PROJECT REPORT

Terrapoint #: 2010-105-U Task Order #001 – Channel Islands ARRA LiDAR Originally submitted: Monday, January 31, 2011

Presented to:

Dewberry Davis Tampa Bay, Florida

Submitted by:



Client Program Management Group Houston, Texas



EXECUTIVE SUMMARY

This LiDAR project is to provide high accuracy calibrated multiple returns LiDAR for 197 square miles (510 square kilometers) representing Dewberry's Channel Islands ARRA LiDAR Task Order, off the shore of Santa Barbara, California.

The LiDAR data was acquired and processed by Terrapoint USA. The deliverable products were calibrated raw LiDAR points and associated reports. All elevation products were acquired and processed to meet: *"U.S. Geological Survey National Geospatial Program Base LiDAR Specifications, Version 12".*

All data delivered will meet and exceed Terrapoint's deliverable product requirements as set out by Terrapoint's I-PROVE program.

The elevation data was verified internally, prior to delivery, to ensure it met fundamental accuracy requirements when compared to McGee Static GPS checkpoints. Below is the summary of the test for all islands:

• The LiDAR dataset was tested to 0.067m vertical accuracy at 95 percent confidence level, based on consolidated RMSE_z (0.034m x 1.960) when compared to 25 GPS static check points.

Please note that this report focuses solely on the Terrapoint activities pertaining to the LiDAR component of this project.

All data delivered meets or exceeds Terrapoint's deliverable product requirements as set out by Terrapoint's I-PROVE program.



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CHANNEL ISLANDS ARRA LIDAR PROJECT REPORT

1. Introduction

LiDAR data is remotely sensed high-resolution elevation data collected by an airborne collection platform. By positioning laser range finding with the use of 1 second GPS with 100 Hz inertial measurement unit corrections; Terrapoint's LiDAR instruments are able to make highly detailed geospatial elevation products of the ground, man-made structures and vegetation.

The LiDAR ground extraction process takes place by building an iterative surface model. This surface model is generated using three main parameters: building size, iteration angle and iteration distance.

The purpose of this LiDAR data was to produce high accuracy 3D terrain geospatial products for flood mapping.

This report covers the mission parameters and details, processing step outlines and deliverables.

Please note that this report focuses solely on the Terrapoint activities pertaining to the LiDAR component of this project.



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2. Project Boundary





3. LiDAR Acquisition

3.1. Riegl LMS-Q560 Helicopter LiDAR System

Terrapoint used our latest helicopter-based LiDAR sensor. The Riegl LMS-Q560 helicopter-mounted system is designed specifically for small block sites and corridor applications and integrated with the most advanced remote sensing technologies available.

3.1.1. System Details

- Riegl LMS-Q560 Laser Scanner
 - o Measurement rate up to 133kHz
 - o Full Waveform Recorded for Each Pulse
 - o 0.5 mRad Beam Divergence
 - o Class 1 eye safe laser
 - o 2 to 1000 metres AGL operation
- NovaTel DL-4 L1/L2 GPS Receiver
- IMAR IMU for Precise Georeferencing

3.1.2. The Laser Scanner

The full-waveform Riegl LMS-Q560 is a high-performance eye-safe 2D laser scanner yielding superior density and evenly-distributed ground coverage. Unlike discrete laser sensors, full-waveform analysis gives access to an almost unlimited number of returns per shot and high multiple-target resolution. In other words, features typically not detected by traditional laser scanners are more likely to be detected using the full-waveform as the entirety of each pulse return is recorded to a data recorder. Full waveform LiDAR is also excellent for characterizing vegetation.



Technical Data of RIEGL	LMS-Q56	60		
Range Measurement Performa	nce			
Maximum Measurement Range ¹⁾	@ Laser PRR	50 kHz	100 kHz	200 kHz
natural target $\rho \ge 20$ %		1200 m	1000 m	700 m 700 m
$\begin{array}{c} \text{natural largel } p \geq 60 \ \% \end{array}$	20	1800 m	1200 m	700 m
Accuracy ²⁾	30 m 20 mm			
Precision ²⁾	10 mm			
Laser Pulse Repetition Rate ³⁾	up to 200 000	Hz		
Effective Measurement Rate	up to 100 kHz	@ 45 deg scal @ 60 deg scal	n angle n angle	
Laser Wavelength	near infrared		angio	
Laser Beam Divergence ⁴⁾	≤ 0.5 mrad		E)	
Number of targets per pulse	unlimited for di	gitized wavefo st pulso in opli	rm [®] , no monitorir	na data
Eve Safety Class		sc pulse in onin	60825-1·1993	19 Uata 3+A1·1997+A2·2001
	CLASS 1 T LASER PRODUCT C	he following clause app complies with 21 CFR 10 b Laser Notice No. 50, d	lies for instruments o 040.10 and 1040.11 ated July 26, 2001.	elivered into the United States: except for deviations pursuant
Scanner Performance				
Scanning Mechanism	rotating polygo	n mirror		
Scan Pattern	parallel scanni	ng lines E dog total		
Scan Angle Range Scan Speed	$\pm 22.5 \text{ deg} = 4$ 10 - 160 scans	/sec		
Angle Step Width $\Delta 9^{3}$	$\Delta \vartheta \ge 0.004$ de	g (@ PRR 10	0 000 Hz ⁷⁾)	
between consecutive laser shots Angle Readout Resolution	0.001 deg			
Intensity Measurement				

For each echo signal, high-resolution 16-bit intensity information is provided which can be used for target discrimination and/or identification/classification.

