NOAA FORM 76-35A

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE

DATA ACQUISITION AND PROCESSING REPORT

Type of Survey Hydrographic/Lidar

Project No. OPR-I305-KRL-06

Registry No. H11557 – H11567

LOCALITY

State Puerto Rico

General Locality Southwest Puerto Rico

Sublocality See Descriptive Report

Section A: Area Surveyed

2006

HYDROGRAPHER	**CHIEF OF PARTY**
MARK SINCLAIR	DARREN STEPHENSON

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HYDROGRAPHIC TITLE SHEET

NOAA FORM 77-28U.S. DEPARTMENT OF COMMERCE (11-72) NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION **HYDROGRAPHIC TITLE SHEET**	REGISTRY NO. **H11557-H11567**
INSTRUCTIONS – The Hydrographic Sheet should be accompanied by this form, filled in as completely as possible, when the sheet is forwarded to the Office	FIELD No. **N/A**

State: Puerto Rico

General Locality: Southwest Puerto Rico

Sub-Locality: See Descriptive Report, Section A: Area surveyed

Scale: 1:10,000 **Date of Survey:** April 7 to May 15, 2006

Instructions dated: February 8, 2006 and May 5, 2006 **Project No:** OPR-I305-KRL-05

Vessel: Tenix LADS Aircraft, VH – LCL

Hydrographer: M.J. Sinclair **Chief of Party:** D.J. Stephenson

Surveyed by: M.S. Hawkins, J.K. Young, B.C. McWilliam, M. Blackbourn, W.T. Newsham

Soundings taken by echo sounder, hand lead, pole: Laser Airborne Depth Sounder

Graphic record scaled by: J.K. Young, L.R. Chamberlain, V. Sicari and B. Weidman

Graphic records checked by: S.R. Ramsay and J.G. Guilford

Protracted by: N/A **Automated plot:** N/A

Verification by:

Soundings in: Meters at MLLW

REMARKS: Contract # NC-NJ3000-4-00010 01

Contractor: Tenix LADS Incorporated, 925 Tommy Munro Drive, Suite J, Biloxi MS 39532

Sub contractor: John Oswald and Associates, 12001 Audubon Dr, Anchorage, AK, 99516

Times: All times are recorded in UTC.

Purpose: The purpose of this survey is to provide NOAA with modern, accurate hydrographic survey data with which to update the nautical charts of the assigned area. Projection is UTM Zone 19.

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A. EQUIPMENT

The LADS Mk II hydrographic survey system comprises two main sub-systems: the Airborne System (AS) used for acquiring raw bathymetric data, and the Ground System (GS) which is used to plan operations, calculate depth values from the raw data, provide tools which allow the hydrographic surveyor to validate processed depth values, apply tidal corrections, export smooth sheet data and digital survey data and conduct general survey management. These two sub-systems are complemented by other tools required for quality control activities, in particular contouring and 3-D visualization and post-processed kinematic GPS positions. Third party software is also used for product compilation, image creation and survey management, namely CARIS, Terramodel and ARCGIS. The general data flow between the sub-systems and tools is illustrated in Figure 1.

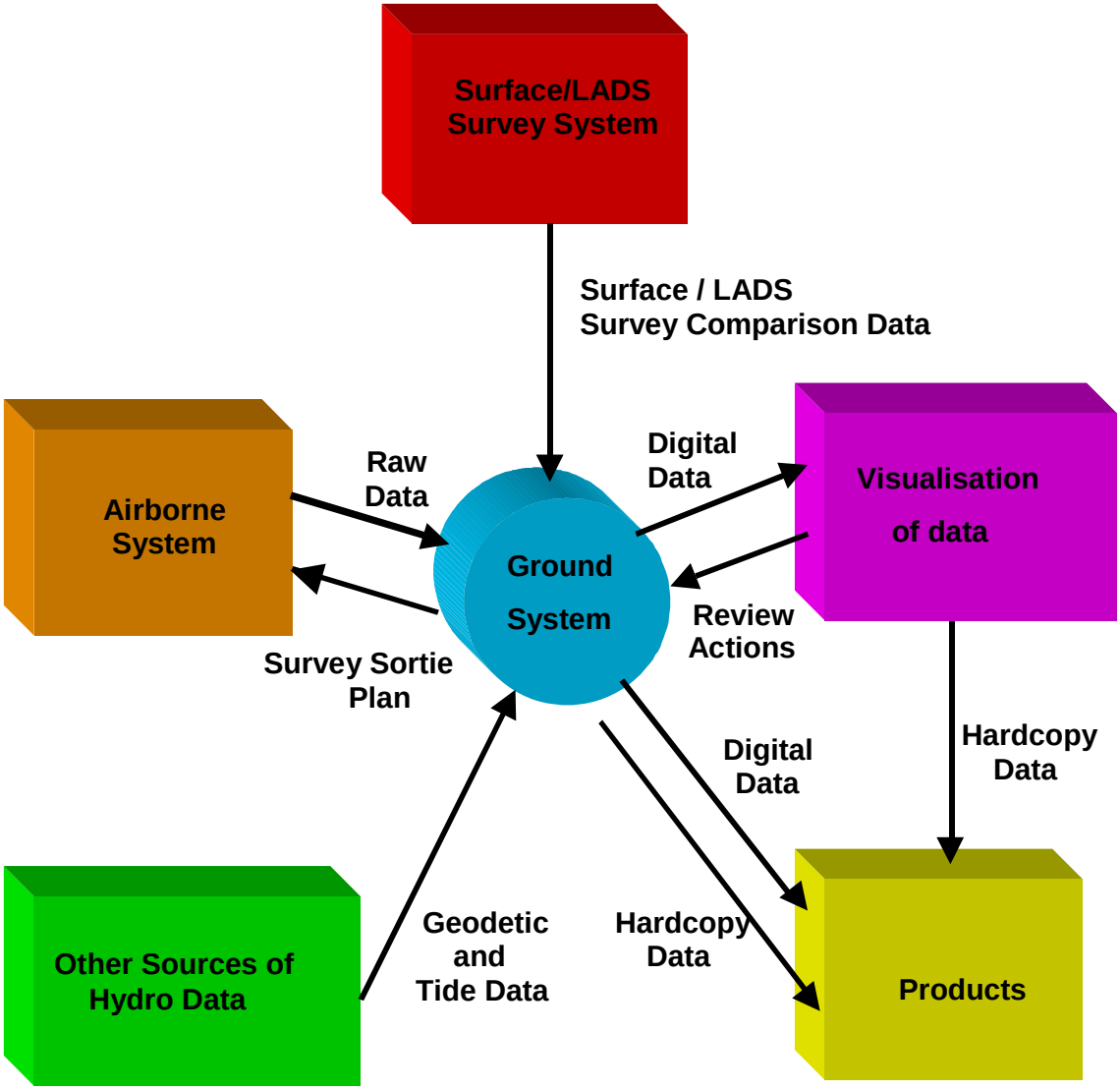


Figure 1 – General data flow within LADS Mk II

A.1 AIRBORNE SYSTEM

A laser, scanner, optical system, photo-multiplier tube and conditioning electronics collect the raw sounding signal. These items are mounted on a stabilized platform controlled via servo systems using information from an Attitude and Heading Reference System (AHRS) mounted on the platform. Aircraft position information is obtained from the Global Positioning System. Figure 2 illustrates the major components of the AS. Three computers, linked via an FDDI optic fiber network, control and monitor the AS operations. These computers are:

- The System Control Computer (SCC) for operator interface, logging and overall system coordination,
- The Navigation System and Support (NSS) computer for position monitoring and control, and
- The Laser Control and Acquisition (LCA) computer for control of the scanner and laser and digitization of raw sounding data. The LCA also synchronizes overall AS timing.

AS system time is synchronized with GPS time and all data acquired for logging is appropriately time stamped at the point of acquisition then passed to the SCC to be written to digital linear tape.

Ancillary equipment includes:

- A downward video camera and VCR to provide images below the aircraft and a forward-looking video camera.
- Systems for temperature control of equipment.
- VHF transceiver and aircraft intercom.

The operator interface allows the operator to monitor the quality of sounding, position and other data in order to set appropriate system parameters and control the sequence of sortie operations.

Detailed descriptions of equipment and their function are given under the following headings:

- Sounding Equipment
- Positioning Equipment
- Sortie Control
- Ancillary Equipment
- Operator Interface

A.1.1 Sounding Equipment

Soundings in the LADS Mk II system are obtained by the transmission of laser pulses from the aircraft through a scanning system and detecting return signals from land, the sea surface, the water body and the seabed. The transmitting and receiving components are housed on a stabilized platform that compensates for aircraft pitch and roll. The return signals are electronically amplified and conditioned prior to being digitized and logged.

The primary sounding components of the AS are:

- Laser. A Nd: Yag laser producing IR energy at a wavelength of 1064nm at 990 pulses per second of which 900 pulses are used for sounding purposes.
- Optical Coupler. The optical coupler is used to split the IR beam. Part of the IR beam is transmitted vertically to nadir on the sea surface. The other part of the split beam is frequency doubled to produce green laser pulses of wavelength 532nm. The green pulses are transmitted onto the mirror of the scanner.
- Scanning System. The scanning mirror is oscillated in both the major (across track) and minor (along track) axes. The required scan pattern is generated by controlling software. All possible patterns are listed in the Sounding Patterns section.
- Optical Receivers. The IR and green return signals are detected by two separate receivers. The IR return from the surface of the sea is used to establish a height datum. The IR receiver is a solid state detector producing an electronic signal from the IR return. The green return comprises energy returned from the surface, subsurface and seabed and is used to determine water depth. The green return is transmitted via the scanner into a photomultiplier tube. The electronic output of the two return signals are electronically mixed prior to digitization.
- Attitude and Heading Reference System (AHRS). The AHRS is a laser gyro inertial navigation system providing platform attitude information to the platform servo system that in turn maintains platform stability. The AHRS also reports platform attitude to the LCA computer and provides height data.
- LCA computer. This controls the laser and scanner operations and digitizes (8 bits at 500MHz) appropriate sections of the composite electronic red/green return signal along with platform attitude data and other system parameters. This digital information is passed to the System Control Computer (SCC) where it is logged to digital linear tape.
- Waveform Display. This CRT display presents the operator with sounding waveforms as digitized and is used by the operator to check data quality during acquisition.

A.1.2 Position Equipment

The center of the scanning mirror is the survey reference point on the aircraft. The GPS antenna is positioned relative to this point as described in Laybacks.

The signal from the antenna is split and fed to two independent GPS receivers, one is used for real-time aircraft position fixing and track keeping and the second to record GPS data for calculating KGPS positions.
The output of the real-time GPS receiver is fed to the NSS to:

- Fix aircraft position and determine ground speed.
- Calculate aircraft cross track error and automatically maintain track along survey lines.
- Provide pilot display information.
- Establish and maintain system UTC time.

The NSS passes the received GPS and derived information to the SCC computer for logging.

Two GPS receivers are used on the aircraft. An Ashtech GG24 single frequency GPS receiver is used to provide positioning of the aircraft and an Ashtech Z12 dual frequency GPS receiver is used to compute post-processed positions. The data from this receiver is independently logged and post-processed.

A.1.3 Sortie Control

A sortie plan is generated on a floppy disk on the GS to transfer survey information to the AS. The sortie plan contains spheroidal and grid parameters and a list of survey objectives including the line number, start/end coordinates and coordinates for navigation checks. During the course of the sortie the airborne operator amends the sequence of execution to suit local conditions and can amend the scan pattern parameters for the survey lines to suit survey requirements.

