NOAA Technical Report OTES 11

USER REQUIREMENTS AND A HIGH LEVEL DESIGN OF THE HYDROGRAPHIC SOFTWARE/DATA PROCESSING SUBSYSTEM OF AN AIRBORNE LASER HYDROGRAPHY SYSTEM

Rockville, Md.
December 1982

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Ocean Technology and Engineering Services

NOAA TECHNICAL REPORTS

...n Technology and Engineering Services Series

... below are available in both hard copy and microfiche form ... Technical Information Service, U.S Department of Commerce, ...5285 Port Royal Road, Springfield, VA 22161. Prices on request. Order by accession number (given in parentheses).

OTES 1 Error Analysis of Pulse Location Estimates for Simulated Bathymetric Lidar Returns. Gary C. Guenther and Robert W.L. Thomas, July 1981. (PB82 109448)

OTES 2 Simulations of the Impact of Inhomogeneous Water Columns on the Temporal Stretching of Laser Bathymeter Pulses. Gary C. Guenther and Robert W.L. Thomas, August 1981. (PB82 128224)

OTES 3 Bias Correction Procedures for Airborne Laser Hydrography. Gary C. Guenther and Robert W.L. Thomas, August 1981. (PB82 130089)

OTES 4 OTEC Mooring System Development: Recent Accomplishments. Jonathan M. Ross and William A. Wood, October 1981. (PB82 156878)

OTES 5 An Estimate of the Area Surveyable With an Airborne Laser Hydrography System at Ten U.S. Sites. David B. Enabnit, Gary C. Guenther, Jerome Williams and Frederick A. Skove, September 1981. (PB82 170184)

OTES 6 Effects of Detection Algorithm on Accuracy Degradation From Logarithmic and Difference Processing for Airborne Laser Bathymetry Returns. Gary C. Guenther, February 1982. (PB82 215138)

OTES 7 Intercomparison of Primary and Secondary Standard Seawater Samples. Michael A. Basileo and Alisa F. Akimova, March 1982. (PB82 215716)

OTES 8 Characterization Tests of Datawell HIPPY 120C Vessel Motion Sensor. Donald Pryor, May 1982. (PB83 111492)

OTES 9 Performance Characteristics of the Bathymetric Swath Survey System. Donald Pryor, May 1982. (PB82 247313)

OTES 10 Improved Depth Selection in the Bathymetric Swath Survey System (BS^3) Combined Offline Processing (COP) Program. Gary C. Guenther and John E. Green, December 1982. (PB83 210542)

NOAA TECHNICAL MEMORANDUMS

OTES 1 Monte Carlo Simulations of the Effects of Underwater Propagation on the Penetration and Depth Measurement Bias of Airborne Laser Bathymeter. Gary Guenther. (PB83 157545)

OTES 2 Depth Estimation in the Airborne Oceanographic LIDAR Postflight Bathymetry Processor. Gary Guenther, November 1981. (PB82 188194)

OTES 3 Weather Constraints on Airborne Laser Hydrography Operations. Robert Scott January 1982. (PB82 189754)

OTES 4 FY 1983 - Airborne Laser Hydrography. David B. Enabnit, May 1982. (PB83 158451)

NOAA Technical Report OTES 11

USER REQUIREMENTS AND A HIGH LEVEL DESIGN OF THE HYDROGRAPHIC SOFTWARE/DATA PROCESSING SUBSYSTEM OF AN AIRBORNE LASER HYDROGRAPHY SYSTEM

Jeffrey D. Childs
Systems and Applied Sciences Corporation

and

David B. Enabnit
Ocean Technology and Engineering Services

Rockville, Md.
December 1982

U.S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

National Oceanic and Atmospheric Administration
John V. Byrne, Administrator

Ocean Technology and Engineering Services
M.E. Ringenbach, Director

Mention of a commercial company or product does not constitute an endorsement by NOAA (OA/OTES). Use for publicity or advertising purposes of information from this publication concerning proprietary products or the tests of such products is not authorized.

CONTENTS

Section Page

List of Figures iv
List of Tables iv
Abstract.................................... 1

1.0 Introduction.................................... 1

2.0 Subsystem Requirements.................................... 5
2.1 General Requirements.................................... 5
2.2 Constraints.................................... 5
2.3 Data Set Characteristics.................................... 7
2.3.1 Airborne Laser Bathymeter Data Set.................................... 7
2.3.2 Position and Attitude Measurement Data Set.................................... 8
2.3.3 Tide Measurement Data Set.................................... 9
2.3.4 Manually Recorded Data Set.................................... 9
2.3.5 Automated Contemporary Comparison Data Set.................................... 10
2.3.6 Historical Comparison Data Set.................................... 10
2.4 Planned Operating Scenario.................................... 10
2.5 Detailed Requirements - Subsystem Developer.................................... 11
2.6 Detailed Requirements - Subsystem User.................................... 15
2.6.1 Automated Preliminary Processing Requirements.................................... 16
2.6.2 Interactive Intermediate Processing Requirements.................................... 42
2.6.3 Final Processing Requirements.................................... 68

3.0 Requirements Analysis.................................... 69
3.1 Timing Considerations - Automated Processing.................................... 71
3.2 Timing Considerations - Interactive Processing, Data I/O and Graphics....................................102
3.2.1 Introduction....................................102
3.2.2 Preliminary Processing....................................102
3.2.3 Intermediate and Final Processing....................................103
3.2.4 Hardware....................................106
3.3 Airborne Oceanographic Lidar Data Processing System....................................109
3.4 Summary 110

4.0 High Level Design....................................112
4.1 Baseline Design....................................112
4.1.1 Introduction....................................112
4.1.2 Design Concepts - the Queue....................................113
4.1.3 The Interactive System....................................115
4.1.4 Software Module Sizing....................................125
4.2 Database Specifications....................................129
4.3 Operating Environment....................................137

5.0 Development Plan....................................141

6.0 Conclusions and Recommendations....................................146

References....................................155

CONTENTS (CONT)

Section Page

Appendix A. Instruction Load for Least-Squares Fit.............156

Appendix B. Computer Simulation of Laser Scan Patterns..........160

Appendix C. HS/DP Data Flow Diagrams............................167

Appendix D. High Density Tape Drives............................192

FIGURES

Figure Page

1.1 Received Laser Sounding Waveform.................................. 2
1.2 Block Diagram of the Planned NOAA Airborne
Laser Hydrography System.. 3
2.1 Hydrographer's Actions - Anomalous Intraswath Depths.............. 45
2.2 Hydrographer's Actions - Disagreement in Coincident Soundings..... 47
2.3 Hydrographer's Actions - Anomalous Intraswath Positions........... 50
2.4 Hydrographer's Actions - Anomalous Contours....................... 53
2.5 Hydrographer's Actions - Anomalous Interswath Positions........... 55
2.6 Hydrographer's Actions - Disagreement in Swath Overlap............ 57
2.7 Hydrographer's Actions - Disagreement in Interswath Depths........ 59
2.8 Hydrographer's Actions - Gaps in Coverage......................... 60
2.9 Treatment of Resurvey Data.. 65
2.10 Treatment of Historical Data...................................... 66
2.11 Treatment of Contemporary Data.................................... 66
2.12 Hydrographer's Actions - Anomalies in All Data Examination........ 67
3.1 Layout of Preflight Data on Flight Tape........................... 80
3.2 Definitions of Waveform-Based Parameters.......................... 88
4.1 The Active Queue Area...114
4.2 Data Flow in the Active Queue Area................................116
4.3 Structure of Interactive System...................................119
4.4 HS/DP Hardware Configuration......................................138
5.1 ALH System Development..142
5.2 ALH Software Development..142
6.1 Processor Cost versus Speed.......................................148

TABLES

Table Page

3.1 Instruction Load per Sounding..................................... 76
3.2 Summary of Instruction Load for Automatic Processing..............102
3.3 Human Interaction in Preliminary Processing.......................103
3.4 Timing Factors for Interactive Steps..............................106

4.1 Summary of Data Base Sizes for ALH (Nominal Four Hour Mission)....126

USER REQUIREMENTS AND A HIGH LEVEL DESIGN OF THE HYDROGRAPHIC SOFTWARE/DATA PROCESSING SUBSYSTEM OF AN AIRBORNE LASER HYDROGRAPHY SYSTEM

Jeffrey D. Childs
Systems and Applied Sciences Corp.
Riverdale, Md

David B. Enabnit
National Oceanic and Atmospheric Administration
Office of Ocean Technology and Engineering Services
Engineering Development Office
Rockville, Md

ABSTRACT

The requirements for the Hydrographic Software/Data Processing Subsystem of an Airborne Laser Hydrography System were documented. A timing analysis of the automated processing determined that a 10 million-instruction-per-second computer would be needed to satisfy the requirements and meet the other constraints. A timing analysis of the required interactive data processing determined that 50-60 man hours of interactive processing would be needed for each hour of data collection. A high-level software design was produced from which the expected number of lines of code was estimated to be 20,000. A conceptual hardware configuration and a development plan were produced. Using the results of the timing and hardware analyses, changes in the requirements and constraints were recommended which make the HS/DP Subsystem feasible while preserving its technical performance.

1.0 INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA) has been investigating airborne laser hydrography for several years. The technique uses an aircraft mounted, scanning beam, pulsed laser system to measure water depths. Bathymetric soundings resulting from a laser survey are intended for use by NOAA in the production of nautical charts. Separate studies (refs. 1, 2, 3) have shown that this technique can gather large quantities of accurate bathymetric soundings at a lower cost and with less manpower than present methods. The improved cost- and manpower-effectiveness for hydrographic surveying are the reasons for NOAA's interest.

Laser hydrography systems determine water depth by measuring the difference in arrival times at an airborne receiver of the sea surface reflection and the sea bottom reflection of a laser pulse (Figure 1). This time-of-flight difference is proportional to the water depth. Any depth can be measured if both the surface reflection and the bottom reflection can be detected in the received laser sounding waveform.

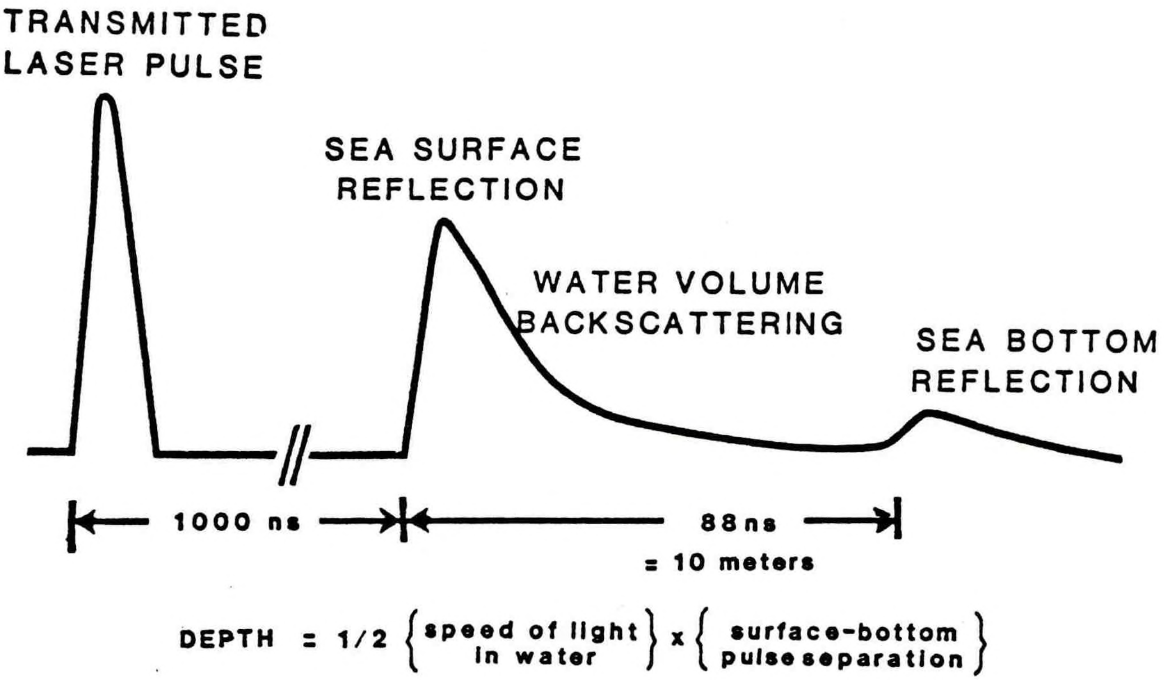


Figure 1.1 Received Laser Sounding Waveform

Figure 1.2 is a block diagram of the airborne laser hydrography system proposed for NOAA. The Airborne Laser Bathymeter Subsystem (ALBS) will transmit the laser sounding pulse and will receive, digitize, and record the returning laser sounding waveform. The Position and Attitude Measuring Subsystem (PAMS) will measure aircraft position and attitude in order to compute the geographic coordinates of each depth sounding. The Hydrographic Software/Data Processing (HS/DP) Subsystem will use the raw data gathered by the ALBS and PAMS to compute the depths and positions, to perform data quality control, and to prepare the final survey products. The HS/DP Subsystem is the subject of this Technical Memorandum. Three other Subsystems complete the airborne laser hydrography system: the aircraft, the Mobile Ground Facility (MGF), and the Tides Measurement Subsystem (TMS). Further details of the planned system can be found in refs. 4 through 6.

Airborne laser hydrography will be a massive data processing and data management problem. A nominal four-hour mission will gather 8.6×10^6 laser sounding waveforms and four hours of positioning data. Accurate depth must be computed from each waveform using sophisticated algorithms that compensate for distortion of the laser sounding pulse as it propagated through the water. Positions must be computed for each sounding for a system that has eight degrees of freedom. System performance must be monitored. Automated data quality control must be performed followed by interactive data quality control steps to allow a meaningful, manual examination of the data by a hydrographer while still at the survey site. Finally, those soundings necessary for nautical charting must be selected from among all the gathered soundings and final survey products prepared.

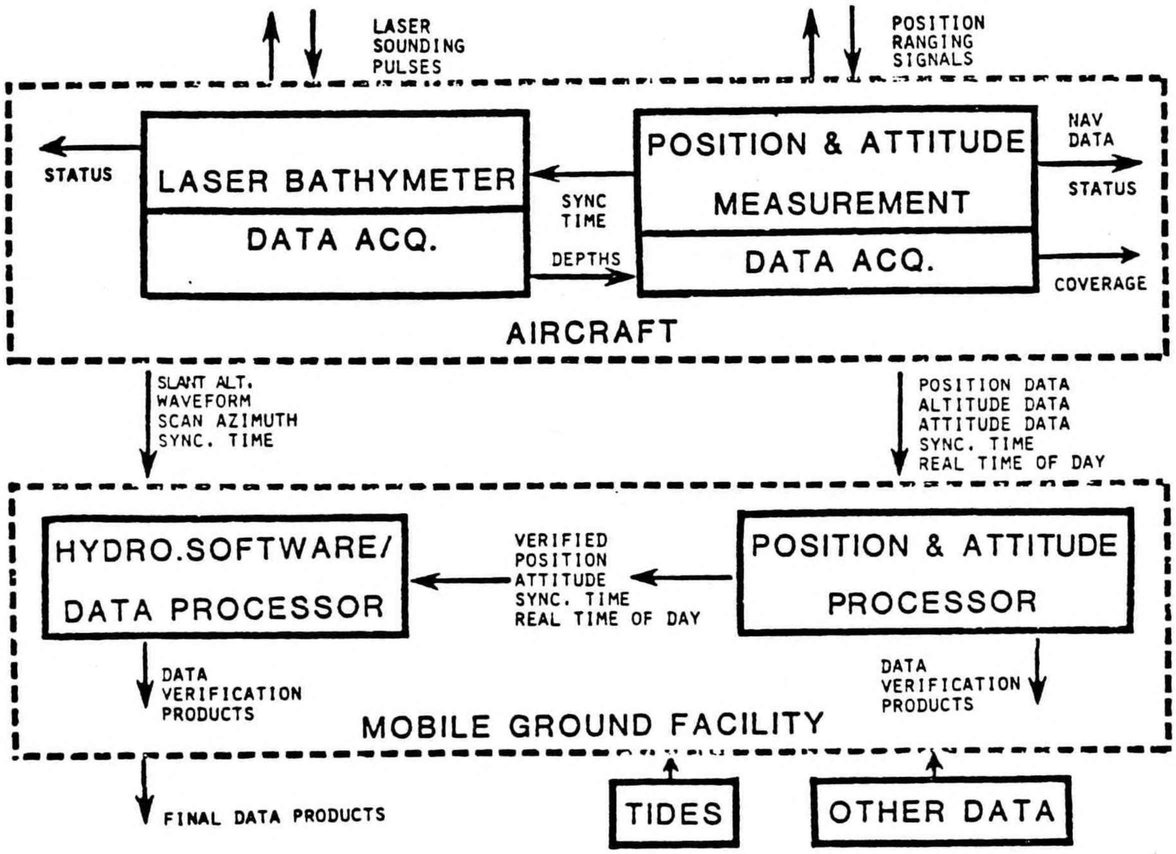


Figure 1.2 Block Diagram of the Proposed NOAA Airborne Laser Hydrography System

The data processing required for airborne laser hydrography has been concentrated in the HS/DP Subsystem. It is the purpose of this study to examine those data processing requirements and to determine the feasibility of implementing the HS/DP Subsystem as conceptualized. The detailed, data processing requirements are presented in Section 2.

The data processing requirements are analyzed in Section 3. Questions of feasibility are considered in light of known constraints and anticipated data volume. A detailed timing study is made of the minimum amount of software that would satisfy the requirements for the non-interactive parts of the system. Analysis is also made of the interactive parts of the system (i.e., those processing steps that require human involvement with the system). Those requirements are identified that must drive the processing. System feasibility is studied in terms of these driving requirements. Conclusions are arrived at and recommendations are made based on the results of the analysis.

Section 4 contains a high level design for the HS/DP Subsystem. A baseline design is presented that is considered an appropriate framework for any implementation of the Subsystem. Hardware recommendations are made in light of the current performance and budget constraints. Several system implementation alternatives are considered, including hardware-enhancement.

Section 5 contains the development plan for the HS/DP Subsystem. Schedules are presented for software and documentation development, hardware procurement and installation, and system integration.

This study was performed for a limited purpose and should be used cautiously outside of that purpose. It was performed to document the expected data processing requirements of an airborne laser hydrography system; to determine the feasibility of implementing those requirement; and to estimate the scope of work necessary for implementation. Certain approximations were made which preclude using the study as a final design document. For example, many of the processing algorithms are untested or are only partially accurate. Also, only a general description of the interactive data evaluation steps were provided, and the intended system user has not necessarily agreed to them. These assumptions are valid for the purposes of this study, but further quantification of the requirements and development and testing of algorithms to satisfy those requirements would be needed before a final HS/DP design document could be written. The question of feasibility studied in this Technical Memorandum is an important consideration during any further refinement of the requirements.

2.0 SUBSYSTEM REQUIREMENTS

2.1 General Requirements

General Problem: Produce complete and accurate bathymetric surveys of an area using data provided by the Airborne Laser Hydrography (ALH) system.

General User Requirements for an Hydrographic Software/Data Processing (HS/DP) Subsystem:

1. Accept all necessary data.

2. Process that data to provide depths and associated positions.

3. Perform automated quality control and allow for manual quality control of the depth/position sounding records and supporting data.

4. Prepare survey output products.

5. Perform as a development tool for the entire ALH System.

2.2 Constraints

System Performance Related Constraints

- o Must handle the anticipated volume of data (see Section 2.3, Data Set Characteristics).

- o Must process the data in less than two hours of processing time for every one hour of data acquisition and should not run more than two hours behind.

- o Must be operable according to the planned scenario (see Section 2.4, Planned Operating Scenario).

- o Must allow the bulk of the processing time for the interactive evaluation of data by the hydrographer (see Section 2.6.2, Interactive Intermediate Processing Requirements).

- o Must possess sufficient excess capacity to allow for future system growth.

Data Quality Control Related Constraints

- o Promulgating erroneous data is considered the most serious system failure possible. Producing insufficient data is less serious but also a major concern.

- o Soundings must be traceable, that is one must be able to reconstruct how any data in the final sounding record was arrived at from the recorded depth sounding waveform. This includes how it was computed and why it was selected for inclusion in the final data set.

- o The system should not crash during operational use and hydrographers should not have to deal with system crashes. This means that the software must be tolerant of erroneous data and unforeseen circumstances.

- o Protection must be provided against software changes except by authorized personnel.

Human Engineering Related Constraints

- o The HS/DP must capitalize on the existing experience and tools of the anticipated operating personnel, particularly with respect to evaluating the gathered data.

- o Must be designed for ease of use, e.g. ten-page operator's manual, self-explanatory diagnostics, machine-generated prompting, etc.

- o The developer's tools must be easy to use since there will be limited manpower.

- o All geographic displays of sounding data must include: latitude, longitude, north, direction of flight, and a length scale.

System Maintenance and Upgrade Related Constraints

- o The system must be flexible in use since optimum setup parameters and special algorithms have not been determined and will be changed during developmental testing.

- o The system must allow easy modification since major modifications can be expected as a result of developmental testing in the fourth year of the system development program.

- o The computer language used and level of documentation must allow for operation over the eight year design lifetime with several changes of operating personnel.

- o The system developer must be able to change the software to reflect knowledge gained through system use.

Schedule and Procurement Related Constraints

- o Maximum use of commercially available hardware and software is desired to reduce development time and risk, and to ease maintenance.

- o The HS/DP Subsystem must be built in two years. A subsequent one-year modification period is planned to incorporate changes identified during developmental testing.

- o Only one suite of hardware can be afforded. It must serve as both the developmental system and the operational system.

- o All Subsystems of the laser hydrography system will be built simultaneously so some Subsystem characteristics will not be known in advance to the developer of the HS/DP.

- The system software design will not be completed before hardware procurement must begin.

- Total HS/DP Subsystem cost should not exceed $750K including software, hardware, documentation, training, installation, testing, etc.

- Software modification and maintenance will continue for eight years using both Government and contract personnel. Design should allow for such a fluid maintenance situation.

- Software and hardware will be developed and implemented by contractors.

2.3 Data Set Characteristics

Note: All resolutions stated in this section are greater than those actually available in the data sets. They were selected as maximum potential values for use only in determining conservatively the number of bits required for computer storage.

2.3.1 Airborne Laser Bathymeter Data Set

The following data will be provided to the HS/DP Subsystem from the Airborne Laser Bathymeter Subsystem (ALBS). Data will probably be provided on a high density magnetic tape in a nonstandard format.

- 400 - 600 laser sounding waveforms per second

- 600 - 2,000 bits per sounding waveforms

- scanner azimuth angle measured with 12 bits of resolution for each sounding, 0 - 360 degree range

- laser pulse peak power measured for each sounding to nearest kw over a range of 0 - 800 kw

- system synchronization time recorded for each sounding to nearest 150 microseconds for the 4 hour nominal, 6 1/2 hour maximum mission duration

- slant altitude measured for each sounding with a range of values of $0\text{-}6.7 \times 10^{-6}$ second to nearest 3×10^{-10} second (these may have been converted to distance using the speed of light)

- system failure messages and diagnostic messages issued to aircrew - probably a number between 0 and 512 to be used as a reference to a maintenance manual

- system diagnostic messages not issued to aircrew - probably a number between 0 and 512 to be used as a reference to the operator's manual

- approximate depth presented to aircrew at a rate of 5 per second with range of values of 0 - 70 meters to nearest meter

- temperatures - probably three with range of values zero to 100 degrees Celsius to nearest 1 degree Celsius (filter, coolant, electronics) - each recorded once per second

- o flashlamp output - one measurement per pulse - range and resolution unknown

- o overall system power; zero to 10 kw to nearest 0.1 kw - once per second

- o other housekeeping parameters to be specified - once per second

- o data will be provided on magnetic tape of undetermined kind and undetermined format

- o depth accuracy is expected to be ±30 centimeter RMS

- o depths will be computed to the nearest one centimeter

2.3.2 Position and Attitude Measurement Data Set

The following data will be provided to the HS/DP Subsystem from the Position and Attitude Measurement Subsystem (PAMS) with no more than the indicated maximum potential resolution. It will probably be provided as a magnetic tape cassette.

- o latitude to the nearest 0.01 second (.3 meter)

- o longitude to the nearest 0.01 second (.3 meter)

- o altitude, 0 - 10,000 meters to the nearest ten centimeters

- o heading, 0 - 360 degrees to the nearest 0.05 degrees

- o pitch, 0 - 20 degrees to the nearest 0.025 degrees

- o roll, 0 - 20 degrees to the nearest 0.025 degrees

- o The six positioning parameters will be gathered by the PAMS 20 times per second or less.

- o The six positioning parameters will not necessarily be synchronous, that is, each may be made a different time and so each will have an associated synchronization time.

- o Synchronization time recorded to the nearest 150 microseconds for each positioning parameter measured. This gives between 20 per second (if all positioning parameters are measured simultaneously) and 120 per second (if all positioning parameters are measured at different times).

- o The PAMS contractor will provide an algorithm to the HS/DP developer which will use the PAMS data, the six positioning parameters, the synchronization times and allow computation of laser sounding position at an arbitrary time (the scanner azimuth, a seventh position parameter, will come from the ALBS).

- o PAMS failure codes provided to aircrew - probably a number between 0 and 512 to be used as a reference to the operator's manual

- o PAMS failure codes not provided to aircrew - probably a number between 0 and 512 to be used as a reference to a maintenance manual

- o real-time-of-day, measured once per minute to the nearest minute (24 hour clock)

- o PAMS housekeeping parameters (to be determined)

- o positions are expected to be accurate to 4.5 meters RMS

- o positions are measured to the nearest 0.3 meter

2.3.3 Tide Measurement Data Set

The following data will be provided to the HS/DP Subsystem from the Tides Measuring Subsystem (TMS) with no more than the stated maximum potential resolution. It will probably be provided on a magnetic tape cassette and/or punched paper tape. Once tape will be provided from each tide station.

- o tide level (range of tides 0-50 feet, recorded to nearest 1/100 foot)

- o one measurement every six minutes

- o 1 - 15 different tide stations will be running simultaneously

- o real-time-of-day to the nearest minute (24 hour clock)

- o Julian date

- o the recording type and format are undetermined

- o locations of tide stations - latitude, longitude, to nearest 0.01 second (0.3 meter) - probably will have to entered manually

2.3.4 Manually Recorded Data Set

These soundings will be made by the laser survey party at no greater than the stated maximum potential resolution as an accuracy check on the laser soundings, to resolve discrepancies, and to fill in small gaps in coverage.

- o Handwritten records of soundings gathered manually by the laser survey party. Depths will be between 0 and 70 meters to the nearest centimeter.

- o Handwritten records of the position of soundings gathered manually by the laser survey party. Positions will be latitude and longitude to the nearest 0.03 seconds.

- o Approximate number of soundings gathered manually - 1,000 per 4 hour laser mission.

- o Real-time-of-day to nearest 1 minute (24 hour clock) for each sounding.

- Method of measurement - lead line or sonar.

- Julian date of the day the soundings were made.

2.3.5 Automated Contemporary Comparison Data Set

This will be standard NOS sonar survey data gathered at no greater than the stated maximum potential resolution for the purpose of building confidence in laser soundings, to resolve discrepancies in the laser data, and to fill gaps in the laser survey.

- Present surveys are recorded on paper tape in a known format.

- HS/DP will be interested in the following data from the set.

  - depth 0 - 70 m to nearest one centimeter
  - latitude, longitude, to nearest 0.01 second (.3 meter)
  - real-time-of-day to nearest one minute
  - tide corrector if already applied

- Other sonar surveying correctors are assumed to have been already applied by the sonar survey party.

2.3.6 Historical Comparison Data Set

These are data provided to the survey party from the NOS data base of hydrographic data. These data will be provided on a magnetic tape at no greater than the stated maximum potential resolution. The format can be defined by the HS/DP developer.

- depths; 0 - 70 meter, to nearest one centimeter

- latitude, longitude, to nearest 0.01 second (.3 meter)

- datum

- tide corrector, 0 - 50 feet to nearest 0.1 inch

- shoreline; straight line segments recorded as pairs of endpoints

- depth curves; straight line segments recorded as pairs of endpoints

2.4 Planned Operating Scenario

- System will be flown 600 hours per year with up to 400 hours of actual data collection.

- Mission durations are nominally four hours with no more than 6 1/2 hours being flown within a 24 hour period.

- Four to ten sites per year will be surveyed. All data processing must be completed before the site is vacated.

- All processing will be done in a trailered Mobile Ground Facility containing the HS/DP hardware, the PAMS data processing hardware, and a mission planning area.

- A survey party of five is planned. Of these, one person will be fully responsible for all HS/DP processing and data evaluation. Part-time of a second person may also be available.

- One scientifically trained person will be on call to respond to problems that are not resolvable by the survey party and which are related to Subsystem performance or development.

- Most of the Subsystem development work will be done at a separate location from the survey party, e.g. Rockville.

- No hardware or software maintenance or modification capability will be available in the field except for routine maintenance done by a contractor.

- The data that leaves the field are to represent a completed survey. No further processing (except for the possible application of smoothed tides data) is to be required.

- System design lifetime is eight years.

- Contract software and hardware maintenance will be available to the field party, e.g. DEC service representatives.

- Soundings are spaced an average of 4.5 meters apart. They are gathered in 220 meter wide swaths which overlap by 20 percent, and in swaths which are an average of 50 kilometers long.

- The responsibility of the survey party (hydrographers) will be survey operations and data processing. Their duties during the data processing will be operational - not developmental.

- During the Intermediate Processing, the hydrographer will be applying his general, hydrographic knowledge to assess the plausibility of the data. He will not be debugging the system or trying to understand the details of laser depth soundings.

2.5 Detailed Requirements - Subsystem Developer

Airborne Laser Hydrography is a new technique using a new and complicated system. It is expected that both the laser sounding technique and the laser hydrography system will be undergoing continual refinement and modification as experience grows. The following data processing tools will be needed by the system developer. The more important ones are marked with an asterisk. These development tools will not be used simultaneously with the operational processing of a survey.

The developer is principally interested in determining how a value was arrived at, is it correct or is it an unanticipated exception, and if it is not correct, what should be done about it. Corrective software must then be developed, tested, and implemented. If it is not a critical flaw, the developer cannot usurp the HS/DP from the survey party. They must still continue routine operations.

The processed, operational survey data should include a list of setup parameters, system parameters, edit criteria, etc., so the developer can reconstruct the processing that gives anomalous answers.

Developer's Tools:

I. Software Configuration Control

* 1. Must be able to do software development and analysis of data for development purposes at locations other than the MGF. This may be a remote terminal that time shares on the MGF computer, a duplicate system, or an HS/DP simulator on a main frame computer. Consider how the choice would aid real-time remote discussion of problems between the developer and the survey party.

* 2. Change control on the operational software and its documentation must be exercised.

3. A means must be provided to write and test the effect of software changes before they are implemented in the operational software. This need not be done at the Mobile Ground Facility (MGF) but changes should be tested on the operational system in the MGF before they are implemented. No duplicate HS/DP will be available.

II. Data Accessing Techniques

* 1. The capability of accessing specific soundings or groups of soundings for further examination. This may be a specific sounding, a set of soundings related by synchronization time, a set of soundings related by another parameter such as azimuth or bottom signal strength, or a set of soundings related by space such as along a selectable path or within a polygonal area.

* 2. Access to the principal parameters of a sounding record for an identifed set of soundings. The principal parameters of a sounding record is comprised of:

1. laser return waveform
2. indicators showing the system's choice for the surface and bottom
3. pulse synchronization time
4. final corrected depth
5. raw depth
6. wave corrector
7. tide corrector
8. water property corrector
9. S/N ratio

10. local average S/N ratio average

11. laser power

12. depth computing method (zero depth or pulse separation)

13. interface or volume surface return

14. scan azimuth

15. x, y position

16. altitude

17. pitch, roll, heading

* 3. Ability to access soundings or areas identified by the hydrographer or developer as of concern or uncertainty. There must also be a way of communicating why the hydrographer was concerned and what action he took with respect to those soundings.

4. Access to the secondary parameters sounding records for an identified set of soundings. The secondary parameters are most of the other parameters in the sounding record. It might be easier to have a menu of all secondary parameters and let the developer choose those he wants at a particular time.

5. Capability of accessing for study pulses which were deleted. One could consider collating these on a separate tape but that would destroy the capability of looking at surrounding soundings which were not deleted.

III. Data Analysis Techniques

* 1. The capability must exist of presenting profiles of any parameter. An arbitrary parameter vs. synchronization time is essential. An arbitrary parameter along a selectable geographic path is less important but still of interest. Both of the two parameters being plotted as one point on the profile (e.g. depth and synchronization time) will be from the same sounding record.

* 2. Simple statistics. Correlation coefficients are mentioned in III.4. The capability is also needed to make histograms and to compute means and standard deviations for any parameter of a selectable group of soundings.

* 3. Be able to treat changes in parameters just like the parameters themselves. That is, where the earlier tools call for doing something with a parameter, such as plotting a profile of depth vs. synchronization time, these tools should also operate on changes in depth and plot depth difference vs. synchronization time. Changes in parameters for both temporal neighbors and along selectable paths will be looked at.

4. Compute the correlation coefficient of any pair of parameters. These parameters, both here and for the other tests, can be any parameters appearing anywhere in the processing, even ones which might not normally be saved as part of a sounding record.

5. Scatter plots of any two parameters. This tool must be user oriented, e.g. scatter plots should be autoscaling and labeled. The values of the two parameters being plotted will be from the same sounding record.

6. Two-Dimensional (or pseudo three-dimenstional) plots of any of parameters. Most common would be parameters like the diffuse attenuation coefficient "K" or the wave corrector against geographic coordinates. Again, as in 5., ease of use is important. Values of the two or three parameters being plotted will come from one sounding record.

IV. System Capabilities and Control

* 1. The capability of changing processing setup parameters will be needed. These should be changeable in both a temporary and a permanent manner. Comparative runs of the program will be made using old and new parameters. This has been done extensively in the past making 10 - 15 runs on one set of data while varying four setup parameters. Percent thresholds used to "locate" pulses and edit criteria are expected to be the parameters changed most often.

* 2. The ability to override deletions.

* 3. Should be able to do processing using data from other than a raw flight tape. For example, if one wants to make several runs on a subset of the raw flight data, it should not be necessary to keep rewinding the flight tape. Likewise, a simulated data set may be needed for testing, but it should not have to physically be put on a high density flight tape.

* 4. The capability must exist for tracing where a number came from, i.e., understanding how it was computed and seeing the values that went into its computation. The requirement to trace any sounding back to original, raw data is a legal requirement.

* 5. Printed output. In the past, large quantities of printed output have been used. A teletype or hardcopy machine would be inadequate for the quantity forseen.

* 6. Hardcopy of key graphics material is necessary.

7. Should have some means of interrupting the processing and looking at intermediate results. Alternately, one should be able to do the processing in steps where the software halts after each step to allow intermediate results to be pondered.

8. Should be able to compare the approximate depths being determined by the Airborne Laser Bathymeter Subsystem for display to the aircrew with the depths determined by the HS/DP. This is a quality control tool.

9. The ability to save data which would normally be discarded as an intermediate processing result.

10. Should be able to suppress any correctors. This will probably be used mostly against the preflight correctors and possibly the internal calibration pulse correctors.

11. Should be able to change the raw data in the sense of being able to duplicate the raw data, change the duplicate, and process that changed data set. True raw data must be inviolate.

12. Auxiliary, general purpose computing capability for the system developer to use should be available in the MGF.

2.6 Detailed Requirements - Subsystem User

Constraints

1. All correctors are to be saved temporarily as is the raw value to which they are applied. The correctors will be purged during the Intermediate Processing.

2. Each sounding record will be a continuously growing list of items as the preliminary processing proceeds. If possible, it should all be saved until the PURGE step in the Intermediate Processing.

3. Within the sounding record there should be one corrected depth for each corrector. This is so the developer can see the effect of each corrector if they are not applied in a simple fashion such as addition.

4. Deleted pulses should be deleted by flagging rather than be erasure.

5. Deleted pulses should continue to be processed in some cases. Those cases are: when sufficient information exists to allow continued processing (e.g. a complete waveform), and when the inclusion of that pulse will not distort running averages.

6. Pulses which have been identified as failing a quality control criteria and which are deletable should be deleted as early in the processing as possible in order to continually minimize subsequent processing.

7. One should be able to compute averages with as many as 50 percent of the soundings deleted.

8. The software in general should be very robust such that it does not crash over problem data. This reflects the fact that, during routine operation, no developmental personnel will be with the system and system crashes will not be resolvable by the survey party personnel.

9. The preliminary processing is to be as highly automated as possible.

10. When a pulse or pulse property is compared with a local average, it is usually a spatial or temporal average around that pulse rather than just an average of the preceding pulses.

2.6.1 Automated Preliminary Processing Requirements

Preliminary processing will start with the raw, digitized, laser return waveforms, compute depth and depth correctors, merge depth and position, and perform some quality control functions. The preliminary processing will be largely automated and will operate using only properties of the data set itself.

LIST OF PRELIMINARY PROCESSING STEPS

1.0 Flight Tape Initialization
2.0 Print Initialization Parameters
3.0 Flight Tape Duplication
4.0 Accept Preliminary Processing Parameters
5.0 Read and Process Preflight Calibration Data

a. Altitude Calibration
b. Depth Calibration
c. Laser Power Monitor Calibration
d. Gain and Time Base Calibration
e. Transmit Pulse Stability
f. Radiometric Calibration
g. System Noise
h. Calibration Pulse Calibration

6.0 Read and Unpack Raw Data
7.0 Delete Unacceptable Returns

a. Waveform Test for Deletable Pulses
b. Laser Power Test for Deletable Pulses
c. Azimuth Test for Deletable Pulses
d. Synchronization Time Test
e. Other Housekeeping Parameters
f. Approximate Slant Altitude

8.0 Identify and Process Internal Calibrator Pulse; Apply Correctors
9.0 Apply Low Pass Filter
10.0 Compute and Apply Environmental Subtraction
11.0 Compute Pulse Location on Bathymetric Waveform
12.0 Compute Apparent Depth
13.0 Zero Depth Test and Computation
14.0 Compute Waveform Based Parameters
15.0 Accept Position Data and Compute Laser Sounding Position
16.0 Compute and Apply Depth Correctors
17.0 Compute Slant Altitude
18.0 Compute and Apply Wave Corrector
19.0 General Edit
20.0 Read, Edit and Correct Tides Data
21.0 Compute and Apply Tide Correctors

Detailed Description of Preliminary Processing Steps

Note: The following symbols are used for sources of inputs and destinations of outputs:

SU - setup parameter list
FT - flight tape
PO - print out
Q - sounding data queue entry
PT - PAMS tape
TT - tides tables
SOP - stored output parameter

Step 1. <u>Flight Tape Initialization</u> - Puts mission parameters on the magnetic tapes to be used in the aircraft. Performed in the Mobile Ground Facility with magnetic tape hand carried to aircraft.

List of initialization parameters:

- off-nadir angle; range of values = 0 - 30 degrees; resolution = one degree
- field-of-view; range of values = 20 - 80 milliradians; resolution = one milliradian
- transmitter beam divergence; range = 3-21 milliradians; resolution = one milliradian
- maximum expected depth; range = 0 - 70 meters; resolution = one meter
- filter parameters; filter bandpass, e.g. 510 - 513 nm with a nonsense value for no filter
- pulse repetition rate; range = 5 - 600 pulses per second; resolution = one pulse per second
- laser power setting; range = 50 - 800 kw; resolution = one kw
- scan rate; range = zero to ten scans per second; resolution = one scan per second
- altitude cutoff for laser power; one value between zero and 150 meters
- survey altitude; range = 0 - 1,000 meters; resolution = one meter
- survey identification number composed of a three character field (three alphas), followed by a four character field (one alpha, three numerics), followed by a two character field (two alphas), followed by a two character field (two numerics)
- Julian date

- o survey location; name plus latitude and longitude of boundary coordinates (some areas may be polygonal)

- o survey party members

Step 2. Print Initialization Parameters - The printed copy of what was initialized in Step 1 will be used as mission instructions to the aircrew. This printing will use equipment in the Mobile Ground Facility.

Survey takes place at this time

Step 3. Flight Tape Duplication - This is a standard precautionary procedure used by NOS. The duplicate will be stored at a separate site and processing will proceed using the original tape. The duplicate will be recycled or destroyed after the survey. The original will be submitted with the survey results and archived.

Step 4. Accept Preliminary Processing Parameters - These parameters will be manually input. They are a series of constant values to be used in subsequent algorithms. There will probably be a lot of adjusting of these values during the first few years of system operation to find an optimal set. Since the list is extensive, it should be a prerecorded setup that is altered manually as needed.

The list of actual parameters has been dispersed in this study to the steps in which they are used.

Step 5. Read and Process Preflight Calibration Data - The preflight calibrations are tests performed on the ground by the flight crew to see that the system is functioning properly and to measure any system parameters that will be needed in later processing. Immediate feedback on system functioning will be provided to the flight crew by the Airborne Laser Bathymeter Subsystem. Responsiblity for defining the preflight calibration procedure belongs to the Airborne Laser Bathymeter Subsystem contractor. The HS/DP Subsystem will have to read the preflight calibration data, compute and subsequently apply the required correctors, and print the calibrations and their results for the final report. One should be able to turn these correctors off if desired.

The following calibrations are typical:

a. Altitude Calibrations - The laser beam is deflected down the runway to a reflector placed at several known distances. The crew enters the distance to the reflector on the flight tape and fires the laser briefly at each of three distances.

Computation Procedure

- o read distances (altitudes) entered manually by survey party

- o find on the data tape and read slant "altitude" timer/counter in each laser pulse record

- o compute the pulse separation in units of time and convert it to differential range, d = ct/2
- o compute the average differential range for all the pulses fired at each distance
- o compute the standard deviation of the differential ranges for each of the three distances
- o compute the difference of the entered differential ranges and the average measured differential ranges for each of the three cases
- o compute the average difference
- o print the three entered differential ranges, the three average laser measured differential ranges, the three standard deviations, the three differences between entered and measured differential ranges, and the average difference for inclusion in the final report
- o store the average difference between the entered and the laser measured differential ranges to use as a corrector for use in Step 12

Input

(FT) three differential ranges
(SU) speed of light in air, C
(FT) laser waveforms for each range

Output

(PO) three entered differential ranges, three average laser measured differential ranges, three standard deviations, three differences between entered and measured differential ranges, average difference
(SOP) differential range corrector

c. Laser Power Monitor Calibration

Computing Procedure

- o read power level entered manually on tape by survey party
- o find laser power monitor data in routine housekeeping data
- o compute the average and standard deviation of the difference between the manually entered power level and the monitored power level

- convert time to distance ($d = ct/2$) for each pulse
- compute the average of the laser measured distances for each of the three cases
- compute the standard deviation of the laser measured distances for each of the three cases
- compute the difference between the distances entered by the survey party and the average laser measured distances for each of the three cases
- compute the average of the three differences
- print the average laser measured distances (three values), the standard deviation (three values), the three differences between the entered and measured distances, and the average difference
- store the average difference between the entered and laser measured distances for used as a corrector in step 17

Inputs

(SU) speed light in air, C
(FT) three "altitudes" manually entered
(FT) group of times (altitudes) for each test range

Outputs

(PO) average laser measured distances, three standard deviations,

three differences between entered and measured distances, average distance

(SOP) altitude corrector

b. Depth Calibration - This calibration is similar to the altitude calibration but uses two reflectors; the first one (closest to aircraft) being partially reflecting and the second fully reflecting. This allows calibration of the system's differential ranging accuracy. One should be able to turn this corrector off if desired.

Computing Procedure

- read differential ranges entered by survey party
- find return waveforms for this calibration in the laser bathymeter data set
- compute the pulse locations of the first and second pulses in each waveform using Step 11

- o print for final report

Inputs

(FT) power reading entered manually
(FT) power measured as housekeeping parameter

Outputs

(PO) standard deviation, average

d. Gain and Time Base Calibration

A preset series of waveforms will be input to calibrate the system's gain and time base. This calibration will allow one to compare the true system performance to that which is assumed during depth computation. These waveforms should be a series of distinct pulses which run throughout x amplitudes at each of y time locations to span the full range of anticipated laser sounding waveforms. The result of the calibration will be an array that says, for example, multiply the amplitude of point i by x and delay its time value by y.

This calibration will be used during preflight calibration by the air crew to adjust the Airborne Laser Bathymeter Subsystem using equipment provided with that Subsystem. The correctors will not be applied by the HS/DP unless the internal calibrator pulse concept (Step 8) turns out to be infeasible.

Computing Procedure

- o find the approximate calibration waveform recorded by the system
- o find the known calibration waveform that was input to the system
- o difference the two on a point-by-point basis
- o compute the gain multiplier for each point
- o compute the time multiplier for each point
- o store and print the results

Inputs

(SU) calibration waveforms
(FT) laser waveform

Outputs

(SU) table of correctors
(PO) table of correctors (2 x 200 correctors)

e. Transmit Pulse Stability - Some of the transmitted pulses will be reflected directly to the receiver for this.

Computing Procedure

o average these pulses together on a a point-by-point basis to get an average waveform

o compute the mean and standard deviation of each of the 200 points

Inputs

(FT) laser waveforms

Outputs

(PO) 200 means, 200 standard deviations

f. Radiometric Calibration - A known optical source will be applied to the receiver to measure its absolute response.

Computing Procedure

o find the appropriate waveforms
o print the amplitude of the pulse or DC level

This value is monitored for optical train deterioration.

Inputs

(FT) waveforms
(SU) optical source(s) power level

Outputs

(PO) input power vs. output level

g. System Noise - This calibration looks for transmitter/receiver crosstalk and general system noise

Computing Procedure

o gather "waveforms" when all the laser pulse is transmitted but not received, i.e., when there is no target

o compute the mean and standard deviation for each point on the "waveform"

o print the output

o do the same but without transmitting

Inputs

(FT) waveforms

Outputs

(PO) 200 mean and standard deviations

h. Calibration Pulse Calibration - Checks that the correctors determined with the internal calibration pulse (Step 8) are the same as those determined in d. above.

Computing Procedure

- compute gain correctors from internal calibrator pulse (see Step 8)
- difference these gain correctors from those in d.
- print the results
- compute time correctors from internal calibration pulse
- difference these time correctors from those in 5d.
- print the results

Inputs

(SU) correctors computed in 5d.
(FT) internal calibration waveform

Outputs

(PO) list of point-by-point differences between each of the correctors (200 differences for gain and 200 for time)

Step 6. Read and Unpack Raw Data

(self explanatory)

Inputs

(FT) sounding records as described elsewhere under "laser data set"

Output

(Q) unpacked laser data

Step 7. Delete Unacceptable Returns - Finds incomplete records or obvious malfunctions by looking at some of the parameters in the sounding record. Causes for deletion are:

a. Waveform Test for Deletable Pulses

Computing Procedure

- o tests bins x through y to see that they're greater than z
- o failure of this test should cause deletion of the pulse from all further processing
- o count should be kept of the number of pulses deleted

Inputs

(Q) sounding records
(SU) x, y, z

Outputs

(Q) flagged pulses
(PO) number of pulses deleted

b. Laser Power Test for Deletable Pulses

Computing Procedure

- o test to see that laser power is within a preset range by comparing the laser power monitor reading in the sounding record with a preset value
- o flag as deletions those that fail, but continue processing them
- o compile a three-point histogram of laser power; above, below, and within the acceptable range

Inputs

(SU) acceptable power range
(Q) laser power

Outputs

(Q) flagged pulses
(PO) three-point histogram of laser power

c. Azimuth Test for Deletable Pulses

Computing Procedure

- o test to see that a value for azimuth angle was recorded
- o test to see that the azimuth angle being tested is greater than its predecessor by a preset amount

- o if a few are missing, fill them in by interpolation (five is a few)
- o flag those where the azimuth was determined by interpolation
- o delete pulses where azimuth cannot be assigned by interpolation but keep processing these deletions
- o keep track of how many have no azimuth and the number of azimuths generated by interpolation

Inputs

(Q) azimuth
(SU) difference allowable between successive azimuths
(SU) number of azimuths generated by interpolation

Outputs

(Q) flagged pulses
(Q) interpolated azimuths
(PO) number of missing azimuths
(PO) number of interpolated azimuths

d. Synchronization Time Test

- o see that there is a synchronization time value
- o see that it is greater than its predecessor by a preset amount
- o interpolate if necessary to replace up to m missing synchronization times where m is a small preset number
- o flag the interpolated synchronization times
- o delete those sounding records where synchronization time cannot be established but keep processing them
- o keep track of the number of deleted soundings and the number of interpolated soundings

Inputs

(Q) synchronization time
(SU) required increase in synchronization time
(SU) m, the number of allowed interpolations

Outputs

(Q) flagged pulses
(Q) interpolated synchronization times
(PO) number of missing synchronization times
(PO) number of interpolated synchronization times

e. <u>Other Housekeeping Parameters:</u> temperatures, system power levels, etc.

- o treat as "laser power" in b. above

f. <u>Approximate Slant Altitude</u>

<u>Computing Procedure</u>

- o see that there is a slant altitude value from the slant altitude counter/timer
- o see that it lies within a preset range of the survey altitude
- o see that it does not change from its predecessor by more than a preset amount
- o if there is no slant altitude, delete the pulse but continue processing
- o keep track of the number of deletions

<u>Inputs</u>

(Q) slant altitude
(Init) planned survey altitude
(SU) acceptable change in sequential altitude measurements
(SU) acceptable difference from planned survey altitude

<u>Outputs</u>

(Q) flagged pulses
(PO) number of deleted pulses

Step 8. <u>Identify and Process Internal Calibrator Pulse; Apply Correctors</u> - This is a standard pulse that the Airborne Laser Bathymeter Subsystem generates and substitutes for a laser sounding periodically (one in 600). Its purpose is to allow changes in system response to be compensated for.

