SHOALS-1000T LIDAR and Image Data Acquisition

for

Grand Canyon Monitoring and Research Program

Lees Ferry and San Juan Study Areas, AZ

Survey Report

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REPORT CERTIFICATION
FOR

SHOALS-1000T LIDAR and Image Data Acquisition

Grand Canyon Monitoring and Research Program

Lees Ferry and San Juan Study Areas, AZ

FP-6088.008-RPT-01-00

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The following versions of this report have been issued:

0	2/25/2005	Grand Canyon	NK/JM	CAL	DM
REV	DATE	DESCRIPTION			

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1 INTRODUCTION

Fugro Pelagos, Inc (FPI) was contracted by the US Army Corps of Engineers (USACE) to conduct surveys of two study areas for the US Geological Survey's (USGS) Grand Canyon Monitoring and Research Center (GCMRC).

The first study area, Lees Ferry, is within the Colorado River corridor, starting near the Lees Ferry boat dock and extending upstream 2.5 miles (Figure 1-1). The second study area, San Juan, starts 37km from the San Juan River's confluence with Lake Powell and extends up the river 33 km (Figure 1-2).

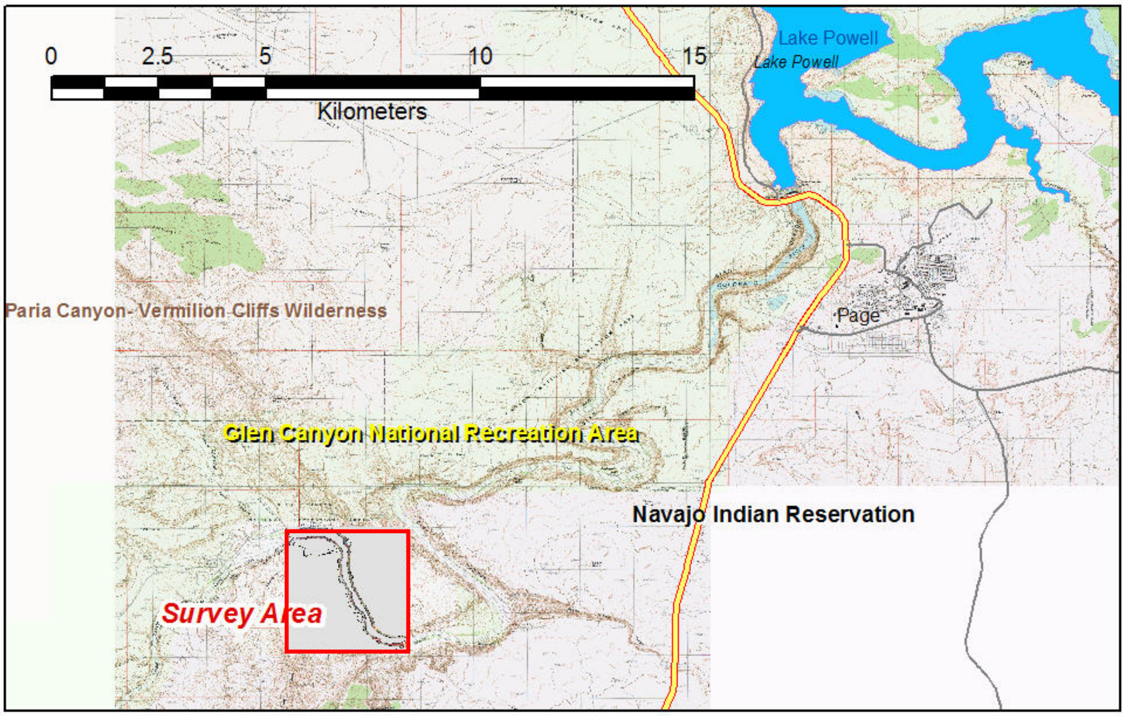

Figure 1-1 Lees Ferry Survey Location

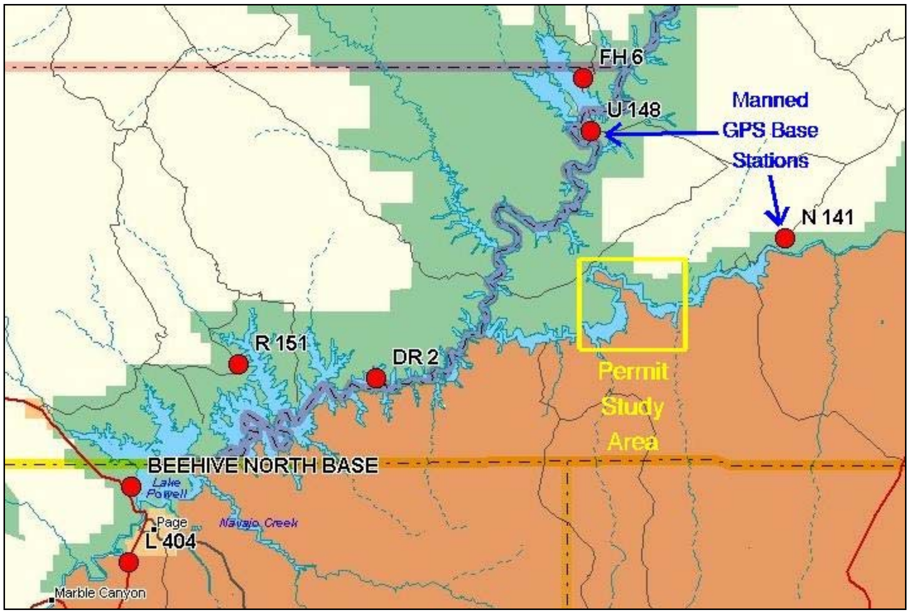

Figure 1-2 San Juan River Survey Location

The objective of the survey was to obtain the existing bathymetric conditions of the river and some land area along its margins to support sediment storage and movement studies being conducted in late November. The data will be used by GCMRC to model sediment response to dam operations within the Colorado River.

The survey took place on November 26 - 28, 2004, during the low flow period following the dam's flow spike. During this period, the following information were collected:

- Bathymetric LIDAR data from the SHOALS-1000T (including land data from the bathymetric laser)
- Digital Aerial Photography from the SHOALS-1000T
- GPS Ground Control

All times quoted in this report are UTC, unless otherwise stated.

1.1 AREA SURVEYED

The total area surveyed at Lees Ferry and San Juan was approximately 0.89 mi^2 (2.3 km^2) and 12.6 mi^2 (32.7 km^2) in size, respectively. The bathymetric laser was operated to achieve 2m x 2m spot spacing over the river and surrounding land, flying at 300m altitude and approximately 65 knots. The survey lines were planned with 50% overlap.

At San Juan, the laser was operated to achieve 4m x 4m spot spacing at 300m altitude and approximately 65 knots. Very few bathymetric data points were acquired in the San Juan study area due to extremely dirty water conditions (Figure 1-3).

Figure 1-3 Dirty Water in the San Juan Study Area

2 DATA ACQUISITION

Operations for this survey were based out of the Courtyard Marriott hotel in Page, Arizona, where a temporary office was established. The base airport for operations was Page (PGA), Arizona.

The ground control stations were occupied each morning prior to the first flight of the day. Base station data were acquired by the client, with the exception of the PAG1 station and LES1, run by FPI.

A detailed daily operations log is given in APPENDIX A.

2.1 PROJECT DATUM

The project control was established in the NAD83 datum. Online acquisition and post-processed data were conducted in the project datum. Data results were projected to the State Plane Coordinate System Zone 202 (Central Arizona) in meters.

The vertical datum for the project was NAVD88 with units in meters. Conversion from NAD83 ellipsoid elevations to NAVD88 used the GEOID03 model. All coordinates conversions were performed using POSPac v4.2 software.

2.2 GROUND CONTROL

In order that a post-processed Kinematic GPS (KGPS) solution could be used for final positioning and refinement of the inertial solution, it was necessary to acquire dual frequency GPS data at a known location on the ground.

GPS data was collected at five ground control points: N141, U148, LFRG, PAG1, and LES1. The GPS measurements at LFRG, N141, and U148 were collected by the client. The GPS measurements at PAG1 and LES1 were collected by FPI personnel and equipment (Figure 2-1). Detailed specifications for FPI ground control equipment can be found in APPENDIX B. Dual frequency GPS data were acquired at 1-second intervals in all cases.

NGS datasheets for LFRG, N141, and U148 can be found in APPENDIX C. Precise coordinates for these stations were provided by the client.

GPS field logs for PAG1 and LES1 can be found in APPENDIX D, while station descriptions can be found in APPENDIX E.

Figure 2-1 FPI GPS Base Stations: PAG1 (left) and LES1 (right)

2.2.1 SECCHI DISK MEASUREMENTS

Secchi disc measurements were not taken. During visual inspection at the ground truth locations, and from review of the imagery the water was clear and the riverbed visible at Lees Ferry (Figure 2-2). At San Juan access to the survey area was not possible. However, the imagery indicates that this water is saturated with sediment, proving too dirty for LIDAR depths to be acquired (see Figure 1-3).

Figure 2-2 Water Clarity at Western Edge of Lees Ferry Study Area

2.3 AIRBORNE SURVEY

The Bell 206 L-III Long Ranger (call sign N1085T) equipped with a SHOALS-1000T LIDAR System was used for the project (Figure 2-3). Technical specifications for the helicopter are located in APPENDIX F. Detailed equipment specifications for the SHOALS-1000T are available in APPENDIX G.

Figure 2-3 Bell Long Ranger (N1085T)

2.3.1 HELICOPTER MOBILISATION

The helicopter was mobilized at Oxnard Airport, California with the assistance of Optech staff. The airborne component of the SHOALS-1000T consists of three separate modules. The lasers and camera are housed in a single package that was bolted to a flange above the camera door. An equipment rack, containing the system cooler and power supplies, was installed aft of the laser on the starboard side. The operators console was attached to the aft port side directly beside the power supply. The console was installed so the operator was facing backward. Equipment installation required about 4 hours.

Prior to helicopter mobilization, the system had been installed in a fixed-wing aircraft. Ground truth data were flown before demobilization of the aircraft and after remobilization of the helicopter to ensure all calibration and offset values were valid.

2.3.1.1 OFFSET MEASUREMENTS

The only offset measurement required during system mobilization is from the POS AV Inertial Measurement Unit (IMU) to the POS AV GPS antenna. The IMU is completely enclosed within the laser housing. The offsets from the IMU to a common measuring point (CMP) on the outside of the housing are known.

Offsets were measured using a total station. An arbitrary base line was established along the port side of the helicopter. Ranges and bearings were measured from the total station to the CMP on the top of the laser housing. Additional measurements where made to the sides and top of the housing to determine its orientation. A final measurement was made to the center of the POSAV GPS antenna. The IMU to POS AV GPS offsets are calculated using the known IMU to CMP offsets. A summary of the offset measurements can be found in Table 2-1, below.

Table 2-1 Helicopter Offsets

OFFSET	X	Y	Z
IMU to CMP	0.073	-0.230	-0.415
CMP to POS AV GPS Antenna	-2.164	0.527	-1.059
IMU to POS AV GPS Antenna	-2.091	0.297	-1.474

The offsets from the IMU to the POS AV GPS antenna are entered in to the POS AV console prior to survey.

2.3.2 POSITIONING

Position was determined in real time using a differential GPS (DGPS) solution. However, final positions were determined using a post-processed kinematic GPS solution (KGPS) (Section 3.2.2).

The primary position GPS antenna was a NovAtel 512 airborne L1/L2, which was connected to a NovAtel Millennium GPS card residing in the POS AV (Section 2.3.3)

An AeroAntenna AT-3065-9 antenna was used to acquire differential corrections. Two differential receivers were available: the OmniSTAR 3100LM and a CSI MBX-3S Coast Guard beacon receiver. The OmniSTAR was the primary source of differential corrections for this project.

Dual frequency GPS data was also acquired with the NovAtel Millennium card in the POS AV. These data were used in post-processing, along with the dual frequency ground control data to provide a KGPS solution.

2.3.3 SENSOR ORIENTATION

The Applanix POS AV 410 provides orientation parameters (roll, pitch and heading). The system consists of a POS AV computer with a NovAtel Millennium GPS card, an Inertial Measuring Unit (IMU), and one NovAtel 512 airborne L1/L2 GPS antenna.

The IMU is permanently mounted within the SHOALS-1000T sensor. It uses a series of linear accelerometers and angular rate sensors that work in tandem to determine orientation.

The POS AV information is used in post-processing to determine position of the laser spots. However, analog data from the POS AV is also used during acquisition to maintain a consistent laser scan pattern.

2.3.4 LIDAR SYSTEM

The SHOALS-1000T was used to acquire both bathymetric and topographic LIDAR data during the project, using the 1 kHz bathymetric laser.

The 1-kHz bathymetric laser (or hydro laser) was used to collect data over the entire survey area. All hydrographic lines for Lees Ferry were run at approximately 300m altitude and 65 knots with a 2x2m spot spacing. All hydrographic lines for San Juan were run at approximately 300m altitude and 65 knots with a 4x4m spot spacing. Background theory on bathymetric LIDAR can be found in the paper, "*Meeting the Accuracy Challenge in Airborne LIDAR Bathymetry*" (Guenther, et al.[1]). However, in general, the laser outputs a green and infrared beam. The infrared beam is used to detect the water surface and does not penetrate this. The green beam penetrates the water and is used to detect the seafloor. The green beam also excites water molecules at the air/water interface generating radiation known as Raman backscatter that can also be used to detect the sea surface. Distances to the sea surface and seafloor are calculated from the times of the laser pulses, using the speed of light in air and water.

Data received by the airborne system were continually monitored for data quality during acquisition operations. Display windows showed coverage and information about the system status. In addition, center waveforms at 5Hz were shown. All of this information allowed the airborne operator to assess the quality of data being collected.

In addition to LIDAR data, a DuncanTech DT4000 digital camera was also used to acquire one 24-bit color photo per second. The camera, mounted in a bracket at the rear of the sensor, captures imagery of the area being over flown, and can be used during post-processing.

[1] *"Meeting the Accuracy Challenge in Airborne LIDAR Bathymetry", Gary C. Guenther, A. Grant Cunningham, Paul E. LaRocque, David J. Reid (available by request).*

2.3.4.1 LIDAR CALIBRATION

A LIDAR in-flight calibration was performed in Toronto, Canada prior to this project. Values were confirmed after mobilization in to the helicopter by flying ground truth data in Oxnard, CA. This “raster pattern” calibration is used in the determination of the small offsets of the scanner mirror frame relative to the optical axes of the system. To calculate the angular offsets, an average of the water surface is derived by the system. The raster pattern calibration required flying reciprocal straight lines over a relatively calm water surface for at least 5 minutes, into and against the waves. In addition, ground truth data were acquired over Oshawa runway (Toronto), and these were used to determine system biases.

2.4 CHALLENGES ENCOUNTERED

Water clarity was an issue at the San Juan site. However it was decided to continue to survey the site to acquire elevations above the waterline.

On November 27, 2005 the client’s base stations U148 and N141 were demobilized approximately an hour prior to completion of data collection. For this remaining period the base station used was the one set up at the Marriott hotel in Page (PAG1) by FPI.

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3 DATA PROCESSING

Data were provisionally processed at the temporary office base in Page, AZ to determine data coverage. The remaining data were processed in FPI's San Diego office. An overall processing flow is given in Figure 3-1, below.

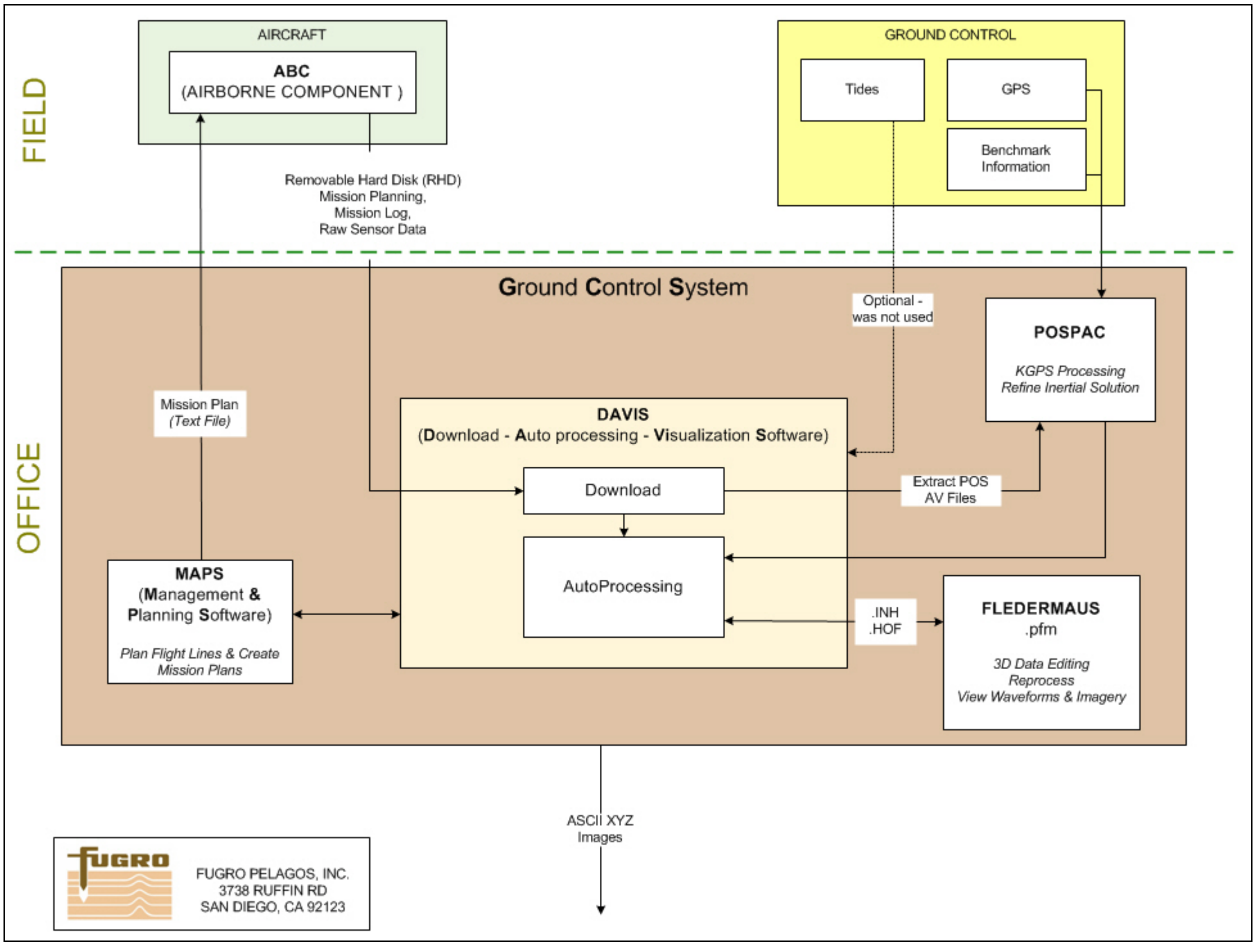

Figure 3-1 Processing Data Flow

3.1 GROUND CONTROL

The client provided dual frequency GPS data for stations U148, N141 and LFRG stations, for which accurate positions were known (APPENDIX C). To calculate coordinates for PAG1 and LES1, these data along with the data provided for U148, N141 and LFRG were processed as a static baseline network, with the client coordinates held as fixed. Baseline processing was carried out using GNSS Studio software. Final adjusted coordinates for PAG1 and LES 1 are presented in Table 3-1. Static GPS network processing results are attached in APPENDIX H.

Table 3-1 Adjusted Coordinates for FPI Control Stations

	Latitude	Longitude	Ellipsoid Height (m)
PAG1	36º 55' 31.47067" N	111º 28' 07.88500" W	1212.061
LES1	36º 51' 58.81624" N	111º 35' 13.05479" W	933.651

3.2 LIDAR DATA

All data were processed using the Optech SHOALS-1000T Ground Control System (GCS) on Windows XP workstations. The GCS includes links to Applanix POSPac software for GPS and inertial processing, and IVS Fledermaus software for data visualization and 3D editing.

The GCS was used to process the KGPS and inertial solutions, apply environmental parameters, auto-process the LIDAR waveforms, apply the vertical datum offsets, edit data and export accepted data to an ASCII file.

3.2.1 PRE-PROCESSING

Once data had been downloaded to DAViS (Download, Auto processing and Visualization Software), hardware related calibration information was entered into the GCS. A list of the calibration values used can be found in APPENDIX I.

In addition to the hardware values, some default environmental parameters were also set. Surface detection method was selected to use the IR channel initially. If no IR pick were found then the Raman would be used.

3.2.2 KGPS PROCESSING

For every mission, a new project was set up in POSPac. POS data downloaded from the air were then extracted from DAViS into the POSPac project.

Using POS GPS, GPS data from the air and ground control base station were converted from the native NovAtel and base station formats respectively, to the POS GPS .gpb format. The KGPS data were then post-processed for position, using the ground control coordinates given in Table 3-2, as the master control coordinates.