3.1.3. Positioning and Attitude Systems

the Novatel DL-4 is a high performance, high accuracy, GPS receiver with fast data update rates and integrated memory for data logging. The DL-4 is capable of receiving and tracking the L1 C/A code, L1 and L2 carrier phase and L2 P-Code (or encrypted Y-Code) of up to 12 satellites. Patented Pulsed Aperture Correlator (PAC) technology combined with a powerful microprocessor make possible multipath-resistant processing and excellent acquisition and re-acquisition times.

Unlike other positioning and attitude sensors, the iMAR IMU allows our engineers and scientists access to raw inertial data. Commercially available positioning and attitude systems are designed as a "black box" solutions, and the accuracy and quality of the solution is left to the mercy of the "black box" post-processing In combination with the iMAR IMU data and our software. proprietary GPS-INS post processing software, aircraft trajectories



can be generated using a combination of approaches, weighting GPS and INS measurements according to their quality in tightlycoupled or loosely-coupled Kalman filters.

	PRF (kHz)	(kHz)	100
	Effective	(kHz)	67
	Optimal Height		
	AGL	(m)	600
Scan	Aircraft Speed	(kts)	50
Settings	Scan Angle	(Degrees)	60
Point	Scan Rate	(Scans/Sec)	50
Spacing	Swath Width	(m)	692
	Flight Line		
	Spacing	(m)	343
	Laser Spot		
	Diameter	(m)	0.3
	Along Track	(m)	0.51
Scan	Across Track	(m)	0.52
Settings	PRF (kHz)	(kHz)	100
	Nominal Single		
Doint Donsity	Swath	(Pts/m2)	3
Point Density	With 50%		
	overlap	(Pts/m2)	7

3.1.4. LiDAR System Parameter Overview

3.2. Aircraft

The aircraft used for the survey was a Bell 206 Jet Ranger, registration N49643 with an endurance of approximately 3 hours.

3.3. Base Station and Control GPS Receivers

California Continuously Operating Reference Stations (CGPS) stations were used exclusively to support the airborne operations of this survey and to establish the GPS control network.



3.4. Missions Statistics

				Number of LiDAR
Block	Origin	Mission Name	Calendar Date	Production Lines
Santa				
Barbara/Anacapa	BAR1/ANA1	M110070A	11-Mar	11
Anacapa	ANA1	M110071A	12-Mar	6
Santa Cruz	CRU1	M110071B	12-Mar	10
San Miguel	MIG1	M110073A	14-Mar	20
San Miguel	MIG1	M110074A	15-Mar	8
Santa Rosa	SRS1	M110074B	15-Mar	12
Santa Rosa	SRS1	M110075A	16-Mar	5
Santa Rosa	SRS1	M110075B	16-Mar	8
Santa Rosa	SRS1	M110076A	17-Mar	9
Santa Rosa	SRS1	M110077A	18-Mar	4
Santa Rosa	SRS1	M110079A	20-Mar	5
Santa Rosa	SRS1	M110080A	21-Mar	10
Santa Cruz	CRU1	M110081A	22-Mar	3
Santa Cruz	CRU1	M110081B	22-Mar	11
Santa Cruz	CRU1	M110082A	23-Mar	9
Santa Cruz	CRU1	M110085A	26-Mar	4
Santa Cruz	CRU1	M110085B	26-Mar	6
Santa Rosa	SRS1	M110086A	27-Mar	9
Santa Cruz	CRU1	M110087A	28-Mar	9
Santa Cruz	CRU1	M110092A	02-Apr	4
Santa Cruz	CRU1	M110096A	06-Apr	6
Santa Rosa	SRS1	M110097A	07-Apr	1
San Miguel	MIG1	M110097B	07-Apr	4
Santa Cruz	CRU1	M110098A	08-Apr	23
			LiDAR missions	197
Totals		Lida	R Production Lines	24

LiDAR flightlines were flown in a multiple orientation block designed to best optimize flying time considering the layout for the islands. A graphical representation of the planned flightlines and trajectories are located in Appendix A. A copy of the mission logs can be found in Appendix C

3.5. Horizontal and Vertical Reference Coordinate System Used

Five CGPS were observed in a GPS control network by McGee Surveying and used to control all flight missions and McGee Surveying static ground surveys. The published horizontal datum of the stations is



NAD83 (2007 Epoch) and the vertical datum is NAVD88. The following are the final coordinates of the control points used in this project:

Block	Station	Latitude (D M S Hem)	Longitude (D M S Hem)	H-Ell (m)
Santa				
Barbara	BAR1	33.480451	-119.029735	14.8146
Anacapa	ANA1	34.015005	-119.363468	22.4411
Santa				
Cruz	CRU1	34.029259	-119.78481	702.1957
Santa				
Rosa	SRS1	34.004335	-120.065219	68.2316
San				
Miguel	MIG1	34.038258	-120.35139	130.9455

The projection used for all deliverables was UTM 10 and 11 (Natural Zone) and units are meters. The breakdown of zones per island is as follows:

Block	UTM Zone
Santa Barbara	11
Anacapa	11
Santa Cruz	11
	10 + 11 (two complete
Santa Rosa	deliverable sets)
San Miguel	10

3.6. Geoid Model Used

All elevations were referenced to the GEOID09 model, published by the National Geodetic Survey (NGS), was used to reduce all ellipsoidal heights to orthometric.

