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-P135-KRL-07

Time frame April – June 2007

LOCALITY

State Alaska

General Locality Southeast Coast of Kodiak Island

2007

HYDROGRAPHER	**CHIEF OF PARTY**
MARK SINCLAIR	SCOTT RAMSAY

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NOAA FORM 77-28 (11-72) U.S. DEPARTMENT OF COMMERCE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION	REGISTRY No.
HYDROGRAPHIC TITLE SHEET	**H11664 – H11668**

State Alaska

General Locality Southeast Coast of Kodiak Island

Scale 1:10,000 **Date of Survey** April 27 to June 21, 2007

Instructions dated March 15, 2007 **Project No.** OPR-P135-KRL-07

Vessel Tenix LADS Aircraft, call sign VH-LCL

Hydrographer M.J. Sinclair **Chief of Party** S.R. Ramsay

Surveyed by J.G. Guilford, M.S. Hawkins, W.T. Newsham, M.H. Blackbourn, J.K. Young, B.A. Weidman, K.J. Oberhofer, C.N. Waite, B.C. McWilliam, G.X. Lotsos, D.J. Stubbing

Soundings by Laser Airborne Depth Sounder

Graphic record scaled by B.A. Weidman

Graphic record checked by S.R. Ramsay, J.G. Guilford **Automated Plot** N/A

Verification by

Soundings in Meters at MLLW. Islet heights are positive and are related to MHW.

REMARKS

Requisition / Purchase Req. # NCNJ3000-7-09220

Contractor Tenix LADS, Incorporated, 925 Tommy Munro Dr., Suite J, Biloxi, MS 39532

Sub-Contractor John Oswald and Associates, 12001 Audubon Dr., Anchorage, AK 99516

Times All times are recorded in UTC.

Datum and Projection NAD83, UTM (N) Zone 5

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.

Acronyms A complete list of all acronyms used throughout this report is provided at Appendix I of the Separates Report.

TABLE OF CONTENTS

A. EQUIPMENT

The LADS Mk II hydrographic survey system comprises two main subsystems. The Airborne System (AS) is used to acquire raw bathymetric data, real-time Global Positioning System (GPS) data, downward-looking video and digital imagery. The Ground System (GS) is used to plan operations, calculate depth values from the raw data, apply post-processed kinematic GPS (KGPS) positioning, apply tidal corrections, provide tools to allow the collected data to be evaluated and export digital data for the compilation of final survey deliverables. These two subsystems are complemented by other tools required for quality control activities; in particular, contouring, 3-D visualization and georeferenced imagery review. Third party software is also used for product compilation, image creation and survey management, namely CARIS and Terramodel. The general data flow between the subsystems and tools is illustrated in Figure 1.

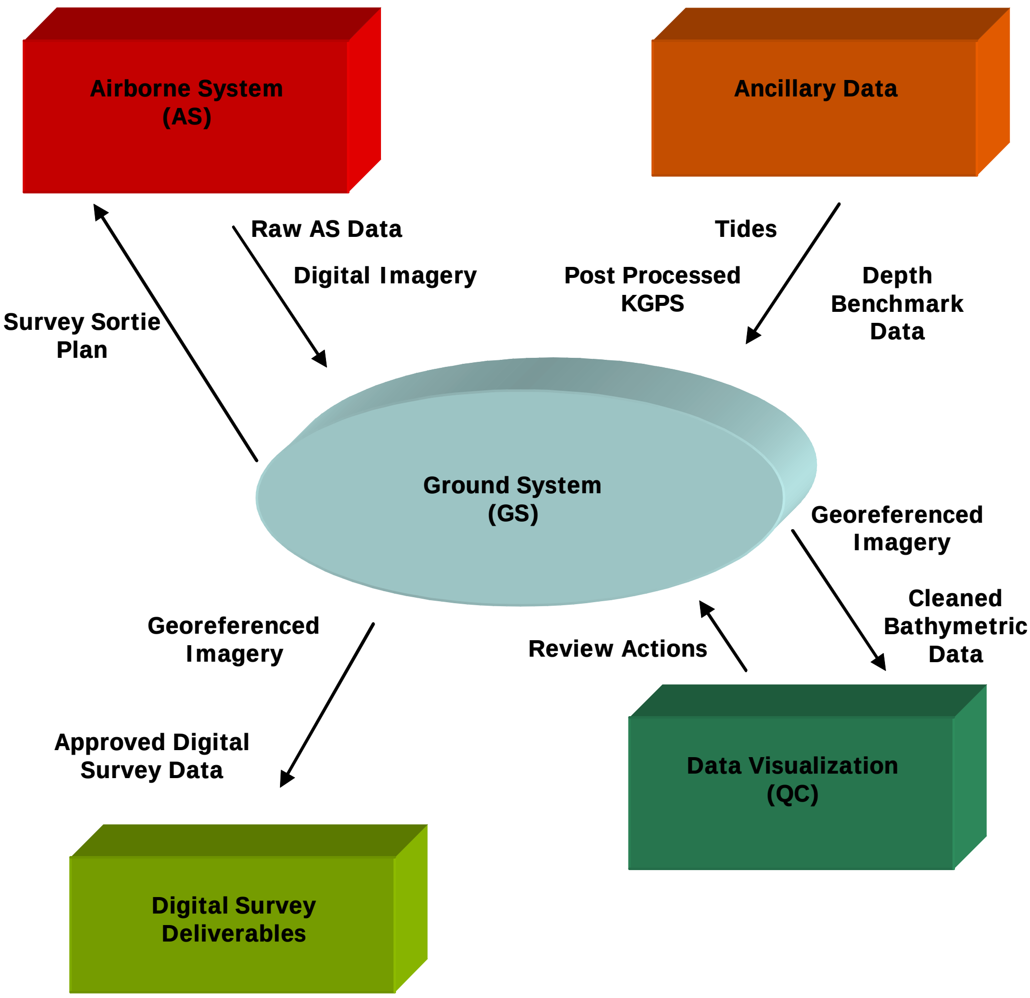


Figure 1 – General data flow within LADS Mk II

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 that is controlled via servo systems, using information from an Attitude and Heading Reference System (AHRS) mounted on the platform. Aircraft position information is obtained using GPS. 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:

a. The System Control Computer (SCC) for operator interface, logging and overall system coordination.

b. The Navigation System and Support (NSS) computer for position monitoring and control.

c. 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 (DLT).

Ancillary equipment includes:

- A video camera and VCR to display and record the view below the aircraft and a forward-looking video camera for real-time operator awareness.
- A Redlake MegaPlus II ES 2020 digital camera used to capture georeferenced imagery below the aircraft.
- Systems for temperature control of equipment.
- VHF transceiver and aircraft intercom.
- Satellite phone.

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 the main AS components and their functions are given under the headings below. Each of these components was checked by the LADS Technical Department on trials flights conducted during March 2007, in order to achieve the requirements of the LADS Mk II Performance Verification Certificate (provided at Appendix III).

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

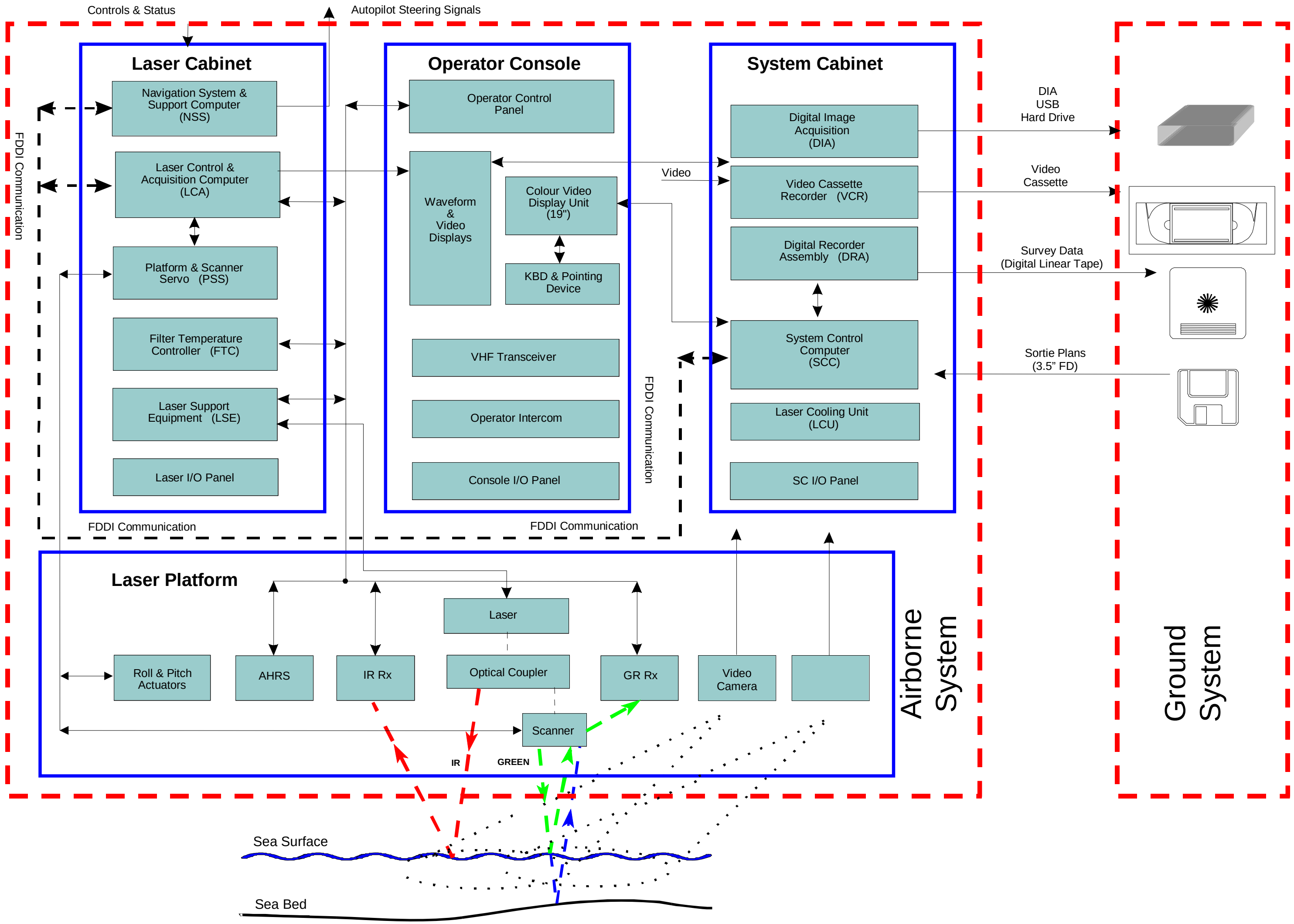


Figure 2 – AS Functional Block Diagram

A.1.1 Sounding Equipment

Soundings in the LADS Mk II system are obtained by the transmission of laser pulses via a scanning system aboard the aircraft and by 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. An 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, water column and seabed, and is used to determine water depth (refer to Figure 3 and Figure 4). The green return is transmitted via the scanner into a photomultiplier tube. The electronic outputs of the two return signals are electronically mixed prior to digitization.
- AHRS. The AHRS is a laser gyro inertial navigation system providing platform attitude information to the platform servo system, that in turn maintains platform stabilization. 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 SCC where it is logged to DLT.
- Waveform Display. This Cathode Ray Tube (CRT) display presents the operator with real-time sounding waveforms and is used by the operator to check data quality during acquisition.

