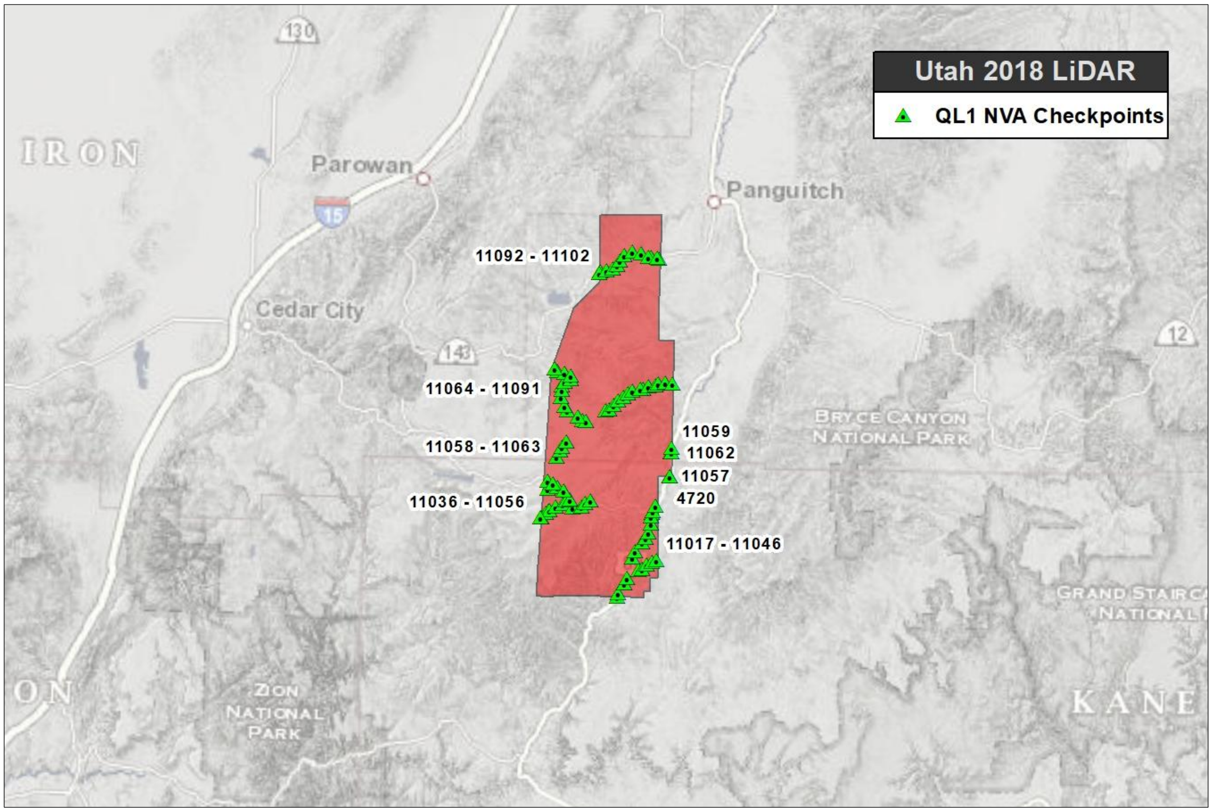
k. **Intensity Image Creation.** TerraScan software was used to create the deliverable Intensity Images. All overlap classes were ignored during this process as it helps to ensure a more aesthetically pleasing image. ESRI ArcMap software was then used to verify full project coverage. TIF/TFW files were provided as the deliverable for this dataset requirement.