<u>Computing Procedure</u>

- o Calibration pulse should always occur at about the same azimuth.
- o Test to identify the calibration pulse if they are not flagged on the flight tape

$$\sum_{i} \left(\text{Point}^{i}_{\text{sounding waveform}} - \text{Point}^{i}_{\text{setup parameters of calibration pulse}} \right) = X$$

Looking for a minimum in X. Since its occurence is periodic, N pulses can be skipped before applying this locator algorithm again.

- It might also be possible to have an identifier bit set in the sounding record of the calibration pulse or force it to occur at one and only one azimuth.

- Processing of the located calibration pulse will be a point-by-point comparison (probably subtraction) of the reference calibration waveform (a setup parameter) and the recorded calibration waveform.

- The result of each comparison will be used to compute a time and gain corrector for each point of the actual sounding waveforms.

- For example, a constant DC level might be used to calibrate gain. The difference between the known input DC level and the way it appears in the sounding record is a measure of system distortion.

- The correctors to be computed are those needed to restore the distorted calibration waveform to its original level or shape.

- Time base calibration is not as clear cut as amplitude calibration. An example of a time base calibration would be a waveform with a series of narrow pulses. The software would compute the "depth" between the first and second, the first and third, etc. Since the separation they were generated with is known, a different answer would be distortion induced and could be compensated for.

- It is possible that more than one type of calibration waveform might be needed to do the job.

- The generated correctors will be applied as appropriate. For the example, a gain corrector would be applied to each point of every waveform between successive calibrations. The time corrector would be applied to raw depth.

- A new set of correctors will be generated from each internal calibration waveform and applied to succeeding sounding pulses.

- An indication of what types of correctors were applied and how rapidly system performance varied should be provided. For the examples discussed, a time profile of gain correctors for three points and depth correctors for three depths would be adequate. A less desirable substitute would be the mean and standard deviation for three points of each corrector.

- Gain correctors should be applied immediately.

- Time base correctors should be computed as an amount of depth to change each raw depth by and applied in Step 16.

- o If the calibration correctors surpass a preset threshold indicating unacceptable performance, start deleting everything without any subsequent processing, until the calibration waveform correctors return to bounds. Keep a count of deletions.

Inputs

(Q) inflight calibration waveforms (time and gain)
(SU) reference calibration waveforms (time and gain)
(SU) preset corrector thresholds (time and gain)

Outputs

(Q) gain correctors (200 values)
(Q) time base correctors (200 values)
(PO) time profile of gain correctors for three points
(PO) time profile of depth correctors for three depths
(PO) count of deletions

Step 9. Pass Waveform Through Low Pass Filter

(the need for this is uncertain)

Inputs

(Q) waveform
(SU) filter parameters

Outputs

(Q) filtered waveforms

Step 10. Compute and Apply Environmental Subtraction - This is a procedure used in the past to remove system and environmental noise. Its necessity for future systems is not certain. The algorithm went like:

Computing Procedure

- o Find sounding waveforms in water too deep to detect the bottom pulse. The only information in these waveforms will be the surface reflection of the sounding pulse, the volume backscatter of the water, and the system noise.
- o Sort these deep water pulses on the basis of the amplitude of their surface return pulses. Average the return waveforms with the same surface return pulse amplitude on a point-by-point basis for each surface return amplitude (or a small range of amplitudes). The average waveform is a point-by-point average of all waveforms of the appropriate surface amplitude.
- o For soundings where the water is shallower and a bottom pulse is expected, find the average waveform whose surface amplitude is

closest to that of the real sounding and perform a point-by-point subtraction of the two waveforms. Use the difference waveform to locate the bottom pulse in Step 11 and the real sounding waveform to locate the surface return.

Inputs

(Q) waveforms
(SU) deep water pulse class definitions (2 x 100 numbers)

Outputs

(DW) average waveform for 100 classes (100 x 200 numbers)

Step 11. Compute Pulse Location on Bathymetric Waveform - This is a three step process - locate the pulse, subtract the background, and compute the pulse location. It must be done for both the surface pulse and the bottom pulse.

Computing Procedure

a. Pulse location is done by tracking pulses from preceding waveforms with rules to follow if it is lost. To locate the surface pulse, search ±x points around the average location of the peak of the last N surface pulses for a local maximium (excluding boundary maximums).

   o If there is no local maximum, go to point one and search M bins for a local max.

   o When a local maximum is found, test the leading edge and the width of the pulse to see that its an acceptable pulse and not a noise spike. An acceptable pulse will have a monotonically-increasing leading edge whose slope exceeds a threshold, and a width greater than the transmit pulse. If it is not an acceptable pulse, continue the search.

   o If there is more than one maximum, pick the earliest in time.

b. To locate the bottom pulse, search ±y points around the average location of the bottom return peak in the last n bottom pulses for a local maximum (excluding boundary maximums).

   o If there is no local maximum, go to the last point and search towards earlier time for one.

   o When a local maximum is found, test the width and leading edge shape of the pulse to see if its an acceptable pulse. An acceptable pulse will have a monotonically-increasing leading edge whose slope exceeds a threshold, and a width greater than the transmit pulse. If it is not an acceptable pulse, continue the search.

   o If there are no acceptable pulses, delete the sounding and do no further processing on it.

- o Test to be sure that the surface pulse was not also picked as the bottom pulse.

c. Remove the DC background level

- o Move b points earlier than the bottom peak and B points later than the surface peak. Average k points in this region and subtract the average from every point in the waveform.

- o When there are not adequate points for this procedure, one will probably go to some points after the bottom pulse peak.

d. Compute the pulse locations

- o The surface pulse location will be one of the following

  - o a fixed percent of the peak amplitude, probably 50 percent, found by locating the peak amplitude and moving toward earlier times until the amplitude drops below 50 percent of the peak, or

  - o a fixed percent of the width of the leading edge, or

  - o that point at which a fit to the leading edge reaches zero amplitude.

- o Interpolation between points will be needed.

- o Save the computed location.

- o The bottom pulse will be done similarily but with different percentages.

e. Flag sounding records for which only one pulse was found. They will be tested for the zero depth case.

Inputs

(Q) waveform
(SU) x search region
(SU) N number pulse average
(SU) M maximum surface search region
(SU) leading edge slope
(SU) width criteria
(SU) surface percent threshold
(SU) z percent of leading edge width
(SU) y point search region
(SU) b, B, k
(SU) bottom percent threshold
(SU) bottom percent leading edge width

Outputs

(Q) surface peak location
(Q) average peak location
(Q) surface pulse location
(PO) surface amplitude histogram
(Q) bottom peak location
(Q) DC background
(PO) DC background profile
(Q) bottom pulse location
(PO) "one pulse" flagging

Step 12. Compute Apparent Depth - For those waveforms found in Step 11 to have two distinct pulses, compute the depth as follows:

Computing Procedure

- o Compute the separation in points of the two pulses located in Step 11.
- o Convert points to time using a preset relationship.
- o Convert time to distance $d = c't/2$.
- o Store apparent depth for each sounding.
- o Add or subtract the depth calibration corrector determined in Step 5b.

Input

(SU) point-to-time conversion relationship
(SU) c' = speed of light in water
(Q) depth calibration corrector

Output

(Q) apparent depth

Step 13. Zero Depth Test and Computation - For cases where the system only finds one pulse, it may be working in shallow water. This causes the surface and bottom pulses to overlap so that a separate algorithm must be used to compute a depth.

Computing Procedure

a. First, it has to be decided if the case applies by applying the following four tests.

- o Looking at the most recent waveforms where two pulses were found, determine if the water was shallow.
- o Is the amplitude of the single pulse x percent larger than the amplitude of the average surface pulse when two pulses were found on the waveform.

- o Is there an inflection point on the trailing edge of the single pulse?
- o Is the width of the single pulse greater than the transmitted pulse width by z percent or more?

b. If any one of the tests is passed, the zero depth case applies. The zero depth algorithm will compute apparent depth directly (this is done for other soundings in Steps 12 and 16). The depth computing algorithm will look like:

- o An algebraic expression involving the zero depth pulse amplitude and the average surface return amplitude for cases where the waveform had two pulses, or
- o An algebraic expression involving the full width at half maximum of the return pulse and the transmit pulse full width at half maximum. FWHM of the return pulse will have to be computed from the waveform.

c. Treatment of transition cases between two pulses and the zero depth one pulse case is not clear.

d. Waveforms failing the zero depth test and for which there were fewer than two pulses on the waveform should be deleted from all further processing. Keep a count of these deletions.

e. Zero depth pulses should not be used in Step 14 to compute waveform based parameters.

f. Pulses deleted here in d. above may be needed for the Environment Calibration (Step 10.).

g. Some point on the leading edge must be picked and defined as the surface return for use in computing slant altitude in Step 17. It will probably be the amplitude level on the leading edge of the pulse that was being picked for two-pulse cases.

Inputs

(SU) y - zero depth test point number
(SU) x percent
(Q) average surface pulse amplitude
(SU) transmit pulse width

Outputs

(Q) apparent depth
(PO) number of deletions
(Q) zero depth flag to eliminate from averages

Step 14. Compute Waveform Based Parameters

Computing Procedure

a. Width of leading edge of surface return for interface/volume discrimination.

- o Fit the peak and leading edge with a quadratic and measure the half-width at a preset percent of peak amplitude.
- o Save the value as part of the sounding record.
- o Compile a histogram of leading edge widths.

Inputs

(Q) waveform
(SU) percent of peak amplitude at which to measure the half-width

Outputs

(Q) half-widths
(PO) histogram of half-widths

b. Pulse Width for pulse stretching verification and water optical parameter determination.

- o For both the surface and the bottom returns, compute the full width at z percent of the peak amplitude.
- o Save the values as part of the sounding record.
- o Compile a histogram of the full widths for surface and bottom returns.

Inputs

(Q) waveforms
(Q) location of peaks
(SU) z percent

Outputs

(Q) half-widths
(PO) histograms

c. Signal-to-Noise-Ratio

- o Divide the bottom return amplitude by the DC background computed in Step 11c (or another number computed in a similar fashion).
- o Save the result as part of each sounding record.
- o Delete and do no further processing on those sounding records whose S/N is less than a threshold. Keep a count of the deleted pulses.

o Compile a histogram of signal-to-noise ratios.

Inputs

(Q) bottom return amplitude
(Q) D C background
(SU) S/N threshold

Outputs

(Q) S/N ratio
(Q) delete flag for bad S/N
(PO) histogram of S/N ratio

d. Effective Diffuse Attenuation Coefficient "K"

o Starting at the peak of the surface return pulse, compute a sliding average slope over n points on the logarithm of the trailing edge.

o Look for a plateau or inflection point on the slope vs. n relationship.

o Do an algebraic computation of that slope to get K.

o If no plateau or inflection point exists, use the slope from p to p + r bins after the surface peak in the algebraic computation.

o Average the K's for several (20) pulses around the one in question (and including it) using an algorithm based on azimuth and synchronization time to identify which K's to include.

o Store the average value of K as part of the sounding record.

o Store the raw value of K to compute the average K for succeeding pulses.

o Delete values of average K which change by more than a preset amount from the preceeding average and replace it with an interpolated value.

o Do not use zero depth case pulses to compute K.

o Compile a histogram of K's.

Inputs

(SU) n points
(SU) algebraic computation parameters
(SU) p, r
(Q) waveform

(Q) surface peak location
(Q) surrounding raw K's
(Q) azimuth
(Q) synchronization time
(SU) acceptable change in K

Outputs

(Q) average K
(Q) raw K
(PO) histogram of K

e. ω_o, Single Scattering Albedo

- ω_o will be entered as a setup parameter

Inputs

(SU) ω_o

Outputs

(Q) ω_o

f. A, Beam Attenuation Coefficient

- K/A is related to ω_o using a known curve (entered as a table).
- Use K and ω_o from earlier to compute A.

Inputs

(SU) K/A vs ω_o curve

Outputs

(Q) A

g. Phase Function

- Probably will be guessed at using a binary selection based on K.

Inputs

(Q) K
(SU) binary selection rule

Outputs

(Q) phase function

Alternative procedure - Look the phase function up in a table which is indexed on a percent threshold (which in turn is selected based on actual off-nadir angle) and depth.

Inputs

(SU) table of phase functions
(Q) threshold
(Q) depth

Outputs

(Q) phase function

Step 15. Accept Position Data and Compute Laser Sounding Position.

Computing Procedure

- Read data from PAMS tape.

- PAMS supplies raw data for six degrees of aircraft freedom plus system synchronization time. An algorithm supplied by the PAMS contractor will be used for computing the six degrees of freedom at arbitrary synchronization times.

- Use the synchronization time of each laser pulse and compute the six positioning parameters.

  - Algorithms will probably be interpolations between a pair of PAMS values.

  - PAMS data will not be synchronous with laser data.

- Compute sounding position - This will be an algebraic computation using the six values from PAMS, the scan azimuth from the laser sounding record, the off-nadir angle, and some alignment parameters.

- Correct for undercutting using a lookup table of additive correctors indexed on azimuth.

- Change datum (if appropriate) using an algebraic expression and setup parameters (geodetic coordinate system).

- Record the six degrees of freedom values, the datum changed position, and the undercut corrected position.

- Compute the real-time-of-day (RTOD) for the sounding and record it. RTOD will be interpolated from PAMS data.

- Do not compute positions for soundings which have been deleted and on which no further processing is being done.

- Delete those records for which pitch and roll exceed a preset threshold, but keep processing them.

- Delete but keep processing those soundings whose PAMS data quality indicator falls below a preset threshold or which have no positioning data.

Inputs

(PT) PAMS tape
(SU) PAMS interpolation algorithm
(Q) synchronization time of laser pulse from sounding record
(Q) azimuth
(SU) off-nadir angle
(SU) undercutting correctors
(SU) datum change parameters
(SU) alignment parameters
(SU) pitch and roll deletion thresholds

Outputs

(Q) laser sounding position
(Q) values for six degrees of freedom
(Q) undercut position
(Q) datum changed position
(Q) RTOD

Step 16. Compute and Apply Depth Correctors - For each sounding, a corrector must be applied to compensate for laser pulse propagation-induced depth errors.

Computing Procedure

- o The correctors are in a look-up table which was entered with the setup parameters.

- o The table requires seven indices to find the corrector. They are:

  - o True off-nadir angle - this must be computed algebraically using the off-nadir setting entered as a set-up parameter, azimuth for the pulse being corrected, aircraft attitude at the time of the pulse, and some alignment parameters.

  - o AD where A was a waveform based parameter computed in Step 14 and D is the apparent depth. AD is determined as follows:

    - o Measure K as before.

    - o Find most recent depth "D" estimate in sounding record.

    - o Assume $\omega_o = 0.8$.

    - o K/A related to ω_o by a curve (table).

    - o Solve for AD.

    - o Single scattering albedo, ω_o, the waveform based parameter computed in Step 14.

- o Phase function, a waveform based parameter computed in Step 14.

- o D, apparent depth computed in Step 12.

- o Threshold fraction which was entered as a setup parameter and used to compute the bottom pulse location.

o Transmit laser pulse width (a change in pulse width would change the entire table).

o The corrector will be applied algebraically.

o The corrector should be kept as part of the sounding record.

o A histogram of correctors should be developed.

o Another corrector must be applied algebraically. This one will be determined from the threshold fraction used to define the location of the surface pulse and whether the surface pulse is an "interface" or a "volume backscatter" return. Values of this corrector will be available from a look up table or from a simple algebraic expression.

o Only non "Zero Depth" case sounding records get corrected in this manner.

Inputs

(SU) written table of correctors
(Q) scanner azimuth
(SU) off-nadir angle
(SU) alignment parameters
(Q) aircraft attitude
(Q) apparent depth
(Q) A, beam attenuation coefficient
(Q) ω_o, single scattering albedo
(Q) phase function
(SU) transmit laser pulse width
(SU) surface pulse detection threshold
(Q) determination of an "interface" surface return or a "volume backscatter" surface return (binary value).

Outputs

(Q) water parameter and system parameter based corrector (#1)

For each sounding:

(Q) threshold fraction based corrector (#2) for each sounding
(Q) corrected depth one
(Q) corrected depth two

Step 17. Compute Slant Altitude - Combines altitude time/counter data with surface pulse location in sounding waveform to get a slant altitudes for each sounding pulse

Computing Procedure

- o Altitude timer/counter gives altitude to nearest 100 picoseconds.
- o Time must be converted to distance using d = ct/2.
- o Surface pulse location was determined in Step 11. The location must be converted to a distance using a look-up table.
- o The two distances are summed and stored as slant altitude.
- o Delete the sounding records for which:
    - o The change in slant altitude from the previous pulse exceeds a threshold. That threshold is an algebraic computation involving off-nadir, azimuth, aircraft pitch (PAMS), roll (PAMS), altitude (PAMS), and the standard deviation of the most recent (500) slant altitudes. Delete but continue to process these pulses.
    - o Cases where slant altitude could not be determined. Do not continue to process these.
- o Count the deletions.
- o Record slant altitudes.

Inputs

(Q) surface pulse location
(Q) slant altitude time
(SU) C - speed of light in air
(Q) scanner azimuth
(Q) off-nadir angle
(SU) surface pulse location-to-time corrector table
(SU) allowable pulse-to-pulse slant altitude change
(Q) PAMS data
(Q) standard deviation of 500 most recent slant altitudes

Outputs

(Q) slant altitude
(PO) number of deletions

Step 18. Compute and Apply Wave Corrector - Compensates for sea surface waves to give water depth from the local mean sea level, i.e., from a flat sea.

Computing Procedure

- o Compute a predicted slant altitude using aircraft altitude from PAMS, scanner azimuth, off-nadir setting, pitch and roll, plus coordinate frame offsets.
- o Subtract predicted slant altitude from measured slant altitude (Step 17) on a pulse-by-pulse basis.
- o Add this difference to the depth measurement. It is the negative of the wave height for that pulse.
- o Store the corrector and the corrected depth.
- o Compute and print the correlation coefficient of the change in altitude with the change in depth.
- o Develop a histogram of wave corrector values.

Alternate Procedure

- o Compute a predicted slant altitude by:
- o Using the measured slant altitudes, perform something like a five parameter fit to the theoretical scan pattern equation of the laser.
- o This involves taking a running group of 100 measured slant altitudes and will probably be a least squares-type fit.
- o Using the five parameters determined from the fit, compute a slant altitude for each pulse, difference the measured slant altitude and the slant altitude from the five-parameter fit and apply the difference as the wave corrector.
- o Duplicate the remaining steps from above.

Inputs

(SU) coordinate frame offsets
(Q) altitude, azimuth, pitch, and roll
(SU) off-nadir
(Q) measured slant altitudes

Outputs

(Q) wave corrector
(Q) corrected depth
(PO) correlation coefficient
(PO) histogram of wave correctors

Step 19. General Edit

Computing Procedure

a. Delete those pulses (but continue to process them) which

   - Have depths different from their predecessor by more than ±n standard deviations where the standard deviation uses about 1,000 sequential pulses.

   - Other threshold-type tests to be defined.

b. Delete those pulses that fail a simple slope test, e.g. $£D_i - D_{i-1}£$ > THRESHOLD. Do all the pairwise slope calculations first, get a measure of the variance of the data, then look at the individual values and test to see if they are much greater than the normal variance.

c. Delete a block of pulses when the precision of the block is worse than a preset threshold. The block is a group of > 1,000 sequential pulses.

d. Delete those pulses where depth and altitude change in the same direction from their predecessors.

e. Delete those pulses remaining when the density of pulses has dropped below a preset threshold, e.g. 20 percent of the original density remaining in a sequential block of one to ten thousand pulses.

f. Delete every pulse whose position from its temporal neighbor is greater than a preset threshold.

   - Keep a count of the deleted pulses and the reasons.

   - These deletions should be selectable, that is, they should be defeatable through the setup parameters

Inputs

(SU) n
(SU) slope threshold criteria
(SU) standard deviation threshold criteria
(SU) signal-to-noise threshold criteria
(SU) spatial density of soundings threshold
(SU) change in position threshold

Outputs

(Q) threshold-type test flags
(Q) pair-wise slope test flag
(Q) block precision flag
(Q) $|\Delta D - \Delta A|$ test flag
(Q) pulse density flag
(Q) pulse position flag

Step 20. Read, Edit, and Correct Tides Data

Computing Procedure

- o See data descriptions for information on tides data.

- o Tide data will be used to adjust all depths to Mean Lower Low Water.

- o Each tide gage record must be manually examined and data values inserted or changed to give a complete and continuous record of the tides at each tide station.

Step 21. Compute and Apply Tide Correctors

Computing Procedure

- o Based on the geographic location of the sounding being corrected, select the appropriate subset of the tide gages using a preset algorithm.

- o Interpolate the gage records in time (using real-time-of-day) and space to get the tide corrector at the site of the sounding. This will require another pre-established algorithm - probably a linear interpolation if only two gages are involved or a least squares plane fit to the applicable stations with the tide corrector then picked off the appropriate point of the plane.

- o Store the corrector.

- o Subtract the corrector from the depth.

- o Soundings that fall above the Mean Lower Low Water line after the tide corrector has been applied will be stored as negative soundings. They are used to determine those areas on a chart which are shaded indicating land covered at high water and uncovered at low water.

Inputs

(TT) tides data
(Q) RTOD (PAMS)
(SU) station locations

Outputs

(Q) corrector
(Q) corrected depth

(At this point the data should be made ready for entry into the Intermediate Processing.)

2.6.2 Interactive Intermediate Processing Requirements

The intermediate processing is the quality control phase in which the survey party examines the data for completeness and accuracy. Intermediate processing is interactive and takes advantage of a hydrographer's experience.

LIST OF INTERMEDIATE PROCESSING STEPS

1.0 Intraswath evaluation

- 1.1 Anomalous depths
- 1.2 Agreement of coincident soundings
- 1.3 Anomalous positions
- 1.4 Anomalous contours

2.0 Interswath evaluation

- 2.1 Anomalous position
- 2.2 Disagreements in areas of swath overlap
- 2.3 Anomalous depths
- 2.4 Gaps in coverage (also for Intraswath evaluation)

3.0 Purge
4.0 Crossline Comparison
5.0 Flag for examination by system developer (all Intermediate Processing steps)
6.0 Merge of resurvey data
7.0 Treatment of historical data
8.0 Contemporary comparison data
9.0 All data examination

Detailed Description of Intermediate Processing Steps

2.6.2.1 Intraswath Evaluation

<u>2.6.2.1.1 Anomalous Depths.</u> Definition: These are soundings or groups of soundings whose depths, when compared to their spatial neighbors, appear incorrect in the opinion of the hydrographer.

Examples: The following are examples of what a hydrographer might see and consider anomalous. It is assumed that he will be examining some type of display on which soundings are plotted at their correct relative locations.

1. Isolated individual soundings different from their neighbors (causes - system noise; true, isolated soundings which are special cases for which depth computing algorithms fail; incorrect synchronization time; surface/volume ambiguity; bad wave or other corrector; wrong pulse located on waveform; low S/N ratio; specular reflection in zero depth case; environmental such as fish, rock, suspended sediment).

2. Frequent, scattered soundings which are different from their neighbors (causes - low S/N ratio; rocky bottom; surface/volume ambiguity; specular reflection in zero depth case - most of the case one causes apply here also).

3. Related soundings which are different from their neighbors ["related" here means that their geographic relationships makes the anomaly look

like a system effect rather than an environmental effect, e.g., a portion of one scan area or a straight line anomaly]. (Causes - system locks in on a system noise spike; distorted periodic calibration pulse; erroneous water optical property estimate used in corrector; wrong DC backgrond level subtracted; incorrect meshing of zero depth case with regular depth case; attitude bias causing wrong corrector to be selected from table; swell.)

4. Groups of soundings which are different from their neighbors ["group" here refers to a geographic relationship of the anomalies which appears unrelated to a system parameter such as scan arc, but which might be environmentally induced, e.g., collections of potentially anomalous depths that might look like a kelp bed, a wreck, or a dirty water plume at a river mouth] (causes - kelp; rock; crib; wreck; patch with different water optical properties from the neighborhood; changing wave structure due to wind sheltering effects or changed bathymetry).

Courses of action: When faced with potentially anomalous depths, the hydrographer will act as shown in Figure 2.1.

Required Tools: In order to determine if a potentially anomalous depth is system induced, environmentally induced, or not anomalous the hydrographer will be trying to find some indication of erroneous system behavior. In the case of examples 1 and 2, this will be done by examining the level one sounding record for the suspect soundings and for some selected neighboring soundings which are not suspect. The principal parameters of a sounding record include:

1. laser return waveform
2. indicators showing the system's choice for the surface and bottom
3. pulse synchronization time
4. final corrected depth
5. raw depth
6. wave corrector
7. tide corrector
8. water property corrector
9. S/N ratio
10. local average S/N ratio
11. laser power
12. depth computing method (zero depth or pulse separation)
13. interface or volume surface return
14. scan azimuth
15. x, y position
16. attitude
17. pitch, roll, heading

In the case of example 3, a means will be needed to try and relate the anomalies to a system parameter on the principal parameter list. An acceptable way would be to show profiles of items 4, 5, 6, 7, 8, 9, 10, 11 vs. 3 (synchronization time) along a geographic line through the data defined by the hydrographer. That line might be a straight line or a scan arc. If a relationship appears between a principal parameter and the suspect depth, they will be considered erroneous and deleted. Deletion must be possible at any time in the examination and deleted soundings must be flagged for the system developer. A count should be kept of the number of deleted soundings.

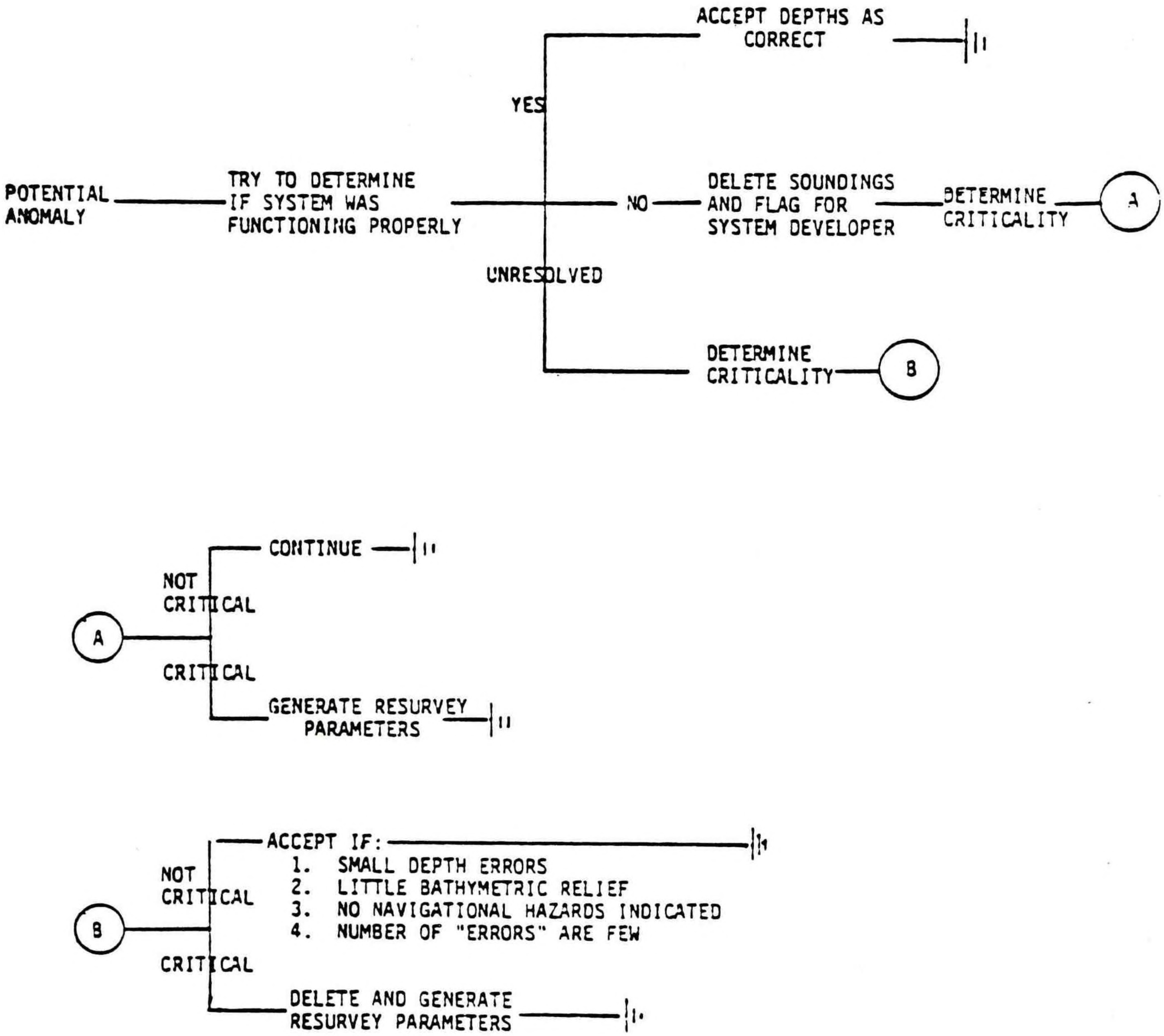


Figure 2.1 Hydrographer's Actions - Anomalous Intraswath Depths

When soundings are deleted, criticality will be determined (defined in "Anomalous Positions") and resurvey parameters determined.

If an area is resurveyed, the deleted data must be compared to the resurvey data to insure that an acceptable survey of the area has been performed. After the comparison, the accepted data must be merged with the larger survey data set.

For examples 3 and 4, the hydrographer will want to examine supporting soundings around the suspect feature. This means looking at depth values nearby to see if there is a trend supporting the feature. Nearby means spatially to distances of 100 meters.

2.6.2.1.2 Agreement of Coincident Soundings. Definition: Soundings taken at the same geographic location should give the same depth.

Examples: Permissible changes in depth between soundings should be related to how close together they are. By examining the correlation of depth changes to position changes (separation), the hydrographer will be looking for the following:

1. Repeatable system performance (an additional check for the existence of depth errors, data errors, and position errors; indication of rapid system performance change [one to two seconds]; pitch induced depth errors because pitch will change the incidence angle of the laser pulse [pitch may be a function of azimuth so coincident soundings may occur at different pitch]; fluctuations in system correctors based on the waveforms; repeatability of wave correction; consistent performace of the "calibration waveform" concept; for zero depth case, should be able to see if changing surface signal strength is occuring and impacting amplitude or width based depth estimators; loss of synchronization time or synchronization time jump).

2. Environmentally induced differences in depth (inadequately sampled small features and items [pilings, wrecks, cribs]; natural phenomena [fish, flotsam, kelp]; cases where the soundings appear coincident because of positioning uncertainty).

Courses of action: When faced with an apparent disagreement between coincident soundings, the hydrographer will act as shown in Figure 2.2.

Required tools: A means will be needed to determine if depth changes and position changes are correctly correlated. Something like a plot of change in depth vs. change in position would be appropriate. A single measure like the correlation coefficient would not be appropriate since it deals with an "average" property of the data rather than the exceptions.

The change in depth vs. change in position should be plotted for each sounding, pair-wise with each of the four to ten nearest spatial neighbors to the sounding. Neighbors along the scan are accessible through synchronization time. Neighbors on adjacent arcs are accessible through azimuth angle. Actual coordinates can be used to determine if soundings on adjacent arcs are closer than ones further along the arc of the sounding in question.

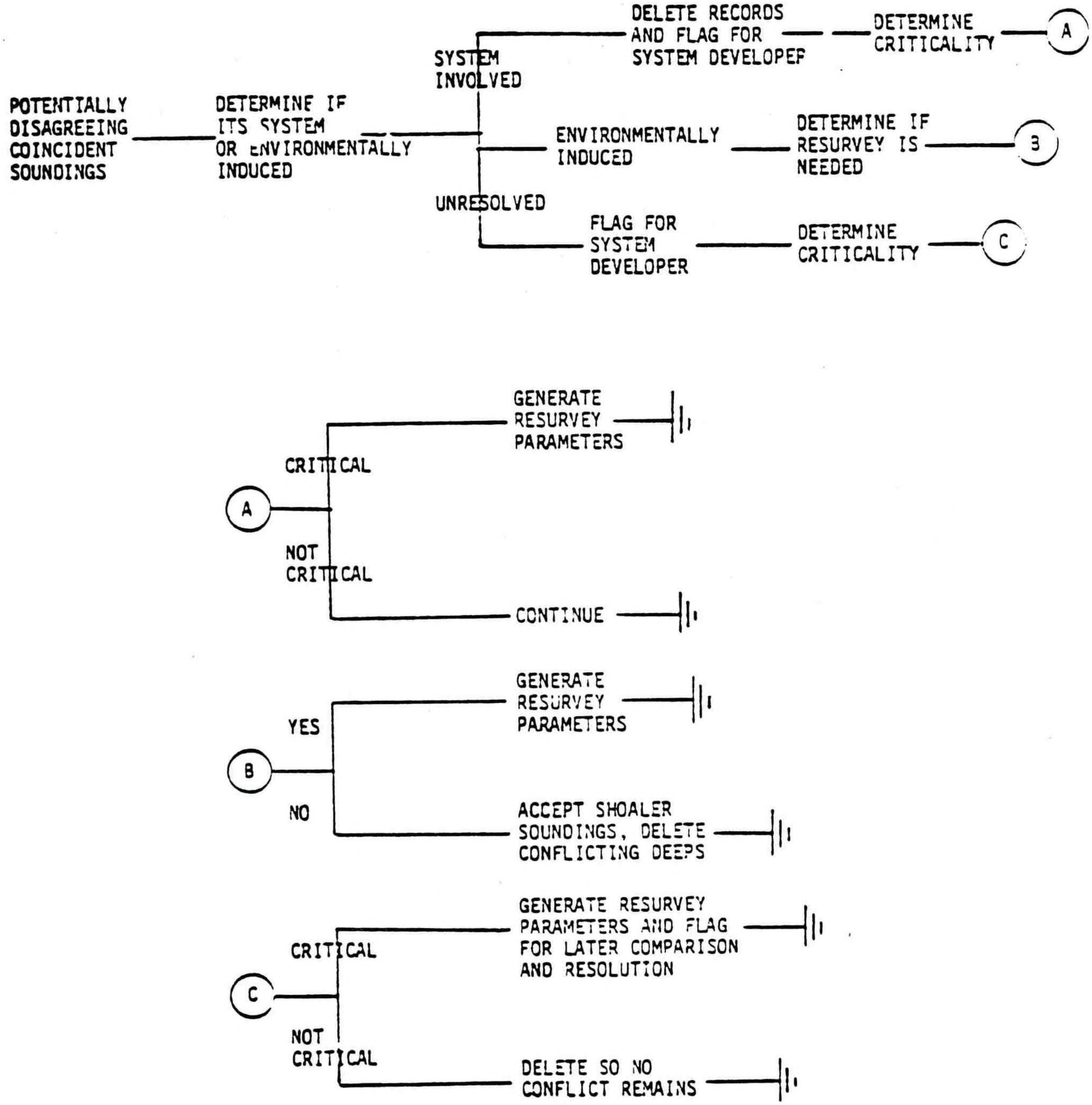


Figure 2.2 Hydrographer's Actions - Disagreement in Coincident Soundings

To assess if the disagreement is system or environmentally induced, the hydrographer should be able to identify the offending soundings on a scatter plot of change in depth versus change in position and then view them with respect to all the geographically close surrounding soundings on a different display. For example, if a pseudo three-dimensional presentation of the depths is being used elsewhere, the offending soundings might be highlighted. A random distribution of disagreements are probably system induced. If the disagreements are clustered, then they are probably environmentally induced. The principal parameters of the Sounding Record should also be available for soundings chosen by the hydrographer to resolve the system/environment question (see subsection on "Anomalous Depths" for definition).

Deletion of offending soundings should be allowed to occur at any time and from any display.

To determine if a resurvey is needed, the hydrographer should assess the criticalness of the area (see Anomalous Positions for definition) and examine other records (presurvey review, existing chart) for known or suspected hazards.

"Generate resurvey parameters" was described under Anomalous Positions.

In order to "Accept Shoaler Soundings" the hydrographer must be able to tell which is the deeper of the conflicting soundings, and then to delete them.

"Later Resolution" is described elsewhere.

A count of the number of deleted pulses, traceable to the cause of the deletion, must be kept for the final report.

2.6.2.1.3 Anomalous Positions. Definition: Those soundings whose locations, when compared to their spatial neighbors, appear incorrect in the opinion of the hydrographer.

Examples: The following are examples of what a hydrographer might see and consider potentially anomalous. It is assumed that he will be examining some type of display on which soundings are plotted at their correct relative locations.

1. Overlaid soundings (causes - unchanging value of azimuth angle; unchanging value of one or both horizontal position coordinates; unchanging synchronization time).

2. Distorted bathymetric features or contours (causes - irregularly changing value of any parameter used in computing position; depth errors).

3. Distorted swath (causes - aircraft motion; aircraft crabbing; optical misalignment such as an azimuth bias; periodic errors in synchronization time, roll, pitch, or altitude; change of satellites if GPS is used for positioning).

4. Distorted scan pattern (causes - optical misalignment such as azimuth bias; real or apparent aircraft motion; incorrect horizontal position coordinates; periodic errors in altitude).

5. Non-uniform sounding density (causes - irregular synchronization time; irregular azimuth; irregular values of other positioning parameters).

6. Incorrect swath width (causes - incorrectly initialized off-nadir laser pointing angle; altimeter bias; roll bias).

Courses of action: When faced with potentially anomalous positions, the hydrographer will act as shown in Figure 2.3.

Required tools: In order to first identify potential anomalies in position, the hydrographer must examine the sounding positions in their correct relative positions. The physical scale of errors being detected at this step does not include large biases which apply to the whole survey (absolute errors). Examples of an adequate display to detect anomalous positions are:

1. A two-dimensional position plot of as many positions as can be displayed at once yet having adequate resolution to see the errors listed in the examples.

2. A pseudo three-dimensional plot which shows both depth and position. The comment about resolution applies here also.

In order to determine if the system was functioning properly, the hydrographer will be allowed to go back in the source data used to compute position. He will be allowed to go back only one step however. For positioning, the "one step back" is conceptualized as profiles of each of the positioning parameters vs. synchronization time. The positioning parameters are: x, y, altitude, pitch, roll, heading, and azimuth, laser slant altitude, and computed velocity. Synchronization time should be viewed as a profile against an arbitrary unit (such as display element) to assess the regularity of its change.

The following defects in the profiles would be adequate grounds for deleting the sounding records in question:

1. Discontinuity or repetition in synchronization times,

2. Discontinuities in any of the profiles,

3. High variability in all the parameters not confirmed by the pilot as turbulent conditions,

4. High variability in a small number of the parameters which would indicate turbulence but which are not confirmed by turbulence-like variations in the other parameters,

5. Biases in heading,

6. Biases in pitch or roll not confirmed by the pilot,

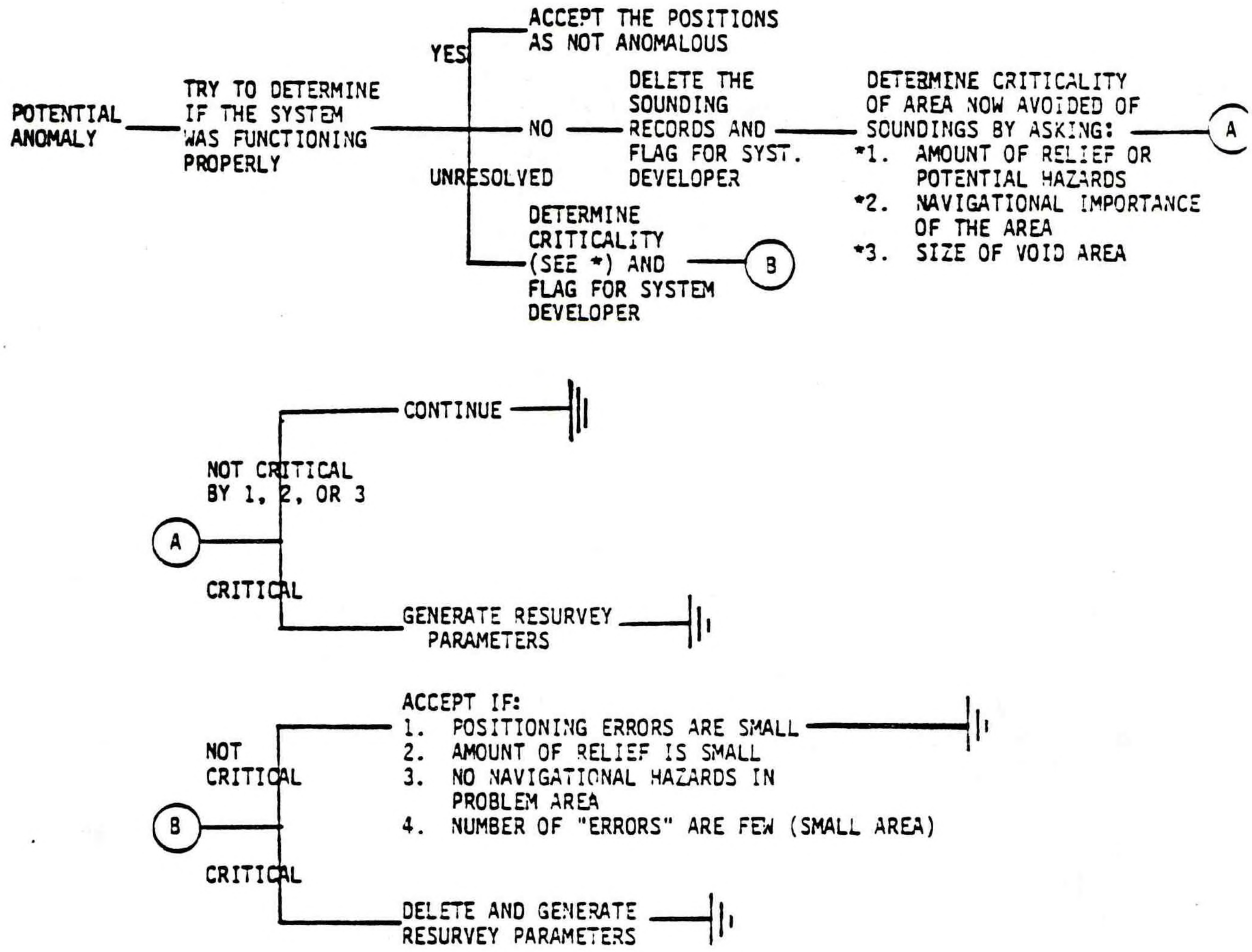


Figure 2.3 Hydrographer's Actions- Disagreement in Coincident Soundings

7. Acceleration in azimuth,

8. Variations in altitude not confirmed by the pilot, his barometric altimeter, or changes in the average laser slant altitude.

If the source profiles indicate the data is correct, a means will be needed to accept the data.

If the source profiles indicate the data is incorrect, or if the hydrographer is convinced of error using only the higher level display, the means must exist to delete (by flagging) the unacceptable sounding records. Deletion should be performable from any display.

If deletion of records is anticipated, an assessment of the criticality of the area is needed. The hydrographer will need the following to determine criticality:

1. the location of the proposed deletion so it can be related to an existing chart for assessment of navigational importance,

2. the bathymetry as measured by the laser to assess the amount of relief and the indications of a hazard to navigation.

If the area is critical, then resurveying parameters will need to be generated. Since resurveying will probably only take place if a large number of soundings are deleted, the boundaries of a polygon enclosing the area should be sufficient.

If data is actually to be deleted, a means to delete by flagging will be necessary. A count should be kept on the number of records deleted on the basis of position anomalies.

If an area is to be resurveyed, the deleted data should be compared to the resurvey data by the hydrographer to insure adequate coverage. The resurvey data, if acceptable, must be merged with the total data set.

The option should exist to print or write on magnetic tape those sounding records which were deleted. These records would then be available as a developmental tool.

<u>2.6.2.1.4 Anomalous Contours.</u> Definition: Contours whose characteristics are unrealistic in the opinion of the hydrographer.

Examples: Most of the hydrographer's previous experience which can be applied to laser surveying will be in terms of what bathymeteric features can occur and what they look like in survey data. Contours define these features and are a familiar means of presenting them. They should be made available. The following types of distortions to contours might be seen and might indicate erroneous data or poorly defined hazards to navigation:

1. Highly irregular contours (causes - low S/N ratio; varying water optical properties; true bathymetric irregularities; laser system noise; inadequate averaging of water optical properties used in computing depth correctors; multipath errors in the positioning

Subsystem; severe aircraft motion due to turbulence; synchronization time jitter; environmental factors such as grass, fish, pilings, and high wave conditions; [beam steering errors]).

2. Crossing contours (causes - swell; erroneous wave correction; changing optical properties with erroneous depth correctors; large number of sequential sounding having errors listed in 1. above; abrupt shift in synchronization time).

3. Very close contours indicating improbable depth gradients (causes - abrupt optical properties shift; swell; incorrectly computed aircraft velocity; positioning multipath; environmental factors such as kelp bed, or crib).

4. Contours are not smoothly bending (causes - too many edited soundings; environmental features such as kelp beds, or crib; poorly sampled steep slope).

5. Adjacent contours do not look alike (causes - swell; noisy data as in 1. above).

6. Systematic bend in all contours beyond what is natural (causes - incorrect off-nadir angle corrector to depth).

Courses of action: When faced with anomalous contours the hydrographer will act as shown in Figure 2.4.

Required Tools: The first item that would be needed are the contours. Two types should be considered. The more sophisticated version grids the data and interpolates between grid points as it constructs the actual contours. The simpler version merely highlights depths in certain ranges or connects depths which are about the same. The software should automatically determine the range of depths being studied, select the appropriate contour values, and then draw and label them. Contour intervals should also be selectable.

To determine if anomalous contours are system or environmentally induced, the depths surrounding the questionable areas should be examined to see if they support the contour. If the contour is being driven by a few soundings, then the principal parameters in the sounding record and the positioning parameter profiles might be examined to determine if the depths or positions are anomalous.

The S/N ratio for regions of highly irregular contours and a comparison value of an "acceptable" S/N ratio would be useful to distinguish system and environmental effects. "Acceptable" would be one from an area whose contours were not irregular.

For some distortions, an examination of selected parameters along a definable straight line will be needed. Examples of this are:

1. Wave corrector to find swell induced anomalies,
2. Depths along the line,
3. Principal parameters of soundings.

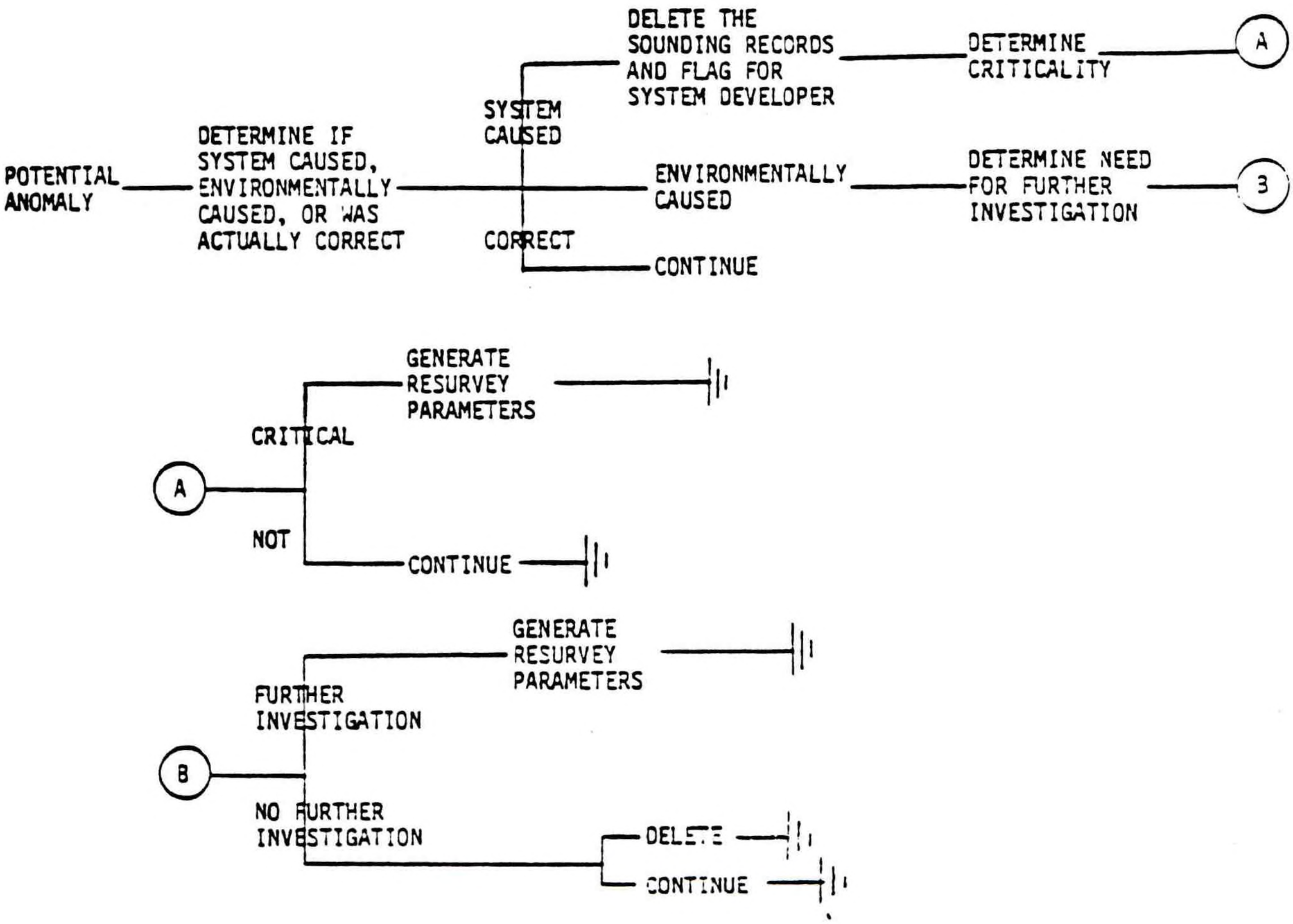


Figure 2.4 Hydrographer's Actions - Anomalous Contours

If the anomalous contours are felt to be system induced and soundings are to be deleted, then they should be removed from any display and the contours redrawn.