Table 3-2 Coordinates for control stations (NAD83)

	Latitude	Longitude	Ellipsoid Height (m)
LFRG	36º 51' 40.44281" N	111º 36' 04.00607" W	968.95
U148	37º 27' 11.86283" N	110º 42' 40.46805" W	1173.065
N141	37º 18' 26.66190" N	110º 22' 33.79759" W	1167.966
PAG1	36º 55' 31.47067" N	111º 28' 07.88500" W	1212.061
LES1	36º 51' 58.81624" N	111º 35' 13.05479" W	933.651

Multi-base station solutions were used extensively throughout the data processing. The Lees Ferry site was processed using control stations LFRG and PAG1, whilst the San Juan site used

U148, N141 and PAG1. Station LES1 was used for ground truth survey processing at the Lees Ferry site. A summary of the GPS processing results can be found in APPENDIX K. While graphic plots of PDOP during the survey can be found in APPENDIX J.

POSPac then used the post-processed GPS positions to post-process the POS orientation data and refine the inertial solution. The final solution was exported to a sbet.out file, which was then used by the GCS during LIDAR auto processing.

3.2.3 AUTO PROCESSING

Once calibration values are set, environmental parameters selected and KGPS data processed, the LIDAR data can be auto processed using the GCS. The auto processing routine contains a waveform processor to select surface and bottom returns from the bathymetry data, and surfaces from the bathymetric laser. In addition, it contains algorithms to determine position for each laser pulse.

The auto process algorithms obtained inputs from the raw data and calculated a height, position and confidence for each laser pulse. This process, using the set environmental parameters, also performed a first cut at cleaning the data of poor land/seafloor detections. Questionable soundings were flagged as suspect, with attached warning information.

Data were then imported into a project PFM format file to allow data inspection and editing in Fledermaus.

3.2.4 DATA VISUALIZATION & EDITING

Data visualization and editing was done using Fledermaus. Fledermaus was used to view a gridded surface of the entire dataset in 3D (Figure 3-2). Any areas with questionable soundings/elevations were then reviewed using the 3D area-based editor, which displayed each individual sounding in 3D (Figure 3-3). This was used on smaller subsets of the data. Gross fliers were rejected. Other data of uncertain quality requiring more examination were reviewed along with the waveform window, showing shallow and deep channel bottom selections, and IR and Raman surface picks (Figure 3-4). Other metadata such as confidence and warnings are also incorporated into the viewer. In addition, the camera image associated with the laser pulse was also displayed.

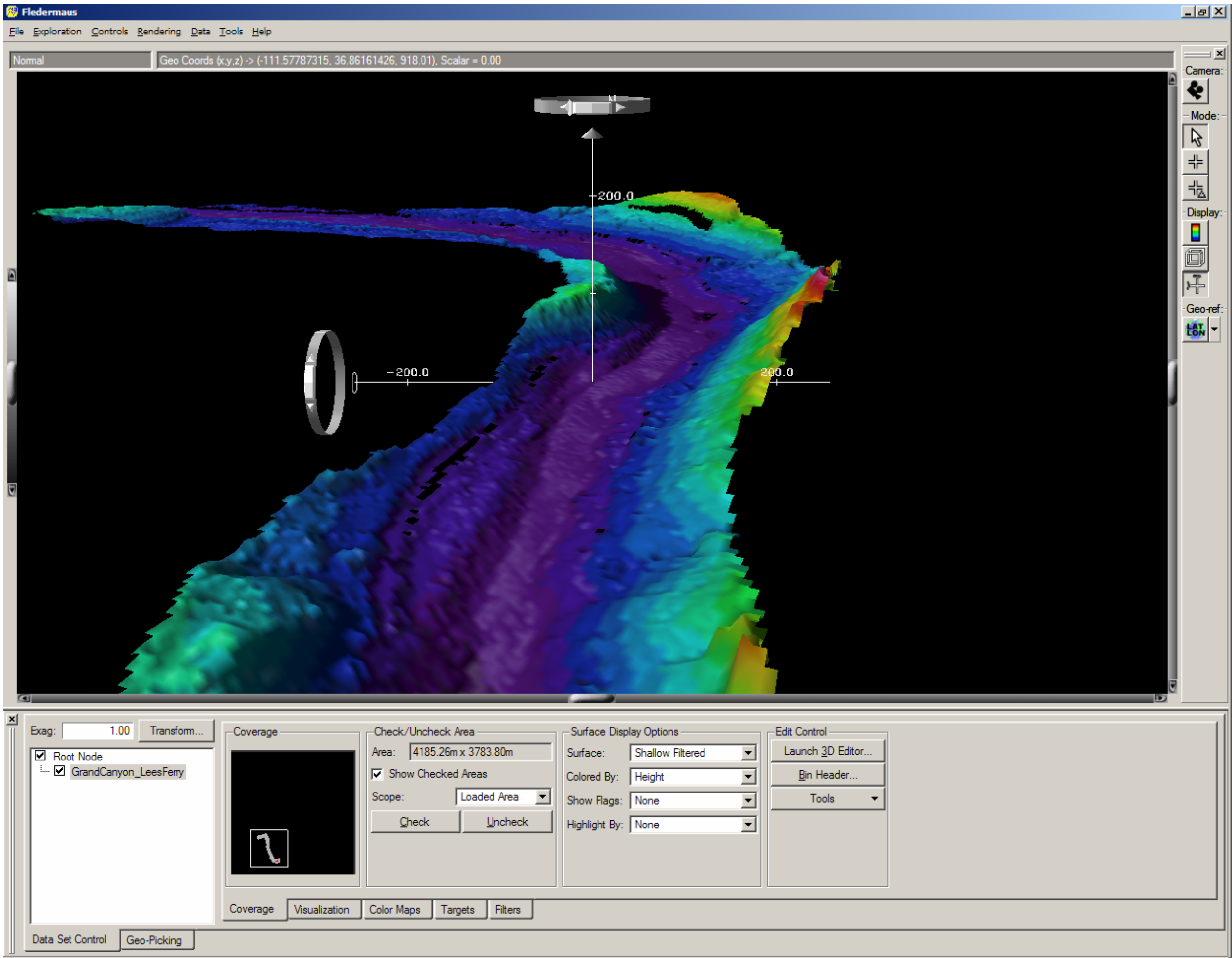

Figure 3-2 Viewing the Dataset Surface in Fledermaus

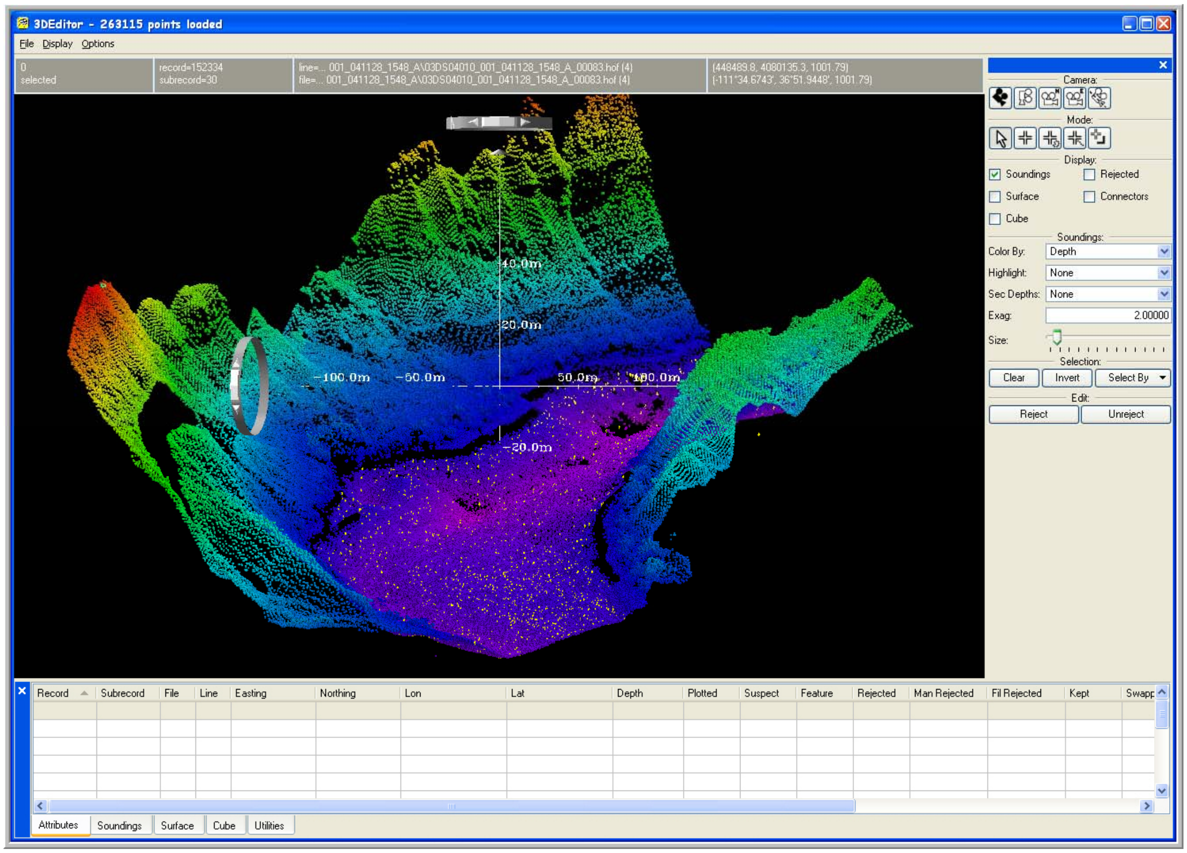

Figure 3-3 Fledermaus 3D Editor

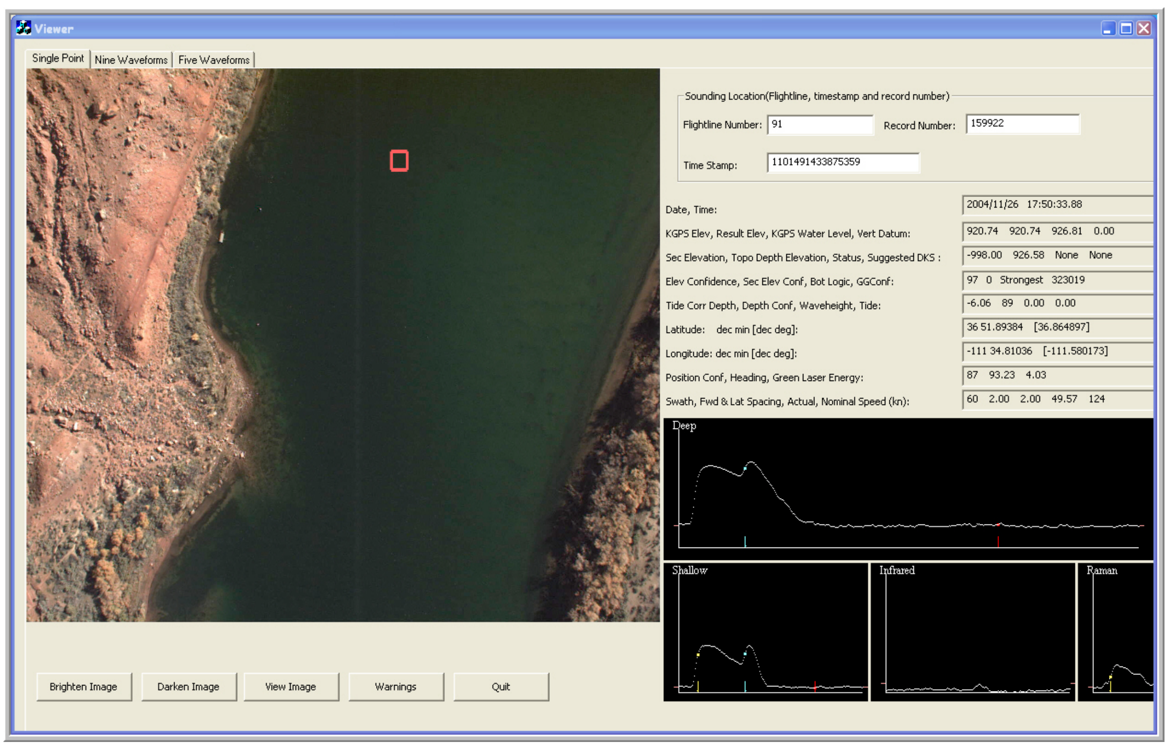

Figure 3-4 Waveform Viewer

Other SHOALS specific tools, such as swapping a sounding falsely recognized as water to land, were used inside Fledermaus.

In general, manual editing was used to remove obvious anomalies in the data mostly due to turbidity. As mentioned previously almost no data were collected in the San Juan River itself due to extremely poor water clarity. When water is turbid most of the laser energy is absorbed and is not reflected back to the receiver. This is apparent in the waveforms and images collected during this survey.

An example of a typical waveform return for this project is given in where it is compared to a waveform from clearer water conditions. As can be seen in Figure 3-5, the energy in the San Juan waveform is absorbed. The initial reflection seen in the deep and shallow channels is from the surface, but no bottom reflection occurs after this, and the signal is quickly absorbed. In the Lake Ontario sample, the reflection from the surface is followed by some volume backscatter, and then the bottom reflection. No data from the San Juan contained a clear bottom return, resulting in no depths being achieved.

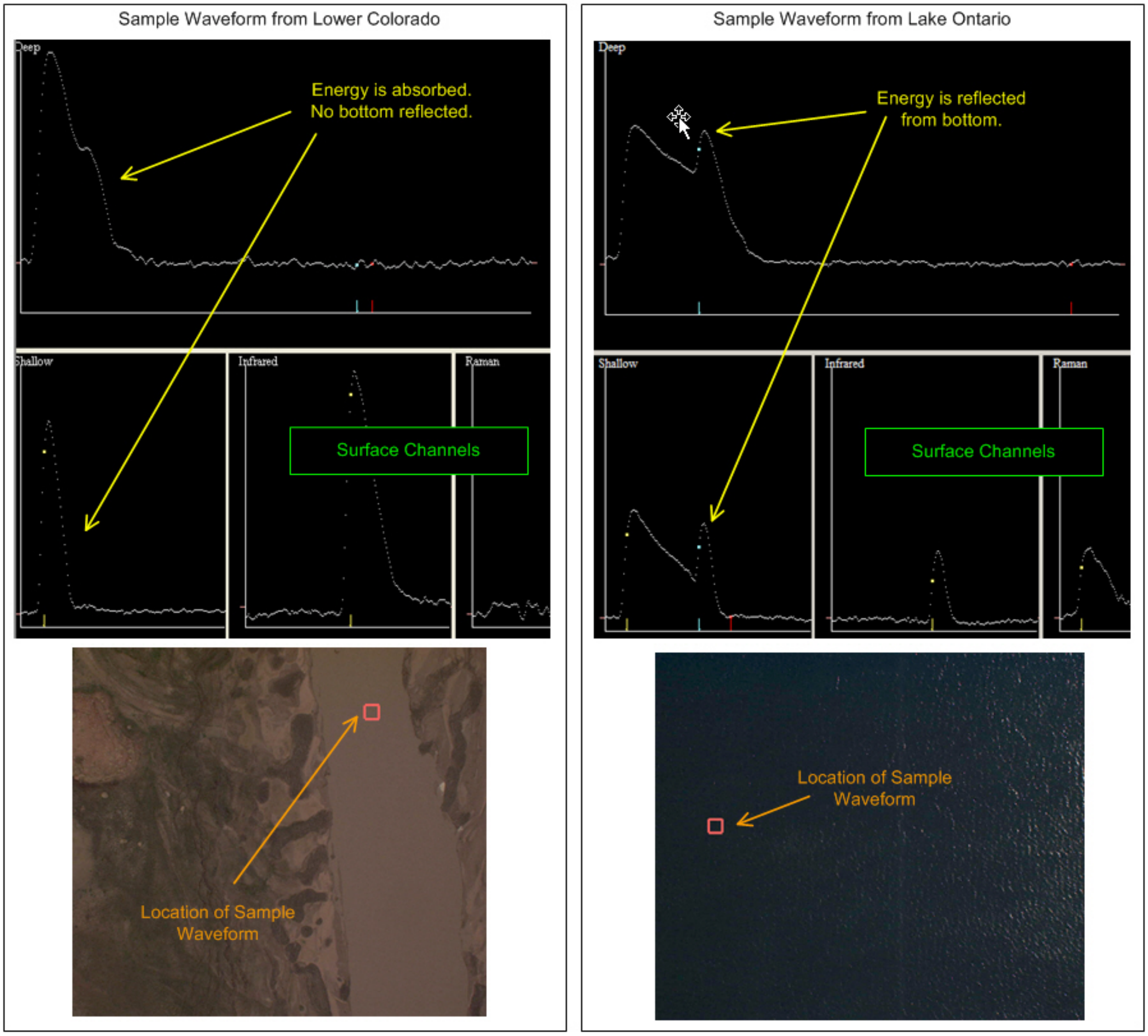

Figure 3-5 Sample Waveforms indicating Differences in Water Clarity

3.2.5 ASCII XYZ File

Once all editing was completed in Fledermaus, the GCS was used to export ASCII XYZ files of all remaining accepted data. Exported data were in NAD83, with elevation in meters. The data were transformed to the final charting datum, given in Table 3-3, using POSPac. Data were delivered with elevations in NAD83 and NAVD88, both in meters.

Table 3-3 Geodetic Parameters for Deliverables

Datum	NAD83
Coordinate System	U.S State Plane 1983
Zone	Arizona Central (Zone 202)
Horizontal Units	Meters

3.2.6 QUALITY CONTROL

Two ground truth surveys were planned and acquired over a land section in Lees Ferry. The survey consisted in observing points with a kinematic GPS rover station on terrain covered by the LIDAR scanning. A difference analysis between the observed points and LIDAR survey lines was performed using the Crosscheck program within Fledermaus.

The crosscheck program was used to create an average grid of the LIDAR data at ~3m. The ground truth points were then compared to the grid.

The results of the crosscheck are included in Table 3-3.

Table 3-3 QC Results

	All Soundings
No. of Samples	96
Mean Difference	-0.0629m
Std. Dev.	0.1676m
% of Samples with <0.15m Difference	68%

4 DATA PRODUCTS

After all processing was completed, the following deliverables for the survey were provided:

- Report :
    - Lees Ferry & San Juan Study Areas (FP-6088.008-RPT-01-00) (DOC& PDF on CD)
- ACSII XYZ Files with NAD83 heights (DVD)
- ASCII XYZ Files with NAVD88 heights (calculated using Geoid03) (DVD)
- All digital imagery acquired with associated world file(DVD)
- Image index files giving image coordinates and aircraft orientation(DVD)
- FGDC compliant Metadata(DVD)
- Flight Line Index as ArcGIS Coverage(DVD)
- Flight Line Index as ArcGIS SHP File(DVD)

APPENDIX A : DAILY LOG

TIMES BELOW ARE LOCAL

Date: 25-November-2004 Julian Day: 330

FLIGHT SUMMARY:

	ENGINE TIME			PLANE TIME		
	START	STOP	RUN	TAKE OFF	LAND	FLYING
FLIGHT 01	09:16	10:40	1h 24m	09:32	10:36	1h 04m
FLIGHT 02	10:54	11:48	0h 54m	11:03	11:44	0h 41m
FLIGHT 03			??	TRANSIT TO PAGE		

GENERAL:

TIME	EVENT
07:30	Depart hotel for Oxnard Airport.
07:45	Arrive at Airport.
08:00	Setup GPS receivers on control point at Airport.
08:30	Back at hotel analyzing KGPS data.
10:00	Possible problem with mission plan having lever arms in wrong location.
10:15	Create new mission plan and head to Oxnard Airport.
10:45	Deliver new mission plan to Dennis T.
11:00	Back at hotel checking flight 01 data.
11:45	KGPS processing was successful.
12:00	Haresh H. leaves for LAX Airport.
12:15	Checking data from flight 02.
12:25	System checks complete.
12:30	Packing equipment that will go on Helicopter.
12:45	Depart hotel for Oxnard Airport.
13:00	Finish loading equipment on Helicopter.
13:05	Take down GPS receivers & depart Airport for hotel.
13:25	Dushan A. and Dennis T. Depart hotel for LAX Airport.
18:00	Meet Pepe M. at Phoenix Airport.
10:00	Arrive at Page, Arizona.

AIRBORNE CREW:

TIME	EVENT
	Dennis Tobin
07:00	Preflight Safety and toolbox meeting.
07:30	Depart hotel for Oxnard Airport.
07:45	Arrive at Airport.
08:00	Setup GPS receivers on control point at Airport.
09:16	Start engines.
10:40	Stop engines.
10:54	Start engines.
11:48	Stop engines.