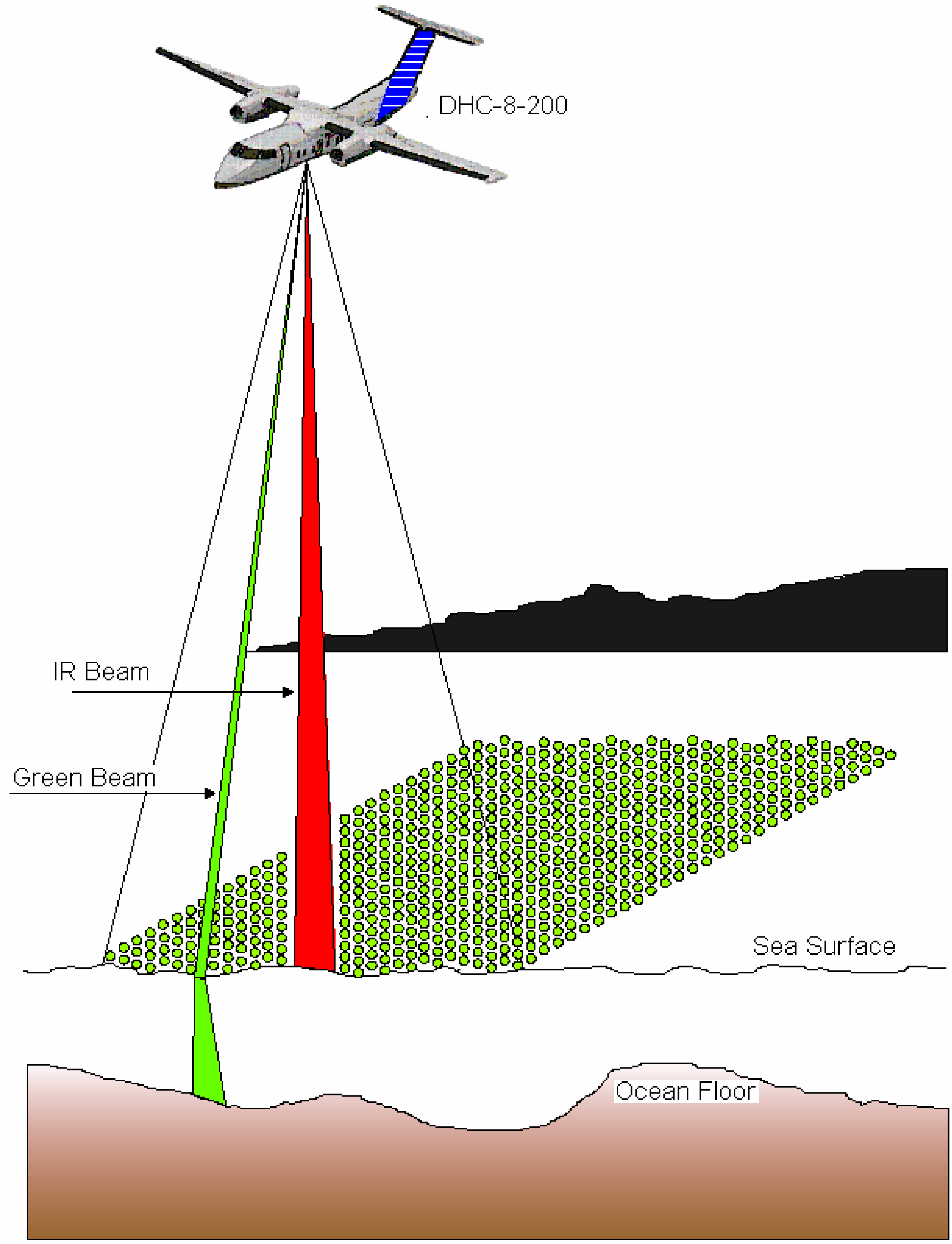


Figure 3 – The Laser Scan

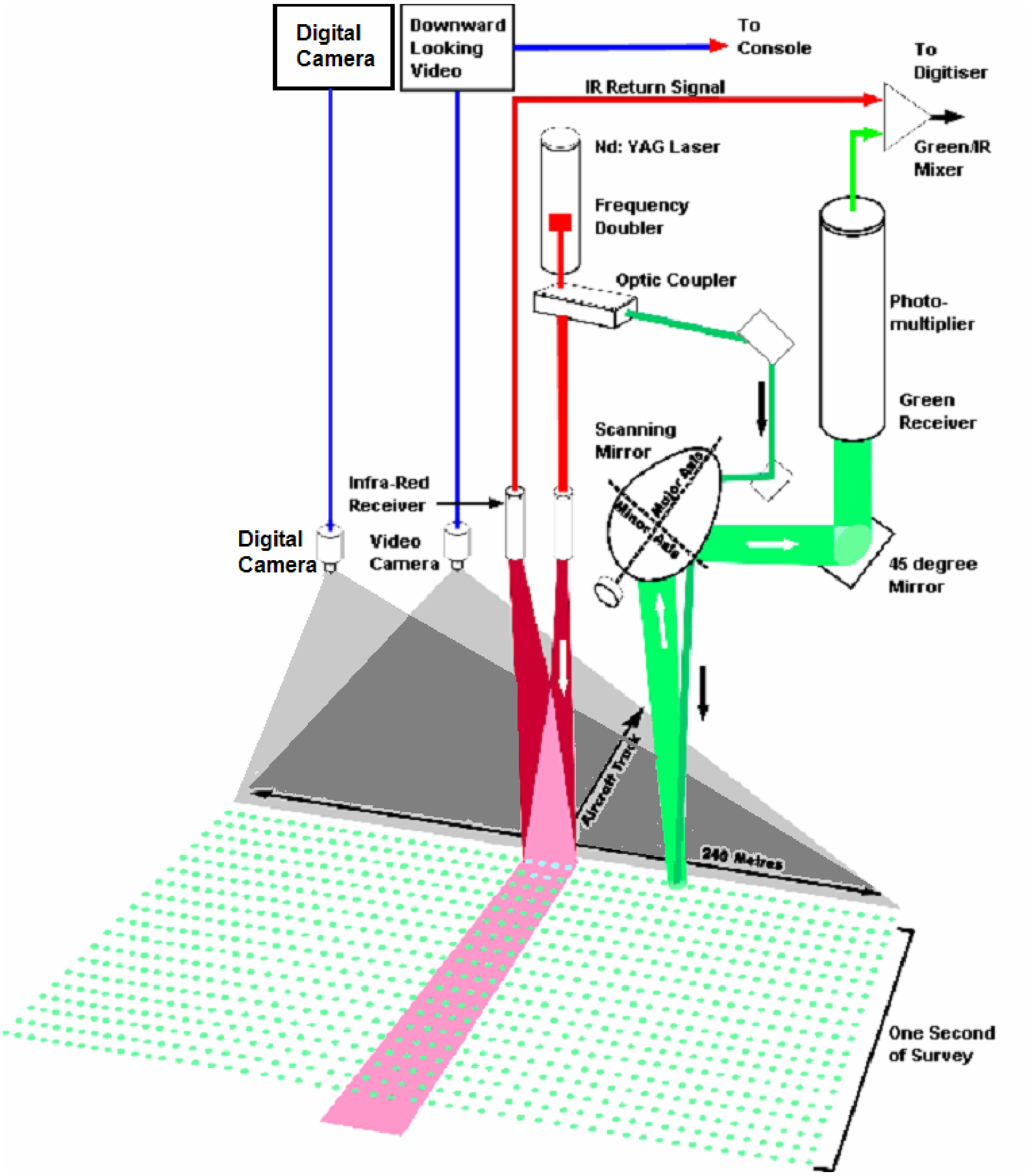


Figure 4 – The AS Scanner, Laser and Receivers

A.1.2 Positioning 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 Section C.

The signal from the GPS 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 is used to record GPS data for calculating post-processed KGPS positions. An Ashtech GG24 single-frequency GPS receiver is used to provide real-time positioning of the aircraft. An Ashtech Z12 dual-frequency GPS receiver is used to independently log and compute post-processed 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 for logging.

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, grid and magnetic variation parameters and a list of survey objectives including the line number, start and end coordinates, and coordinates for navigation position checks. During the course of the sortie, the airborne operator amends the sequence of survey objectives and aircraft altitude to suit environmental conditions and amends the scan pattern parameters for the survey lines to suit survey specifications.

The SCC controls the sequence of survey operations by:

- Planning all required flight paths and communicating these to the NSS.
- Transmitting required parameters for scan patterns, aircraft altitude, 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 and re-order the sequence of objectives 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 positioning 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 objectives execution can be impacted by both low cloud coverage and high ground in the survey area. LADS Mk II is able to operate at different survey heights, irrespective of scan pattern, so that adequate aircraft clearances can be maintained above high terrain or below low cloud ceilings as required. Survey altitudes at 200ft increments are available from 1,200 to 2,200ft (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.

A forward-looking video camera is also provided to assist the AS operator for the purpose of evaluating conditions ahead of the aircraft.

A Digital Imagery system provides georeferenced imagery. This system comprises a Redlake MegaPlus II ES 2020 digital camera, a Matrox 4Sight M frame grabber and a Matrox embedded computer running Windows EP embedded operating systems. Images are taken at one-second intervals with a 1600x1200 resolution and a 2-megapixel interline-transfer camera head and controller. At the end of each sortie, the images are copied to the LADS GS with the use of a removable hard drive.

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 displayed is each of the mixed red / green sounding return signals as digitized by the LCA (the traces are overlaid). 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 is 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, signal to noise ratio (SNR) 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. In addition, the topographic range may be reduced due to returns from thick foliage such as spruce trees, which may prevent laser returns from being received from ground level.