3.7. Data Coverage

On a mission and project level, a daily coverage check is performed in the field as per Terrapoint I-Prove requirements.

4. LiDAR Processing

4.1. Airborne GPS Kinematic

Airborne GPS kinematic data was processed on-site using GrafNav kinematic On-The-Fly (OTF) software. Flights were flown with a minimum of 6 satellites in view (13° above the horizon) and with a



PDOP of better than 4. Distances from base station to aircraft were kept to a maximum of 20km.

For all flights, the GPS data can be classified as excellent, with GPS residuals of 3cm average or better but no larger than 10cm being recorded.

4.2. Generation and Calibration of Laser Points (raw data)

The initial step of calibration is to verify availability and status of all needed GPS and Laser data against field notes and compile any data if not complete.

Laser data points are generated using Terrapoint's proprietary laser post-processing software. This software combines the raw laser range and angle data file with the finalized GPS/IMU information. The resulting point cloud has been projected into the desired coordinate system in LAS binary format. All missions are validated against the adjoining missions for relative vertical biases and collected GPS kinematic and static ground truthing points for absolute vertical accuracy purposes.

On a project level, a supplementary coverage check is carried out, to ensure no slivers not found or reported by Field Operation are present.



4.3. Vertical Bias Resolution

The following vertical biases were detected in LiDAR data when compared to the GPS kinematic and static points.

Mission	Lines	Vertical Adjustment
m110073a	All lines	+0.07m
m110074a	All lines	+0.05m
m110075a	line 7404	+0.05m
m110077a	All lines	+0.05m

4.4. Data Classification and Editing

The data was processed using the software TerraScan, and following the methodology described herein. The initial step is the setup of the TerraScan project, which is done by importing project defined tile boundary index encompassing the entire project areas. The acquired 3D laser point clouds, in LAS binary format, were imported into the TerraScan project and divided into file size optimized tiles. Once tiled, the laser points were classified using a proprietary routine in TerraScan. This routine removes any obvious outliers from the dataset following which the ground layer is extracted from the point cloud. The ground extraction process encompassed in this routine takes place by building an iterative surface model.

This surface model is generated using three main parameters: building size, iteration angle and iteration distance. The initial model is based on low points being selected by a "roaming window" with the assumption is that these are the ground points. The size of this roaming window is determined by the building size parameter. The low points are triangulated remaining evaluated and the points are and subsequently added to the model if they meet the iteration angle and distance constraints. This process is repeated until no additional points are added within iteration.

A second critical parameter is the maximum terrain angle constraint, which determines the maximum terrain angle allowed within the classification model.



4.5. Deliverable Product Generation

4.5.1. Deliverable Tiling Scheme

LiDAR deliverables were provided in a 2000mX2000m tiling scheme with a total of 280 tiles (75 duplicates due to Santa Rosa being delivered in both UTm10 and 11).

4.5.2. LAS files

Once the data has been quality controlled and considered complete, the LAS format 1.0 format points are converted to LAS 1.2 Point Data Record Format 1 and the classification scheme, retiled from the USGS Quarter Quad subdivided tiles to the client 2000m x 2000m tiles and converted to the required ASPRS classification scheme (1=Unclassified) from Terrapoint Proprietary classification scheme.

The following fields within the LAS files are populated to the following precision: Adjusted GPS Time as defined as standard GPS time minus 1*10° (0.000001 second precision), Easting (0.01 foot precision), Northing (0.01 foot precision), Elevation (0.01 foot precision), Intensity (integer value - 12 bit dynamic range), Number of Returns (integer - range of 1-4), Return number (integer range of 1-4), Scan Direction Flag (integer - range 0-1), Classification (integer), Scan Angle Rank (integer), Edge of flight line (integer, range 0-1), User bit field (integer - flight line information encoded).

The LAS file also contains a Variable length record in the file header.

Please note that no automated and manual classification was performed on these LAS files from Terrapoint.

The LAS data tiles were also delivered in strips.

4.5.3. Waveform files

The waveform files were provided in Terrapoint's proprietary format TWF for all missions. A copy of the waveform file structure can be found in Appendix D.



5. Quality Control

5.1. Quality Control for Data Acquisition

The acquisition of overlapping calibration lines for every mission is key to the QC process since it helps identify any systematic issues in data acquisition or failures on the part of the GPS, IMU or other equipment that may not have been evident to the LiDAR operator during the mission.

Ground truth validation is used to assess the data quality and consistency over sample areas of the project. To facilitate a confident evaluation, existing survey control is used to validate the LiDAR data. Published survey control, where the orthometric height (elevation) has been determined by precise differential levelling or GPS observation, is deemed to be suitable.

Ground truth validation points may be collected for each of the terrain categories to establish RMSE accuracies for the LiDAR project. These points must be gathered in flat or uniformly sloped terrain (<20% slope) away from surface features such as stream banks, bridges or embankments. If collected, these points will be used during data processing to test the RMSE_z accuracy of the final LiDAR data products.

The Field Project Manager performs kinematic post-processing of the aircraft GPS data in conjunction with the data collected at the Reference Station. Double difference phase processing of the GPS data is used to achieve the greatest accuracy. The GPS position accuracy is assessed by comparison of forward and reverse processing solutions and a review of the computational statistics. Any data anomalies are identified and the necessary corrective actions are implemented prior to the next mission.