The SC computer controls the sequence of survey operations by:

- Planning all required flight paths and communicating these to the NSS.
- Transmitting required parameters for scan patterns etc. to the LCA.
- Initiating the starting and stopping of system operations, via commands sent to the LCA and NSS at specific waypoints on the run-in and run-out of survey lines.

The operator may abort and restart the sortie operations at any time and the sequence of objectives may be amended at any time. Scan patterns can be amended on all lines except the executing objective. A display of the planned survey line and received GPS data is situated in the cockpit and used to advise the pilots of required aircraft configurations. The display provides an indication of cross track error with required and actual values for altitude and ground speed.

Aircraft position during survey acquisition is under automatic control of the NSS via the aircraft autopilot. Aircraft turns are under pilot control assisted by the display. Aircraft altitude and speed are under pilot control, and communication between the operator and pilots is via the aircraft intercom system.

The management of survey operations can be impacted by both low cloud and high ground in the survey area. LADS Mk II is able to operate at different survey heights so that adequate clearances can be maintained while surveying and survey activities can continue below low cloud ceilings. Survey altitudes at 200ft increments are available from 1,200 to 2,200 feet (366 to 671m). Altitudes must be constant for the duration of a survey line but may be varied from line to line by the AS operator during the course of a sortie.

During daytime operations a narrow band green filter is used to filter out other light frequencies from the photomultiplier tube. This filter has a slight attenuating effect on the laser returns, which reduces the maximum depth performance. This filter can be removed once the ambient sunlight levels drop which results in improved performance at night.

Glassy sea conditions may result in very strong IR surface returns that can saturate the IR receiver causing a loss of surface datum. The AS monitors the IR surface return performance and advises the operator if IR saturation occurs. The operator can activate an IR attenuator that provides correct IR surface return amplitudes to be fed to the IR receiver. Should sea surface conditions change which may result in lower IR return amplitudes the AS informs the operator to deactivate the IR attenuator.

The laser is designed to be eye safe in accordance with the following standards:

a. ANSI Z136.1-2000, American National Standard for Safe Use of Lasers.

b. IEC 60825-1 (Edition 1.2) International Standard – Safety of Laser Products.

c. AS/NZS 2211.1 Supplement 1:1999 Australian/New Zealand Standard Laser Safety.

The laser power can be reduced by a further factor of four using a built-in green attenuator. The operator may activate/deactivate the green attenuator at any time.

A.1.4 Ancillary Equipment

A video camera is positioned on the stabilized platform and directed downward at nadir. A calibrated graticule is superimposed on the camera image to provide the operator with a scan width and distance reference. The image, graticule and other relevant system information including position and time are presented to the operator and recorded throughout a sortie. The images as recorded are used as supplemental information during sounding validation.

A prototype Digital Imagery Capture system has been installed to provide georeferenced imagery. This prototype system comprises a laptop computer with ImpreX VCE-PRO 2.5 Analog Video Capture card and captures from the LADS downward Looking Analog Camera

in JPEG format at 752x582 resolution. The digital images are then time-stamped with LADS Airborne System time for the future geo-referencing. At the end of sortie the digital images are transferred to the LADS Ground System and the reference files are calculated for each image. The georeferencing and subsequent mosaicing of the images is performed in BlueMarble Geographic Transformer 5.1.

A forward-looking video camera is also provided to assist the Airborne Systems Operator evaluate conditions ahead of the aircraft.

A.1.5 Operator Interface

The operator monitors and controls system operation from the console. The following key information is provided to monitor system performance:

- Sortie Information. The Sortie ID, spheroid and grid in use and available survey objectives are displayed. Sortie objective information includes the scan pattern set for the objective and estimated time to complete the objective.
- Objective Information. The Objective ID, selected scan pattern, required speed and altitude pertaining to the current objective being executed and objective status such as time to completion are presented.
- Waveform Display. This display is a CRT on which is displayed each of the mixed red/green sounding return signals as digitized by the LCA (the traces are overlayed). The operator continually assesses this display to determine data quality.
- Depth Profile. A depth profile determined from nadir soundings is available to the operator with an associated confidence factor. As the algorithm is limited by real-time considerations these depths and confidences are only indicative.
- Aircraft Position, Speed, Altitude and Cross Track Error. A number of displays including a copy of the pilot display are available to the operator to determine the aircraft position and performance parameters. Speed and altitude are continually monitored and the pilot informed of deviations from the desired values.
- GPS status. The operator is provided with the data from the GPS receiver including number of satellites, satellite altitudes and azimuths, S/N ratio and which satellites are being used.
- Equipment Status. System status and performance parameters are available to the operator including laser power and temperature, dynamic gain values, AHRS status and scanner performance.

Items controlled by the operator for sortie execution and data acquisition are:

- Sequence of objective execution.
- Scan pattern for each objective.
- Operating height for each objective.

- Depth logging range and topographic height range for each objective.
- Dynamic gain limits.
- IR and green receiver attenuator positions.
- Seabed reflectivity and seabed gradient controls.

A.1.6 Depth and Topographic Mode

During normal bathymetric survey mode (Depth Mode) LADS Mk II determines the depth of water with the height datum being determined from the reflected IR laser signal, GPS height and AHRS height. When over land this IR signal is not valid and the height datum is obtained from the GPS and AHRS.

This ancillary height datum allows LADS Mk II to measure topographic heights. The topographic height range is dependent on the depth range in use.