A.1.7 LADS Mk II Aircraft and System Specifications

Aircraft Type	De Havilland Dash 8-200, twin turbo prop, high wing
Aircraft Modifications	Long range tanks, pressurized laser bay window and autopilot interface
Transit Cruise Speed	250kts (maximum 275kts)
Transit Altitude	To 25,000ft
Survey Speed	Dependent on Scan Pattern: Nominal 140-210kts (72-108m per second)
Survey Height	1,200 to 2,200ft (366 to 671m) in 200ft increments
Survey Track-Keeping	+/- 5m (manual or via autopilot coupling)
Survey Endurance	8 hours nominal
Operational Capability	Day / Night Operation
Depth Sounding Rate	900 soundings per second
Swath Width	Dependent on Scan Pattern: 50-288m (independent of aircraft height and water depth)
Scan Pattern	Rectilinear
Sounding Density	Variable: 6x6m, 5x5m, 4x4m, 3x3m and 2x2m
Soundings per sq km	Dependent on scan pattern. For 4x4m – 75 000/km^2 (assuming 32m overlap)
Soundings per hour	Up to 3 million
Topographic and Depth Range	-50m (topo) to 70m (depth)
Area Coverage	Dependent 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	DLT, VHS Video Tape, USB Hard Drive
Digital Camera	Image Area at 1500ft operating altitude: ~330m x 250m. Image Resolution: >4 pixels/m at an altitude of 1600ft. Digital Image Capture Rate: 1 per second. Digital Image Horizontal Accuracy: +/-5m (95% confidence).

A.1.8 Logging Parameters

A.1.8.1 Position Fixing

The AS 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 4x4m spot density but have different swath width and survey speeds. All patterns are available at each of the operational altitudes (1,200 – 2,200ft in 200ft increments).

Sounding Density (m)	**Swath Width (m)**	**Line Spacing 200% Coverage (m)**	**Line Spacing 100% Coverage (m)**	**Survey Speed m/sec (knts)**
6x6	288	125	250	108 (210)
5x5	240	100	200	90 (175)
4x4	192	85	170	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 AS to final depth data is accomplished on a GS (refer to Figure 5). There are four GS's available for operations, as follows:

a. GS Bilbo, comprising a single CPU Compaq (DEC) Alpha Series 4100 Server with 256MB ram, up to 750GB disk space, DLT and Digital Audio Tape (DAT) drives.

b. GS Frodo, consisting of a Compaq Alpha 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. GS Gandalf, consisting of a Compaq Alpha ES40 3-processor Server with 1 GB EEC RAM, 764 GB disk space, Super DLT (SDLT), DLT, and DAT drives, a CD-ROM drive and is networked to a series of 8 HP Small Form Factor PCs with Windows and Linux (dual boot) that serve as processing terminals for GAP, Fledermaus, CARIS, etc. Gandalf is also networked to an HP 750c DesignJet plotter, printers and QC workstations.

d. GS Katrina, consisting of a Compaq Alpha ES40 3-processor Server with 1 GB EEC RAM, 764 GB disk space, SDLT and DLT drives and magazines, DAT drive, CD-ROM drive and is networked to an HP 800ps DesignJet plotter, printers, and QC workstations.

The GS 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 final digital deliverables.

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, depth benchmark areas and 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.
- Quality Control. Utilities within the GS for data integrity checks include the Positioning Analysis Software (PAS) for generating static and dynamic GPS check reports and data, navigation position checks, depth benchmark comparisons and crossline comparisons.
- 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 senior surveyor and finally approved by the Field Party Leader.

- Data output. Approved data is output to the client in S-57 digital format.

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

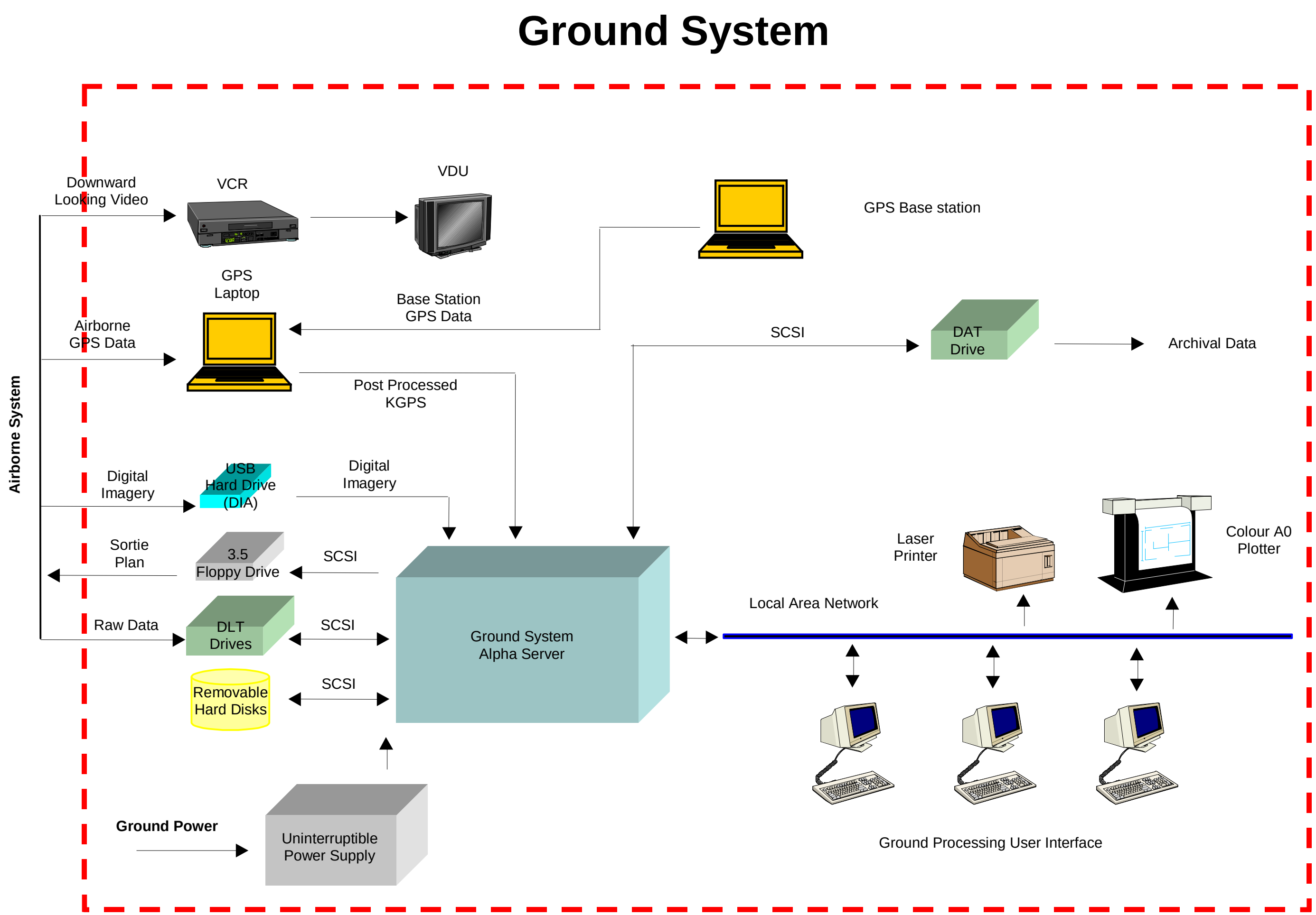


Figure 5 – Block Diagram of the LADS Mk II GS

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 within 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 Sortie Processing

Processing parameters are set prior to sortie 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 quality control checks, 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 the survey lines the data is grouped into one-second frames made up of 18 scans of 48 sounding pulses (864 pulses per frame).

A.2.5 Primary and Secondary Soundings

All processed 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 subset 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 1m has been used, which means all soundings have been hydrographically reviewed and all valid soundings have been provided in the final data set. All incorrect secondary soundings were set to primary during the course of data validation, checking and approval and were excluded from the final dataset.

A.2.6 Automatic Data Processing

Automatic processing is completed in two stages:

1. 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.

2. 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 position data to the raw data and digital images from the downward-looking camera.
- Process the raw waveform to identify surface reflections.
- Process the raw waveform to identify and calculate initial depths. Up to five possible seabed returns can be established per waveform.
- Classify each of the identified seabed return pulses by SNR, agreement with near neighbors and a maximum likelihood estimator.
- Select the most likely seabed return pulse based on the above classification and a shoal weighting function.
- Model the sea surface from the available surface pulses.
- Correct the calculated 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 (based on SNR)

  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 subset (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.

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 multiple 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 subsequently excluded from final data output.

A.3 GROUND SYSTEM – USER INTERFACE

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

A.3.1 Composite Data Display

The Composite Data Display is used for overall assessment of the depths along the line and the general quality of the data. The operator may pan along and zoom into specific areas of 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 other displays are initialized at the position of the cross hairs.

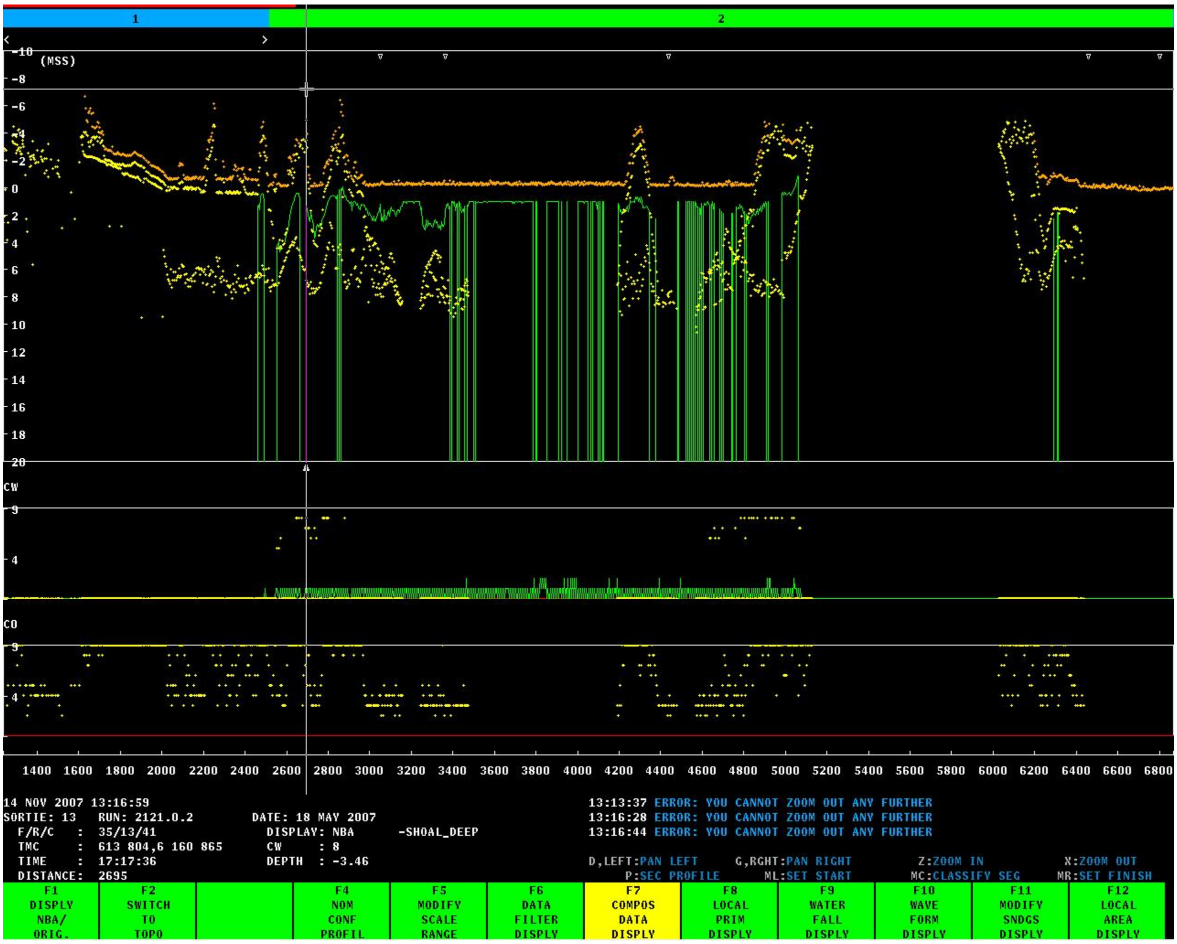


Figure 6 – Composite Data Display

Three profiles, with distance along track on the X axis and depth on the Y axis, 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.