The quality control of LiDAR data and data products has proven to be a key concern by Terrapoint's clients. Many specifications detail how to measure the quality of LiDAR data given RMSE statistical methods to a 95% confidence level. In order to assure meeting all levels of QC concerns, Terrapoint has quality control and assurance steps in both the data acquisition phase and the data processing phase. Any acquired data sets that fail these checks are flagged for re-acquisition.



5.1.1. System Logger – Power Up Health Checks

The system logging software performs automatic system and subsystem tests on power-up to verify proper functionality of the entire data acquisition system. Any anomalies are immediately investigated and corrected by the LiDAR operator if possible. Any persistent problems are referred to the engineering staff, which can usually resolve the issue by telephone and/or email. In the unlikely event that these steps do not resolve the problem, a trained engineer is immediately dispatched to the project site with the appropriate test equipment and spare parts needed to repair the system.

5.1.2. System Logger – Real Time Acquisition Checks

The system logging software continuously monitors the health and performance of all subsystems. Any anomalies are recorded in the System Log and reported to the LiDAR operator for resolution. If the operator is unable to correct the problem, the engineering staffs are immediately notified. They provide the operator with instructions or on-site assistance as needed to resolve the problem.

If any aspect of the data does not appear to be acceptable, the operator will review system settings to determine if an adjustment could improve the data quality. Navigation aids are provided to alert both the pilot and operator to any line following errors that could potentially compromise the data integrity. The pilot and operator review the data and determine whether an immediate reflight of the line is required.

5.1.3. Post Acquisition Data Check

After the mission is completed, raw LiDAR and imagery data on the removable disk drive is transferred to the Field PC at the field operations staging area. An automated QA/QC program scans the System Log as well as the raw data files to detect potential errors. Any problems identified are reported to the operator for further analysis. Data is also retrieved from all GPS Reference Stations, which were active during the mission and transferred to the Field PC. The GPS data is processed and tested for internal consistency and overall quality. Any errors or limit violations are reported to the operator for more detailed evaluation.



5.1.4. Data Viewer Analysis

The Field Project Manager utilizes a data viewer installed on the Field PC to review selected portions of the acquired LiDAR and imagery data, this permits a more thorough and detailed analysis of the data corrupted files or problems in the data itself are noted. If the data indicates improper settings or operation of the LiDAR sensor and camera, the Field Project Manager determines the appropriate corrective actions needed prior to the next mission.

5.1.5. Data Backup with Redundancy

All LiDAR, imagery and GPS data is copied from the Field PC onto two separate removable hard drives: one for transfer to Calibration, and one for local backup. Each hard drive is reviewed to ensure data completeness and readability.

5.2. Quality Control for Data Processing

Quality assurance and quality control procedures for the raw LiDAR data and processed deliverables for the DEM and derivative products are performed in an iterative fashion through the entire data processing cycle. All final products pass through a six-step QC control check to verify that the data meets the criteria specified by Terrapoint.

The following list provides a step-by-step explanation of the process used by Terrapoint to review the data prior to customer delivery.

5.2.1. LiDAR Calibration

5.2.1.1. Calibration Setup and Data Inventory

Data collected by the LiDAR unit is reviewed for completeness and to make sure all data is captured without errors or corrupted values. In addition, all GPS, aircraft trajectory, mission information, and ground control files are reviewed and logged into a database.

5.2.1.2. Boresight

The LiDAR data is post processed and calibrated as a preliminary step for product delivery initially with default values from the LiDAR system manufacturer or the last mission calibrated for the system. The initial point generation for each mission calibration is



inspected for flight line errors, flight line overlap, slivers or gaps in the data, point data minimums, or issues with the LiDAR unit or GPS. If a calibration error greater than the project specification is observed within the mission, the roll, pitch and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality. Flight line swath overlap is confirmed to the adjacent flight lines at the tolerance specified by the client for overlap throughout the project area thus enabling an evaluation of data reproducibility throughout the areas.

5.2.2. Calibrated Ground Truth Validation

A preliminary $RMSE_z$ error check is performed at this stage of the project life cycle in the raw LiDAR dataset against GPS static and kinematic data and compared to $RMSE_z$ project specifications. The LiDAR data is examined in open, flat areas away from breaks and under specified vegetation categories. This step is repeated in production against the final bare earth LiDAR model.

5.3. LiDAR Production

5.3.1. Production Setup Quality Control

Once the data enters the bare earth extraction stage, a checklist verifying all the components of the project have been received in good order.

5.3.2. Automated Bare Earth Ground Truth Validation

RMSEz is inspected in the automated bare earth model and compared to project specifications. RMSEz is examined in open, flat areas away from breaks and under specified vegetation categories. All accuracy results are reported to the 95% confidence interval for the different categories as available and required. A point comparison of a recently acquired or existing high confidence ground survey point to a TIN generated from the bare earth LiDAR surface. The tolerance for comparisons of control data to the LiDAR TIN elevation is that all sides of the TIN triangle must not be longer than 4.5m to ensure an accurate comparison of surface to the discrete points.



6. Positional Accuracy

6.1. Vertical Positional Accuracy

Prior to delivery the elevation data was verified internally to ensure it met fundamental accuracy requirements when compared to McGee static GPS checkpoints.