TIME	EVENT
11:50	Depart Airport for hotel to check data.
12:30	Packing equipment that will go on Helicopter.
12:45	Depart hotel for Oxnard Airport.
13:00	Finish loading equipment on Helicopter.
13:00	Helicopter leaves for Page, Arizona.

GROUND CONTROL CREW:

TIME	EVENT
	None

Date: 26-November-2004 Julian Day: 331

FLIGHT SUMMARY:

	ENGINE TIME			PLANE TIME		
	START	STOP	RUN	TAKE OFF	LAND	FLYING
FLIGHT 01	10:17	11:35	1h 18m	10:25	11:33	1h 08m
FLIGHT 02	12:44	14:56	2h 12m	12:56	14:52	1h 56m
	DAILY TOTAL		3h 30m	**DAILY TOTAL**		3h 04m
	PROJECT TO DATA		7h 03m	**PROJECT TO DATA**		5h 39m

NOTE: Total does not include Transit to Page, Arizona.

GENERAL:

TIME	EVENT
07:30	Arrange to pick up rental cars.
08:15	Picked up rental cars and arrived back at hotel.
08:30	Depart hotel for Airport.
09:30	Setup system to use OmniStar.
10:00	Head back to hotel.
11:00	Processing equipment arrives at hotel.
11:45	Setting up processing equipment.
12:00	Received data from Lees Ferry site.
12:10	Downloading and checking data.
12:30	Continue setting up processing equipment.
14:30	Received call from Dennis T. indicating that water quality was poor at San Juan site. Informed him to abort and return if he was not getting any data.
15:30	Spoke to the client and he indicated that at minimum he would like to get terrestrial data at San Juan.
16:00	Checking data from San Juan.
16:30	As per client request will continue San Juan tomorrow. Informed James H. of the clients request.

AIRBORNE CREW:

TIME	EVENT

TIME	EVENT
	Dennis Tobin
07:00	Preflight Safety and toolbox meeting.
08:30	Depart hotel for Page Airport.
08:40	Arrive at Airport.
08:45	Remove cover for laser.
08:55	Clean laser cover and camera lens and lens cover.
09:15	Get Helicopter out of hanger.
09:30	Reprogram POS for OmniStar & Reprogram OmniStar.
10:17	Start engines.
11:35	Stop engines.
11:40	Depart Airport for hotel to check data.
12:15	Depart hotel for Page Airport.
12:25	Arrive at Airport.
12:44	Start engines.
14:56	Stop engines.
15:10	Get Helicopter back in hanger.
15:25	Depart Airport for hotel.

GROUND CONTROL CREW:

TIME	EVENT
	Pepe Martinez
10:00	Setting up base station PAG1 in hotel parking lot in Page.
10:30	Depart to ground truth site in Lees Ferry.
11:40	Arrived to Lees Ferry. Scouting site for ground truth survey. Setting up base station LES1.
12:00	Start logging base station on LES1. Setting up rover station.
12:20	Start logging rover in kinematic mode. Start ground truth survey.
13:25	End ground truth survey. Stop logging rover station.
13:55	Stop logging base station on LES1. Breaking down station.
14:10	Depart to hotel.
15:10	Arrive to hotel.
15:17	Stop logging base station on PAG1. Breaking down station.

Date: 27-November-2004 Julian Day: 332

FLIGHT SUMMARY:

	ENGINE TIME			PLANE TIME		
	START	STOP	RUN	TAKE OFF	LAND	FLYING
FLIGHT 01	08:39	11:18	2h 39m	08:55	11:15	2h 20m
FLIGHT 02	11:51	14:32	2h 41m	11:59	14:30	2h 31m
FLIGHT 03	15:15	16:58	1h 43m	15:22	16:55	1h 33m
	DAILY TOTAL		7h 03m	**DAILY TOTAL**		6h 24m

PROJECT TO DATA	14h 06m	PROJECT TO DATA	12h 03m

NOTE: Total does not include Transit to Page, Arizona.

GENERAL:

TIME	EVENT
06:00	Haresh H. departs for Toronto.
08:00	Continue processing Lees Ferry data.
17:00	Received word that the base station was demobilized approximately an hour prior to completion of data collection.
17:30	Discussed issue with office and concluded that we will try to use the backup station setup at the hotel in Page.
17:45	Received data from San Juan survey. Downloading and processing data.
19:00	Mark G. (USGS) arrived at hotel with San Juan base station data.
20:00	Completed downloading base station data.

AIRBORNE CREW:

TIME	EVENT
	Dennis Tobin
07:00	Preflight Safety and toolbox meeting.
08:00	Depart hotel for Page Airport.
08:10	Arrive at Airport.
08:39	Start engines.
11:18	Stop engines @ Airport close to survey area for fuel.
11:51	Start engines.
14:32	Stop engines @ Airport close to survey area for fuel.
15:12	Start engines.
16:59	Stop engines @ Page Airport.
17:05	Get Helicopter back in hanger.
17:20	Depart Airport for hotel.

GROUND CONTROL CREW:

TIME	EVENT
	Pepe Martinez
09:50	Setting up base station on PAG1
10:07	Start logging base station on PAG1
10:20	Depart to Lees Ferry site
11:35	Arrive to Lees Ferry. Setting up base station on LES1.
11:44	Start logging base station on LES1. Setting up rover station.
12:06	Start logging rover station. Start ground truth survey.
13:41	End ground truth survey. Stop logging rover station.
14:01	Stop logging base station on LES1. Breaking down station.
14:45	Depart to hotel.
16:25	Arrive to hotel.
18:02	Stop logging base station on PAG1.

Date: 28-November-2004 Julian Day: 333

FLIGHT SUMMARY:

	ENGINE TIME			PLANE TIME		
	START	STOP	RUN	TAKE OFF	LAND	FLYING
FLIGHT 01	08:39	09:32	0h 53m	08:50	09:29	0h 39m
FLIGHT 02			??	TRANSIT TO OXNARD		
	DAILY TOTAL		0h 53m	**DAILY TOTAL**		0h 39m
	PROJECT TO DATA		14h 59m	**PROJECT TO DATA**		12h 42m

NOTE: Total does not include Transit to Page, Arizona and back to Oxnard, California.

GENERAL:

TIME	EVENT
07:30	Heading to Page Airport.
08:40	Adjusting Gain values on Digital Camera to see vegetation in the water.
09:30	Flight complete. Setting gain values on Camera back to original.
10:00	Helicopter departs for Oxnard, California.
10:15	Back at hotel.
10:30	Continue processing data.
12:00	Processing San Juan GPS data as multi base solutions.
15:00	Dennis T. and Pepe M. start packing equipment.
17:00	Completed processing San Juan GPS.
18:00	Packing rest of the equipment for shipping to Redding, California.

AIRBORNE CREW:

TIME	EVENT
	Dennis Tobin
07:00	Preflight Safety and toolbox meeting.
07:30	Depart hotel for Page Airport.
07:45	Arrive at Airport.
07:55	Get Helicopter out of hanger.
08:39	Start engines.
08:40	Readjust gain on system Camera.
09:32	Stop engines.
10:00	Depart Airport for hotel.

GROUND CONTROL CREW:

TIME	EVENT
	Pepe Martinez
08:00	Setting up base station on PAG1.
08:15	Start logging base station.
10:06	Stop logging base station. Breaking down station.

APPENDIX B : GROUND CONTROL EQUIPMENT

THALES NAVIGATION

SUPERIOR RTK PERFORMANCE IN A MODULAR DESIGN

Z-Max Surveying System

The Z-Max™ surveying system from Thales Navigation is a precision GPS surveying solution designed for topography and construction. Offering superior RTK performance, an innovative design and a total software solution, Z-Max delivers survey grade positioning on demand.

Superior RTK Performance

Z-Max rises above other GPS receivers with ADAPT-RTK™. This breakthrough technology dramatically expands centimeter-accurate coverage by rapidly adapting to current conditions. With ADAPT-RTK, Z-Max ensures exceptional RTK coverage and data confidence. Z-Max is capable of using VRS and FKP, so that optimal results can be obtained in networks of reference stations.

Innovative Modular Design

Z-Max features a unique modular design, with interchangeable base and rover receivers, for quick and easy system optimization in the field. The versatile system offers options for power, portability, communications, data collection, downloading and post-processing.

Wireless Roving: Integrated Bluetooth™ advanced wireless system enables a convenient cable-free RTK rover.

Long-Range Communication: UHF or cellular – or a uniquely combined UHF + GSM module – simply snap into place.

New Vortex™ UHF Antenna: Breakthrough technology eliminates conventional radio antennas and cables.

On-Board Software: A full range of options are available, including control, stop and go, RTK setup and data collection – all without the need of an additional field controller.

The Total Surveying Solution

The Z-Max system leverages the latest in surveying technology by integrating field and office software solutions focused on topographic and construction surveying. With this comprehensive suite of software tools, the Z-Max total surveying solution can enhance your surveying capabilities, boost your productivity, improve your data quality, and upgrade your deliverables.

FAST Survey™ software is a powerful graphical field companion to Z-Max that enables feature coding, real-time line work, coordination of system setup, COGO (Coordinate Geometry) and seamless connectivity to a variety of optical total stations – all available through a simple touch-screen menu.

GNSS Studio™ software is the Z-Max GPS surveying office manager, intuitively guiding you through the entire GPS data collection process, from planning to professional quality deliverables.

www.thalesnavigation.com

THALES
NAVIGATION

Z-Max Surveying System

Technical Specifications

Features	Benefits
ADAPT-RTK. Automatic Decorrelation and Parameter Tuning.	Adapts to different environments to maximize coverage area of centimeter-accurate solutions for RTK. Two second initialization (typical) baselines <20 km (12 miles) centimeter-level solution availability up to 50 km (31 miles) in long-range mode.
Z-Max modular design	Tripod mounted data collection, cable-free RTK rover and RTK rover with a backpack, all with the same GPS receiver platform.
On-Board control software	Perform control, topo and even RTK surveys all without the need for additional field computer and software.
Integrated software solution for Topography and Construction	Move jobs from planning through deliverable with GNSS Studio office software and FAST Survey field software.
Bluetooth wireless connectivity	Eliminates the cost and hassles of cables.
Modular Communications technology	Flexible communications options, including Thales UHF, Pacific Crest UHF, GSM cellular and GSM plus UHF, are modular and simply snap on to the Z-Max.
Vortex UHF antenna technology	UHF antenna integrated with range pole provides superior range and physical durability.
Modular, lithium-ion power technology -14 hour size - 7 hour size	Smart battery system provides long runtime, an integral charger and up-to-the-minute capacity information and reliable, trouble-free operation.
Dual-frequency GPS all-in-view operation	Maximize GPS measurement redundancy for surveying by tracking all observables of all GPS satellites visible above the horizon.
P-Code decryption using patented Z-tracking™ technique	The cleanest signal quality commercially available for civilian use.
Automatic multipath mitigation	Robust operation in real-world surveying environments.
Reference station network compatibility	Using the VRS or FKP positioning, Z-Max obtains optimal results from networks of reference stations in seconds.

Performance Specifications

Static, Rapid Static *
- Horizontal 0.005 m + 0.5 ppm (0.016 ft + 0.5 ppm)
- Vertical 0.010 m + 0.5 ppm (0.033 ft + 0.5 ppm)

Post-Processed Kinematic
- Horizontal 0.010 m + 1.0 ppm (0.033 ft +1.0 ppm)
- Vertical 0.020 m + 1.0 ppm (0.065 ft +1.0 ppm)

Real-Time DGPS position
- < 0.8 m (2.62 ft)

Real-Time Kinematic Position (fine mode)
- Horizontal 0.010 m + 1.0 ppm (0.033 ft + 1.0 ppm)
- Vertical 0.020 m + 1.0 ppm (0.065 ft + 1.0 ppm)

ADAPT-RTK Initialization
- 99.9% reliability
- Typical 2 second initialization for baselines < 20 km

Technical Specifications

GPS Receiver Environmental
- Meets IP54 for moisture *
- Operating temperature: -30° to +55°C (-22° to +131°F)
- Storage temperature: -40° to +85°C (-40° to +185°F)
- Shock: 1.5 m (4.92 ft) pole drop
- Vibration: MIL-STD-810F Method 514.4 (I-3.1.1, I-3.4.8, I-3.4.9) *

Physical
- Receiver Module: 1.371 kg (3.02 lb)
- Antenna Module: 0.64 kg (1.17 lb)
- Power Module: 0.52 kg (0.96 lb)

Power *
- 9-24 VDC input
- 10-24 VDC output on serial ports
- Max-Run battery > 14 hrs. run-time @ 0 ºC
- Max-Lite battery > 7 hrs. run-time @ 0 ºC

Memory
- 48 hours of 1 sec. raw GPS data with 64 MB Secure digital
- 128 MB SD card available

Languages Supported in Controller
- English
- French
- German
- Portuguese
- Spanish

Standard Features
- Dual frequency with Z-Tracking
- On-board controller software
- 10 Hz Data recording

Optional System Components
- Thales Navigation UHF Communication Module
- Pacific Crest UHF Communication Module
- GSM Communication Module
- GSM+UHF Communication Module
- Z-Max GPS Antenna
- Padded Carry Bag
- Hard Shell Case

System Software

GNSS Studio Office Software
- L1 Processing
- RTK Support
- L1 + L2 Processing Option

FAST Survey Field Software
- GPS Control
- Optical Instrument Control
- Advanced Road Construction (optional)

Performance values assume minimum of 5 satellites, following the procedures recommended in the product manual. High-multipath areas, high PDOP values and periods of severe atmospheric conditions may degrade performance.

**Based on preliminary tests.*

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Thales Navigation follows a policy of continuous product improvement; specifications and descriptions are thus subject to change without notice. **Please contact Thales Navigation for the latest product information.**

THALES NAVIGATION

APPENDIX C : NGS DATASHEETS

```
The   NGS   Data   SheetSee   file     dsdata.txt   for   more   information   about   the
datasheet.DATABASE = Sybase ,PROGRAM = datasheet, VERSION = 7.12
1        National Geodetic Survey,   Retrieval Date = FEBRUARY  1, 2005
 DG5953 ***********************************************************************
 DG5953  DESIGNATION -  LFRG
 DG5953  PID         -  DG5953
 DG5953  STATE/COUNTY-  AZ/COCONINO
 DG5953  USGS QUAD   -  LEES FERRY (1985)
 DG5953
 DG5953                         *CURRENT SURVEY CONTROL
 DG5953  ___________________________________________________________________
 DG5953* NAD 83(1992)-  36 51 40.44281(N)    111 36 04.00607(W)     ADJUSTED
 DG5953* NAVD 88     -       992.3    (meters)    3256.     (feet)  GPS OBS
 DG5953  ___________________________________________________________________
 DG5953  X           -  -1,881,216.565 (meters)                     COMP
 DG5953  Y           -  -4,751,141.067 (meters)                     COMP
 DG5953  Z           -   3,805,664.431 (meters)                     COMP
 DG5953  LAPLACE CORR-         -2.76  (seconds)                     DEFLEC99
 DG5953  ELLIP HEIGHT-        968.95  (meters)        (06/28/04) GPS OBS
 DG5953  GEOID HEIGHT-        -23.34  (meters)                      GEOID03
 DG5953
 DG5953  HORZ ORDER  -  A
 DG5953  ELLP ORDER  -  THIRD     CLASS II
 DG5953
 DG5953.The horizontal coordinates were established by GPS observations
 DG5953.and adjusted by the National Geodetic Survey in June 2004.
 DG5953
 DG5953.The orthometric height was determined by GPS observations and a
 DG5953.high-resolution geoid model.
 DG5953
 DG5953.The X, Y, and Z were computed from the position and the ellipsoidal ht.
 DG5953
 DG5953.The Laplace correction was computed from DEFLEC99 derived deflections.
 DG5953
 DG5953.The ellipsoidal height was determined by GPS observations
 DG5953.and is referenced to NAD 83.
 DG5953
 DG5953.The geoid height was determined by GEOID03.
 DG5953
 DG5953;                    North         East     Units Scale Factor Converg.
 DG5953;SPC AZ C     -   650,118.386   241,496.164   MT  0.99990975   +0 11 21.5
 DG5953;UTM  12      - 4,079,647.414   446,418.032   MT  0.99963537   -0 21 38.2
 DG5953
 DG5953!             -  Elev Factor  x  Scale Factor =   Combined Factor
 DG5953!SPC AZ C     -   0.99984796  x   0.99990975  =   0.99975773
 DG5953!UTM  12      -   0.99984796  x   0.99963537  =   0.99948339
 DG5953
 DG5953                          SUPERSEDED SURVEY CONTROL
 DG5953
 DG5953.No superseded survey control is available for this station.
 DG5953
 DG5953_U.S. NATIONAL GRID SPATIAL ADDRESS: 12SVF4641879647(NAD 83)
 DG5953_MARKER: DO = NOT SPECIFIED OR SEE DESCRIPTION
 DG5953_SETTING: 35 = SPLINED REBAR
 DG5953_STAMPING: NO STAMPING
 DG5953_MAGNETIC: I = MARKER IS A STEEL ROD
 DG5953_STABILITY: C = MAY HOLD, BUT OF TYPE COMMONLY SUBJECT TO
 DG5953+STABILITY: SURFACE MOTION
 DG5953_SATELLITE: THE SITE LOCATION WAS REPORTED AS SUITABLE FOR
 DG5953+SATELLITE: SATELLITE OBSERVATIONS - 2003
 DG5953
 DG5953  HISTORY     - Date     Condition        Report By
 DG5953  HISTORY     - 2003     MONUMENTED       GRANCN
```

```
DG5953
DG5953                        STATION DESCRIPTION
DG5953
DG5953'DESCRIBED BY GRAND CANYON MONITORING AND RESEARCH 2003 (FMG)
DG5953'FROM THE U.S. POST OFFICE IN MARBLE CANYON LODGE, FOLLOW THE ROAD TO
DG5953'LEE'S FERRY FOR 5 MILES TO THE RANGER STATION ON THE LEFT AT THE LARGE
DG5953'WATER TOWER. TURN RIGHT ON THE ROAD THAT LEADS TO THE RESIDENTIAL AREA
DG5953'FOR LEE'S FERRY PARK EMPLOYEES. FOLLOW ROAD TO ITS END ON THE SOUTH
DG5953'SIDE  OF THE RESIDENTIAL AREA. THE STATION IS 43 METERS SOUTH OF THE
DG5953'SW FENCE  CORNER AND 35 METERS SW OF THE NORTHERLY OF 2 MANHOLES.
DG5953'
DG5953'THE STATION IS A ONE-HALF INCH SPLINED REBAR WITH A 1-INCH STEEL CAP,
DG5953'CEMENTED TO  A DEPTH OF 10 INCHES.

*** retrieval complete.
Elapsed Time = 00:00:00
```

Coordinates for N141 and U148 as provided by the client.