To determine the need for further investigation of environmentally caused anomalies, an examination should be made of the principal parameters along definable straight lines crossing the anomalous areas. Areas felt to be, for example, kelp, will have the soundings deleted and the area marked as kelp. Resurvey by aircraft would not be productive, but resurvey parameters may be provided to a boat to verify that it was indeed kelp.

Criticality should also be determined before any resurveying is done.

A count must be kept of deleted soundings.

2.6.2.2 Interswath Evaluation

2.6.2.2.1 Anomalous Positions. Definition: Those soundings whose location, when compared to their spatial neighbors in adjacent swaths, appear incorrect in the opinion of the hydrographer.

Examples: This evaluation is intended to detect positioning errors which could not be found by examining a single swath of data. It is assumed that the hydrographer will be examining some type of display on which soundings are plotted at their computed positions. The following examples describe what might be seen.

1. Contours/features do not line up in adjacent swaths (causes - bias in the along-track position from, for example, an uncompensated offset of the ranging system antenna in the aircraft; roll bias; optical alignment change; bias or bias change in horizontal position; scan azimuth offset change).

2. Swaths in incorrect relative location such as lack of overlap or too much overlap (causes - bias in across track coordinate; new roll bias; apparent altitude change; erroneous navigation data to pilot).

3. Swaths crossing in main-scheme lines (causes - incorrect navigation data to pilot; drift in inertial measurement unit if not updated).

4. Different swath widths between adjacent swaths (causes - altitude bias).

5. Different sounding densities (causes - change in synchronization clock rate; change in laser pulse rate, aircraft speed changes).

6. Different scan patterns (causes - change in one or more of the positioning parameters between swaths).

7. Random depth differences (causes - random position differences or random depth differences).

Courses of Action: Errors affecting more than a small area are serious. If they cannot be resolved, then the entire survey is suspect and might be discarded. When faced with potentially anomalous positions in the interswath evaluation, the hydrographer will act as shown in Figure 2.5.

Required Tools: In order to determine if apparent interswath position induced differences are acceptable, the hydrographer will need to know what differences are expected. Position offsets of $\sqrt{4.6^2 + 4.6^2} = 6.5$ m between swaths are acceptable. Depth differences of $\sqrt{0.3^2 + 0.3^2} = 0.4$ m between swaths are also acceptable and, if they occur as a local bias,

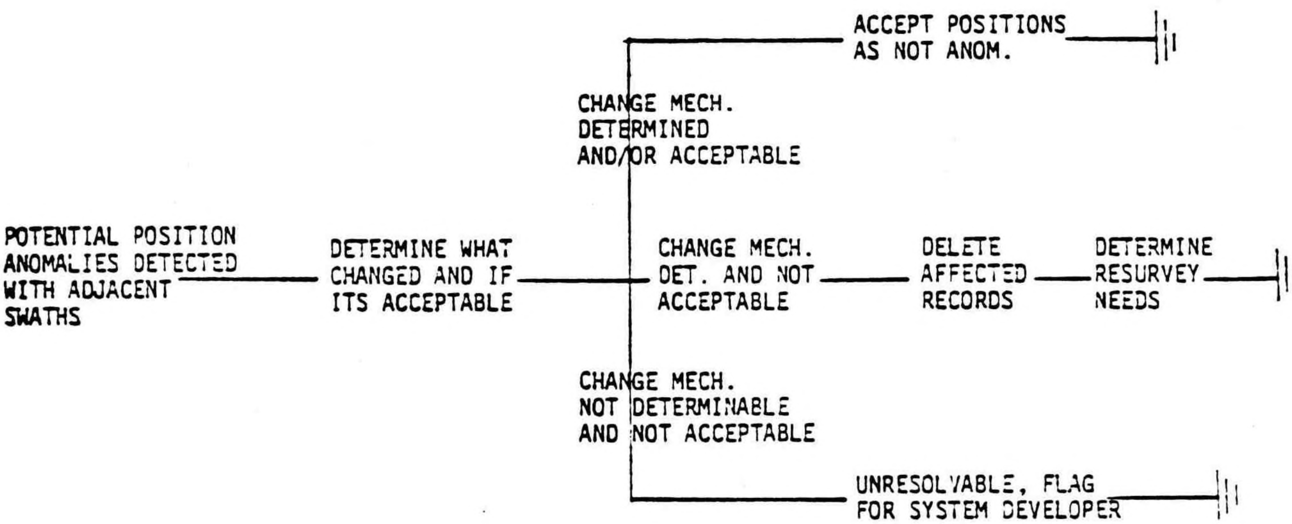


Figure 2.5. Hydrographer's Actions - Anomalous Interswath Position

will shift the contours by up to $\frac{0.4\ \text{m}}{\tan\ (\text{bottom slope})}$. Displaying the root-summed-squared of these acceptable local biases will allow the hydrographer to assess if his observed offsets are smaller.

Some type of tool will be needed to examine the relative positions of soundings in adjacent swaths. The tool should be appropriate for the listed examples. It should have a scale to allow relative mispositioning to be estimated.

If examples 2 - 6 occur, it will be necesary to see that the difference was arrived at in a natural fashion. An acceptable solution would be to examine the time history profiles of each positioning parameter (see Intraswath - Anomalous Positions) for the two swaths simultaneously. This would allow, for example, to see that the altitude for one swath was increasing so that the swath should be growing and encroaching on its neighbor.

The final way to determine what has changed is to compute pitch, roll, and altitude from the slant altitudes measured by the laser bathymeter. These should then be compared to the same parameters as measured by the PAMS (see "Preliminary Processing", Step 17).

The above paragraphs describe how to determine if the magnitude and/or cause of a relative position difference is acceptable. If the mechanism is determined and not acceptable, the resurvey needs will be affected by how widespread the error is so the hydrographer would need to see several swaths of adjacent data to assess this.

2.6.2.2.2 Disagreements in Areas of Swath Overlap. Definition: Disagreement in areas of swath overlap would be caused by depth or position errors. Such errors would be treated as previously described.

Tools Required: Some disagreement is expected because of acceptable errors in depth and position. Tools will be needed to show the acceptable and actual differences.

The acceptable depth error between 2 swaths is:

$$1.41 \left[(3^2 + [4.6 \tan (\text{bottom slope})]^2\right)^{1/2} \text{ meters} \qquad \text{RMS}$$

This should be computed and shown for the area in question. Tools showing the actual difference could be one or more of the following:

1. A plot of the actual depth differences between a sounding in one swath and its nearest neighbor(s) in the other swath, all shown in their correct relative geographic locations.

2. A series of depth profiles of each swath through the region of overlap with a scale shown.

3. Three distributions; one for each swath separately showing the distribution of depth differences between each sounding and its neighbors (as in Intraswath Evaluation Agreement of Coincident Soundings); and one for the overlap showing the depth differences for each sounding in one swath to its neighbors in the adjacent swath. The distribution for the overlap should be comparable to the worse of the individual swath distributions.

Deleting soundings should be possible at any point in the data examination. Deletions should be identifiable by cause, and a count should be kept of the number of soundings deleted.

Real-time-of-day and the tides corrector should be examined to see if the error can be attributed to tides, e.g., is the total disagreement smaller than the tide range or larger?

Determining prevalence should be covered in "Examine All Data". Also, see Figure 2.6.

2.6.2.2.3 Anomalous Depths. Definition: Those depths which in the opinion of the hydrographer appear incorrect when compared to soundings in neighboring swaths.

Examples: This examination is intended to detect depth errors which cannot be found within one swath. Examples are:

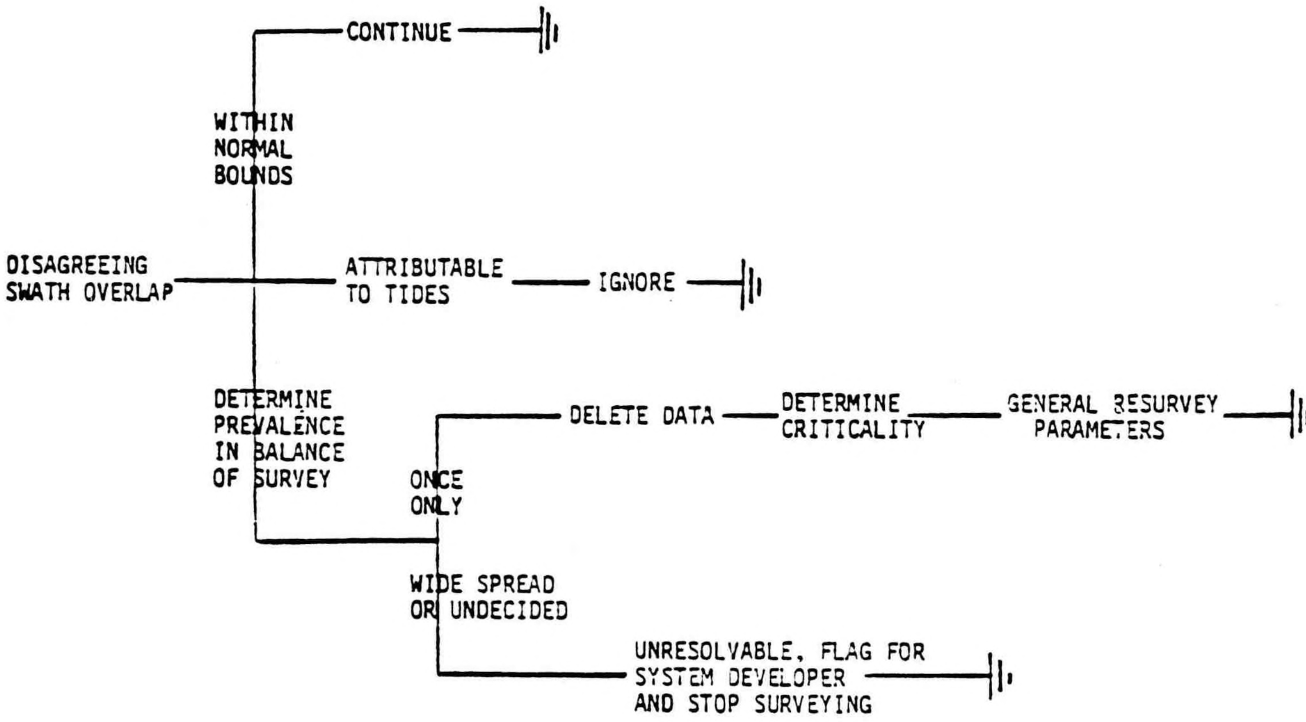


Figure 2.6. Hydrographer's Actions - Disagreement in Swath Overlap

1. Systematic depth disagreement between adjacent swaths (causes - tide corrector error; change in water optical properties; change in sea state which changes wave corrector; drift in system performance; change in DC background level; interface/volume surface returns intermixed).

2. One swath is noisier than its neighbor (causes - change in system noise; change in sea state and wave corrector; change in water optical properties causing lower S/N ratio; increased daylight background).

3. Features in one swath which do not continue in its neighboring swaths (causes - system caused depth errors such as locking on a noise spike; swell; incorrect meshing of zero depth with regular depth computing technique).

4. Features showing in all swaths indicating a system error (causes - nadir angle depth corrector error; roll bias error causing wrong corrector to be selected).

Most of the anticipated problems can only be system induced because environmental and bathymetric events are unaware of laser swaths and their orientation. Also, some of the examples might look like, or actually be, positioning errors.

Courses of Action: When faced with adjacent swaths of soundings whose depths and features do not seem to agree, the hydrographer will act as shown in Figure 2.7.

Required Tools: In order to determine if interswath depth differences are erroneous, the hydrographer must know what differences would be acceptable. An acceptable difference is less than or equal to

$$(0.42^2 + (\frac{6.5}{\tan\text{ (bottom slope)}})^2)^{1/2}$$

This is the combination of the allowable depth and position errors. Some fraction of the tide range might have to be combined with this. However the hydrographer is presented with data from adjacent swaths, he must also have a means of quantifying the change in depth to compare it with that allowed. Manually interpolating between contours might be acceptable, but seems awkward.

In order to assess if the anomaly is survey-wide, a simultaneous look at more than two swaths will be needed.

To assess the cause of interswath change in depth one should see profiles of several principal parameters (see Interswath Evaluation, Anomalous Depths) along paths defined by the hydrographer. One of these parameters will be tides. The paths will necessarily cross several swaths.

In deciding whether to delete both swaths or just one (and which one), a determination should be made of which swath is in error by looking at profiles of several principal parameters along selectable paths. The same procedure will be used to determine the cause of the error. Examining the depths in crosslines that intersect the questionable swaths should also be used.

Cases where the principal parameter profiles show a tide corrector sufficiently different to account for the anomalous changes in depth and where the rest of the profiles appear normal will be accepted as correct. Hopefully, subsequent tides processing at the Marine Center might resolve the discrepency. Unacceptable changes in depth not attributable to tides will be treated as due to serious system malfunctions.

Should be able to access the principal parameters of the sounding record of any sounding(s) identified by the hydrographer.

For examples 3 and 4, the hydrographer should be able to examine supporting soundings in areas of suspect features.

<u>2.6.2.2.4 Gaps in Coverage (also for Intraswath Evaluation).</u> Definition: A gap in survey coverage exists when the hydrographer feels there are insufficient soundings to adequately describe the bathymetry.

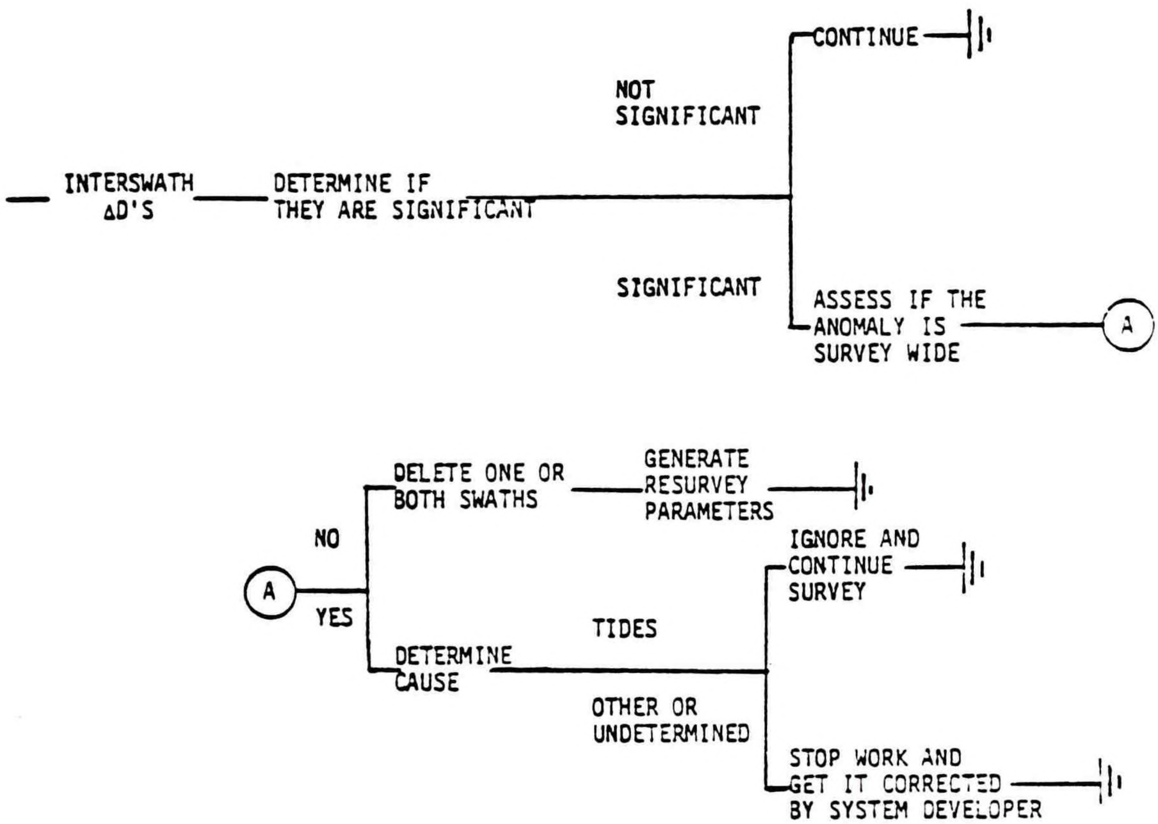


Figure 2.7. Hydrographer's Actions - Disagreement in Interswath Depths

Examples: Gaps in coverage can occur for three reasons: either the area was never overflown; it was overflown but soundings were deleted during the Preliminary or Intermediate Processing; or the survey was performed at too low a sounding density. Gaps may thus be areas without soundings or with sparse soundings.

Causes of Action: When faced with gaps in coverage, the hydrographer will act as shown in Figure 2.8.

Required Tools: In order to identify potentially unacceptable gaps in coverage, the hydrographer must examine a display of acceptable soundings in their correct relative locations. Examples of adequate displays are:

1. A 2-dimensional plot of acceptable soundings, e.g.,
2. A pseudo 3-dimensional plot which shows both depth and position.

In order to determine the cause for the gaps it must be determined if the aircraft overflow the area. This could be determined from:

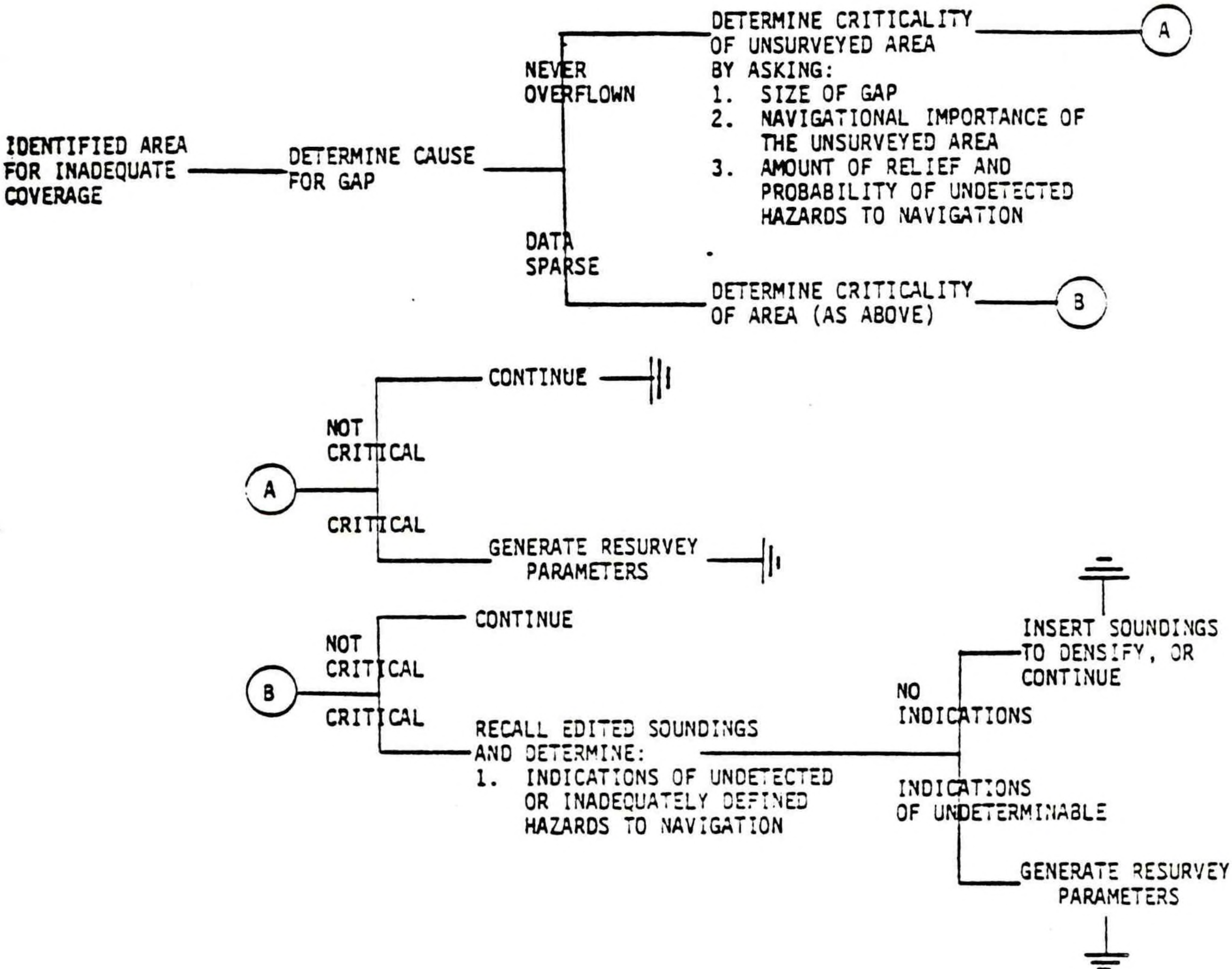


Figure 2.8 Hydrographer's Actions - Gaps in Coverage

1. The planned flight lines and swath width,
2. The actual flight lines and swath width, and
3. Searching the data base for sounding records which fall within the gap.

If the area was never overflown, then other information will be needed in order to assess criticality. That information is:

1. Chart coordinates in order to refer to an existing chart for an assessment of navigational importance, known relief, and probable occurence of hazards to navigation;

2. The relief in the surrounding area as measured by the laser; and

3. A scale to determine the size of the gap.

If the hydrographer decides to (re)survey the area then (re)survey parameters will be needed. The boundaries of a polygon enclosing the gap should be adequate.

If the area was overflown, too much data could have been deleted in the preliminary or intermediate processing. The hydrographer will be allowed to override certain types of edits to densify the data and avoid unnecessary resurveying. Such an approach will not be used in navigationally important areas or areas of high relief. Tools required for this densification are:

1. Display of the deleted soundings (highlighted against the display of accepted soundings) which could be restored along with the accepted soundings,

2. Indication of the causes for deletion,

3. Means to reset the delete flag,

4. A scale to determine the size of the remaining gap, and

5. A flag in the sounding record to indicate those cases where a deletion had been overridden.

The types of deletions which the hydrographer will be allowed to override are:

1. Those soundings he deleted,

2. Soundings which were acceptable singly, but which were discarded as part of the large-area deletion in regions of noisy data,

3. Soundings that were deleted when the aircraft attitude moderately exceeds an attitude parameter threshold, and

4. Soundings deleted in areas where the data was too sparse (Step 19e in Preliminary Processing).

2.6.2.3 Purge. All data from the sounding record of one swath is purged except the following: X, Y, D, RTOD, tide corrector and swath identifier. The data to be purged is from the "older" of the two swaths being compared. The entire record of all soundings edited by flagging is purged. This data set is sufficient to produce the final survey product and to help locate any soundings if the entire record must later be recomputed. This purge is performed to reduce the amount of information being stored.

2.6.2.4 Crossline Comparison. Crosslines are laser soundings gathered in swaths perpendicular to main scheme survey lines. They will be processed like all swaths of laser data. Automated comparison of crosslines will be made with the main scheme lines they cross. Manual evaluation of the overlap will be possible and statistics on the comparison will be computed, displayed, and reported. Editing by flagging will be allowed.

2.6.2.5 Flag for Examination by Systems Developer (all Intermediate Processing Steps). Definition: Inconsistencies, disagreements, and deleted data must be identified for use by the system developer in modifying the system.

Examples: The basic actions the hydrographer can take in his evaluation are to:

1. delete data as:

   a. system error(s)
   b. environmental error(s)
   c. unresolved cause(s)

2. accept data

3. generate resurvey parameters for areas requiring further investigation

Cases 1 and 3 should automatically be identified to the system developer. Sometimes the hydrographer may feel that some Case 2 data indicate an unusual or changing system behavior that needs examination by the system developer.

Required Tools: Automatic identification of Cases 1 and 3. Manual tool for the hydrographer to flag Case 2 data. The developer will want to see not only the questionable data, but some spatially neighboring, unquestioned data.

A method of annotating the data should be provided to indicate:

1. why data was deleted

2. what was questioned about accepted data

3. why an area was resurveyed.

2.6.2.6 Treatment of Resurvey Data. Definition: Resurvey data is laser hydrography data gathered in areas specifically identified by the hydrographer as a result of his evaluation of the basic survey data.

Examples: Areas will be resurveyed by laser to:

1. Fill gaps in coverage,

2. Resolve discrepancies between adjacent swaths and coincident data,

3. Further develop suspected hazards to navigation,

4. Gather comparison data to resolve potential system modifications,

5. Quantify potential environmental effects on system performance, and

6. Test ability to generate adequate tide correctors by reflying one survey line several times within a tidal cycle.

Courses of Action: Resurvey data will be handled as shown in Figure 2.9.

Resurvey data will first be treated as regular survey data and examined under the Intraswath and Interswath evaluations. Then it will be used for its intended purpose.

In resolving whether a hazard exists, the hydrographer will examine a display of the depths shown in their correct, relative geographic locations. Both the resurvey data and the basic survey data should be available simultaneously. He will then use his judgement to determine if a hazard exists (enough soundings rising x feet above the surroundings). Merging the resurvey data with the basic survey data should allow some or all of the data to be accepted. Simultaneously, some of the basic survey data may be deleted. The option to ignore the data exists because resurvey data will probably never mesh perfectly with basic data. If it adds no hazards then it should not be used in order to avoid confusing the sounding selection (Final Processing).

For the data gathered to fill in survey gaps, an assessment must first be made if adequate data has been gathered. A display of the resurvey data and the basic data, plotted in their correct geographic locations, would be adequate for this and the Course of Action from "Gaps in Coverage" can be followed.

To determine if resurvey data mesh around the edges of a gap in coverage, treat them as "Areas of Swath Overlap". Merge the acceptable and necessary portions of the resurvey data with the basic survey data. Unnecessary data should not be merged, to avoid confusing the sounding selection.

To determine if resurvey data have resolved a discrepancy, the hydrographer must simultaneously see the basic and resurvey depths plotted in their correct geographic locations. He must also know what is an acceptable discrepancy (see "Disagreements in Areas of Swath Overlap") and have a scale with which to judge the agreement. Allowable actions are combinations of acceptance and deletion from all groups of data involved.

Resurvey data incorporated in a basic survey should be flagged. Deletions should be counted.

2.6.2.7 Treatment of Historical Data. Definition: Data gathered in prior years and provided to the survey party for comparison with the laser survey data.

Examples: Comparisons with prior survey data will be made in order to:

1. Guarantee general agreement between laser data and data gathered by other means as a way of establishing confidence in laser hydrography.

2. Insure that all hazards to navigation identified in prior surveys have been adequately surveyed by laser.

Comparison data will be provided on magnetic tape (type of recorder is unknown). The data will be at a spatial density of approximately one twentififth to one one-hundredth that of the laser survey.

Courses of Action: Historical Data is handled according to Figure 2.10.

The distribution of differences between historical depths and each of the laser depths within, say, ten meters horizontal distance, should be used to help determine agreement of the two data sets.

In order to determine if the two data sets agree, the hydrographer should view them simultaneously with the depths plotted at their correct geographic locations. He should also see the contours that have been inferred from the historical data. A scale will be needed to help estimate the depth differences.

Where historical data has indicated hazards to navigation, a careful examination will be made of the laser soundings in that area to see if they support the hazard.

The soundings from the historical data will be merged with the laser data.

To determine if the tide corrector is sufficient to cause the disagreement seen, the value of the tide corrector for the laser data and for the historical data should be compared. If the tide correctors are large enough to permit the observed discrepancy (about four times larger than the discrepancy) then the difference will be attributed to tides. Otherwise it will be treated as a serious system malfunction.

Results from the comparison should appear in the final report. The distribution of differences between historical and laser data would be acceptable.

2.6.2.8 Contemporary Comparison Data. Definition: Data gathered by means other than the laser.

Examples: A small subarea will be surveyed by another means and probably more than once to provide a check on laser system performance. The laser system should survey this test patch every time it is in the air. The purpose is to establish confidence in laser system performance.

The test patch will be surveyed with sonar or using manual techniques. Sonar will provide recorded data. Manual techniques will provide handwritten depths, positions, and RTOD.

Courses of Action: See Figure 2.11.

Required Tools: Same as for "Comparison of Historical Data".

Crosslines will also be treated this way.

2.6.2.9 All Data Examination. Definition: A manual examination of as large an area as can be presented at once (area should be <u>at least</u> one km square).

Examples: This examination is to look for gaps in coverage, anomalous features, and inadequately depicted hazards to navigation of a scale that could not be detected in earlier examinations. The following types of problems might be seen.

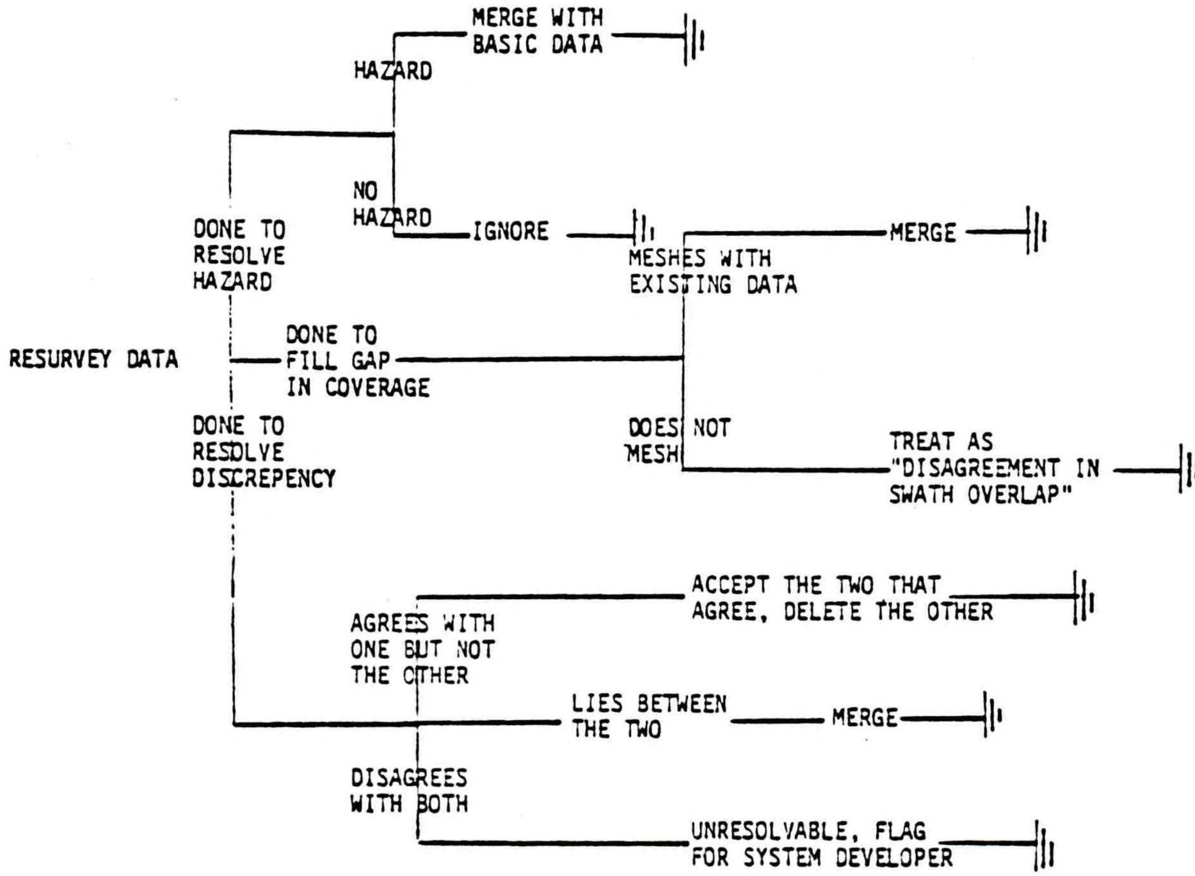


Figure 2.9. Treatment of Resurvey Data

1. Sparse data over a large area (causes - low S/N ratio; large number of deletions by hydrographer; patchy water optical properties).

2. Features that start and stop (causes - masking by turbid water; noise induced features; swell).

3. Periodic variations in features (causes - optical and positioning system misalinement; swell).

4. No feature where one is expected (causes - optically obscuring layer; system seeing a persistent noise spike).

Courses of Action: Sparse data will be treated according to "Gaps in Coverage". See Figure 2.12 for action to be taken in the case of anomalies.

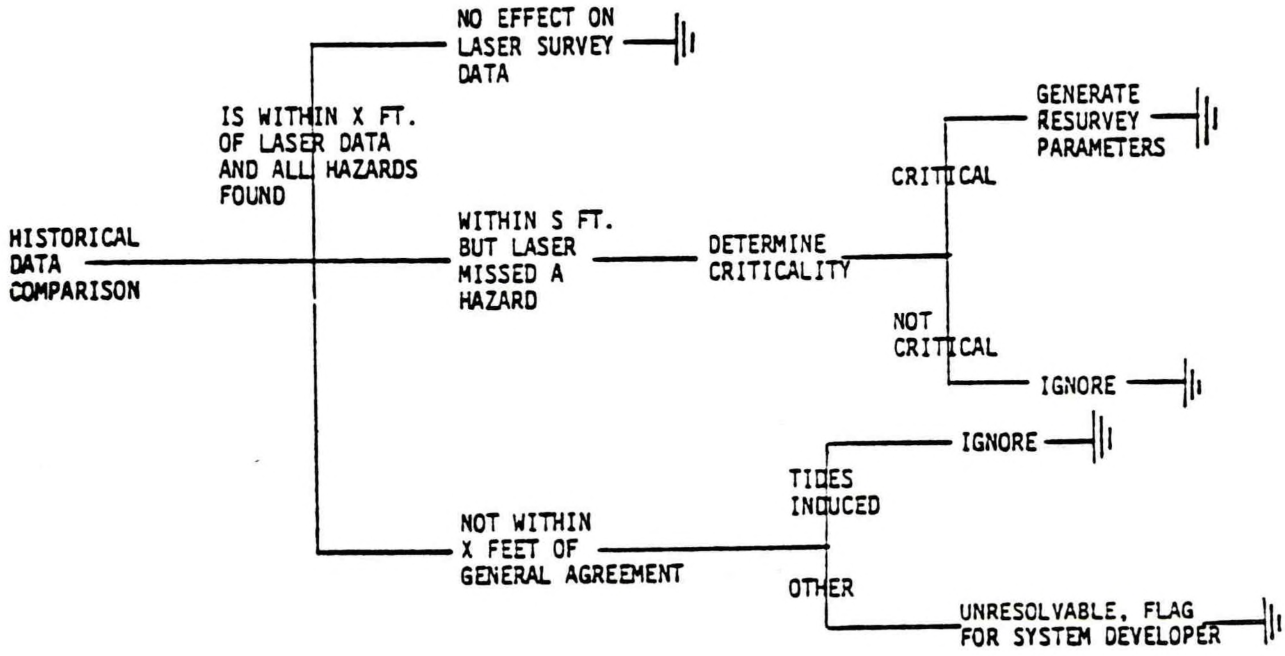


Figure 2.10. Treatment of Historical Data

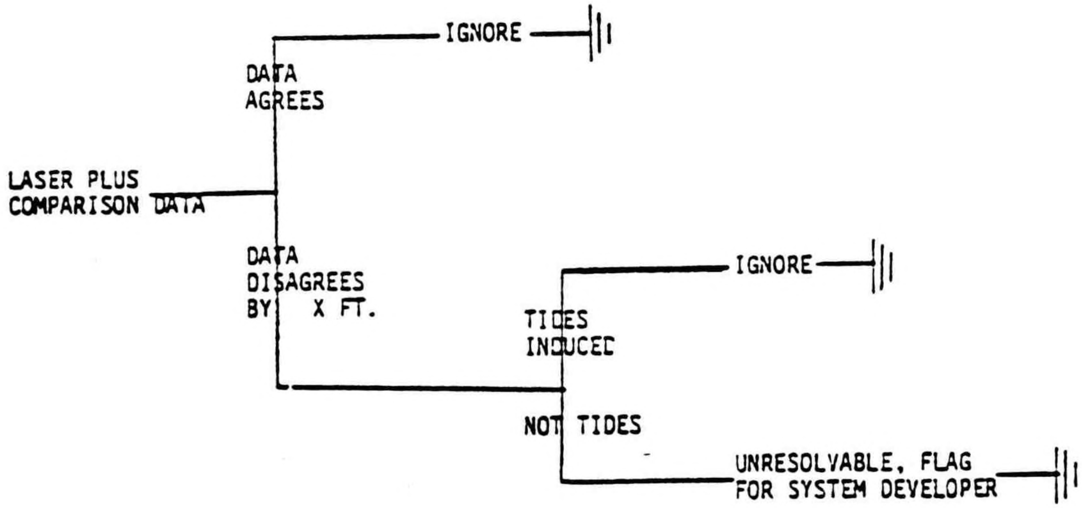


Figure 2.11 Treatment of Contemporary Data

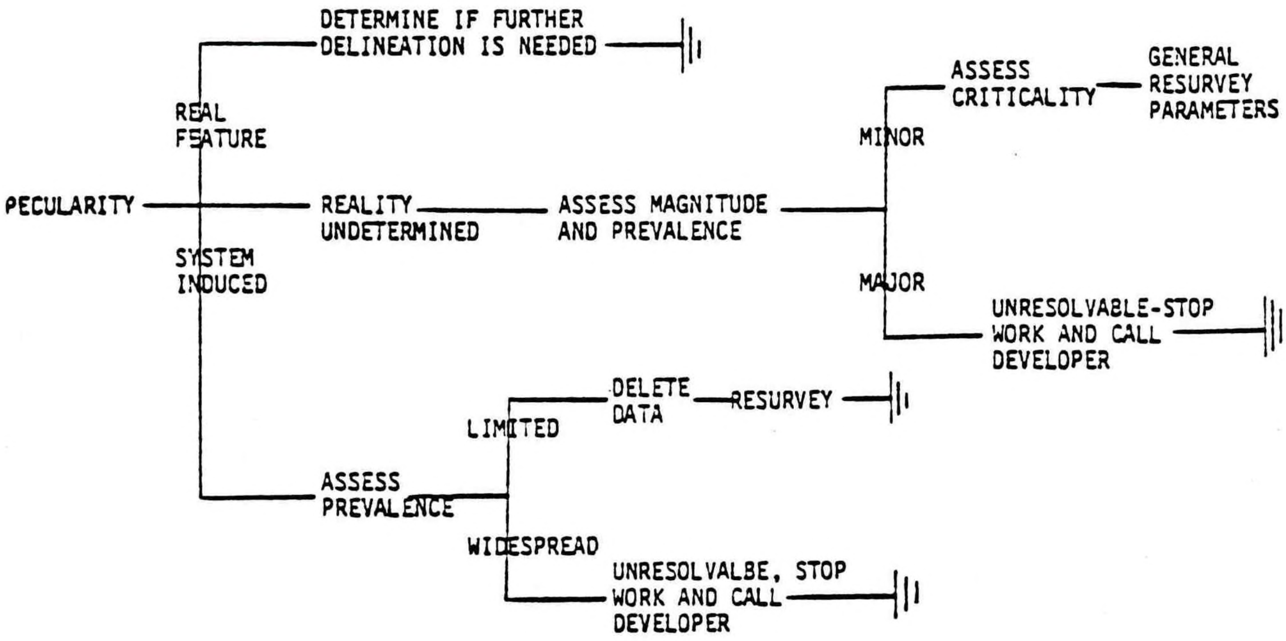


Figure 2.12 Hydrographer's Actions- Anomalies in All Data Examination

Required Tools: In order to assess if an observed pecularity is real, the hydrographer will examine surrounding soundings for trends, e.g., the start of a rise on either side of a ridge. A plot of depths in their correct geographic relationship would allow this. So would depth profiles through the area. Features which are adequately supported in the opinion of the hydrographer will be accepted as real. Resurvey will be performed according to criteria set in "Gaps in Coverage". Supporting soundings might be looked for at a distance of about 1/2 the feature size from its edge.

The magnitude of a pecularity has to do with its difference in depth from what the hydrographer thinks the depth should be based on surrounding soundings. He must, therefore, have enough depth values (rather than a pseudo depth plot) to determine if the pecularity is less than one to two feet different from the expected. If it is less, it could be ignored. If it is more, it is major flaw.

To determine the prevalence of a pecularity, the hydrographer should be able to view a larger area still to see how the feature propagates or recurs.

To determine if a pecularity is system induced, its periodicity or persistence should be assessed. Periodic, persistent cases will be considered system problems.

The shoreline (historical data) should be compared to the zero depth curve from the laser survey.

2.6.3 Final Processing Requirements

Final processing prepares the output products of the survey. It is partially automated.

LIST OF FINAL PROCESSING STEPS

1.0 Hydrographic sounding selection
2.0 Examination of selected soundings
3.0 Product preparation

Detailed Description of Final Processing Steps

1.0 Hydrographic Sounding Selection

Definition: Choose a subset of those soundings which were not deleted to submit as the survey results.

Discussion: Hydrographic sounding selection is done to avoid innundating the subsequent data users. About 1 in 100 soundings will be selected. Those soundings selected will typically be no closer than 50 meters to each other. Soundings will be chosen to: delineate hazards to navigation, delineate the general bathymetry, and to give complete coverage of the survey site.

The specific algorithm that will be used is undefined. Whatever algorithm is used should give a result such that if depth is linearly interpolated between selected soundings, the interpolated depth will not differ from an actual sounding in the interpolation region by more than +x and -y (preset criteria). If it does, then more soundings need to be selected. If this interpolation region grows beyond z meters without a selection being required, a sounding will be picked arbitrarily so that all areas will have some soundings selected.

The algorithm might look like:

- o pick a modest size area (500 m x 500 m)
- o fit a surface to the data around the boundary (maybe a plane)
- o test the points inside the boundary
- o select those passing a threshold, such as R feet, shallower than the plane at the location of the sounding being tested.
- o select a few of the boundary points so the surface could be reconstructed from them
- o make sure that at least k soundings per unit area have been selected
- o move to an adjacent, and overlapping, area.

The threshold x and y will be determined from the standard deviation of the entire (maximal) set of accepted soundings and the scale of the survey.

Survey scale is related to sounding density by a known rule and the scale will be input by the hydrographer. Clearly, z is dependent on scale too by a simple algebraic expression. The standard deviation of the data set should be computed using only non-deleted soundings.

Soundings should be selected by setting a flag.

2.0 Examination of Selected Soundings

Definition: A manual examination of the selected soundings by the hydrographer.

Discussion: The hydrographer will be examining those soundings which were selected and comparing them to the soundings that were not selected. He will be insuring that the hazards and bathymetry are adequately delineated, that an appropriate number of soundings were selected, and that those selected accurately reflect the navigational characteristics of the area.

To perform this examination, the hydrographer will need to view all the soundings with the selected soundings highlighted. This could be accomplished by using large subareas if necessary. Selected and non-selected soundings should be shown in their proper, relative locations. Depths must be determinable so the difference between selected and non-selected can be estimated.

The hydrographer must be able to add or delete selected soundings. He would do this, for example, where special features such as a navigation channel require added delineation. He must be able to blank out entire areas and/or make special annotations in the data set for that area, e.g., kelp, foul with wrecks.

A count should be kept of the total number of soundings selected for inclusion in the final report.

The result of this step are the certified survey results.

Contours should also be examined with respect to the selected soundings to see that the contours are adequately supported.

3.0 Product Preparation

Definition: Prepares final products of survey.

Discussion: Products are:

1. A digital tape of the selected soundings. The sounding data for each selected sounding will be: depth, position, tide corrector, RTOD, Julian date, and swath ID. Soundings will have to be sorted on positions according to a known convention and formatted to be compatible with a known recipient system. Survey identification information will also be needed such as: survey number, site, dates, laser data identifier, and sufficient references to locate all the other raw data and reports associated with the survey.

2. Raw flight tape for archives. Duplicate tape should be degaussed or discarded.

3. Final report. HS/DP produced data for the final report is:

   a. hardware setup parameters from flight tape and manual inputs
   b. software setup parameters
   c. preflight calibration data and correctors
   d. profiles of selected parameters

      1. laser power
      2. temperatures
      3. diffuse attenuation coefficient
      4. others

   e. statistics on several parameters

      1. standard deviation of depths for data set
      2. others as identified on earlier pages

   f. deletion summary showing numbers of soundings deleted and reasons
   g. total number of soundings made
   h. total number of soundings selected
   i. comparison results from the inter-data set comparison

3.0 REQUIREMENTS ANALYSIS

3.1 Timing Considerations - Automated Processing

The HS/DP Subsystem is required to handle a large volume of data in a short time. The Airborne Laser Bathymeter Subsystem is the main data generator, with a steady data rate of up to 1.3 megabits per second for a period of up to 6.5 hours. System performance constraints dictate that the data be fully analyzed within two hours for every one hour of data acquisition, and that the bulk of this processing time be allocated for interactive evaluation of the data. Thus, a typical mission data set (4hr), 8.6 million soundings, will have to be fully analyzed within eight hours.

The steps required to reduce and analyze the raw laser data are very complex. Each sounding will be unpacked, examined for errors, calibrated, and associated with positioning information. Depths will be calculated and correctors will be applied for water properties, wave motion and tides. Soundings are then examined in groups for anomalous depths, positions, and contours. Overlapping soundings will be examined for agreement. The aggregate set of acceptable soundings will then be compared (as appropriate) with known shoreline data, historical measurements, contemporary data sets, and existing digitized charts. A subset of soundings (about 1 in 100) adequate to compile a chart are then selected and further examined. The final product will be a set of certified, selected soundings.

The bulk of the processing is to be performed without human intervention. Thus, all data reduction and computations defined under the category of Preliminary Processing will be completely automated, except under the conditions of abnormal system performance or measurements. Similarly, two of the three steps of Final Processing will be performed automatically, namely, sounding selection and product preparation. Most of these automated processing steps have been fairly well defined in the requirements.

Because of the strict mission processing time requirement and the large volume of data, it is especially important to examine the operational feasibility of the ALH system as defined by the requirements and constraints. This section presents such an examination. The automated reduction and analysis steps are examined in detail, down to the level of computer instructions. The total number and type of such instructions necessary for the automated aspects of the processing are summarized by steps so that minimum required processor capability may be defined.

The basic goal is to determine the number and type of instructions required to prepare a single "normal" sounding from raw tape to final product. Then given the total number of soundings, it is possible to determine the automated processing load for a mission. The totals should be taken as minimum figures.

The formalism used in generating the instruction count is Program Design Language (PDL). PDL is a structured English representation of program logic that uses simple imperative verbs and structured programming constructs such as IF-THEN-ELSE, DO-WHILE, and DO-UNTIL. A simple conditional statement is represented by an IF-FI block of code, where the condition follows the IF in parentheses, the code to be executed if the condition is true is indented after the IF, and the end of the block is denoted by a reverse IF, namely FI.

Examples:

```
.
.
.
IF (condition)
      .
      . (code to be executed if condition is true)
      .
FI
.
.
.
```

A multiple condition is represented by IF-THEN-ELSE constructs.

```
.
.
.
IF (condition)
      .
      . (code for condition true)
      .
ELSE
      .
      . (code for condition false)
      .
FI
```

Loops under conditions are represented by DO-WHILE and DO-UNTIL constructs.

```
.
.
.
DO WHILE (condition)
      .
      . (code to be executed while condition is true)
      .
OD
.
.
.
```

A form of the DO loop is also used for repeated operations on different data:

```
.
.
.
DO FOR (data range)
      .
      . (code)
      .
OD
```

Simple formulas are included in the PDL to express the computation algorithms.

The requirement steps for automated processing have been cast in algorithms expressed in PDL. Many assumptions have been made in order to estimate processing steps that are not currently well defined. Such assumptions have been noted in the analysis.

The instructions have been chosen as if the logic or the PDL were implemented in assembly language. The following set of assembly instructions are used for the estimating:

SYMBOL	INSTRUCTION	ALSO USED FOR
A	Add	Subtract
L	Load	Store
M	Multiply	Divide
Sh	Shift	
C	Compare	Branching
AD	Double Add	Double Subtract
MD	Double Multiply	Double Divide

Floating point data are assumed to be processed with the AD and MD instructions.

The logic developed for this examination could certainly be used as a guide in later software implementation. It is expected, however, that the bulk of the programming will be implemented in a high level language such as Fortran rather than assembly language.