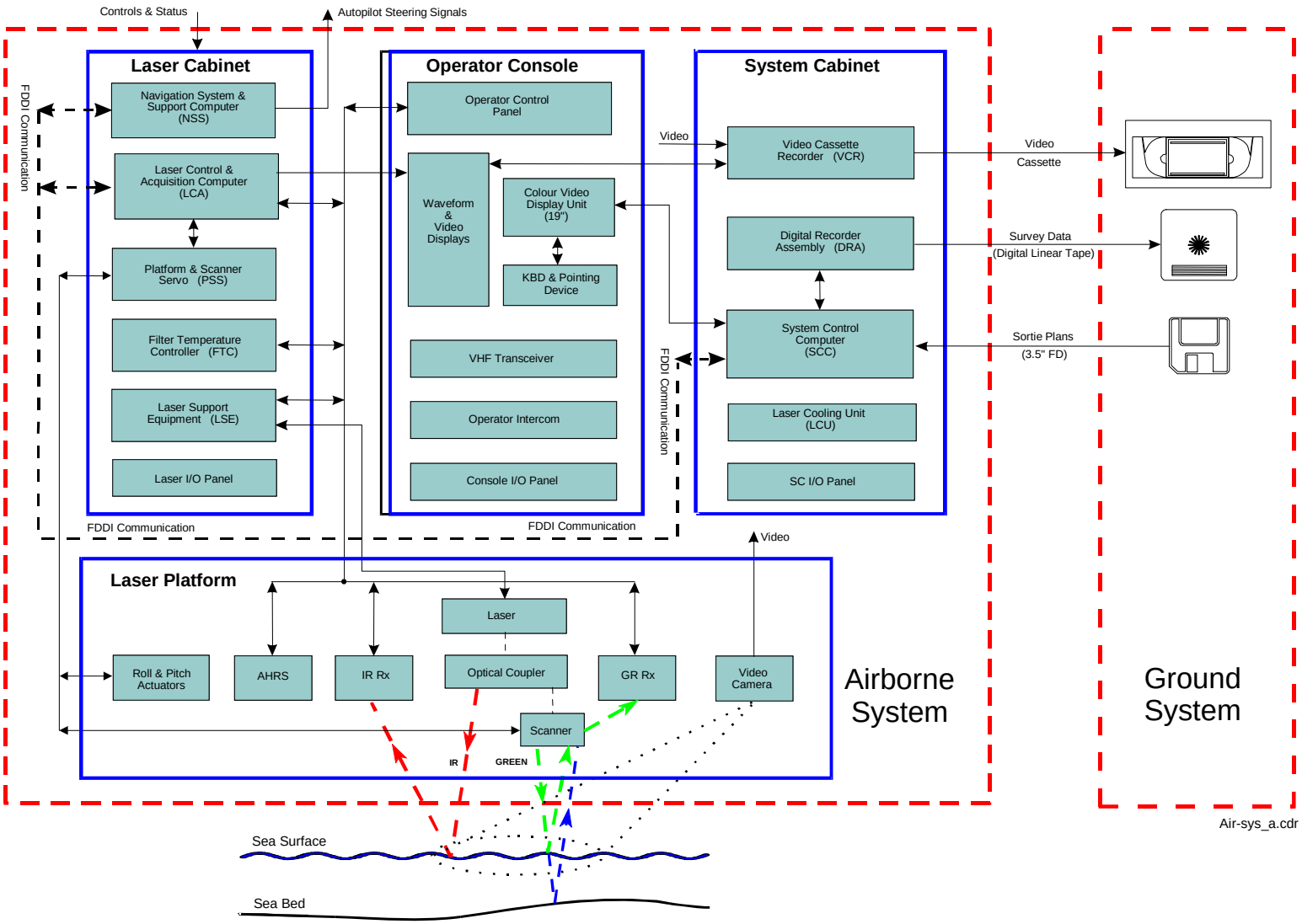


Figure 2 – Airborne System Functional Block Diagram

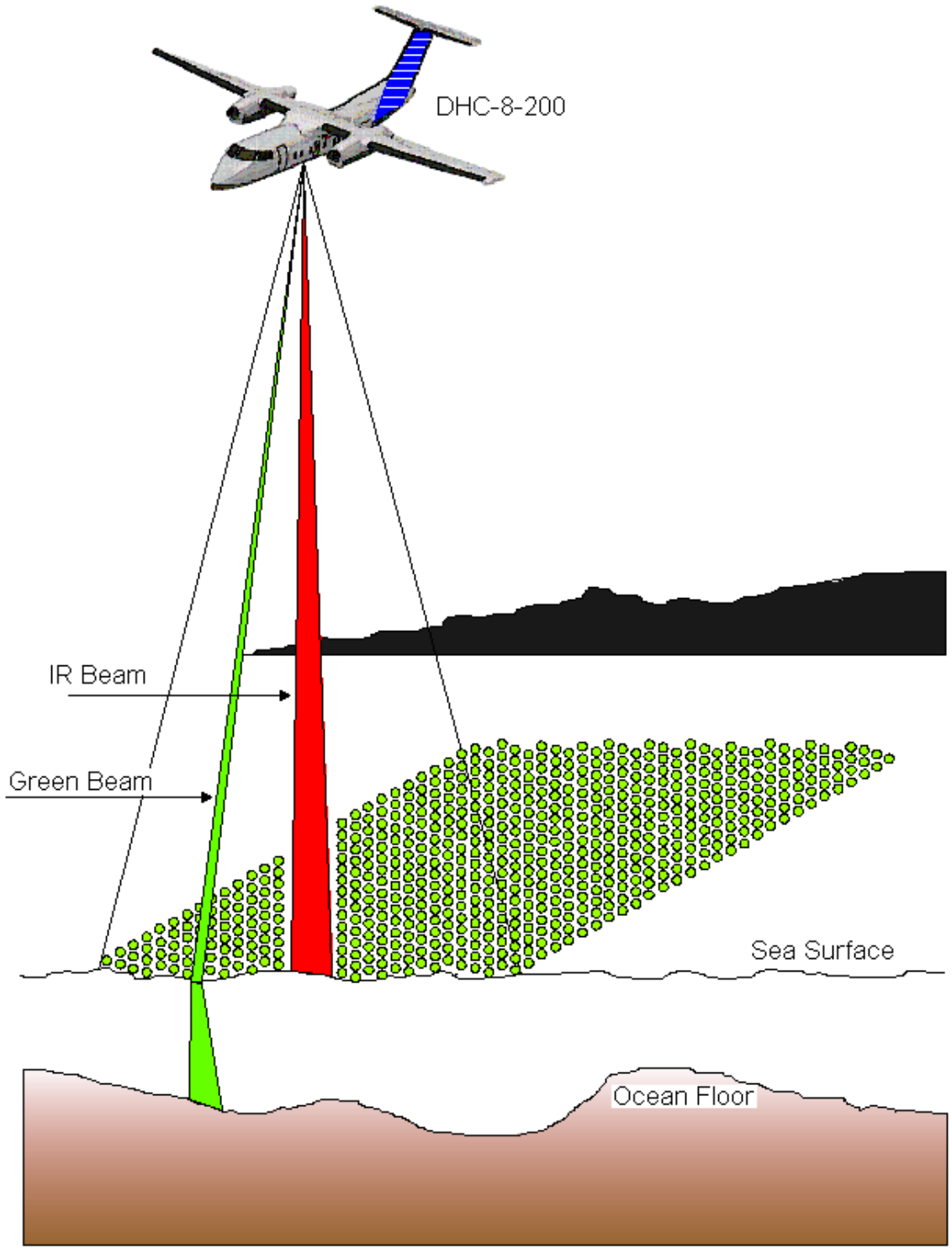


Figure 3 – The Laser Scan

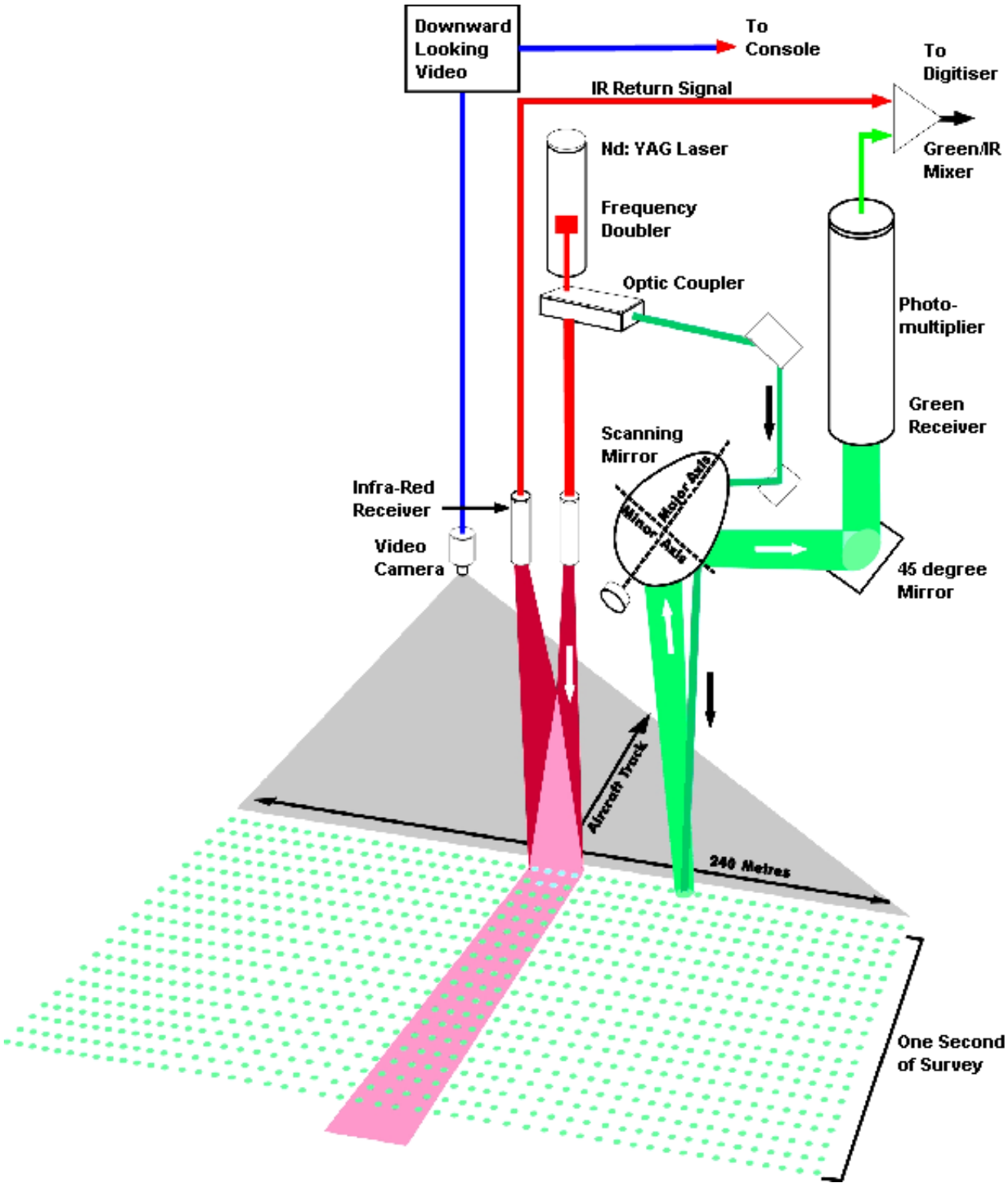


Figure 4 – The Airborne System Scanner, Laser and Receivers

A.1.7 LADS Mk II Aircraft and System Specifications

Aircraft Type	DeHavilland Dash 8-200, twin turbo prop, high wing
Aircraft Modifications	Long range tanks, pressurized laser bay window and autopilot interface
Transit Cruise Speed	250 knots (maximum 275 knots)
Transit Altitude	To 25,000 feet
Survey Speed	Dependant on Scan Pattern: Nominal 140 – 210 knots (72-108 meters per second)
Survey Height	1,200 feet to 2,200 feet (366 meters to 671 meters) in 200 feet increments
Survey Track-Keeping	+/- 5 m (manual or via autopilot coupling)
Survey Endurance	8 hours nominal
Operational Capability	Day/Night Operation
Depth Sounding Rate	900 soundings per second
Swath Width	Dependant on Scan Pattern: 50 – 288 meters (independent of aircraft height and water depth)
Scan Pattern	Rectilinear
Sounding Density	Variable: 6x6m, 5x5m, 4x4m, 3x3m and 2x2m
Soundings per sq km	Dependant on scan pattern. For 4x4m – 75 000/ km^2 (assuming 32m overlap)
Soundings per hour	Up to 3 million
Topographic and Depth Range	-50 meters (topo) to 70 meters (depth)
Area Coverage	Dependant on scan pattern. For 4x4m – up to 41.5km^2/hour (12.1 sq nm/hr) assuming 32m overlap
Position Fixing	Autonomous GPS and post-processed L1 + L2 dual frequency KGPS
Recording Media	Digital Linear Tape (DLT) and VHS/PAL Video Tape
Prototype Digital Image Capture System	Image Area @ 1600ft operating altitude: ~420m x 315m at the sea surface. Digital Image Resolution: 752 x 582 Digital Image Pixel Size: ~0.6m per pixel at sea surface Boresight Accuracy: ~2.0m at sea surface Digital Image Capture Rate: 1 per second Digital Image Horizontal Accuracy: ~5m (1 sigma)

A.1.8 Logging Parameters

A.1.8.1 Position Fixing

The Airborne System obtains a position fix every 0.5 seconds.

A.1.8.2 Navigation Update

While executing a survey line under AS control navigation correction is passed to the aircraft autopilot every 0.5 seconds.

A.1.8.3 Post-Processed GPS

The GPS airborne and base logging stations log position information from GPS satellites at 0.5 second intervals.

A.1.8.4 Sounding Rates

LADS Mk II obtains depth soundings in a rectilinear pattern where the sounding density is variable (see Table 1) but sounding rate is invariant.

For all sounding patterns the soundings are grouped into one second frames made up of 18 scan lines. Each of the 18 scan lines contains 50 laser pulses, of which 48 pulses are used for depth sounding. The outermost laser pulses are not used for depth sounding. This provides an effective sounding rate of 864 soundings per second.

A.1.9 Sounding Patterns

LADS Mk II has variable scan pattern functionality as detailed in the following table. The 4x4 and 4ax4a patterns both provide 4x4 meter spot density but have different swath width and survey speeds. All patterns are available at each of the operational altitudes (1,200 – 2,200ft at 200ft increments).

Sounding Density (m)	Swath Width (m)	Line Spacing 200% Coverage (m)	Line Spacing 100% Coverage (m)	Survey Speed m/sec (kts)
6x6	288	125	250	108 (210)
5x5	240	100	200	90 (175)
4x4	192	80	160	72 (140)
4ax4a	150	60	120	90 (175)
3x3	100	40	80	77 (150)
2x2	50	20	40	72 (140)

Table 1 – Scan Configuration

A.2 GROUND SYSTEM – OVERVIEW

Conversion of raw sounding data from the Airborne System to final data is accomplished on a Ground System. There are four Ground Systems available for operations, as follows:

a. Ground System Gandalf, consisting of a Compaq Alpha ES40 Server 3 processor server with 1 GB EEC RAM, 764 GB disk space, DLT drives and magazines, DAT drive, CD ROM drive and is networked to 12 Compaq 1.5 GHz PCs.

b. Ground System Frodo, consisting of a Compaq Alpha Server ES40 3 processor server with 1 GB EEC RAM, 764 GB disk space, DLT drives and magazines, DAT drive, CD ROM drive and is networked to up to 12 Compaq 1.5 GHz Pcs.

c. Ground System Hobbes, comprising a four CPU Compaq (DEC) Alpha Series 4100 multi-processor server with 256MB ram, up to 750GB disk space, digital linear tape (DLT) drives, digital audio tape (DAT) drives and networked to a series of X-term or personal computer operator consoles, HP 750c DesignJet plotter, printers and QC workstations.

d. Ground System Katrina, consisting of a Compaq Alpha Server ES40 3 processor server with 1 GB EEC RAM, 764 GB disk space, DLT drives and magazines, DAT drive, CD ROM drive and is networked to up to 12 Compaq 1.5 GHz Pcs.

The hydrographic software is a Tenix LADS Inc. proprietary package written in ADA to operate in a UNIX True-64 (DEC) environment.

The GS provides the facilities for all LADS survey management tasks from initial mission planning through to production of smooth sheets and deliverable digital data.

The primary functions are:

- Mission planning. This includes the specification of the total survey area, spheroid and grid, survey sub-areas, line spacing, swath widths, survey lines to cover the sub-area, individual survey lines, crosslines, tidal areas and navigation check points.
- Sortie planning. A sortie plan is the specification of a series of survey objectives to be executed by the AS. Survey lines and navigation check objectives are selected by the operator and written to floppy disk along with grid and spheroidal information.
- Sortie processing. This function calculates sounding depths and positions from the raw sounding data logged by the AS. Depths and positions are associated with various confidence metrics.
- Data validation, checking and approval. Surveyors validate the calculated soundings on a run-by-run basis editing soundings as appropriate. The validated data is checked by a more senior surveyor and finally approved by the Field Party Leader.
- Data output. Approved data is output to the client in digital form along with hardcopy smooth sheets.

In addition, the GS provides facilities for the generation of survey management plots and reports.