Stations were used for water penetrating LIDAR contract, San Juan Arm Nov-Dec. 2004

Station	Latitude	Longitude	Ortho.03	Geoid03	Ellipsoid
N 141	37 18 26.66190N	110 22 33.79759W	1189.697	-21.697	1167.966
U 148	37 27 11.86283N	110 42 40.46805W	1195.592	-22.545	1173.065

The NGS Data SheetSee file dsdata.txt for more information about the datasheet.DATABASE = Sybase ,PROGRAM = datasheet, VERSION = 7.10

```
1        National Geodetic Survey,   Retrieval Date = NOVEMBER 27, 2004
HN0156 ***********************************************************************
HN0156  DESIGNATION -  N 141
HN0156  PID         -  HN0156
HN0156  STATE/COUNTY-  UT/SAN JUAN
HN0156  USGS QUAD   -  WHIRLWIND DRAW (1987)
HN0156
HN0156                        *CURRENT SURVEY CONTROL
HN0156  ___________________________________________________________________
HN0156* NAD 83(1986)-  37 18 44.     (N)    110 22 06.     (W)    SCALED
HN0156* NAVD 88     -      1189.698  (meters)    3903.20    (feet)  ADJUSTED
HN0156  ___________________________________________________________________
HN0156  GEOID HEIGHT-         -21.67  (meters)                      GEOID03
HN0156  DYNAMIC HT  -       1188.412 (meters)    3898.98    (feet)  COMP
HN0156  MODELED GRAV-     979,509.8   (mgal)                        NAVD 88
HN0156
HN0156  VERT ORDER  -  FIRST     CLASS II
HN0156
HN0156.The horizontal coordinates were scaled from a topographic map and have
HN0156.an estimated accuracy of +/- 6 seconds.
HN0156
HN0156.The orthometric height was determined by differential leveling
HN0156.and adjusted by the National Geodetic Survey in June 1991.
HN0156
HN0156.The geoid height was determined by GEOID03.
HN0156
```

```
HN0156.The dynamic height is computed by dividing the NAVD 88
HN0156.geopotential number by the normal gravity value computed on the
HN0156.Geodetic Reference System of 1980 (GRS 80) ellipsoid at 45
HN0156.degrees latitude (g = 980.6199 gals.).
HN0156
HN0156.The modeled gravity was interpolated from observed gravity values.
HN0156
HN0156;                    North         East    Units  Estimated Accuracy
HN0156;SPC UT S     - 3,072,250.      600,310.      MT  (+/- 180 meters Scaled)
HN0156
HN0156                          SUPERSEDED SURVEY CONTROL
HN0156
HN0156  NGVD 29 (??/??/92) 1188.807  (m)         3900.28   (f) ADJ UNCH    1 2
HN0156
HN0156.Superseded values are not recommended for survey control.
HN0156.NGS no longer adjusts projects to the NAD 27 or NGVD 29 datums.
HN0156.See file dsdata.txt to determine how the superseded data were derived.
HN0156
HN0156_U.S. NATIONAL GRID SPATIAL ADDRESS: 12SWG559296(NAD 83)
HN0156_MARKER: DB = BENCH MARK DISK
HN0156_SETTING: 66 = SET IN ROCK OUTCROP
HN0156_STAMPING: N 141 1962
HN0156_STABILITY: A = MOST RELIABLE AND EXPECTED TO HOLD
HN0156+STABILITY: POSITION/ELEVATION WELL
HN0156
HN0156  HISTORY     - Date     Condition        Report By
HN0156  HISTORY     - 1962     MONUMENTED       CGS
HN0156
HN0156                          STATION DESCRIPTION
HN0156
HN0156'DESCRIBED BY COAST AND GEODETIC SURVEY 1962
HN0156'42.0 MI S FROM FRY CANYON.
HN0156'ABOUT 12.5 MILES SOUTHEAST ALONG UTAH STATE HIGHWAY 95 FROM THE POST
HN0156'OFFICE AT FRY CANYON.  THENCE 19.5 MILES SOUTHWEST ALONG A GRADED DIRT
HN0156'ROAD.  THENCE 10.0 MILES SOUTHWEST ALONG A BULLDOZED ROAD LEADING TO
HN0156'THE SAN JUAN RIVER, 367 FEET EAST-SOUTHEAST OF THE CENTERLINE OF THE
HN0156'ROAD, 161 FEET EAST-SOUTHEAST OF A METAL WITNESS POST, 3 1/2 FEET EAST
HN0156'OF A ROCK CAIRN, ABOUT 5 FEET BELOW THE LEVEL OF THE ROAD, AND SET IN
HN0156'THE TOP OF A LARGE FLAT ROCK OUTCROP THAT PROJECTS ABOUT 7 INCHES.

*** retrieval complete.
Elapsed Time = 00:00:02
```

```
The NGS Data SheetSee file dsdata.txt for more information about the
datasheet.DATABASE = Sybase ,PROGRAM = datasheet, VERSION = 7.10
1        National Geodetic Survey,   Retrieval Date = NOVEMBER 27, 2004
 HN0302 ***********************************************************************
 HN0302  DESIGNATION -  U 148
 HN0302  PID         -  HN0302
 HN0302  STATE/COUNTY-  UT/SAN JUAN
 HN0302  USGS QUAD   -  HALLS CROSSING (1987)
 HN0302
 HN0302                         *CURRENT SURVEY CONTROL
 HN0302  ___________________________________________________________________
 HN0302* NAD 83(1986)-  37 27 00.     (N)    110 41 41.     (W)     SCALED
 HN0302* NAVD 88     -      1195.592  (meters)    3922.54   (feet)  ADJUSTED
 HN0302  ___________________________________________________________________
 HN0302  GEOID HEIGHT-         -22.53  (meters)                      GEOID03
 HN0302  DYNAMIC HT  -       1194.271 (meters)     3918.20  (feet)  COMP
 HN0302  MODELED GRAV-     979,485.2   (mgal)                        NAVD 88
 HN0302
 HN0302  VERT ORDER  -  FIRST     CLASS II
```

```
HN0302
HN0302.The horizontal coordinates were scaled from a topographic map and have
HN0302.an estimated accuracy of +/- 6 seconds.
HN0302
HN0302.The orthometric height was determined by differential leveling
HN0302.and adjusted by the National Geodetic Survey in June 1991.
HN0302
HN0302.The geoid height was determined by GEOID03.
HN0302
HN0302.The dynamic height is computed by dividing the NAVD 88
HN0302.geopotential number by the normal gravity value computed on the
HN0302.Geodetic Reference System of 1980 (GRS 80) ellipsoid at 45
HN0302.degrees latitude (g = 980.6199 gals.).
HN0302
HN0302.The modeled gravity was interpolated from observed gravity values.
HN0302
HN0302;                    North         East    Units  Estimated Accuracy
HN0302;SPC UT S     - 3,087,240.      571,250.      MT  (+/- 180 meters Scaled)
HN0302
HN0302                         SUPERSEDED SURVEY CONTROL
HN0302
HN0302  NGVD 29 (??/??/92) 1194.587  (m)         3919.24   (f) ADJ UNCH    1 2
HN0302
HN0302.Superseded values are not recommended for survey control.
HN0302.NGS no longer adjusts projects to the NAD 27 or NGVD 29 datums.
HN0302.See file dsdata.txt to determine how the superseded data were derived.
HN0302
HN0302_U.S. NATIONAL GRID SPATIAL ADDRESS: 12SWG270448(NAD 83)
HN0302_MARKER: DB = BENCH MARK DISK
HN0302_SETTING: 66 = SET IN ROCK OUTCROP
HN0302_STAMPING: U 148 1962
HN0302_STABILITY: A = MOST RELIABLE AND EXPECTED TO HOLD
HN0302+STABILITY: POSITION/ELEVATION WELL
HN0302
HN0302  HISTORY     - Date     Condition        Report By
HN0302  HISTORY     - 1962     MONUMENTED       CGS
HN0302  HISTORY     - 1973     GOOD             NPS
HN0302  HISTORY     - 1973     GOOD             NPS
HN0302
HN0302                         STATION DESCRIPTION
HN0302
HN0302'DESCRIBED BY COAST AND GEODETIC SURVEY 1962
HN0302'62.55 MI SW FROM FRY CANYON.
HN0302'12.5 MILES SOUTHEAST ALONG UTAH HIGHWAY 95 FROM THE POST OFFICE AT FRY
HN0302'CANYON.  THENCE 19.5 MILES SOUTHWEST ALONG A GRADED DIRT ROAD. THENCE
HN0302'15.0 MILES WEST ALONG A GRADED DIRT ROAD THAT LEADS THROUGH CLAY HILLS
HN0302'DIVIDE.  THENCE 15.55 MILES NORTHWEST ALONG A BULLDOZED ROAD LEADING
HN0302'TO HALLS CROSSING ON THE COLORADO RIVER, 23.05 MILES WEST OF GREEN
HN0302'WATER SPRING, 129 FEET SOUTH-SOUTHWEST OF A CURVE IN THE ROAD, 71.0
HN0302'FEET WEST-SOUTHWEST OF A METAL WITNESS POST, ABOUT 3 FEET ABOVE THE
HN0302'LEVEL OF THE ROAD, AND SET IN THE TOP AND CENTER OF A 30X75 FEET EGG
HN0302'SHAPED ROCK OUTCROP PROJECTING ABOUT 3 FEET ABOVE THE GROUND AT THE
HN0302'HIGHEST POINT.
HN0302
HN0302                         STATION RECOVERY (1973)
HN0302
HN0302'RECOVERY NOTE BY NATIONAL PARK SERVICE 1973
HN0302'RECOVERED IN GOOD CONDITION.
HN0302
HN0302                         STATION RECOVERY (1973)
HN0302
HN0302'RECOVERY NOTE BY NATIONAL PARK SERVICE 1973
HN0302'RECOVERED IN GOOD CONDITION.
```

APPENDIX D : FPI GPS BASE STATION FIELD LOGS

Project No. & Name: *6088.008 Lidar-Grand Canyon*
Client Name: *USGS*
Location: *Page, Arizona*

GROUND CONTROL
BASE STATION LOG

SITE INFORMATION Site ID: LES1 Site Name: Lees Ferry

Site Type: ☒ Horiz Cntrl ☒ Vert Cntrl ☒ New ☐ Reoccupation

Receiver Type: Z-Max S/N: 200339011 Antenna Type: Z-Max S/N: 200342038

ANTENNA HEIGHT PARAMETERS Phase Offset Included? ☒ Yes ☐ No

Mean Antenna Height-Slant Start	Mean Antenna Height-Slant End	Ant. Radius	Vert. Offset	Ant. Measuring Point Sketch
1.730 m	1.7307 m	Plate 0.09 m	0.774 m	0.774; Plate; 1.730; Mark
in	in	in	in	

OBSERVATIONS Date: 26-Nov-04 Observer: J. Martinez

	Time	Memory	Recording	SV #	PDOP	Record Interval
Start:	1900	33 (% Used)	☒ Yes ☐ No	9	2.3	1 secs
End:	2055	35 (% Used)	☒ Yes ☐ No	8	2.2	

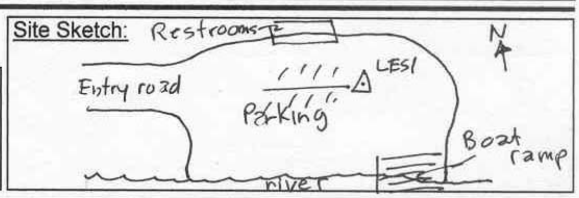
ALERTS
Ant. Ht 1.727
+0.774
2.501 m

OK.
Office Checked By: ________

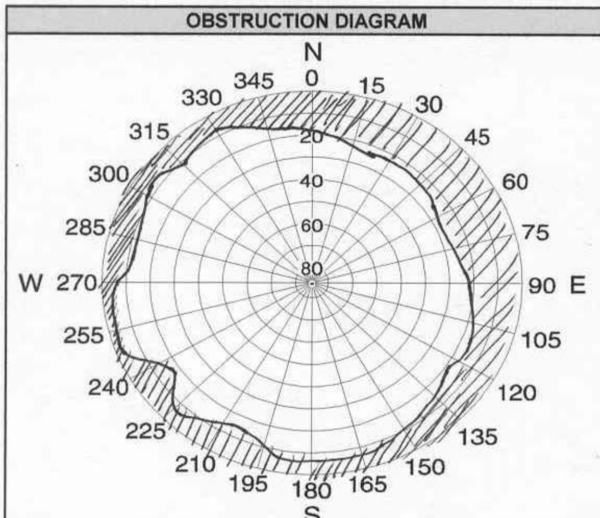
SITE SKETCH & NOTES

Start Antenna Height	End Antenna Height
1. 1.730	1. 1.731
2. 1.730	2. 1.731
3. 1.730	3. 1.730

Site Sketch:



OBSTRUCTION DIAGRAM



MONUMENT RUBBING / DESCRIPTION

Black paint cross on flat boulder located in the parking lot of the boat launching ramp in Lees Ferry.

Project No. & Name: *6088.008 Lidar-Grand Canyon*
Client Name: *USGS*
Location: *Page, Arizona*

GROUND CONTROL BASE STATION LOG

SITE INFORMATION Site ID: LES1 Site Name: Lees Ferry

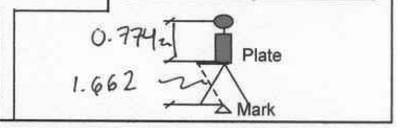
Site Type: ☒ Horiz Cntrl ☒ Vert Cntrl ☒ New ☐ Reoccupation

Receiver Type: Z-Max S/N: 200339011 Antenna Type: Z-Max S/N: 200342038

ANTENNA HEIGHT PARAMETERS Phase Offset Included? ☒ Yes ☐ No

Mean Antenna Height-Slant		Ant. Radius	Vert. Offset
Start	End	Plate	
1.6623 m	1.6665 m	0.09 m	0.774 m
65 7/16 in	in	in	in

Ant. Measuring Point Sketch



OBSERVATIONS Date: 27 Nov 04 Observer: J. Martinez

	Time	Memory	Recording	SV #	PDOP	Record Interval
Start:	1844	17 (% Used)	☒ Yes ☐ No	8	2.0	1 secs
End:	2103	20 (% Used)	☒ Yes ☐ No	8	2.5	

ALERTS Antenna might have shifted. or error measurement. Will use initial measurement

1.659
+0.774
2.433 m

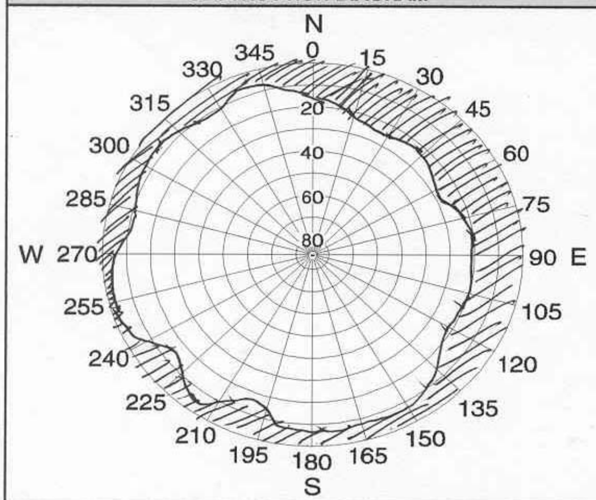
Office Checked By: OK

SITE SKETCH & NOTES

Start Antenna Height		End Antenna Height
1. 1.662	65 7/16"	1. 1.666
2. 1.663		2. 1.6665
3. 1.662		3. 1.667

Site Sketch:

OBSTRUCTION DIAGRAM



MONUMENT RUBBING / DESCRIPTION

Black paint cross on Flat boulder located in the parking lot of the boat launching ramp in Lees Ferry.

Project No. & Name: *6088.008 Lidar-Grand Canyon*
Client Name: *USGS*
Location: *Page, Arizona*

GROUND CONTROL BASE STATION LOG

SITE INFORMATION Site ID: PAG1 Site Name: Marriott Hotel Page

Site Type: ☒ Horiz Cntrl ☒ Vert Cntrl ☒ New ☐ Reoccupation

Receiver Type: Z-Max S/N: 200348070 Antenna Type: Z-Max S/N:

ANTENNA HEIGHT PARAMETERS Phase Offset Included? ☒ Yes ☐ No

Mean Antenna Height-Slant Start	Mean Antenna Height-Slant End	Ant. Radius	Vert. Offset
1.604 m	1.6033 m	Plate 0.09 m	to L1 0.327 m
in	in	in	in

Ant. Measuring Point Sketch: 0.327 — Plate; 1.604 — Mark

OBSERVATIONS Date: 26Nov04 Observer: J. Martinez

	Time	Memory	Recording	SV #	PDOP	Record Interval
Start:	1711	10 (% Used)	☒ Yes ☐ No	5	3.7	1 secs
End:	2217	17 (% Used)	☒ Yes ☐ No	8	2.0	

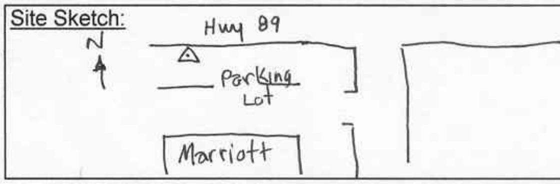
ALERTS
Ant Ht: 1.601
+ 0.327
1.928 m

OK
Office Checked By:

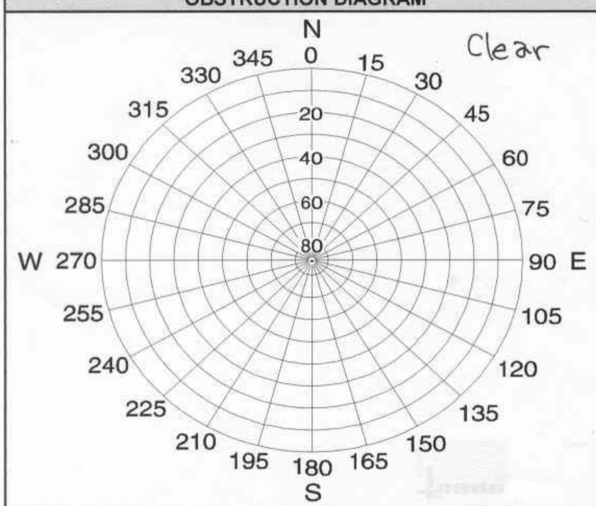
SITE SKETCH & NOTES

Start Antenna Height	End Antenna Height
1. 1.604	1. 1.603
2. 1.604	2. 1.604
3. 1.604	3. 1.603

Site Sketch:



OBSTRUCTION DIAGRAM



MONUMENT RUBBING / DESCRIPTION

PK nail and Flagging tape driven in tarmac surface in parking lot on the North side of it.

Project No. & Name: *6088.008 Lidar-Grand Canyon*
Client Name: *USGS*
Location: *Page, Arizona*

GROUND CONTROL BASE STATION LOG

SITE INFORMATION Site ID: PAG1 Site Name: Marriott Hote Page

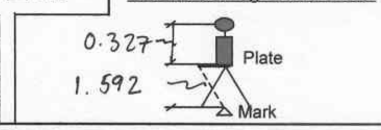
Site Type: ☒ Horiz Cntrl ☒ Vert Cntrl ☒ New ☐ Reoccupation

Receiver Type: Z-Max S/N: 200348070 Antenna Type: Z-Max S/N:

ANTENNA HEIGHT PARAMETERS Phase Offset Included? ☒ Yes ☐ No

Mean Antenna Height-Slant		Ant. Radius	Vert. Offset
Start	End	Plate	
1.5923 m	1.5924 m	0.09 m	0.327 m
in	in	in	in

Ant. Measuring Point Sketch



OBSERVATIONS Date: 27-Nov-04 Observer J.Martinez

	Time	Memory	Recording	SV#	PDOP	Record Interval
Start:	1707	7 (% Used)	☒ Yes ☐ No	8	1.9	1 secs
End:	0102 (28-Nov)	18 (% Used)	☒ Yes ☐ No	8	2.1	

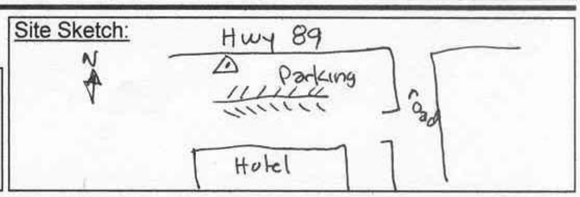
ALERTS Ant Ht. 1.589
+ 0.327
1.916 m

OK
Office Checked By:

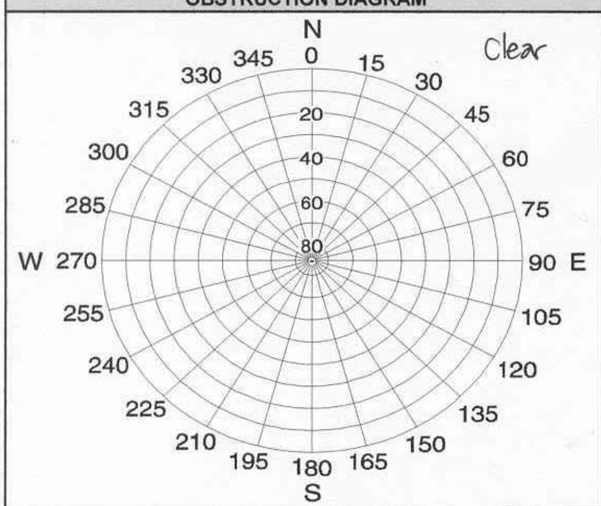
SITE SKETCH & NOTES

Start Antenna Height	End Antenna Height
1. 1.592	1. 1.592
2. 1.592	2. 1.5925
3. 1.593	3. 1.5926

Site Sketch:



OBSTRUCTION DIAGRAM



MONUMENT RUBBING / DESCRIPTION

PK nail and flagging tape driven in tarmac surface in the North side of parking lot

Project No. & Name: *6088.008 Lidar-Grand Canyon*
Client Name: *USGS*
Location: *Page, Arizona*

GROUND CONTROL BASE STATION LOG

SITE INFORMATION Site ID: PAG1 Site Name: Marriott Hotel Page

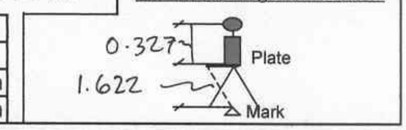
Site Type: ☒ Horiz Cntrl ☒ Vert Cntrl ☒ New ☐ Reoccupation

Receiver Type: Z-Max S/N: 200848070 Antenna Type: Z-Max S/N:

ANTENNA HEIGHT PARAMETERS Phase Offset Included? ☒ Yes ☐ No

Mean Antenna Height-Slant		Ant. Radius	Vert. Offset
Start	End	Plate	
1.6213 m	1.622 m	0.09 m	0.327 m
62 13/16 in	in	in	in

Ant. Measuring Point Sketch



OBSERVATIONS Date: 28 Nov 04 Observer: J. Martinez

	Time	Memory	Recording	SV #	PDOP	Record Interval
Start:	1515	19 (% Used)	☒ Yes ☐ No	8	1.8	1 secs
End:	1706	21 (% Used)	☒ Yes ☐ No	8	1.8	

ALERTS Ant Ht 1.619 + 0.327 = 1.946 m

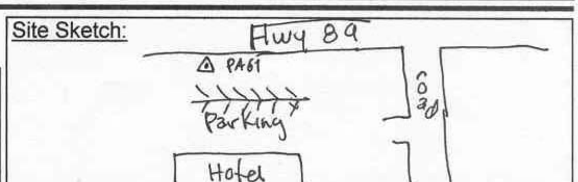
OK

Office Checked By:

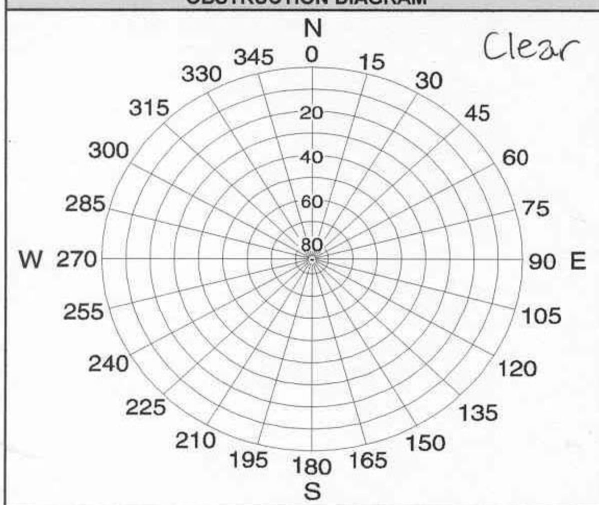
SITE SKETCH & NOTES

Start Antenna Height		End Antenna Height
1. 1.621	62 13/16"	1. 1.622
2. 1.621		2. 1.622
3. 1.622		3. 1.622

Site Sketch:



OBSTRUCTION DIAGRAM



MONUMENT RUBBING / DESCRIPTION

PK nail and Flagging tape on tarmac surface.