The Composite Data Display is also used to segment the data into the following line subsets:

- Accepted – data is to be cleaned and exported in the final dataset.
- Anomalous – data is rejected and will not be exported, but adequate coverage exists from overlapping sub-areas.
- Rejected – data is rejected and the survey line must be reflown to obtain adequate coverage.

A.3.2 Local Primary Display

The Local Primary Display shows the depths of all soundings across the 18 scans conducted during one second of data acquisition. 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, secondary soundings are yellow and NBD soundings are 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, such as the Waveform Display or Sounding Audit Display, are required.

The survey line identifier, position, time, frame, row, column and confidences are displayed for the sounding at the bottom of the Local Primary Display.

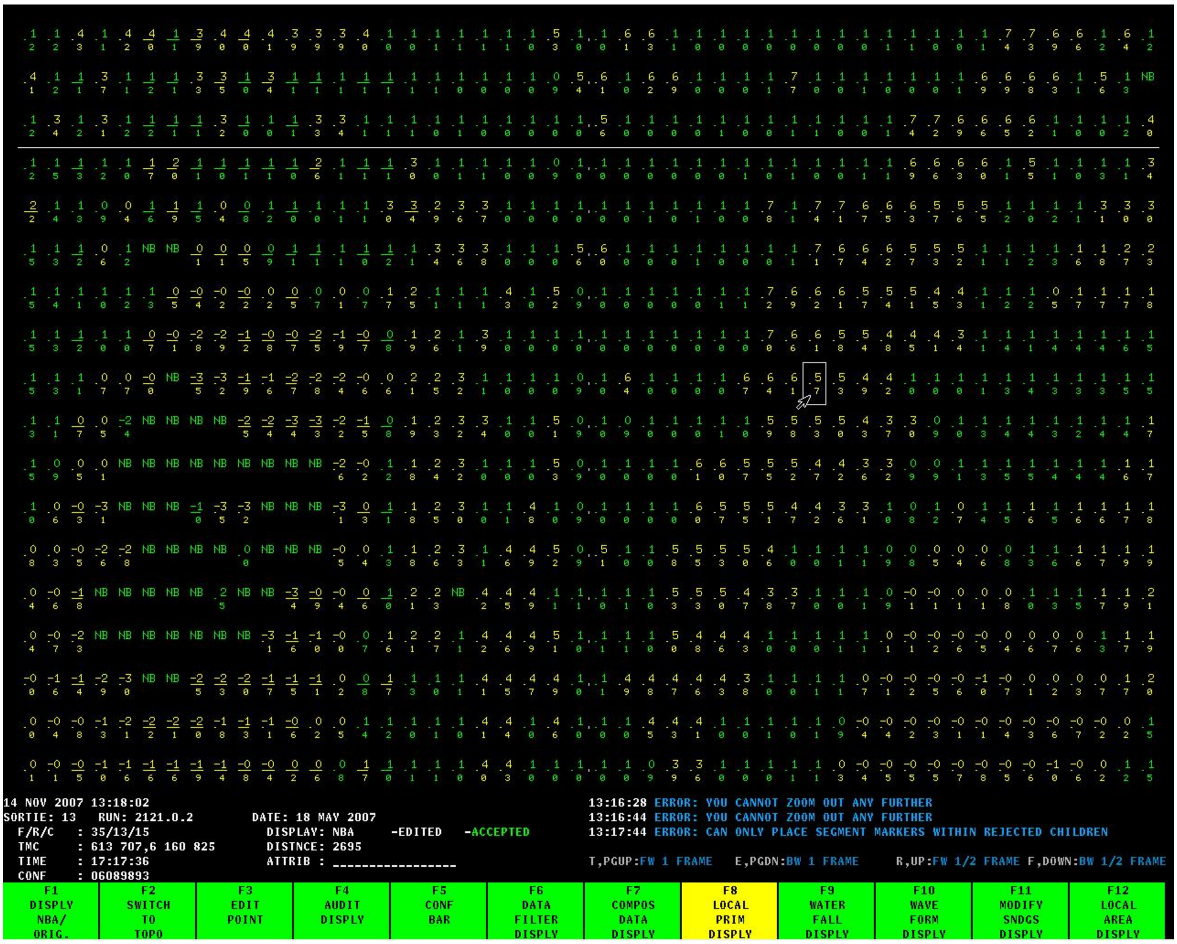


Figure 7 – Local Primary Display

A.3.3 Waveform Display

The Waveform Display shows a matrix of nine sounding waveforms, centered on the nominated sounding. The display is invoked from the Composite Data, Local Primary, Waterfall and Local Area Displays. This display allows an operator to assess the quality of the laser waveform and to resolve or clarify specific sounding values, such as 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, alternate contender depth and SNR are presented. A more detailed discussion of the interpretation of waveforms is given in Section B.9.

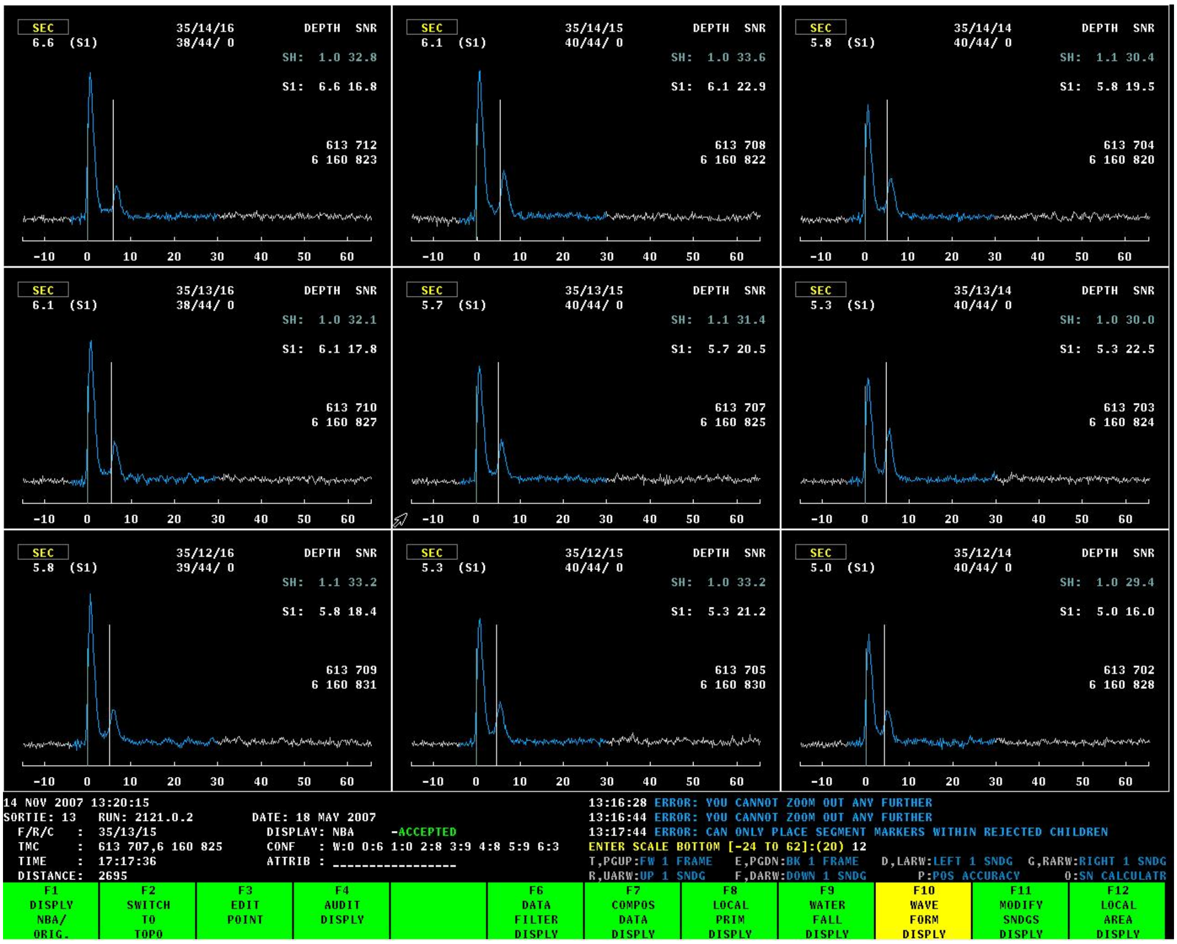


Figure 8 – Waveform Display

A.3.4 Waterfall Display

The 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 and spurious noise outliers.