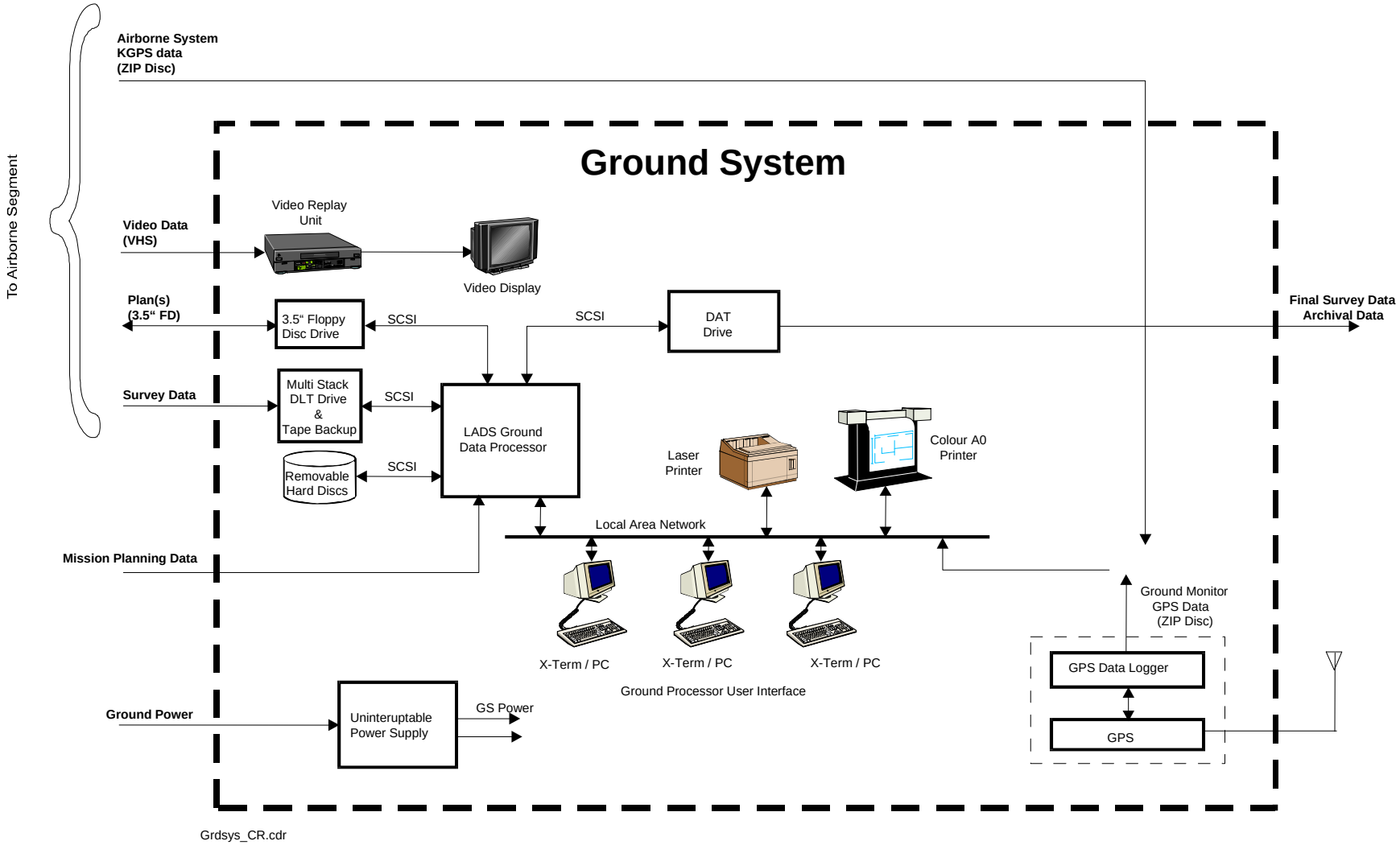


Figure 5 – Block Diagram of the LADS Mk II Ground System

A.2.1 Mission Planning

At the commencement of a survey one or more databases are established on the GS. Each database contains spheroid and grid data, tide data and survey objectives.

Sub-areas are defined covering the specific areas to be surveyed. Survey lines are then generated with each sub-area at operator specified line spacing. Other survey lines can be specified by entering start and end coordinates.

A.2.2 Sortie Planning

Prior to each sortie survey objectives are selected from the appropriate database. The start and end coordinates of the required survey lines are written, together with spheroid and grid data, to a sortie plan on a floppy disk. This plan is read by the AS and used to control sortie operations.

A.2.3 Data Processing

Processing parameters are set prior to processing. The post processed KGPS positions from the local reference station are applied first. Preliminary tides are applied and final verified tides can be reapplied at a later time.

Raw sounding data logged by the AS is automatically processed by the GS to produce depth, position and a series of confidence parameters.

On completion of automatic line processing operator validation, checking and approval of the sounding data can be conducted.

A.2.4 Data Organization

Data within the GS database is held on a line-by-line basis. Within lines data is grouped into one second frames made up of 18 scans of 48 sounding pulses i.e. 864 pulses per frame.

A.2.5 Primary and Secondary Soundings

All soundings comprise the primary sounding set. Where data set reduction is required a shoal-biased subset of the primary soundings called secondary soundings is created. Secondary soundings form a shoal-biased sub-set based on operator selected confidence and secondary selection radius criteria. Only secondary soundings are validated, checked, approved and output. For this survey a secondary sounding reduction radial of one meter has been used which means all soundings have been hydrographically reviewed and all valid soundings have been provided in the final data set.

A.2.6 Automatic Data Processing

Automatic processing is completed in two stages:

i. Sortie Tape Processing (STP).
STP reads the data on the tape and stores it in the internal GS database for further processing. The data is line based, and consists of raw waveform data, navigation data, platform data, system data, and error and event logs. This process also includes producing a backup of the Raw Data Tape on DAT or DLT.

ii. Sortie Run Processing (SRP).
SRP is the second and major processing phase during which sounding depths and positions are calculated on a line-by-line basis. The process is normally triggered automatically by STP as each line becomes available but may be invoked later by the operator if reprocessing of lines with different processing parameters is required.

The major processing steps of SRP are:

- Apply post-processed KGPS positions and height to the raw data.
- Process the Raw Waveform to identify surface reflections.
- Process the Raw Waveform to identify and calculate initial depths for the two most likely bottom return pulses.
- Classify each of the identified bottom return pulses by signal noise ratio, agreement with near neighbors and a maximum likelihood estimator.
- Select the most likely bottom return pulse based on the above classification and a shoal weighting function.
- Model the sea surface from the available surface pulses.
- Correct the bottom depths for sea surface datum including tide, slant range, optical propagation and early/late entry. Tidal corrections may be reapplied later if required.
- Calculate position of each sounding on the seabed. This algorithm uses KGPS fixes, aircraft track and speed, antenna offsets, platform attitude (heading, roll and pitch), beam scan angles and sounding depth. Where the GS is unable to determine a depth from the raw data the sounding is classified as “No Bottom Detected” (NBD).
- Calculate primary confidence indices (0-9) for each non-NBD sounding and all frames where:

  C0 = Subsurface Pulse Confidence (signal to noise)

  C1 = Near Neighbor Confidence

  C2 = Pulse Type Confidence

  C3 = Position Confidence

  C4 = Sea Surface Reference Confidence

C5 = Not Used

C6 = Coverage Confidence (confidence that the swath covered the planned width)

CW = Weighted Primary Confidence

- Store each sounding and associated confidence data in the database.
- Determine the secondary sounding sub-set (it may be appropriate to have all soundings classified as secondary) and for each secondary sounding calculate and store secondary confidences.

  CS1 = Secondary Neighbor Confidence (near neighbor agreement)

  CS2 = Useable Points Confidence

  CS3 = Secondary Area Confidence

  CSW = Weighted Secondary Confidence

A.2.7 Bottom Object Detection (BOD)

A particular feature in the SRP improves the ability of the LADS Mk II GS to detect small objects on the seabed.

The BOD algorithm proceeds in two phases, each phase can be independently enabled/disabled and tuned via a series of BOD processing parameters set by the operator prior to SRP processing.

Phase one of the algorithm is designed to detect objects 2-3m in height while phase two is only invoked if phase one fails. Phase two is more sensitive and intended to find objects less than 2m in height.

A.2.8 Line Reprocessing and Segmentation

It may be necessary to reprocess the same raw sounding data with different processing parameters. The run identification scheme adopted in LADS Mk II provides a mechanism to manage the reprocessing of survey line data a number of times.

After a line is reprocessed the required segment can then be set to accepted, and the remaining data can be set to anomalous or rejected and is therefore ignored by the system.

A.3 GROUND SYSTEM – USER INTERFACE

The following displays and their associated operations are the primary tools used for validation, checking and approval.

A.3.1 Composite Depth Profile Display

The Composite Depth Profile is used for overall assessment of the depths along the line and the general quality of the data. The operator may pan and zoom along/into the line. The position in eastings and northings of the nadir at that point, the distance along track, time of acquisition and frame number of the point under the cross hairs is displayed as the operator pans along the line.

The operator can position cross hairs at the point of interest on this display before invoking more detailed displays. The new displays are initialized at the coordinates of the cross hairs.

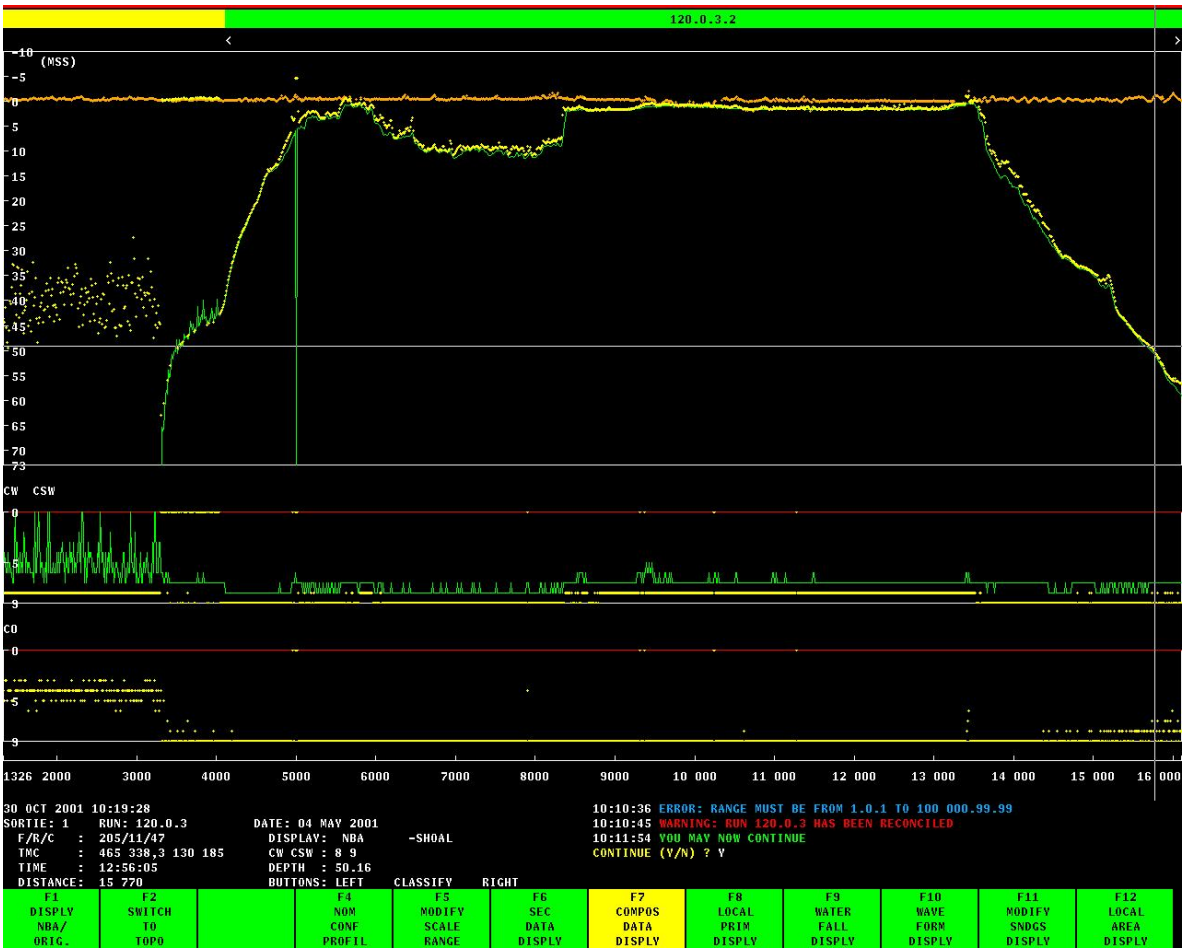


Figure 6 – Composite Depth Profile Display

Three profiles, with distance along track on the X axis and depth on the Y, are superimposed on this display:

- For each scan the average of all soundings across a scan is graphed as a green line. If the number of NBD soundings in the scan exceeds a specified number (set as a processing parameter) the green line is drawn across the bottom of the display.
- The shoalest secondary sounding in each scan can be displayed as a yellow dot.
- The deepest secondary sounding in each scan can be displayed as a yellow dot.