The preliminary processing steps are considered first. PDL is included for the offline steps (online meaning part of the queue processing), although no instruction analysis is made for those steps. For each function the step number from the requirements (Section 2.6.1) is included in parentheses. A summary of the instruction load appears as Table 3.1.

STEP	FUNCTION	ADD	MULTIPLY	STORE COMP	LOAD	MISC	AD	MD	SUM FOR STEP
6	Read raw data								
	Unpack raw data				558	390			948
7	EDIT:								
	Waveform test			41	24				65
	Housekeeping, Parameter test			40	120				160
	Azimuth test	3		3	7	L.S.F. on bad vals			13
	Synch time test	3		3	7				13
	Slant altitude			2	6				8

STEP	FUNCTION	ADD	MULTIPLY	STORE COMP	LOAD	MISC	AD	MD	SUM FOR STEP
8	Identify internal CAL pulse			1	1				2
	Process or apply internal gain CAL pulse	B		B	2B				800
	Process time base pulse			2	17	9	5		33
9	Apply low pass filter	2B-2		B-2	2B-1	2B-2 1-bit shifts			1393
10	Environmental Subtraction:								
	Find deep soundings			2	2				4
	Average deep soundings	40		22	142				204
	Apply Env. correctors	401		200	1402				2003
11	Compute Pulse locations:								
	Locate surface peak	1		72	93	50	50		266
	Locate bottom peak	1		72	93	50	50		266
	Tests	21		69	71				161
	Subtract D.C. background	252	1	250	252				755
	Compute pulse locations (3rd order, 10 pts.)	388	42	1062	2154		460	660	4766
12	Zero depth test								
	Test	2	1	13	56		51	55	178

STEP	FUNCTION	ADD	MULTIPLY	STORE COMP	LOAD	MISC	AD	MD	SUM FOR STEP
13	Waveform-based parameters								
	Leading Edge			20	80		80	100	280
	Pulse width			40	160		150	200	560
	S/N ratio				2			1	3
	K			14	117		71	50	252
	Average K's	108		1169	1224		25	1	2527
	B/K's			14	117		71	50	252
	Average B/K's	24		49	172		25	1	271
	ω_0				3			1	4
	α				8		3	3	14
	ϕ				4		1	1	6
14	Apparent Depth				3		1	2	6
15	Merge PAMS data			34	96		22	21	173
	Compute laser hit position			36	36		84	132	288
16	Apply Depth correctors	18	9	56	104		97	144	428
	Apply time base corrector				2		1	1	4
17	Compute slant altitude	1		1	14		10	8	33
18	Wave Corrector:								
	Compute predicted SA, #1			36	39		87	132	294
	Compute predicted SA, #2	17	2	85	175		55	65	399
	Compute wave corrector								

STEP	FUNCTION	ADD	MULTIPLY	STORE COMP	LOAD	MISC	AD	MD	SUM FOR STEP
	Apply wave corrector			4	11		5	2	22
19	General Edit:								
	Value test			1	5		3	1	10
	Slope test			1	9		5	2	17
	Block Precision S/N test			1	6				7
	ΔD - ΔA test			1	8		2		11
	Density test	2		1	5				8
	Position test			2	10		3	2	17
21	Compute and apply tides			10	95		45	30	180
(FP)	Sounding Selection				30		10	10	50

Table 3.1 Instruction Load Per Sounding

Flight Tape Initialization and Printing (Steps 1, 2)

An interactive program for the user to manually enter and review mission parameters, generate hardcopy, and write parameters to the flight tape.

```
PDL:
     PRINT introductory information
     DO FOR each data item
               PROMPT user for item to be entered, format, etc.
               READ in parameter
     OD
     DO UNTIL (indefinitely)
               PROMPT user for function code
               READ function code
               IF (code = DISPLAY) display all mission parameters
               IF (code = HARDCOPY) issue hardcopy of display
               IF (code = PARMNO) read in corresponding corrected
                    parameters
               IF (code = END) exit from DO UNTIL loop
     OD
     STOP
```

Accept Preliminary Processing Parameters (Step 4)

An interactive program for the user to review the present list of processing parameters and to optionally modify them. A table is then written onto a disk file to be accessed later.

PDL:

```
    PRINT introductory information
    DO FOR each processing parameter
              DISPLAY current value, including format (for changing)
              DO UNTIL (indefinitely)
                   PROMPT for function code
                   READ function code
                   IF (code = (return)) exit DO UNTIL loop
                   IF (code = RETYPE) redisplay value of
                        parameter
                   IF (code = CHANGE) READ new changed
                        value
              OD
    OD
    DO UNTIL (indefinitely)
              PROMPT user for function code
              READ function code
              IF (code = DISPLAY) display all parameters
              IF (code = HARDCOPY) issue hardcopy of display
              IF (code = SAVE) write parameter table to disk
              IF (code = END) exit from DO UNTIL loop
              IF (code = PARMNO) read in changed parameter
    OD
    STOP
```

Process Preflight CAL Data (Step 5)

Preflight calibration tests are instrument checkout tests performed prior to (and possibly after) the data-taking of a survey. Currently, ten such tests have been identified:

altitude calibration
depth calibration
laser pulse monitor calibration
gain calibration
time base calibration
transmit pulse stability test
radiometric calibration
system noise test
CAL pulse gain calibration
CAL pulse time base calibration

Each test consists of a set of laser sounding measurements along with some manually entered data (e.g., test ID, reflector distances, power reading, test waveform ID, start and stop times for tests, etc.). All tests will be analyzed sequentially, with the resulting correctors to be written to a disk file for later access. The following correctors have been identified:

altitude corrector
differential range corrector
gain corrector
time base corrector
CAL pulse gain corrector
CAL pulse time base corrector

Statistics will be computed and printed for each test. Figure 3.1 shows a possible layout for the flight tape including initialization parameters, preflight tests and the start of the survey data. It should be assumed that not all tests will be performed, and that correctors that were not tested should be unity.

PDL:

```
    INITIALIZE correctors = 1.0
    DO FOR each test
            READ annotation (T1, T2, test ID, etc.)
            DO for T1 to T2 (or else EOF encountered)
                    READ soundings
                    ACCUMULATE data
            OD
            COMPUTE statistics
            Compute corrector (if applicable)
            ENTER corrector into table (if applicable)
            PRINT statistics, corrector
    OD
    WRITE corrector table to disk file
```

Read and Unpack Data (Step 6)

The raw data must be unpacked from the flight tape into the processing queue in convenient boundaries (words, bytes, etc.) for further processing. The major part of the task is in unpacking the waveform bin values (i.e., the digitized points on a boundary waveform). Assume that each bin has ten bits and that these values are stored consecutively in the raw bit stream. The number of bins is B. Assume that data is read off the tape in eight-bit bytes:

The ten-bit items are to be stored into 16-bit words in a bin array in the sounding queue. The procedure is to load either a word or two bytes into a register, shift off the unwanted bits, shift to align the items and store the item in the array. In the PDL, assume indexing within the arrays to be automatic and 16-bit architecture.

```
PDL:                                                     INSTR.
    DO FOR (B/8 TIMES)
            LOAD WORD 1
            RIGHT SHIFT
            STORE                                         2L,Sh
            LOAD BYTES 2 AND 3
            2 SHIFTS
            STORE                                         3L,2Sh
            LOAD WORD 2
            2 SHIFTS
```

```
STORE                                                  2L,2Sh
LOAD BYTES 4 AND 5
2 SHIFTS
STORE                                                  3L,2Sh
LOAD BYTES 6 AND 7
RIGHT SHIFT
STORE                                                   3L,Sh
LOAD WORD 4
2 SHIFTS
STORE                                                  2L,2Sh
LOAD BYTES 8 AND 9
2 SHIFTS
STORE                                                  3L,2Sh
LOAD WORD 5
2 SHIFTS
STORE                                                  2L,2Sh
OD
                          Total =                     20L,14Sh
```

For 200 bins (B = 200) needed to represent each waveform, the load would be 25 times the above loop, or 500 loads and 350 shifts. Unpacking the non-waveform sounding data (about 230 bits per sounding waveform) would be roughly equivalent to adding 230/2000 = 0.115 times the bin instruction load. The total instruction load for unpacking is then 558 loads and 390 shifts. 32-bit architecture would slightly reduce the number of loads (16 instead of 20 in loop), bringing the total to 446 loads and 390 shifts (or an instruction load reduction of 12 percent). The value in Table 3.1 assumes 16-bit architecture.

Waveform Test Edit (Step 7)

System malfunction is indicated by a null return waveform. A flag is set if any of the channel values between bin X and bin Y are lower than a threshold Z.

```
PDL:                                                          INSTR.
     DO FOR EACH SOUNDING
          INITIALIZE FLAG                                          L
          BIN = X                                                  L
          DO UNTIL (BIN = Y)                               N*(L,C,C)
               IF (VALUE (BIN) .GT.Z) SET FLAG; EXIT DO LOOP
               NEXT BIN
          OD
          IF (FLAG SET) BUMP FLAG COUNTER BY 1                C,L,St
     OD
```

Here, N is the range of channels Y - X. The value in Table 3.1 assumes a range of 20 bins.

Housekeeping Parameter Test (Step 7)

Specified housekeeping parameters (e.g., laser power, slant altitude, etc.) are expected to have certain ranges. Those soundings whose housekeeping parameters are outside of the expected range are flagged.

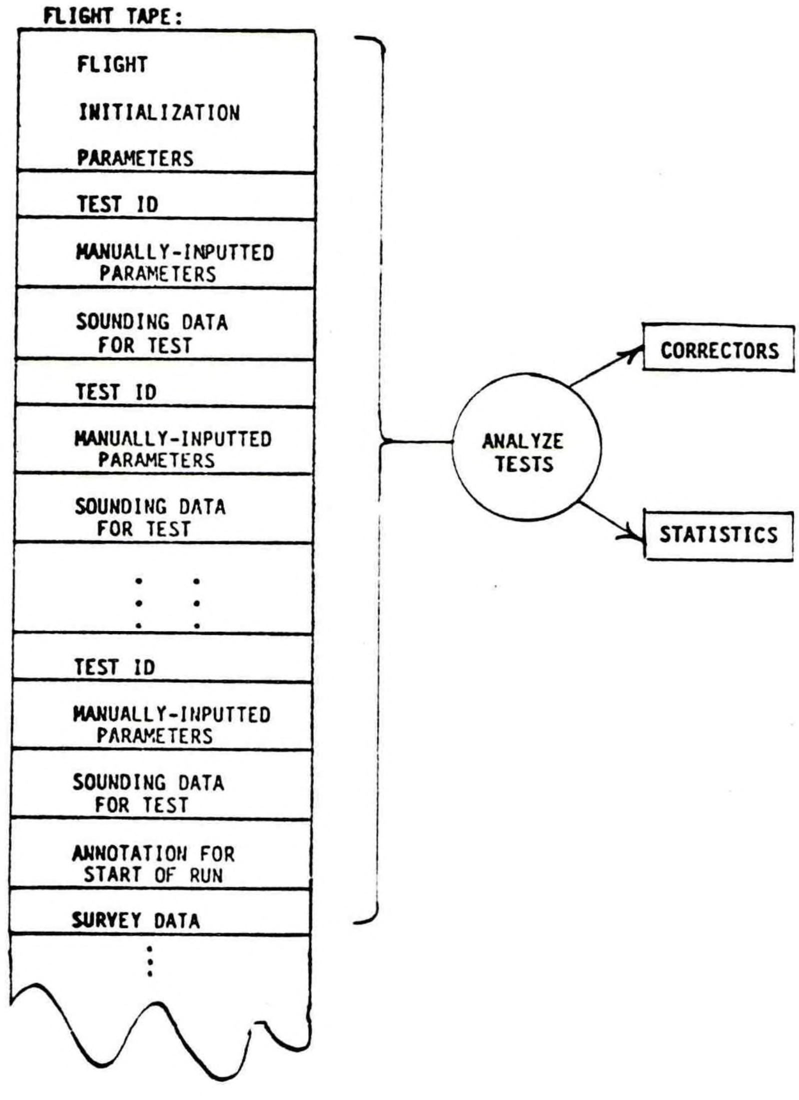


Figure 3.1 Layout of Preflight Data on Flight Tape.

PDL:

```
                                                       INSTR.
    DO FOR EACH SOUNDING
        DO FOR EACH HOUSEKEEPING PARAMETER                L
            FLAG = OK                                     L
            IF (VALUE .LT. LOWER LIMIT)                   C
                FLAG = LOW                                L
            FI
            IF (VALUE .GT. UPPER LIMIT)                   C
                FLAG = HIGH                               L
            FI
```

```
                BUMP APPROPRIATE HISTOGRAM BIN                    L,St
            OD
        OD
```

The entry in Table 3.1 assumes 20 such housekeeping parameters to check, or 120 loads and 40 compares.

Synch. Time Test (Step 7)

The synchronization time is expected to be a smoothly increasing parameter which will recycle periodically. Bad time values or discontinuities should be flagged, and statistics maintained on such edits.

```
    PDL:                                                        INSTR.
        PROCESS FIRST SOUNDING
            SET PREV = SYNCH TIME                                    L
            SET FLAG = UNKNOWN                                       L
        DO FOR ALL REMAINING SOUNDINGS                             C,L
                FLAG = OK                                            L
                IF (SYNCH TIME .LT. PREV)                          L,C
                    SYNCH TIME = SYNCH TIME + MAX                  A,L
                FI
                IF (|SYNCH TIME - PREV - ΔT|                   A,A,L,C
                    .GT. THRESH) FLAG = BAD                         St
                    BUMP BAD TIME COUNTER BY 1                    L,St
                FI
        OD
```

Azimuth Test (Step 7)

The azimuth is expected to be a smoothly varying parameter. Bad azimuth values or missing values should be replaced by interpolated values based on good neighboring values. Discontinuities should be checked versus discontinuities in synchronization time.

```
    PDL:                                                        INSTR.
        PROCESS FIRST SOUNDING
            SET PREV = AZIMUTH                                      St
            SET FLAG = UNKNOWN                                      St
        DO FOR ALL REMAINING SOUNDINGS                               L
            IF (AZIMUTH .LT. PREV) AZIMUTH = AZIMUTH + 360°        C,A
            IF (|AZIMUTH - PREV -ΔA|.LE. THRESH) FLAG = OK    A,A,L,C,
            ELSE FLAG = BAD, BUMP COUNTER                        L,L,S
        OD
        DO FOR ALL SOUNDINGS
            IF (FLAG = OK OR UNKNOWN), NEXT SOUNDING               L,C
            ELSE IF (TOO MANY BAD VALUES IN A ROW)         (#B)*(L,L,C)
                    FLAG = NOT CORRECTABLE
            ELSE IF (NOT ENOUGH GOOD NEIGHBORING VALUES
                FOR INTERPOLATION)                         (#N)*(L,L,C)
                    FLAG = NOT CORRECTABLE                         L,S
                ELSE
                    INTERPOLATE BAD VALUES             (least squares fit)
                    SET FLAGS = INTERPOLATED                         L
```

```
                BUMP COUNTERS                                2L
                SKIP TO NEXT GOOD VALUE                      L
    OD
```

Notes:

#B = # bad values in a row (assume 5)
#N = # good neighboring values in a row (assume 5)

The value in Table 3.1 assume the normal case of no bad values.

Calibration Pulse Processing (Step 8)

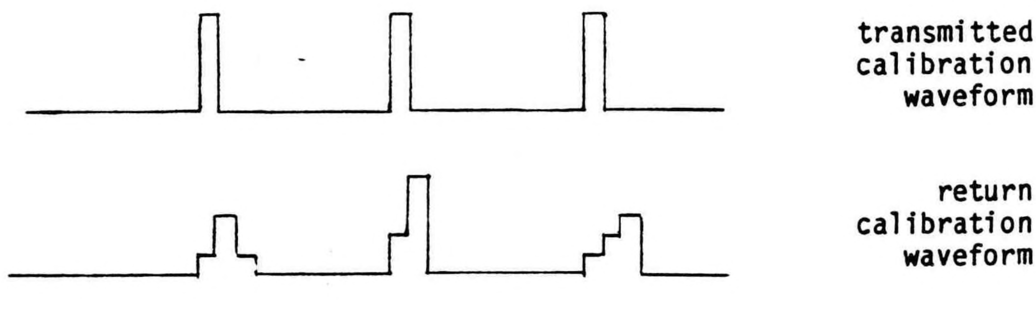
Periodically a calibration pulse will be inserted into the data stream (one in 100 or one in 600 total pulses) by the Airborne Laser Bathymeter Subsystem. Assume that there will be a bit set to identify calibration pulses. Each calibration pulse must be identified and processed. Each succeeding data pulse (until the next calibration pulse) must be corrected using the processed calibration pulse.

```
PDL:                                                     INSTR.
    IF (CAL bit on)                                         L,C
        DO FOR (all bins)                                  #b*C
            CORRECTOR = CAL value - STND value        #b*(A,2L)
        OD
    ELSE
        DO FOR (all bins)                                  #b*C
            CORRECTED VALUE = UNCORRECTED             #b*(A,2L)
                VALUE + CORRECTOR
        OD
    FI
```

Notes:

#b = number of bins in waveform

The time base calibration pulse also has to be processed and correctors applied to all succeeding laser soundings up until the next time base calibration pulse. Assume that the time base calibration pulse is a series of single bin spikes in a waveform. The expected response would be a calibration waveform with the pulses shifted by some amount, occupying from one to three adjacent bins:



The actual bin locations are a weighted average of the one to three bin pulse response $B_{actual} = \Sigma\ WT_i * B_i$. The corrector for each spike would be the difference between the expected value and the actual value: $C_B = B_{expected} - B_{actual}$. Correctors are then determined for all of the 200 bins by linear interpolation of correctors from nearby spike pulses. Thus, each bin in the waveform would have an effective bin number (a floating point number) which is corrected for time base errors.

```
PDL:                                                              INSTR.
     DO FOR (each CAL pulse j)                                        L
               DO UNTIL (value of bin .GT. threshold)               L,C
                    READ next bin B_i of the CAL waveform             L
               OD
                    READ next bin B_i+1                               L
               IF (value of B_i+1 .LT. threshold)                     C
                    CAL_j = B_i                                      St
               ELSE
                    READ next bin B_i+2                               L
                    IF (value of B_i+2 .LT. threshold)                C
                    CAL_j = WT_i*B_i + WT_i+1*B_i+1          4L,2MD,AD
               ELSE
                    READ next bin B_i+3                               L
                    IF (value of B_i+3 .GT. threshold)                C
                         SET error flag                            L,St
               ELSE
                    CAL_j =    WT_i*B_i +                   6L,3MD,2AD
                         WT_i+1*B_i+1 + WT_i+2*B_i+2
               FI
          FI
     FI
     COR_j = CAL_j - EXP_j                                        2L,AD
     OD
(calculate correctors for all bins of waveform:)
     GET COR_1, B_1, COR_2, B_2                                      4L
     DO FOR (all bins)                                              L,C
          COR_i = (B_i-B_1)/(B_2-B_1)*(COR_2-COR_1) + COR_1   2MD,4AD,St
     OD
```

If we assume ten spikes in the calibration waveform and a waveform size of 200 bins, the total instruction load per calibration pulse would be:

spike processing	490L,31C,40AD,30MD
generation of bin correctors	1200L,200C,400MD,800AD

Now if we assume that only one in 100 soundings would be a time base calibration pulse, the per sounding instruction load would then be about 17 loads, two compares, nine double adds, and five double multiplies.

<u>Low Pass Filter</u> (Step 9)

A low pass filter may need to be applied to the waveform in order to reduce the effect of system ringing or high frequency noise. A simple example of such a filter would be a triangular filter, wherein each bin B_i is replaced as follows:

$$1/2\ B_i + 1/4\ (B_{i-1} + B_{i+1})$$

Successive applications of this filter would further smooth the data; for example, two applications of the triangular filter would results in B_i being replaced by:

$$3/8\ B_i + 1/4(B_{i-1}+B_{i+1}) + 1/16\ (B_{i-2} + B_{i+2})$$

The following PDL assumes a simple triangular filter. Multiple applications of this simple filter should be considered for particularly noisy data.

PDL:	INSTR.
PREV = B_1	L
B_1 = (PREV + B_2)/2	A,Sh,St
DO FOR (bins 2 through #b-1)	C
IFILT = (B_i + (PREV + B_{i+1})/2)/2	2A,2Sh
PREV = B_i	L
B_i = IFILT	St
OD	
$B_{\#b}$ = (PREV + $B_{\#b}$)/2	A,Sh,St

Environmental Subtraction (Step 10)

Environmental subtraction is an alternate approach to processing laser sounding waveforms. The data analysis proceeds as usual (call it the first pass) up through the Zero Depth Test, at which point deep water returns are identified and flagged. Here test(s) would be performed to distinguish genuine deep water returns from shallow returns or bad waveforms. Also at this time, the deep water return will be classified as to its surface return amplitude. When the entire queue has been so processed, a second pass is made through the queue to average the deep water returns by surface return amplitude class. A third pass is then made through the queue wherein each waveform is normalized to its surface return amplitude class, by subtraction. The location of the bottom return pulse is determined as usual and the processing continues.

How does environmental subtraction affect the instruction load per sounding? The Computation of Pulse Location (Step 11) is unaffected because the surface peak is located in the first pass and the bottom peak is located in the third pass. The Zero Depth Test (Step 13) would be augmented by tests that would identify and classify deep water returns

PDL:	INSTR.
IF (peak shape is characteristic)	2L,2C
SET deep water flag	2L
CLASS = FUNCTION (surface return amplitude)	2L,2M,A
FI	

The averaging of the waveforms would include an alignment of the surface return location to a standard bin number.

```
PDL:                                                          INSTR.
     DO FOR (all classes)                                       L,C
          POPULATION (class) = 0                                2L
          DO FOR (all bins)                                     L,C
               ACCUM (bin, class) = 0                           2L
          OD
     OD
     DO FOR (all waveforms)                                     L,C
          IF (DEEP WATER FLAG is set)                           L,C
               DISPL = STANDARD - LOCATION                      2L,A
               POPULATION (class) = POPULATION (class) + 1      3L,A
               DO FOR (all bins)                                L,C
                    ACCUM (bin, class) = ACCUM (bin, class)     6L,2A
                                   + WAVEFORM (bin - DISPL)
               OD
          FI
     OD
     DO FOR (all classes)                                       L,C
          DO FOR (all bins)                                     L,C
               AVE (bin, class) = ACCUM (bin, class)            5L, MD
                                  POPULATION (class)
          OD
     OD
```

Here b is the number of bins, c is the number of classes, t is the total number of soundings, and f is the fraction of soundings that are deep water. Only the averaging itself will contribute significantly to the instruction load per sounding, viz, t*(2L, 2C, f* (5L, 2A, b* (7L, C, 2A))). If we assume 200 bins and 10 percent of the soundings to be deep water, this would result in about 142 loads, 22 compares and 40 adds per sounding.

Finally, the environmental subtraction itself would involve an aligned bin-by-bin normalization of each waveform.

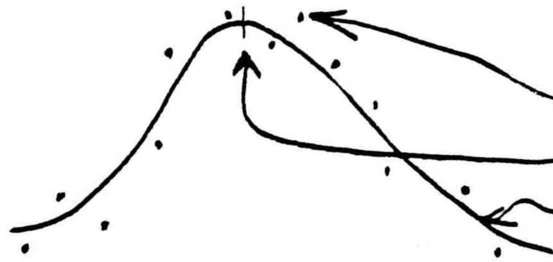
```
PDL:                                                          INSTR.
   DO FOR (each waveform)                                       L,C
        DISPL = STANDARD - LOCATION                             2L,A
        DO FOR (all bins)                                       L,C
             WAVEFORM (bin) = WAVEFORM (bin) -                  6L,2A
                  AVE (bin + DISPL, class)
        OD
   OD
```

The instruction load per sounding for 200 bins would be 1402 loads, 200 compares and 401 adds. The grand total for this approach under the assumptions mentioned is then 1546 loads, 224 compares and 441 adds.

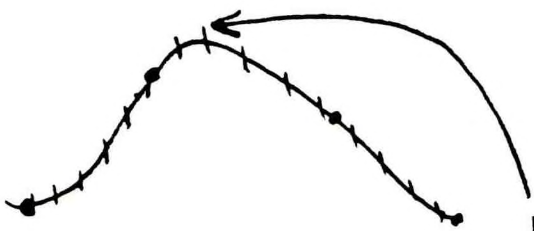
<u>Compute Pulse Location</u> (Step 11)

To find peak locations, the following procedure is assumed:

1. The peak is localized (i.e., the maximum value bin is located).
2. The data is fit to a polynomial (or perhaps fit to an expected analytic peak shape).
3. The fitted peak is evaluated to get the location of the maximum.



Appendix A shows an algorithm for least-squares fit to a polynomial taken from Bevington (ref. 8). The algorithm has been analyzed for machine instruction load for the cases of third- and fourth-order polynomials fitting either 10 or 20 data points. Given a bin location representing the maximum in the polynomial fit, one can subdivide the bins into fractions on either side of the maximum to locate the true fitted maximum to higher resolution.



Using this approach it should require about eight to ten evaluations to obtain peak locations to 0.1 bin accuracy. A single evaluation of a third-order polynomial

$$a_0 + a_1x + a_2x^2 + a_3x^3$$

will require the following instruction load:

5 MD, 3AD, 4LD, C, AD

including a compare and an increment. The following table summarizes the instruction load for finding the peak location to 0.1 bin, given a third- or fourth-order polynomial fit to the data:

	C	LD	AD	MD
third order	10	40	40	50
fourth order	10	50	50	70

The following PDL computes the peak location given the bin location of the previous peak (OLDPEAK) and a range +/- x.

```
PDL:  locate maximum bin value:                          INSTR.
      MAX = 0                                                L
      DO FOR (bins OLDPEAK-X to OLDPEAK+X)                 20C
            IF VALUE .GT. MAX)                         20L,20C
                  MAX = VALUE                              10L
                  LOC = LOC(VALUE)                         10L
            FI
      OD
      (fit peak to polynomial - see Appendix A)
```

```
(test leading edge:)
DO FOR (bin LOC-10 to LOC)                                    L,A
     IF (BIN .GT. LOC-10)                           10L,10A,10C
          IF (VALUE (bin) .LE. PREV)                     18L,9C
               SET BAD FLAG                                   L
               EXIT
          FI
          SLOPE = VALUE (bin) - PREV                     18L,9A
          IF (SLOPE .LT. T1 .OR. SLOPE .GT. T2)             18C
               SET BAD FLAG                                   L
               EXIT
          FI
     FI
     PREV = VALUE (bin)                                     10L
OD
(test width:)
DO FOR (bins LOC to #b)                                      5C
     IF (VALUE(BIN) .LE. 1/2 VALUE (LOC))                 5L,5C
          HALFMAX2 = bin                                      L
          EXIT
     FI
OD
DO FOR (bins LOC to 1)                                       5C
     IF (VALUE(bin) .LE. 1/2 VALUE(LOC))                  5L,5C
          HALFMAX1 = bin                                      L
          EXIT
     FI
OD
IF (HALFMAX2 - HALFMAX1 .LT. R1 or .GT. R2)               A,2C
          (alternate search - start at bin 1)
FI
IF (NO PULSE) SET flag
(dc level:)
SUM = 0                                                       L
DO FOR (bins SURF+B TO BOTTOM-b)                            50C
     SUM = SUM + VALUE(BIN)                             50L,50A
OD
DCLEVEL = SUM/(BOTTOM-b - SURF+B + 1)                  2A,M,St
DO FOR (all bins)                                          #b C
     VALUE(bin) = VALUE(bin) - DCLEVEL                 #b(A,St)
OD
```

In Table 3.1 the example of a ten-point third order fit is used for both surface and bottom peaks.

<u>Zero Depth Test and Computation</u> (Step 12)

Determination of the zero depth condition depends in part on the most recent waveform which was clearly identified as having distinct bottom and surface return pulses. In the sequential processing of Step 11, an address register should be maintained that points to the most recent waveform satisfying the two-pulse condition. Any subsequent waveforms that appear to contain only one pulse (i.e., zero depth candidates) would then be referred back to this most recent two-pulse waveform.

To test for genuine zero depth cases, four conditions should be checked:

1. There exists only one pulse (from Step 9).
2. The most recent two-pulse waveform indicates a shallow measurement (i.e., the bottom and surface return pulses are very close together).
3. The amplitude of the single pulse is consistent with two close pulses.
4. There is no inflection point on the single pulse.

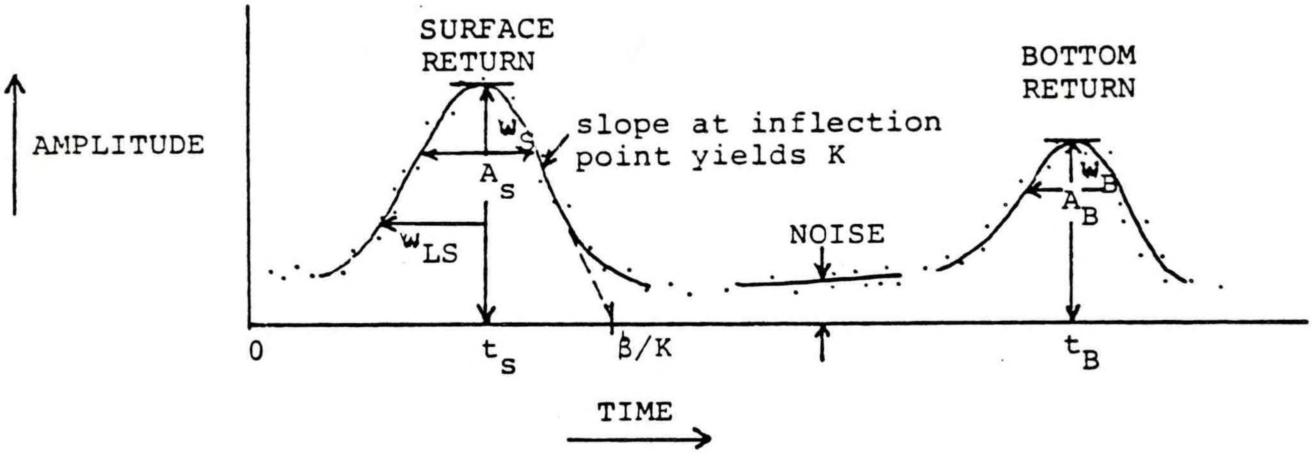
Note that item 4 requires the kind of computation employed in the determination of the effective diffuse attenuation coefficient K (Step 12).

The two-pulse distinction determination would then involve a peak-fitting procedure over the single pulse, making use of pulse-fitting parameters (e.g., width, amplitude, shape) from the most recent two-pulse waveform.

PDL:	INSTR.
CHECK for one pulse	L,C
CHECK for locations of previous two-pulse case	3L,A,C
COMPARE amplitude with previous two-pulse case	2L,M,C
SEARCH for inflection point	10C,40L,50AD,50MD
FIT pulse	(Step 11 fit)
FIND locations of two pulses	6L,A

Compute Waveform-Based Parameters (Step 13)

There are several quantities derived from the waveform which are used to compute depth correctors. These waveform-based parameters are illustrated in Figure 3.2.



ω_{LS}	=	Width of leading edge of surface return at preset of A_s
ω_s	=	Full width at Z% of A_s for surface return
ω^s	=	Full width at Z% of A_B for bottom return
S/N	=	Signal-to-noise ratio (= A_B/NOISE)
K	=	Effective diffuse attenuation coefficient (function of slope of trailing edge of surface return at plateau or inflection point)
B/K	=	Slope of volume backscatter extrapolated back to zero time
ω_o	=	ω_o (B/K), single scattering albedo
A	=	A (K, ω_o), beam attenuation coefficient
ϕ	=	ϕ (K), phase function

Figure 3.2 Definitions of Waveform-Based Parameters

a. Width of Leading Edge of Surface Return.

Using the polynomial fit to the surface peak obtained in Step 11, the distance between the location of the peak maximum and the leading edge at a preset percentage of peak amplitude is computed and stored.

```
PDL:                                                        INSTR.
     GOAL = X% * PEAKHEIGHT                                  2L,MD
     X = max peak location                                       L
     DO UNTIL (VALUE(X) .LE. GOAL)                             L,C
          X = X +  ΔX                                         L,AD
          EVALUATE polynomial at X                      4L,4AD,5MD
     OD
     IF (VALUE(X)=GOAL)                                        L,C
          X' = X                                                St
          EXIT
     ELSE
          EVALUATE polynomial at X- ΔX/2                4L,4AD,6MD
               etc.
```

In this fashion, the preset percentage point can be attained to any desired accuracy Δ X by successive evaluations of the fitted polynomial.

b. Pulse Width.

The full width at Z percent maximum of both the surface and bottom peaks are to be calculated and saved. A procedure identical to Step a. would be used in both cases.

c. Signal-to-Noise Ratio

The bottom return pulse amplitude is divided by the DC background (determined in Step 11), and the result is saved and tested.

```
PDL:                                                        INSTR.
     RATIO = A_B/NOISE                                       2L,MD
     IF (RATIO .LT. S/N THRESHOLD)                               C
          SET flag                                              St
     FI
```

d. Effective Diffuse Attenuation Coefficient "K".

K is an algebraic computation of the slope on the plateau or the inflection point of the trailing edge of the surface return pulse. We first condsider the calculation of K itself. Then the problem of averaging neighboring K's is considered.

Slopes are calculated along the trailing edge of the surface return peak by evaluating the polynomial on a specified interval grid and taking differences. The inflection point is then found by taking the differences of adjacent slopes and looking for values closest to zero.

```
PDL:                                                              INSTR.
    IF (not zero depth case)                                        L,C
        DO FOR (a prespecified grid along the                       L,C
            trailing edge of the surface return pulse)
                EVALUATE polynomial                  times   4L,4AD,5MD
                COMPUTE slopes s_i                   grid         2L,AD
                COMPUTE slopes of slopes s_i'        size         2L,AD
        OD
        INFLECTIONPOINT = MIN(|s_i'|)                                 C
        K = function of s_i at the inflection point               2L,AD
            or an average if s_i at specified region
    FI
    AVERAGE all legitimate K's for 20 neighboring points (see below)
    IF (K bad  or |K- AVE (K)| .LT.  ΔK)                       4L,2C,AD
        K = AVE (K)                                                  St
        SET flag                                                     St
    FI
```

Now consider the averaging of 20 neighboring K's. A "box" of 24 neighboring soundings can be located by including +/-1 and +/-2 soundings from the current sounding, as well as the five nearest soundings from each of the +/-1 and +/-2 scans from the current scan. The nearest sounding to the current sounding in a nearby scan can be located by finding that sounding in the nearby scan whose scan azimuth is closest to the scan azimuth of the current sounding.

The following procedure can be used to locate the neighboring soundings in +/-1, +/-2 scans: First assume no discontinuities in the data (i.e., check discontinuity flags forward and backward in time). Read forward each record, looking for t_i .GE. t_0 + ΔT, where t_0 is the time of the current sounding and T is approximately 80 percent of the minimum expected time for a scan. When t_i .GE. t_0 + ΔT, start looking for scan azimuth angle differences $\Delta \phi_i = |\phi_0 - \phi_i|$, base 360 degrees. Expect $\Delta \phi_i$ to decrease to a minimum value, then increase. The sounding where $\Delta \phi_i$ is a minimum and t_A .LE. $|t_0 - t_i|$ .LE. t_B is the nearest neighbor, where t_A and t_B are the minimum and maximum acceptable scan times, respectively.

The above procedure is repeated for each of the four neighboring scans. At each scan, take soundings at i+/-1 and i+/-2 from the "nearest" sounding. Adjacency of these soundings should be verified by looking at $|t_0 - t_i|$ .LE. Δt where Δt is the maximum expected time between subsequent soundings expected.

At each of the 24 nearby soundings, look at the K_i flag to verify if K_i can be included in the average.

The following instruction load computation assumes 600 soundings per second and five scans per second, or about 120 soundings per scan.

```
PDL:                                                        INSTR.
     Get t                                                      L
     DO FOR (100 soundings)                             100L,100C
          VERIFY discontinuity flag                     100L,100C
     OD
      Δ φ  = big                                                L
     DO FOR (20 soundings)
          VERIFY discontinuity flag                       20L,20C
           φ_i  = scan azimuth angle                          20L
          IF ( φ_i .LT.  φ_o)                                 20C
                φ_i = φ_i + 360°                              A,L
          FI
           Δ φ_i = |φ_i - φ_o|                            20A,20L
          IF  (Δ φ_i .GT. Δ φ) EXIT                           20C
          IF  (Δ φ_i .LT. Δ φ)                                20C
                 Δ φ = Δ φ_i                                    L
          FI
     OD
```

The above procedure will be done four times per sounding (i.e., for scans +/-1 and +/-2). Then for each of the 24 nearby soundings:

```
     IF ( |t_o - t_i| .LE.  Δt ) and (K flags OK)         5L,A,2C
          ΣK = ΣK + K_1                                      L,AD
          #K = #K + 1                                           L
     FI
```

Then the average is computed and the current K compared with it:

```
     K̄ = ΣK/#K                                              2L,MD
     IF ( (|K̄ - K_i| .LT. Δ K), use K_i else use K̄.      2L,AD,C
```

e. B/K

B/K is obtained by extrapolating the slope of the volume backscatter back to time zero. The instruction load should be the same as for K, including the averaging steps. The main difference is that the location of the neighboring values has already been performed in Step d.

f. Single Scattering Albedo, ω_o

Determination of the single scattering albedo ω_o should be a simple table lookup given the value of B/K.

g. Beam Attenuation Coefficient, A

Determination of the beam attenuation coefficient A should be a simple table lookup based on the values of ω_o and K.

h. Phase Function, ϕ

Determination of the phase function ϕ should be a simple table lookup based on the value of K.

Compute Apparent Depth (Step 14)

The apparent depth is simply the difference between preset locations on the bottom and surface peaks in time, converted to distance.

PDL:	INSTR.
$SEP = T_B - T_S$	2LD,AD
$T = SEP * CONV$	MD
$D = T * C'$	MD,L

Compute Laser Sounding Position (Step 15)

The geographic position of the laser sounding will be a function of the following parameters:

six degrees of freedom of aircraft (from PAMS)
scan azimuth angle
off-nadir angle
surface pulse return time

Given a vector in a coordinate system fixed with respect to the airplane, it would require at most a rotation and a translation to a fixed coordinate system (latitude, longitude, altitude). A general rotation of coordinates would probably involve about 12 trig functions.

Trig functions can be computed most efficiently with Taylor series expansions using tables for the coefficients. Consider the cosine function. If a simple efficient cosine can be formulated, the sine could be calculated by simply subtracting 90 degrees from the argument, the tangent from ratioing the sine to the cosine, etc. We will further restrict the argument range to zero to PI/2 radians. The Taylor expansion for the cosine is:

$$\cos x = 1 - x^2/2! + x^4/4! - x^6/6! + \ldots$$

The worst case (i.e., the most terms) for our range is for the largest x value, namely x = PI/2. The following table shows the value and subtotal for each term in the cosine expansion for x = PI/2.

Term	Value	Subtotal
1	+1.000000000	+1.000000000
2	-1.233700551	-.233700551
3	+0.253669508	+0.019968957
4	-0.020863481	-0.000894524
5	0.000919260	+0.000024736
6	-0.000025202	-0.000000466
7	+0.000000471	+0.000000005
8	-0.000000006	-0.000000001

Thus it is possible to attain seven-figure accuracy with only six terms.

The instruction load analysis assumes that there exists a table with factorials stored (2!, 4!, ... 10!).

```
                                                                    INSTR.
sin(x): x = 90° - x                                                   AD
cos(x): x = x * conv                                                L,MD
    if (x .GT. 2π )                                                    C
        DO UNTIL (x .LT. 2π )                                          C
            x = x - 2π                                                AD
        OD
    FI
    SIGN = +1                                                          L
    IF (x .LT. 3/2 π ) (i.e., fourth quadrant)                         C
        x = 2 π     - x                                               AD
    ELSE IF (x .GT. π ) (i.e., third quadrant)                         C
        x = x - π                                                     AD
        SIGN = -1                                                      L
    ELSE IF (x .GT.   π/2) (i.e., second quadrant)                     C
        x =  π - x                                                    AD
        SIGN = -1                                                      L
    FI
    x^2                                                               MD
    1                                                                 LD
    -x^2/2!                                                        MD,AD
    +(x^2)^2/4!                                                   2MD,AD
    -(x^2)^3/6!                                                   2MD,AD
        .                                                              .
        .                                                              .
    -(x^2)^5/10!                                                  2MD,AD
```

Thus an efficient trig function (sine, cosine) would involve three loads, seven double adds, 11 double multiplies and three compares. A general rotation of coordinates with 12 trig functions would then entail 36 loads, 84 double adds, 132 double multiplies and 36 compares.

An alternate approach for obtaining trigonometric functions may be to keep a table in memory. For example, it would require 6000 real words to store the sine and cosine of the angle range zero to 90 degrees to 1/100 degree accuracy. The trade-off per trig evaluation is 16 instructions with a 20-byte table using the series method, or 2 instructions with a 24,000 byte table in memory (disk would be far too slow for storing the table). The net difference for a coordinate rotation would then be 168 instructions, probably not a large enough load to justify the memory required for the table.

PAMS position data has to be read off the PAMS data base and interpolated to the synch time of each sounding. It is assumed that a linear interpolation will be employed for each value. Given two values for a position quantity P_1 and P_2 measured at times t_1 and t_2 and a sounding time t_s such that t_1 .LT. t_s .LT. t_2, the position of the sounding can be calculated:

$$P_s = (t_s - t_1)/(t_2 - t_1) * (P_2 - P_1). \qquad \text{6L,3AD,2MD,2C}$$

Seven positioning parameters (six degrees of freedom plus real time of day), would then have an instruction load of 42 loads, 21 double adds, 14 double mutiplies, and 14 compares.

Corrections to the time and position parameters would involve table lookups for the undercutting corrections, and an algebraic expression for the change of datum:

$P_i = P_i$ * CORRECTOR 6*(5L,MD)
$T = T*T_0 + T_1$ 4L,MD,AD

Finally, pitch and roll and all data quality indicators are to be compared against thresholds for erroneous values. If we assume ten such quantities, then we need 20 more loads and compares.

Compute and Apply Depth Correctors (Step 16)

Each depth is corrected for laser pulse propagation-induced errors using a seven-dimensional table (which has been previously generated as a data set on disk). The seven indices are the true off-nadir angle, AD, the single scattering albedo, ω_o, the phase function φ, the apparent depth (Step 14), the bottom pulse threshold fraction and the laser transmit pulse width. A second corrector is determined from the surface pulse threshold fraction and a binary descriptor of the surface pulse (interface or backscatter). The calculation of the true off-nadir angle is assumed to be of the complexity of a coordinate rotation. Each parameter must be converted to an index, checked for an out-of-limit value, and incorporated into the overall table address, viz.,

```
PDL for quantity X:                                          INSTR.
    INDEX = A * X + B                                        3LD,MD,AD
    IF (INDEX .GT.I1 .AND. INDEX .LT. I2)                    2L,2C
         ADDRESS = ADDRESS + N * (INDEX - 1)                 2L,2A,M
    ELSE
         SET FLAG FOR BAD
    FI
```

The net instruction load for each quantity is then four loads, two compares, two adds, a multiply, three double loads, a double add and a double multiply.

The overall logic for applying the depth correctors is then:

	INSTR.
Application of first corrector (table lookup):	
true off-nadir angle: rotate vector from airplane-fixed coordinate system to sea surface-fixed coordinate system	41L,A,M,38C 87AD,133MD
AD	4L,2C,2A,M,3LD,AD,MD
ω_o	4L,2C,2A,M,3LD,AD,MD
φ	4L,2C,2A,M,3LD,AD,MD
D	4L,2C,2A,M,3LD,AD,MD
threshold fraction (bottom pulse)	4L,2C,2A,M,3LD,AD,MD
transmit pulse width	4L,2C,2A,M,3LD,AD,MD
Corrector application:	
DEPTH = DEPTH*a_1 = a_2	2L,MD,AD

```
        Add to histogram of correctors                          3L,A,2C,MD
    Second Corrector:
        threshold fraction (surface pulse)          4L,2C,2A,M,3LD,AD,MD
        surface pulse type                          4L,2C,2A,M,3LD,AD,MD
        Corrector application
            DEPTH = DEPTH*b1 + b2                               2L,MD,AD
        Time base corrector application
            DEPTH = DEPTH*c1 + c2                               2L,MD,AD
```

Compute Slant Altitude (Step 17)

The slant altitude is the aircraft-to-surface distance measured along the laser firing angle. For each sounding, the slant altitude can be determined by looking at the surface pulse return time compared to the actual firing time of the laser. This time must be converted to distance. Tests on the slant altitude would include a pairwise difference comparison with a threshold determined from the aircraft-to-surface geometry and the standard deviation of several hundred preceding slant altitudes. The logic would look as follows:

```
PDL:                                                             INSTR.
        INDEX = surface peak location                                 L
        TIME2 = F(INDEX)                                              L
        TIME1 = altitude counter                                      L
            SAi = (TIME2-TIME1)*c/2                              AD,2MD
            (mean of SAi's)                                        A,AD
            (standard deviation of SAi's)                     2L,2AD,MD
            THRESHOLD = FUNCTION(ONA, φ ,pitch,roll,         6L,5AD,5MD
                ALTIT, σ (SA))
            IF (|SAi - SAi-1| .GT. THRESHOLD)                   2L,AD,C
                SET flag                                              L
        FI
```

Compute and Apply Wave Corrector (Step 18)

Each sounding depth must be corrected for local wave effects. There are two methods of calculating this correction. The first method involves determining a predicted slant altitude from the aircraft coordinates, the laser pulse geometry, and the known altitude (from PAMS). The second method involves doing a least-squares fit of about 100 slant altitudes (from Step 17) to an expected scanning configuration. This fit would yield predicted slant altitudes at each sounding. In both cases, the correction is the actual slant altitude from Step 17 minus the predicted slant altitude. The slant altitude test consists of a determination of a correlation coefficient between the depth differences and the altitude differences.

In method 1, the function that determines the predicted slant altitude is undefined, but is assumed to be of the complexity of a coordinate rotation. For estimating method 2, we assume that a new 100-data point least-squares fit is made every 20 points, and we make use of the least-squares fit analysis from Step 9.

	INSTR.
Method 1:	
$SA_{i,pred}$ = FUNCT(ONA,azi.,pitch,roll,alt.,x,y,z)	39L,87AD, 132MD,36C
Method 2:	
fourth order least-squares fit to 100 points	352A,31M,1700C 3500L,1100AD 1300MD
done every 20th sounding:	17A,2M 85C,175L,55AD 65MD
$DIFF_i = SA_i - SA_{i,pred}$	L,AD
$DEPTH_i = DEPTH_i + DIFF_i$	L,AD
Store $DEPTH_i$, $DIFF_i$	2L
Histogram $DIFF_i$'s	2L,AD,MD,2C
COR.COEF. = $(DEPTH_i - DEPTH_{i-1}) / (ALT_i - ALT_{i-1})$	5L,2AD,MD
test on COR.COEF.	2C

General Edit (Step 19)

a. Depth Deviation and Threshold Tests

For a standard deviation test, each sounding depth must be included in a computation of an average and a standard deviation at least once. The deviation of the depth from the aggregate mean is also performed. At present, the other threshold-type tests are not defined.

PDL:	INSTR.
MEAN = $D_1 + D_2 + \ldots$	L,A
DEV = SQRT $(((MEAN - D_1)^2 + (MEAN - D_2)^2 + \ldots)/N)$	2L,M,A
DIFF = $\lvert D_i - MEAN \rvert$	2L,A
IF (DIFF .GT. THRESH)	C
SET FLAG	
FI	

b. Slope Test

Each depth is required in two pair-wise slope calculations. These slopes are averaged, a deviation calculated, and the mean compared with the individual slopes.

PDL:	INSTR.
$SLOPE_i = (D_i - D_{i-1}) / (T_i - T_{i-1})$	4L,2A,M
MEAN = $(SLOPE_1 + SLOPE_2 + \ldots)/N$	L,A
DEV = SQRT $(((SLOPE_1 - MEAN)^2 + \ldots)/N)$	2L,M,A
DIFF = $\lvert SLOPE_i - MEAN \rvert$	2L,A
IF (DIFF .GT. THRESH)	C
SET FLAG	
FI	

c. Sequential Sounding Precision Test

The precision of a block of sequential pulses is compared to a standard; if the precision exceeds a limit whose value is yet to be established, the block is rejected. It is assumed that the precision quantity is obtained from the means and standard deviations calculated in part a. Since a block is a very large number of soundings (at least 1000), the per sounding instruction load of a block precision test should be negligible.

d. Signal-to-Noise Test

The signal-to-noise value of each sounding (computed in Step 13c) must be compared to a standard, and a flag set if it exceeds the standard.

```
PDL:                                                        INSTR.
     IF (RATIO .GT. STANDARD)                                 2L,C
          SET FLAG                                               L
     ELSE
          SET FLAG                                               L
     FI
     ENTER INTO HISTOGRAM                                       2L
```

e. Depth-Altitude Correlation Test

The pair-wise change in depth and altitude for all adjacent soundings is calculated, and the signs of the changes are compared. If the signs agree, the sounding is flagged.

```
PDL:                                                        INSTR.
     SIGN 1 = SIGN (D_i - D_i-1)                              3L,A
     SIGN 2 = SIGN (ALT_i - ALT_i-1)                          3L,A
     IF (SIGN 1 .eq. SIGN 2)                                     C
          SET FLAG 1                                             L
     ELSE
          SET FLAG 2                                             L
     FI
```

f. Pulse Density Test

The block density of pulses is the number of successful, unedited soundings divided by the number of attempted soundings. A running average of the block density of pulses is maintained; those time periods wherein the density drops below a preset limit would be flagged.

```
PDL:                                                        INSTR.
     IF (ACCEPT FLAG OK)                                       L,C
          TOTAL ACCEPTED = TOTAL ACCEPTED + 1                 2L,A
     FI
     TOTAL = TOTAL + 1                                        2L,A
```

g. Position Test

The position test is designed to eliminate soundings with erroneous positions. The spatial distance of each pulse from its temporal neighbor is to be calculated and compared to a set of limits. If the distance exceeds either limit, the sounding is flagged. We assume that the distances are kept squared for the calculations:

```
PDL:                                                          INSTR.
    D^2 = (x1 - x2)^2 + (y1 - y2)^2                      7L,3AD,2MD
    IF (D^2 .GT. L1 .OR. D^2 .LT. L2)                         2L,2C
         SET FLAG                                                 L
    FI
```

Read, Edit and Correct Tides Data (Step 20)

There are one to 15 tide stations for which exact positions are known. Every six minutes, each station records the time (including date) and tide.