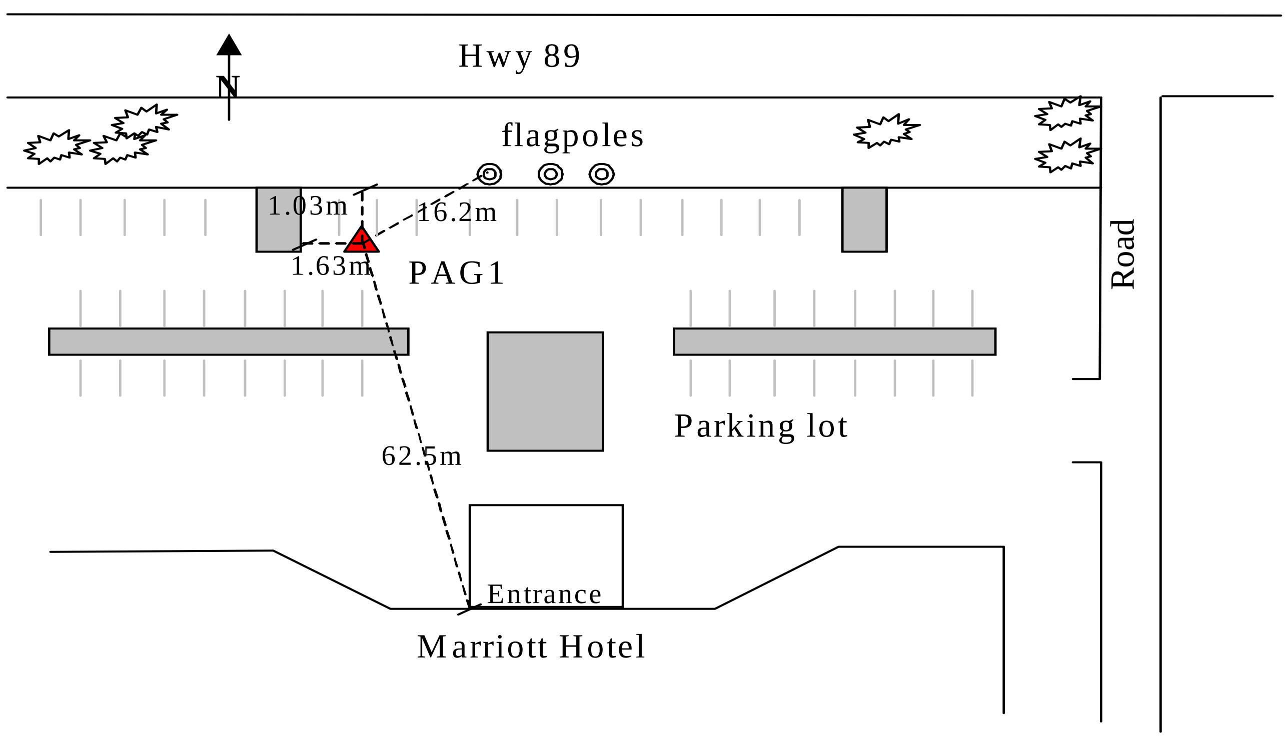
APPENDIX E : STATION DESCRIPTIONS (LES1 & PAG1)

COUNTRY	AREA/REGION	STATION NAME
USA	Page, AZ	PAG1

National System	N/a	**Station No in System (if any)**	N/a

	Co-ordinates System 1	Co-ordinates System 2	Datum Shift System 1 to System 2
Spheroid	GRS80	ITRF2000	
Datum	NAD83 2002.0	ITRF2000	
Latitude	36 55 31.47067 N		
Longitude	111 28 07.88500 W		
Spheroid Ht.	1212.061		
Easting	458242.107		Scale Factor System 1
Northing	4086700.394		
Elevation	1235.516		
Elev. Datum	NAVD88 (orthom)		
Projection	UTM Z12N m		
False Easting	500000 m		Scale Factor System 2
False Northing	0 m		
C. Meridian	111 00 W		
Date of Survey	26-28/Nov/04	**Lastest revision**	22/Feb/05
Source of Data		Adjusted static GPS data	
Description of Station Mark		PK nail driven in paved surface	

Site Plan with Witness Marks:

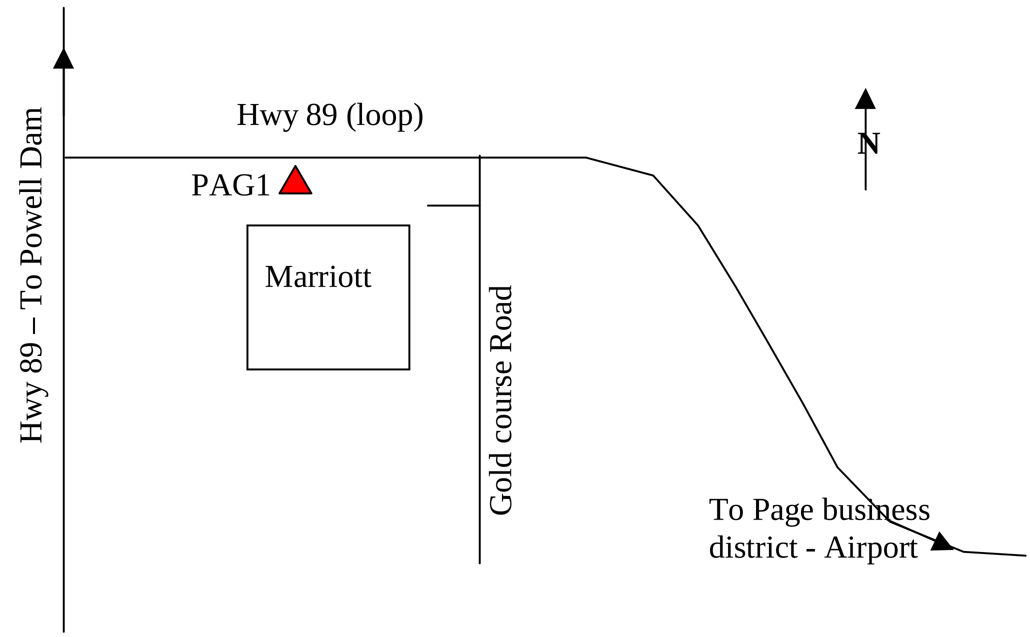


STATION NAME	PAG1

LOGISTIC INFORMATION			
Main Supply	Page	**How Far?** 5 min	**What Supply?** Everything
Diesel Fuel/Petrol	Yes	**Where From?**	Page
Water (potable)	Yes	**If No-Where?**	--
Watchmen	Yes	**Security Problems?**	Hotel parking lot
Local Contact	N/a		
Seasonal Status Local Roads	Good year-round		
Travel Time to Accom	Right there	**Nearest Accom**	Courtyard Marriott
Mast Required?	No	**If Yes, How High?**	N/a
Official Docs req'd	No		
4WD Vehicle	No	**Vehicles From?**	Airport rentals
Site Owner/Tenant	Courtyard Marriott		
Other Information			
Compiled By	J.Martinez	**Date**	26/Nov/04

STATION NAME	PAG1	NATIONAL SYSTEM MAP SHEET REF	N/a

ACCESS MAP:



DESCRIPTION OF ACCESS:

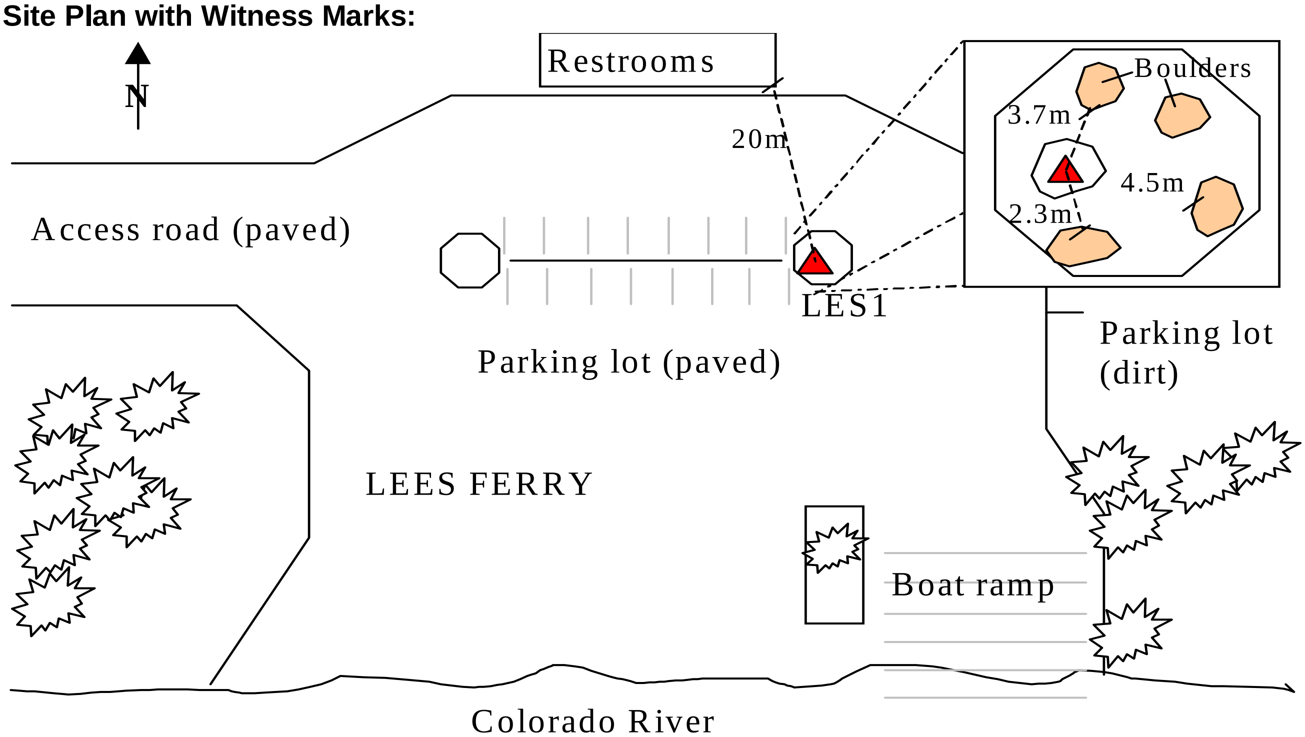
To reach the station mark is located in the parking lot of the Courtyard Marriott Hotel in Page, AZ close to the North intersection of Hwy 89 and Hwy 89 business loop. The mark is located on the North side of the hotel parking lot, 62.5m North from the Hotel's main entrance; 16.2m West from the westerly flagpole; and 1.03m South and 1.63m East from concrete curbing.

SURVEY STATION DESCRIPTION

COUNTRY	AREA/REGION	STATION NAME
USA	Page, AZ	LES1
National System N/a	**Station No in System (if any)** N/a	

	Co-ordinates System 1	**Co-ordinates System 2**	**Datum Shift System 1 to System 2**
Spheroid	GRS80	ITRF2000	
Datum	NAD83 2002.0	ITRF2000	
Latitude	36 51 58.81624 N		
Longitude	111 35 13.05479 W		
Spheroid Ht.	933.286 m		
Easting	447683.106 m		Scale Factor System 1
Northing	4080205.736 m		
Elevation	956.651 m		
Elev. Datum	NAVD88		
Projection	UTM Z-12N		
False Easting	500000 m		Scale Factor System 2
False Northing	0 m		
C. Meridian	111 00 W		
Date of Survey	26-27/Nov/04	**Lastest revision**	22/Feb/04
Source of Data		Adjusted static GPS data	
Description of Station Mark		Painted black cross on flat boulder	

Site Plan with Witness Marks:

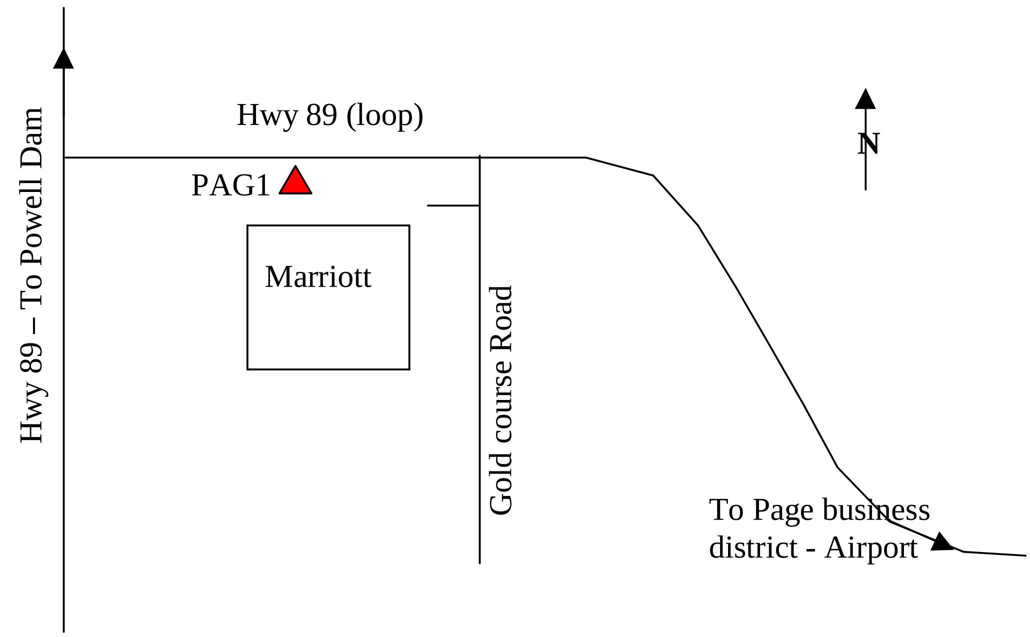


STATION NAME	LES1		

LOGISTIC INFORMATION			
Main Supply	Page	**How Far?** 40 min	**What Supply?** Everything
Diesel Fuel/Petrol	Yes	**Where From?**	Page
Water (potable)	Yes	**If No-Where?**	--
Watchmen	Yes	**Security Problems?**	Public area
Local Contact	N/a		
Seasonal Status Local Roads	Good year-round		
Travel Time to Accom	40 min	**Nearest Accom**	Courtyard Marriott
Mast Required?	No	**If Yes, How High?**	N/a
Official Docs req'd	No		
4WD Vehicle	No	**Vehicles From?**	Airport rentals
Site Owner/Tenant	Parks and Recreation		
Other Information			
Compiled By	J.Martinez	**Date**	29/Nov/04

STATION NAME	LES1	NATIONAL SYSTEM MAP SHEET REF	N/a

ACCESS MAP:



DESCRIPTION OF ACCESS:

To reach the station mark from Page, AZ, get down on Hwy 89 South 22 miles to the intersection with Hwy 89 Alt. Turn right (North) and continue for 14 miles upon the Marble Canyon bridge. After crossing to the West side of the bridge follow signs to enter the Glen Canyon National Rec. Continue for 5 miles upo the end of the road at Lees Ferry. The mark is located in the parking area of the boat ramp at Lees Ferry on a flat boulder 20 m South of the restrooms building. The flat boulder is surrounded by four other boulders; one is 3.7m North; other is 4.5 m SE and another 2.3m South. The marking is a painted black cross.

APPENDIX F : HELICOPTER SPECIFICATIONS

HEICOPTER	BELL LONGRANGER
Official Number	N1085T
Owner	Aspen Helicopters
Blade Span	37 ft 0 in
Fuselage Length	32 ft 2 in
Gross Weight	4,150 lbs
Typical Empty Weight	2500 lbs
Survey Mode Duration	~2.5 hours
Engine	RR250-C30P Jet Turbo Shaft

APPENDIX G : SHOALS-1000T EQUIPMENT SPECIFICATIONS

SHOALS Specifications

Hydrographic Mode

Guidelines only. Actual specifications depend on SHOALS product and operating environment.
All specifications subject to change without notice.

Measurement rate	1000 Hz
Operating altitude	200-400 m
Depth measurement accuracy	IHO Order 1 (25 cm, 1 σ)
Depth penetration	0.1-50 m
Maximum depth	kD = 3.0
Scan angle	20° forward arc
Sounding density	2x2, 3x3, 4x4, 5x5 m
Swath width	Variable, up to 0.58 x altitude
Scan frequency	Variable, depends on scan pattern
Horizontal accuracy	IHO Order 1 (2.5 m, 1 σ)
Laser classification	Class IV laser product (US FDA CFR 21)
Eyesafe altitude	150 m
Power requirements	100 A @ 28 VDC
Operating temperature	5-40° C
Aircraft speed	125-175 knots

Topographic Mode

Measurement rate	1000 Hz
Operating altitude	300-700 m
Horizontal accuracy	DGPS - 2.5 m, 1 σ; KGPS - 1/200 x altitude
Vertical accuracy	25 cm, 1 σ

Equipment

Sensor dimensions	50 x 50 x 60 cm
Sensor weight	65 kg
Control rack dimensions	60 x 60 x 70 cm each
Control rack weight	65 kg each

POS AV™

position & orientation system **airborne vehicles**

Aided Intertial Solutions for Airborne Applications

POS AV is a fully integrated position and orientation system designed specifically for airborne applications. The system integrates precision GPS with inertial technology to provide real-time and post-processed (POSPac) measurements of the position, roll, pitch and heading of airborne sensors. Engineered for use with aerial cameras, scanning lasers, imaging scanners and synthetic aperture radar (SAR) – POS AV enables the rapid creation of digital terrain models (DTMs), orthophotos and digital maps.

A Revolution in Airborne Surveying and Mapping

Over the last few years there has been a large increase in the number of digital sensors used for airborne data collection. Scanning lasers and line scanners, for example, are now widely used for aerial surveying and mapping. POS AV has been the enabling technology behind this growth, because it allows you to do what was never before possible: quickly and accurately motion compensate and geocode airborne sensor data. With POS AV, data can be geometrically corrected and then geographically encoded and mosaicked to produce precise DTMs and orthophotos.

POS AV Increases Your Productivity

By directly measuring the sensor's position and attitude with high accuracy and at high data rates, POS AV greatly reduces the need for labour-intensive ground control and elaborate post-processing. This allows you to carry out aerial surveys quickly and cost-effectively, with turnaround times as short as 24 hours for:

- mapping of uniformly textured areas (water, deserts, forests)
- stripline mapping
- spot mapping
- coastal surveying (highway, pipeline and powerline)
- flood plain mapping

Image courtesy of Northwest Geomatics

POS AV is...

