Project PI: Hugo A. Gutierrez Jurado

1. ALTM Specifications

This survey used an Optech GEMINI Airborne Laser Terrain Mapper (ALTM) serial number 06SEN195 mounted in a twin-engine Cessna Skymaster (Tail Number N337P).

System specifications appear below in Table 1.

Operating Altitude	80 - 4000 m
Horizontal Accuracy	1/11,000 x altitude; ±1-sigma
Elevation Accuracy	5 - 10 cm typical; ±1-sigma
Range Capture	Up to 4 range measurements per pulse, including last
Intensity Capture – see note below	4 Intensity readings with 12-bit dynamic range for each measurement
Scan Angle	Variable from 0 to 25 degrees in increments of ±1degree
Scan Frequency	Variable to 100 Hz
Scanner Product	Up to Scan angle x Scan frequency = 1000
Pulse Rate Frequency	33 - 167 KHz
Position Orientation System	Applanix POS/AV including internal 12-channel 10Hz GPS receiver
Laser Wavelength/Class	1047 nanometers / Class IV (FDA 21 CFR)
Beam Divergence nominal (1\e full angle)	Dual Divergence 0.25 mrad or 0.80 mrad

Table 1 Optech GEMINI specifications.

See http://www.optech.ca for more information from the manufacturer.

2. Survey Area

The survey area was located east of Ladron Peak in New Mexico, about 40 kilometers north-northwest of Socorro. It consisted of a single polygon as shown in the figure below. The polygon enclosed an area of approximately 40 Km^2