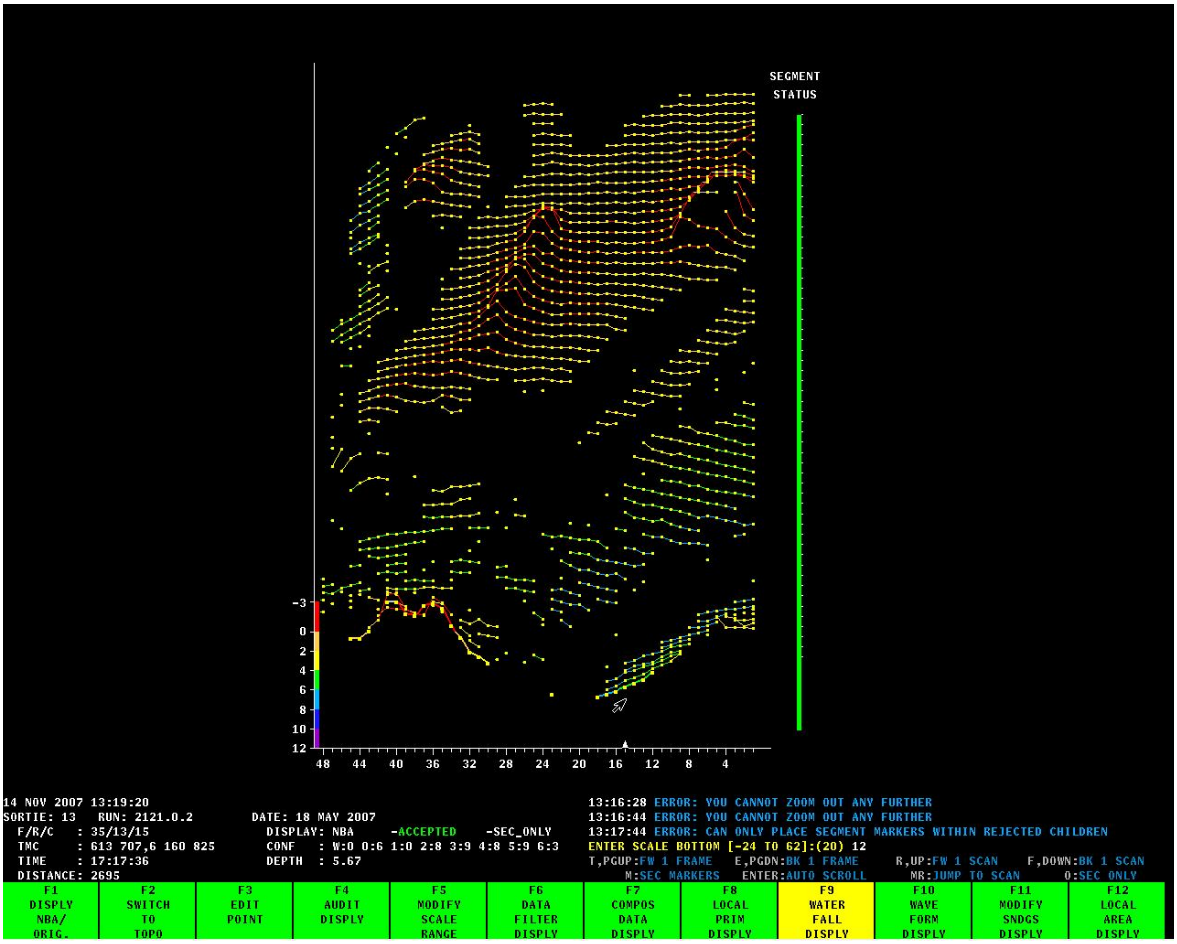


Figure 9 – Waterfall Display

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 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.

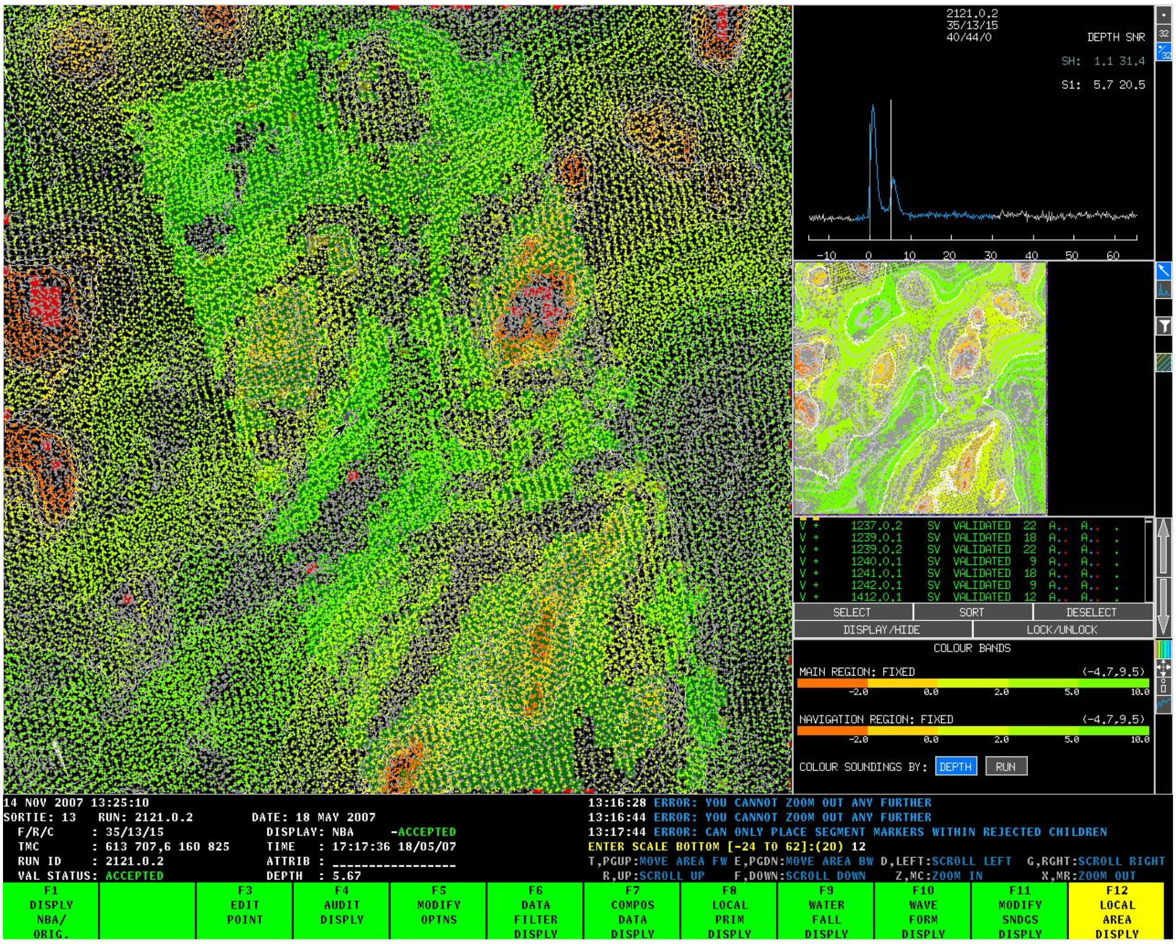


Figure 10 – Local Area Display – Small Scale

The display is divided into five sub-windows, as shown in Figure 11:

a. 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 rectangle within the navigation window shows the position and extent of the area displayed in the working window.

b. The waveform window, positioned in the top right of the display, shows the waveform for the currently selected sounding, highlighted by a white triangle in the working window.

c. The navigation window, positioned middle right in the display, provides a top-level view of the area currently selected.

d. The runs window, directly below the navigation window, lists the overlapping runs along with the status of the line, e.g. Accepted, Anomalous or Rejected.

e. The color band window shows the color band depth ranges for displayed soundings in the navigation and working windows. The soundings can be colored by depth or by line.

The lower region of the screen displays summary information similar to that on the Composite and Primary Displays.

TIN contours of the displayed soundings can be shown in both the navigation and working windows and contour intervals can be amended as required.

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. When there is no sounding coverage from any survey line, the cell is colored bright red. When there is coverage from overlapping survey lines, but not the primary line, the cell is displayed black. When there is sounding coverage from both the primary and overlapping lines, the cell is color filled green, olive, brown, or dark red. The color of a cell indicates the degree of variation in the depths of soundings within the cell. Green represents a mean depth variation from the primary survey line sounding of less than 0.5m, olive less than 1.0m and so on.

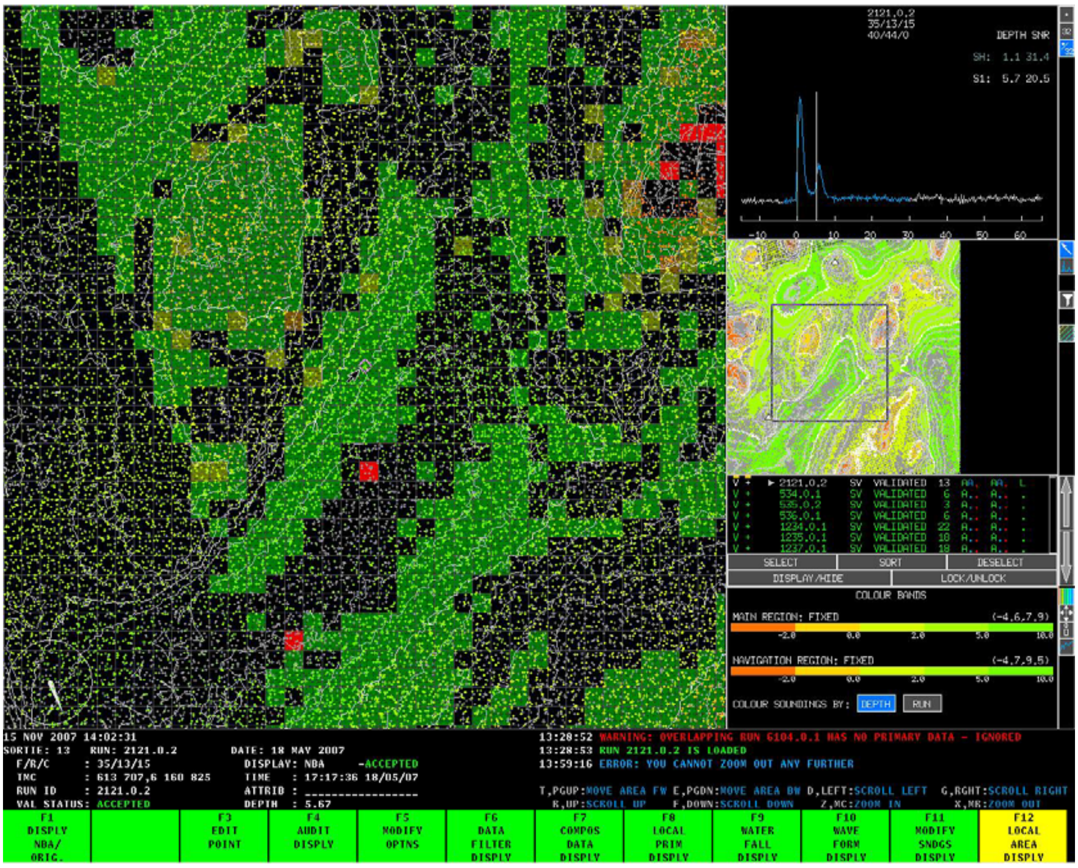


Figure 11 – Local Area Display – Medium Scale

In both the navigation and working window, the soundings are displayed at their geographical positions. As the operator zooms in on the working window, symbols in the working window are replaced by depth values (refer to 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.