Accurate with high-bandwidth

- 0.005 pitch/roll, 0.008 heading (POS AV 510 – post-processed)
- 5-10 cm sensor positioning (post-processed)
- 200 Hz data rates
- Real-time data with < 3 msec latency
- Precise time-alignment of POS data with airborne sensor

Modular

- Compact, lightweight IMU (Inertial Measurement Unit) mounts easily on any airborne sensor
- Powerful PCS (POS Computer System) contains:
  - the core POS processor
  - PC drive
  - removable PC-card disk
  - embedded, low-noise, dual-frequency GPS receiver

Flexible

- Real-time and post-processed operation
- Data logging via Ethernet and/or removable PC-card disk for post-processing on PC laptop
- Multiple, reconfigurable interfaces for:
  - differential GPS
  - time alignment of airborne sensors
  - flight management systems
  - stabilized platforms

Convenient

- System can be installed in only a few hours
- In-air alignment capability
- Menu-driven controller and display software run under Windows on your PC laptop
- Autonomous, stand-alone operation

Reliable

- Rugged PC-based computer designed specifically for airborne applications
- Fully shock-and vibration-tested
- Temperature-and altitude-tested

Fully Supported

- Full installation, training and customer support by highly qualified field specialists
- Developed by a solid company with years of experience in aided inertial technology for airborne applications

direct georeferencing of aerial sensors

POS AV Models with POSPac™

Applanix has developed four POS AV models that provide accuracy levels suitable for the full range of airborne sensors. Each model is sold with our post-processing software POSPac, which optimally blends integer carrier-phase GPS data with inertial data, significantly increasing your productivity.

POS AV™ 210:

Roll/pitch: 0.04° RMS/ 2 arcmin RMS (post-processed)
Heading: 0.08° RMS/ 5 arcmin RMS (post-processed)
Sensor position: 5-10cm RMS

POS AV™ 310:

Roll/pitch: 0.013° RMS/ 50 arcsec RMS (post-processed)
Heading: 0.035° RMS/ 2 arcmin RMS (post-processed)
Sensor position: 5-10 cm RMS

POS AV™ 410:

Roll/pitch: 0.008° RMS/ 30 arcsec RMS (post-processed)
Heading: 0.015° RMS/ 1 arcmin RMS (post-processed)
Sensor position: 5-10 cm RMS

POS AV™ 510:

Roll/pitch: 0.005° RMS/ 20 arcsec RMS (post-processed)
Heading: 0.008° RMS/ 30 arcsec RMS (post-processed)
Sensor position: 5-10 cm RMS

DG Option (Direct Georeferencing) – POSEO™:

Each POS AV system can be used to automatically generate plotter-ready exterior orientation (EO) data for frame cameras simply by adding the software module POSEO to the post-processing software suite.

Inertial/GPS Integration

All POS systems blend linear acceleration and angular rate measurements provided by the inertial sensors, with position and velocity measurements of GPS to compute a highly accurate solution for all motion variables. POS retains the best capabilities of both inertial and GPS, with performance characteristics that are better than those of either GPS or inertial alone.

Using GPS data to calibrate inertial sensors on-line, POS maintains the dynamic fidelity of the inertial solution, yet removes any long-term, systematic drifts from the inertially derived position and orientation. The calibrated inertial solution allows POS to maintain accuracy while navigating through GPS outages.

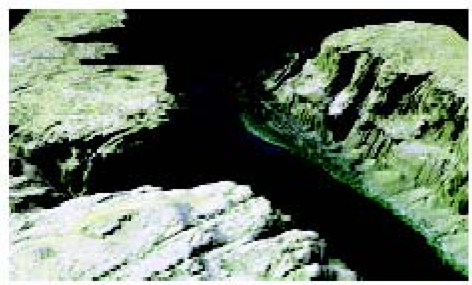


Image courtesy of EarthData

The image above (a colorized infrared orthophoto draped over a LIDAR Digital Elevation Model) was obtained using EarthData Technologies' LIDAR system and Applanix' POS AV at 2140m AMT. EarthData flew this LIDAR for the Grand Canyon Monitoring and Research Center.

POS AV System Inertial Measurement Unit (IMU), POS Computer System with embedded GPS reciever, and antenna

OmniSTAR® 3100LM DGPS Receiver Module

The Global Positioning System

The OmniSTAR 3100LM combines the reception of high performance differential corrections with a compact, light weight and robust design, ideally suited for backpack or On-the-Belt applications.

The OmniSTAR 3100LM is a fully functional differential corrections receiver, designed to be used with an external (handheld) GPS receiver. Its design is based on proven OmniSTAR OEM technology, currently utilised in many OmniSTAR compatible applications.

Features

- Compact, light weight portable receiver
- Robust design with high quality components
- Minimal power requirements
- Real time status indicators
- Output RTCM 104
- Remote access facility (via satellite link)
- Compatible with most common antenna systems
- Internal antenna splitter
- Designed for portable use; all connectors and indicators located on one side of the receiver
- Free 24 hour technical support
- Quality control statistics available to the user

OmniSTAR DGPS services

OmniSTAR transmits differential GPS data world wide using a global network of reference stations to measure errors in the GPS system and generate corrections

This reference data is gathered at a network control centre where it is checked for integrity and reliability and is up-linked to a series of geo-stationary satellites, which distribute the data around the world. The OmniSTAR service is available by subscription.

VBS - Virtual Base Station

OmniSTAR's Virtual Base Station (VBS) Service is a unique world-wide high precision service with sub-meter accuracy throughout the coverage area (subject to the quality of the GPS receiver used).
The high level of accuracy is made possible by processing all available reference data into a set of corrections, optimised for the users actual location. This provides the end-user with a consistent and high accuracy over a large area.

The features of OmniSTAR's differential corrections service

- OmniSTAR differential corrections are highly reliable (not dependent on any single reference station)
- No position jumps due to switching from one reference station to another
- All reference stations have dual data connections to their network control centre
- Multiple up-links are used (primary and backup)
- The European continent is covered by several satellite services

OmniSTAR Global Coverage

OmniSTAR corrections can be utilised around the world.

We operate a world-wide network of reference stations, controlled by two Network Control Centres. These Network Control Centres also provide free of charge, 24 hour technical support to OmniSTAR users, should they require it.

OmniSTAR Applications

- Airborne geophysics
- Mapping & boundary marking
- Precision farming
- Aerial farming applications
- Search & rescue guidance
- Vehicle location & positioning
- Navigation
- Environmental monitoring
- GIS data acquisition
- Defence application
- Asset management
- Aviation photogrammetry
- Surveying

MBX-3

2 Channel Automatic Differential Beacon Receiver

Standalone Radiobeacon Receiver

FEATURES

- Dual independent channels for superior automatic beacon tracking
- State-of-the-art digital architecture enhances beacon reception
- Fast acquisition times ensure you are up and running quickly
- 2-line by 16-character LCD display provides more information simultaneously
- Global beacon table listing gives you quick access to beacons by name
- Low power consumption gives extended battery life for portable applications
- Automatic and manual tune modes provide operational versatility
- Optional internal splitter and GPS signal output port for use with combination GPS/beacon antennas
- Firmware upgrades are easily loaded into the receiver through the serial port
- Wide selection of antennas available

Advanced Beacon Receiver Technology

The CSI MBX-3 beacon receiver employs CSI's third generation of digital receiver technology to receive free DGPS signals broadcast by the networks of 300 kHz radiobeacons deployed worldwide.

Using these signals, the MBX-3 beacon receiver outputs differential correction data in the industry standard RTCM SC-104 format accepted by differential-ready GPS receivers.

The advanced digital signal processing techniques of the MBX-3 allow for reliable extraction of DGPS data from the beacon broadcasts, even in noisy environments.

Ease of Operation

The MBX-3 incorporates a large 2-line by 16-character display and 3-switch keypad. The intuitive menu system provides access to receiver status information and operating parameters.

You may configure the MBX-3 beacon receiver for either automatic or manual tune operation using the convenient menu system. A new global beacon table within the receiver menu system allows selection of beacons by name.

Automatic Operation

In automatic mode, the two channels of the beacon receiver cooperatively construct and maintain a table of radiobeacons available in your area. The receiver's primary channel automatically locks to the station providing the highest quality signal. This ensures that the MBX-3 is always locked to the best beacon in the area.

Antennas

The MBX-3 receiver may use any of a variety of antennas offered by CSI. Options include an E-field Whip antenna, two varieties of H-field beacon Loop antennas, and a combination GPS/beacon antenna.

All CSI antennas incorporate band-pass filtering and integral preamplifiers. The MBX-3 receiver provides power to these active antennas.

H-field beacon Loop antennas do not require a counterpoise ground connection and are ideal for portable applications. They are also less susceptible than a conventional whip antenna to predominate E-field noise, including precipitation static.

Hassle-Free Upgrading

The MBX-3 supports firmware upgrades as improvements to firmware or changes to the global beacon table are made. These upgrades are easily loaded into the receiver through the serial port using a PC computer.

Configuration Software

CSI offers custom Windows 95® software for beacon receiver configuration, monitoring receiver performance, and decoding RTCM data. A terminal interface and data logging capability are also included.

Warranty

CSI is committed to supporting its products and offers a one-year warranty on parts and labor.

Contact us to discover why the MBX-3 is the right choice for your application.

MBX-3 – *2 Channel Automatic Differential Beacon Receiver*

Receiver Specifications

Channels:	2 independent channels
Frequency Range:	283.5 to 325.0 kHz
Channel Spacing:	500 Hz
MSK Bit Rates:	50, 100, and 200 bps
Cold Start Time:	< 1 minute
Warm Start Time:	< 2 seconds
Demodulation:	Minimum shift keying
Sensitivity:	2.5 µV/m for 10 dB SNR
Dynamic Range:	100 dB
Frequency Offset:	± 5 Hz
Adjacent Channel Rejection:	60 dB
Correction Output Protocol:	RTCM SC-104
Input/Status Protocol:	NMEA 0183

Communications

Interface Level:	RS-232C or RS-422
Baud Rates:	2400, 4800, 9600

Environmental Specifications

Operating Temperature:	-30°C to +70°C
Storage Temperature:	-40°C to +80°C
Humidity:	95% non-condensing
EMC:	EN 60945 EN 50081-1 EN 50082-1 FCC: Part 15, sub-part J, class A digital device

Power Specifications

Input Voltage:	9 - 40 VDC
Nominal Power:	2.5 W
Nominal Current:	210 mA
Antenna Voltage Output:	10 VDC (5 VDC optional)

Mechanical Specifications

Dimensions:	150 mm L x 125 mm W x 51 mm H (5.9" L x 4.9" W x 2.0" H)
Weight:	0.64 kg (1.4 lb)
Display:	2-line by 16-character LCD
Keypad:	3-key switch membrane
Power Connector:	2-pin circular locking
Data Connector:	DB9-S
Antenna Connector:	BNC-S
Optional GPS Output Port:	TNC-S

Operating Modes

MBX-3 Mode (Default):	RTCM SC-104 correction and NMEA status message output (Default Mode)
MBX-E Mode:	RTCM SC-104 correction and NMEA status message output and GPS NMEA message input for position and satellite status display.

NMEA 0183 I/O

- Receiver Automatic and Manual tune command
- Frequency and data rate query
- Receiver performance and operating status queries
- Automatic search almanac queries (proprietary)
- Baud rate selection command (proprietary)
- Receiver tune command
- Force cold start command (proprietary)
- Software upgrade command (proprietary)
- Configuration up-load command (proprietary)

Accessories

Antenna:	Various
Power Cables:	Various
Antenna Cables:	Various
Data Cables:	Various
CSI Beacon Command Center:	MS Windows 95® beacon control software

Pin-Out, RS-232C

DB9 Pin #	Description
2	TXD, RTCM SC-104 / status output
3	RXD, configuration input
5	Signal return

Pin-Out, RS-422

DB9 Pin #	Description
1	TXD +, RTCM SC-104 / status output
2	TXD -, RTCM SC-104 / status output
4	RXD -, configuration input
5	Signal return
7	RXD +, configuration input

CSI Authorized Dealer

Communication Systems International, Inc.
1200 – 58th Avenue S.E., Calgary, AB, Canada, T2H 2C9
Phone: (403) 259-3311 Fax: (403) 259-8866
Web: www.csi-dgps.com e-mail: info@csi-dgps.com

DT4000

1-CCD Camera
1600(H) x 1200(V) Pixels
Color or Monochrome

HIGH RESOLUTION DIGITAL CAMERA

High Resolution 1600 x 1200 Progressive Scan Digital Camera in RGB AccuColor and Monochrome Configurations

DuncanTech's *DT4000 Digital Camera* provides the crisp, clear images that only all-digital processing can provide. The camera uses the latest in advanced large-fomat progressive scan CCD sensors to maximize quantum efficiency and sensitivity. Both color and monochrome configurations are available. The 11.8 x 8.9 mm sensor has 3.5 times the sensing area of a 1/2" sensor and twice the sensing area of a 2/3" sensor delivering a significant increase in sensitivity. Interline transfer technology provides electronic shuttering.

In color configurations, the *DT4000* employs DuncanTech's proprietary *AccuColor* algorithm to deliver crisp, clear color images directly from the camera - no need for post-processing. *AccuColor* improves resolution and minimizes color aliasing, rivaling the image quality of many 3-CCD cameras.

The camera's advanced digital processing offers a number of features to maximize usability and image quality. Auto-exposure control and semi-automatic white-balance optimize performance. Digital Crosshairs simplify camera targeting. Multiple triggering modes provide accurate acquisition timing. Programmable control of image plane multiplexing enables display and output of the composite image, any single color plane, the raw pixel data, or any combination of these.

A Camera Link data interface supports the latest generation of digital framegrabbers. LVDS and RS-422 parallel options are also available. The *DirectView* analog video option adds the capability to simultaneously preview or record the image in NTSC, PAL, or progressive scan RGB format at resolutions up to 1280x1024.

FEATURES

- 1600(H) x 1200(V) CCD imaging sensor (11.8 mm x 8.9 mm)
- Available in RGB color or monochrome
- Frame rate of 10 fps
- *AccuColor* in-camera, real-time color interpolation
- 7.4 micron square pixels for accurate image metrics
- Display composite RGB or individual color plane images as monochrome images
- Digital Image Output - Camera Link, LVDS, or RS-422
- Auto-exposure control and semi-auto white balance for ease of use
- External trigger input with three operating modes
- Digital cross-hairs for easy camera targeting
- Analog gain control for each color maximizes dynamic range
- Digital gain and exposure control
- RS-232 interface for configuration and control
- Compact, rugged package
- Uses standard Nikon Bayonet Mount and High Resolution Graphics Lens
- Optional *DirectView* video preview with built-in zoom

DuncanTech
A SPECTRUM OF SOLUTIONS

4000-1-12/17/01

SPECIFICATIONS: DT4000

Image Device:	1 - Inch Interline Transfer CCD
Picture Elements:	1600(H) x 1200(V)
Pixel Size:	7.4 x 7.4 micron
Pixel clock rate:	22 MHz max
Sensing Area:	11.8 x 8.9 mm
Frame Rate:	10 frames per second - Standard. 5 frames per second - Low Noise Mode
Digital Image Output:	8 bits x 4 taps or 10 bits x 3 taps, Camera Link, EIA-644 (LVDS) or RS422
Signal/Noise:	54 dB - Standard. 60 dB - Low Noise Mode.
Sensitivity:	.5 lux - color; .2 lux - monochrome
Lens Mount:	C-Mount and Nikon Bayonet Mount
Electronic Shutter:	Range: 1/10,000 - 1/10 sec - Standard. 1/6,000 - 1/5 sec - Low Noise Mode.
Gain Selection:	Range: 0-36 dB. Controlled via RS-232 input.
External Trigger Input	Edge or level, Three modes
External Trigger Source:	BNC or Frame Grabber. (Optical isolator on BNC)
Exposure Control:	Manual or Automatic
White-Balance:	Manual or Semi-Automatic
Noise Reduction:	Correlated Double Sampling
Usability Features:	Digital Crosshairs, Color-Plane Multiplexing
Operating Temperature:	0-50 C
Operating Voltage:	12 VDC
Power Consumption:	10 Watts
Weight:	.98 kg
Programmable Functions:	Gain, integration time, multiplexing, trigger modes, custom processing.
Options:	
DirectView Video Output:	NTSC,PAL, S-video and Progressive Scan RGB (1280x1024 max display resolution). Gamma correction. 2x and 4x digital zoom.

APPLICATIONS

The fine resolution and crisp colors of the DT4000 make it the ideal imaging tool for a number of applications. AccuColor real-time color interpolation delivers crisp 24 or 30 bit RGB images directly from the camera. Automatic features for exposure control and white balance provide ease of use. DirectView analog option adds video preview. CameraLink interface supports the latest in acquisition technology.

- General Purpose Imaging
- Graphics Imaging for Press and Web Graphics
- Medical/Scientific Imaging
- Industrial Vision Applications for Semiconductor Inspection, Color Inspection
- Microscopy
- Metrology

DuncanTech
A SPECTRUM OF SOLUTIONS

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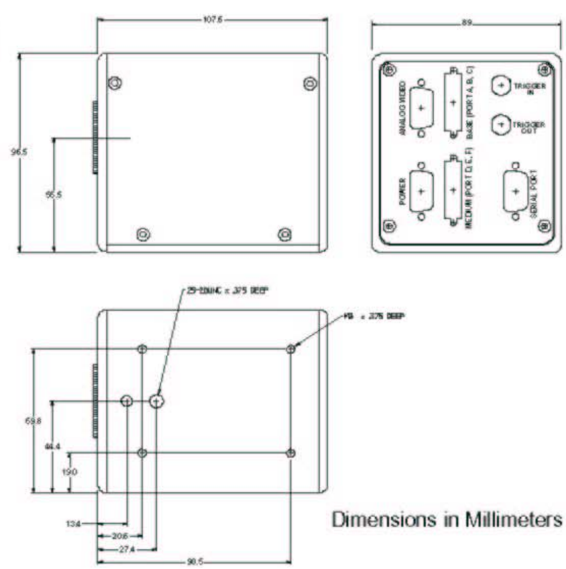
Web: www.duncantech.com

DIMENSIONS



Dimensions in Millimeters

APPENDIX H : STATIC GPS NETWORK PROCESSING

Static GPS Survey Overview

GNSS Studio, Copyright (C) 2004 by Thales Navigation, 2/7/2005 7:18:08 PM
www.thalesnavigation.com

Project Name : GrandCanyon
Spatial Reference System : NAD 83 Geographic
Time Zone : (GMT) Greenwich Mean Time : Dublin, Edinburgh, Lisbon, London
Linear Units : Meters

Control Points

Name		Components	95% Error	Status	Control Error
LFRG	X	111° 36' 04.00607"W	0.000	FIXED	
	Y	36° 51' 40.44281"N	0.000	FIXED	
	Z	968.950	0.000	FIXED	
N141	X	110° 22' 33.79759"W	38.416	FIXED	
	Y	37° 18' 26.66190"N	38.416	FIXED	
	Z	1167.966	38.416	FIXED	
U148	X	110° 42' 40.46805"W	38.416	FIXED	
	Y	37° 27' 11.86283"N	38.416	FIXED	
	Z	1173.065	38.416	FIXED	

Logged Points

Name		Components	95% Error	Status
LES1	X	111° 35' 13.05479"W	0.002	Adjusted
	Y	36° 51' 58.81624"N	0.002	Adjusted
	Z	933.286	0.002	Adjusted
PAG1	X	111° 28' 07.88500"W	0.012	Adjusted
	Y	36° 55' 31.47067"N	0.012	Adjusted
	Z	1212.061	0.014	Adjusted

Files

Name	Start Time	Sampling	Epochs	Size (Kb)	Type
BPAG1B04.331	04/11/26 17:12	1	18331	16403	L1/L2 GPS
BLFRGA04.331	04/11/26 14:07	1	26120	22227	L1/L2 GPS
BU148A04.331	04/11/26 19:07	1	16980	15028	L1/L2 GPS
BPAG1A04.332	04/11/27 17:07	1	28466	25986	L1/L2 GPS
BU148A04.332	04/11/27 15:28	1	24655	21520	L1/L2 GPS
BN141A04.332	04/11/27 15:58	1	21545	19046	L1/L2 GPS
BLES1A04.331	04/11/26 19:00	1	6881	5895	L1/L2 GPS
BLES1A04.332	04/11/27 18:44	1	8383	7158	L1/L2 GPS

Observations

Site	Antenna Type	Antenna Height	Height Type	Receiver Type	Start Time	File Name
PAG1	ZMax GPS	1.928	True	Z-MAX	04/11/26 17:12:09	BPAG1B04.331
LFRG	701975-01 +GP	1.500	Vertical	UZ-12	04/11/26 14:07:31	BLFRGA04.331
U148	701975-01 +GP	1.374	Vertical	UZ-12	04/11/26 19:07:31	BU148A04.331
PAG1	ZMax GPS	1.917	True	Z-MAX	04/11/27 17:07:34	BPAG1A04.332
U148	701975-01 +GP	1.348	Vertical	UZ-12	04/11/27 15:28:01	BU148A04.332
N141	701975-01 +GP	1.358	Vertical	UZ-12	04/11/27 15:58:31	BN141A04.332
LES1	ZMax GPS UHF	2.502	True	Z-MAX	04/11/26 19:00:24	BLES1A04.331
LES1	ZMax GPS UHF	2.435	True	Z-MAX	04/11/27 18:44:07	BLES1A04.332