A routine is required to input the tides data from each station (via a to be determined medium), review and correct the data, generate a table of tides for each station, and write the table to disk for future access.

```
DO FOR each station
     READ tides data
     DO UNTIL (indefinitely)
          PROMPT for option
          READ option
          IF (option = TABLE) display table of data
          IF (option = PLOT) generate tide vs. time plot
          IF (option = MOD) read time and new value
          IF (option = SMOOTH) smooth tides data
          IF (option = END) exit this loop
     OD
     WRITE tides record onto disk
OD
```

MASTER TIDES INDEX: for each station	1.	# stations
	2.	lat./long. of station 1
	3.	T1, T2 for station 1
	4.	# data points for station 1
	5.	data

Compute and Apply Tide Correctors (Step 21)

The tides data have been collected into gage tide records in Step 20. For each sounding, a determination of the appropriate tide gages to use for the tide corrector has to be made. Let us assume that there are ten such gages. We can calculate the squared distances from the sounding position to each of the gages using:

$$D^2 = (x_1 - x_2)^2 + (y_1 - y_2)^2 \qquad \text{7L,3AD,2MD}$$

Then by finding the shortest distances, we would choose the closest one to three tide gages for determining the tide value at the sounding position. For each gage chosen, the tide value has to be interpolated over the real time of day to obtain the tide value at the time of the sounding. Finally, if more than one gage is to be used, the tide values would be weighted, based on the sounding distance from the various gages. The instruction load would then include:

D^2 .LT. D^2_{min} 10C

$TIDE_s = (t_s - t_1)/(t_2 - t_1) * (TIDE_2 - TIDE_1)$ 3*(6L,3AD,2MD)

$TIDE_s = (\sum_{i=1}^{3} WT_i * TIDE_i)/\sum_i WT_i$ 6L,6AD,4MD

where we have assumed three gages involved in the calculation. Then the tide corrector will be added to the depth and stored along with the corrected depth value. Total per sounding instruction load: 95 loads, 45 double adds, 30 double multiplies, and ten compares.

FINAL PROCESSING - Hydrographic Sounding Selection

In computer time, the most costly step in the Final Processing phase of the data analysis is the hydrographic sounding selection. This is the last step that involves computations on the entire set of acceptable soundings. The second step in the Final Processing, examination of selected soundings, is an interactive step involving the display of all selected, selected and nonselected or nonselected soundings in a fashion similar to the display functions of the Intermediate Processing. The third step in Final Processing, product preparation, consists of writing an output tape of the selected soundings and generating a final report. The final report will require summaries of statistics which have been accumulated during previous processing steps. Both the tape and the report generations should require little computer load per original sounding because sounding selection has reduced the total number of soundings by approximately a factor of 100.

Although a detailed algorithm for the sounding selection has not yet been defined, the requirements offer a suggested approach. This approach involves picking a region for sounding selection, fitting a plane to the points in the region, determining the distances of all points in the region to that plane, picking those points that deviate by a preset threshold from the plane, fitting new planes based on the extreme points, measuring distances of all points to the new planes, etc. When eventually all the data in the region can "be represented" by the planes, a set of soundings are picked that lie on the boundaries of the planes. The suggested size for the region of analysis is 500 x 500 m^2. Such an area should contain about 10,000 soundings. A reduction in the sounding set by a factor of 100 would then yield about 100 final selected soundings from the region.

The following algorithm is assumed for our analysis. Three boundary points of the 500 x 500 m^2 region are picked and a plane is fitted to them. The plane is then evaluated at all sounding locations. That sounding which is most divergent and is divergent by more than a preset threshold is chosen as the boundary of a triplet of planes, each of which has two other points from the previous plane. The three planes are then fitted and the distance of all points to them is determined.

If, again there are points (depths) differing from the value of the plane at their locations, the most divergent is added to the set of boundary points and the plane within which it lies is trisected. This procedure would continue until there are enough planes defined to fit the data within acceptable limits. For example, consider a region where the trisection of planes has occurred fivefold. There would then be $3^5 = 243$ planes from which to select about 100 points to represent the region. In this example there would be a total of 364 planes fitted (one in Step 0, three in Step 1, nine in Step 2, etc.). Every point in the region, except for boundary points, will be evaluated at each planar trisection, i.e., five times. Clearly, smooth regions should require fewer trisection steps; highly structured regions may require more.

Now consider the details of the procedure. A plane is defined by three noncolinear points in space. We can parameterize a plane in a convenient form:

$$z = Ax + By + C$$

where x and y are the latitude and longitude, and z is the depth. If we pick three points from the boundary of the region (x_1,y_1,z_1), (x_2,y_2,z_2), and (x_3,y_3,z_3) we have three equations with three unknowns A, B and C:

$$\begin{aligned} z_1 &= Ax_1 + By_1 + C \\ z_2 &= Ax_2 + By_2 + C \\ z_3 &= Ax_3 + By_3 + C \end{aligned}$$

These can be solved to yield the following expressions for A, B and C:

$$A = \frac{(z_2-z_1)\ (y_3-y_1) - (z_3-z_1)\ (y_2-y_1)}{(x_2-x_1)\ (y_3-y_1) - (x_3-x_1)\ (y_2-y_1)}$$

$$B = \frac{(z_2-z_1)}{(y_2-y_1)} - A * \frac{(x_2-x_1)}{(y_2-y_1)}$$

$$C = z_1 - Ax_1 - By_1$$

We the analyze the following logic for instruction load:

LOGIC:	INSTR.
$Z_2 = z_2 - z_1$	3L, A
$Z_3 = z_3 - z_1$	3L, A
$Y_2 = y_2 - y_1$	3L, A
$Y_3 = y_3 - y_1$	3L, A
$X_2 = x_2 - x_1$	3L, A
$X_3 = x_3 - x_1$	3L, A
$A = \frac{Z_2Y_3 - Z_3Y_2}{X_2Y_3 - X_2Y_2}$	7L,5MD,2AD
$B = (Z_2 - AX_2)/Y_2$	5L,2MD,AD
$C = z_1 - Ax_1 - By_1$	6L,2MD,2AD

Thus to parameterize a plane given three points requires 36 loads, nine double multiplies, and 11 double adds. For five trisection steps the parameterization of 364 planes would take 13,104 loads, 3276 double adds and 4004 double multiplies. However, the region covers about 10,000 soundings, so that the per sounding load is about one load, and a fraction of an add and a multiply. This instruction load is clearly negligible.

Each point in the region must be evaluated at each of the five steps in the trisection procedure. A single evaluation appears as follows:

$$z = Ax + By + C \qquad \text{6L,2AD,2MD}$$

The instruction load for five steps is then 30 loads, ten double adds and ten double multiplies.

This analysis could be made considerably more costly by the substitution of a least-squares planar fit to the data. The advantage would be fewer plane fits, because each plane would better represent the data. The disadvantage would be a much more complex procedure of determining each plane. A compromise procedure might involve not simply using three points on the boundary of the region, but rather using the averages of points within three subregions along the boundary of the region. Locating and averaging 20 points, say, within a subregion might take 40 loads, 20 double adds, and one double multiply. At three subregions per plane, and 255 planes per region, the instruction load <u>per sounding</u> would only be increased by about three loads and 1.5 double adds.

<u>Summary</u>

Table 3.1 lists the instruction load for each processing step of a normal pulse that is part of a steady pulse stream. The symbol "B" stands for the number of bins in the waveform, which was assumed to be 200 for the calculation. Other assumptions have been pointed out in the corresponding text.

A summary of the instruction loading in the automated processing by steps is shown in Table 3.2.

STEP	NUMBER OF INSTRUCTIONS	% OF TOTAL
Read and Unpack	948	7
Edit	259	2
Calibration Processing	835	6
Pulse Location	6214	44
Zero Depth (1 out of 20 pulses)	178	1
Waveform-Based Parameters	4169	29
Apparent Depth	6	-
Position Determination	461	3
Correctors	432	3
Slant Altitude	33	-
Wave Corrections (#2)	421	3

General Edit	70	-
Tide Correction	180	1
Sounding Selection	50	-
	14,256	

Table 3.2 Summary of Instruction Load for Automated Processing

The "hot spots" in the processing steps are the pulse location (44 percent), computation of the waveform-based parameters (29 percent), and the initial reading and unpacking of the raw data (7 percent).

If a simple low pass filter were applied to the waveforms, the instruction load would be increased by 10 percent.

The effect of an environmental subtraction technique for peak locations is highly dependent on the fractions of total soundings that are deep water soundings. For the example calculated, namely 10 percent deep water soundings, environmental subtractions would increase the processing load by 16 percent.

3.2 Timing Considerations - Interactive Processing, Data I/O and Graphics

3.2.1 Introduction

There are two aspects to the analysis of processing timing with the interactive phases of the laser data analysis: hardware and human. The hardware aspects involve the amount of computer time to fetch the data for a given display, to format the data (e.g., choosing a color or grey level for a particular depth representation), and to transfer the image to the display device. The hardware timing contributions to interactive processing depend on many factors: the design of the internal laser data base, the display techniques to be used, the choice of hardware for both the host computer and the display device, the total number of displays to be generated for a given run, the techniques for interactively editing or modifying the data, and the frequency of errors that require interactive correction.

3.2.2 Preliminary Processing

Table 3.3 lists the various actions that a user would have to perform in the preliminary processing phase of the data analysis. Items 1, 3, 5, 6, and 7 are not time-consuming operations and can be ignored for our timing analysis. Items 2, 4, and 8 involve review and modification of parameters or data and therefore should be considered. It should take a few minutes for the approximately 20 mission parameters to be entered, verified, and possibly corrected. The preliminary processing parameter data set could contain up to 100 run parameters in addition to a number of standard waveforms. These parameters will likely exist as a default set, with the user being able to review the entire set and modify certain values. Such actions should again take a few minutes.

1. User brings up system, loads programs, initializes tables.

2. User initializes flight tape
   - o user types in mission parameters using interactive program on CRT, reviews parameters typed in, makes corrections if necessary, then prompts system to write parameters to flight tape (and line printer).

3. User mounts flight tape and loads preliminary processing system.

4. User reviews default set of preliminary processing parameters* on CRT, modifies them as necessary, reviews final set.

5. User initiates preflight CAL processing (data read in, processed, results printed on line printer).

6. User initiates automated part of preliminary processing system.

7. User mounts PAMS tape.

8. User manually inputs tides data via interactive program, reviews the interpolated results.

*including run parameters (e.g., interrupt options, intermediate backup and examine options, deletion options)

Table 3.3 Human Interaction in Preliminary Processing

The editing and correction of the tides data (item 8) may require an appreciable amount of time. Each of up to 15 stations will have a set of tides measurements. At one measurement every six minutes, there will be at least 40 such measurements per station in a mission. The operator must manually input the location of the station and review a time plot of the tides data. Modification of the tide records are likely in order to have a smoothly-varying set of measurements. These operations could take up to minute per station.

3.2.3 Intermediate and Final Processing

The human aspects of the interactive timing analysis in the Intermediate and Final Processing involve somewhat more subjective factors: the recognition of the "correctness" of a display, the ability to identify causes of errors in a timely fashion, and the ability to make edits or modifications to data values. All of these factors of the human engineering aspects of the interactive processing are highly dependent on an effective and viable technique of displaying and permitting modifications to the data.

Consider the human aspects of the interactive processing first. No specific implementation of a display system shall be addressed, but rather only the estimated human response times based on some general assumptions shall be considered. For this analysis various assumptions are made about the amount of data in a display and the number of errors in the data that can be recognized and corrected.

Assume first a display that covers a 220 m x 220 m area, i.e., the area necessary to display one entire scan. With an aircraft velocity of 75 m/sec, such a display would include about three seconds worth of sounding data. At 600 soundings per second, the display would contain 1800 soundings. Such a display might be used in the intraswath evaluation phase of the laser data analysis, wherein a screen with about 2000 data points may be a reasonable image to evaluate. Note that we make no assumptions about the display technique (vector, color, grey-scale) or technique of identifying overlapped soundings.

There will be 4800 such 220 m x 220 m displays in a nominal four-hour survey. Let us then assume that it will take the hydrographer an average of five seconds to determine whether a given display contains any correctable errors. If there are no errors in the data for an entire mission then the time to evaluate all 4800 displays would be 6.7 hours.

Now, consider the time required for an error correction procedure. The hydrographer looks at a display and determines that some anomalous condition is present. He pinpoints the region of concern by zooming in to a smaller region. He identifies the bad pixel(s) with a cursor or lightpen, and fetches the ancillary data associated with the bad sounding(s). From a menu he chooses a technique of displaying the ancillary data such as a table, a plot versus time, a plot versus position, or a plot of one parameter versus another parameter. He evaluates this information and perhaps utilizes more tools from the menu. He determines whether the soundings are to be kept, corrected, or flagged out (deleted). If he chooses to edit certain soundings, the data must be fetched, modified, and written back into the data base.

Suppose that the hydrographer has become very adept at applying the diagnostic and correction tools. Some errors are easy to fix; others may be more complex to analyze. Assume then that on the average it takes one minute for the hydrographer to resolve the errors in one anomalous display covering a 220 m x 220 m area, i.e., one minute for him to look, decide, and correct the error. If one display out of ten contains anomalies to be corrected, the total intraswath evaluation and correction processing time for a mission would be 14 hours. If only one display out of every 25 contains anomalies (i.e., one error every 50,000 soundings), the total intraswath evaluation and correction processing time would be 9.6 hours.

Interswath evaluation is concerned with the quality of sounding overlap between adjacent swaths. For this phase in the laser data analysis let us assume a display that effectively covers a 440 m x 440 m area of the water surface. The display would show a 440 m long overlap region between two adjacent swaths. Using the above data and assuming a 10 percent overlap between swaths, there would be about 360 potentially overlapping soundings displayed. There would be 2400 such displays for a nominal four-hour mission. Assume again five seconds for an errorless display examination and 60 seconds for an anomalous display correction. With no errors, interswath evaluation would take 3.3 hours. With one error every ten or 25 displays, the interswath evaluation would require 7.0 and 4.8 hours, respectively.

There are several other steps in the intermediate and final processing phases of the laser data analysis that involve human evaluation of displays. Those steps that are required for every mission include the crossline swath comparison, the "all data" examination, and the selected sounding examination. Those steps which are optional for each mission include comparison with shoreline data, comparison with historical data, and comparison with contemporary data. For all of these steps a display should include data from several swaths. Consider two cases: a 1 km x 1 km region, and a region based on the pixel representing the resolution limit of 4.5 m.

A display screen representing 1 km^2 covers about five full swaths, including overlap. At an aircraft velocity of 75 m/sec, the entire screen would contain about 67 seconds worth of data, or 40,000 soundings. There would be at least 215 such displays in a mission, depending on the compactness of the swath pattern.

A display screen with each pixel of size 4.5 m will cover much more area. If the screen has a 512 x 512 pixel area, the area displayed will be 2.3 km x 2.3 km. This is an area 11.5 swaths wide containing 5.9 minutes worth of data, or 210,000 soundings. At least 40 such displays would be required for a mission.

The crossline swath evaluation is a comparison of the depths obtained from a single swath that was flown perpendicular to the mission swath pattern. If we assume the 1 km x 1 km scale display for evaluation, we can estimate roughly 20 displays to be analyzed. Possible techniques would include a blink comparison, the mission pattern masked out by the crossline swath, and correlation statistics. The hydrographer would be able to choose his methods of evaluation, and flag certain regions to be rejected and/or reflown. Assuming no major error corrections, such a display might require up to one minute for analysis.

The data comparison steps involve determining the correlation of the mission run data with digitized data sets of historical, contemporary, or shoreline data. Historical data (e.g., previously measured sonar chart data) may cover the entire mission region, but it is unlikely that the contemporary data (e.g., sonar spot measurements, lead line measurements) or shoreline data would involve comparison with all of the mission data. The tools and techniques available to the hydrographer would be the same as for the crossline comparison above.

The "all data" examination step is intended to be a look at the survey data at a scale suitable to see data gaps, anomalous features, and inadequately depicted navigation hazards. The shoreline data comparison will probably be incorporated into this step. The 2.3 km x 2.3 km scale could be used as the basic display. Each display may require about one minute for analysis.

The selected sounding comparison is a manual examination of the results of the automated sounding selection. The one in 100 selected soundings are compared with the total survey data, and any inadequately depicted important features are emphasized by deletion and addition of soundings to the selected set. Also in this step the hydrographer will annotate certain features that would be highlighted in a chart product. A 1 km x 1 km display contains 40,000 survey soundings and therefore about 400 selected soundings. Although this scale may be good for overall examination, a finer scale may be required for detailed deletion and addition of soundings to the selected set. A 440 m x 440 m scale with 3600 survey soundings and about 40 selected soundings would be a more manageable display for modification and annotations.

There are 8.6 million survey soundings in a four-hour mission, so that the selected set of soundings will contain about 100,000 entries. If one of every 50 selected soundings gets modified, there will be some 2000 changes to the final data base. It would perhaps take about one minute to effect each such change.

Table 3.4 summarizes the timing factors for the interactive steps in the laser data analysis. For the assumptions previously stated (four-hour mission, 600 pulses per second, etc.) the total amount of time required for human interaction for a mission would range from 48 to 59 hours, well above the eight-hour design limit.

STEP	SCREEN SIZE (m^2)	NUMBER OF DISPLAYS	TIME (hr.)
Preliminary Processing	-	-	0.5
Intraswath Comparison	220x220	4800	7 to 14
Interswath Comparison	440x440	2400	4 to 7
Crossline Comparison	1000x1000	20 ?	0.3
Historical Comparison	1000x1000	215	2 to 3
Contemporary Comparison	1000x1000	5 ?	0.1
All Data Examination } Shoreline Comparison }	2300x2300	50	1
Selected Set Examination	1000x1000	215	2
Selected Set Modification	440x440	1000 ?	30
		8705	48 to 59

Table 3.4 Timing Factors for Interactive Steps

3.2.4 Hardware

The other contribution to the timing analysis of the interactive phases of the laser data processing is the hardware time. Here we will consider such factors as setting up displays from the data bases and making modifications to the data bases. We will also consider the general I/O operations for the entire system. First let us look at the data transfer operations.

In order to handle the required amounts of data, the HS/DP Subsystem will have to perform large numbers of I/O data transfer operations. In a nominal four-hour run the ALH system can generate up to 19 billion bits of raw data. This data must be maintained on some kind of data storage media such as disk or tape. The amount of time required to transfer such a quantity of data to and from storage to the various processing and display elements is an important factor in timing analysis.

Assume the following hardware and procedural implementation of the ALH HS/DP Subsystem for our analysis. Assume a high density tape unit that stores the raw laser data read in real time. The processing unit has attached to it two disk drives which will hold intermediate queue data for two adjacent swaths, as well as the purged data set and all programs and tables. The sounding data are processed and maintained as a queue on disk. One laser sounding generates one 375-byte entry in the queue. In a four-hour mission with 8.6 million soundings, there will be a total queue load of 3.2 billion. We assume that the post-purge data will be sufficiently reduced in quantity (less than 10 percent of the pre-purge sounding entries) so that we may ignore subsequent I/O operations in the processing. The processing entails the following four steps:

1. Read raw data from tape.
   Unpack, merge, edit, accumulate running averages, etc.
   Write queue entries to disk.

2. Read queue entries from disk.
   Perform all other preliminary processing functions.
   Write processed queue to disk.

3. Read processed queue from disk.
   Generate displays for intraswath comparison.
   Write queue to disk.

4. Read queue from disk for two adjacent swaths.
   Generate displays for interswath evaluation and purge.
   Write one queue and one purged swath to disk.

For these steps there will be one tape read of all the raw data, seven disk I/O's for all queue data, and one purged data write to disk (to be ignored in this study). The high density tape unit can transfer data at a rate on the same order as the data was read in. For the disk I/O operations, the queue data is being transferred to and from a fixed-sized region of core. Arguments to be presented subsequently will show that this region will be greater than 300 KB of memory and that data will be transferred two scans (or about 100 KB) at a time. Consider for example the IBM 2314 disk with a transfer rate of 312 KB per second. It would take the 2314 a total of 350 msec to transfer the two scans of data (about 30 msec to seek the data on the disk and 320 msec to move the data). For the 72,000 scans in a four-hour mission, this will result in 3.5 hours to completely transfer the queue a single time. With the above hypothetical "four-pass" system, it will take about 24.5 hours to perform all disk I/O operations. The IBM 3330 disk has a transfer time of 806KB per second. Similar analysis for the 3330 would result in a total disk I/O time of 10.5 hours. Clearly this result depends directly on the transfer and latency times of the disk unit chosen.

Consider the general problem of generating a display. We have already examined the problem of reading the data queue from the disk into memory. We shall now consider the generation of the image in memory and the transfer of that image to the display device.

For the purposes of displaying sounding data, each sounding entry contains three relevant values x, y, and z corresponding to the latitude, longitude, and depth of the measurement. This triad must be converted to appropriate display values x', y', and z' corresponding to the pixel addresses on the screen and the color or grey-scale to be used in representing the measurement. The transformation of x and y should be possible through a simple linear translation and a rotation about some axis, viz.,

translate $$X = A * x + B$$
$$Y = C * y + D$$

rotate $$X = x * \cos(\phi) + y * \sin(\phi)$$
$$Y = - x * \sin(\phi) + y * \cos(\phi)$$

where ϕ is the angle of rotation about the axis. The complete transformation of x and y to x' and y' is then

$$x' = a_0 + a_1 * x + a_2 * y, \qquad \text{x1.le.x'.le.x2}$$
$$y' = b_0 + b_1 * x + b_2 * y, \qquad \text{y1.le.y'.le.y2}$$

where comparisons are made to insure that the point lies within the pixel address limits of the display screen x1 to x2 and y1 to y2. To convert the depth z to color z' should require only a linear transformation

$$z' = c_0 + c_1 * z, \qquad \text{z1.le.z'.le.z2}$$

where again a limit check is made on the result. The instruction load to convert one sounding to a display pixel would then be 11 loads, five double multiplies, five double adds, three convert to integers, six compares, and one store, for a net of 31 instructions per sounding.

The complete processing of a mission requires five visual examinations of all the data (intraswath comparison, interswath comparison, historical comparison, all data and shoreline examination, and selected set examination) as well a several visual examinations of part of the data set (crossline comparison, contemporary comparison, and selected set modification). If we assume that each sounding is to be displayed seven times during the analysis of a mission, and that each of the 8.6 million soundings in a four-hour mission require 31 instructions to be transformed for display, then the net load would be 1.9 billion instructions per mission (or about 30 minutes on a machine with an instruction time of one microsecond, e.g., a VAX). The largest scale display analyzed above (2.3 km x 2.3 km) contains some 210,000 soundings. Such a display would require 6.5 million instructions to create (or 6.5 seconds on a one microsecond machine). All other display sizes considered with fewer soundings would of course require correspondingly less computer time to generate.

The speed of transmission of the image data from the central processor memory to the display device memory depends on the kind of interface connecting the two devices. A serial interface such as the RS-232 standard can handle data rates of up to 19.2 KBaud, or 19,200 bits per second. A 512 x 512 byte^2 image would require 109 seconds to transmit at 19.2 KBaud. At this rate the 8705 displays listed in Table 3.3 would require 264 hours to transmit to the display device, a prohibitively large amount of time. Far preferable would be a parallel interface, such as direct memory access (DMA). Typical DMA transfer times of 500 KB/sec would enable a

512 x 512 byte^2 image to be transferred in .52 seconds, a length of time short compared to the several seconds or minutes that the hydrographer needs to evaluate the display. With DMA, the entire set of 8705 displays can be transferred in 76 minutes.

3.3 Airborne Oceanographic Lidar (AOL) Data Processing System

A laser data processing system that has already been developed was considered to provide a second timing estimate. The Airborne Oceanographic LIDAR System is a scanning pulsed laser bathymeter developed for NASA Wallops Flight Center in 1977. Its primary use was as a research tool to determine the operational feasibility of a laser bathymeter.

Data from the laser system consisted of a digitized return waveform encompassing both surface and bottom return pulses, time, scan angle information, and housekeeping and status information. Aircraft attitude and position data were measured by an LTN-51 Inertial Navigation System and merged with the laser data by the onboard processor. Absolute positioning data was provided by radars at Wallops Flight Center, Wallops Island, Virginia. The laser had a maximum firing rate of 400 Hz.

An AOL postflight data processing, reduction, and analysis program was developed by Wolf Research and Development Group (ref. 9). This program performed the following functions:

1. decode, deblock, and edit raw data
2. collate ancillary data (preflight parameters)
3. process and apply calibration data (deep-water technique)
4. calculate depth
5. correct for tides and biases
6. generate selected outputs
7. perform statistical analyses

Inputs to the program were an AOL data tape and a set of keyword control cards that contain information related to the run sequencing, edit criteria, calibration parameters, bias correctors, and tide correctors. The AOL data tape contained mission files which consisted of a header record, laser data records, scan encoder records, and navigational data records. Outputs from the program were a line printer listing containing results of the laser data reduction and statistical analyses, as well as three optional tapes: a processed bathymetry tape, an inertial navigation system tape, and a science support statistics tape. The code consisted of approximately 4400 lines of reasonably well-structured Fortran.

Listings of the AOL program which had been run on an IBM 360/65 were obtained. The load module occupied 238K bytes of memory If it is assumed that the logic occupies about 150KB of the memory and that one machine instruction requires about three bytes, then the program appears to contain on the order of 50,000 machine instructions.

Several runs were examined wherein data was processed with the following options: no waveform smoothing, no tide or wave correction, calibration file read in from a tape, process one out of every ten records, no interpolation of navigational data, and no output tapes generated. The program was able to process from 1700 to 2000 laser pulses in about 20 minutes CPU time.

The AOL processing system is similar in nature to a simplified version of what we seek for ALH. If the performance data of the AOL processing system is applied to the ALH laser data rates, it would require about 1400 hours of computer time to process a four-hour ALH run on the IBM 360/65 using the AOL program. Unfortunately, it is not possible to obtain a copy of the AOL processor in order to study more closely its timing requirements. The AOL processor was not designed to be a fast production program for analyzing laser data, but rather a well-structured, easily-modifiable test program. The AOL processor generated a great deal of intermediate output for diagnostics, but the statistical techniques employed were not overly complicated.

The timing estimates obtained from the AOL processor indicate the order of magnitude of the processing time required to analyze laser data. Such estimates may be more realistic than the study performed in Sections 3.1 and 3.2, because the AOL procesor was an actual running system written in Fortran that analyzed laser data.

3.4 Summary

Probably the most important factor in this analysis is time. Section 3.1 analyzes the number of instructions required to process a single sounding. Section 3.2 deals with interactive timing considerations, from the point of view of the user, the software, and the data. The following table summarizes the estimated times required to perform key functions in the processing of the laser data. We have assumed a four-hour mission with a laser pulse rate of 600 pulses/sec.

Function	Time (hours)
play back recorded data	4
data disk I/O transfers	10 to 24
automated processing (1 microsec. instruction, e.g., a VAX 11/750)	34
(100 nsec instruction, e.g., an IBM 3081)	3.4
interactive processing	48 to 59
graphics processing	2
TOTAL	67 to 123

The requirements specify that the four-hour mission is to be fully analyzed in a time period not to exceed twice the time to acquire the data, or eight hours. Our examination of the timing requirements indicate that the laser data analysis would take about ten times that amount of time. Moreover, it is clear that no single function of the analysis or requirement is responsible for not meeting the analysis time budget. The CPU processing time and the I/O transfer times for "affordable" hardware each will exceed the total time budget, and the interactive processing time itself exceeds the sum of the other two.

There are many similarities between the AOL data processing system and the ALH developmental system. The system for ALH will be a well-structured, easily-modifiable data analysis program that would generate diagnostic information and statistical calculations. The IBM 360/65 used with the AOL processor is comparable in computer speed to the kinds of minicomputers that might be purchased for the ALH project. The problem then is to find a way to reduce the computer time by two orders of magnitude for an operational system. No amount of reasonable code optimization or hardware enhancement will produce such a reduction in computer time.

We can put bounds on the anticipated ALH processing time from examples using the AOL processing program. The extrapolated value of 1400 hours for a mission is probably high, but without the code to work with it is not clear how high. The results of the analysis in Sections 3.1 and 3.2 for the HS/DP Subsystem for a mission is about 100 hours. This value is probably low because the automated processing estimates assume assembly code with no overhead.

4.0 HIGH LEVEL DESIGN

This section presents a design for the HS/DP Subsystem. Section 4.1 contains a description of the software structure and interfaces. The concept of processing the laser sounding data in a circular data queue is discussed. The modules that make up the software are identified with their interfaces (See Appendix C - HS/DP Data Flow Diagrams), and sizing estimates of the modules are presented in order to realize more fully the scope of the effort. The requirements for interactive capabilities are identified, and a design for an interactive system is presented, including software modules, data sets, and examples of a command language with which the user may issue requests. Section 4.2 identifies key data bases and files, their contents and size, so that estimates can be made on the amount of primary and secondary storage. Finally, Section 4.3 presents a possible hardware implementation of the HS/DP Subsystem, with specifications of equipment capabilities and characteristics.

4.1 Baseline Design

The software design developed in this section is based upon the detailed requirements of Section 2.0. It is assumed that Section 2.0 contains all steps necessary and sufficient to process laser sounding data. For this design no consideration is given to the findings of Section 3 concerning timing constraints and feasibility, but rather it is assumed that a processor fast enough to do the job can be found and that all of the interactive activities outlined in the requirements can be performed in a reasonable way.

Discussion regarding timing constraints, soft requirements, etc., will be found in Section 6.

4.1.1 Introduction

For this design it is assumed that heavy use is made of fast secondary storage (i.e., disk). The ALH Subsystem generates a great deal of data which must be processed in a short time. While tape is the natural medium for input data sets and output data products which must be transported between the survey site and Rockville, a faster mode of storage is called for in maintaining the intermediate data sets of the processing.

The amount of laser data to be processed from a mission (more than three billion bytes) makes it unreasonable to expect that all of the data can be stored on disk at the same time. This would require ten 300-MB disks, a formidable array of devices, even if they were not located in the MGF. Because of this, a certain data reduction procedure has been assumed. Starting from one end of the flight pattern, laser data from two adjacent swaths are analyzed and compared. When the processing of the outermost swath is completed, the data from that swath is "purged", i.e., only the key data for each sounding necessary for final product generation is kept. Data from the next adjacent swath is analyzed, compared with the previous swath, and that previous swath is then purged, and so on. With this procedure, only two adjacent swaths of data need to be maintained at any time in complete form (i.e., with waveforms, housekeeping values, intermediate results, etc.).

The processing requirements imply a design philosophy that has a major bearing on the amount of data that must be maintained during processing. The philosophy is that in order for effective interactive quality control of the soundings to take place, the user must have available to him all of the information that went into the determination of their depths and positions. Each value must be traceable back to the raw data. Anomalies observed in a group of soundings should be analyzable with respect to the performance of the data-taking equipment.

4.1.2 Design Concepts - The Queue

The basis for processing the data is a data structure called a queue. The queue contains all sounding records in sequential order for a single survey swath. Each sounding record contains all laser sounding data plus any associated data used in the processing that is to be saved and made accessible for quality control functions. The sounding record will at least include the Level 1 and Level 2 sounding record data referred to in the Requirements (Sec.2.5)

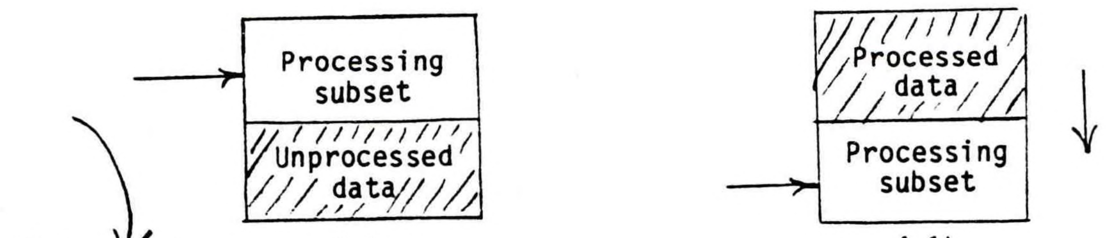
The queue is initialized by allocating an active queue area in memory. This queue area is then "formatted" by propagating a sounding record skeleton through the area. The skeleton provides space for all the data that will be part of the sounding record. The skeleton will also initialize each of these values. For example, all multiplicative correctors would be set to unity, all "test performed" flags set to "NO", all engineering values that are normally not zero set to zero, etc.

Survey data is then read into the sounding records. The data from the laser subsystem is unpacked and put into the queue, with each sounding record containing data corresponding to a single laser pulse. The position and attitude data from the PAMS is interpolated in synch time and merged into the queue, with position and attitude values for each sounding record. The tides data from the tide tables (already constructed on disk) is interpolated in synch time and position and merged into the queue, with a tide corrector for each sounding record.

All preliminary processing functions are performed with the sounding records in the active queue area. Intermediate processing data values that are required for later processing or quality control evaluation are entered into their respective slots in the sounding records. An area of the sounding record is reserved for binary flags which are used to indicate the completion of certain functions, the results of certain edit tests, etc.

Most preliminary processing functions are singular; i.e., the inputs and outputs for the function involve sounding data from a single sounding record. Some functions (e.g., the calculation of K) involve sounding data from many sounding records, both prior to and following the sounding being processed. The active queue area in memory should be large enough to include all data that has to be read backward and forward for such functions being performed on an interior subset of the sounding records of a queue. This approach avoids costly disk I/O that would be required for such backward and forward reading.

A processing pass involves a complete pass of all sounding records in a swath through the memory queue area. In core, the sounding records are arranged in the form of a circular queue. We define a processing subset as that part of the queue that includes the current sounding record being processed plus all previous and subsequent sounding records containing data required for the processing of the current sounding. The processing subset "moves" in time as the run proceeds. Figures 4.1a and 4.1b show the active queue area at two different times. In Figure 4.1a the processing subset is beginning to move through the queue as each of the "current" sounding records is sequentially processed. Eventually the queue area will look like 4.1b, where there exists no more unprocessed data to be included in the processing subset. At this point, the region of processed data is written out into the queue on disk, and an equal amount of unprocessed data (subsequent in time to the processing subset) is read in and replaces the data written out. Processing then continues until the processing subset encloses this new data. Thus the queue on disk is "peeled off" into memory sequentially and the pass is complete when all queue data has been so handled.



4.1a 4.1b

All preliminary processing functions will be performed on data in the queue except for the following ancillary functions:

- o Flight Tape Initialization and Printing (Steps 1, 2)
- o Accept Preliminary Processing Parameters (Step 4)
- o Process Preflight Calibration Data (Step 5)
- o Read, Edit, and Correct Tides Data (Step 20)

These ancillary functions will be done prior to queue processing. The output of these ancillary functions are tables on disk which can be accessed during the queue processing.

All queue processing will take place in several passes through the queue. It is important to minimize the number of such passes through the data because each pass requires disk I/O time. The preliminary processing functions currently defined will probably take either two or three passes to complete. During intermediate processing the queue is then read in from disk for display and analysis.

Advantages of the queue approach are the visibility of the data at all points of the analysis, the facility of quality control and testing, and the aim of making the system as "crash-proof" as possible. After each pass is completed, the queue is accessible on disk for any kind of manual examination, manipulation, or modification. For example, utility routines could be developed to print, plot, or display any of the data generated or modified by a particular pass. Appropriate flags are set to indicate those functions that have and have not been performed. Intermediate stored results would indicate the correctness of the processing in mid-stream. Tape dumps of troublesome regions of the queue could be made for subsequent analysis. Finally, system crashes will not necessitate any extensive reprocessing, as long as the integrity of the disk remains intact. After a crash, the state of the flags in the queue sounding records will indicate the exact point where processing was cut off. Resumption of processing would only entail the loading of appropriate programs and data tables and "peeling off" the current location of the queue.

Details of the Active Queue Area in Core

The active queue area in core has both a physical structure and a logical structure. Physically, the queue area is a large contiguous region in memory which contains an integral number of sounding records. Logically the queue area is a circular list. We define the following addresses in memory:

PTOQ - physical top of queue (fixed for run)
PBOQ - physical bottom of queue (fixed for run)
CSR - current sounding record
TOPS - top of processing subset
BOPS - bottom of processing subset
TOQ - top of queue
BOQ - bottom of queue

Figure 4.2 shows a sequence of "snapshots" of the active queue area in core during a typical processing sequence. Figure 4.2a shows the queue area at the start of processing, where the entire area has been loaded with unprocessed data. Processing continues until the BOPS reaches the BOQ (Figure 4.2b). The processed data between TOQ and TOPS is written out onto disk, an equal amount of unprocessed data is read from disk into the queue area, and the TOQ and BOQ pointers are reset appropriately (Figure 4.2c). Processing continues, etc. In this example the last block of unprocessed data read in from disk fills only part of the space between BOPS and TOPS (Figure 4.2h, 4.2i) so that BOQ is set only to the end of the data.

4.1.3 The Interactive System

The need for interactive capabilities in the ALH HS/DP Subsystem comes from each of the three phases of the operational data analysis (Preliminary, Intermediate, and Final) as well as from the developers tools. Indeed, such capabilities should be implemented early in the development of the Subsystem to facilitate development and testing of the automated software functions.

From the requirements for the laser data processing as well as for the developer's tools, one can identify a basic set of capabilities that the ALH interactive system should have. First a parameter that can be displayed or modified defined. Then the conditions under which sounding records are chosen must be defined, and the actions that may be made on or to the data specified, such as plotting, printing or data modification. The following list summarizes these capabilities:

1. Define a parameter.

   o any of the principal or secondary parameters of a sounding record

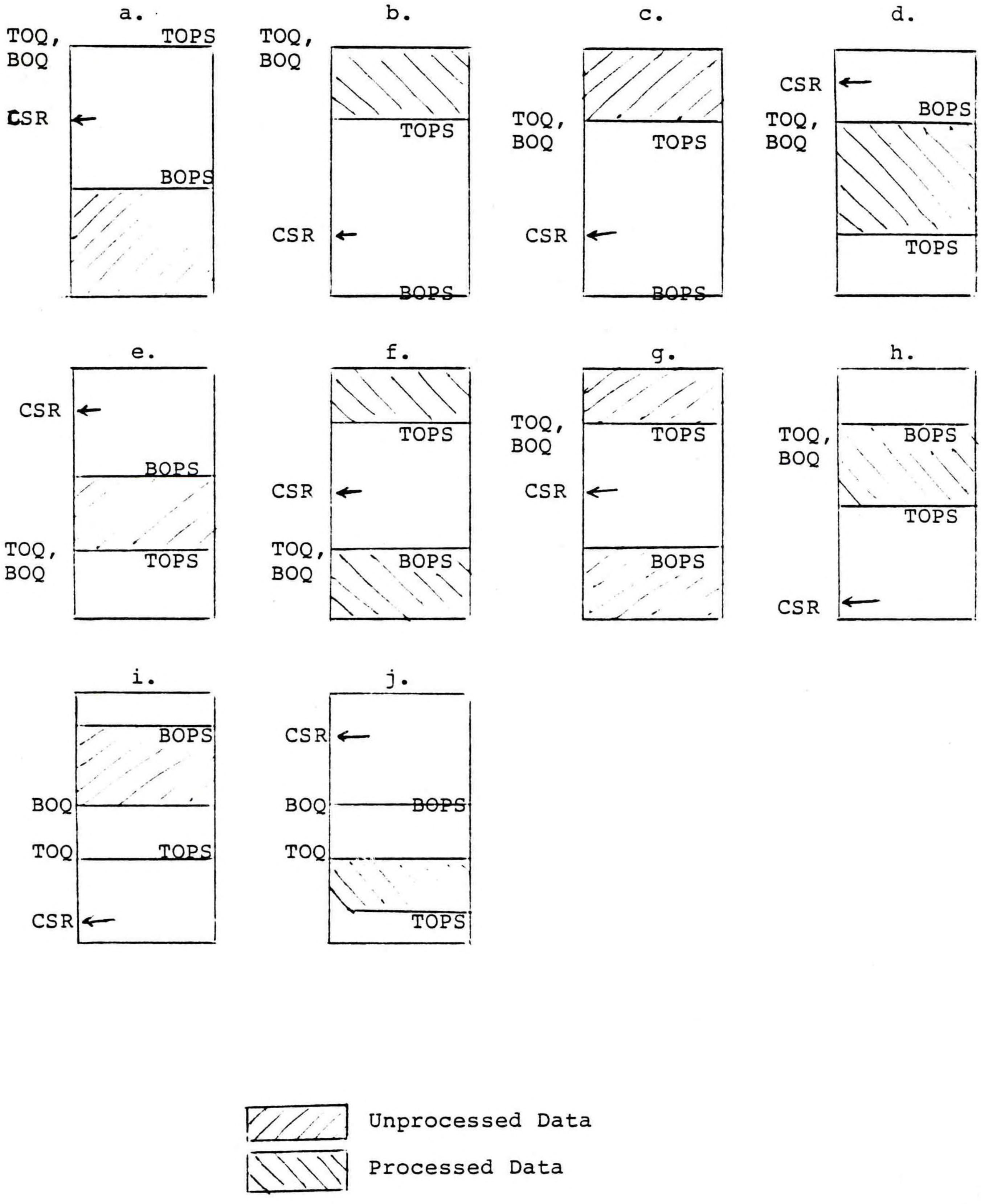


Figure 4.2 Data Flow in the Active Queue Area

- o any of the parameters of the purged data stream
- o any parameters from auxiliary data sets (e.g., historical, contemporary or shoreline data sets, tides tables, planned flight line tables, aircraft quick-look data sets)
- o new parameters that are a function of parameters from two related sounding records (e.g. slope of bottom, running Δ D and Δ P)

2. Define condition or region for choosing soundings.

   A condition may comprise any number of the following:

   - o parameter has certain value
   - o flag is set a certain way
   - o parameter exceeds a threshold
   - o soundings are geographically related:
     - o by specifying latitude and longitude limits
     - o by specifying a line, i.e., point A to point B
     - o by a region defined by the lightpen or cursor
   - o soundings are time-related (e.g., scan arc; time t_1 to time t_2)
   - o choose by swath identifications

3. Generate a three-dimensional plot of a defined region (e.g., a grey scale or pseudo-color plot or some parameter versus position).

   - o distinguish individual soundings (in particular, coincident soundings within a swath or from different swaths)
   - o highlight soundings under condition
   - o overlay related data set in same geographical region (e.g., shoreline data, flight line data)
   - o display numbers in actual locations
   - o contours
   - o display and hardcopy

4. Generate two-dimensional plot of a parameter versus another parameter under conditions.

   - o scatter plots (parameter A versus parameter B)
   - o histograms (frequency versus value of a parameter)
   - o profile plots (parameters versus time or position)
   - o displayed plots should be autoscaled and labeled
   - o display and hardcopy

5. Examine a sounding record.

   - o display or print actual numbers
   - o choose by lightpen or condition

6. Save sounding records on tape under condition.

7. Modify sounding records.

   - o set flags on or off. The following flags have been identified for this action:

     a. refly
     b. system developer
     c. anomalous depth
     d. deeper of pair of coincident soundings
     e. hazard
     f. kelp or other environmentally caused anomaly
     g. accept by overriding (e.g., to densify)
     h. reject as region of bad soundings
     i. system error
     j. reject for unknown cause
     k. accept

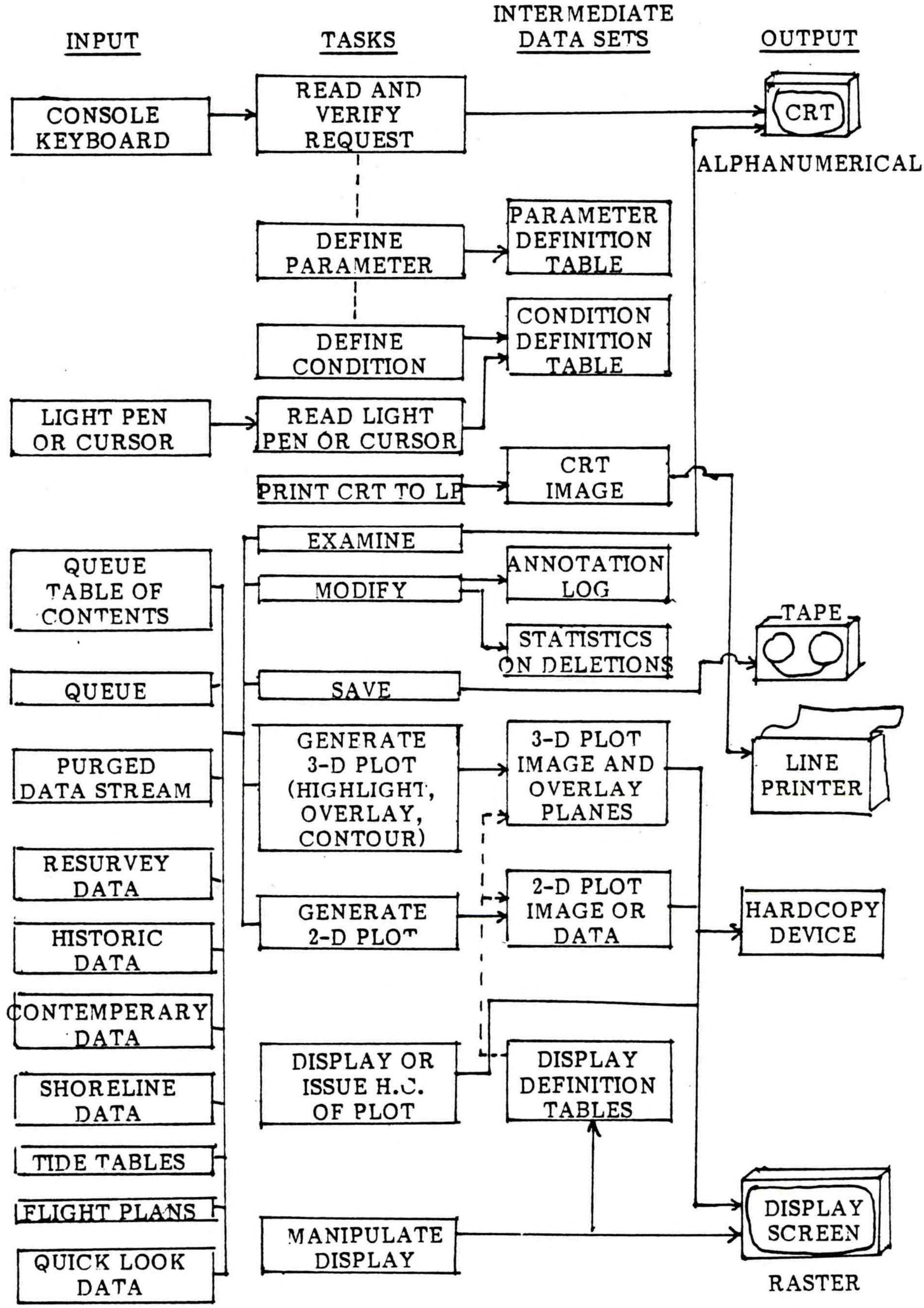
   - o annotate soundings (e.g., a log of user comments identified by time or position)

   - o maintain statistics on modifications to sounding records (e.g., delete flags)

Figure 4.3 shows schematically the structure of an interactive system incorporating the above requirements. There are four columns in the figure. The first column represents devices or data sets that are input to the system. The second column consists of tasks (or software) that perform the processing of the data and control of the system. The third column contains intermediate data sets that are generated and used by the system. It is expected that nearly all of these data sets will be resident in core (except perhaps the annotations log). Most of these data sets are transient (except for the annotations log and the statistics on deletions). The fourth column contains output devices that will display or save intermediate processing data products.

In order to generate requests to the interactive system, a control language will be employed. A request shall comprise an action verb followed by modifiers. A verification task will parse and verify each request as it is received from the sytem console. Upon verification of a request, control will then pass to the appropriate application task along with any related command parameters. Upon completion of the applications task, control will then return to the request read task, which will then await a further request. In a more sophisticated implementation of the system, tasks could be prioritized and run in parallel (e.g., while the queue is being searched for data for a scatter plot, the hydrographer could be looking at a three-dimensional plot).

Figure 4.3. Structure of Interaction System.



The tasks shown in Figure 4.3 are now defined. Along with each task description are examples of command language requests that could be implemented.