• The LiDAR dataset was tested to 0.067m vertical accuracy at 95 percent confidence level, based on consolidated RMSE_z (0.034m x 1.960) when compared to 25 GPS static check points.

6.2. Horizontal Positional Accuracy

Compiled to meet 3.5 foot horizontal accuracy at the 95% confidence level (2 sigma = RMSE * 1.96) in all but extremely hilly terrain.

7. Issues and Resolutions

7.1. Acquisition

7.1.2. Sensor Malfunction

Terrapoint began observing some slight inconsistencies in the midrange sensor data from Channel Islands, which we believe may be due to a minute change in the characteristics of the laser scanner. Terrapoint has since been monitoring the data quality very closely to ensure it meets the project accuracy requirements. As such, we believe the situation has not degraded since it was discovered, and that the data is meeting the required project specifications.

In summary, Terrapoint has observed instances of "cornrows" in the Channel Island data with the following characteristics:

- The cornrow amplitude is within the 7cm RMSEz specification
- No cornrows greater than 10cm observed
- Observed on all sites throughout the project, however it is only visible on 75% of the terrain
- The cornrows are less visible in Santa Barbara and Anacapa due to steep relief
- More obvious on flat terrain (such as the calibration site at the airport and flat areas of the islands)



Otherwise the data meets the other accuracy requirements of the project:

- Flightline to flightline relative accuracy is better than the required 7cm RMSEz specification requirement
- Absolute accuracy tested at 3cm RMSEz
 - Intensity looks good





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The system has since been serviced by Riegl and found The laser polygonal mirror coefficients were off hence the laser required a new internal calibration. It doesn't appear that the laser beam itself degraded. At the time of report submission, Terrapoint has received the repaired system and we are presently in the process of testing the system to ensure no cornrows are being observed.

7.1.3. Project Timeline

The project acquisition stage was longer due to circumstances outside of Terrapoint's control, hence cost overruns were encountered to complete this project; in summary:

At the onset of the project

- this project was priced using our Optech sensor and we changed to the mid-range sensor during the planning phase; this would increase our costs (post contract signing with no opportunity to renegotiate)
- this project was planned without tide restrictions, as discussed during the discovery and proposal/pricing stage of the project (that is, only San Francisco had the tide restrictions)

During the Acquisition Stage of the project

- the tide restrictions precluded long missions, and resulted in more missions to calibrate and process
- the terrain played a factor in acquisition efficiency



- the winds and general weather conditions often precluded flights and/or caused shortened or aborted missions
- extended ferry times increased helicopter costs (no fuel stores on the islands)
- due to the bird migrations etc, we could not land or refuel on the islands, nor fly as low as we would have liked

7.2. Calibration

7.2.2. Project Timeline

Due to the circumstances outlined above in the problems with project acquisition stage; the calibration timelines were also longer due to circumstances mainly outside of Terrapoint's control, hence cost overruns were encountered to complete this project; in summary:

- there were a lot more missions than anticipated due to flight restrictions/shortened missions (see above)
- again, terrain
- calibration hours quadrupled looking into the data issues we found

8. Conclusion

Overall, the LiDAR data products submitted to Dewberry meet or exceed both the absolute and relative accuracy requirements set out in the Statement of Work for this project. The quality control requirements of Terrapoint's I-PROVE program were adhered to throughout the project cycle to ensure product quality.



Appendix A Planned Flight Lines and Trajectories

The top image represents the planned flighlines. Production flightlines are in blue atop the project boundary in red. Terrapoint acquired a minimum of 1 cross lines per island in yellow for validation purposes. The bottom images represent the actual trajectories color coded by missions.



San Miguel Island



Terrapoint #: 2010-105-U



Santa Rosa Island



Terrapoint #: 2010-105-U



Santa Cruz Island



Terrapoint #: 2010-105-U



Anacapa Island



Terrapoint #: 2010-105-U



Santa Barbara Island



Appendix B Validation Points

Embedded below as file objects are the McGee static GPS checkpoints comparison results:



santa_barbara_G T_autoclean.txt









This Dian Line #	I IDAD Sile Name	Fight	613/1		LIGHT YOOM	g	Please periodically record:
		Direction	Start	End	Time NI	I to End	Outside Temps Least Temps Duski (Mithis)
PASS	100511-202200	100	H119434	119115			GOD
C 8455	HEP207-115001	290	192914	0246/4			(101)
			4121400	2121584			ANALARA KAR
_	1/203/v = 2.16(17	270	SLLTIM	122132			6000
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gins On (Hobbs)	Ramp Out	Tribut	<	1 gring 1 60	wgit AGL	Szan Angle (C	(ibaid)	Time CIGP: Pre Mission	Mari koo	14983617
gine Of (Hobis)	Ramp In	12:55 c.		Source State	d Speed	Minor Sean	Hate	KAR Base KAR Base	500610	801050
Kal hrs (+lobbs)	Total hrs	Total his		Fleet, ast Ab	emailing Return	LINE R.H.	Totals	Pos! Mission	507620	562109
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14	1003/1-	CHSHIPI	27.0	503160	505560				6000	
15	100317-	195014	9.0	507790	3341090				(100 y	
19	1075512-	Jusson	270	504730	504150				GOOD.	
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14	10021	125431	097	SCHH488	5/47:5			9045		
51	10031	-220245	100	SIMANY	SISTAS			CHOND		
1.01	1003NL	120035	417	515456	5(S177			COOD		
1	10021	9116152-	100	515471	516320			Gool	0	
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16	1002/1	27-1550	100	5217245	517475			CODY	0	