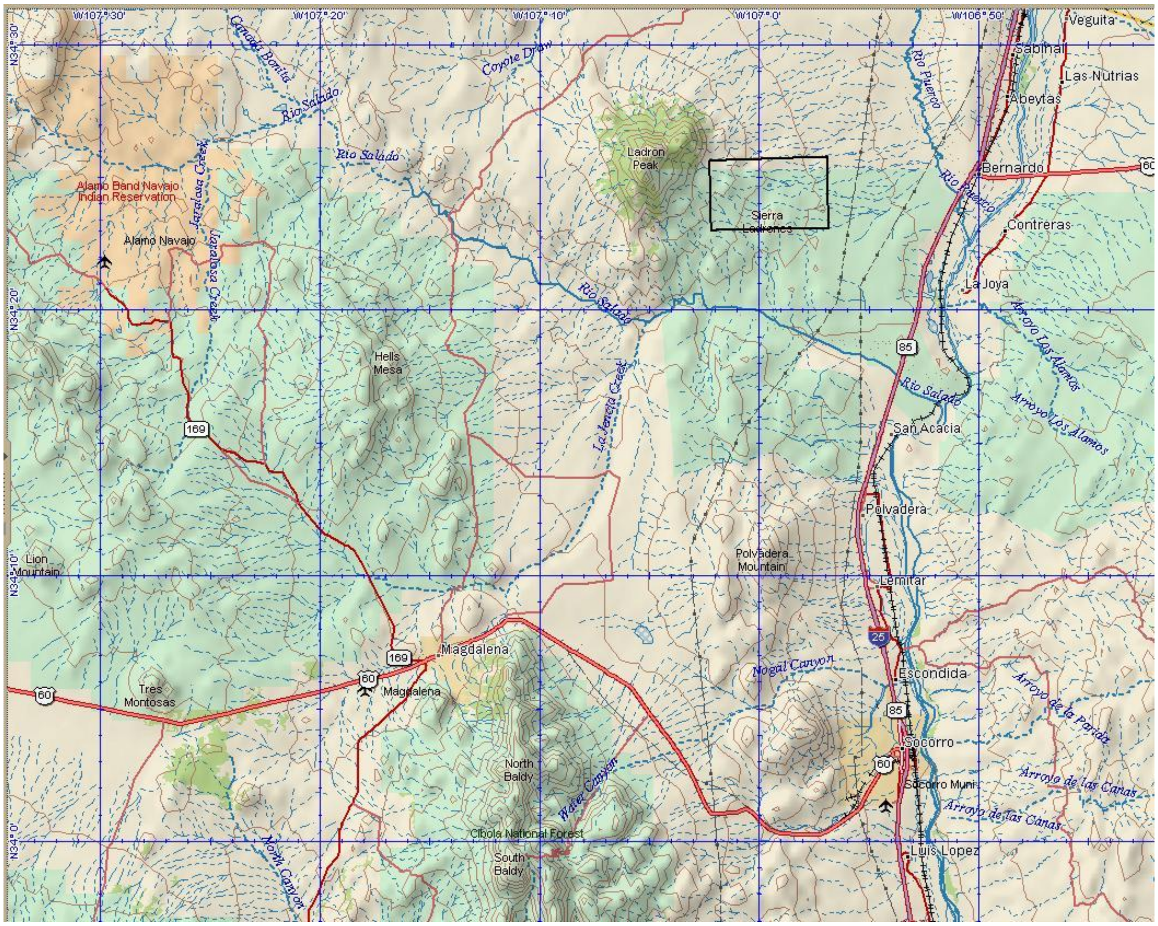

Figure 1 - Survey Area

3. Survey Time

The survey was carried out on September 25, 2007, in a single flight.

4. Survey Parameters

The survey required 19 flight passes, shown below in Figure 2.

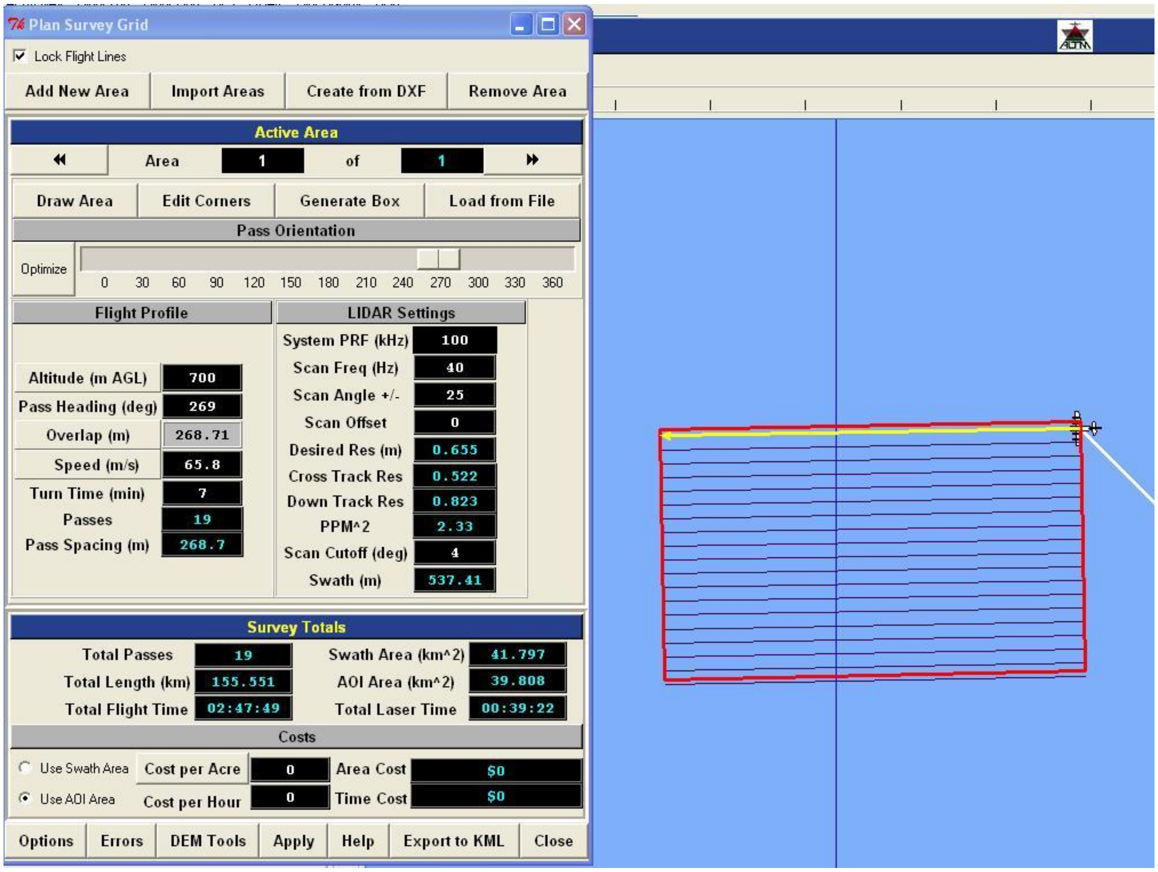

Figure 2 - Flight lines with planning parameters.