1) READ AND VERIFY REQUESTS - This task accepts a request entered at the keyboard, parses it, verifies the legality of the request and calls the appropriate application task. This input task can access a list of all possible legal requests. For each request it will verify the appropriate modifiers, converting character strings into numbers for the invoked task.

2) DEFINE PARAMETER - This task establishes the identity of a parameter which is to be tested, examined, modified, plotted or printed. It sets up the parameter definition table which associates a parameter ID (e.g., DEPTH, A, 1) with an input data set type and a relative address into the data set. There may be set up a general list of predefined parameters which can be used during a run. The user may also define new parameters as he chooses. Parameters may also be defined as functions of parameters already in the table. Examples of parameter definitions in the command language are:

DEFINE PAR	DEPTH	DATA SET = QUEUE	ADDR = 48
VERB	PARAMETER ID	DATA SET ID	RELATIVE ADDRESS

DEFINE PAR	DIFF	DEPTH + CORRECTOR 1
VERB	ID	FUNCTION OF EXISTING PARAMETERS

DEFINE PAR	SLOPE	FUNCT1 (DEPTH, LAT, LONG)
VERB	ID	PREDEFINED FUNCTION

3) DEFINE CONDITION - This task establishes conditions under which records are to be picked for examination, modification, saving, or plotting. A condition statement contains a logical combination of tests or parameters. For example time, swath ID, latitude, longitude, flags and depths are all examples of parameters that may be tested. Again, there may exist a predefined set of useful conditions in the condition definition table that are available for the user. A condition must also be defined as a logical combination of defined conditions. Examples in command language are:

DEFINE CONDITION	DEEP	DEPTH GT 30
VERB	CONDITION ID	CONDITION

DEFINE CONDITION	ANOMAL	(DELD GT 0) AND (DELP GT 0)
VERB	ID	LOGICAL COMBINATION OF CONDITIONS

```
DEFINE CONDITION      CASE 2    (ANOMALY) AND (DEEP)
      VERB               ID     LOGICAL COMBINATION OF
                                  DEFINED CONDITIONS
```

DEFINE CONDITION UNKNOWN (FLAG6 ON) AND NOT (CASE 2)
DEFINE CONDITION SAVE (TIME GT 1200) AND (TIME LT 1300)

4) READ LIGHTPEN OR CURSOR - This task takes the pixel spot defined by the lightpen or the cursor position, converts it to map units on the plot (e.g. latitude and longitude) and enters the value in the condition table. That location then becomes a condition for accessing a point. If two points are read in, a line is defined. If three or more points are read in, a polygon is defined. Examples in the command language are:

```
  READ PEN          POINT 1
    VERB          CONDITION ID

 DEFINE LINE        LINE 1         POINT A, POINT B
    VERB          CONDITION ID        END POINTS

DEFINE POSITION    BAD AREA        P1, P2, P3, P4
    VERB          CONDITION ID        END POINTS

 SHOW POLYGON      BAD AREA
    VERB          CONDITION ID
```

5) PRINT CRT - This task makes a copy of the CRT screen on the line printer.

6) EXAMINE - This task would display on the alphanumeric CRT a sounding record or other data record specified by a previously defined condition (or light pen position). Examples are:

```
EXAMINE     QUEUE     BAD AREA       displays first record
                                     satisfying the condition
  VERB     DATASET    CONDITION

 NEXT                                displays next record
                                     under the condition
 VERB
```

EXAMINE TIDETABLE STATION 2

7) MODIFY - This task modifies a specified parameter in all records of a dataset satisfying a specified condition. Presumably only certain parameters in the sounding record, for example, would be

normally modifiable in an operational mode (e.g. flags for deletions override). The system developer's version would be more general, allowing large scale modification of the data sets for system testing. Examples of this command would be:

MODIFY	FLAG 23	ON	IF	POLYGON A
VERB	PARAMETER ID	VALUE		CONDITION ID

MODIFY ACCEPT FLAG OFF IF KELPAREA
MODIFY LOG IF KELPAREA 'KELP HERE'

8) SAVE - This task would save on magnetic tape sounding records or other datasets under a specified condition. Examples of this command are:

SAVE	QUEUE	KELPAREA
VERB	DATASET ID	CONDITION ID
SAVE	PURGED	LOWTIDE

9) GENERATE THREE-DIMENSIONAL PLOT - This task generates in memory a display image of a specified parameter under a specified condition with a specified scale. It is assumed that some kind of grey-scale or color scale plot of the parameter versus position will be displayed. It should be possible to highlight points under specified conditions by perhaps blinking those points. Contours may be seen by overlaying a bit plane with computed contours displayed in a contrasting color.

As an example of a display consider a 512 x 512 pixel^2 screen displaying two adjacent swaths. A convenient scale size would 512 m x 512 m. If one picks a 4 m x 4 m box as the limit of resolution, then the screen would contain 128 x 128 display boxes, each with 16 pixels. If overlaps occur, then the box could be divided into smaller regions showing the value (or color) of the sounding record parameter within that 4 x 4 m box.

<u>e.g.</u>

1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1

one sounding

1	1	1	1
1	1	1	1
2	2	2	2
2	2	2	2

two soundings

1	1	1	1
1	2	2	2
3	2	2	2
3	3	3	3

three soundings

1	1	2	2
1	1	2	2
3	3	4	4
3	3	4	4

four soundings, etc.

There will probably be a substantial fraction of boxes that are not filled by points (see Appendix B - Computer Simulation of Laser Scan Pattern). Such boxes may just be left empty (or black). One could fill such gaps with the average of neighboring values, but this would tend to smooth over the individual sounding distinctions. Examples of plot generating commands are:

PLOT 3D	DEPTH	IF	TIME A	SCALE	500
VERB	ITEMS TO PLOT		CONDITION		SCALE FACTOR

CONTOUR	DIFF = 10	LABEL
VERB	DEFINES CONTOURS (10 METERS)	LABEL CONTOURS

HIGHLIGHT	IF	KELPAREA
VERB		CONDITION ID

10) GENERATE TWO-DIMENSIONAL PLOT - This task generates in memory a display image of a scatter plot, histogram, or time profile of a parameter. Upon invoking this task, all records under the specified condition are read in and the appropriate parameter(s) are accumulated. Upon completion of the data fetch, the plot image is constructed. Scaling would be automatic, using the limits of the accumulated values. Labels would be devised from definition of the parameters involved. It should also be possible for the user to attach a string of characters to the plot as a title, for handcopy archives. Examples of two-dimensional plot commands are:

HISTOGRAM	K	IF	DEEPWATER
VERB	PARAMETER		CONDITION ID
SCATPLOT	DELDEPTH, DELPOSITION	IF	NEIGHBORS
VERB	PARAMETERS		CONDITION
PROFILE	CORRECTORA	IF	LINEA
VERB	PARAMETER		CONDITION

In the last example, the PROFILE command expects the condition to be either a time period or scan arc (t1 to t2) or a straight line (point one to point two). Again, the capability of highlighting points under a specific condition would be an option.

11) DISPLAY OR GENERATE HARDCOPY OR PLOT - This task would transfer the three-dimensional or two-dimensional plot images in memory to either the display screen or a hardcopy device.

13) MANIPULATE DISPLAY - This task would enable the user to alter that region of the plot image in memory that is displayed. Examples would include scrolling, zooming, and shifting an image.

An example of a more complex operation would be a rotation of the image by a specified angle. With any manipulation on a three-dimensional plot, the mapping of the screen pixels to the represented position (latitude and longitude) will be maintained so that a cursor or lightpen reading can be uniquely identified with a specific sounding record. Examples of image manipulation commands are:

SCROLL	UP DOWN	BY	n	DEGREES KM
SHIFT	LEFT RIGHT	BY	n	DEGREES KM
ZOOM	BY	FACTOR	f	
ROTATE	CW CCW	BY	n	DEGREES

In the above text we have outlined a basic system that should fulfill the requirements of the interactive ALH processing. This basic system can be implemented in a modular and open-ended fashion to permit additional tasks to be added as the ALH system is developed and tested. The framework is general enough to allow any disk or tape dataset to be accessed for processing. For example, the editing and smoothing operations on tide data can be performed with the above set of commands.

There are several enhancements to the basic system that would make interactive operations more efficient and user-oriented. These include the use of procedures, concurrent execution of tasks, and hardware implementation of certain functions.

A procedure is a combination of basic commands that define a particular job that a user would perform often. For example, if the hydrographer finds himself constantly checking plots of peak widths versus depth for shallow water soundings on his three-dimensional display, a procedure could be set up which would define the appropriate parameters and conditions and set up and display the plot he wants. The procedures could have arguments which are passed to the basic commands. Procedures may also be called by procedures, so that, for example, a series of commonly used diagnostic tests could be involved by issuing the name of one master procedure. A procedure handler task would add the names of procedures to the "legal verb" table, so that the request verification task would identify procedures. The procedure handler would act as a console keyboard, issuing task commands to the request reader in the same way that the user would type in commands, but in a much quicker and error-free fashion.

Parallel execution of tasks is possible if the basic system is implemented as a real time system. Tasks would be assigned priorities, and a scheduler task would be used to invoke tasks, monitor performance,and police task interference (e.g., if the user requests two three-dimensional plots and there is only one plot buffer, the second request will have to await completion of the first). Simultaneous task execution will speed user performance, particularly for slow I/O-sound tasks. As an example, the preliminary processing program could itself be a task that runs in parallel with interactive analysis. One is limited only by memory and disk space (i.e. trade off of task-swapping versus memory) and CPU speed. Real time task execution is a possible system enhancement prior to entering the operational phase of the ALH program. As such, the various components of the processing system should be implemented with such an environment in mind.

The basic system defined above performs all image manipulation and processing within the CPU of the main computer. The display screen is assumed to be a slave to the main computer and perhaps share memory with it. The use of an "intelligent" image processing device should permit the relegation of many of the image-manipulation functions away from the main processor. A function keyboard may also be very useful. On such a device, commonly used task procedures would be assigned to buttons on the keyboard permitting the user to perform his analysis with a minimum of string typing.

4.1.4 Software Module Sizing

Software sizing must be estimated in order to determine the scope and complexity of the software effort. The functional decomposition process which resulted in the multi-leveled bubble diagrams of Appendix C transforms the requirements into elementary, separable software tasks. The size of each of these software modules can be estimated to a certain accuracy. It is assumed that the entire system will be implemented in a higher level language (such as Fortran). The estimates are expressed in lines of code.

The estimates were determined by comparing the algorithms and functions to be performed with similar Fortran code.

Following this text is a list of the software modules identified by the data flow diagram numbering scheme (Table 4.1). Also included are the elements of the interactive system (Section 4.1.3) as well as additional software functions that have been identified as necessary for the system. Developer's tools are assumed to be satisfied by the interactive capabilities.

The accuracy of the estimates may be considered to be about 25 percent in either direction. The following symbols are used in the Notes column:

A	-	assembly language assumed
I	-	interactive
?	-	highly uncertain estimate (50 percent)
H	-	very hardware - dependent estimate

Summaries for the number of lines of code are broken down as follows:

Preliminary Processing	6600
Interactive Subsystem	4550
Additional Intermediate Processing	1600
Final Processing	1600
Data Management	490
Total	14,840

The range of total lines of code is about 11,000 to 19,000 considering the 25 percent uncertainty. It should be noted that traditionally no matter how accurately estimates are generated for sizing software, the prediction is generally short of the final count. A safe estimate then would be 20,000 lines of code. At 20 lines of code (designed, coded, tested, documented) per working day, this would yield about 4.4 man-years for software development.

A - assembly language assumed
I - interactive
? - highly uncertain estimates (50 percent)
H - very hardware dependent

	LOC	NOTES
1.0 Preliminary Process	200	
1.1 Initialize Flight Tape	50	I
1.1.1 Accept Valid Request	10	I
1.1.2 Implement Request	10	I
1.1.3 List Parameters on CRT	50	I
1.1.4 Print Parameters on Line Printer	50	I
1.1.5 Set Parameter	30	I
1.2 Perform Survey		
1.3 Merge and Edit	100	
1.3.1 Duplicate Tape	30	
1.3.2 Unpack Raw ALBS Data	100	A
1.3.3 Construct Tide Table	50	I
1.3.3.1 Accept Valid Request	10	I
1.3.3.2 Implement Request	10	I
1.3.3.3 List Table	50	I
1.3.3.4 Print Table	50	I
1.3.3.5 Plot Tide Data	100	I
1.3.3.6 Modify Tide Values	30	I
1.3.3.7 Smooth Tide Data	50	I
1.3.3.8 Set Up Table	50	I
1.3.4 Construct Queue	50	
1.3.4.1 Initialize Queue (skeleton)	200	
1.3.4.2 Merge Unpacked ALBS Data	150	
1.3.4.3 Interpolate Attitude, Position, and RTOD of Sounding from PAMS	150	
1.3.4.4 Interpolate Tide of Sounding	100	
1.3.5 Edit Unacceptable Returns	70	
1.3.5.1 Perform Waveform Test	30	
1.3.5.2 Perform Housekeeping Tests (20 Tests)	400	
1.3.5.3 Perform Azimuth Test	20	
1.3.5.4 Interpolate Azimuth	30	
1.3.5.5 Perform Synch. Time Test	20	
1.3.5.6 Interpolate Synch. Time	30	
1.3.5.7 Perform Slant Altitude Test	20	
1.4 Calibrate	100	
1.4.1 Compute Preflight Calibration Correctors	200	
1.4.1.1 Compute Altitude Corrector	50	
1.4.1.2 Compute Pulse Locations	100	
1.4.1.3 Compute Differential Range Corrector	50	
1.4.1.4 Compute Laser Power Variance	30	
1.4.1.5 Compute Gain Corrector	50	
1.4.1.6 Compute Time Base Corrector	100	?
1.4.1.7 Compute Transmit Pulse Stability	50	
1.4.1.8 Compute Radiometric Stability	50	
1.4.1.9 Compute Noise	70	
1.4.1.10 Compute Calibration Pulse Gain Corrector	50	

1.4.1.11 Compute Calibration Pulse Time Base Corrector	100	?
1.4.2 Apply Low Pass Filter	30	
1.4.3 Compute Inflight Calibration Correctors	100	
1.4.3.1 Compute Gain Corrector	50	
1.4.3.2 Flag for Bad Gain Corrector	20	
1.4.3.3 Compute Time Base Corrector	100	?
1.4.3.4 Flag for Bad Time Base Corrector	20	
1.4.4 Calibrate Flight Data	50	
1.5 Compute Depths	200	
1.5.1 Perform Environmental Subtraction	20	
1.5.1a Sort Deep Water Returns	20	
1.5.1b Average Deep Water Returns	30	
1.5.2 Compute Pulse Locations	80	
1.5.2.1 Find Surface Pulse Maximum	200	
1.5.2.2 Find Bottom Pulse Maximum	100	
1.5.2.3 Compute D.C. Background	40	
1.5.2.4 Subtract D.C. Background	10	
1.5.2.5 Locate Surface Peak	50	
1.5.2.6 Locate Bottom Peak	50	
1.5.3 Zero Depth Test	50	
1.5.3.1 Perform Shallow Water Trend Test	50	
1.5.3.2 Perform Pulse Width Test	50	
1.5.3.3 Check for Inflection Point	50	
1.5.3.4 Perform Percent of Transmitted Pulse Test	20	
1.5.4 Compute Apparent Depth (Zero Depth Case)	50	
1.5.5 Compute Apparent Depth (Nonzero Depth Case)	20	
1.5.6 Compute Waveform-based Parameters	80	
1.5.6.1 Compute Width of Leading Edge of Surface Return	30	
1.5.6.2 Compute Bottom Pulse Width	30	
1.5.6.3 Compute Surface Pulse Width	30	
1.5.6.4 Compute Signal-to-Noise Ratio	10	
1.5.6.5 Check Signal-to-Noise Ratio	20	
1.5.6.6 Compute K	50	
1.5.6.6.1 Compute Sliding Average Slope	20	
1.5.6.6.2 Test for Plateau or Inflection Point	20	
1.5.6.6.3 Compute K Algebraically	10	
1.5.6.6.4 Compute K in Alternative Fashion	30	
1.5.6.6.5 Locate 20 Nearby K's	50	
1.5.6.6.6 Average K's	10	
1.5.6.6.7 Test on Change in K, Interpolate	50	
1.5.6.7 Compute Beam Attenuation Coefficient	30	
1.5.6.8 Compute Phase Function	10	
1.5.7 Apply Depth Correctors	50	
1.5.7.1 Compute True Off-nadir Angle	20	
1.5.7.2 Compute Depth Corrector	50	
1.5.7.3 Apply Depth Corrector	20	
1.5.7.4 Apply "Other" Corrector	40	

1.6 Correct for Waves	50	
1.6.1 Compute Slant Altitudes	40	
1.6.1.1 Compute Altitude	20	
1.6.1.2 Compute Slant Altitude	10	
1.6.1.3 Compare with Previous Slant Altitude	30	
1.6.1.4 Compute Slant Altitude Threshold	30	
1.6.1.5 Compute Standard Deviation of Slant Altitudes	30	
1.6.2 Compute Wave Correctors	50	
1.6.2.1 Compute Aircraft Altitude	10	
1.6.2.2 Compute Predicted Slant Altitude	50	
1.6.2.3 Subtract for Wave Corrector	20	
1.6.2.1a Fit Slant Altitude Pattern	200	
1.6.2.2a Compute Predicted Slant Altitude	30	
1.6.3 Correct Depths for Waves	20	
1.7 Compute Laser Sounding Position	50	
1.7.1 Compute Raw Laser Souding Position	50	
1.7.2 Correct for Undercutting	20	
1.7.3 Correct for Datum	20	
1.7.4 Perform Pitch and Roll Test	20	
1.8 General Edit	100	
1.8.1 Compute Standard Deviation of Depths	50	
1.8.2 Check for Change in Depths; Other Tests	20+	
1.8.3 Compute Depth Pair Variance	50	
1.8.4 Check for Depth Change Variance	20	
1.8.5 Compute Block Precision	50	
1.8.6 Check for Block Precision	10	
1.8.7 Check for Sign of $\Delta D/\Delta h$		
1.8.8 Compute Local Pulse Density	50	
1.8.9 Check for Low Density	20	
1.8.10 Check for Change in Position	20	
1.9 Correct For Tides	20	
2.0 Intermediate Processing (Code in addition to 4.0; e.g., data management)	300	
2.1 Intraswath Sort (i.e., set up 3-D display)	300	I
2.2 Intraswath Evaluation	50	I
2.3 Interswath Evaluation	100	I
2.4 Purge	200	
2.5 Compare Crosslines	100	I
2.6 Edit Depths and Positions	200	I
2.7 Compare with Shoreline Data	100	I
2.8 Compare with Historical Data	100	I
2.9 Compare with Contemporary Data	100	I
2.10 Merge Resurvey Data	100	I
2.11 Edit All Data	50	I
3.0 Final Processing		
3.1 Reduce Number of Soundings	1000	?
3.2 Examine Selected Soundings	100	I
3.3 Generate Final Products (report, tape, etc.)	500	

4.0	Interactive Subsystem	200	I
4.1	Read and Verify Request	200	I
4.2	Define Parameter	500	I
4.3	Define Condition	300	I
4.4	Read Lightpen or Cursor	200	I,H
4.5	Copy CRT to Line Printer	50	I,H
4.6	Examine	300	I
4.7	Modify	200	I
4.8	Save	200	I
4.9	Generate 3-D Plot	300	I
4.9.1	Highlight	100	I
4.9.2	Overlay	50	I,H
4.9.3	Contour	1000	I?
4.10	Generate 2-D Plot	500	I
4.11	Display Plot	150	I,H?
4.12	Manipulate Display	300	I,H?
Miscellaneous Items:			
	Queue Data Management	50	A
	Set up queue table of contents	100	A
	Locate specific entry	30	A
	Fill empty active queue area	30	A
	Advance pointers	20	A
	Refill active queue area	50	A
	Empty active queue area	30	A
	Purged Dataset Management	50	A
	Set up purged data table of contents	50	A
	Locate specific entry	20	A
	Fill memory buffer	20	A
	Refill memory buffer	20	A
	Empty memeory buffer	20	A

Table 4.1 HS/DP Software Sizing

4.2 Database Specifications

Databases for the ALH HS/DP Subsystem can be categorized as either external or internal. External databases are input to or output from the Subsystem. Internal databases are set up and used by the Subsystem.

The external databases of the HS/DP are the following:

Input -
- Laser Data Set
- Positioning Data Set
- Tides Data Set
- Manually Recorded Data Set
- Contemporary Comparison Data Set (Automated)
- Historical Comparison Data Set
- Shoreline Data Set
- Flight Initialization Parameter Set
- Preliminary Processing Parameter Set

Output -
Duplicate of Flight Tape
Final Tape

The internal databases of the HS/DP that have thus far been identified are the following:

Data Queue
Purged Data Set
Tide Tables
Accumulators for Running Statistics (e.g., histograms)
Averaged Deep Water Returns (for environmental subtraction technique only)

Laser Data Set

Item	Range	Resolution	Number of Bits	Frequency	Rate Kbps) (@ 600 Hz)
Waveform			600-2000	1/sounding	360-1200
Scanner azimuth	0-360^o	±0.1^o	12	1/sounding	7.2
Laser power	0-800 kw	±1 kw	10	1/sounding	6.0
Synch time	0-6.5 hrs	±0.150 msec	28	1/sounding	16.8
Slant altitude	0-6.7x10^{-6}	±3x10^{-10} sec	23	1/sounding	9.0
System failure codes	0-512	--	10	unknown	0.1 ?
System diag. codes	0-512	--	10	unknown	0.1?
Depth for crew	0-200 m	±1 m	8	5/sec	0.04
Temperatures	0-100^{o}C	±1^{o}C	3x7	1/sec	0.02
Flashlamp output	TBD	TBD	10 ?	1/sounding	6.0
System power	0-10 kw	0.1 kw	7	1/sec	0.01
Other housekeeping	TBD	TBD	100 ?	1/sec	0.1
TOTAL					405.4-1245.4

The data rate will be 0.5 to 1.3 Mbps at 600 laser pulses per second, and 0.3 to 0.9 Mbps at 400 laser pulses per second. For a typical four-hour mission, the total laser data set would be six to 18 billion bits at 600 laser pulses per second, or four to 12 billion bits at 400 pulses per second.

Positioning Data Set

Item	Range	Resolution	Number of Bits	Frequency	Rate
Latitude	-90° to +90°	± 0.01"	25	20/sec	380 bps
Longitude	-180° to +180°	± 0.01"	26	20/sec	380 bps
Altitude	0-10,000 m	± 0.1 m	17	20/sec	340 bps
Heading	0-360^o	± 0.05^o	13	20/sec	260 bps
Pitch	0-20^o	± 0.025^o	10	20/sec	200 bps
Roll	0-20^o	± 0.025^o	10	20/sec	200 bps

Time	0-6.5 m	± .15 msec	28	20-120/sec	560-3360bps
Failure codes	0-512	---	10	unknown	10 bps ?
RTOD	0000-2359	± 1 min	12	1/min	0.2 bps
Housekeeping	TBD	TBD		1/min ?	2 bps
TOTAL					2332.2-5132.2 bps
					(i.e., 2-5 Kbps)

For a typical four-hour mission, the positioning data set would contain 34 million to 84 million bits.

Tides Data Set

Item	Range	Resolution	Number of Bits
Tide	0-50 ft	0.01 ft	13
RTOD	0000-2359	1 min.	12
Julian date	1-366	1	9
TOTAL			34

There may be up to 15 tide stations for a mission. Each station will make a tide measurement every six minutes. For a typical four-hour mission, there could be as many as 600 measurements. The tides data sets would then be less than 20,400 bits.

Manually Recorded Data Set

Item	Range	Resolution	Number of Bits
Depth	0-200 m	±0.01 m	15
Latitude	-90° to +90°	±0.01"	25
Longitude	-180° to +180°	±0.01"	26
RTOD	0000-2359	± 1 min	12
Technique	1-3	--	2
Julian date	0-366 day	± 1 day	9
TOTAL			89 bits

For a typical mission it is expected that no more than 1000 soundings would be manually recorded. Such a dataset would contain less than 90,000 bits.

Automated Contemporary Comparison Data Set

Item	Range	Resolution	Number of Bits
Depth	0-100 m	± 0.3 m	12
Latitude	0- 90°	± 0.01"	27
Longitude	0-360°	± 0.01"	28
RTOD	0000-2359	±1 min	12
Tide corrector	0-100 m	± 0.03 m	12
TOTAL			91 bits

In a typical mission, it is expected that one million soundings would be included in a contemporary comparison data set. Such a data set would comprise about 90 million bits.

Historical Comparison Data Set

Item	Range	Resolution	Number of Bits
Depth	0-200 m	± 0.01 m	15
Latitude	-90° - +90°	± 0.01"	27
Longitude	0-360°	± 0.01"	28
Datum	0-2000	--	11
Tide corrector	0-16 m	±0.002 m	13
TOTAL			94 bits per sounding

A typical chart covering the area surveyed is a four-hour mission (about 60 square nautical miles) contains about one million soundings. The historical comparison data set then would comprise about 90 million bits.

Shoreline Data Set

Item	Range	Resolution	Number of Bits
Latitude	-90° to +90°	±0.01"	27
Longitude	0°-360°	± 0.01"	28
Tide Corrector	0-16 m	± 0.002 m	13
TOTAL			68 bits/point

In a typical four-hour mission, approximately 200 square kilometers can be surveyed. Assume that the area surveyed is a 14 km x14 km box, the shoreline is five times the length of the side of the box (70 km.), and the resolution is that of the laser soundings (about five meters). Then there would be about 14,000 shoreline points in the data set which would then contain about one million bits.

Flight Initialization Data Set

Item	Number of Bits
Off-Nadir Angle	32
Field-of-View	32
Laser Beam Divergence	32
Maximum Depth For Time Base Setting	32
Filter Configuration	32
Pulse Power String	32
Survey I.D. Number	32
Julian Date	32
Location (20 Characters)	160
Survey Party Members (100 Characters)	800
Scan Rate	32
Ground Range Lengths For Preflight Cal. (10, say)	320
Altitude Cutoff for Laser Power (Safety)	32
	1600

The size of this data set is about 1600 bits.

Preliminary Processing Parameter Set

This data set contains all items identified in the preliminary processing requirements as being a set-up parameter. By count there are about 370 scalar values and 4 waveforms. Assuming 16 bits per scalar value and 2000 bits per waveform, the preliminary processing set-up parameter data set would contain 14,000 bits. In addition there is a seven-dimensional depth corrector look up table required for Step 16. If there are ten values for each dimension, this would total 10^7 items, or about 100 million bits.

Final Tape

Item	Range	Resolution	Number of Bits
Depth	0-200 m	0.01 m	32
Latitude	-90^{o} - $+90^{o}$	0.01"	32
Longitude	0^{o}-360^{o}	0.01"	32
Tide corrector	0-50 m	0.01 m	32
			128

It is assumed that each item is written on the tape as a 32-bit floating point number. In a four-hour mission there are 8.6 million soundings. There would then be slightly more than one billion bits in a data set. Such a data set would occupy about 90 percent of a 2400-foot nine-track tape at a recording density of 6250 BPI.

Data Queue

Principal Parameters:		Size	(max.)
1.	laser return waveform (200 x10)	2000 bits	
2.	surface and bottom pulse location indicators	2x8	
3.	pulse synch time	28	
4.	final corrected depth	16	(32)
5.	raw depth	16	(32)
6.	wave corrector		(32)
7.	tide corrector		(32)
8.	water property corrector		(32)
9.	S/N ratio		(32)
10.	local average S/N ratio		(32)
11.	laser power	10	
12.	depth computing method flag (pulse separation zero depth)	1	
13.	interface or volume surface return		32
14.	scan azimuth	12	(32)
15.	x, y position	2x32	(2x64)
16.	altitude	20	(32)
17.	pitch, roll, heading	40	3x32)
		2415	(2599)

Other items identified in the requirements are as follows:

Processing Step	Item	Size
7a	waveform test flag	2
7b	laser power test flag	2
7c	azimuth test flag	2
7c	interpolated azimuth	16
7d	synch time test flag	2
7d	interpolated synch time	16
7e	flags (assume 20)	40
7f	S.A. flag	2
8	gain corrector (200 x 8)	1600
8	time base corrector (200 x 8)	1600
9	filtered waveform (200 x 10)	2000
11	surface peak location	8
	average peak location	8
	surface pulse location	8
	bottom peak location	8
	D.C. background	16
	bottom pulse location	8
12	apparent depth	32
13	zero depth flag	2
14a	half width	16
14b	pulse width	16
14c	S/N ratio	16
	S/N flag	2
14d	average K	16
	raw K	16
	K flags	16

14e	ω_o	16
14f	A	16
14g	phase function	16
15	laser sounding position (32 x 2)	64
	6 degrees of freedom	192
	undercut position	192
	R to D	16
16	corrector	16
	corrected depth	16
17	slant altitude	16
18	wave corrector	16
	corrected depth	16
19	threshold test flags	10
	pair-wise slope test flag	2
	block precision flag	2
	Δ D to Δ A test flag	2
	pulse density flag	2
	pulse position flag	2
21	tide corrector	16
	corrected depth	16
Intermediate Processing	flags: refly	2
	system developer	2
	anomalous depth	2
	deeper of pair of coincident soundings	2
	hazard	2
	kelp or other environmentally-caused anomaly	10
	accept (e.g., to density)	2
	reject as bad region	2
	system error	2
	unkown error	10
	accept/reject	2
		6140

Total number of bits for a sounding record in the data queue is 8555 bits.

Purged Data Set

Item	Number of Bits
position	2x32
depth	32
time	2x32
tide corrector	32
swath id.	32 (also other id.)
	224 bits/sounding

At 600 soundings/sec., four hours of laser data yields 8.6×10^6 soundings or two billion bits of data. A 6 1/2 hour missing yields 1.4×10^7 soundings or three billion bits or data.

Tide Tables

Item	Range	Resolution	Number of Bits
Tide	0-50 ft	0.01 ft	13
RTOD	0000-2359	1 min.	12
Julian date	1-366	1 day	9
			34

Assume 15 tide stations each of which makes a measurement every six minutes. Each station is identifed by a coordinate position (latitude and longitude) accurate to 0.03 seconds. For a four-hour mission, the tide table set would contain 15*(40*34+55) = 21,225 bits.

Deep Water Returns

If it is assumed that ther are 100 classes of deep water returns, each identified by an eight-bit code and containing a 2000-bit waveform, then the deep water return data set would contain 200,800 bits.

Accumulators for Statistics

The size of this data set is dependent on the number of items for which histograms or statistics are to be kept during the processing. The histogram resolutions may vary from item to item. Assume that there are 100 data items to be tracked, 50 of which are to be simply accumulated into three-bit histograms, and 25 of which are to be accumulated into 20-bit histograms. With 32 bits per accumulator, it will require 20,000 bits for all 100 items.

Table 4.1 Summary of Database Sizes for ALH (Four-Hour Mission)

	Database	Size (bits)	Medium
External:	Laser Data Set	18 billion	tape
	Positioning Data Set	84 million	tape
	Tides Data Set	20,400	tape
	Manually Recorded	90,000	tape
	Automated Contemporary	90,000	tape
	Historical Comparison	90,000	tape
	Shoreline Data Set	1 million	tape
	Flight Initialization Parameters	1600	tape
	Prel. Proc. Setup Parameters	14,000	memory
	Depth Corrector Look-up Table	100 million	disk
	Final Tape	1 billion	tape
Internal:	Data Queue	74 billion	disk
	Purged Data Set	2 billion	disk
	Tide Tables	21,225	disk/memory
	Deep Water Returns	200,800	disk
	Accumulators for Statistics	20,000	memory
	Trig lookup tables (See Section 3.1, Step 15)	192,000	memory

4.3 Operating Environment

The hardware required for the ALH HS/DP Subsystem consists of the following devices (see Figure 4.5):

- processing unit with fast RAM
- console terminal (CRT plus keyboard)
- high density tape drive
- line printer/plotter
- graphics display screen
- cursor control device (e.g. lightpen, joystick, trackball)
- graphics hardcopy device
- disk unit
- 9-track tape drive

Optionally, the system may include the following additional devices:

- array processor
- typewriter terminal
- additional high density tape drive
- additional disk unit

The characteristics of the hardware devices are determined mainly by the data processing requirements, but the system design developed in this document leads to other necessary or desirable characteristics. Other recommendations are based on operating efficiency and the need for backup support in the event of failure.

Each of the hardware devices will be examined, noting their required and desirable characteristics. Where possible, examples of available products are mentioned.

Processing Unit - The processing unit must be capable of at least eight million instructions per second in order to perform the steps necessary to process the laser sounding data (detailed in Section 2.0). It must be capable of high speed transfer of data between its memory and peripheral devices such as disk, display screen, etc. (e.g., DMA transfer) It should have its floating point instructions implemented in hardware in order to speed up the time required to perform curve fits, least squares fits and coordinate transformations.

The operating system must be able to support a high level language (such as Fortran) and must have a good editor. It should provide memory protection so that the software and operating system itself are protected from unauthorized users. There should also be protection capabilities on all data set files containing crucial software and data.

Console Terminal - A keyboard plus CRT display screen will serve as the console terminal. All commands to the system as well as to the interactive routines would be issued at the keyboard and echoed on the screen. Any messages and prompts from the system and application routines would appear on the screen (critical messages would be highlighted by blinking or accompanied by audible alarms).

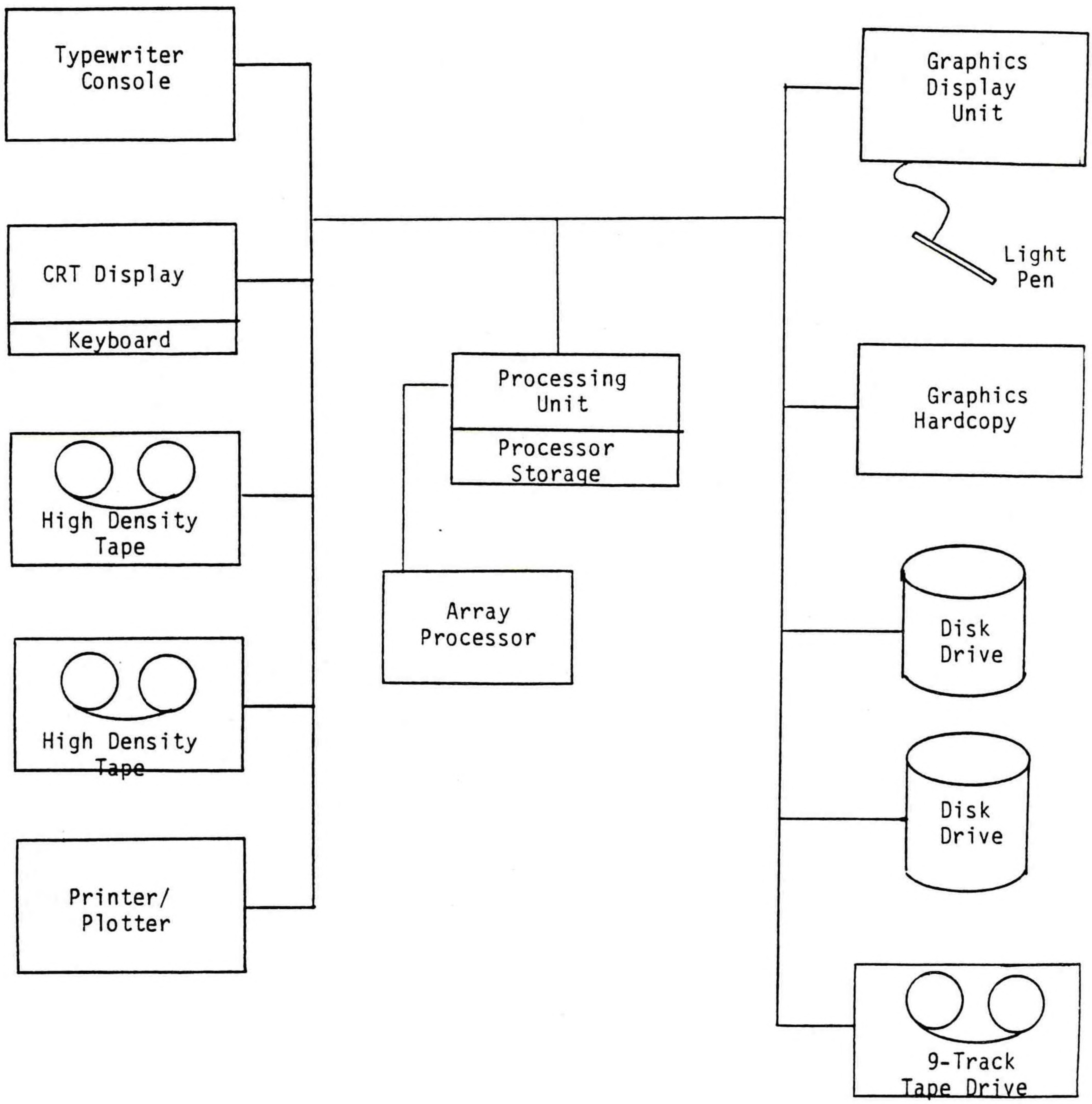


Figure 4.4. HS/DP Hardware Configuration

Typewriter Terminal - It is recommended that a typewriter terminal be used as the main computer console, with the CRT and keyboard device being used as input to the applications routines. The following advantages can be realized:

1) System control functions are isolated onto a dedicated input device, with all commands and messages being automatically logged in a printed form. Such a log would have clock times appended by the operating system and would serve as a permanent record of the analysis session.

2) Device redundancy is provided for. In the event of hardware failure of either the CRT or the typewriter, the other device could temporarily be used for all input to the system, permitting data analysis to continue.

Note that this terminal is in no way meant to replace the functions of the line printer, although the typewriter does provide an alternate (less efficient) medium for printed output in the event of line printer failure.

High Density Tape Drives - One high density tape drive will be required to record data from the ALBS and play it back for later analysis to the HS/DP Subsystem. Such a device must have sufficient bandwidths to record data at the required rate, 1.4 Mbps. It must also be able to play back the data at least as fast for analysis. Since one hour's worth of laser data must be analyzed within two hours, and since the bulk of the two hours analysis time should be allocated for interactive processing (which takes place after the data has been read off the high density tape), the play back speed ought to be much faster than the required record speed. For example, the following might be time allocations for analysis:

20 min	-	play back, queue construction, first pass
20 min	-	completion of preliminary processing
60 min	-	intermediate processing
20 min	-	final processing

During the first 20 minute time slot, the data would be read off the high density tape, unpacked, organized into the queue structure, and partially analyzed. All further processing would be performed using data from disk data sets.

A second high density tape device is a requirement because the flight tape must be duplicated at the start of the analysis (and there is too much data to efficiently copy onto nine-track format). In the proposed data processing scenario, however, the flight tape is read only once, early in the analysis, and could logically serve as its own backup of the raw data.

A second high density tape drive could be justified in on the grounds of redundancy in the case of hardware failure. The flight recorder is the key data processing hardware unit, without which no data taking or playback can occur. A computer failure would postpone analysis, but data accumulation could still continue. A high density recorder failure would curtail both data accumulation and data processing.

For an analysis of airborne high density tape drives, see Appendix D.

Line Printer/Plotter - There are requirements for both large amounts of printed hardcopy as well as plot hardcopy. Both of these requirements can be satisfied by a single device such as a Versatec Printer/Plotter. If very clean pen-and-ink plots are required, or standard width line printer output (132 characters per line) is desirable, then the procurement of a separate printer and plotter would be called for. These devices will require a considerable amount of maintenenace and supplies (mechanical alignment, chemicals or ink, paper, etc.).

Graphics Display Screen - The present document did not attempt to evaluate the optimal techniques for interactive analysis of hydrographic soundings, so no specific recommendations for a graphics display can be made here. In order to carry out the design and sizing, a technique is assumed which may or may not turn out to be the final approach used. That technique employs pseudo-color representations of depth data on map-like displays. With a color scale (or grey scale) the contour levels can be easily seen as different lines (or grey levels). Auxiliary data sets (shoreline, historical, etc.) can be overlaid on the display in contrasting colors. For this approach, a raster-type display screen with at least a 512 by 512 pixel^2 resolution is recommended. Clearly, however, if another technique is found optimal (such as line graphics), other characteristics would be required.

Cursor Control Device - Some sort of cursor control device (such as a lightpen, trackball or joystick) will greatly speed up the interactive phases of the analysis, both in the issuance of command requests to the system as well as the delineation of points or regions on a display. For example, rather than the user typing in requests on a keyboard, he can point the lightpen or cursor to the desired request on a menu display. On a display representing a depth map, the cursor or lightpen can be used to identify a sounding, a scan arc, the end points of a line, or a polygon region for detailed analysis.

Graphics Hardcopy Device - There should exist the capability of generating hardcopy of the graphics display screen for archives and diagnostic study. The device could be as simple as an "instant camera" mounted on a hood in front of the display screen. There are also stand-alone devices that generate 8 inches x 10 inches full color photographs of a screen image by reading values from the display buffer.

Disk Unit - A disk unit will provide high speed secondary storage for the vast quantites of data that the ALH produces.

Nine-Track Tape Drive - Standard digital tape should be used to transfer data (other than ALBS data) between the various Subsystems. Tape is a convenient means of transferring data and programs between different facilities (e.g., survey site to Rockville). It is also the required medium for the final product from the HS/DP.

5.0 DEVELOPMENT PLAN

5.1 Introduction

This section presents a software development plan for the ALH HS/DP Subsystem. This plan addresses the software development life cycle and relates this cycle to the ALH System development as a whole. Within each phase of the cycle, appropriate software engineering practices will be described. Topics which are discussed include test plans, configuration management, documentation, training, review and reporting activities, and resource and manpower estimates.

Figure 5.1 is a schedule of the ALH system development. The items marked "Requirements Analysis" and "High-level Designs" are satisfied by this document. The activity marked "Additional Studies" consists of a series of analyses, some of which are identified in Section 6 of this document and others of which may arise from the studies themselves. The purpose of these studies is to determine the overall feasibility of the ALH requirements in light of the findings of this Technical Memorandum to identify which, if any, compromises to the requirements may be accepted, to further define the interactive procedures and displays and to determine the future of the ALH project.

Under the condition that ALH is considered feasible and the remaining major issues are resolved, the project should enter the procurement phase. Upon award of contract for the data processing software and hardware, detailed software design should proceed and hardware installation and testing begin as soon as possible. The software development cycle continues through the coding, unit testing, training, documentation, system testing, and acceptance testing phases. The software development time from detailed design to final testing will take two years. The development of the ALBS and TMS should be scheduled so that acceptance testing of all components of the ALH System is completed at the same date. From that point on, integration and testing of the entire ALH system can proceed.

The basic assumption for this schedule is the requirement that the HS/DP be built in two years and tested (and modified) in one year. It is also assumed that integration of the various ALH components (HS/DP, ALBS, TMS) can occur in a timely fashion.

5.2 Software Development Cycle

Figure 5.2 is a chart depicting the ALH HS/DP software development schedule. Certain key algorithms have been singled out for scheduled development (Sounding Selection, Contouring).

The following is a description of the objectives and activities that comprise the major software development phases:

Detailed Design - The primary objective is a baseline design for the operational and support programs. Other activites would include the establishment of change control procedures, finalizing manpower requirements and schedules for the rest of the project, setting up preliminary acceptance test specifications and setting up a project

FIGURE 5.1 ALH SYSTEM DEVELOPMENT

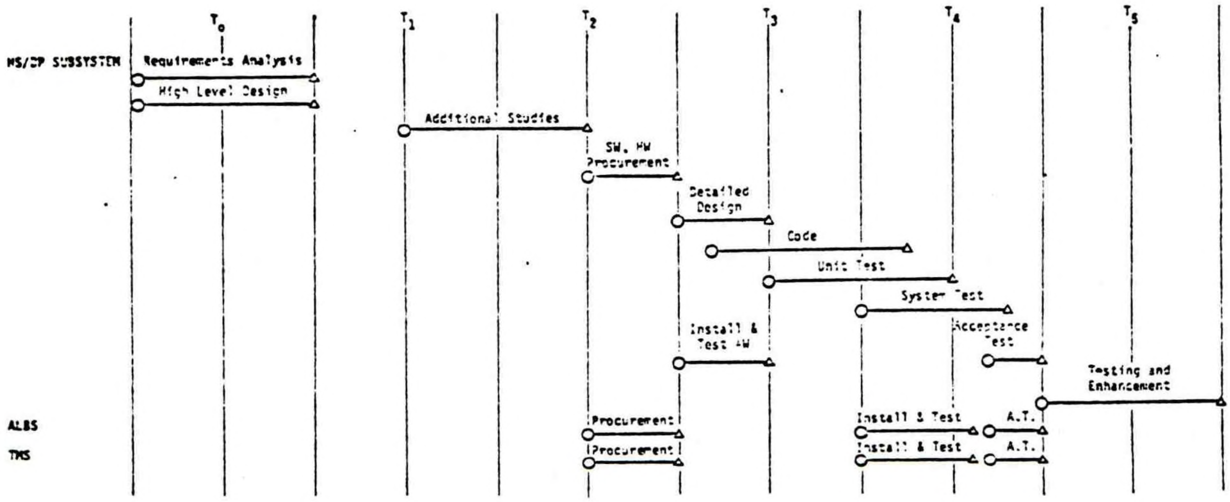
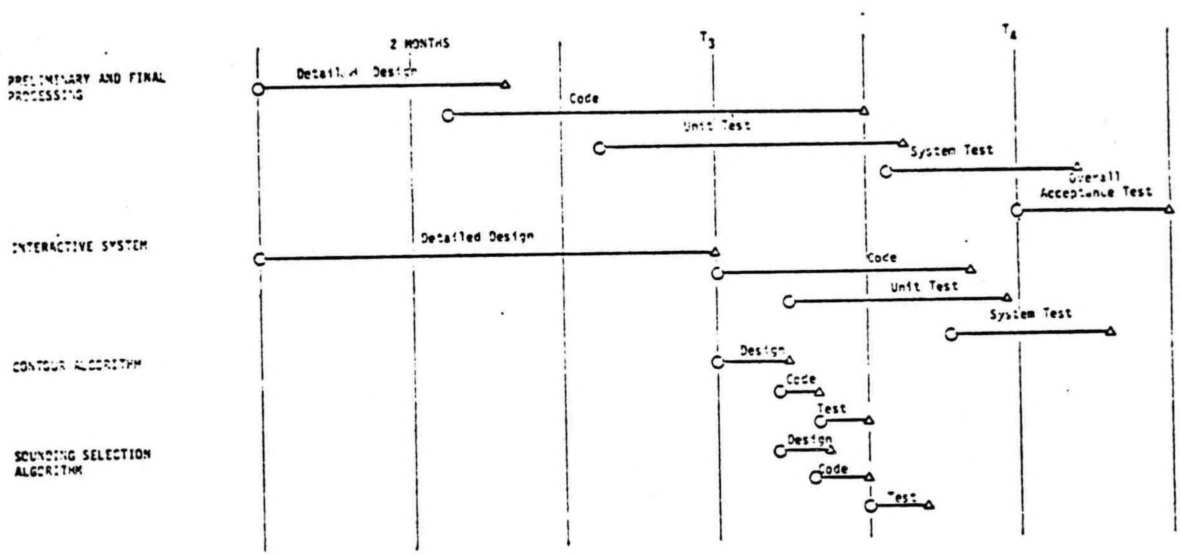


FIGURE 5.2 ALH SOFTWARE DEVELOPMENT



library. Milestones relevant to this phase include acceptance of the design specifications, acceptance of preliminary acceptance test specifications, and one or more design reviews.

Code - The coding phase entails writing software using the design specifications documents.

Unit Test - The objective is a thorough test of each of the software modules developed in the coding phase. For a major item such as Preliminary Processing, the unit test phase overlaps the coding phase; modules are unit tested as soon as they are coded. With top-down software development, unit testing can be made a part of system integration testing. The highest level of the system is developed and tested first. Then as each new module is written, it can be tested in its place in the final system.

System Test - The objective of this phase is to test the system out as a whole, including all of the tested constituent modules. Other activities include establishing test data bases and procedures to be used as a baseline for change control, completion of acceptance test specifications and development of customer training procedures, and user documents. Effective training and user documents for the interactive system will be most crucial so that NOAA personnel unskilled in computer systems may quickly learn to run the HS/DP Subsystem.

Acceptance Test - In this phase, the completed ALH HS/DP Subsystem, including documentation, is demonstrated and turned over to NOAA. Acceptance criteria which were established in previous development phases will be tested. Also, in this phase training of NOAA personnel in the use of the system will take place. All documentation will be completed and updated.

After these phases, the HS/DP Subsystem is integrated with the other ALH Subsystems, and extensive operational testing takes place. During this period, it is expected that major modifications or enhancements will be made to the HS/DP software as operational problems are found and data processing procedures are defined.

5.3 Testing

There are several levels of testing of the ALH System. For the HS/DP software there are the unit tests and system tests. For the HS/DP hardware there is acceptance testing. Upon integration of the HS/DP hardware and software, there is an integrated acceptance test. Finally, upon integration of the components of the ALH system, there is system integration testing, resulting perhaps in substantial modifications to the HS/DP software. These tests form a hierarchy; it is crucial that testing be completed at each level before going on to the next level.

Testing at all levels should be documented. Such documentation should include the test objectives, procedures, results, as well as any test data bases and test programs that were developed to support the testing activities.