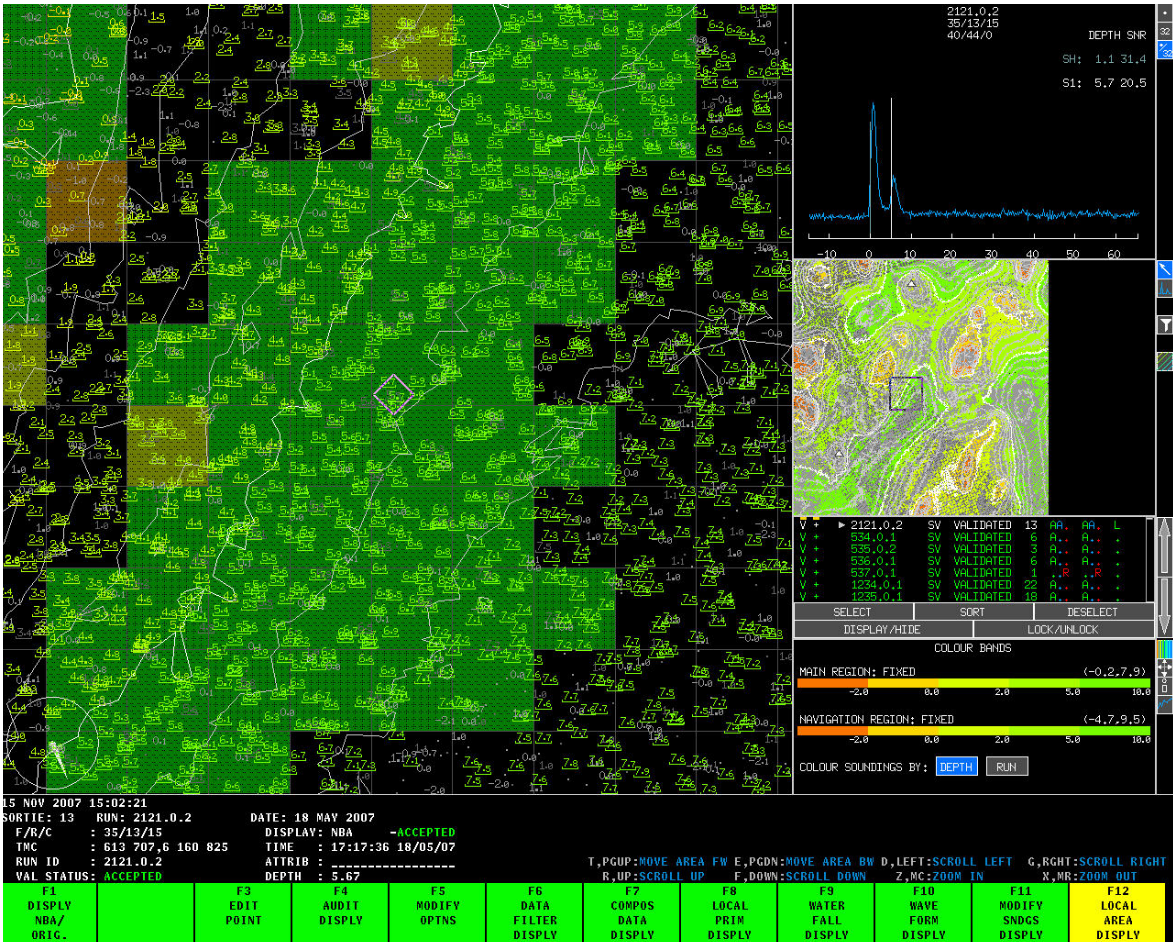


Figure 12 – Local Area Display – Large Scale

A.3.6 GS Digital Image Window

The imagery, collected by the downward-looking digital camera in real-time, is processed along with the raw data. These images are georeferenced and can be either manually or automatically displayed alongside of the Raw Data Display, the Waveform Display or the Local Area Display. The images are automatically rotated to fit the current display.

These images are displayed in the GS Digital Image Window on the second dual screen monitor. This display is automatically linked to all of the GS displays mentioned previously and the selected sounding is highlighted in the downward-looking image with a yellow circle of 5m diameter.

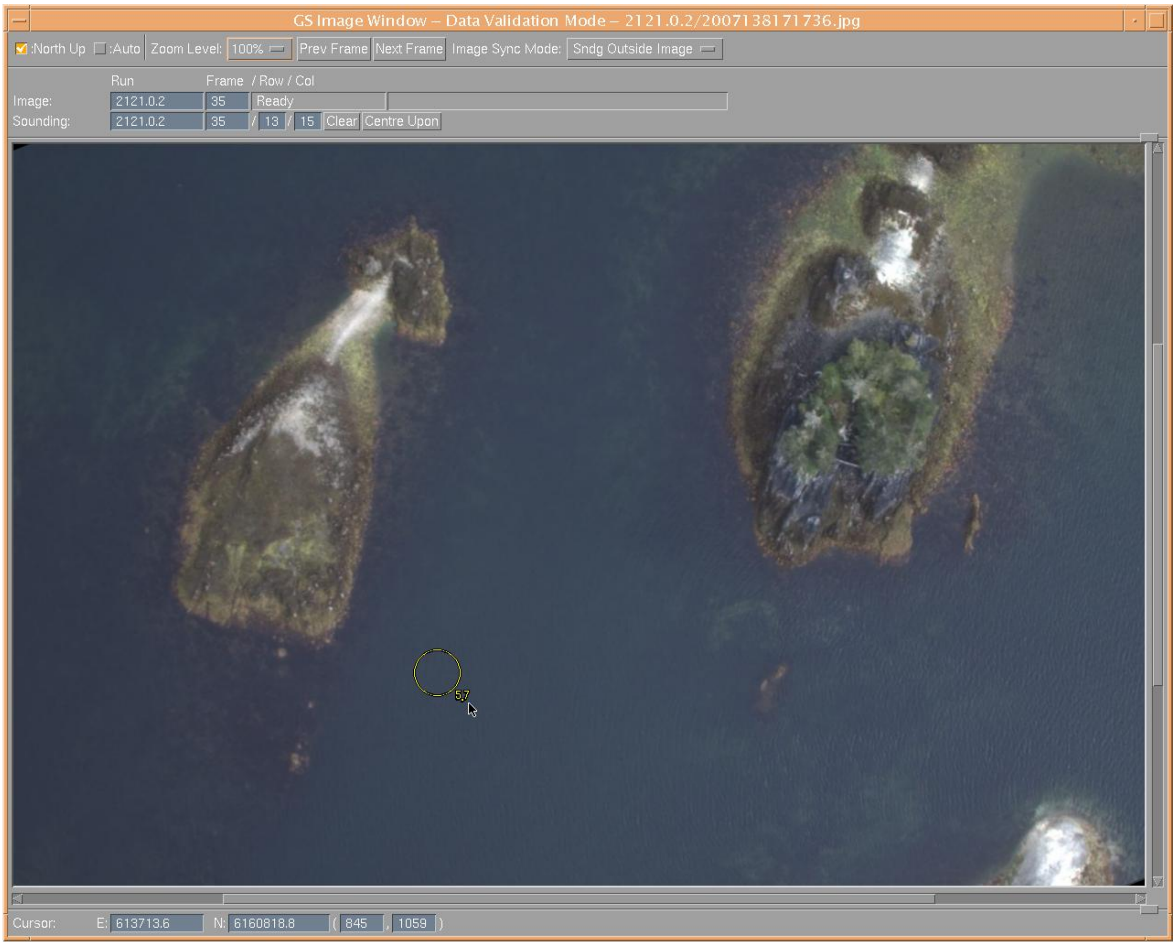


Figure 13 – GS Digital Image Window

The GS Digital Image Window enables the operator to easily correlate features such as coastline, islands, islets, drying rocks, rocks awash, shallow rocks, kelp, beacons, buoys, boats, jetties, buildings and trees in the image with the data presented in the different GS displays. The quality of imagery and zoom functionality of the window even enables discernment of biological data artifacts, such as bird strikes and whale returns. Sea lions sunning themselves on drying rocks have also been noted in the imagery.

A.3.7 Audit Display

The Audit Display is used to view additional data associated with a single 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 (refer to Figure 14).

```
                              AUDIT DATA DISPLAY

CHILD RUN        2121.0.2.2               GS S/W VERSION    E7.2/019

EQUIPMENT CONFIGURATION
  HEIGHT ERROR CONNECTED Y                BANK DEMAND CONNECTED  Y
AIRCRAFT
  HEADING        160.13                   HEIGHT         488.5
PLATFORM
  PITCH    0.02          ROLL       0.02
SCAN ANGLES   4.510      0.088      -0.001             PATTERN   P4_1600
ERROR FLAGS
   1 00000000  2 00000000  3 00000000  4 00000000  5 00000000  6 00000000
   7 00000000  8 00000000  9 00000000 10 00000000 11 00000000 12 00000000
ISLAND MODE      00                       AS PROC HEIGHT 489.30

FRAME
  TIDE CORRN     -0.86       30           SEA STATE      0.03
  MEAN DEPTH     1.1                      DEVIATION      0.73
POINT
  TIME           17:17:36                 POSITION       613 707,6 160 825
  DEPTH          5.67                     BIAS           0.16
  MIN SRCH DEPTH -5.0                     MAX SRCH DEPTH 30.0
  ROW            13                       COLUMN         15
  BACKSCATTER    0                        CW, C0 - C6    0 6 0 8 9 8 9 3
  MAG VARIATION  21.54EAST
```

Figure 14 – Audit Display

A.3.8 Data Filter Display

The Data Filter Display is used to edit numerous points at one time. The display contains two separate windows (refer to Figure 15). The first is representative of the shoalest and deepest soundings per scan, similar to the Composite Data Display. The second window displays numerous filter tabs, each of which are used to set the parameters for the required block edit.

The Data Filter Display essentially enables the operator to reapply the sortie processing parameters to specific survey lines, or areas of lines, with amended values to reduce the single point editing required to validate, check and approve the data. The filters can highlight specific types of soundings and tags and rapidly set soundings to NB, primary or secondary within different depth ranges and SNR's.