These profiles enable the operator to rapidly assess where there is a high NBD count and assess where there are areas of noise.

Below the depth profiles two operator selectable profiles are displayed. Each of these can be one of:

- Any of the primary or secondary confidences.
- Parameters related to the integrity of the height datum.
- Tidal correction and tidal area boundaries.

A.3.2 Local Primary Display

The Primary Depth Display shows the depths of all soundings across and along one second of the swath. Soundings are arranged logically (not by position) as a row per scan of 48 soundings across the row, a white bar between rows indicates a frame boundary. Primary soundings are green and secondary yellow with NBD soundings marked as “NB”.

The length of the bar between the integer and decimal values of the depth of each sounding is proportional to the primary (CW) or secondary weighted confidence (CSW) as appropriate.

The operator may scroll forward or backward along the line and position the cursor over soundings for which detailed displays e.g. waveform display or sounding audit display are required.

The position, time, frame, row, column and confidences are displayed for the sounding under the cursor.

Figure 7 – Local Primary Display

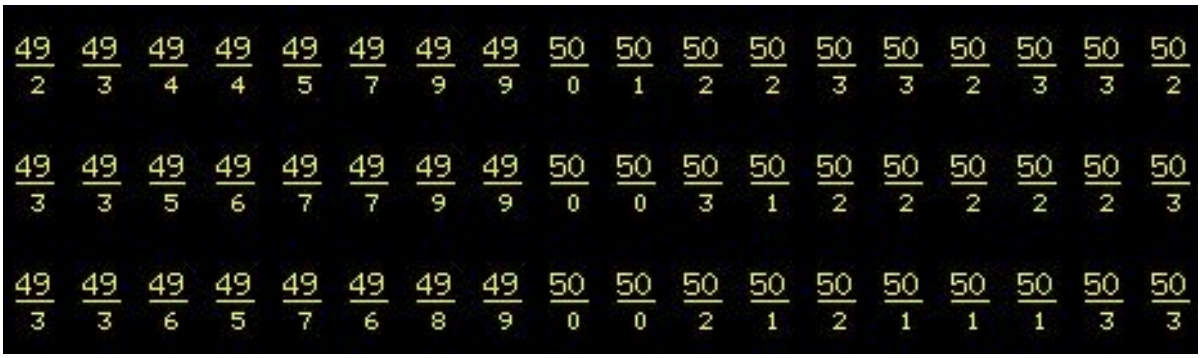


Figure 8 – Enlarged depiction of soundings in Figure 7

A.3.3 Sounding Waveform Display

The Sounding Waveform Display shows a matrix of nine sounding waveforms centered on the current or nominated sounding. The display is invoked from the primary or waterfall displays and can then be scrolled along or across the swath. This display allows an operator to assess the actual quality of the data and to resolve or clarify specific sounding values eg. incorrect selection from multiple bottom returns or a false sounding value due to noise in the signal.

Within each waveform window the frame, row, column, gain settings, position, depth, and signal/noise ratio are presented. A more detailed discussion of the interpretation of waveforms is given in the Laser Waveforms – Nature and Interpretation section.

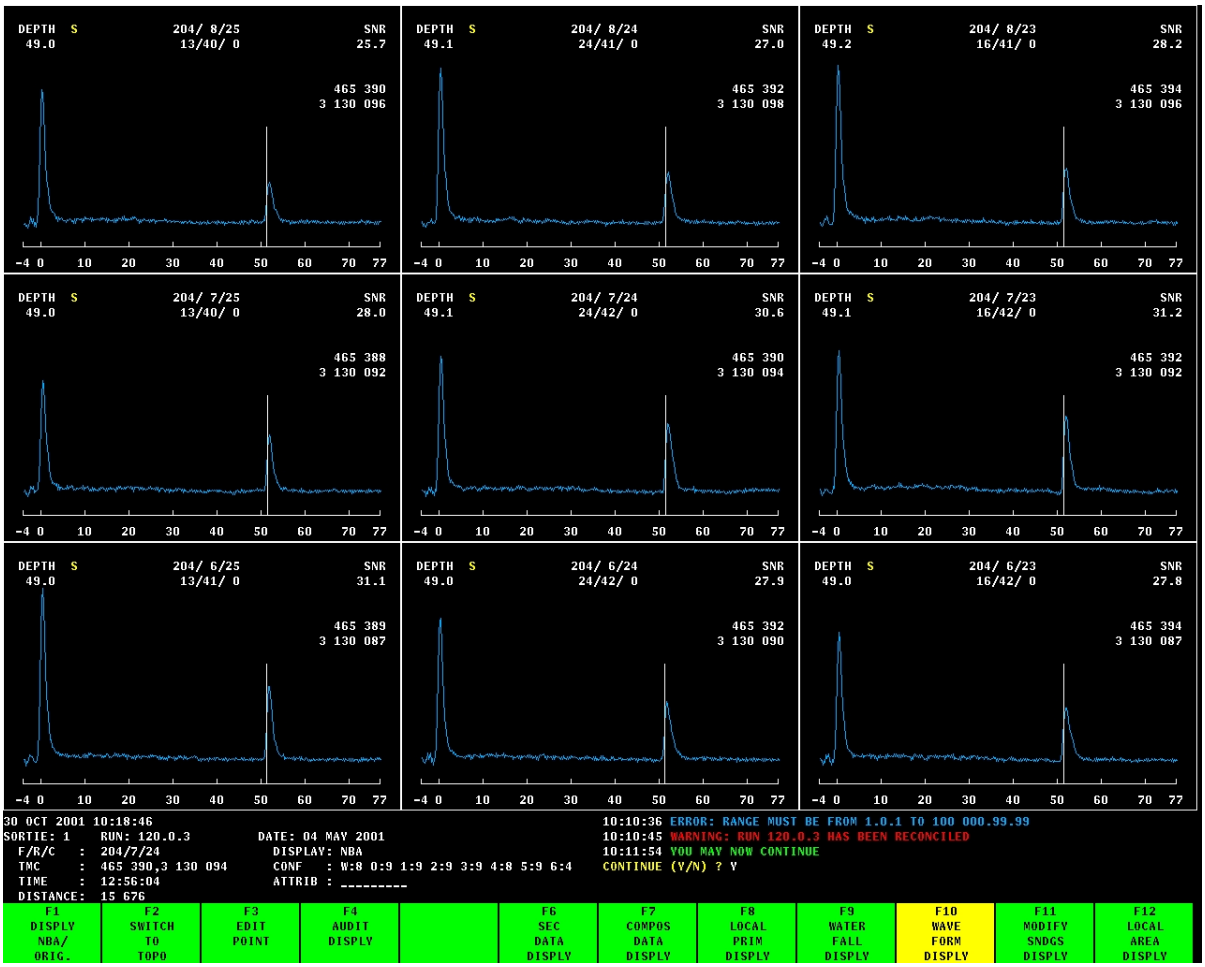


Figure 9 – Sounding Waveform Display

A.3.4 Depth Waterfall Display

The Depth Waterfall Display is a pseudo 3-D display constructed from multiple color coded profiles of the depths across each swath for three frames along a line. Secondary soundings are displayed as yellow dots. The operator may scroll forward or back along a line and select an individual sounding for which to invoke the waveform display.

The display allows an operator to gain a general assessment of the shape and nature of the bottom and is particularly good for identifying seafloor objects or anomalous or noisy data.

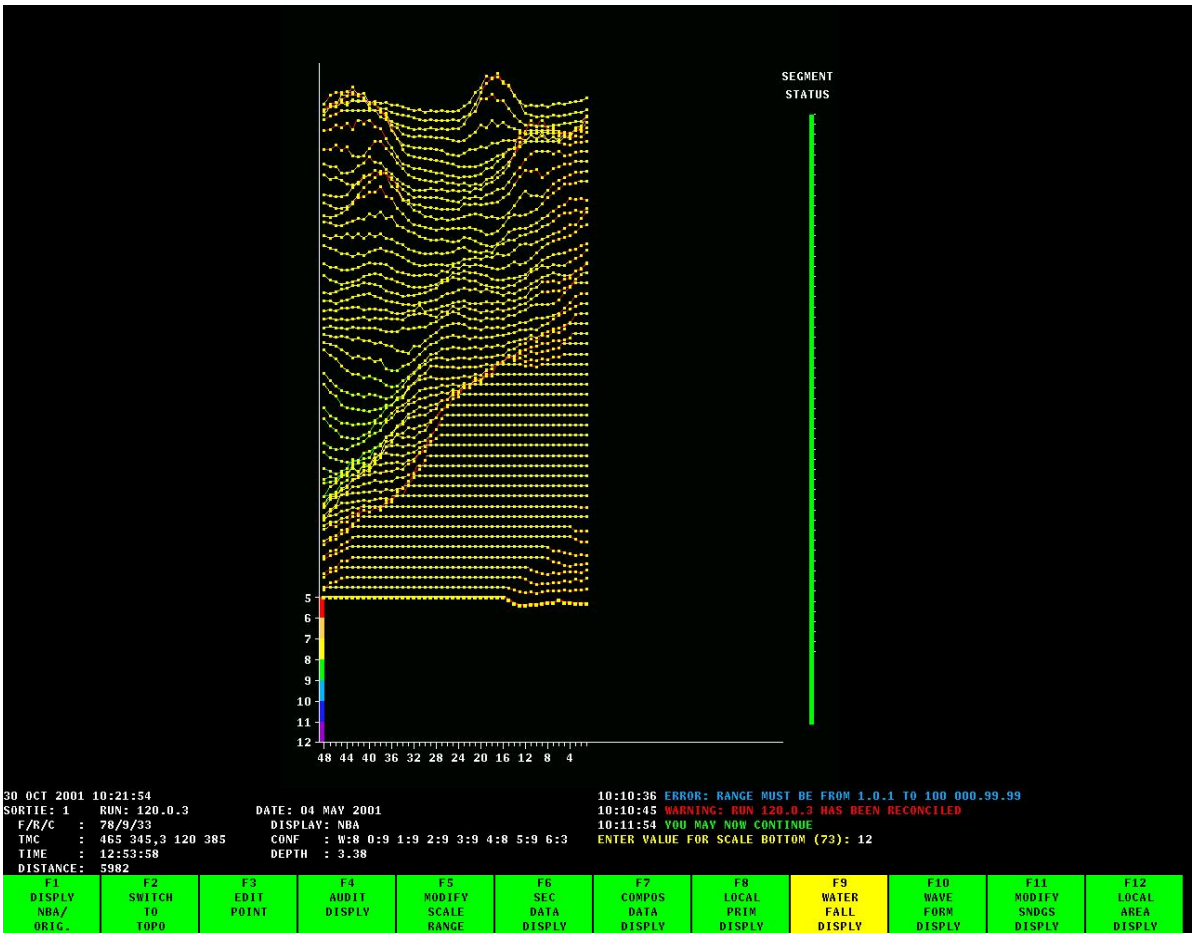


Figure 10 – Depth Waterfall Display

A.3.5 Local Area Display

The primary purpose of the Local Area Display is to check consistency of data across overlapping runs. Facilities provided include coverage and depth variation checks (based on grid cells of nominated size) and tinned contouring.