Survey totals appear below in Table 2.

Survey Totals	
Total Passes	19
Total Length	155.5 km
Total Flight Time	04:45
Total Laser Time	00:51:10
Total Swath Area	39.8 km^2
Total AOI Area	54.926 km^2

Table 2 Survey totals. Area of Interest is abbreviated AOI.

LiDAR settings are shown in Table 3.

LiDAR Settings	
Desired Resolution	0.655 m
Cross Track Resolution	0.522 m
Down Track Resolution	0.823 m
Scan Frequency	40 Hz
Scan Angle	+/- 25 deg
Scan Cutoff	+/- 4.0 deg
Scan Offset	0 deg
System PRF	100 kHz
Swath Width	537.41 m

Table 3 LiDAR settings.

Planned flying altitude was 700 meters AGL (Above Ground Level).

5. GPS Reference Stations

Two independent locations were used for GPS reference stations. One position was located at the Alexander Municipal airport, where NCALM field personnel observed an NGS control monument known as Belair (PID = EQ1063 in NGS database), and the other location was a CORS: station SC01 in Socorro NM. All GPS observations were logged at a 1-second rate and observations from the NCALM airport station were submitted to the NGS on-line processor OPUS with a solution file included as Appendix A. Final coordinates for this reference stations were calculated from the OPUS solutions. Final Coordinates for SC01 were obtained from National Geodetic Survey (NGS).

For further information on OPUS see http://www.ngs.noaa.gov/OPUS/ and for more information on the CORS network see http://www.ngs.noaa.gov/CORS/ NCALM GPS equipment consisted of ASHTECH (Thales Navigation) Z-Extreme receivers, with choke ring antennas (Part# 700936.D) mounted on 1.500-meter fixed-height tripods.

6. Navigation Processing

Airplane trajectories for this survey were processed using KARS software (Kinematic and Rapid Static) written by Dr. Gerry Mader of the NGS Research Laboratory. The KARS processing engine uses the dual-frequency phase history files of the reference and airborne receivers to determine a fixed integer ionosphere-free differential solution. Each trajectory was processed twice, using both ground reference stations and then coordinate differences between the separate solutions were plotted. Figure 3 is a plot of the differences in Easting, Northing, and Height of two trajectories solutions.