Processes

Reference	Reference File	Rover	Rover File	Mode	Num
U148	BU148A04.332	LES1	BLES1A04.332	Static	1
U148	BU148A04.332	N141	BN141A04.332	Static	2
U148	BU148A04.332	PAG1	BPAG1A04.332	Static	3
U148	BU148A04.331	PAG1	BPAG1B04.331	Static	4
U148	BU148A04.331	LES1	BLES1A04.331	Static	5
LFRG	BLFRGA04.331	U148	BU148A04.331	Static	6
LFRG	BLFRGA04.331	LES1	BLES1A04.331	Static	7
LFRG	BLFRGA04.331	PAG1	BPAG1B04.331	Static	8
N141	BN141A04.332	PAG1	BPAG1A04.332	Static	9
N141	BN141A04.332	LES1	BLES1A04.332	Static	10
PAG1	BPAG1A04.332	LES1	BLES1A04.332	Static	11
PAG1	BPAG1B04.331	LES1	BLES1A04.331	Static	12

Processed vectors

Vector Identifier	Vector Length	95% Error		Vector Components	95% Error	SV	PDOP	QA	Solution
PAG1 - LES1	12406.339	0.060	X	-11156.749	0.024	9	1.9	**No**	Fixed
04/11/26 19:00			Y	409.220	0.024				
			Z	-5410.798	0.024				
PAG1 - LES1	12406.337	0.060	X	-11156.754	0.024	10	1.8	**No**	Fixed
04/11/27 18:44			Y	409.198	0.024				
			Z	-5410.786	0.024				
LFRG - PAG1	13777.450	0.067	X	12465.944	0.027	9	1.4	**No**	Fixed
04/11/26 17:12			Y	-531.269	0.027				
			Z	5842.615	0.027				
LFRG - LES1	1383.971	0.007	X	1309.206	0.003	9	1.9		Fixed
04/11/26 19:00			Y	-122.020	0.003				
			Z	431.818	0.003				
LFRG - U148	102804.728	0.498	X	87995.398	0.202	9	1.4	**No**	Fixed
04/11/26 19:07			Y	8333.275	0.202				
			Z	52499.319	0.202				
U148 - LES1	101474.190	0.492	X	-86686.179	0.199	10	1.7	**No**	Fixed
04/11/26 19:07			Y	-8455.291	0.200				
			Z	-52067.509	0.199				
U148 - PAG1	89219.520	0.432	X	-75529.427	0.175	6	2.1	**No**	Fixed
04/11/26 19:07			Y	-8864.521	0.175				
			Z	-46656.711	0.175				
U148 - PAG1	89219.565	0.432	X	-75529.479	0.175	8	1.9	**No**	Fixed
04/11/27 17:07			Y	-8864.563	0.175				
			Z	-46656.705	0.175				
U148 - N141	33820.861	0.164	X	24354.649	0.066	7	2.7	**No**	Fixed
04/11/27 15:58			Y	-19622.038	0.066				
			Z	-12871.570	0.066				
U148 - LES1	101474.200	0.491	X	-86686.175	0.199	10	1.8	**No**	Fixed
04/11/27 18:44			Y	-8455.304	0.199				
			Z	-52067.534	0.199				
N141 - LES1	118283.908	0.573	X	-111040.822	0.232	10	1.8	**No**	Fixed
04/11/27 18:44			Y	11166.736	0.232				
			Z	-39195.952	0.232				
N141 - PAG1	105990.692	0.513	X	-99884.319	0.208	9	1.4	**No**	Fixed
04/11/27 17:07			Y	10757.318	0.208				
			Z	-33785.052	0.208				

Repeat vectors

Repeat Vector			Difference	Length	QA
PAG1 - LES1		X	0.005	12406.339	**No**
	04/11/26 19:00	Y	0.022		
	04/11/27 18:44	Z	-0.013		
U148 - PAG1		X	0.052	89219.520	**No**
	04/11/26 19:07	Y	0.042		
	04/11/27 17:07	Z	-0.006		
U148 - LES1		X	-0.004	101474.190	**No**
	04/11/26 19:07	Y	0.013		
	04/11/27 18:44	Z	0.025		

Adjusted vectors

Vector Identifier	Vector Length	Length Resid.		Vector Components	Resid.	Tau Test	QA
PAG1 - LES1	12406.335	0.005	X	-11156.746	0.002		
04/11/26 19:00			Y	409.221	0.001		
			Z	-5410.793	0.005		
PAG1 - LES1	12406.335	0.025	X	-11156.746	0.007		
04/11/27 18:44			Y	409.221	0.023		
			Z	-5410.793	-0.008		
LFRG - PAG1	13777.456	0.029	X	12465.953	0.009		
04/11/26 17:12			Y	-531.241	0.028		
			Z	5842.612	-0.003		
LFRG - LES1	1383.971	0.000	X	1309.206	-0.000		
04/11/26 19:00			Y	-122.020	-0.000		
			Z	431.818	0.000		
LFRG - U148	102804.748	0.046	X	87995.422	0.024		
04/11/26 19:07			Y	8333.314	0.039		
			Z	52499.312	-0.007		
U148 - LES1	101474.217	0.058	X	-86686.216	-0.037		
04/11/26 19:07			Y	-8455.334	-0.043		
			Z	-52067.494	0.015		
U148 - PAG1	89219.554	0.056	X	-75529.469	-0.043		
04/11/26 19:07			Y	-8864.555	-0.034		
			Z	-46656.701	0.010		
U148 - PAG1	89219.554	0.013	X	-75529.469	0.009		
04/11/27 17:07			Y	-8864.555	0.007		
			Z	-46656.701	0.004		
U148 - N141	33820.864	0.014	X	24354.654	0.005		
04/11/27 15:58			Y	-19622.030	0.008		
			Z	-12871.581	-0.010		
U148 - LES1	101474.217	0.065	X	-86686.216	-0.041		
04/11/27 18:44			Y	-8455.334	-0.030		
			Z	-52067.494	0.040		
N141 - LES1	118283.936	0.074	X	-111040.870	-0.048		
04/11/27 18:44			Y	11166.696	-0.040		
			Z	-39195.913	0.039		
N141 - PAG1	105990.545	0.260	X	-99884.123	0.196		
04/11/27 17:07			Y	10757.475	0.157		
			Z	-33785.120	-0.068		

APPENDIX I : SHOALS CALIBRATION VALUES USED

SHOALS-1000T SYSTEM#3 November 17, 2004 – rev2

BELL LONGRANGER (N1085T):

DAVIS → Auto Process → Topo Parameters

BELL LONGRANGER (N1085T)

horiz_misalign_angle:	n/a
vert_misalign_angle:	n/a
pitch_offset	n/a
topo_elevation_bias_300:	n/a
topo_elevation_bias_700:	n/a

DAVIS → Utilities → LIDAR Parameters (Hardware - system_params_03.txt)

bathy_topo_bias_200:	- 0.21
bathy_topo_bias_300:	- 0.21
bathy_topo_bias_400:	- 0.21
deep_bias_left_200:	+ 0.050
deep_bias_left_300:	+ 0.070
deep_bias_left_400:	+ 0.090
deep_bias_right_200:	+ 0.040
deep_bias_right_300:	+ 0.060
deep_bias_right_400:	+ 0.080
apriori_depth_bias_shallow	- 0.28
apriori_depth_bias_deep	- 0.28
rcvr_horiz_misalign_angle:	- 0.125
rcvr_vert_misalign_angle:	+ 0.455
imu_sensor_pitch_offset:	- 0.353
scan_x_yaw_misalign_angle	- 0.180

For information only – do NOT change the following values for processing.

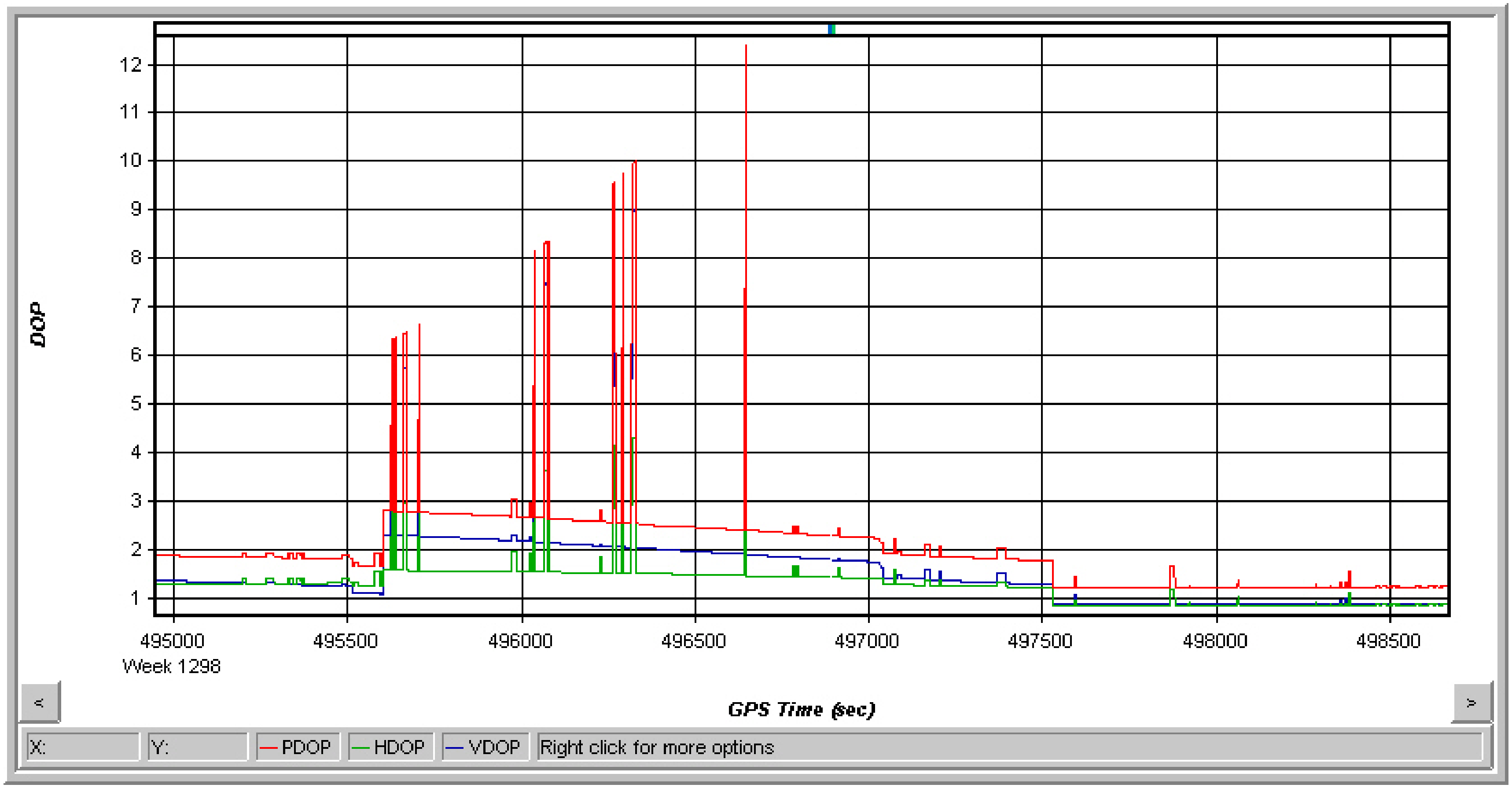
sensorref_antenna_lever_arm (x, y, z):	-2.164, 0.527, -1.059
imu_antenna_lever_arm (x, y, z):	-2.091, 0.297, -1.474

DAVIS → Utilities → Camera Parameters

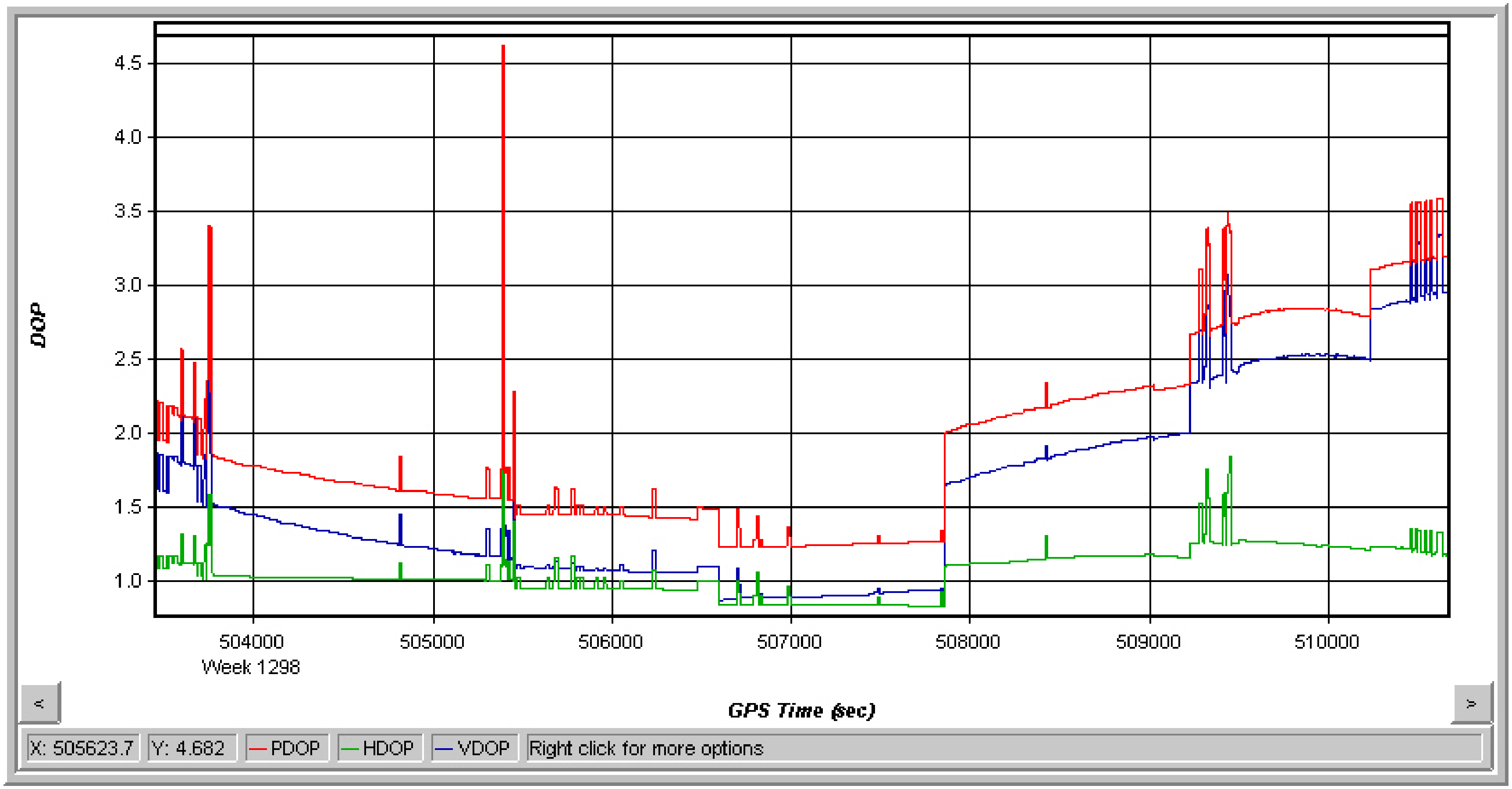
camera_boresight_roll:	+0.08
camera_boresight_pitch:	+10.77
camera_boresight_heading:	-0.80