When a line is selected for validation, all lines overlapping the selected line are available to view and compare within this display. The operator nominates overlapping lines appropriate for the current validation. When this display is invoked, the soundings from the currently selected line and nominated overlapping lines, centered on the current cursor position (as set in the Composite or Primary Displays), are shown. Soundings are presented in their true geographic positions and color banded by depth.

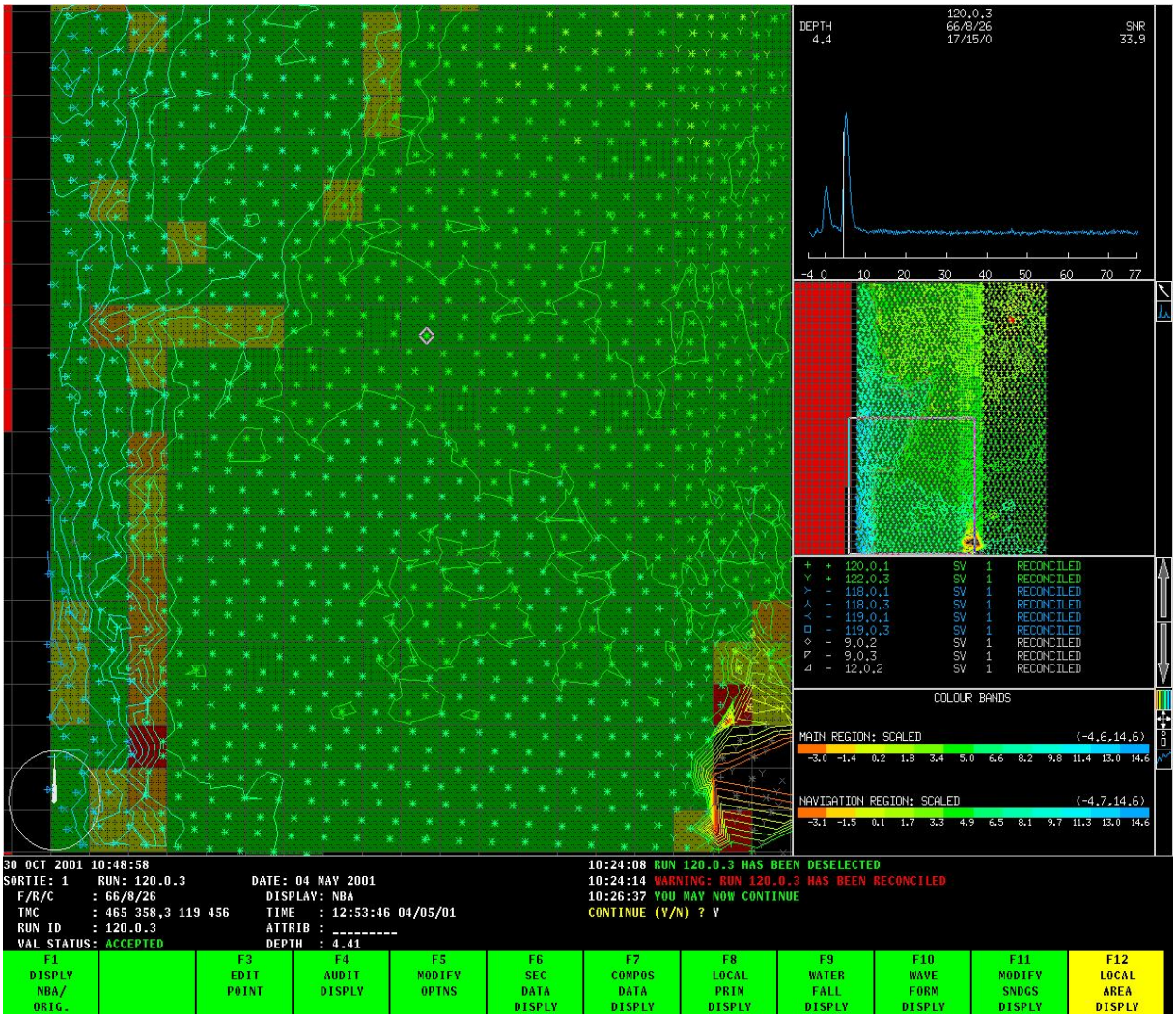


Figure 11 – Local Area Display – Small Scale

The display is divided into five sub-windows:

- The navigation window, second on the right, provides a top-level view of the area currently selected.
- The working window, on the left, provides a detailed scalable view of a sub-region. The operator may pan, zoom and select soundings in this window. A white rectangle within the navigation window shows the position and extent of the area displayed in the working window.
- The waveform window, top right, shows the waveform for the currently selected sounding, highlighted by a white triangle, from the working window.
- The runs window, third on the right, lists the nominated overlapping runs along with the symbol used to represent soundings from that line. A subset of the runs may be selected for display and analysis and these are highlighted.
- The color band window shows the operator set color band ranges for the navigation and working windows.

The lower region of the screen displays summary information similar to that on the Composite and Primary Displays i.e. eastings, northings, time etc.

TIN contours of the displayed soundings are typically shown in both the navigation and working windows.

For the purposes of coverage and depth variation checks the operator selects a cell size appropriate to the sounding density. For each cell the system checks coverage criteria, cells that pass are color filled and failed cells are displayed as black. The color of a cell indicates the degree of variation in the depths of soundings within the cell. Green represents small variation with an increasing red component as the depth variation increases (Figure 11).

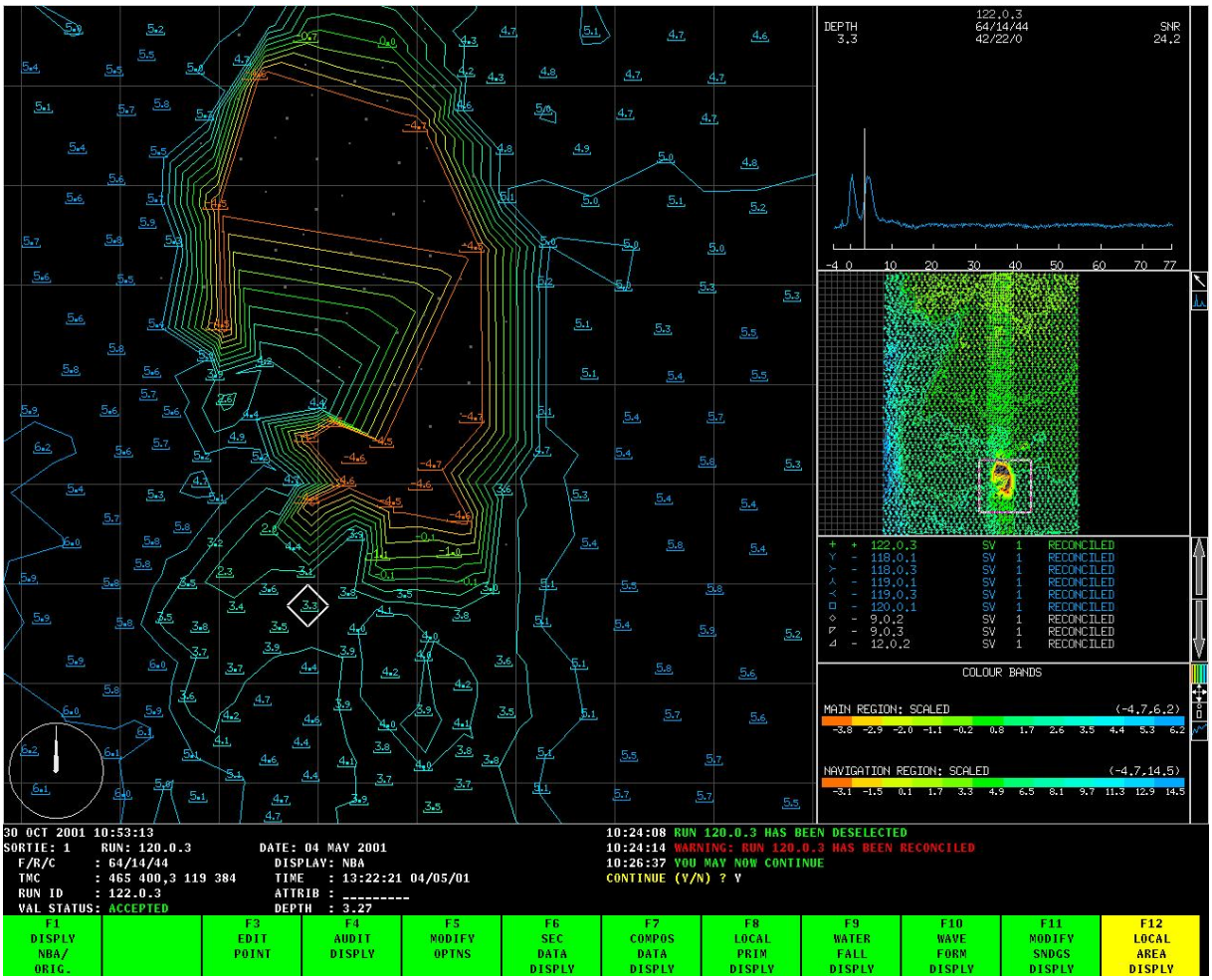


Figure 12 – Local Area Display – Medium Scale

In both the navigation and working window the soundings are displayed at their geographical positions. Soundings are shown as symbols (a separate symbol per line) in the navigation window and at small (zoomed out) scales in the working window (Figure 11). As the operator zooms in on the working window symbols in the working window are replaced by depth values (Figure 12). The sub-region displayed in the working window is represented by a white square in the navigation window.

On selecting a sounding in the working window the sounding is highlighted with an enclosing diamond and its waveform is shown in the waveform window.

A.3.6 Audit Display

The Audit Display is used to check additional data associated with a sounding. The display enables an operator to check details such as the aircraft height and heading, platform angles, mirror scan angles and tidal reduction of the sounding.