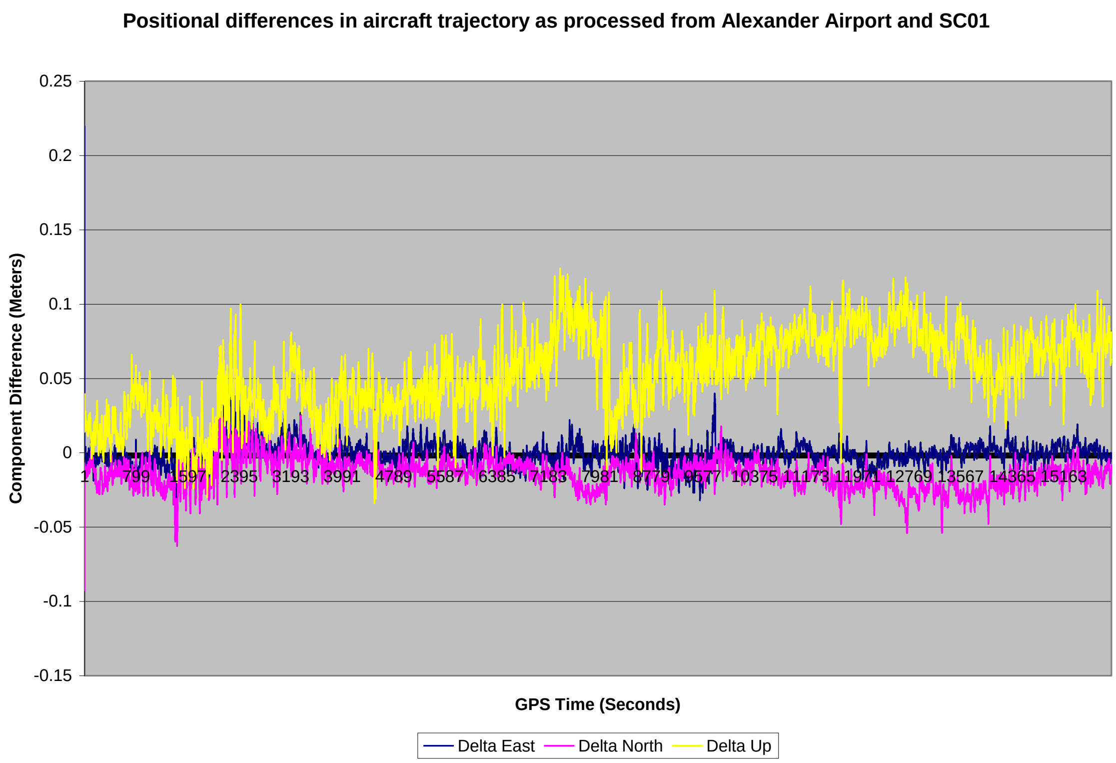

Figure 3 - Positional differences in aircraft trajectories with respect to time as processed from 2 base stations.

	D East	D North	D Up
Average	-0.001	-0.014	0.053
Std	0.009	0.010	0.027

Table 4 Positional difference statistics.

7. Laser Point Processing and Calibration

After GPS processing was completed for the flight, the final GPS trajectory and the raw IMU (Inertial Measurement Unit) data collected were input into APPLANIX software POSPROC Version 4.3.1. This software employs a Kalman Filter algorithm to combine the 1-Hz final differential GPS solutions with the raw 200-Hz IMU orientation measurement data and their respective error models. The final result is a smoothed and blended solution of both aircraft position and orientation at 200 Hz, in SBET format (Smoothed Best Estimated Trajectory). The SBET, laser range, and mirror-angle measurement data were combined using Optech's DASHMap Version 3.0 processing suite to generate point clouds in selected calibration areas, usually locations where cross-lines were flown or ground truth was collected.

System calibration was then performed as a 2-step process: step one (relative calibration) is to adjust the bore sight values of heading, roll, pitch, and scanner mirror scale such that systematic positional errors are minimized; and step two is an absolute calibration such that the laser DEM will match the height values of ground truth collected by vehicle-mounted GPS.

Step 1: Relative calibration was performed in TerraMatch software please see (http://terrasolid.fi/ENG/Products.htm) for detailed information.

A general description of the relative calibration procedure follows.

1. Cross-lines are flown for every flight with a heading perpendicular to the project flight line heading.
2. Small polygons containing these cross lines along with project flight lines are processed using approximate calibration values for heading, roll, pitch, and scanner mirror scale. Each line is processed separately.
3. Continuing to process each line separately, all lines are filtered (if necessary) to remove vegetation; then individual flight line surfaces are created.
4. Using TerraMatch, an iterative algorithm is applied to compute the best-fit between the individual flight line surfaces: simultaneously solving for the optimal bore sight values of heading, roll, pitch, and scanner mirror scale.
5. These updated bore sight values are then entered into DashMap; new output is produced and checked for all flights.
6. Complete and final output is run using the optimized calibration values for each flight.

Very stable calibration values were observed during the processing of this flight. Average height differences of 0.04 meters were computed between surfaces created from adjacent flight lines in the calibration areas.

Step 2: Absolute calibration is done by comparing the height of the nearest neighbor laser point to the height of a set of check points that are collected by vehicle-mounted GPS.

Table 5 below shows the difference statistics

Average	0.084
Standard Deviation	0.039

Table 5 Height difference values statistics

During processing, a scan cutoff angle of 4.0 degrees was used to eliminate points at the edge of the scan lines. This was done to improve the overall DEM accuracy as points farthest from the scan nadir are the most affected by small errors in pitch, roll and scanner mirror angle measurements.

All coordinates were processed with respect to NAD83. The projection is UTM Zone 13, with units in meters. Heights are NAVD88 orthometric heights computed using NGS GEOID03 model. The flight strip point cloud files were tiled into 1 kilometer square blocks with a naming convention using the lower left coordinate (minimum X, Y) as the seed for the file name as follows: Unfiltered_XXXXXX_YYYYYYY for unfiltered point cloud tile (Unfiltered replaced by filtered for filtered point cloud tile). For example if the tile bounds coordinate values from easting equals 317000 through 318000, and northing equals 3809000 through 3810000 then the tile filename is Filtered_317000_3809000.