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Aircraft Bio	ock Time DUT mes o	continued with pillot	Г	L	Mission	Plan		Static	& KAR GPS // IN	S Alignment
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Channel Islands ARRA LiDAR
Project Report

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Aircraft Bloc	X Time Times or	onfirmed with pilot	Г		Mission F	dan	Γ	Static	SKAR CPS//IN	5 Alignment
Om (Hobits)	Rano Out	Taveof	Т	F ying H	teight AG.	Scar Ange (Cpiech)		Time DGP.	S Sat	field
AN TON		w hail	2	60	No.Y	80		Pre Mission	53666	570470
Off (Hoctes)	Ramo In	Landing Line of Di		Groat	M Speed	Minor Scan Rate		KAR Base	STSQLIC	574(90)
N-L-N		ANDUNA	2	5	1 Kr5	200		KAR Bane	RACE AN	CRINCH
, Histois	Toteline	701hs		FISHLEEVAL	Emailing Return	100 RHZ		Fost Masion	582.200	282500
			Flight	GPS/L	JTC Time	Fight Abore	p	đ	hoto Evens / Comme	str.
nt Plan Line #	LIDAK	IIIe Name	Direction	Start	End	Time NM	to End	Atside Temp: Ann Temp:	Cabin Terry: Den Undelni	
11	100820.	15750 B	245	57452.0	575222			3	(gag)	
5	100320-	155052	53	STSHLA	576250			14	AURE OFF	2-SUE
	100320 -	120625	345	STIGHT D	51215			2	Gaco:	
11	1-055001	19212	65	a publis	579030			0	AF LOJE	
-	101520	51(5)	59	574247	597552			60	arguere D	
4	1-025001	Chipper	245	FP48F2	ACHPTH			ONE SHAL	L CLOUD A	Ver WD
110	1015520-1-	10359	52	574455	5799.59				60.9	
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Injectin	101050	DISCOC.	V II	A 2500		0		シ	errap	point
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es Corplete		Operator Ocerete	410	2	Shutter Speed Photo Freq.					
son Objective					IMU GPS Ric Deta Drive		Cutsids Temp @ Cutsids Temp @	TO LO' C OM	de Pransure @ TO: 3 de Pressure @ LA: 3	218
Aircraft Bloc	K Time Thres co	nfirmed with pilot	Г		Mission	Plan		Static	& KAR GPS // INS	S Alignment
ine On (Hobte)	Rama Out	Taiwof	Г	Fying	Haight AG.	Scan Argle (Optech)	Time DGP	dat .	Erd
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151	100321-	144000	342	17223	13155				(90)	
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toject	CHAUMER ISHOP	About	Ner TSC	CANER.	System #					
Cubez	C XUMAD	Call Sign	N219	543	Lener Scanner					
urvey Block	SAUTA CRUZ	Pliet	ALC 1	V-R.Y	Camerul Lons Sh					
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ngine Cin (Hotes)	Ramp Out	1000 J		ingi-1	KOC	6 O	(Linear)	Pie Mission	0Hbhhl	P1560
rgine Cif (Hoths)	Ramp in	(andrig		5	und Speed	Mirror Scan	覆	KAR Base	148509	148187
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		DIIIPAL	Direction	Start	End	Time	NM to End	Oute de l'amp:	Cabin Terror O Acot Obolish	
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Ş	10052	19539	30	120452	151/98			4	or house	450