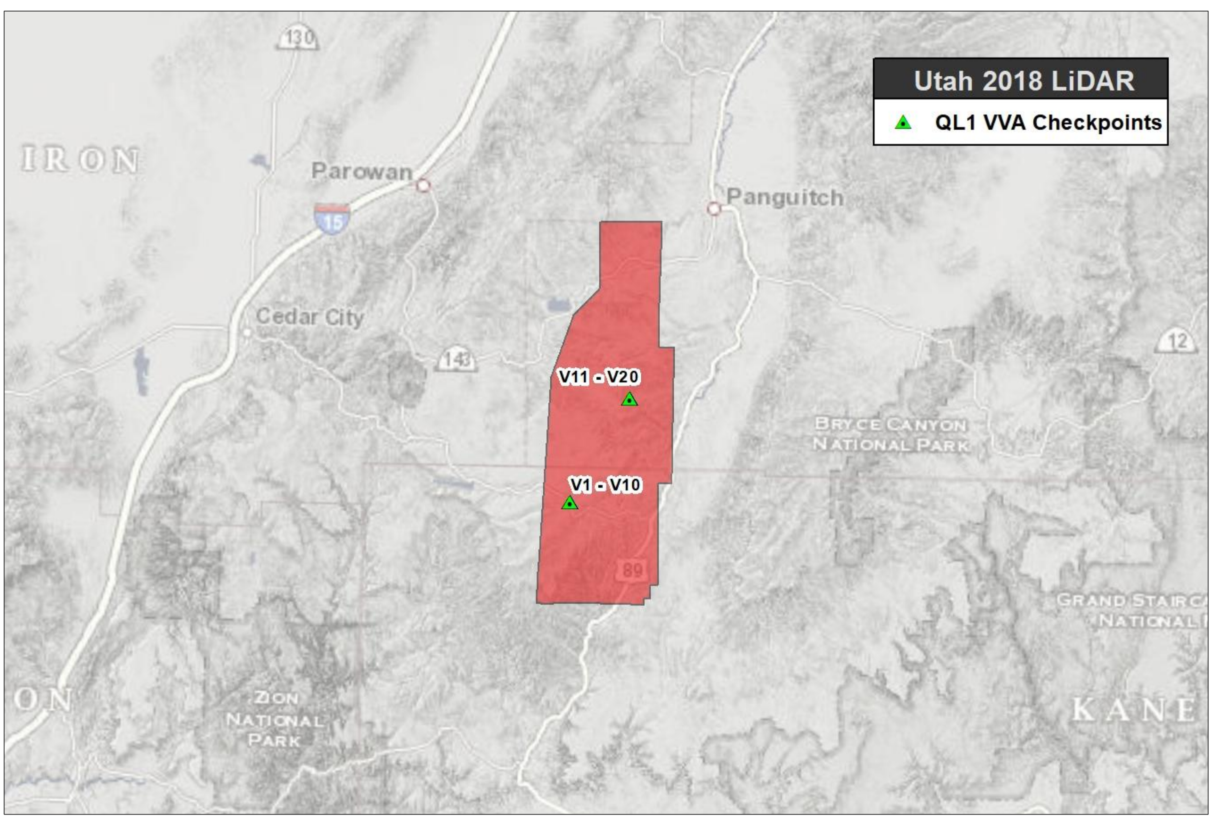
l. **Issues.** During acquisition, the aircraft experienced turbulence that affected the lidar scan pattern; this presents as clustering along the flight path. Data was tested and meets specifications for ANPS, Smooth Surface Repeatability, and Vertical Accuracy. No artifacts or irregularities exist in the surface model as a result of the scan pattern.

4. Ground Control and Check Point Survey

Aero-Graphics' professional land surveyor identified, targeted, and surveyed 7 ground control points for use in data calibration as well as 100 QC check points in Vegetated and Non-Vegetated land cover classifications as an independent test of accuracy for this project. A combination of precise GPS surveying methods, including static and RTK observations were used to establish the 3D position of ground calibration points and QC check points. Calibration control point and QC check point coordinates are included in the deliverable ESRI shapefiles. Base station coordinates can be found in Appendix A.




Utah 2018 LiDAR
QL1 NVA Checkpoints
IRON
Parowan
15
Panguitch
Cedar City
143
130
12
11092 - 11102
11064 - 11091
11058 - 11063
11036 - 11056
11059
11062
11057
4720
11017 - 11046
BRYCE CANYON NATIONAL PARK
GRAND STAIRCA NATIONAL
ZION NATIONAL PARK
KANE


Utah 2018 LiDAR
QL1 VVA Checkpoints
IRON
Parowan
15
Panguitch
Cedar City
143
130
12
89
V11 - V20
V1 - V10
BRYCE CANYON NATIONAL PARK
GRAND STAIRCA NATIONAL
ZION NATIONAL PARK
KANE

5. Accuracy Testing and Results

5.1 Relative Calibration Accuracy Results

Between-swath relative accuracy is defined as the elevation difference in overlapping areas between a given set of two adjacent flightlines. The results are based on the comparison of the flightlines and points for each area.

Brian Head Addition QL1 AOI

- Between-swath relative accuracy **average** of 0.033 meters

Within-swath relative accuracy is the amount of vertical separation, or "noise," among a set of points on open, paved ground that should have the same elevation. The within-swath relative accuracy average is less than **0.008 meters.**

5.2 Calibration Control Point Testing

Calibration Control Point reports were generated as a quality assurance check. Note that the results are not an independent assessment of the accuracy of the project deliverables, but rather an additional indication of the overall accuracy of the dataset. The location of each control point is displayed on page 7.