Figure 4 (below) is an image of the 1 kilometer tile footprints overlaid onto a shaded relief image of the bare-earth Digital Elevation Model (DEM).

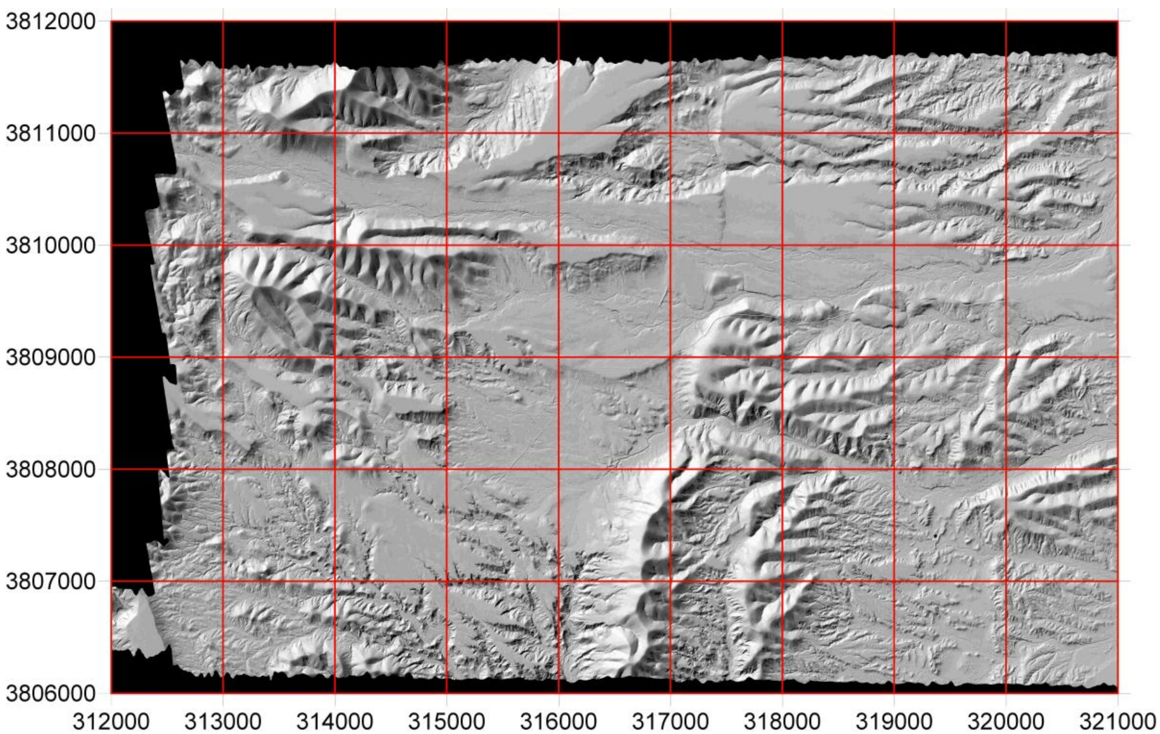

Figure 4 - Tile footprints overlaid on a shaded relief image of the bare-earth DEM.

8. Filtering and DEM Production

TerraSolid's TerraScan (http://terrasolid.fi) software was used to classify the ground points from the LiDAR points and generate the "bare-earth" dataset.

1) Removal of Isolated Points: Isolated points routine classifies points which do not have very many other points within a 3Dsearch radius. This routine is useful for finding isolated points up in the air or below the ground.

2) Parameters used for this routine were:

```
Fewer than: 1 point
Within: 5m
```

3) Removal of "Low Points". This routine was used to search for possible error points which are clearly below the ground surface. The elevation of each point (=center) is compared with every other point within a given neighborhood and if the center point is clearly lower then any other point it will be classified as a "low point". This routine can also search for groups of low points where the whole group is lower than other points in the vicinity. The parameters used on this dataset were:

```
Search for: Groups of Points
Max Count (maximum size of a group of low points): 6
More than (minimum height difference): 0.2
Within (xy search range): 3 m
```

4) Ground Classification. This routine classifies ground points by iteratively building a triangulated surface model. The algorithm starts by selecting some local low points assumed as sure hits on the ground, within a specified windows size. This makes the algorithm particularly sensitive to low outliers in the initial dataset, hence the requirement of removing as many erroneous low points as possible in the first step.