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ste	Acru 22	Julian Day	0		ALMIS/Optioch	Γ	Additional Notes:			
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nes Complette		Operator	210	1	Shutter Speed	T				
and the second se		Otherver		T	PIUD FIRE	T				
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Aircraft Blo	dk Time Times co	ariamed with pilot	Г		Mission	Plan		Static	& KAR GPS // INS	Alignment
ngine Cn (Hobas)	Ramp Out	Takeof		Fhingh	teight A.G.	Scan Angle	(Cprech)	Thre CGPS	196	ä
		11/sc.ml	2	60	<0	XC	~	Pie Mission	1609755	COL191
gine CT (Hotdis)	Remp in	Lendro /	0	E Cau	ld Spaed	Minor Sas	n Rate	KAR Base	165450	165725
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K Man Life #	DURN BILL YMPTH	Direction	Starf	End	Time	NM to End	Outside Tampi Cable Tampi Lasse Tampi Outside Tampi Cable Tampi Ca
191	100323-60074b		Į.	1			AL NAV ROZE
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ete Indient Majing Indient Indient Indiente Indiente	Verly 23 2010 Were Beler 34	Tulien Dey A round Call Sign Call Sign Death Operation Closen with	the second	82 2563	ALMIS/Optiech System # Lever Sommer Comment unit Sh Shuffer Spread Photh Frac, MU GPB RA, Clan Dha	(H)	Adding Ad	al Notes: widdy Temp @ TC	2 1 g / C action Press	ann @ 10. 30 sairs @ Let 37.	,61Hz 0244
Aircraft Bloc	K Time K Times con	witned with pilot	Г		Mis	sion Plan			Stafe & KA	R GPS // INS	Aignment
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2.0. 90 the	Ramp In	174:01			GOUND SORA	5	F O H 7		KAR Base 23	9115	239560
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hojoct C	CONTRY MONTH	Alroad:	Ner	Paderst-	System #	T				
age grow	11.07 A. 14117	Pilot	NH PIC	417	Carrent Jens SV	T				
nee Complete	11-231	Operator Otherver	Scot		Shutter Speet Photo Free	Π				
lasion Objactive					II/U GPS 3x	Π	Outside Tamp @	TC: , Calside Piv	wasare @ TO:	
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Aircreft Bloc	k Time D Times	continued with pilot	Г		Mission	Plan		Static & Ku	AR G2S//INS	Alignment
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gins OY (Hcb.s)	Riamp In	Landing 17. C.X	Г	S LA	Int Speed	Minor Scan	Rate	MR. Base 6/	97230	0398464
(all hrs Hobbe)	toal hs	1514(5		Frankastik	lienaling Return	LaserPades	Rate	Post Meaion	501222	602255
Clinic Clinic 1	a a a a	To Manual	Flight	GPS /	UTC Time	Flight A	borted	Proto E	Evens / Commen	12
		DIIBN DI	Direction	Start	End	Time	NM to End	Duble Temp.	Cabin Terrp Dute 4 (WHE)	
142	100306-	182635	285	299900R	149750			- h Lot of	F CRAB	
151	100324 -	135107	SS	299988	504760			600b, I	Sherth.	
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opect	CHUNNEL I.	Alicatit	25	States	Sjetem #					
Euga	Shirth GUZ	Call Sign	Sher	523	Laser Scamer	1				
vey Block	FURD ADDA	Filet	あたい	してい	Camera/Lens Sh					
es Compleie	1-231 1-63-1S	Operator	500	Y	Sturter Speed	Τ				
eine (Marth.o.					The second second	T				
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Aircraft Blo-	ck Time D Times cor	nitrmed with pilot			Mission	Plan		Static	& KAR GPS // INS	S Algnment
phe On (Hohba)	Ramp Out	Takeoff	_	EN4	ND HAIGHT AGL	Scan Angle (0)	prech/	Time CIGPS	B	B
LEAL		SP-14	-		× 93	09		Pre Mission	E31788	569431
jine Cif (Hottis)	Ramp In	Lencing		8.7	cound Speed	Minter Scenie	inte	KAR Base	509211	507550
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a hrs (Hottes	Totalins	Totalitis	-	Fisher	Whitemating Return	/ OTD auto-	Rate	Post Mission	SH100	SHXHS
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Citebi Dian Lina #	1 IDAR FILe	s Name	Fight	GPS	I/UTC Time	Flight Ac	borhed	d a	pto Evens / Comme tease psripditally rectic	nts 1.
agentine turke		2000	Direction	Start	End	Time	NM to End	Outside Territ	Color Terry Door 4 Water	8
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16-7	100323	O YEHIT	255	510354	510560			6000	(wear la	(4)
501	- 926001	2)5105	55	510674	510458			Crop	CUER E	101
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120	108326-	SHADITZ	55	511503	B11848			500T	> (were	(90
124	100326-1	221257	255	511965	「トセントマ			600	DLUES E	(ar



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ed	Maryler sector 57	Altonit	19.1	Chuller,	System #	Τ	viat an	C PAL PLAN	ICAR DAR T	o water
and the Color	CUARD OF C	Cell Sign	9 PHIN	1.7	Laser Scanner	T	PLL ONE	近上の後	THE STATES C	345
s Complete 4	2011 2 100 -	Operator	No.	211	Shutter Speed	Τ	NEVE 0	THE SLOWING	a town.	
	Contractor 31	Otherwer	_		Photo Freq.	Τ				
av piete					IMU GPS R± Deta Drive	Π	Ouside Temp @ Ouside Temp @	TO 71+ CUIS	da Presure @ TC: 5	240
Aircraft Bloc	& Time Times o	onfirmed with pilot	Г	L	Mission F	lan		Static	& KAR CPS // INS	Alignment
re On (Hobbs)	Ramp Out	Tareeff	Г	Fying	Height AGL	Scar Ange (Cptech)	Time DGP	S 3ter	ň
3:12		13:16		60	Mac	09		Pre Mission		
ne Cif (Hobbs)	Ramp In	12:53		99 Z.	and Speed	Mmor Szar	Rate	KAR Base	593454	693690
The Helder	Total ter	Treating	Т	Forth and	Handler Dater	1 near Bule	Pate	NAME COMPANY	- manut	1
isono d'au	2	-hise	A			100	4	Post Meson	019409	604750
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		2110A12	Orection	Start	End	Time	NM to End	Outside Terry:	Cabin Terip. Data: # Manuar	
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10]	100327.5	14912	65	595195	5160915			62	(10)	
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1455	2-175001	222433	65	594033	599915			3	000	
(AR				599916	600245					
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X 9255			150	601912	PCH109			3	(100)	



Flight Aborted Pho	Time NM to End Outset Terre:	0										
GPS/UTC Time	Start End	602640 603290	603460 604260									
Fight	Direction	100507-252855	THEE2-12504									
Clinit New Jacob		XQAS	X Thish									