APPENDIX J : PDOP GRAPHS

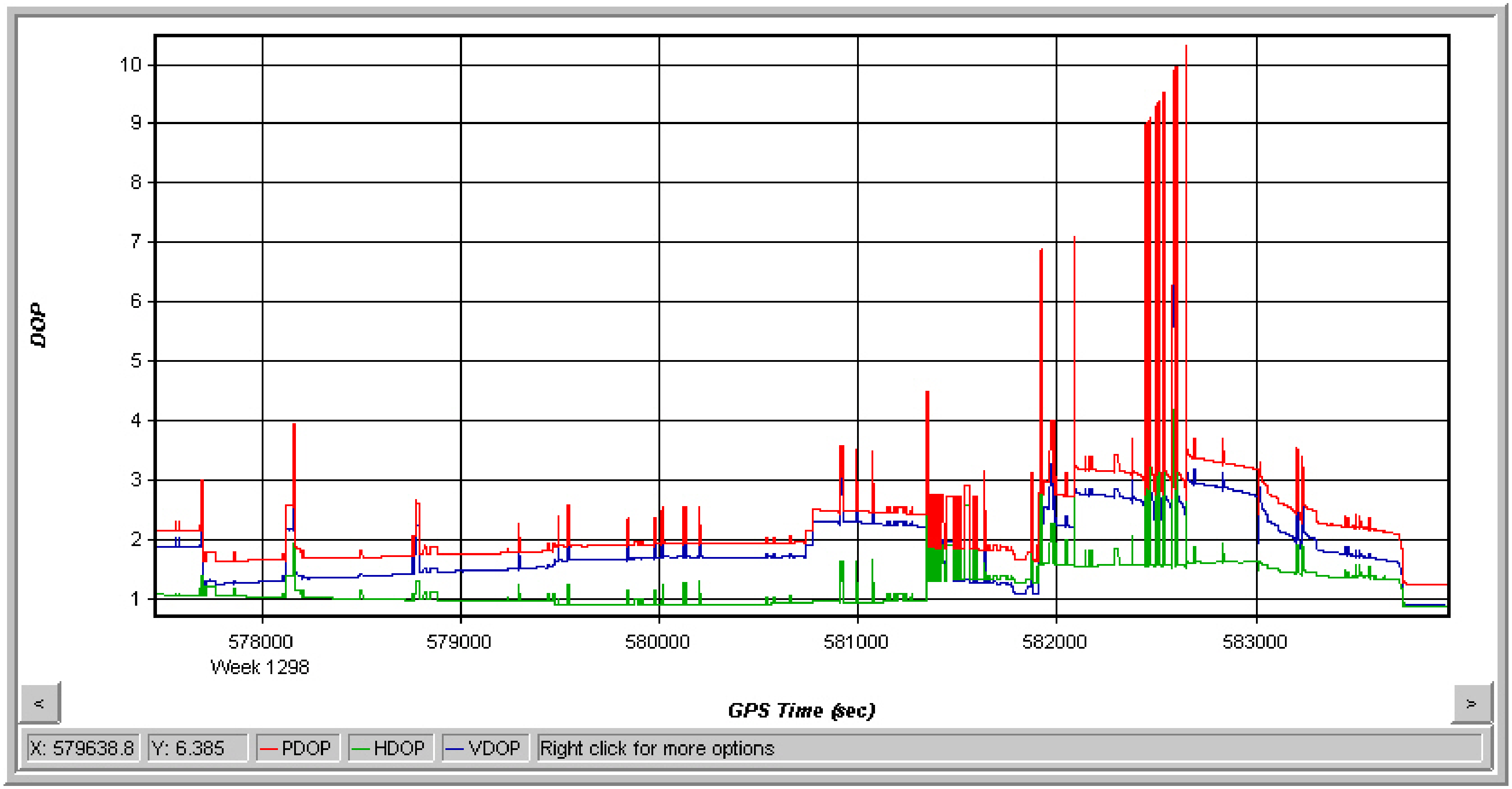
2004-11-26 Flight 1



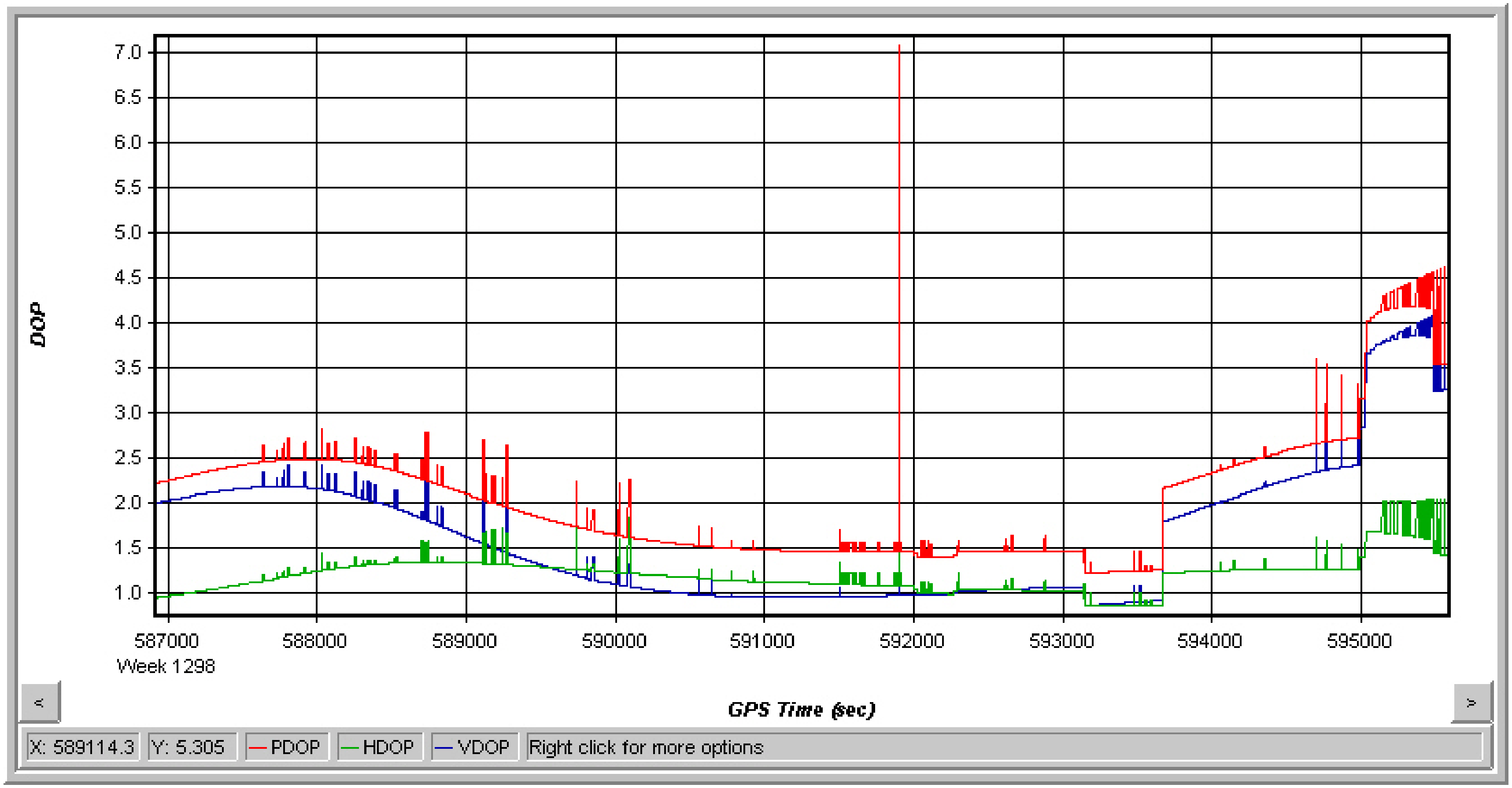
2004-11-26 Fight 2



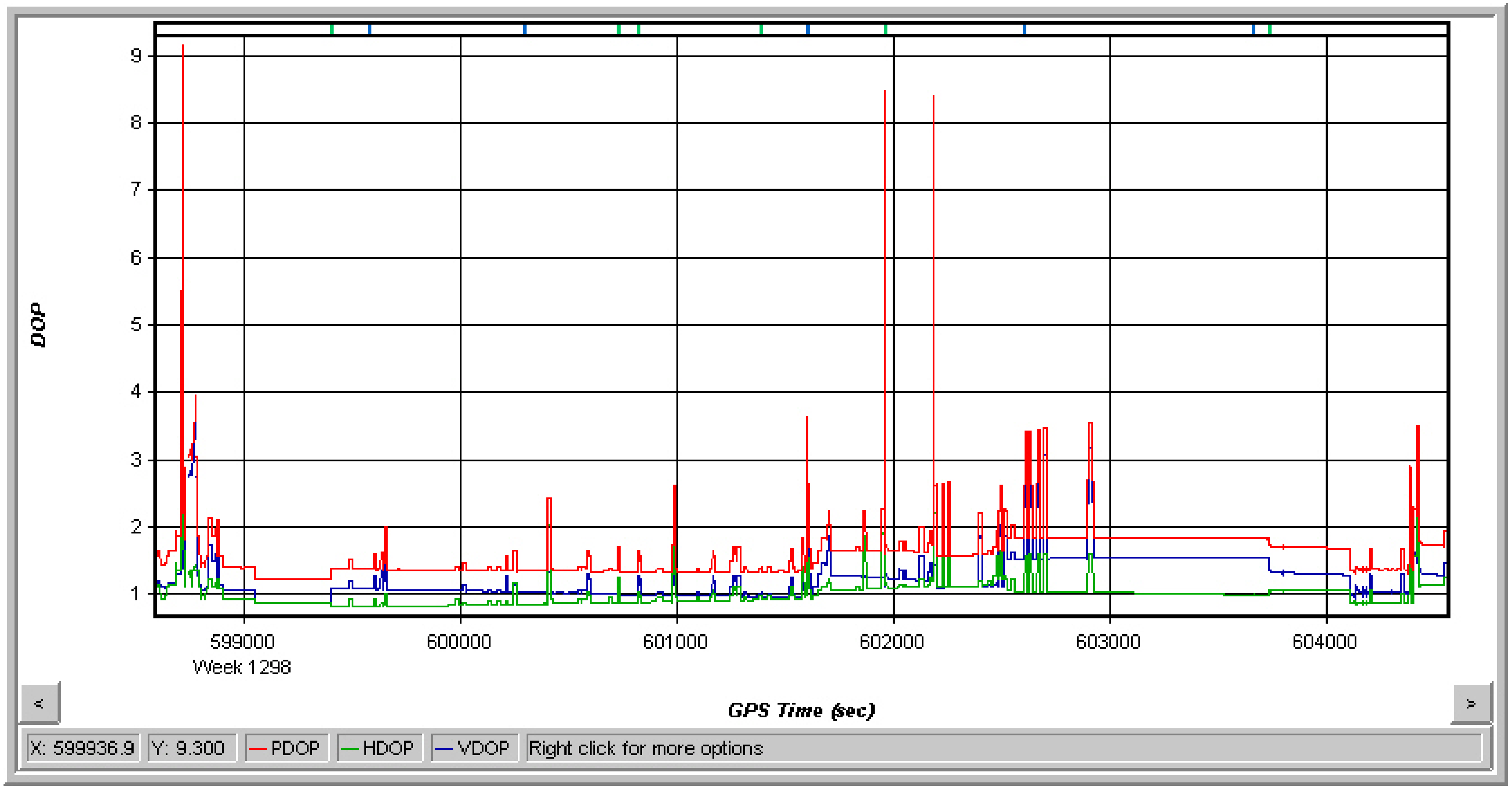
2004-11-27 Flight 1



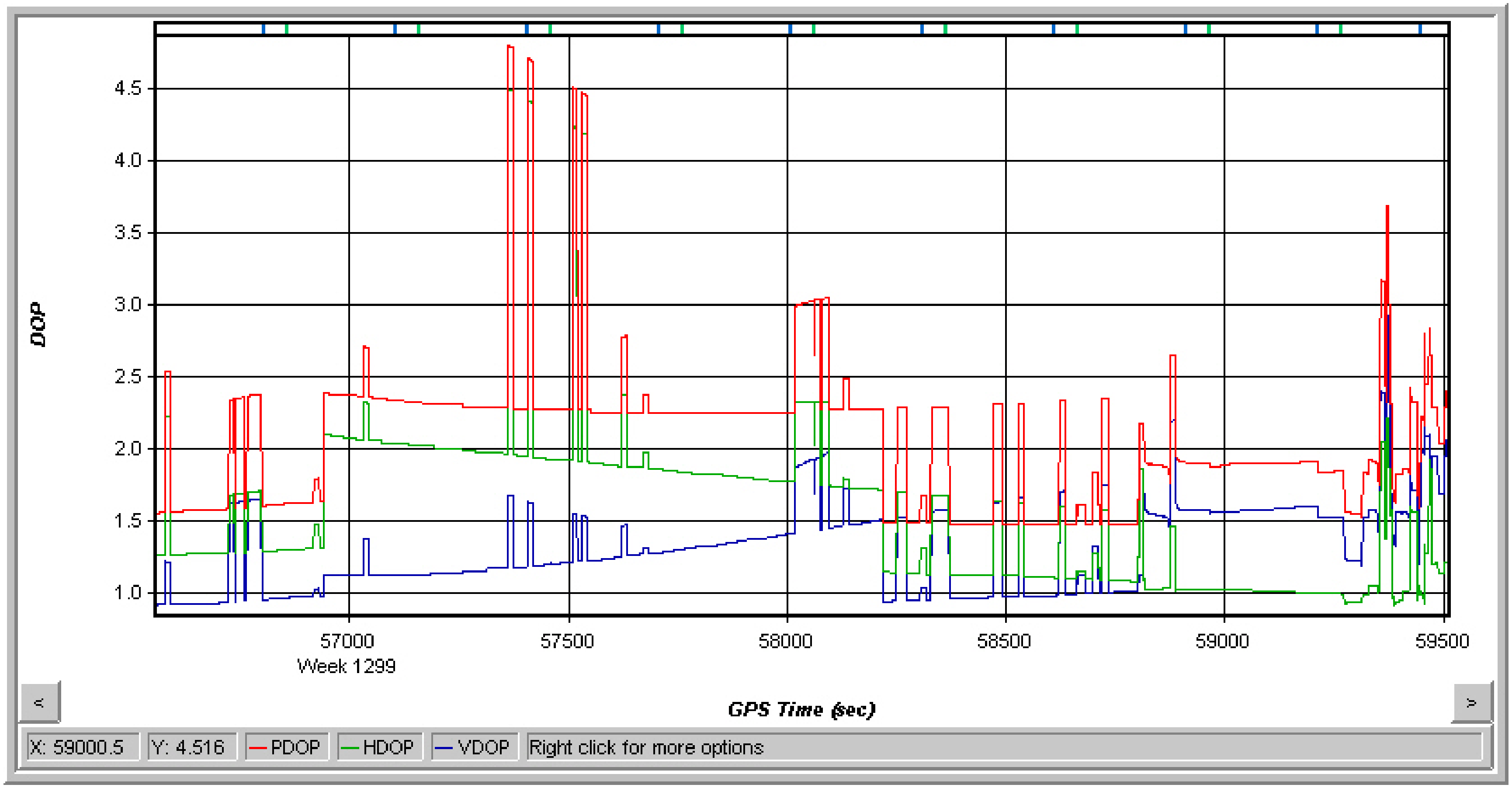
2004-11-27 Flight 2



2004-11-27 Flight 3



2004-11-28 Flight 1



APPENDIX K : KGPS PROCESSING RESULTS

```
          Processing Summary Information
Program: POSGPS
Version: 4.20
Project:P:\Projects\FP6088.008_LIDAR-GrandCanyon\03_processing\GCS_GPS\2004-11-26-Flt1-PAG1\GPS\Combined (1).gnv

Solution Type:      Combined Fwd/Rev

Number of Epochs:

       Total in GPB file:        8752
       No processed position:    5020
       Missing Fwd or Rev:       0
       With bad C/A code:        0
       With bad L1 Phase:        0

Measurement RMS Values:

       L1 Phase:     0.0192 (m)
       C/A Code:     1.04 (m)
       L1 Doppler:   0.078 (m/s)

Fwd/Rev Separation RMS Values:

       East:         0.025 (m)
       North:        0.039 (m)
       Height:       0.094 (m)

Fwd/Rev Sep. RMS for 25%-75% weighting (3732 occurances):

       East:         0.025 (m)
       North:        0.039 (m)
       Height:       0.094 (m)

Quality Number Percentages:

       Q 1:   81.0 %
       Q 2:   18.8 %
       Q 3:    0.2 %
       Q 4:    0.0 %
       Q 5:    0.0 %
       Q 6:    0.0 %

Position Standard Deviation Percentages:

       0.00 - 0.10 m:      98.6 %
       0.10 - 0.30 m:       1.4 %
       0.30 - 1.00 m:       0.0 %
       1.00 - 5.00 m:       0.0 %
       5.00 m + over:       0.0 %

Percentages of epochs with DD_DOP over 10.00:

       DOP over Tol:2.3 %

Baseline Distances:

       Maximum:      8.158 (km)
       Minimum:      0.731 (km)
       Average:      4.833 (km)
       First Epoch:  7.541 (km)
       Last Epoch:   7.295 (km)
```

```
          Processing Summary Information
Program: POSGPS
Version: 4.20
Project: P:\Projects\FP6088.008_LIDAR-GrandCanyon\03_processing\GCS_GPS\2004-11-26-Flt2-PAG1\GPS\Combined (1).gnv

Solution Type:      Combined Fwd/Rev

Number of Epochs:

       Total in GPB file:        14991
       No processed position:    7748
       Missing Fwd or Rev:       0
       With bad C/A code:        0
       With bad L1 Phase:        0

Measurement RMS Values:

       L1 Phase:     0.0180 (m)
       C/A Code:     0.92 (m)
       L1 Doppler:   0.077 (m/s)

Fwd/Rev Separation RMS Values:

       East:         0.041 (m)
       North:        0.069 (m)
       Height:       0.059 (m)

Fwd/Rev Sep. RMS for 25%-75% weighting (592 occurances):

       East:         0.082 (m)
       North:        0.076 (m)
       Height:       0.063 (m)

Quality Number Percentages:

       Q 1:   98.0 %
       Q 2:    2.0 %
       Q 3:    0.0 %
       Q 4:    0.0 %
       Q 5:    0.0 %
       Q 6:    0.0 %

Position Standard Deviation Percentages:

       0.00 - 0.10 m:      100.0 %
       0.10 - 0.30 m:       0.0 %
       0.30 - 1.00 m:       0.0 %
       1.00 - 5.00 m:       0.0 %
       5.00 m + over:       0.0 %

Percentages of epochs with DD_DOP over 10.00:

       DOP over Tol:0.5 %

Baseline Distances:

       Maximum:      56.346 (km)
       Minimum:      1.446 (km)
       Average:      24.173 (km)
       First Epoch:  1.527 (km)
       Last Epoch:   2.082 (km)
```

```
          Processing Summary Information
Program: POSGPS
Version: 4.20
Project: P:\Projects\FP6088.008_LIDAR-GrandCanyon\03_processing\GCS_GPS\2004-11-27-Flt1-Multi\GPS\Combined (2).gnv

Solution Type:      Combined Fwd/Rev

Number of Epochs:

       Total in GPB file:        17438
       No processed position:    10913
       Missing Fwd or Rev:       0
       With bad C/A code:        0
       With bad L1 Phase:        0

Measurement RMS Values:

       L1 Phase:     0.0165 (m)
       C/A Code:     0.92 (m)
       L1 Doppler:   0.053 (m/s)

Fwd/Rev Separation RMS Values:

       East:         0.078 (m)
       North:        0.064 (m)
       Height:       0.055 (m)

Fwd/Rev Sep. RMS for 25%-75% weighting (6399 occurances):

       East:         0.078 (m)
       North:        0.065 (m)
       Height:       0.054 (m)

Quality Number Percentages:

       Q 1:   75.4 %
       Q 2:   22.7 %
       Q 3:    1.9 %
       Q 4:    0.0 %
       Q 5:    0.0 %
       Q 6:    0.0 %

Position Standard Deviation Percentages:

       0.00 - 0.10 m:      98.2 %
       0.10 - 0.30 m:       1.8 %
       0.30 - 1.00 m:       0.0 %
       1.00 - 5.00 m:       0.0 %
       5.00 m + over:       0.0 %

Percentages of epochs with DD_DOP over 10.00:

       DOP over Tol:2.3 %

Baseline Distances:

       Maximum:      21.850 (km)
       Minimum:      5.906 (km)
       Average:      18.045 (km)
       First Epoch:  19.770 (km)
       Last Epoch:   5.960 (km)
```

```
         Processing Summary Information
Program: POSGPS
Version: 4.20
Project: P:\Projects\FP6088.008_LIDAR-GrandCanyon\03_processing\GCS_GPS\2004-
11-27-Flt2-Multi\GPS\Combined (1).gnv

Solution Type:      Combined Fwd/Rev

Number of Epochs:

       Total in GPB file:         18874
       No processed position:     10173
       Missing Fwd or Rev:        0
       With bad C/A code:         0
       With bad L1 Phase:         0

Measurement RMS Values:

       L1 Phase:     0.0161 (m)
       C/A Code:     0.78 (m)
       L1 Doppler:   0.048 (m/s)

Fwd/Rev Separation RMS Values:

       East:         0.017 (m)
       North:        0.017 (m)
       Height:       0.043 (m)

Fwd/Rev Sep. RMS for 25%-75% weighting (8701 occurances):

       East:         0.017 (m)
       North:        0.017 (m)
       Height:       0.043 (m)

Quality Number Percentages:

       Q 1:   93.1 %
       Q 2:    6.7 %
       Q 3:    0.2 %
       Q 4:    0.0 %
       Q 5:    0.0 %
       Q 6:    0.0 %

Position Standard Deviation Percentages:

       0.00 - 0.10 m:      99.9 %
       0.10 - 0.30 m:       0.1 %
       0.30 - 1.00 m:       0.0 %
       1.00 - 5.00 m:       0.0 %
       5.00 m + over:       0.0 %

Percentages of epochs with DD_DOP over 10.00:

       DOP over Tol:1.6 %

Baseline Distances:

       Maximum:      22.361 (km)
       Minimum:      1.559 (km)
       Average:      17.139 (km)
       First Epoch:  4.806 (km)
       Last Epoch:   5.863 (km)
```

```
          Processing Summary Information
Program: POSGPS
Version: 4.20
Project: P:\Projects\FP6088.008_LIDAR-GrandCanyon\03_processing\GCS_GPS\2004-11-27-Flt3-Multi\GPS\2004-11-27-Flt3-Multi.gnv

Solution Type:      Combined Fwd/Rev

Number of Epochs:

       Total in GPB file:         11990
       No processed position:     6010
       Missing Fwd or Rev:        3
       With bad C/A code:         0
       With bad L1 Phase:         0

Measurement RMS Values:

       L1 Phase:     0.0277 (m)
       C/A Code:     0.99 (m)
       L1 Doppler:   0.106 (m/s)

Fwd/Rev Separation RMS Values:

       East:         0.128 (m)
       North:        0.133 (m)
       Height:       0.286 (m)

Fwd/Rev Sep. RMS for 25%-75% weighting (3130 occurances):

       East:         0.054 (m)
       North:        0.101 (m)
       Height:       0.155 (m)

Quality Number Percentages:

       Q 1:   91.0 %
       Q 2:    5.9 %
       Q 3:    0.7 %
       Q 4:    1.8 %
       Q 5:    0.6 %
       Q 6:    0.2 %

Position Standard Deviation Percentages:

       0.00 - 0.10 m:      26.5 %
       0.10 - 0.30 m:      70.4 %
       0.30 - 1.00 m:       3.1 %
       1.00 - 5.00 m:       0.0 %
       5.00 m + over:       0.0 %

Percentages of epochs with DD_DOP over 10.00:

       DOP over Tol:1.0 %

Baseline Distances:

       Maximum:      98.791 (km)
       Minimum:      1.535 (km)
       Average:      66.809 (km)
       First Epoch:  98.790 (km)
       Last Epoch:   1.545 (km)
```

```
          Processing Summary Information
Program: POSGPS
Version: 4.20
Project: P:\Projects\FP6088.008_LIDAR-GrandCanyon\03_processing\GCS_GPS\2004-11-28-Flt1-PAG1\GPS\2004-11-28-Flt1-PAG1.gnv

Solution Type:      Combined Fwd/Rev

Number of Epochs:

       Total in GPB file:        5932
       No processed position:    2966
       Missing Fwd or Rev:       3
       With bad C/A code:        0
       With bad L1 Phase:        0

Measurement RMS Values:

       L1 Phase:     0.0148 (m)
       C/A Code:     1.12 (m)
       L1 Doppler:   0.056 (m/s)

Fwd/Rev Separation RMS Values:

       East:         0.059 (m)
       North:        0.079 (m)
       Height:       0.235 (m)

Fwd/Rev Sep. RMS for 25%-75% weighting (2889 occurances):

       East:         0.031 (m)
       North:        0.033 (m)
       Height:       0.058 (m)

Quality Number Percentages:

       Q 1:   98.9 %
       Q 2:    1.1 %
       Q 3:    0.0 %
       Q 4:    0.0 %
       Q 5:    0.0 %
       Q 6:    0.0 %

Position Standard Deviation Percentages:

       0.00 - 0.10 m:      93.0 %
       0.10 - 0.30 m:       7.0 %
       0.30 - 1.00 m:       0.0 %
       1.00 - 5.00 m:       0.0 %
       5.00 m + over:       0.0 %

Percentages of epochs with DD_DOP over 10.00:

       DOP over Tol:1.8 %

Baseline Distances:

       Maximum:      12.908 (km)
       Minimum:      0.305 (km)
       Average:      6.675 (km)
       First Epoch:  1.538 (km)
       Last Epoch:   1.530 (km)
```

APPENDIX L : PERSONNEL

Fugro Pelagos – Field Personnel	
Survey Coordinator / GCS Operator	Dushan Arumugam
Airborne Operator	Dennis Tobin
Surveyor – Ground Control	Jose Martinez
Fugro Pelagos – Office Personnel	
Project Manager	James Hailstones
Data Analyst – GCS,GPS	Jose Martinez
Project Manager – LIDAR	Carol Lockhart