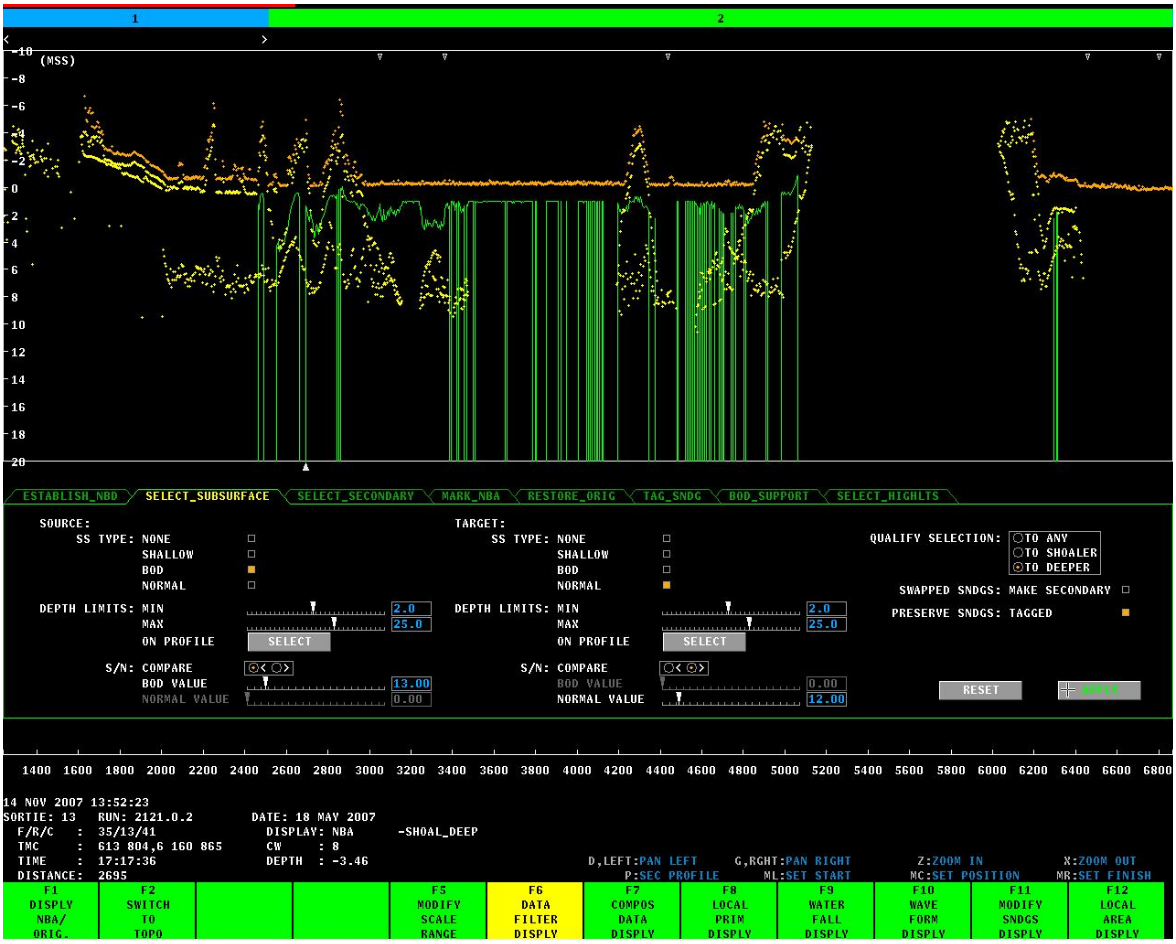


Figure 15 – Data Filter Display

A.4 SOFTWARE VERSIONS

System	Version	Remarks
Tenix LADS AS	AS 8.1.9	
GPS Logging	5.6.0	Ashtech PNAV Data Logger Software
GPS Processing	2.5.5	Ashtech PNAV (Precise Differential GPS Navigation Trajectory Software)
Tenix LADS GS	E7.1.042 to E8.0.004	
CARIS BASE Editor	2.1.0.0	
CARIS HIPS and SIPS	6.1.1.2	
GMT	3.3.1	Component of the LADS ‘QC Tools’
VTK	3.1	Component of the LADS ‘QC Tools’

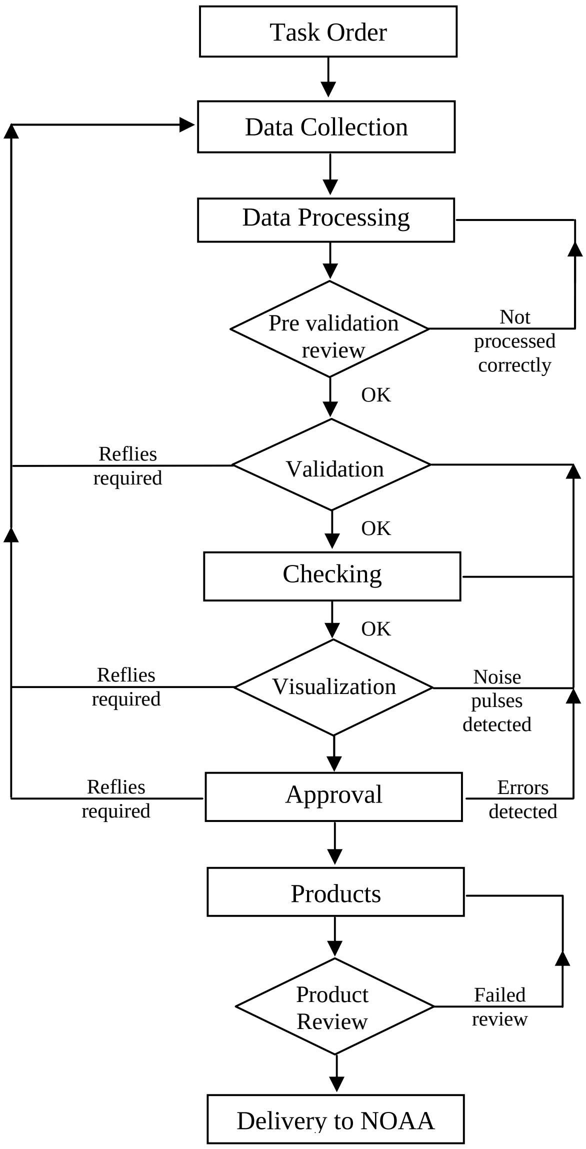
Table 2 – Software versions

B. QUALITY CONTROL

B.1 DATA PROCESSING

Data processing involves the following stages:

- Automatic data processing as described in Section A.2.6
- Survey line acceptance and segmentation by Deputy Project Manager / Project Manager
- Pre-validation of the data by senior surveyors
- Validation of the data by hydrographic surveyors
- Checking of the data by the Deputy Project Manager
- Visualization of the data by a senior surveyor
- Approval of the data by Project Manager



Refer to Section A.3 for the specific GS User Interface displays used to conduct data pre-validation, validation, checking and approval.

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. The survey data that sufficiently passes quality checks is segmented to Accepted status for validation by hydrographic surveyors. When the required coverage is not obtained, the line is nominated to be reflown. The majority of reflies are created during the in-field pre-validation phase. Some data cleaning is also undertaken during the pre-validation stage, with obvious noise, turbidity and datum shifts removed. The majority of pre-validation will be conducted using filters provided in the Data Filter Display (refer to Section A.3.8).

B.3 VALIDATION

Validation proceeds through the following steps:

1. Examining the depth profile on the Composite Data Display for the correct processing and segmentation of each survey line.
2. Examining the position confidence (C3) profile to verify that adequate positioning accuracy is maintained during the survey line. Additional positioning quality confidences, such as PDOP, number of satellites and correction latency, are examined in profile along the survey line.
3. Examining the coverage confidence (C6) profile to verify that no coverage gaps exist due to the aircraft flying off the predetermined track.
4. Examining the Kalman filter tilt and bias for the line to determine areas that datum shifts have occurred due to excessive aircraft roll, poor sea surface datum or prolonged periods flying over topography.
5. Resolving erroneous soundings after examining outlying data points along the survey line using:

a. The Primary Depth Display

b. The Waterfall Display

c. The Waveform Display

d. The Local Area Display

Validation data editing operations are generally applicable to single depth soundings, but data filters may be applied when pre-validation has missed significant areas of erroneous soundings. The typical single point edits required include the selection of an alternate depth contender, inserting a waveform depth contender where an automatic one does not exist and deletion of the sounding, as appropriate. Tagging of soundings is also an integral part of data validation and is discussed in Section B.8.

B.4 CHECKING

Once a line has been validated it goes through an independent checking phase by the Deputy Project Manager. All soundings edited by the validator are highlighted on the line and the checker ensures the correct edit has been made during validation. Checking also involves identification of residual unedited erroneous soundings missed during data validation and review of the tagged data points.

B.5 DATA VISUALIZATION

All 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 to the Project Manager for remedial action in the GS.

A number of software packages are used to produce these products and create query files to be imported into the GS for sounding interrogation.

B.6 APPROVAL

In the final phase the Project Manager reviews each line from start to finish to ensure that all data edits and tags were made correctly during pre-validation, validation and checking and that no erroneous soundings remain in the final dataset. Each survey line is reviewed primarily in the Local Area Display (refer to Section A.3.5).

B.7 AUDIT TRAIL

The significant filter and single point edit 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. All operator actions are logged by the GS for complete traceability.

B.8 TAGGING OF SOUNDINGS

During data processing on the GS, the operators have the ability to assign S-57 and user-defined tags to gaps and features in the data. This enables accurate delineation and attribution of unsurveyed polygons and features requiring further investigation in the S-57 feature file.

The following user-defined tags were used to delineate gaps in the lidar seabed coverage, typically at a 50m interval:

GK	Bathymetry data gap due to kelp.
GW	Bathymetry data gap due to white water.
GS	Bathymetry / topography data gap due to the secondary exclusion zone (SEZ).
GLS	Bathymetry data gap due to glassy seas.

A data gap due to kelp occurs when the laser pulse does not fully penetrate through the kelp bed, resulting in false returns from the kelp, attenuated bottom returns with low SNR, or no seabed returns at all.

A data gap due to white water occurs where sea surface returns from white water areas are saturated, resulting in limited lidar penetration. A gap will occur if there is similarly limited seabed coverage from adjacent lines of survey.

A data gap due to the SEZ 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, these gaps are fully, or partially filled by flying alternate 200% coverage lines at a different tidal state.

A data gap due to glassy seas occurs in extremely calm conditions, where the sea surface laser returns at nadir become saturated, driving the gains down. A gap will occur if there is no data from adjacent lines due to poor water clarity, to cover the area.

The following tags were used in the GS for features that require further investigation:

FEK	Feature for examination in kelp, as the least depth has not been determined.
FERK	Feature for examination of a submerged rock, as the least depth has not been determined, or a higher density of data is required to adequately define the feature.
FERA	Feature for examination of a rock awash, as the feature has not been surveyed adequately due to the presence of white water or limitations of the SEZ.
FEDR	Feature for examination of a drying rock, as a higher density of data is required to adequately define the potentially drying feature.
FE	Feature for examination, generally in deep water, as the least depth has not been found due to poor water clarity.
FINV	Feature for further examination identified in the georeferenced imagery during products compilation.

The tags associated with features requiring further investigation have been compiled in CARIS .hob files (H11664_Inv.hob – H11668_Inv.hob) and each given certain priority and suggested examination method for the undertaking of additional boatwork.