	050101	Sessi	V HO	¥2.5001		2		5	errap	point
999	149241 2.8	Lutes Day	8	13	ALMIS/Drech		Acditional Notes:			
mject //	ANALYER ISLADS	Aircoft	Jer	PAUGTAR.	System #					
Duide,	OXUMEN	Call Sign	A149	51.5	Laser Soamer					
urvey Boek	SAVEN CRUZ	plot	(242)	2.4	Camanulans Sh					
tes Complete	281-361	Oterator	210	12	Stutter Speed	Τ				
ssion Obiective					IWI					
					GPS Rs Deta Drive		Curside Temp @ Curside Temp @ L	UR 21 2 OUB	da Presure @ TO: de Presure @ LA: 3d	16
Aircraft Blo	ok Time D Times oo	ntimed with plict	Г	L	Mission	Plan		Statio	& KAR GPS // INS	Alignment
rgine Chilholdes)	Ramp Out	Takeof	Т	Fying	Height AGL	Scan Angle (C	(plach)	Time DGP	50 Ref.	×
		VARTOUS	-	2	VQG	60		Pre Mesion	52525	1600
sgire Off (Hebbs)	Ramp In	guipus		B	und Speed	Merce Scan	Rate	KAR Base	63248	01070
		いっちちょう			50 kth	20		KAR Base	(Tlevel	V 200 000
this (Hooths)	Total his	Total hrs		Festiven	Atomating Roturn	Leader Pulse			00876	81010
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Elote Diro Line #		e Marrie	Flight	SdD	UTC Time	Flight A	borted	à.	voto Evens / Comme	nts
		2 01 0	Direction	Start	End	Тіте	NM to End	Outside Temp.	Cabn Teng: Diversition	
141	100528-1	11559	1.55	59372	10095				(tap)	
1.0.1	(0:0:348	24674	39	10196	2901L			10	400	
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142	00214.	55,0007	40	Prost	72914				Q60	
KAR				13151	12551					
-AA-1				LILSL	1400D					
1.25	150928-0	11196	252	71275	TT55			~	(100)	
195	110228-3	L926-	60	71930	144140				940	
1 MG	LIDBORK J	10000	1.55	OS76L	8 0565			C I	6000	
KAP				8.045.8	30058					



Plant Dian Inc. of	1 ILLAD CIA Manua	Flight	GP8/I	UTC Time	Fight	Abarted	Please periodically record
ragin main une #	FILMAY FIRE MAILING	Direction	Start	End	Time	NM to End	Ounto Temos Catin Temos Later Temos Catin Temos
LAC.			58658	\$3583			
351.	T.KC/422-8-40001		85875	6/5/5/			(co)
194	100425-252013		85229	35670			(00D)



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Date	-Atack 1	Julian Dey	0	10	ALM8/Option	Adoltonal Notes:			
Project	CHANDEL CELADES	Atoralt	SEC	Children.	System #				
Cuidess	A AMANYO	Cal Spn	NYC	543	Later Scamer				
Survey Block	CALIMATION	Plot	CH	ALLE.	Cornerg/Lens SN	T			
Lines Contrete		Operator	210	E	Shutter Speed Photo Freq.				
Mission Citiective					INU) GPS Ra Data Drive	Dutkibe Twmp (6) Dutkibe Twmp (6)	ITO IL OUR	tie Pressure 億 TO: - 7-0 de Pressure 億 LA:	No in
			Г				Chris	O VAD CSC MING	Allowant
Aintrall	Block Time C Times	confirmed with pilot	T		MISSION	Line of the line o	CIRIC	COLVARY 10-2011	Nugment
Engine On (Hobts)	Remp Out	Takeof (D):07	-	59 29			Pre Mission	Hokloo	Hrlan
Engine Cit (Hochs)	Remp In.	Landing .	1	5	und Speed	Mitror Scen Rate	KAR Base	(1919107	HOTS70
		10:52		13	0413	20	KAR Base	1100100	MADINA
Total his 'Holdos'	Total hrs	Totalins		First/Last	Nomating Rolum	100 KKz	Post Mealon	Lothala	4/0260
			Flaht	SdÐ	UTC Time	Fight Aborted	ā.	icto Evans / Comma	ots
Fight Plan Lit	Te# LIDAR	File Name	Direction	Start	End	Time NM to End	Outside "amp:	Cabin Tenju: Dan a Mathur	
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0	(00/401-1-	11-155		0 64204	76990K			000	
94	1 - Ye'N 003	Caser		408925	400 002			(00)	
ar	100401-	1361		109148	505,202			(00)	



00 Attr. 7 Jan By Control C	Projecu	101050	Sessi	W uo	00524	L Fgn	Log	-	F	errap	point
Bits District Stream District Stream District Stream District Stream Mondial 57/1-53%, J/K District Stream District Str	ate	ARE 2	Julian Day	0	25	ALMS/Cplech	Adollor	al Notes:			
Openation CANALAD Rate Note on the state of the stat	cject 6	LANDER TOMOT	Aircraft	SET	RANGEZ	System #					
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IOD Clipida Note France String BLA Arrest BLA	ess Comziste	124 125-125	Operator Observer	24	F	Stutter Speed Photo Frag					
Arcast Book Time DT music confirmed with plot Mission Plan Status S Koks Solar	salan Ctijective					MU GPS Re Deta Drive	Outside	Temp@TC: Temp@LK:	SL Out	e Pressure & T.D:	Sor
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Appendix D Terrapoint Waveform File Structure