The routine builds an initial model from selected low points. Triangles in this initial model are mostly below the ground with only the vertices touching ground. The routine then starts molding the model upwards by iteratively adding new laser points to it. Each added point makes the model follow ground surface more closely. Iteration parameters determine how close a point must be to a triangle plane so that the point can be accepted to the model. Iteration angle is the maximum angle between point, its projection on triangle plane and closest triangle vertex. The smaller the Iteration angle, the less eager the routine is to follow changes in the point cloud. Iteration distance parameter makes sure that the iteration does not make big jumps upwards when triangles are large. This helps to keep low buildings out of the model. The routine can also help avoid adding unnecessary points to the ground model by reducing the eagerness to add new points to ground inside a triangle with all edges shorter than a specified length. Ground classification parameters used:

```
Max Building Size (window size): 10.0 m
Max Terrain Angle: 88
Iteration Angle: 7.0
Iteration Distance: 1.4 m
```

Digital Elevation Models were produced at 1.0 meter spacing for all areas from unfiltered points as well as classified ground points using SURFER (Golden Software) Version 8.04. Interpolation parameters were as follows in Table 5.

Algorithm	Kriging
Variogram	Linear
Nugget Variance	0.15 meters
MicroVariance	0.00 meters
Quadrant Search	4
Search Radius	variable
Minimum points per quadrant	5
Maximum points per quadrant	7

Table 6 - Gridding parameters.

Digital Elevation Models (DEMs) for both filtered and unfiltered tiles are provided in ESRI format.

APPENDIX A.
GPS Reference Station Coordinates from OPUS

```
                              NGS OPUS SOLUTION REPORT
                              ========================

      USER: michaels@ufl.edu                        DATE: November 07, 2007
RINEX FILE: bela268p.07o                            TIME: 15:37:41 UTC


  SOFTWARE: page5  0612.06 master10.pl             START: 2007/09/25  15:52:00
 EPHEMERIS: igs14462.eph [precise]                  STOP: 2007/09/25  21:24:00
  NAV FILE: brdc2680.07n                        OBS USED: 13707 / 13818   :  99%
  ANT NAME: ASH700936D_M    NONE               # FIXED AMB:    41 /    41   : 100%
ARP HEIGHT: 1.500                            OVERALL RMS: 0.010(m)


 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)           ITRF00 (EPOCH:2007.7336)

         X:     -1520999.490(m)   0.010(m)          -1521000.203(m)   0.010(m)
         Y:     -5028959.297(m)   0.021(m)          -5028957.942(m)   0.021(m)
         Z:      3606793.738(m)   0.028(m)           3606793.620(m)   0.028(m)

       LAT:   34 38 56.68707      0.013(m)        34 38 56.70404      0.013(m)
     E LON:  253 10 19.75880      0.015(m)       253 10 19.71660      0.015(m)
     W LON:  106 49 40.24120      0.015(m)       106 49 40.28340      0.015(m)
    EL HGT:         1556.132(m)   0.030(m)              1555.168(m)   0.030(m)
 ORTHO HGT:         1578.075(m)   0.039(m) [Geoid03 NAVD88]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 13)         SPC (3002 NM C)
Northing (Y) [meters]     3835647.930           404799.806
Easting (X)  [meters]      332487.063           447030.373
Convergence  [degrees]    -1.03946057          -0.32854050
Point Scale                0.99994587           0.99993457
Combined Factor            0.99970167           0.99969038

US NATIONAL GRID DESIGNATOR: 13SCU3248735648(NAD 83)



                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DE6386 ZAB1 ALBUQUERQUE 1 CORS ARP         N351024.854 W1063402.414   62883.8
DE8222 ABQ1 ALBUQUERQUE USCG1 CORS ARP     N345726.546 W1062940.038   45842.2
DG7420 P034 SANDIA_ASLNM2004 CORS ARP      N345644.212 W1062733.318   47129.3

                 NEAREST NGS PUBLISHED CONTROL POINT
EQ1063      BELAIR                         N343856.686 W1064940.241       0.0

This position and the above vector components were computed without any knowledge by the National
Geodetic Survey regarding the equipment or field operating procedures used.
```