5.4 Software Change Control

The design and program specifications serve as baseline documents for the ALH HS/DP Subsystem. These documents must be acceptable for both the software contractor and NOAA. Any changes or additions which are then proposed are made in reference to these baseline documents. The cost and impact of such changes or additions are assessed and reviewed in a formal fashion by a change control committee consisting of representatives from both the contractor as well as NOAA. The committee will then recommend acceptance or rejection of the change or addition. Upon approval by both contractor and NOAA, an accepted change will be implemented to both the software the the relevant documentation. Testing of the change or addition to the HS/DP Subsystem will be documented, and the new Subsystem, as defined by the modified documents, will serve as the new baseline for change control.

5.5 Documentation

In order to facilitate the development, visibility, configuration management and maintenance of the ALH HS/DP Subsystem, a full set of documents are required at several levels. The following is a description of those documents necessary to support the software development.

Requirements Document - A complete description of the requirements of the ALH HS/DP Subsystem as defined by NOAA. These requirements will serve as a baseline for all software development. (Section 2.0 of this document contains the requirements for the HS/DP Subsystem).

Design Document - The solution to the problem described in the Requirements Document. This represents the foundation for program implementation and the baseline for change control. All logic, interface, and data bases are defined. Detailed design includes complete I/O and functional descriptions of all program modules. (Section 4.0 of this document contains a high-level design for the ALH HS/DP Subsystem.)

Program Documents - Detailed descriptions of the logic and file structures pertaining to each software module. Included would be machine-generated listings of the program. These documents are to be delivered at the end of the coding phase.

Change Proposal - A document explaining the need for and impact of a change or addition to the Subsystem. Included would be resource and schedule impact accessments as well as any supporting material which would help explain or solve the problem. A change proposal document may be issued at any time in the development cycle.

Change Notice - A brief summary of a change to the design document as a result of acceptance and implementation of a Change Proposal. The notice may simply consist of pages to be added to or replaced in the design document.

Test Specifications - A description of the objectives, procedures, and success criteria for all software or system tests. These will be test specification documents for the HS/DP Subsystem test, the HS/DP acceptance test and the ALH System integration test. Procedures should include detailed descriptions of data bases and support programs used in the testing. A matrix of test cases versus functions to be tested may be included.

5.6 Software Manpower Estimates

Software for the ALH HS/DP Subsystem is estimated in Section 4.1.4 to total about 20,000 lines of code. In addition, during the Test and Enhancement activities of year T5 (see Figure 5.1), it is expected that roughly 30 percent of the software will be modified or optimized in preparation for the operational phase. The total software for both development and testing will then be about 27,000 lines of code. A realistic industry-wide average for software development is 20 lines of code (designed, coded, tested, documented) per working day. It would then take about six man-years for the total HS/DP Subsystem software.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Driving Requirements

A primary question to be answered is how the ALH requirements can be modified so that a workable processing system is defined without compromising hydrographic goals. Can a small number of driving requirements be identified which consume the majority of the processing resources?

The following key requirements are those most seriously constraining the feasibility of the ALH HS/DP Subsystem:

1. Data volume. Specifically, the laser data set with 400-600 pulses per second and 600-2000 bits per waveform.

2. Processing in two hours that data acquired in one hour.

3. Total cost not to exceed $750K.

4. Interactive processing. Specifically, interswath comparison, intraswath evaluation, and selected set modification which consume over 85 percent of the anticipated 48-59 hours required for interactive processing.

5. Automated data reduction. Specifically, the unpacking of the data, pulse location, and calculation of the waveform-based parameters consume about 80 percent of the projected 34 hours required to process the data on a machine with a one microsecond instruction execution time.

Each of these driving requirements are considered in turn, with mention of possible alternatives for a more workable system.

6.1.1 Data Volume

The data volume question directly affects the processing time. If you halve the number of soundings, the processing time will almost be cut in half (certain overhead functions need to be performed no matter how much sounding data there is to process). If you reduce the number of bits per sounding, the tape and disk I/O transfer time will be correspondingly reduced.

The amount of area to be surveyed in a year is not a variable as far as this study is concerned; it is a matter of hydrographic decision. Similarly, the spatial density of soundings is related to issues of hydrographic feature resolution and the amount of overlap desired between soundings, and is not a study variable.

The number of bits per sounding is an item that can be addressed. Alternatives should be investigated to carrying along all 200 samples of a waveform if only the bins encompassing the surface and bottom return peaks are used in the data reduction. The points outside of the peaks are used for noise calculations; these points may be more efficiently represented by a few average noise level values, calculated early in the processing.

6.1.2 Available Processing Time

The processing time to data collection time ratio of two to one is probably not as serious a constraint as originally imagined. Two facts bears on this problem: 300 flight hours are planned per year, and there are approximately 2000 hours per year available for all laser hydrography operations (flying, analyzing data, moving from site to site, setting up, etc.).

The data collection efficiency is not 100 percent of the flight time. From Rulon (ref. 7) it can be estimated that at the nominal aircraft velocity of 75 m/sec the data collection efficiency is no better than 80 percent, even with long flight lines of 25 nautical miles due to time lost on turns. Also, since laser hydrography will be used primarily to survey near-shore areas, there will be a certain fraction of the data collection time when the aircraft will be over land. Consider, for example, the Chesapeake Bay which is a likely candidate for the laser hydrography technique. The shoreline of the Bay is irregular, with rivers, inlets, and scattered islands throughout the area. No flight patterns can be designed to eliminate the substantial fraction of flight time over land if complete water coverage is to be attained. A realistic estimate of the flight time over water might be 75 percent for such an area. These two factors reduce the 300 hours of flying time to about 180 hours of laser data to be processed in a year.

It is difficult to speculate on the fraction of the remaining 1700 hours that could be allocated to data processing. There are many activites associated with moving the operations from site to site, setting up the equipment at a site, calibrating and tuning the laser hardware, establishing tide and navigation networks, and so forth. Some of these activities could be performed in parallel with data processing operations. A reasonable assumption might be that during 50 percent of the non-flight time, or 850 hours, the MGF would be on site and operational and sufficient personnel would be available to perform data processing operations.

These estimates of available time allocations indicate that the processing time to data collection time ratio of two to one specified in the requirements could be as high as five to one or higher, making the system more feasible.

6.1.3 Cost Constraints

Figure 6.1 is a chart showing current approximate hardware costs for processors of various speeds. The data was obtained by scanning recent industry literature. A straight line through the points yields the relationship $\text{COST} = .22\ (\text{MIPS})^{1.2}$. Although computer hardware costs diminish year-by-year (by about 20 percent), there is still a large gap between HS/DP requirements and the available budget. Table 3.2 indicates that in the non-interactive phases of the processing, 14,000 instructions would have to be executed to process a single, normal sounding. Assuming that one hour of automated processing is allotted for every hour of data collected, there would be 8.4 million instructions per second (MIPS) to be executed. For off-the-shelf processors, these speeds are attained by multi-million-dollar super mainframe computers, not by the size of machine considered appropriate in the laser hydrography operating environment.

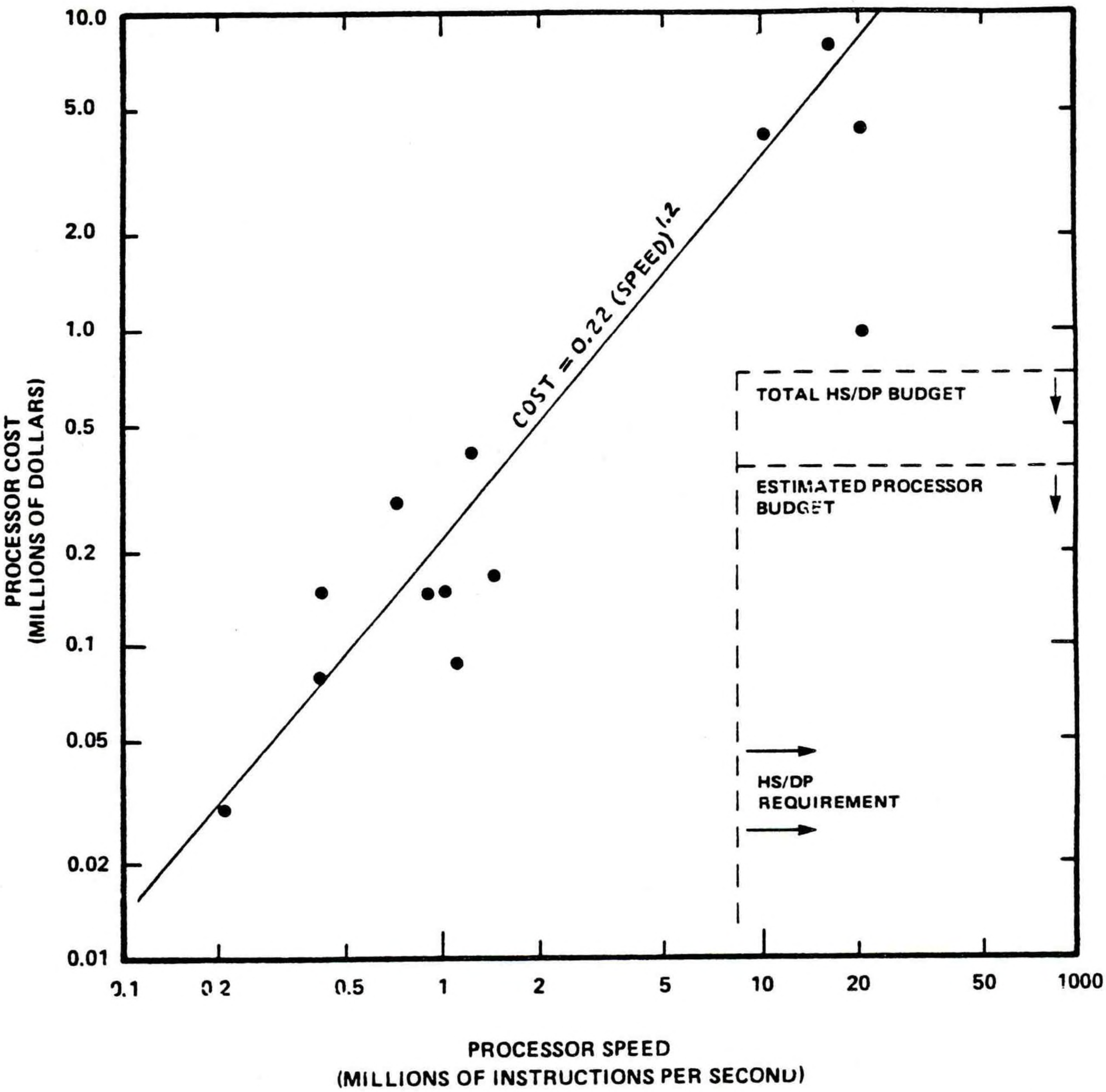


Figure 6.1 Processor Cost Versus Speed

Hardware enhancement can, if optimally programmed, result in processing time reduction of a factor of eight. For example, a PDP-11 with an array processor could attain a speed of eight MIPS, and might be used with ALH if the processing requirements could be tailored to the hardware.

There are major disadvantages, however, to the use of hardware enhancement. To take full advantage of the compute speed, the application must be tailored to the hardware. Programming hardware enhancement devices is a complex specialized task. Modification and enhancement are much more difficult than with straight-forward, structured, high-level language on a standard processor.

6.1.4 Interactive Processing

The projected amount of interactive processing time is determined mainly by the time it takes the human operator to do his evaluation, make decisions and take action. It would, therefore, take more hydrographers rather than more hardware to reduce the amount of time required. Any way that the interactive functions can be automated will greatly reduce the overall processing time. The intraswath and interswath comparison steps require up to 30 percent of the interactive processing. Some techniques of automatically comparing points, throwing out isolated, clearly erroneous measurements, and presenting to the hydrographer only those scenes that are anomalous would reduce interactive involvement. Similarly, software tools which will simplify or speed up the selected set modification will greatly pay off in reducing the projected 50 percent of the total interactive processing required for this one step. Compared to sonar techniques, laser hydrography can yield ten times more area surveyed per year at much higher sounding densities. Either the hydrographer's hours will have to be increased correspondingly, or else a different philosophy regarding his involvement in the processing will have to be invoked. It may be far too much of a luxury to have the hydrographer stare at charts with all soundings represented.

One approach to reduce the interactive processing time is to reduce the number of options available to the hydrographer. The simplest interactive commands would be to save or reject the data, regardless of the cause of anomalies. A possible procedure would be that wherein the hydrographer looks at representations of depth data on a display screen and uses a lightpen to identify soundings or a group of soundings to be rejected. There would be no traceback analysis of the anomalous soundings. This approach, which runs counter to the quality control philosophy implicit in the requirements, would greatly simplify the interactive phases of the processing as well as reduce the amount of ancillary and intermediate data that is to be carried along with each sounding during the processing. A development approach would be to first create a system with all of the interactive capabilities outlined in Section 2.0 and to do all the checkout of the equipment and algorithms with this system. Once the "bugs" are worked out and the laser performance is more fully understood, the interactive part of the system would be streamlined for operational use. It should be determined from the outset that such simplifications will not compromise the quality of the data analysis, for the overall HS/DP feasibility may likely hinge on such operational simplifications.

A recalculation of the interactive processing time can be made under the assumption of a system wherein the hydrographer can either accept or reject soundings in the Intermediate Processing steps, and can accept, eliminate or densify soundings in the Final Processing "All Data Examination " step. Assume the number of displays per four-hour mission is 8705 (see Table 3.4). With so few options, the hydrographer might be able to examine and edit each display in six seconds on the average. Then the entire interactive operation would take about 15 hours of human time instead of 60 hours using nonstreamlined techniques.

If operationally it is not necessary to keep raw data, ancillary data and intermediate values after the Preliminary Processing (since the hydrographer will not be tracing back through anomalous soundings), then the "purge" can be performed as the data is no longer needed. This is a great reduction in the amount of data to be maintained and should reduce the amount of disk I/O by a factor of three. Thus with a disk that has a throughput of 800 kb per second, the I/O transfer time for a survey should be reduced from 10.5 hours to about three hours.

6.1.5 Automated Processing

Section 3 concluded that it would require 14,000 instructions to perform the non-interactive data processing steps. This analysis assumed that the algorithms outlined in Section 2.0 were implemented in assembly language. However, the HS/DP is to be implemented in a well-structured, highly maintainable fashion using a well known high level language such as Fortran. Generally speaking, there is a programming tradeoff between maintainability and efficiency. Highly structured and easily modifiable code tends to be less than optimally efficient, both in the larger numbers of lines to be written as well as the larger number of instructions that need to be executed. For example, modular code requires more linking overhead and bit manipulations are either non-existent or inefficient in most versions of Fortran.

Clearly, it would be advantageous to reduce the automated processing instruction load. This section addresses the specific requirements listed in Table 3.2 that most affect the instruction load. The next section addresses possible alternatives to the overall data processing procedures implied in Section 2.0.

Pulse Location (44 percent of the instruction load) - This step represents nearly one-half of the total automated instruction load. The peak fitting algorithm assumed for the pulse location determination itself requires 4766 instructions, or fully one-third of the total 14,256 instructions for automated processing. The algorithm chosen was a general least-squares routine for a general order fit. Such an algorithm may be too general for HS/DP purposes, and too inefficient to implement. With the laser surface and bottom return pulses, one should be able to predict a priori what the approximate peak shapes and locations will be in most cases. Other yet unknown factors may determine whether the peak parameters (amplitude, locations, slope, half-widths, etc.) can be calculated directly from the data (or filtered data) rather than from a smooth fit to the data. Further study is clearly warranted in this area.

Waveform-Based Parameters (29 percent of the instruction load) - Over half of the instructions with this step are spent in averaging 20 neighboring values of the effective diffuse attenuation coefficient K. If the requirement for spatial averaging were replaced by a temporal averaging, the instruction load would be reduced by about 2000 instructions from 2500, the number required to search out nearby soundings in adjacent scans. Note that if all spatial averaging requirements are eliminated there would be no need to maintain several adjacent scans in memory at one time, thereby easing the processor memory needs.

Read and Unpack (seven percent of the instruction load) - Data unpacking times are related to the number of bits to be unpacked as well as the amount of bit manipulation to be performed. If the data comes off the high density tape already aligned on byte or word boundaries, requiring little or no unpacking, this step time can be greatly reduced. Also, reducing the number of bins in a waveform will directly reduce this load.

There are several arguments in favor of using eight bits per waveform sample. An eight-bit byte (or some multiple of it) is a natural size of a data item on a computer. Data is normally stored in byte units in memory as well as secondary storage. A ten-bit data item, if stored aligned to a two-byte boundary, will result in 40 percent wasted storage space. If it is packed for storage efficiency, there will be packing and unpacking instruction overhead for every access or modification of the value.

Calibration Processing (six percent of the instruction load) - This step is costly because like the unpack step it operates on all samples of the waveform. The bulk of the per sounding instruction load involves the calibration of the current waveform rather than the processing of the calibration pulses themselves. It would make little difference to reduce the number of inflight calibration pulses. Reducing the number of bins in a waveform will reduce this load in direct proportion.

Low Pass Filter (ten percent of the instruction load) - The need for and complexity of this optional step depends on the amount and nature of high frequency noise on the raw waveforms. The instructions load is again directly proportional to the number of bins in a waveform.

Environmental Subtraction (16 percent of the instruction load) - The per sounding instruction load of this optional step is dominated by the correction of the current waveform, not the deep pulse processing. As such, the load is again linear with the number of bins in a waveform.

The impact of all the other steps combined is less than 15 percent of the total load. As a rough estimate of the amount that the processing can be reduced, assume that the waveform consists of 100 eight-bit samples, instead of 200 ten-bit samples. The pulse rate is 400 per second, an efficient means of finding the surface and bottom return peaks on the waveform is found (reducing that load by one-half), and no low pass filtering or environmental subtraction techniques are used. The following instruction load savings per sounding could be realized:

Pulse Location	- 2400 instructions
Waveform-Based Parameters	- 2000 instructions
Read and Unpack	- 600 instructions
Calibration Processing	- 400 instructions

The total savings of 5400 instructions results in a per sounding load of 8800 instructions, instead of the present 14,000 instructions. Assuming the automated processing is done on a one MIPS processor (generally available and cheap), it would take 3.5 hours to perform the automatic processing steps required for one hours' data collection, at 400 pulses per second. Further reductions may be realizable with more detailed analysis of the algorithms.

6.1.6 Processing Procedures

Analysis of the overall processing requirements may result in further streamlining of the throughput. The philosophy to edit early makes good sense in that subsequent processing is reduced or eliminated on those edited sounings. This approach can be carried even further if a preprocessing sounding selection approach is used, such as the following:

1. Edit out all soundings with bad housekeeping, status, calibration, etc.

2. Find the depth of each unedited sounding in an approximate fashion, and then select only the locally deeper soundings.

3. Perform detailed depth determinations as usual on the remaining soundings.

If an efficient way of determining approximate depths can be developed and used early in the processing to reduce the number of soundings, then the rest of the processing steps (depth determination, data examination, sounding selection, etc.) can be applied to a considerably reduced set of soundings. This approach effectively decreases the number of pulses per time or per area that are to be analyzed in detail, while throwing out bad or deeper soundings.

If the requirements for a Mobile Ground Facility were relaxed, a centrally-located dedicated facility for laser data processing could be set up. Such a dedicated facility could process the data 24 hours per day, permitting over 8000 hours per year to handle the processing. Such a facility could include more than one interactive terminal so that parallel operation of the time-costly Intermediate Processing and Sounding Selection Examination could occur.

Another option would be to design the MGF to do the preliminary data editing and approximate depth determination and editing. A centrally-located facility would then be used to perform the bulk of the detailed processing on the reduced data set.

6.2 Recommendations

A detailed analysis of the HS/DP requirements (Section 2.0) pointed to the infeasibility of the project. It was determined that in order to fully analyze the data from a four-hour mission, using an affordable one MIPs processor, it would take about 110 hours. This estimate far exceeds the eight hours allotted for processing permitted by the constraint of two hours processing to one hours data collection.

An examination of driving requirements in the previous section, however, indicates that if certain requirements are modified or eased, it would be possible to analyze the data from a survey in 23.5 hours. The following list shows the allocated time:

Function	Time (hours)
I/O	3
Automated processing	3.5
Interactive processing	15
Graphics processing	2

Under the relaxed ratio of processing time to data collection time of five to one, there would be about 20 hours allocated for the analysis. Thus, under certain conditions, it appears that the HS/DP may be feasible within budget.

The following is a list of recommended design parameters that would make the HS/DP Subsystem viable:

- The ratio of available processing time to data collection time is realistically five to one or better.

- The hydrographer has a simple choice of either accepting or rejecting soundings in the interactive phase of the analysis. He can no longer spend time looking for causes.

- The laser pulse rate is 400 pulses per second.

- There are 100 eight-bit samples per waveform.

- There is no spatial averaging of waveform-based parameters, but only temporal averaging (i.e., only several pulses immediately before and after a given pulse need to be considered).

- An efficient algorithm can be found to determine peak properties (i.e., locations, widths, slopes, and waveform-based parameters) without using time-costly curve fitting techniques.

- A preprocessor is used to edit early those pulses that are clearly erroneous, those that are accompanied by bad housekeeping values or status flags, or those that are locally deeper than surrounding pulses. This last function would involve an approximate depth determination algorithm.

In order to determine whether the HS/DP Subsystem is workable, then, several issues must be examined. It is recommended that before any hardware or software procurements are initiated, studies be performed to answer the following questions:

1. Is the quality and quantity of the final data set compromised by limiting the hydrographer to ACCEPT/REJECT choices during the interactive processing?

2. Are the depth accuracy and resolution goals satisfied by a waveform consisting of 100 eight-bit samples and a pulse rate of 400 pulses per second?

3. Can efficient algorithms be devised to:

    a. determine peak parameters,
    b. obtain approximate depths from the raw data, and
    c. facilitate the hydrographer in his filling and editing after the sounding selection step.

In addition, it is recommended that a study be performed that looks more closely at the interactive analysis. Major items of concern include the following:

1. What technique should be employed to best represent soundings in their proper geographic location, so that bottom features and trends are emphasized?

2. How should unevenly sampled and potentially overlapping points be represented?

3. How much data can effectively be shown in a single display without obscuring anomalies? (i.e., can the projected number of displays, 8000, be reduced?)

If and when these problems can be resolved, development of the HS/DP Subsystem can proceed. An expanded interactive capability should be developed early (see Section 4.1.3) to facilitate the testing of algorithms and the generation of test data bases. Using as realistic data set as possible, the algorithms will be tested, modified, and streamlined. Different approaches to the interactive processing will be explored with an attempt to reduce the user involvement. Timing and throughput studies will be performed. Critical algorithms such as sounding selection will be developed, tested, and streamlined. Critical time-consuming areas of the processing will be identified that may lend themselves to optimization, machine coding, or the application of hardware implementation.

REFERENCES

1. Enabnit, D.B., Goodman, L.R., Young, G.K., Shaughnessy, W.J., "The Cost Effectiveness of Airborne Laser Hydrography", NOAA Technical Memorandum NOS 26, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Washington, D.C., December 1978, 56 pp.

2. "Airborne Laser Hydrography - A Briefing Prepared for the Director of the National Ocean Survey", prepared by the Office of Marine Technology, NOS, May 11, 1979, 32 pp.

3. Enabnit, D.B., "Airborne Laser Hydrography - FY 1982 Issue Paper", Engineering Development Laboratory, Office of Marine Technology, NOS, Version 2, May 1, 1980, 93 pp.

4. Technical Specifications for Procurement of an Airborne Laser Bathymeter Subsystem for an Airborne Laser Hydrography System. Final Report, NOAA/OTES contract NA-80-SAC-00706, Vitro Laboratories Division, Automation Industries, Inc., December 1981, 124 pp.

5. Technical Specifications for Procurement of a Position and Attitude Measuring Subsystem for an Airborne Laser Hyrography System. Final Report, NOAA/OTES contract NA-80-SAC-00706, Vitro Laboratories Division, Automation Industries, Inc., December 1980, 119 pp.

6. Enabnit, D.B., FY 1983 Issue Paper, Airborne Laser Hydrography. NOAA Technical Memorandum OTES 6 National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Washington, D.C., 86 pp.

7. Rulon, T.D., "Laser-Sonar Productivity Comparison", Memorandum to File, Engineering Development Laboratory, National Ocean Survey, NOAA, May 1980, 7 pp.

8. Bevington, P.B., "Data Reduction and Error Analysis for the Physical Sciences", McGraw-Hill, 1969.

9. Guenther, G.C., Borman, K., "Depth Estimation in the Airborne Oceanographic Lidar Postflight Processor", NOAA Technical Memorandum OTES 2, NOAA, U.S. Dept. of Commerce, Washington, D.C., Nov. 1981, 19 pp.

10. Gaertner, W.W., "Technical Report, Requirements Analysis, Multi-spectral Scanner Data Processing System", Interim Report, USAF, Rome Air Development Center Contract F30602-81-C-0035, W.W. Gaertner Research Inc., Stamford, Connecticut, December 1, 1981, 90 pp.

APPENDIX A

Instruction Load for Least Squares Fit

The following subroutines for a polynomial least-squares fit to data were copied from Bevington (Ref. 8). The instruction load analysis follows the procedure outlined in Section 3.1.

```
      SUBROUTINE POLFIT (X,Y, SIGMAY, NPTS, NTEMS, MODE, A, CHISQR)
      DOUBLE PRECISION SUMX, SUMY,XTERM, YTERM, ARRAY, CHISQ
      DIMENSION X(1), Y(1), SIGMAY(1), A(1)
      DIMENSION SUMX(19), SUMY(10), ARRAY(10,10)
C
C        ACCUMULATE WEIGHTED SUMS
C
   11 NMAX = 2*NTERMS - 1                          M,A
      DO 13 N=1, NMAX
   13 SUMX(N) = 0.                                 (C,LD) *NMAX
      DO 15 J=1, NTERMS
   15 SUMY(J) = 0.                                 (C,LD)*NTERMS
      CHISQ = 0.
   21 DO 50 I=1, NPTS                              C            }
      X1 = X(1)                                                 }
      Y1 = Y(1)                                                 }
   31 IF (MODE) 32, 37, 39                                      }
   32 IF (Y1) 35, 37, 33                                        }
   33 WEIGHT = 1. / Y1                                          }
      GO TO 41                                                  }
   35 WEIGHT = 1. / (-Y1)                          LD           }
      GO TO 41                                                  }
   37 WEIGHT = 1.                                               }
      GO TO 41                                                  } *NPTS
   39 WEIGHT = 1. / SIGMAY(1)**2                                }
   41 XTERM = WEIGHT                                            }
      DO 44 N=1, NMAX                              C        }   }
      SUMX(N) = SUMX(N) + XTERM                    2LD, AD  } *NMAX
   44 XTERM = XTERM * X1                           MD       }   }
   45 YTERM = WEIGHT*Y1                            LD           }
      DO 48 N=1, NTERMS                            C        }   }
      SUMY(N) = SUMY(N) + YTERM                    2LD, AD  } *NTERMS
   48 YTERM = YTERM * X1                           MD       }   }
   49 CHISQ = CHISQ + WEIGHT*Y1**2                 LD,MD,AD     }
   50 CONTINUE                                                  }
C
C        CONSTRUCT MATRICES AND CALCULATE COEFFICIENTS
C
   51 DO 54 J=1, NTERMS                            C                   }
      DO 54 K=1, NTERMS                       C        }               }
      N = J + K - 1                           4, A     } *NTERMS       } *NTERMS
   54 ARRAY(J,K) = SUMX(N)                    LD,SD    }               }
      DELTA = DETERM (ARRAY, NTERMS)               (DETERM)
      IF (DELTA) 61, 57, 61                   C
   57 CHISQR = 0.                             LD
      DO 59 J=1, NTERMS                       SD        *NTERMS
   59 A(J) = 0.
      GO TO 80
   61 DO 70 L=1, NTERMS                            C                           }
   62 DO 66 J=1, NTERMS                       C         }                      }
      DO 65 K=1, NTERMS            C       }            }                      }
      N = J + K - 1.               A,A     } *NTERMS    } *NTERMS              } *NTERMS
   65 ARRAY(J,K) = SUMX(N)         LD,LD   }            }                      }
   66 ARRAY(J,L) = SUMY(J)                    LD,LD     }                      }
   70 A(L) = DETERM (ARRAY, NTERMS) / DELTA        (DETERM), MD, LD, LD        }
```

---- CONTINUED ----

```
C
        CALCULATE CHI SQUARE

71   DO 75 J=1, NTERMS                                              C                    }
     CHISQ = CHISQ - 2.*A(J)*SUMY(J)                                LD,LD,MD,MD,SS       }
     DO 75 K=1, NTERMS                      C            }                               } *NTERMS
     N = J + K - 1                          A,A          } *NTERMS                       }
75   CHISQ = CHISQ + A(J)*A(K)*SUMX(N)      LD,LD,MD,MD,AD }                             }
76   FREE = NPTS - NTERMS                             L,A
77   CHISQR = CHISQ / FREE                            L, M, S+
80   RETURN
     END
```

INSTRUCTION LOAD FOR LEAST–SQUARES FIT TO A POLYNOMIAL:

POLYNOMIAL ORDER	NO. OF POINTS	C	A	M	LD	AD	MD
THIRD	10	526	194	21	1057	210	305
THIRD	20	646	194	21	1307	330	425
FOURTH	10	950	352	31	2011	360	576
FOURTH	20	1100	352	31	2321	510	726

(Includes DETERM)

```
      FUNCTION DETERM (ARRAY, NORDER)
      DOUBLE PRECISION ARRAY, SAVE
      DIMENSION ARRAY (10,10)
   10 DETERM = 1.                                                LD
   11 DO 50 K=1, NORDER                                     C      ⎫
C                                                                  ⎪
C        INTERCHANGE COLUMNS IF DIAGONAL ELEMENT IS ZERO           ⎪
C                                                                  ⎪
      IF (ARRAY(K,K)) 41, 21, 41                            C      ⎪
   21 DO 23 J=K, NORDER                                     C     ⎫       ⎪
      IF (ARRAY(K,J)) 31, 23, 31                            L, C  ⎬ *NORDER ⎪
   23 CONTINUE                                                    ⎭       ⎪
      DETERM = 0.                                           LD, S+D       ⎪
      GO TO 60                                                            ⎪
   31 DO 34 1=K, NORDER                                     C     ⎫       ⎪
      SAVE = ARRAY(1,J)                                     LD    ⎬ *NORDER ⎬ *NORDER
      ARRAY(1,J) = ARRAY(1,K)                               LD, ST⎪       ⎪
   34 ARRAY(1,K) = SAVE                                     ST    ⎭       ⎪
      DETERM = - DETERM                                     LD            ⎪
C                                                                         ⎪
C        SUBTRACT ROW K FROM LOWER ROWS TO GET A DIAGONAL MATRIX          ⎪
C                                                                         ⎪
   41 DETERM = DETERM * ARRAY(K,K)                          M             ⎪
      IF (K - NORDER) 43, 50, 50                            C             ⎪
   43 K1 = K + 1                                            A             ⎪
      DO 46 1=K1, NORDER                                    C             ⎫        ⎪
      DO 46 J=K1, NORDER                                    C      ⎫      ⎬ *NORDER ⎪
   46 ARRAY(I,J) = ARRAY(I,J) - ARRAY(I,K)*ARRAY(K,J)/ARRAY(K,K)   4LD,2MD,AD,ST ⎬ *NORDER ⎭  ⎪
   50 CONTINUE                                                                      ⎭
   60 RETURN
      END
```

INSTRUCTION LOAD:

	ORDER	C	M	LD	AD	MD
LINEAR	2	13	2	19	1	2
QUADRATIC	3	28	3	52	5	10
	4	54	4	114	14	28
	5	95	5	215	30	60

APPENDIX B

Computer Simulation of Laser Scan Pattern

A computer program was developed to study the spatial distribution of sounding for various laser scan patterns. Two cases were considered: a single, isolated swath and several swaths overlapping by 10% to 30%. The following are the parameters chosen for the simulation:

Off-nadir angle = 20^o
Scan rate = 5 scans per second
Laser pulse rate = 400 or 600 pulses per second
Aircraft altitude = 300 m
Aircraft velocity = 75 m/sec

The swath pattern was gridded into $(4.5\ m)^2$ boxes for sampling. The following table summarizes the coverage for both single and overlapped swaths. The table values are percent of total $(4.5\ m)^2$ boxes filled, to the nearest percent.

	400 pulses/sec		600 pulses/sec	
Soundings in $(4.5\ m)^2$ box	single	overlapped	single	overlapped
0	60%	50-60%	43%	32-46%
1	33%	28-33%	44%	35-36%
2	6%	9-16%	11%	12-26%
3	0%	2-3%	2%	4-5%
4	0%	0-1%	0%	2-3%
> 4	0%	0%	0%	0%
> 1	7%	12-18%	13%	19-33%

The range of values represent the range of swath overlap (10 to 30 percent).

Several observations can be made based on the calculations. As would be expected, the coverage improves with higher pulse rate and increased swath overlap. For example, at 400 pulses per second and 10 percent overlap only 40 percent of the grid boxes will contain one or more soundings. At 600 pulses per second and 30 percent overlap, 68 percent of the boxes will contain sounding(s).

From the data processing system standpoint, multiply-covered grid boxes represent increased processing time. For the examples given above, the fraction of grid boxes within which overlapping soundings must be resolved range from 12 percent to 33 percent. Overlap processing is a costly (timewise) interactive procedure in the data evaluation.

Mission flight parameters can thus not only affect the total coverage but also significantly affect the processing burden per mission.

The following tables present the simulation in more detail.

SINGLE SWATH RUNS AT 400 PULSES/SEC

Off-Nadir Angle = 20^o
Scan rate = 5 scans/sec
Box Size = $(4.5\ m)^2$

Table of the number of boxes with a given number of soundings for different assumptions of aircraft altitude and velocity:

SOUNDINGS PER BOX	A(m.) = / V(m/s) =	270 / 67.5	270 / 75	270 / 82.5	300 / 67.5	300 / 75	300 / 82.5	330 / 67.5	330 / 75	330 / 82.5
0		1167	1245	1370	1496	1496	1583	1627	1753	1744
1		763	735	617	666	834	742	806	697	818
2		235	200	176	337	150	174	266	240	137
3		34	10	19	1	10	0	1	10	1
4		1	10	18	-	9	1	-	-	-
5		-	-	-	-	1	-	-	-	-
SUM =		2200	2200	2200	2500	2500	2500	2700	2700	2700

Above table expressed in percent of total soundings:

0	53%	57%	62%	60%	60%	63%	60%	65%	65%
1	35%	33%	28%	27%	33%	30%	30%	76%	30%
2	11%	9%	8%	13%	6%	7%	10%	9%	5%
3	2%	-	1%	-	-	-	-	-	-
4	-	-	1%	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-
> 1	12%	10%	10%	14%	7%	7%	10%	9%	5%

Single swath coverage into $(4.5\ m)^2$ grid boxes at 400 pulses/sec:

0 soundings/box -	53 - 65%
1 soundings/box -	26 - 35%
2 soundings/box -	5 - 13%
3 soundings/box -	0 - 2%
4 soundings/box -	0 - 1%
> 4 soundings/box -	0%
> 1 soundings/box -	5 - 14%

OVERLAP SWATH RUNS AT 400 PULSES/SEC

Off-Nadir Angle = 20^o
Scan Rate = 5 scans/sec
Box Size = $(4.5\ m)^2$
Aircraft Altitude = 300 m
Aircraft Velocity = 75 m/sec

Table of number of boxes with a given number of soundings for different assumptions of swath overlap:

SOUNDINGS PER BOX	OVERLAP: =	10%	20%	30%	40%	50%
0		2576	2047	1647	1295	915
1		1214	1263	1049	1004	843
2		378	387	514	480	538
3		121	73	60	81	73
4		10	29	29	30	30
5		1	0	1	9	1
6		-	1	-	1	-
TOTAL =		4300	3800	3300	2900	2400

Above table is percent of total soundings:

0	60%	54%	50%	45%	38%
1	28%	33%	32%	35%	35%
2	9%	10%	16%	17%	22%
3	3%	2%	2%	3%	3%
4	-	1%	1%	1%	1%
5	-	-	-	-	-
6	-	-	-	-	-
> 1	12%	13%	18%	21%	27%

Overlapped swath coverage into $(4.5\ m)^2$ boxes: overlap 10-30%

0	soundings/box	- 50 - 60%
1	soundings/box	- 28 - 33%
2	soundings/box	- 9 - 16%
3	soundings/box	- 2 - 3%
4	soundings/box	- 0 - 1%
> 4	soundings/box	- 0%
>1	soundings/box	- 12 - 18%

SINGLE SWATH RUNS AT 600 PULSES/SEC

Off-Nair Angle = 20^o
Scan Rate = 5 scans/sec
Box Size = $(4.5\ m)^2$

Table of the number of boxes with a given number of soundings for different assumptions of aircraft altitude and velocity:

Soundings per Box	A(m.) = / V(m/s) =	270 / 67.5	270 / 75	270 / 82.5	300 / 67.5	300 / 75	300 / 82.5	330 / 67.5	330 / 75	330 / 82.5
0		834	892	989	1096	1077	1265	1291	1304	1416
1		894	945	878	865	1100	869	940	1055	970

2	371	277	242	504	273	328	401	277	274
3	34	35	80	1	40	37	2	57	33
4	66	50	10	33	9	0	66	7	7
5	1	1	1	1	1	1	0	0	0

Above table in percent of total soundings:

0	38%	41%	45%	44%	43%	51%	48%	48%	52%
1	41%	43%	40%	35%	44%	35%	35%	39%	36%
2	17%	13%	11%	20%	11%	13%	15%	10%	10%
3	2%	2%	4%	-	2%	1%	-	2%	1%
4	3%	2%	-	1%	-	-	2%	-	-
5	-	-	-	-	-	-	-	-	-
> 1	21%	17%	15%	22%	13%	15%	17%	13%	12%

Single Swath Coverage into $(4.5\ m)^2$ grid boxes at 600 pulses/sec:

0 soundings/box - 38 - 52%
1 soundings/box - 35 - 44%
2 soundings/box - 10 - 20%
3 soundings/box - 0 - 4%
4 soundings/box - 0 - 3%
> 4 soundings/box - 0%
> 1 soundings/box - 12 - 22%

OVERLAP SWATH RUNS AT 600 PULSES/SEC

Off-Nadir Angle = 20^0
Scan Rate = 5 scans/sec
Box Size = $(4.5\ m)^2$
Height = 300 m.
Velocity = 75 m/sec

Table of number of boxes with a given number of soundings for different assumptions of swath overlap

Soundings per Box	OVERLAP = 10%	20%	30%	40%	50%
0	1964	1526	1069	835	414
1	1524	1379	1155	952	940
2	510	605	862	739	738
3	180	176	152	343	247
4	111	104	61	30	54
5	10	9	1	1	7
6	1	1	0	0	0
7	0	0	0	0	0
Total	4300	3800	3300	2900	2400

Above table in percent of total soundings:

0	46%	40%	32%	29%	17%
1	35%	36%	35%	33%	39%
2	12%	16%	26%	25%	31%

3	4%	5%	5%	12%	10%
4	3%	3%	2%	1%	2%
5	-	-	-	-	-
6	-	-	-	-	-
$>$ 1	19%	24%	33%	38%	42%

Overlapped swath average into $(4.5m)^2$ boxes: Overlap 10 - 30%

0	soundings/box	-32% - 46%
1	soundings/box	- 35 - 36%
2	soundings/box	- 12 - 26%
3	soundings/box	- 4 - 5%
4	soundings/box	- 2 - 3%
$>$4	soundings/box	- 0%
$>$1	soundings/box	- 19 - 33%

The following two diagrams are printouts of scan patterns for two adjacents swaths with 20% overlap. The first diagram represents a laser rate of 400 pulses per second (pps) and the second 600 pps. The left- and right-most columns define the center of the two swaths, with the aircraft direction of travel going up and down. Each number in the diagram represents the number of soundings received within the corresponding 4.5 by 4.5 $meter^2$ box.

0	1	0	1	0	0	0	0	0	1	0	0	1	0	2	0	0	0	1	1	1	2	1	2	1	0	1	1	0	1	0	0	0	1	0	1	1	0
0	0	0	0	0	2	0	2	0	0	0	0	1	0	2	2	2	2	2	1	2	1	0	3	3	0	0	0	0	1	0	2	0	1	0	0	0	0
1	1	0	1	0	0	0	0	0	1	0	1	0	0	2	1	0	1	1	1	1	1	1	2	1	0	1	1	0	0	0	0	0	0	0	1	1	0
0	1	0	1	0	0	0	0	0	1	0	1	0	0	1	3	0	1	1	1	1	1	1	2	1	0	1	1	0	0	0	0	0	0	0	1	1	0
0	0	0	0	0	2	0	2	0	0	0	0	1	0	2	2	2	2	2	1	2	1	0	4	2	0	0	0	0	1	0	2	0	1	0	0	0	0
1	1	0	1	0	0	0	0	0	1	0	0	1	0	3	0	0	0	1	1	1	2	1	1	2	0	1	1	0	1	0	0	0	1	0	1	1	0
0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	4	0	2	1	2	1	1	1	3	1	0	1	1	0	0	0	0	0	0	0	0	1	0
0	1	0	1	0	1	0	1	0	1	0	0	1	0	2	1	1	1	1	1	1	1	0	2	1	0	0	0	0	1	0	1	0	1	0	1	0	0
0	1	0	1	0	1	0	1	0	1	0	0	1	0	2	1	1	1	1	1	1	1	0	2	2	0	0	0	0	1	0	1	0	1	0	1	0	0
1	0	0	0	0	0	0	0	0	0	0	2	0	0	3	4	0	2	1	2	1	1	1	3	1	0	1	1	0	0	0	0	0	0	0	0	1	0
0	1	0	1	0	0	0	0	0	1	0	0	1	0	2	0	0	0	1	1	1	2	1	2	1	0	1	1	0	1	0	0	0	1	0	1	1	0
0	0	0	0	0	2	0	2	0	0	0	0	1	0	2	2	2	2	2	1	2	1	0	3	3	0	0	0	0	1	0	2	0	1	0	0	0	0
1	1	0	1	0	0	0	0	0	1	0	1	0	0	2	1	0	1	1	1	1	1	1	2	1	0	1	1	0	0	0	0	0	0	0	1	1	0
0	1	0	1	0	0	0	0	0	1	0	1	0	0	1	3	0	1	1	1	1	1	1	2	1	0	1	1	0	0	0	0	0	0	0	1	1	0
0	0	0	0	0	2	0	2	0	0	0	0	1	0	2	2	2	2	2	1	2	1	0	4	2	0	0	0	0	1	0	2	0	1	0	0	0	0
1	1	0	1	0	0	0	0	0	1	0	0	1	0	3	0	0	0	1	1	1	2	1	1	2	0	1	1	0	1	0	0	0	1	0	1	1	0
0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	4	0	2	1	2	1	1	1	3	1	0	1	1	0	0	0	0	0	0	0	0	1	0
0	1	0	1	0	1	0	1	0	1	0	0	1	0	2	1	1	1	1	1	1	1	0	2	1	0	0	0	0	1	0	1	0	1	0	1	0	0
0	1	0	1	0	1	0	1	0	1	0	0	1	0	2	1	1	1	1	1	1	1	0	2	2	0	0	0	0	1	0	1	0	1	0	1	0	0
1	0	0	0	0	0	0	0	0	0	0	2	0	0	3	4	0	2	1	2	1	1	1	3	1	0	1	1	0	0	0	0	0	0	0	0	1	0
0	1	0	1	0	0	0	0	0	1	0	0	1	0	2	0	0	0	1	1	1	2	1	2	1	0	1	1	0	1	0	0	0	1	0	1	1	0
0	0	0	0	0	2	0	2	0	0	0	0	1	0	2	2	2	2	2	1	2	1	0	3	3	0	0	0	0	1	0	2	0	1	0	0	0	0
1	1	0	1	0	0	0	0	0	1	0	1	0	0	2	1	0	1	1	1	1	1	1	2	1	0	1	1	0	0	0	0	0	0	0	1	1	0
0	1	0	1	0	0	0	0	0	1	0	1	0	0	1	3	0	1	1	1	1	1	1	2	1	0	1	1	0	0	0	0	0	0	0	1	1	0
0	0	0	0	0	2	0	2	0	0	0	0	1	0	2	2	2	2	2	1	2	1	0	4	2	0	0	0	0	1	0	2	0	1	0	0	0	0
1	1	0	1	0	0	0	0	0	1	0	0	1	0	3	0	0	0	1	1	1	2	1	1	2	0	1	1	0	1	0	0	0	1	0	1	1	0
0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	4	0	2	1	2	1	1	1	3	1	0	1	1	0	0	0	0	0	0	0	0	1	0
0	1	0	1	0	1	0	1	0	1	0	0	1	0	2	1	1	1	1	1	1	1	0	2	1	0	0	0	0	1	0	1	0	1	0	1	0	0
0	1	0	1	0	1	0	1	0	1	0	0	1	0	2	1	1	1	1	1	1	1	0	2	2	0	0	0	0	1	0	1	0	1	0	1	0	0
1	0	0	0	0	0	0	0	0	0	0	2	0	0	3	4	0	2	1	2	1	1	1	3	1	0	1	1	0	0	0	0	0	0	0	0	1	0
0	1	0	1	0	0	0	0	0	1	0	0	1	0	2	0	0	0	1	1	1	2	1	2	1	0	1	1	0	1	0	0	0	1	0	1	1	0
0	0	0	0	0	2	0	2	0	0	0	0	1	0	2	2	2	2	2	1	2	1	0	3	3	0	0	0	0	1	0	2	0	1	0	0	0	0
1	1	0	1	0	0	0	0	0	1	0	1	0	0	2	1	0	1	1	1	1	1	1	2	1	0	1	1	0	0	0	0	0	0	0	1	1	0
0	1	0	1	0	0	0	0	0	1	0	1	0	0	1	3	0	1	1	1	1	1	1	2	1	0	1	1	0	0	0	0	0	0	0	1	1	0
0	0	0	0	0	2	0	2	0	0	0	0	1	0	2	2	2	2	2	1	2	1	0	4	2	0	0	0	0	1	0	2	0	1	0	0	0	0
1	1	0	1	0	0	0	0	0	1	0	0	1	0	3	0	0	0	1	1	1	2	1	1	2	0	1	1	0	1	0	0	0	1	0	1	1	0
0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	4	0	2	1	2	1	1	1	3	1	0	1	1	0	0	0	0	0	0	0	0	1	0
0	1	0	1	0	1	0	1	0	1	0	0	1	0	2	1	1	1	1	1	1	1	0	2	1	0	0	0	0	1	0	1	0	1	0	1	0	0
0	1	0	1	0	1	0	1	0	1	0	0	1	0	2	1	1	1	1	1	1	1	0	2	2	0	0	0	0	1	0	1	0	1	0	1	0	0
1	0	0	0	0	0	0	0	0	0	0	2	0	0	3	4	0	2	1	2	1	1	1	3	1	0	1	1	0	0	0	0	0	0	0	0	1	0
0	1	0	1	0	0	0	0	0	1	0	0	1	0	2	0	0	0	1	1	1	2	1	2	1	0	1	1	0	1	0	0	0	1	0	1	1	0
0	0	0	0	0	2	0	2	0	0	0	0	1	0	2	2	2	2	2	1	2	1	0	3	3	0	0	0	0	1	0	2	0	1	0	0	0	0
1	1	0	1	0	0	0	0	0	1	0	1	0	0	2	1	0	1	1	1	1	1	1	2	1	0	1	1	0	0	0	0	0	0	0	1	1	0
0	1	0	1	0	0	0	0	0	1	0	1	0	0	1	3	0	1	1	1	1	1	1	2	1	0	1	1	0	0	0	0	0	0	0	1	1	0
0	0	0	0	0	2	0	2	0	0	0	0	1	0	2	2	2	2	2	1	2	1	0	4	2	0	0	0	0	1	0	2	0	1	0	0	0	0
1	1	0	1	0	0	0	0	0	1	0	0	1	0	3	0	0	0	1	1	1	2	1	1	2	0	1	1	0	1	0	0	0	1	0	1	1	0
0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	4	0	2	1	2	1	1	1	3	1	0	1	1	0	0	0	0	0	0	0	0	1	0
0	1	0	1	0	1	0	1	0	1	0	0	1	0	2	1	1	1	1	1	1	1	0	2	1	0	0	0	0	1	0	1	0	1	0	1	0	0
0	1	0	1	0	1	0	1	0	1	0	0	1	0	2	1	1	1	1	1	1	1	0	2	2	0	0	0	0	1	0	1	0	1	0	1	0	0
1	0	0	0	0	0	0	0	0	0	0	2	0	0	3	4	0	2	1	2	1	1	1	3	1	0	1	1	0	0	0	0	0	0	0	0	1	0
0	1	0	1	0	0	0	0	0	1	0	0	1	0	2	0	0	0	1	1	1	2	1	2	1	0	1	1	0	1	0	0	0	1	0	1	1	0
0	0	0	0	0	2	0	2	0	0	0	0	1	0	2	2	2	2	2	1	2	1	0	3	3	0	0	0	0	1	0	2	0	1	0	0	0	0
1	1	0	1	0	0	0	0	0	1	0	1	0	0	2	1	0	1	1	1	1	1	1	2	1	0	1	1	0	0	0	0	0	0	0	1	1	0
0	1	0	1	0	0	0	0	0	1	0	1	0	0	1	3	0	1	1	1	1	1	1	2	1	0	1	1	0	0	0	0	0	0	0	1	1	0
0	0	0	0	0	2	0	2	0	0	0	0	1	0	2	2	2	2	2	1	2	1	0	4	2	0	0	0	0	1	0	2	0	1	0	0	0	0
1	1	0	1	0	0	0	0	0	1	0	0	1	0	3	0	0	0	1	1	1	2	1	1	2	0	1	1	0	1	0	0	0	1	0	1	1	0
0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	4	0	2	1	2	1	1	1	3	1	0	1	1	0	0	0	0	0	0	0	0	1	0
0	1	0	1	0	1	0	1	0	1	0	0	1	0	2	1	1	1	1	1	1	1	0	2	1	0	0	0	0	1	0	1	0	1	0	1	0	0
0	1	0	1	0	1	0	1	0	1	0	0	1	0	2	1	1	1	1	1	1	1	0	2	2	0	0	0	0	1	0	1	0	1	0	1	0	0
1	0	0	0	0	0	0	0	0	0	0	2	0	0	3	4	0	2	1	2	1	1	1	3	1	0	1	1	0	0	0	0	0	0	0	0	1	0
0	1	0	1	0	0	0	0	0	1	0	0	1	0	2	0	0	0	1	1	1	2	1	2	1	0	1	1	0	1	0	0	0	1	0	1	1	0
0	0	0	0	0	2	0	2	0	0	0	0	1	0	2	2	2	2	2	1	2	1	0	3	3	0	0	0	0	1	0	2	0	1	0	0	0	0
1	1	0	1	0	0	0	0	0	1	0	1	0	0	2	1	0	1	1	1	1	1	1	2	1	0	1	1	0	0	0	0	0	0	0	1	1	0
0	1	0	1	0	0	0	0	0	1	0	1	0	0	1	3	0	1	1	1	1	1	1	2	1	0	1	1	0	0	0	0	0	0	0	1	1	0
0	0	0	0	0	2	0	2	0	0	0	0	1	0	2	2	2	2	2	1	2	1	0	4	2	0	0	0	0	1	0	2	0	1	0	0	0	0
1	1	0	1	0	0	0	0	0	1	0	0	1	0	3	0	0	0	1	1	1	2	1	1	2	0	1	1	0	1	0	0	0	1	0	1	1	0
0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	4	0	2	1	2	1	1	1	3	1	0	1	1	0	0	0	0	0	0	0	0	1	0
0	1	0	1	0	1	0	1	0	1	0	0	1	0	2	1	1	1	1	1	1	1	0	2	1	0	0	0	0	1	0	1	0	1	0	1	0	0
0	1	0	1	0	1	0	1	0	1	0	0	1	0	2	1	1	1	1	1	1	1	0	2	2	0	0	0	0	1	0	1	0	1	0	1	0	0
1	0	0	0	0	0	0	0	0	0	0	2	0	0	3	4	0	2	1	2	1	1	1	3	1	0	1	1	0	0	0	0	0	0	0	0	1	0
0	1	0	1	0	0	0	0	0	1	0	0	1	0	2	0	0	0	1	1	1	2	1	2	1	0	1	1	0	1	0	0	0	1	0	1	1	0
0	0	0	0	0	2	0	2	0	0	0	0	1	0	2	2	2	2	2	1	2	1	0	3	3	0	0	0	0	1	0	2	0	1	0	0	0	0
1	1	0	1	0	0	0	0	0	1	0	1	0	0	2	1	0	1	1	1	1	1	1	2	1	0	1	1	0	0	0	0	0	0	0	1	1	0
0	1	0	1	0	0	0	0	0	1	0	1	0	0	1	3	0	1	1	1	1	1	1	2	1	0	1	1	0	0	0	0	0	0	0	1	1	0
0	0	0	0	0	2	0	2	0	0	0	0	1	0	2	2	2	2	2	1	2	1	0	4	2	0	0	0	0	1	0	2	0	1	0	0	0	0
1	1	0	1	0	0	0	0	0	1	0	0	1	0	3	0	0	0	1	1	1	2	1	1	2	0	1	1	0	1	0	0	0	1	0	1	1	0
0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	4	0	2	1	2	1	1	1	3	1	0	1	1	0	0	0	0	0	0	0	0	1	0
0	1	0	1	0	1	0	1	0	1	0	0	1	0	2	1	1	1	1	1	1	1	0	2	1	0	0	0	0	1	0	1	0	1	0	1	0	0
0	1	0	1	0	1	0	1	0	1	0	0	1	0	2	1	1	1	1	1	1	1	0	2	2	0	0	0	0	1	0	1	0	1	0	1	0	0
1	0	0	0	0	0	0	0	0	0	0	2	0	0	3	4	0	2	1	2	1	1	1	3	1	0	1	1	0	0	0	0	0	0	0	0	1	0
0	1	0	1	0	0	0	0	0	1	0	0	1	0	2	0	0	0	1	1	1	2	1	2	1	0	1	1	0	1	0	0	0	1	0	1	1	0
0	0	0	0	0	2	0	2	0	0	0	0	1	0	2	2	2	2	2	1	2	1	0	3	3	0	0	0	0	1	0	2	0	1	0	0	0	0
1	1	0	1	0	0	0	0	0	1	0	1	0	0	2	1	0	1	1	1	1	1	1	2	1	0	1	1	0	0	0	0	0	0	0	1	1	0
0	1	0	1	0	0	0	0	0	1	0	1	0	0	1	3	0	1	1	1	1	1	1	2	1	0	1	1	0	0	0	0	0	0	0	1	1	0
0	0	0	0	0	2	0	2	0	0	0	0	1	0	2	2	2	2	2	1	2	1	0	4	2	0	0	0	0	1	0	2	0	1	0	0	0	0
1	1	0	1	0	0	0	0	0	1	0	0	1	0	3	0	0	0	1	1	1	2	1	1	2	0	1	1	0	1	0	0	0	1	0	1	1	0
0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	4	0	2	1	2	1	1	1	3	1	0	1	1	0	0	0	0	0	0	0	0	1	0
0	1	0	1	0	1	0	1	0	1	0	0	1	0	2	1	1	1	1	1	1	1	0	2	1	0	0	0	0	1	0	1	0	1	0	1	0	0
0	1	0	1	0	1	0	1	0	1	0	0	1	0	2	1	1	1	1	1	1	1	0	2	2	0	0	0	0	1	0	1	0	1	0	1	0	0
1	0	0	0	0	0	0	0	0	0	0	2	0	0	3	4	0	2	1	2	1	1	1	3	1	0	1	1	0	0	0	0	0	0	0	0	1	0
0	1	0	1	0	0	0	0	0	1	0	0	1	0	2	0	0	0	1	1	1	2	1	2	1	0	1	1	0	1	0	0	0	1	0	1	1	0
0	0	0	0	0	2	0	2	0	0	0	0	1	0	2	2	2	2	2	1	2	1	0	3	3	0	0	0	0	1	0	2	0	1	0	0	0	0
1	1	0	1	0	0	0	0	0	1	0	1	0	0	2	1	0	1	1	1	1	1	1	2	1	0	1	1	0	0	0	0	0	0	0	1	1	0