B.9 LASER WAVEFORMS - NATURE AND INTERPRETATION

The annotated Sounding Waveform Display (refer to Figure 16) 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 contender showing selected seabed return ③ and alternate subsurface return contenders ④ if they exist
- The Frame, Row and Column of the active sounding ⑤
- The real-time green receiver gain values for sounding measurement ⑥
- Type of sounding, currently there are up to 5 subsurfaces that can be selected by the GS, a shallow return, two subsurface returns and BOD returns for both subsurfaces ⑦
- Depth values for the possible subsurfaces ⑧ and the SNR for the respective depth values ⑨
- The selected depth and the type of return ⑩
- The status of the sounding, either secondary, primary or NBD ⑪
- Grid coordinates of sounding on the survey spheroid and grid ⑫

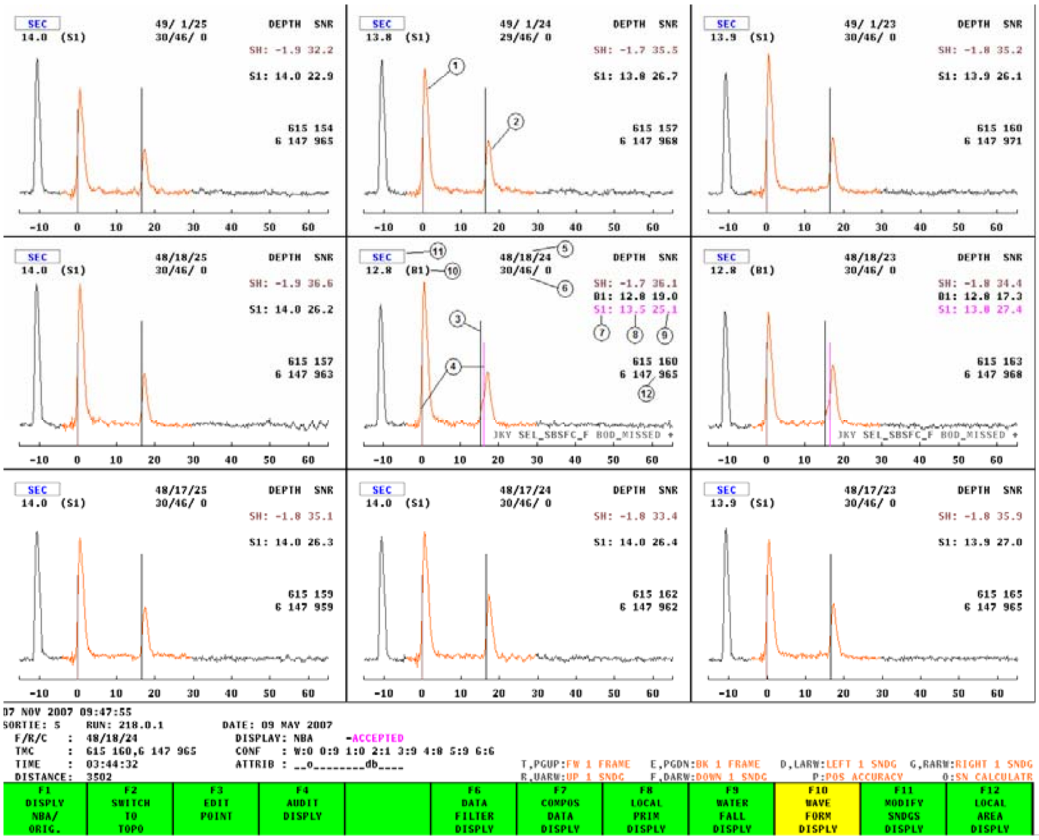


Figure 16 – Annotated Sounding Waveform Display

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 infrared, GPS and inertial AHRS heights and filtered green surface returns. The SRP selects up to five possible seabed returns for each waveform based on SNR 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 more than one seabed return is found, the most likely is selected based on SNR versus depth criteria. The selected return is indicated on the Waveform Display by a white depth contender bar and the alternate depth contender bars are colored 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 return. Detection of an object on the seabed will depend on both the density of the scan pattern, gain of the green receiver, 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 affects 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 influences the maximum depths that can be measured by the system.

The table below lists all of the survey lines flown during the survey and the specific reason for them being conducted:

B.10 DATABASE MANAGEMENT

B.10.1 Survey Line Identification

Sub-Area	Lines	Sounding Density	Line type	Remarks
Depth benchmark comparison runs	1-20	4x4	BM Lines	For absolute depth accuracy checks. Russian Harbour
1	100-135	4x4	Main Survey Lines	200% coverage
2	200-249	4x4	Main Survey Lines	200% coverage
3	300-307	4x4	Main Survey Lines	200% coverage
7	400-457	4x4	Main Survey Lines	200% coverage
5	500-517	4x4	Main Survey Lines	200% coverage
6	600-625	4x4	Main Survey Lines	200% coverage
-	700-718	4x4	Additional Coverage Lines	For additional coverage
8	800-812	4x4	Main Survey Lines	200% coverage
9	900-917	4x4	Main Survey Lines	200% coverage
10	950-962	4x4	Main Survey Lines	200% coverage
-	1000-1084	4x4	Additional Coverage Lines	For additional coverage Low / High water
-	1200-1206	4x4	Additional Coverage Lines	For additional coverage
11	1300-1310	4x4	Main Survey Lines	200% coverage
12	1350-1354	4x4	Main Survey Lines	200% coverage
13	1400-1404	4x4	Main Survey Lines	200% coverage

B.10.2 Line Identifier Convention

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

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

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

e.g. 101.1.2.3

Maximum fields are
100000.99.99.99

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
- 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 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
- 101.1.2.x is the second processing of the first refly

Child – Range 1...99
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. Full details are recorded in the survey data management folders held by TLI.

B.11 ERROR MINIMIZATION AND MODELS

B.11.1 Water Clarity

The greatest contributor to depth performance, seabed coverage and data quality with a Lidar system is water clarity.

The main contributor to poor water clarity in the survey area was large swell, generated by high winds. The area is exposed to the weather from the northeast through to the west. Tidal flow through Geese Channel and Russian Harbor also contributed to the water clarity of the survey area. These local environmental conditions were taken into consideration in the decision to conduct a survey flight on a day-by-day basis.

No secchi observations were taken due to the availability of surface vessels. A recce by light aircraft was conducted on May 16, 2007, after a period of poor weather, to access the water clarity conditions prior to commencing survey flights in the survey area.

B.11.2 Total Propagated Error

A Total Propagated Error (TPE) for the LADS Mk II system is currently being derived in conjunction with the University of New Hampshire. For this survey area, global horizontal and vertical uncertainties have been assigned based on the defined horizontal and vertical error budget, as stated in the Horizontal and Vertical Control Report. The assigned horizontal uncertainty is 3.34m and the assigned vertical uncertainty is 0.50m.

However, when the calculated grid node standard deviation is greater than the assigned vertical uncertainty, the standard deviation is used as the uncertainty value. This has occurred in areas of high relief, which is common throughout the survey area. In some cases the standard deviation may exceed IHO Order-1 limits. This could be attributed to a 3m grid resolution being used.

B.12 DATA OUTPUT AND DELIVERABLES

Digital data deliverables and graphics BASE Surface, S-57 feature file and georeferenced orthophoto mosaic are output and prepared in accordance with:

- NOS HYDROGRAPHIC SURVEYS. SPECIFICATIIONS AND DELIVERABLES. April 2007.
- STATEMENT OF WORK. LIDAR SURVEY SERVICES. OPR-P135-KRL-07 of March 15, 2007.

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

Digital datasets delivered are:

- Full resolution dataset
- BASE Surface created in CARIS
- S-57 feature files 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.

BASE Surface:
Apart from being delivered as its own product, the .CAF file is also imported into 3rd party CARIS for creating the BASE Surface products. The BASE Surface is created using the Uncertainty BASE Surface option in CARIS using a resolution of 3m.

S-57 feature file:
The S-57 feature file contains features such as rocks, islets, MHW line, Mean Lower Low Water (MLLW) line, kelp 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 to check for correct interpolation of the data, particularly in areas of white water and drying rocks or 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 a S-57 feature file (*.000) as a final step.

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

<RegistryNumber> . <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> . <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.12.1 Summary of Digital Deliverables

A directory listing of each digital deliverable is provided at Appendix II.

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 a servo system, with information provided from the AHRS. This minimizes the motion effect (roll and pitch) of the aircraft. All attitude residuals from the local horizontal are logged by the AS for correctional processing by the GS.

Sounding depths and positions are determined in the GS from the raw laser waveform, aircraft height, platform attitude parameters and GPS, as logged by the AS.

The GS 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, depth benchmark comparisons, analysis of overlaps 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 located on the upper side of the aircraft fuselage, forward and to the left of the sounding reference position (refer to Figure 17). 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 GPS antenna with the following axis and sign convention:

- 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

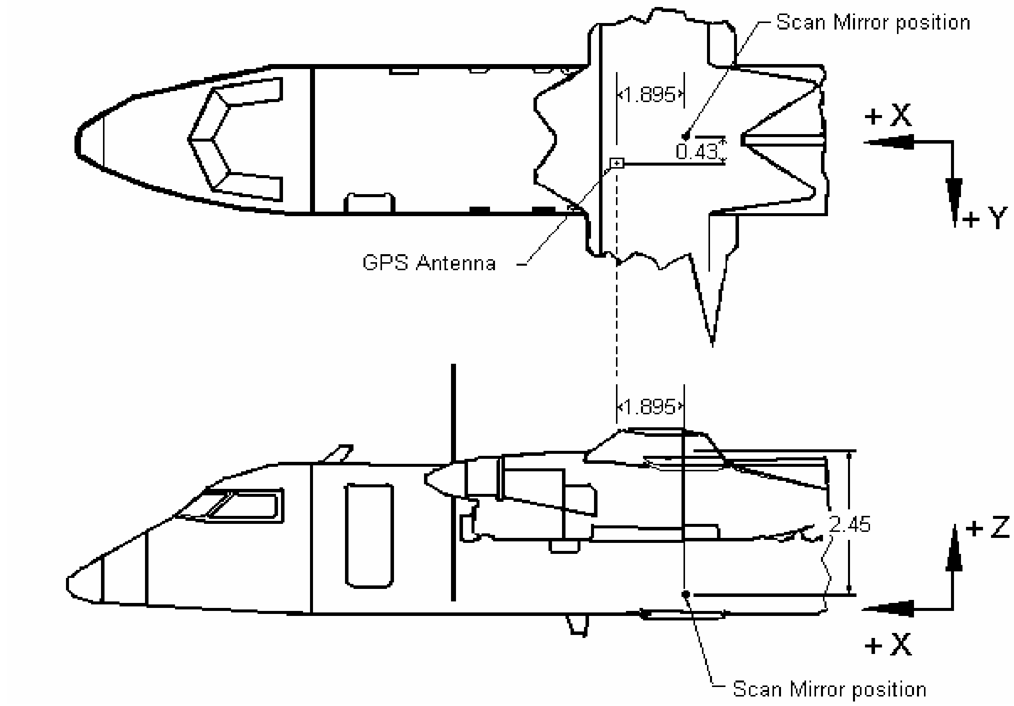


Figure 17 – Laybacks

D. APPROVAL SHEET

LETTER OF APPROVAL – OPR-P135-KRL-07

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	March 24, 2008

Mark Sinclair

Mark Sinclair
Hydrographer
Tenix LADS, Inc.

Date: March 24, 2008