A.4 SOFTWARE VERSIONS

System	Version	Remarks
Tenix LADS Airborne System	AS 8.1.4	
GPS Base Station Receiver	-	Ashtech Z12
GPS Airborne Receiver	-	Ashtech Z12
GPS Logging	5.6.0	Ashtech PNAV Datalogger Software.
GPS Processing	2.5.5	Ashtech PNAV (Precise Differential GPS Navigation Trajectory Software)
Tenix LADS Ground System	E6.10.13 E7.1/031	
CARIS BASE Editor	2.0.0.0	
CARIS HIPS and SIPS	6.0.2.16	

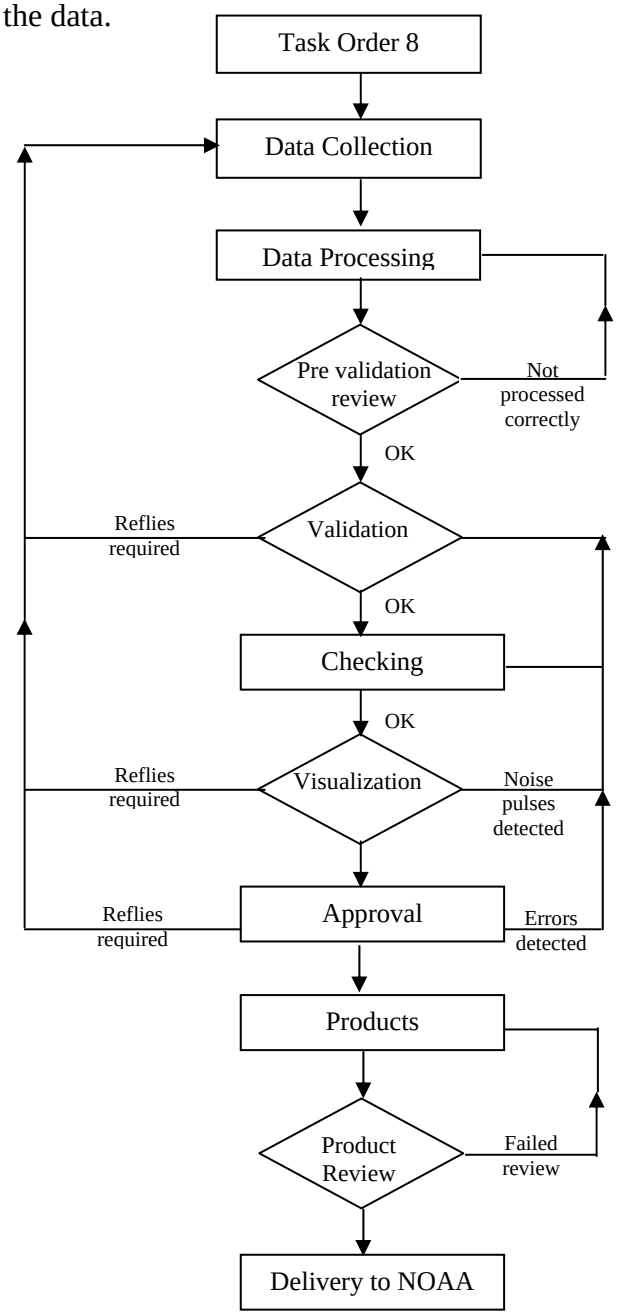
Table 2 – Software versions

B. QUALITY CONTROL

B.1 DATA PROCESSING

Data processing involves the following stages:

- Automatic Data Processing, described earlier.
- Pre-validation of the data by a senior surveyor.
- Validation of the data by a hydrographic surveyor.
- Checking of the data.
- Visualization of the data.
- Approval of the data.



B.2 PRE-VALIDATION

Pre-validation is the first interactive step of data processing.

Pre-validation is conducted to confirm that the automatic data processing has been performed correctly and to give guidance for the validation process. In addition, the required data is segmented to ACCEPTED status for validation by hydrographic surveyors.

Pre-validation is conducted by a senior hydrographic surveyor.

B.3 VALIDATION

Validation proceeds through the following steps:

1. Examining the Depth Profile for the correct processing of each expected Survey Run.
2. Examining the Position Confidence (C3) profile to verify that adequate position accuracy is maintained during the Survey Run. Note: Other profiles of supporting data such as EHE, number of satellites, and latency may also be examined as run profiles.
3. Examining the Coverage Confidence (C6) profile to verify that no coverage gaps exist in the Survey Run.

Resolving anomalous soundings by examining data points in the Survey Run by checking:

a. The Primary Depth Display
b. The Waterfall Display
c. The Waveform Display
d. The Local Area Display

Editing operations include selection of the alternate depth, assignment of NBA or deletion of the sounding as appropriate.

Based on assessments made in the above steps the operator segments the line classifying each segment as:

a. Accepted
b. Anomalous (data not to be used) or
c. Rejected (for refly)

All operator interactions during the validation phase are logged so that complete traceability is maintained.

B.4 CHECKING

When a line has been validated it is passed to a checker. All edits made by the validator are marked on the line and logged in a validation log. The checker independently assesses the line and checks the validation edits.

B.5 DATA VISUALIZATION

All validated and checked data is exported from the GS in a defined ASCII format for spatial presentation and checking. The position, depth, run and other relevant information are extracted from the line-based data for use in the generation of Triangulated Irregular Networks (TINs) and gridded data sets. Both of these are used to produce contour plots, sun-illuminated color banded images and coverage check plots. Anomalies found in these plots are reported back to the checkers for remedial action in the GS.

A number of software packages are used to produce these QC products namely:

Visualization and QC	10.30	Terramodel
	3.3.1	Generic Mapping Tools (GMT)
	3.1	Visualization Tool Kit (VTK)
	4.2	Olex
	6.0.2.16	Caris HIPS / SIPS

B.6 APPROVAL

In the final phase the Survey Team Leader reviews each line prior to approval.

B.7 AUDIT TRAIL

All actions in validation, checking and approval are logged on appropriate forms and the procedures used have been certified as conforming to ISO-9001 Quality Assurance standards. In addition, all operator actions are logged by the GS.

B.8 TAGGING OF SOUNDINGS

The GS supports interactive tagging of soundings by operators using S-57 compliant and operator defined tags.

During the data processing, the following user defined items were tagged:

- Data gap due to mangroves…… GM
- Data gap due to secondary exclusion zone…… GS
- Data gap due to turbidity……... GT

- Data gap due to buildings…….. GB

S-57 compliant tags were also assigned to items such as:

- Buoys
- Jetties and piers

The presence of mangroves in near shore areas in particular, where the mangroves are growing in the water along the shoreline resulted in a first detection foliage before the depth return or true base earthy return. This erroneous data was removed and the extents of the resulting gaps delineated by a “GM” tag. Most often in these cases the high water line has been dashed in BASE editor and exists in the features file. The dashed line has been approximated using a combination of the tags out of the GS and the orthophoto mosaic.

A data gap due to the secondary exclusion zone occurs at the land / sea interface where the waveform return from the seabed is mixed with the waveform return from the sea surface. Neither the seabed nor a drying sounding can be determined so a gap exists in this shallow area. In most cases, the gap is filled by flying alternate lines at a different tidal state. However, this could not be achieved due to the small tidal range throughout the survey area.

A data gap due to turbidity is a gap due to poor water quality, which has not been resolved during the survey.

A data gap due to buildings occurs when man made structures are built to the waters edge and the high water line cannot be derived.

B.9 LASER WAVEFORMS - NATURE AND INTERPRETATION

The Sounding Waveform Display (Figure 13) contains the following data:

- Graphic of raw laser waveforms showing return from the water surface ① and seabed ② for a matrix of 9 adjacent soundings.
- Depth bar showing depth of the seabed ③ and alternative seabed ④ if it exists.
- Depth of the seabed ⑤ and alternative seabed ⑥.
- Signal noise ratio of the seabed ⑦ and alternative seabed ⑧.
- Reference position of sounding in frame/row/column ⑨.
- Real time green receiver gain values for sounding measurement ⑩.
- Grid coordinates of sounding on the survey spheroid and grid ✇.

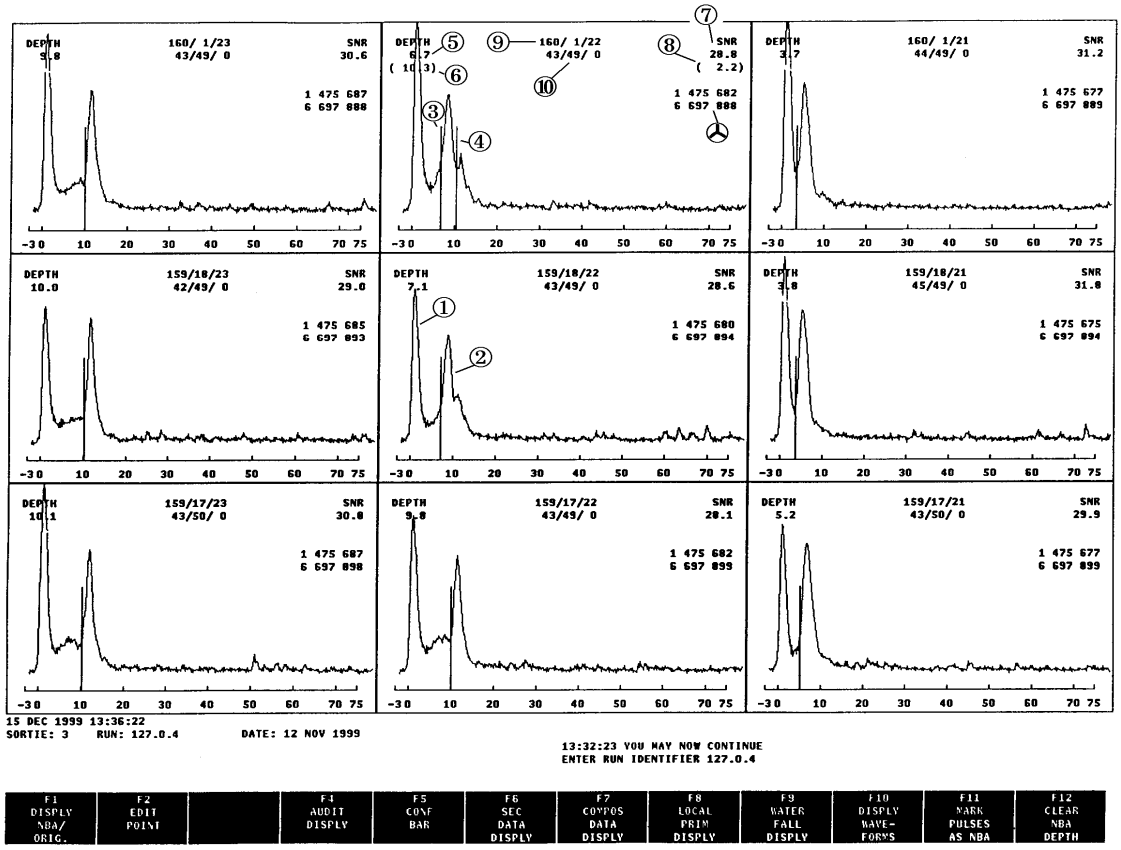


Figure 13 – Annotated Sounding Waveform Display

The raw laser waveform represents the level of energy detected by the green receiver as a function of depth. A surface model, or datum, is then calculated from the infra-red, GPS and inertial (AHRS) heights and filtered green surface returns. The SRP then selects up to two possible seabed returns for each waveform based on signal to noise criteria. If no possible seabed returns are found the sounding is classified as NBD.

Depths, measured from the surface datum to the 50% point on the leading edge of a seabed return, are calculated for each possible seabed return. These depths are then corrected for the optical path of light through the water and the height of tide.

Where two seabed returns were found the most likely is selected based on S/N versus depth criteria. The selected return is indicated on the waveform display by a white depth bar the other in blue. During validation the operator will check these selections and edit as appropriate.

Objects on the seabed will appear on the raw laser waveform before the seabed. Detection of an object on the seabed will depend on both the density of the scan pattern, gain of the system, backscatter from the water column and the ratio between the level of laser energy reflected from the target and that from the illuminated area of the seabed. The latter is in turn influenced by the size of the target, the depth of water (which effects the area of seabed illuminated) and the reflectance of the target compared with the surrounding seabed.

Backscatter from the water column is received as noise on the raw laser waveform and ultimately limits the maximum gain that can be applied which controls the maximum depths that can be measured by the system.