5.3 Point Cloud Testing

The project specifications require that only Non-Vegetated Vertical Accuracy (NVA) be computed for raw LiDAR point cloud swath files. NVA is defined as the elevation difference between the LiDAR surface and ground surveyed static points collected in open terrain (bare soil, sand, rocks, and short grass) as well as urban terrain (asphalt and concrete surfaces). The NVA for this project was tested with 80 check points. These check points were not used in the calibration or post processing of the LiDAR point cloud data. Elevations from the unclassified LiDAR surface were measured for the xy location of each check point. Elevations interpolated from the LiDAR surface were then compared to the elevation values of the surveyed control points.

Raw Non-vegetated Vertical Accuracy (Raw NVA): The tested Raw NVA for this dataset was found to be 0.095 meters in terms of the RMSEz. The resulting NVA stated as the 95% confidence level (RMSEz x 1.96) is 0.186 meters. Therefore this dataset meets the required NVA of 0.196 meters at the 95% confidence level as defined by the National Standards for Spatial Data Accuracy (NSSDA).

5.4 Digital Elevation Model (DEM) Testing

The project specifications require the accuracy of the derived DEM be calculated and reported in two ways: (1) Non-Vegetated Vertical Accuracy (NVA) calculated at a 95% confidence level in “bare earth” and “urban” land cover classes and (2) Vegetated Vertical Accuracy (VVA) in all vegetated land cover classes combined calculated based on the 95th percentile error. The NVA for this project was tested with 80 check points. The VVA was tested with 20 check points.

The tested Non-Vegetated Vertical Accuracy (NVA) for this dataset captured from the DEM using bi-linear interpolation to derive the DEM elevations was found to be 0.094 meters in terms of the RMSEz. The resulting accuracy stated as the 95% confidence level (RMSEz x 1.96) is 0.184 meters. Therefore this dataset meets the required NVA of 0.196 meters at the 95% confidence level.

The tested Vegetated Vertical Accuracy (VVA) for this dataset captured from the DEM using bi-linear interpolation for all classes was found to be 0.155 meters. Therefore this dataset meets the required VVA of 0.294 meters based on the 95th percentile error.

5.5 Data Accuracy Summary

Accuracy has been tested to meet 19.6 cm or better Non-Vegetated Vertical Accuracy at 95% confidence level using RMSEz x 1.96 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation (NDEP)/ASPRS Guidelines.

Area	Raw Point Cloud NVA	DEM NVA	DEM VVA	Points Tested NVA	Points Tested VVA
Brian Head Addition QL1	0.186 m	0.184 m	0.155 m	80	20

6. Project Coordinate System

Projection:		Universal Transverse Mercator (UTM) Zone 12
Datum	Vertical:	NAVD88 (GEOID12B)
	Horizontal:	NAD83 (2011)
Units:		Meters
WKID:		6341

7. Project Deliverables

All required project deliverables and file formats are listed in the table below.

Delivery Item	Format
Raw LiDAR point cloud data swaths	LAS 1.4 (.las)
Classified LiDAR point cloud data tiles	LAS 1.4 (.las)
Bare-earth raster DEM tiles with a cell size of 0.5 meter (QL1) and 1 meter (QL2)	GeoTIFF (.tif)
First-return raster DSM tiles with a cell size of 0.5 meter (QL1) and 1 meter (QL2)	GeoTIFF (.tif)
Intensity image tiles at a resolution of 0.5 meter (QL1) and 1 meter (QL2)	GeoTIFF (.tif)
AOI, Processing Boundary (BPA), and Tile Index	ESRI Shapefile (.shp)
Breaklines used for hydro-flattening	ESRI Shapefile (.shp)
Control Points and QC Checkpoints	ESRI Shapefile (.shp)
Project, Deliverable, and Lift Metadata	XML (.xml)

*Tiling for the LiDAR deliverables is based on the U.S. National Grid System. Tile names are based on the SW corner of the tile. All .LAS tiles are 1,000 meters x 1,000 meters. Raster tiles are a mix of 1,000 meters x 1,000 meters and 2,000 meters x 2,000 meters.

APPENDIX A

BASE STATION COORDINATES

Survey Point	WGS84		
	Latitude	Longitude	Ellipsoid Height (mtr)
EX01_027E	37.62081305	-112.5271572	2226.927