B.10 DATABASE MANAGEMENT AND SURVEY LINE IDENTIFICATION

Sub-Area	Lines	Sounding Density	Line Type	Remarks
Cabo Rojo to Punta Jorobado	100-259	4x4	Survey	Survey mainlines
Bahia Sucia and Bahia de Boqueron	300-306	4x4	Survey	Survey mainlines
Cabo Rojo to Punta Guanajibo	400-627	4x4	Survey	Survey mainlines
Bajo Galardo to Arrecife Tourmaline	812-930	4x4	Survey	Survey mainlines
Punta Jorobado to Isla Matei	1100-1116	4x4	Additional coverage lines	For additional coverage
Canal de Guanajibo	1220-1284	4x4	Additional coverage lines	For additional coverage
North Bahia de Boqueron	1301-1315	4x4	Additional coverage lines	For additional coverage

Sub-Area	Lines	Sounding Density	Line Type	Remarks
South Bahia de Boqueron	1414-1415	4x4	Additional coverage lines	For additional coverage
Canal de Guanajibo	1508	4x4	Additional coverage lines	For additional coverage
Isla Guayacan to Arrecife Romero	1601-1615	4x4	Additional coverage lines	For additional coverage
Turrumote Is. To Bahia Montalva	1650-1652	4x4	Additional coverage lines	For additional coverage
Pasaje de Margarita	1660	4x4	Additional coverage lines	For additional coverage
Cayo Enrique to Arrecife Romero	1702-1706	4x4	Additional coverage lines	For additional coverage

B.10.1 Water Clarity

When the possibility of conducting a lidar survey in Puerto Rico arose, the first cause of action was to conduct a desk study of the proposed survey area. The initial porposed survey area was the west coast of Puerto Rico from Cabo Rojo in the south to Punta Agujereada in the north. The desk study was undertaken to confirm the suitability to conduct a bathymetric lidar survey and analyze the expected effectiveness of such a survey. The desk study indicated that the west coast of Puerto Rico suffers from extensive run off from a number of rivers. The results of the desk study showed that the months of minimal rainfall in Puerto Rico is from January to March and that the rivers have their least flow rates from March to May. Based on these observations it was decided that a field reconnaissance should take place to verify the water clarity and confirm the presence of turbidity due to run off. On January 31, 2006, the first set of secchi disk measurements varied from excellent to marginal. This reconnaissance confirmed the presence of large areas of turbidity due to river out flows. This was reported back to the COTR at NOAA and the proposed survey area was adjusted by limiting the survey area to the north at approximately Punta Guanajibo and extended around Cabo Rojo eastwards along the south coast to approximately Punta Jorobado.

To verify this area, a second set of secchi disk observations were taken where a number were repeated from the first reconnaissance and extend the observations eastward along the south coast. The results from this second reconnaissance confirmed the first reconnaissance and confirmed the suitability of conducting bathymetric lidar along the south coast.

In summary, there will be turbid areas inshore along the west coast. However, offshore and along the south coast are most suitable during spring time to conduct bathymetric lidar. Both water clarity reconnaissance reports are presented in the Separates.

B.10.2 Line Identifiers

Line identifiers within the LADS Mk II system uniquely define a specific line and are made up of 4 fields separated with a point '.' as follows:

(Items in <> are the generic names for the fields.)

<LineNumber>.<Section>.<Sequence>.<Child>

eg. 101.1.2.3

Maximum fields are
100000.99.99.9

LineNumber – Range 1..100000
This field uniquely defines the line and is chosen by the operator when defining a line.

Section – Range 0..99
This field denotes the section of the line.

Zero indicates the whole original line. When the line or part of the line is reflown the section number is incremented. Thus:

101.0.x.x is the original line

101.1.x.x is the first refly and

101.2.x.x is the second refly.

Sequence – Range 1..99
This field denotes the number of times the logged data for the specific <LineNumber> .<Section> has been processed. Each time a line is processed by the Sortie Run Process (SRP) function the GS allocates a new sequence number for the line. Thus:

101.0.1.x is the first processing of the original line
101.0.2.x is the second processing of the original line
101.1.1.x is the first processing of the first refly and
101.1.2.x is the second processing of the first refly.

Child – Range 1..9
This field denotes the segment (or child section) of a <LineNumber> .<Section>.<Sequence>.

Hydrographic surveyors divide lines into ACCEPTED, REJECTED or ANOMALOUS segments during the Line Validation process. These segments are given sequential child numbers. Thus:

101.0.1.1 – is the first child (segment) of the first processing of the original line.

101.1.2.3 – is the third child (segment) of the second processing of the first refly.

B.10.3 Processing Parameters

Each survey line is processed with a specific set of processing parameters, with the set used for the line recorded on the Survey Line History Sheet for the line. Full details are recorded in the survey data management folder held by TLI.

B.11 DATA OUTPUT AND DELIVERABLES

Digital data deliverables and graphics (BAG surface, S-57 feature file) and georeferenced orthophoto mosaic are output and prepared in accordance with:

- NOS HYDROGRAPHIC SURVEYS. SPECIFICATIIONS AND DELIVERABLES. June 2006.
- STATEMENT OF WORK. LIDAR SURVEY SERVICES. OPR-I305-KRL-06 of February 8, 2006.

All data is exported in meters as per the above documents.

Digital datasets delivered are:

- Full resolution dataset
- BAG surface created in CARIS
- S-57 feature file created in CARIS

Full resolution dataset:
A full resolution dataset is created during export from the GS. The export is in a CARIS compatible format (*.CAF) and includes both accepted and rejected data. Data is stored to centimeter precision and is in meters. Soundings are not rounded.

BAG surface:
Apart from being delivered as its own product, the CAF file is also imported into 3rd party CARIS for creating the BAG surface products. The BAG is created in CARIS using the Uncertainty BASE Surface using a resolution typically around 3-4 meters.

S-57 feature file:
The S-57 feature file contains features such as rocks, islets, MHW line, MLLW line, mangrove areas, and has replaced the traditional smooth sheet. All features have been generated and attributed using CARIS software.

MHW and MLLW lines have been interpolated and edited where necessary using CARIS. The BASE surface has been used as the source for the interpolation of linework.

The MHW line was also quality controlled against georeferenced orthophoto mosaics, where available, to check for correct interpolation of the data, particularly in areas of over-hanging vegetation, white water and rocks / islets close to the coast.

Rocks were identified using the measured data, BASE surface and orthophoto then flagged in CARIS HIPS. The features were created as S-57 objects and attributed using CARIS BASE Editor.

All S-57 objects created in BASE Editor were exported to an S-57 file (*.000) as a final step.

File names for all items output by the GS are constructed as follows:

<RegistryNumber>_<VersionNumber>.<Extension>
where <Extension> is derived from the data type as per the following table:

Ext	Data Type	File format
txt	File containing GS export parameters	TXT
caf	LADS Mk II Caris Output Data	Caris compatible format
cbf	LADS Mk II Waveform Data	Caris compatible format

File names for all items output by CARIS are constructed as follows:

<RegistryNumber>_<VersionNumber>. <Extension>
where <Extension> is derived from the data type as per the following table:

Ext	Data Type	File format
.000	S-57 Feature File	.000 Ed 3.1
.hns	CARIS HYDROGRAPHIC NAVIGATION SURFACE	CARIS BASE Surface Format
.xml	CARIS BASE Surface parameters file	XML (Extended markup language)

B.11.1 File Naming Conventions

A directory listing of each delivered digital medium is provided in Appendix III.

C. CORRECTIONS TO SOUNDINGS

The optics and electronics for laser transmission and reflected waveform collection for all soundings is done by equipment mounted on a stabilized platform within the aircraft. This platform is stabilized by an Attitude and Heading Reference System (AHRS) that minimizes the motion effect (roll and pitch) of the aircraft and all residuals from the local horizontal are logged by the Airborne System for correctional processing by the Ground System.

Sounding depths and positions are determined in the Ground System from the raw waveform, aircraft height and platform attitude parameters as logged by the Airborne System.

The Ground System automatically corrects soundings for aircraft height and heading, offsets between sensors, latency, mirror and platform angles, sea surface model errors, refraction of the laser beam at the sea surface, the effects of scattering of the beam in the water column and reduction for tide.

Correct operation of the system is verified by static and dynamic position checks, benchmark lines and analysis of overlaps, redundancy from the 200% coverage of the seabed and crossline comparison results.

All laybacks are measured relative to the survey reference position on the aircraft which is the center of the scanning mirror. The GPS antenna used for position determinations in the AS is positioned on the upper side of the aircraft fuselage forward and to the left (facing forward) of the sounding reference position. The signal from this antenna is passed to a splitter, one signal going to the GPS receiver in the Navigation Systems computer of the AS and the other passes to the GPS airborne logger.

Offsets are from the sounding reference point to the antenna with the following axis and sign convention assuming the aircraft is level:

X positive toward the nose of the aircraft
Y positive to the left facing forward
Z positive vertically up

The offsets are:

X offset:	+ 1.895m
Y offset:	+ 0.43m
Z offset:	+ 2.45m

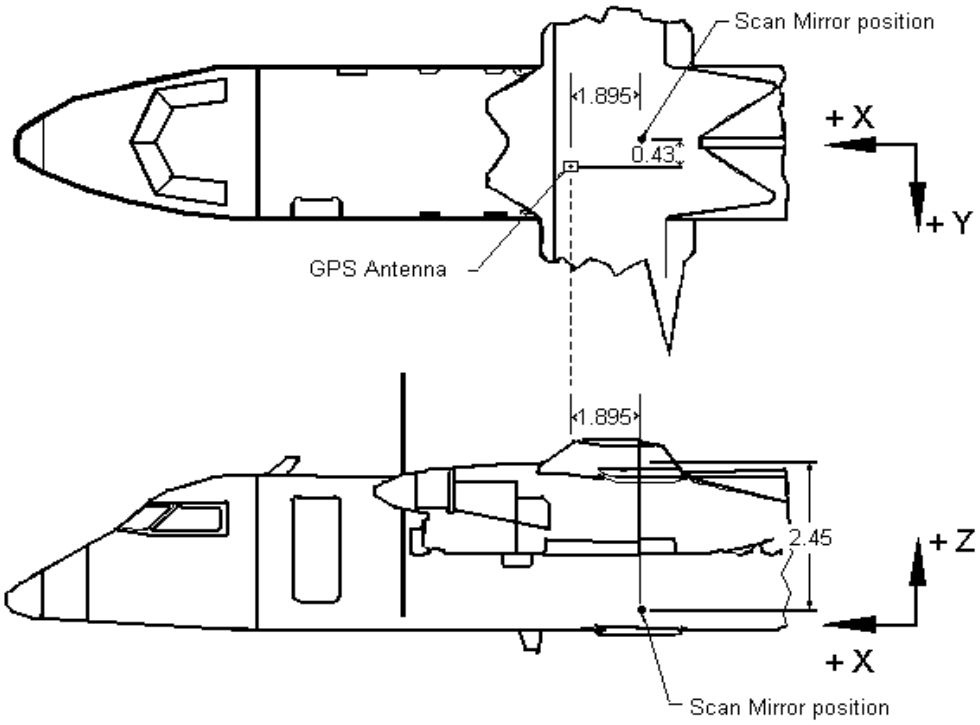


Figure 14 – Laybacks

D. APPROVAL SHEET

LETTER OF APPROVAL – OPR-I305-KRL-06

This report and the accompanying digital data are respectfully submitted.

Field operations contributing to the accomplishment of this survey were conducted under my direct supervision with frequent personal checks of progress and adequacy. This report and the accompanying digital data have been closely reviewed and are considered complete and adequate as per the Statement of Work.

Report	Submission Date
Data Acquisition and Processing Report	January 24, 2007

Mark Sinclair
Hydrographer
Tenix LADS Inc.

Date: January 24, 2007

APPENDIX I – LADS MK II GROUND SYSTEM OUTPUT FORMAT SPECIFICATION FOR CARIS

APPENDIX II – LADS MK II GROUND SYSTEM OUTPUT FORMAT SPECIFICATION FOR NOAA DELIVERABLES

APPENDIX III – LISTING OF DIGITAL AND HARDCOPY MEDIA