0	1	1	1	0	1	0	0	1	1	0	0	1	0	3	2	3	1	2	2	1	2	1	4	1	1	0	1	1	0	0	0	1	1	0	1	1	1
0	0	0	0	0	1	2	2	0	0	0	0	0	2	3	1	2	3	1	1	3	1	1	4	4	0	0	0	0	0	2	2	1	0	0	0	0	0
1	1	1	1	0	0	0	0	1	1	0	1	1	0	3	2	1	1	2	2	0	2	2	2	1	1	1	1	1	0	0	0	0	1	0	1	1	1
0	1	1	1	0	0	0	0	1	1	0	1	1	0	2	4	1	1	2	2	0	2	2	2	1	1	1	1	1	0	0	0	0	1	0	1	1	1
0	0	0	0	0	1	2	2	0	0	0	0	0	2	3	1	2	3	1	1	3	1	1	5	3	0	0	0	0	0	2	2	1	0	0	0	0	0
1	1	1	1	0	1	0	0	1	1	0	0	1	0	3	3	3	1	2	2	1	2	1	3	2	1	0	1	1	0	0	0	1	1	0	1	1	1
0	1	0	0	0	0	0	0	0	1	0	2	0	0	3	3	1	2	2	2	0	3	4	1	2	0	2	1	0	0	0	0	0	0	0	0	1	1
0	0	1	1	0	1	1	1	1	0	0	0	1	1	2	2	2	2	2	2	2	1	1	4	2	1	0	0	1	0	1	1	1	1	0	1	0	0
0	0	1	1	0	1	1	1	1	0	0	0	1	1	2	2	2	2	2	2	2	1	1	4	3	1	0	0	1	0	1	1	1	1	0	1	0	0
1	1	0	0	0	0	0	0	0	1	0	2	0	0	4	4	1	2	2	2	0	3	4	1	2	0	2	1	0	0	0	0	0	0	0	0	1	1
0	1	1	1	0	1	0	0	1	1	0	0	1	0	2	2	3	1	2	2	1	2	1	4	1	1	0	1	1	0	0	0	1	1	0	1	1	1
0	0	0	0	0	1	2	2	0	0	0	0	0	2	3	1	2	3	1	1	3	1	1	4	4	0	0	0	0	0	2	2	1	0	0	0	0	0
1	1	1	1	0	0	0	0	1	1	0	1	1	0	3	2	1	1	2	2	0	2	2	2	1	1	1	1	1	0	0	0	0	1	0	1	1	1
0	1	1	1	0	0	0	0	1	1	0	1	1	0	2	4	1	1	2	2	0	2	2	2	1	1	1	1	1	0	0	0	0	1	0	1	1	1
0	0	0	0	0	1	2	2	0	0	0	0	0	2	3	1	2	3	1	1	3	1	1	5	3	0	0	0	0	0	2	2	1	0	0	0	0	0
1	1	1	1	0	1	0	0	1	1	0	0	1	0	3	3	3	1	2	2	1	2	1	3	2	1	0	1	1	0	0	0	1	1	0	1	1	1
0	1	0	0	0	0	0	0	0	1	0	2	0	0	3	3	1	2	2	2	0	3	4	1	2	0	2	1	0	0	0	0	0	0	0	0	1	1
0	0	1	1	0	1	1	1	1	0	0	0	1	1	2	2	2	2	2	2	2	1	1	4	2	1	0	0	1	0	1	1	1	1	0	1	0	0
0	0	1	1	0	1	1	1	1	0	0	0	1	1	2	2	2	2	2	2	2	1	1	4	3	1	0	0	1	0	1	1	1	1	0	1	0	0
1	1	0	0	0	0	0	0	0	1	0	2	0	0	4	4	1	2	2	2	0	3	4	1	2	0	2	1	0	0	0	0	0	0	0	0	1	1
0	1	1	1	0	1	0	0	1	1	0	0	1	0	2	2	3	1	2	2	1	2	1	4	1	1	0	1	1	0	0	0	1	1	0	1	1	1
0	0	0	0	0	1	2	2	0	0	0	0	0	2	3	1	2	3	1	1	3	1	1	4	4	0	0	0	0	0	2	2	1	0	0	0	0	0
1	1	1	1	0	0	0	0	1	1	0	1	1	0	3	2	1	1	2	2	0	2	2	2	1	1	1	1	1	0	0	0	0	1	0	1	1	1
0	1	1	1	0	0	0	0	1	1	0	1	1	0	2	4	1	1	2	2	0	2	2	2	1	1	1	1	1	0	0	0	0	1	0	1	1	1
0	0	0	0	0	1	2	2	0	0	0	0	0	2	3	1	2	3	1	1	3	1	1	5	3	0	0	0	0	0	2	2	1	0	0	0	0	0
1	1	1	1	0	1	0	0	1	1	0	0	1	0	3	3	3	1	2	2	1	2	1	3	2	1	0	1	1	0	0	0	1	1	0	1	1	1
0	1	0	0	0	0	0	0	0	1	0	2	0	0	3	3	1	2	2	2	0	3	4	1	2	0	2	1	0	0	0	0	0	0	0	0	1	1
0	0	1	1	0	1	1	1	1	0	0	0	1	1	2	2	2	2	2	2	2	1	1	4	2	1	0	0	1	0	1	1	1	1	0	1	0	0
0	0	1	1	0	1	1	1	1	0	0	0	1	1	2	2	2	2	2	2	2	1	1	4	3	1	0	0	1	0	1	1	1	1	0	1	0	0
1	1	0	0	0	0	0	0	0	1	0	2	0	0	4	4	1	2	2	2	0	3	4	1	2	0	2	1	0	0	0	0	0	0	0	0	1	1
0	1	1	1	0	1	0	0	1	1	0	0	1	0	2	2	3	1	2	2	1	2	1	4	1	1	0	1	1	0	0	0	1	1	0	1	1	1
0	0	0	0	0	1	2	2	0	0	0	0	0	2	3	1	2	3	1	1	3	1	1	4	4	0	0	0	0	0	2	2	1	0	0	0	0	0
1	1	1	1	0	0	0	0	1	1	0	1	1	0	3	2	1	1	2	2	0	2	2	2	1	1	1	1	1	0	0	0	0	1	0	1	1	1
0	1	1	1	0	0	0	0	1	1	0	1	1	0	2	4	1	1	2	2	0	2	2	2	1	1	1	1	1	0	0	0	0	1	0	1	1	1
0	0	0	0	0	1	2	2	0	0	0	0	0	2	3	1	2	3	1	1	3	1	1	5	3	0	0	0	0	0	2	2	1	0	0	0	0	0
1	1	1	1	0	1	0	0	1	1	0	0	1	0	3	3	3	1	2	2	1	2	1	3	2	1	0	1	1	0	0	0	1	1	0	1	1	1
0	1	0	0	0	0	0	0	0	1	0	2	0	0	3	3	1	2	2	2	0	3	4	1	2	0	2	1	0	0	0	0	0	0	0	0	1	1
0	0	1	1	0	1	1	1	1	0	0	0	1	1	2	2	2	2	2	2	2	1	1	4	2	1	0	0	1	0	1	1	1	1	0	1	0	0
0	0	1	1	0	1	1	1	1	0	0	0	1	1	2	2	2	2	2	2	2	1	1	4	3	1	0	0	1	0	1	1	1	1	0	1	0	0
1	1	0	0	0	0	0	0	0	1	0	2	0	0	4	4	1	2	2	2	0	3	4	1	2	0	2	1	0	0	0	0	0	0	0	0	1	1
0	1	1	1	0	1	0	0	1	1	0	0	1	0	2	2	3	1	2	2	1	2	1	4	1	1	0	1	1	0	0	0	1	1	0	1	1	1
0	0	0	0	0	1	2	2	0	0	0	0	0	2	3	1	2	3	1	1	3	1	1	4	4	0	0	0	0	0	2	2	1	0	0	0	0	0
1	1	1	1	0	0	0	0	1	1	0	1	1	0	3	2	1	1	2	2	0	2	2	2	1	1	1	1	1	0	0	0	0	1	0	1	1	1
0	1	1	1	0	0	0	0	1	1	0	1	1	0	2	4	1	1	2	2	0	2	2	2	1	1	1	1	1	0	0	0	0	1	0	1	1	1
0	0	0	0	0	1	2	2	0	0	0	0	0	2	3	1	2	3	1	1	3	1	1	5	3	0	0	0	0	0	2	2	1	0	0	0	0	0
1	1	1	1	0	1	0	0	1	1	0	0	1	0	3	3	3	1	2	2	1	2	1	3	2	1	0	1	1	0	0	0	1	1	0	1	1	1
0	1	0	0	0	0	0	0	0	1	0	2	0	0	3	3	1	2	2	2	0	3	4	1	2	0	2	1	0	0	0	0	0	0	0	0	1	1
0	0	1	1	0	1	1	1	1	0	0	0	1	1	2	2	2	2	2	2	2	1	1	4	2	1	0	0	1	0	1	1	1	1	0	1	0	0
0	0	1	1	0	1	1	1	1	0	0	0	1	1	2	2	2	2	2	2	2	1	1	4	3	1	0	0	1	0	1	1	1	1	0	1	0	0
1	1	0	0	0	0	0	0	0	1	0	2	0	0	4	4	1	2	2	2	0	3	4	1	2	0	2	1	0	0	0	0	0	0	0	0	1	1
0	1	1	1	0	1	0	0	1	1	0	0	1	0	2	2	3	1	2	2	1	2	1	4	1	1	0	1	1	0	0	0	1	1	0	1	1	1
0	0	0	0	0	1	2	2	0	0	0	0	0	2	3	1	2	3	1	1	3	1	1	4	4	0	0	0	0	0	2	2	1	0	0	0	0	0
1	1	1	1	0	0	0	0	1	1	0	1	1	0	3	2	1	1	2	2	0	2	2	2	1	1	1	1	1	0	0	0	0	1	0	1	1	1
0	1	1	1	0	0	0	0	1	1	0	1	1	0	2	4	1	1	2	2	0	2	2	2	1	1	1	1	1	0	0	0	0	1	0	1	1	1
0	0	0	0	0	1	2	2	0	0	0	0	0	2	3	1	2	3	1	1	3	1	1	5	3	0	0	0	0	0	2	2	1	0	0	0	0	0
1	1	1	1	0	1	0	0	1	1	0	0	1	0	3	3	3	1	2	2	1	2	1	3	2	1	0	1	1	0	0	0	1	1	0	1	1	1
0	1	0	0	0	0	0	0	0	1	0	2	0	0	3	3	1	2	2	2	0	3	4	1	2	0	2	1	0	0	0	0	0	0	0	0	1	1
0	0	1	1	0	1	1	1	1	0	0	0	1	1	2	2	2	2	2	2	2	1	1	4	2	1	0	0	1	0	1	1	1	1	0	1	0	0
0	0	1	1	0	1	1	1	1	0	0	0	1	1	2	2	2	2	2	2	2	1	1	4	3	1	0	0	1	0	1	1	1	1	0	1	0	0
1	1	0	0	0	0	0	0	0	1	0	2	0	0	4	4	1	2	2	2	0	3	4	1	2	0	2	1	0	0	0	0	0	0	0	0	1	1
0	1	1	1	0	1	0	0	1	1	0	0	1	0	2	2	3	1	2	2	1	2	1	4	1	1	0	1	1	0	0	0	1	1	0	1	1	1
0	0	0	0	0	1	2	2	0	0	0	0	0	2	3	1	2	3	1	1	3	1	1	4	4	0	0	0	0	0	2	2	1	0	0	0	0	0
1	1	1	1	0	0	0	0	1	1	0	1	1	0	3	2	1	1	2	2	0	2	2	2	1	1	1	1	1	0	0	0	0	1	0	1	1	1
0	1	1	1	0	0	0	0	1	1	0	1	1	0	2	4	1	1	2	2	0	2	2	2	1	1	1	1	1	0	0	0	0	1	0	1	1	1
0	0	0	0	0	1	2	2	0	0	0	0	0	2	3	1	2	3	1	1	3	1	1	5	3	0	0	0	0	0	2	2	1	0	0	0	0	0
1	1	1	1	0	1	0	0	1	1	0	0	1	0	3	3	3	1	2	2	1	2	1	3	2	1	0	1	1	0	0	0	1	1	0	1	1	1
0	1	0	0	0	0	0	0	0	1	0	2	0	0	3	3	1	2	2	2	0	3	4	1	2	0	2	1	0	0	0	0	0	0	0	0	1	1
0	0	1	1	0	1	1	1	1	0	0	0	1	1	2	2	2	2	2	2	2	1	1	4	2	1	0	0	1	0	1	1	1	1	0	1	0	0
0	0	1	1	0	1	1	1	1	0	0	0	1	1	2	2	2	2	2	2	2	1	1	4	3	1	0	0	1	0	1	1	1	1	0	1	0	0
1	1	0	0	0	0	0	0	0	1	0	2	0	0	4	4	1	2	2	2	0	3	4	1	2	0	2	1	0	0	0	0	0	0	0	0	1	1
0	1	1	1	0	1	0	0	1	1	0	0	1	0	2	2	3	1	2	2	1	2	1	4	1	1	0	1	1	0	0	0	1	1	0	1	1	1
0	0	0	0	0	1	2	2	0	0	0	0	0	2	3	1	2	3	1	1	3	1	1	4	4	0	0	0	0	0	2	2	1	0	0	0	0	0
1	1	1	1	0	0	0	0	1	1	0	1	1	0	3	2	1	1	2	2	0	2	2	2	1	1	1	1	1	0	0	0	0	1	0	1	1	1

APPENDIX C

HS/DP Data Flow Diagrams

Appendix C contains the processing requirements of Section 2 cast in the format of data flow diagrams. These diagrams are a tool of structured analysis that permit the partitioning of a system into a network of activities and their interfaces. The diagrams are organized in a top-down fashion. At the highest level is the context diagram, which defines the HS/DP subsystem in terms of its inputs and outputs. Three major components of the ALHS HS/DP subsystem are identified and separately diagrammed:

1.0 Preliminary Processing
2.0 Intermediate Processing
3.0 Final Processing

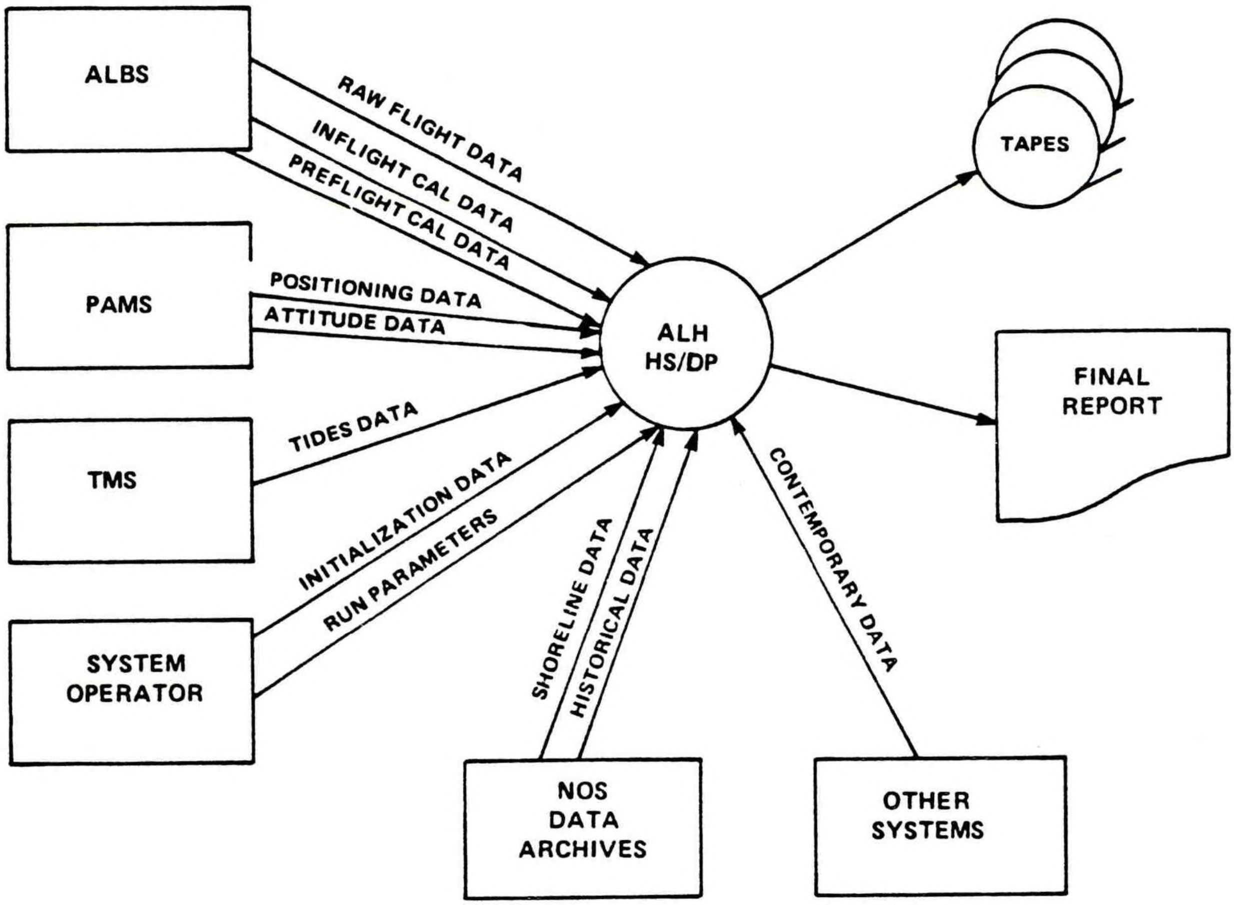
These major components are further expanded into more diagrams, and so on. The numbering system is determined by the generation of the diagrams (for example, bubble 1.3.5.4 - Interpolate Azimuth is the fourth step in the function 1.3.5 - Edit Unacceptable Returns, which is the fifth step of function 1.3 - Merge and Edit, which is the third step in function 1.0 - Preliminary Processing).

The process of decomposing activities into more detailed diagrams is motivated by the goal of reducing the requirements into a collection of simple, identifiable functions. The lowest level bubbles will translate directly into individual software modules which can be separately written and tested. The decomposition is carried out not to attain certain levels uniformly (e.g., the four number level), but rather down to the level where (1) the process is clearly understood and simple (e.g., 1.3.1 - Duplicate Tape), (2) the process has yet to be understood, developed, or defined (e.g., 3.1 - Reduce Number of Soundings) or (3) the process lies outside of the software system (e.g., 1.2 - Perform Survey).

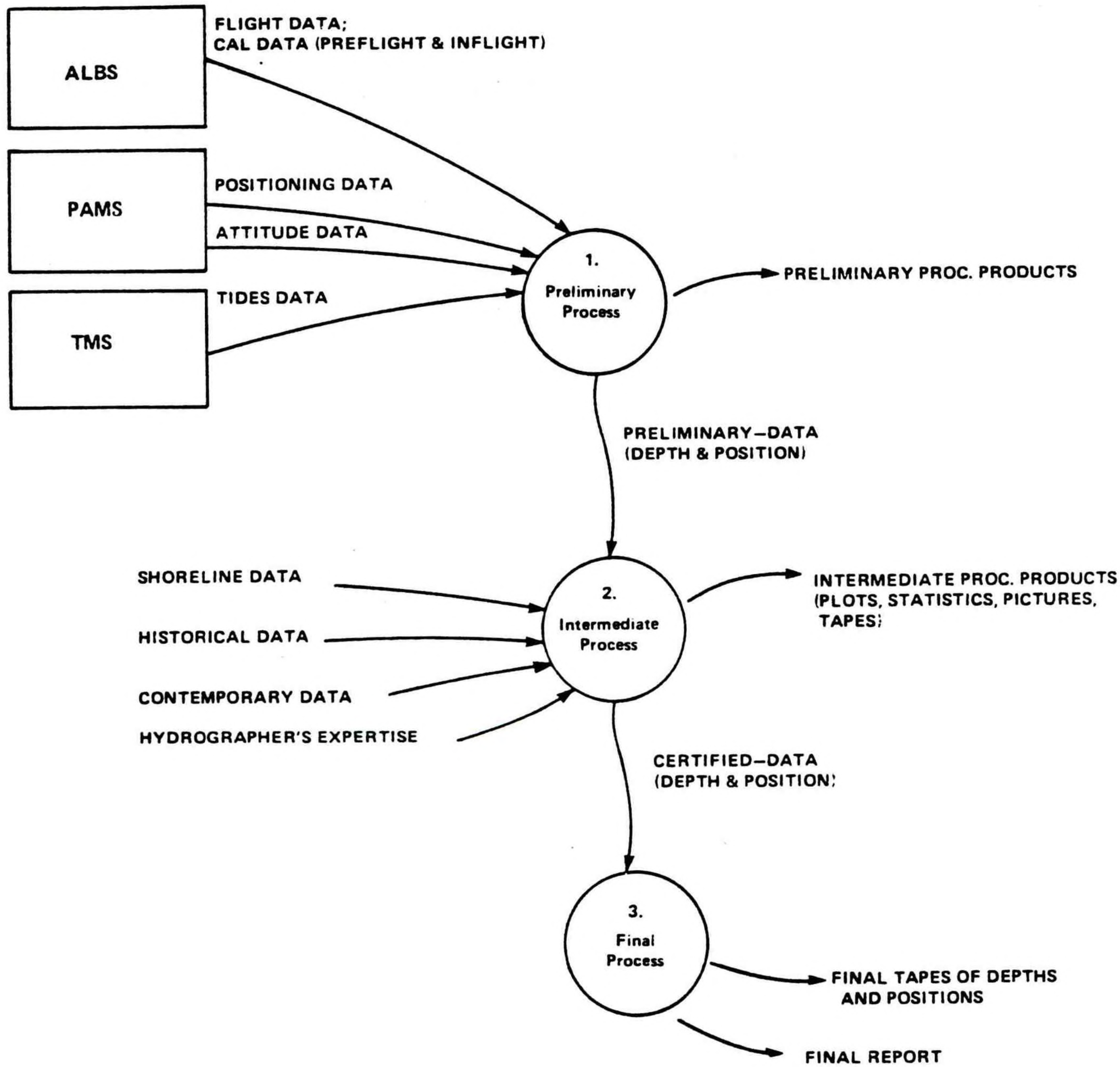
The lines connecting the bubbles represent data flow between the activities. Thus each bubble has its input and output data completely defined. The diagrams of items 1.0 and 2.0 include a double width data flow which represents the queue. Each laser return has a sounding data queue entry which contains all principal and secondary parameters as well as important intermediate values pertaining to that sounding. Functions in the diagrams access and write only specific data from a queue entry (exceptions: 1.3.4.1 - Initialize Queue and 2.4 - Purge).

The function 1.0 - Preliminary Processing is treated in the most detail with the data flow diagrams. The functions 2.0 - Intermediate Processing and 3.2 - Examine Selected Soundings are discussed in Section 4.1.1 wherein is developed a design for the interactive components of the HS/DP subsystem.

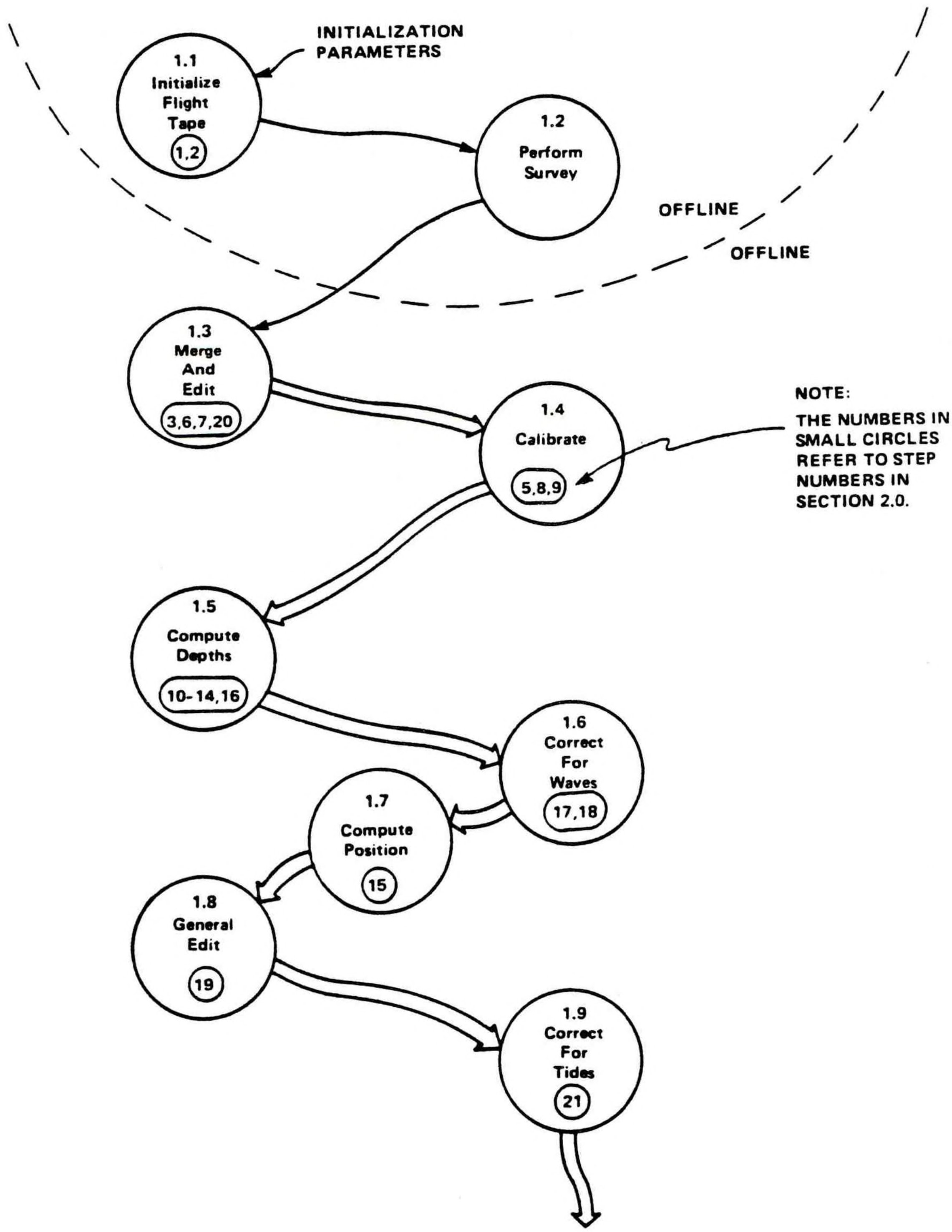
ALH HS/OP CONTEXT DIAGRAM



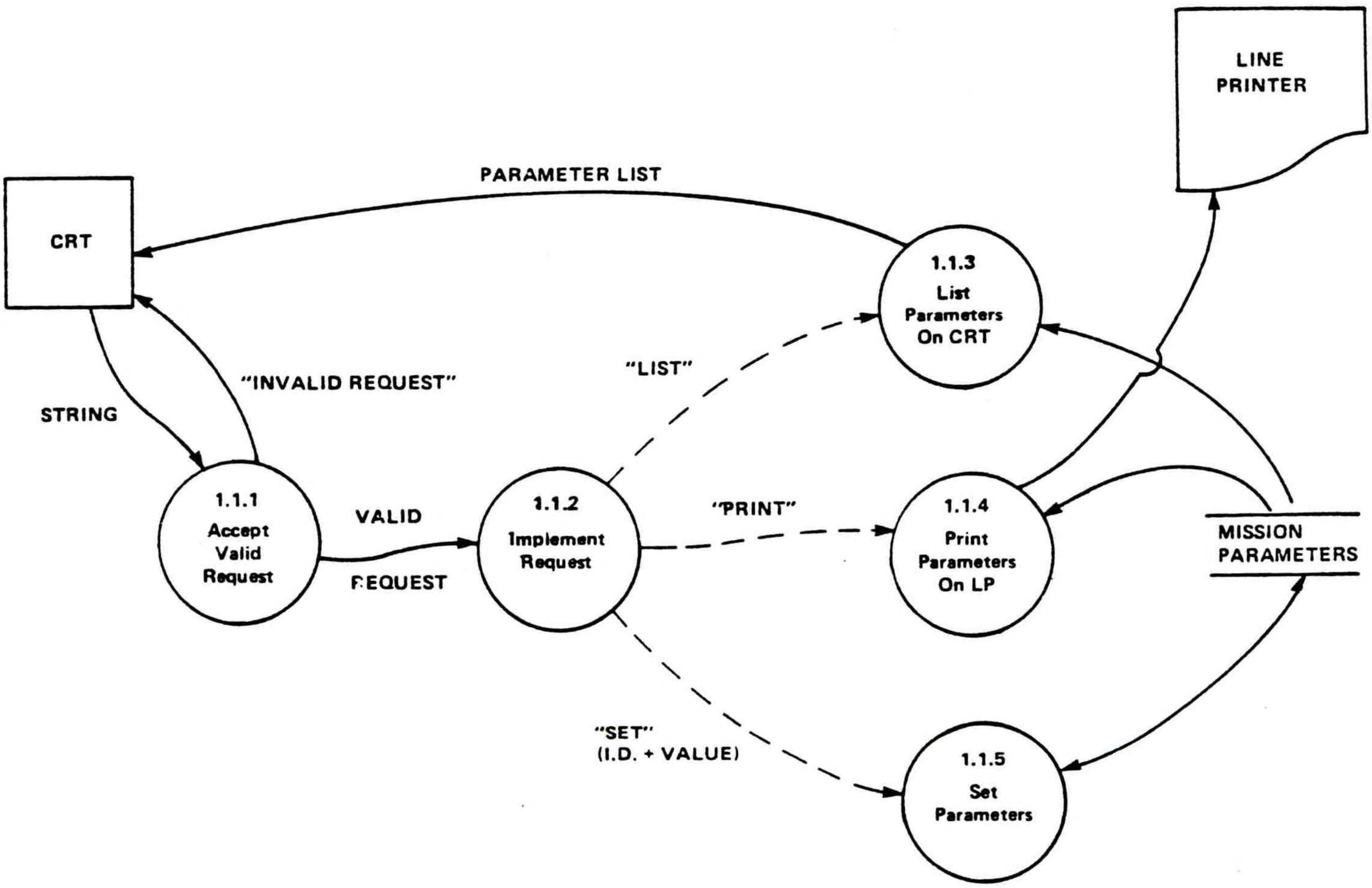
LEVEL 1


ALBS
PAMS
TMS
FLIGHT DATA;
CAL DATA (PREFLIGHT & INFLIGHT)
POSITIONING DATA
ATTITUDE DATA
TIDES DATA
1.
Preliminary
Process
PRELIMINARY PROC. PRODUCTS
PRELIMINARY–DATA
(DEPTH & POSITION)
SHORELINE DATA
HISTORICAL DATA
CONTEMPORARY DATA
HYDROGRAPHER'S EXPERTISE
2.
Intermediate
Process
INTERMEDIATE PROC. PRODUCTS
(PLOTS, STATISTICS, PICTURES,
TAPES)
CERTIFIED–DATA
(DEPTH & POSITION)
3.
Final
Process
FINAL TAPES OF DEPTHS
AND POSITIONS
FINAL REPORT

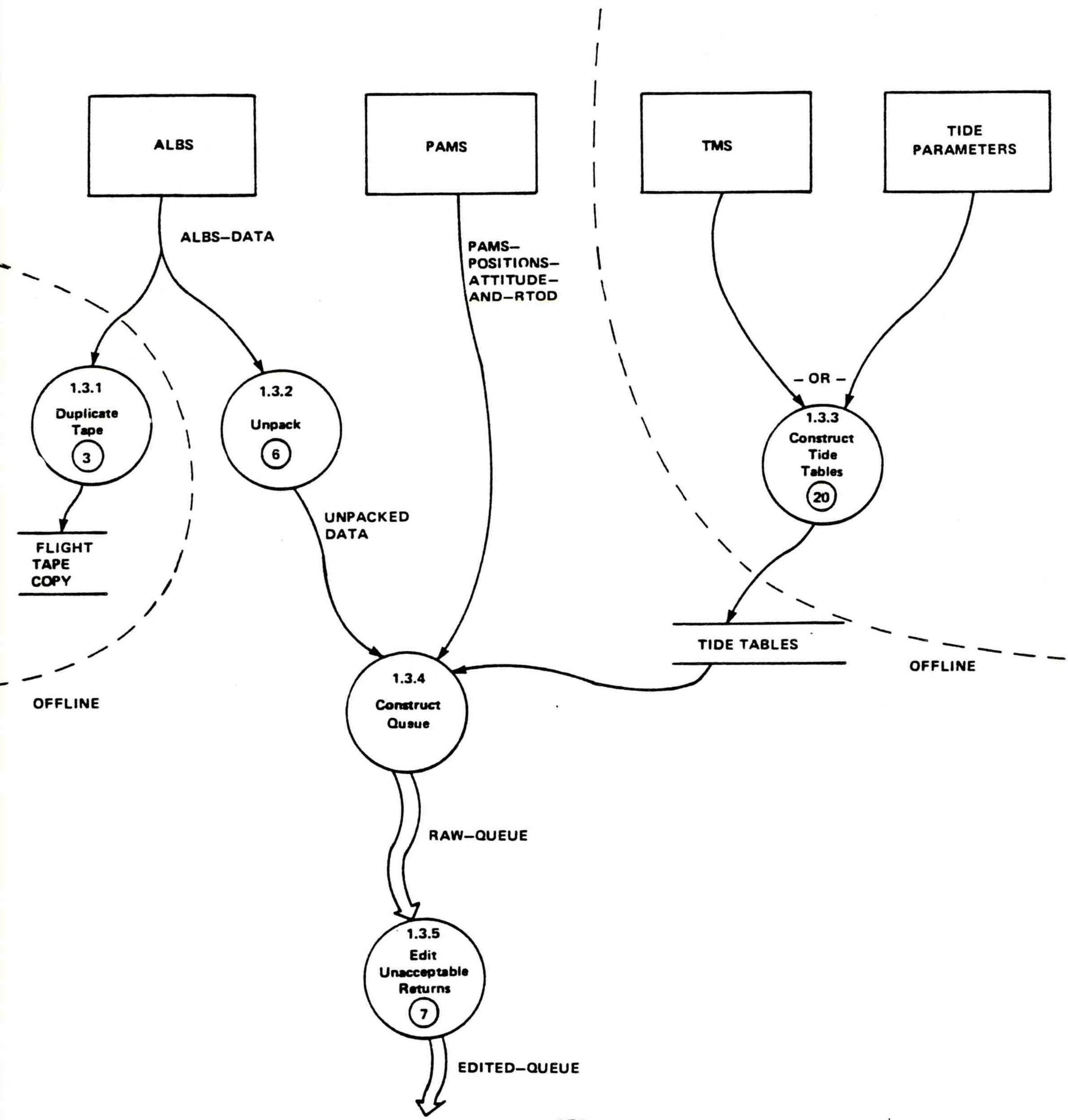
1.0 PRELIMINARY PROCESS



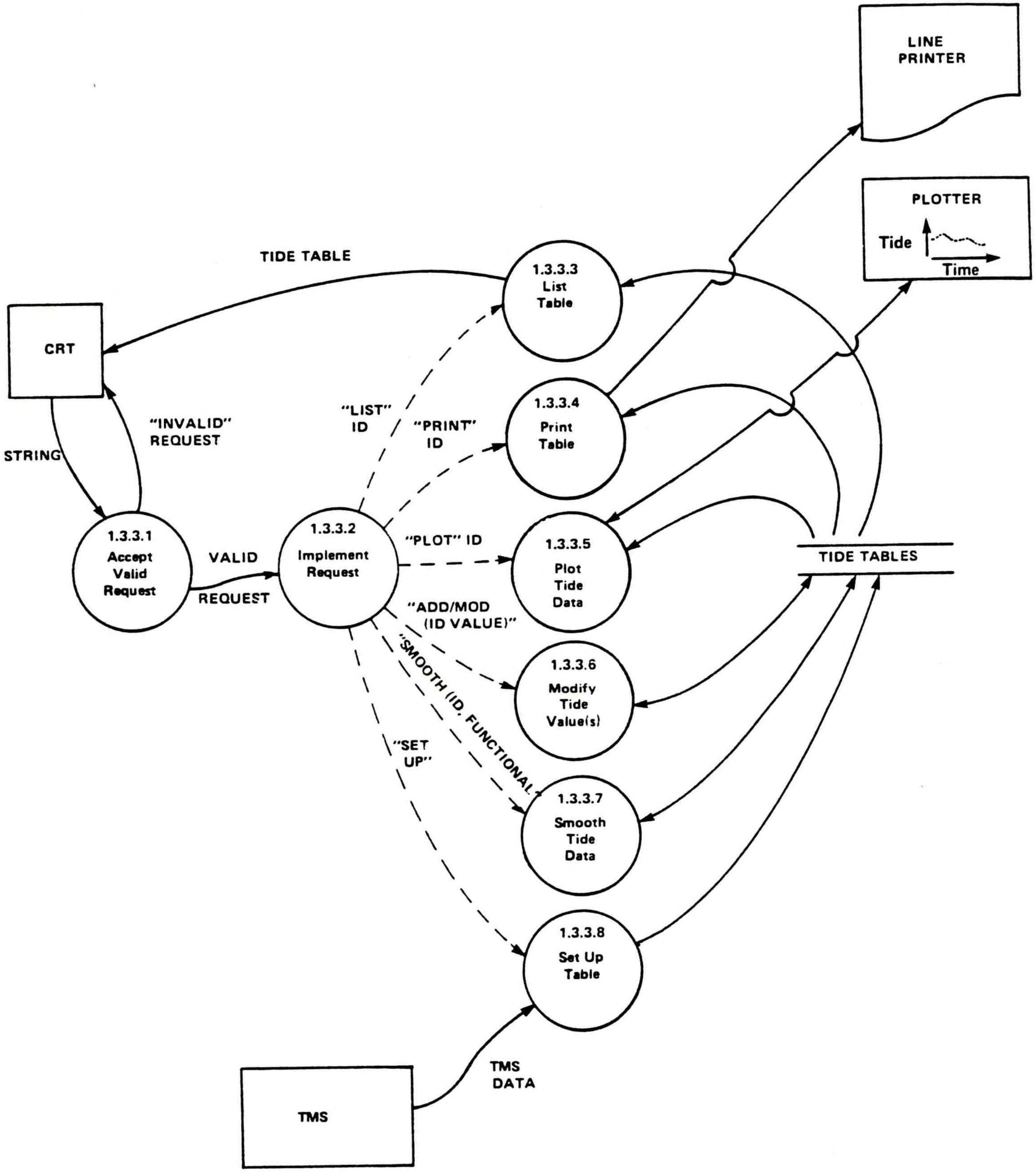
1.1 Initialize Flight Tape



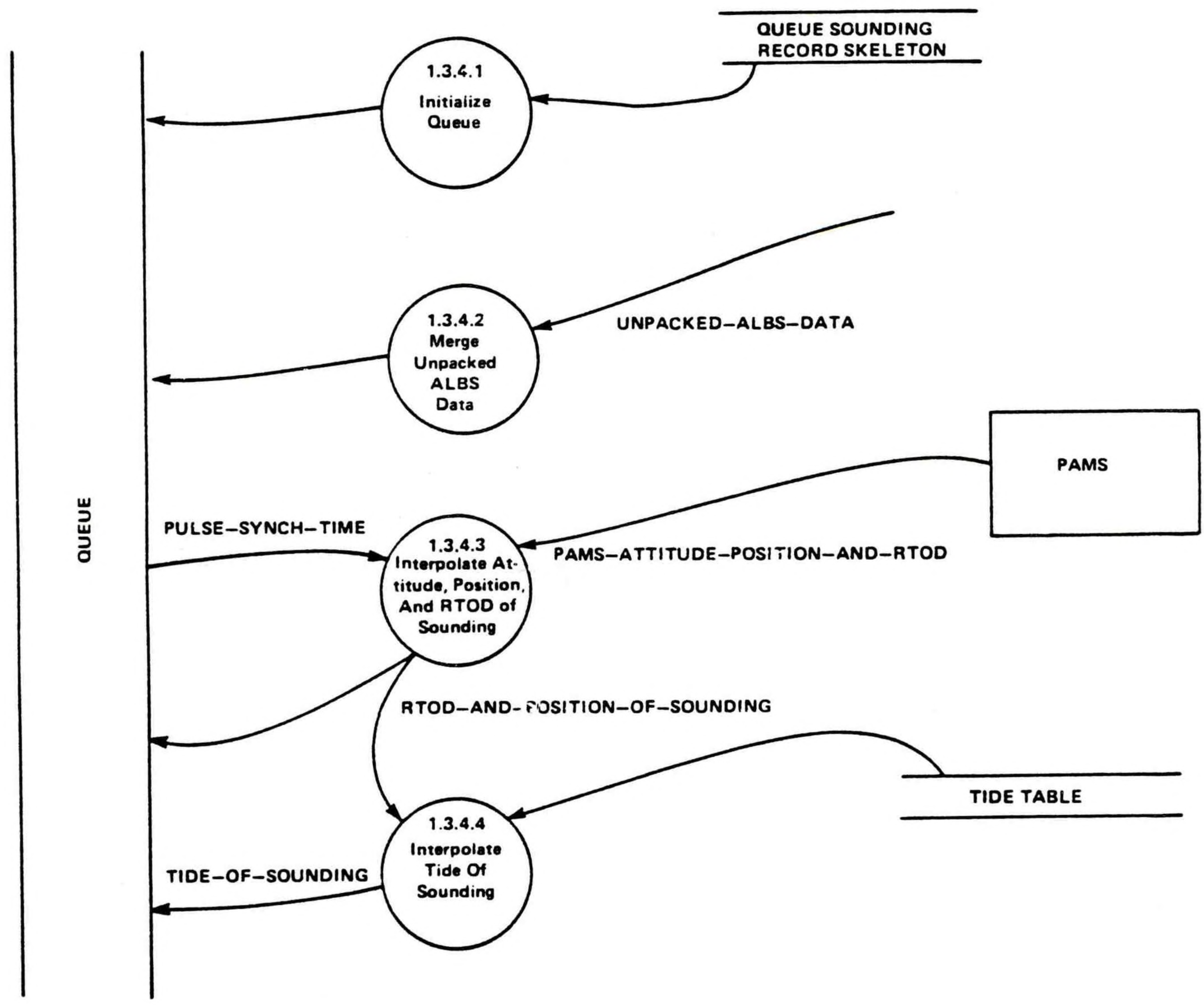
1.3 Merge And Edit



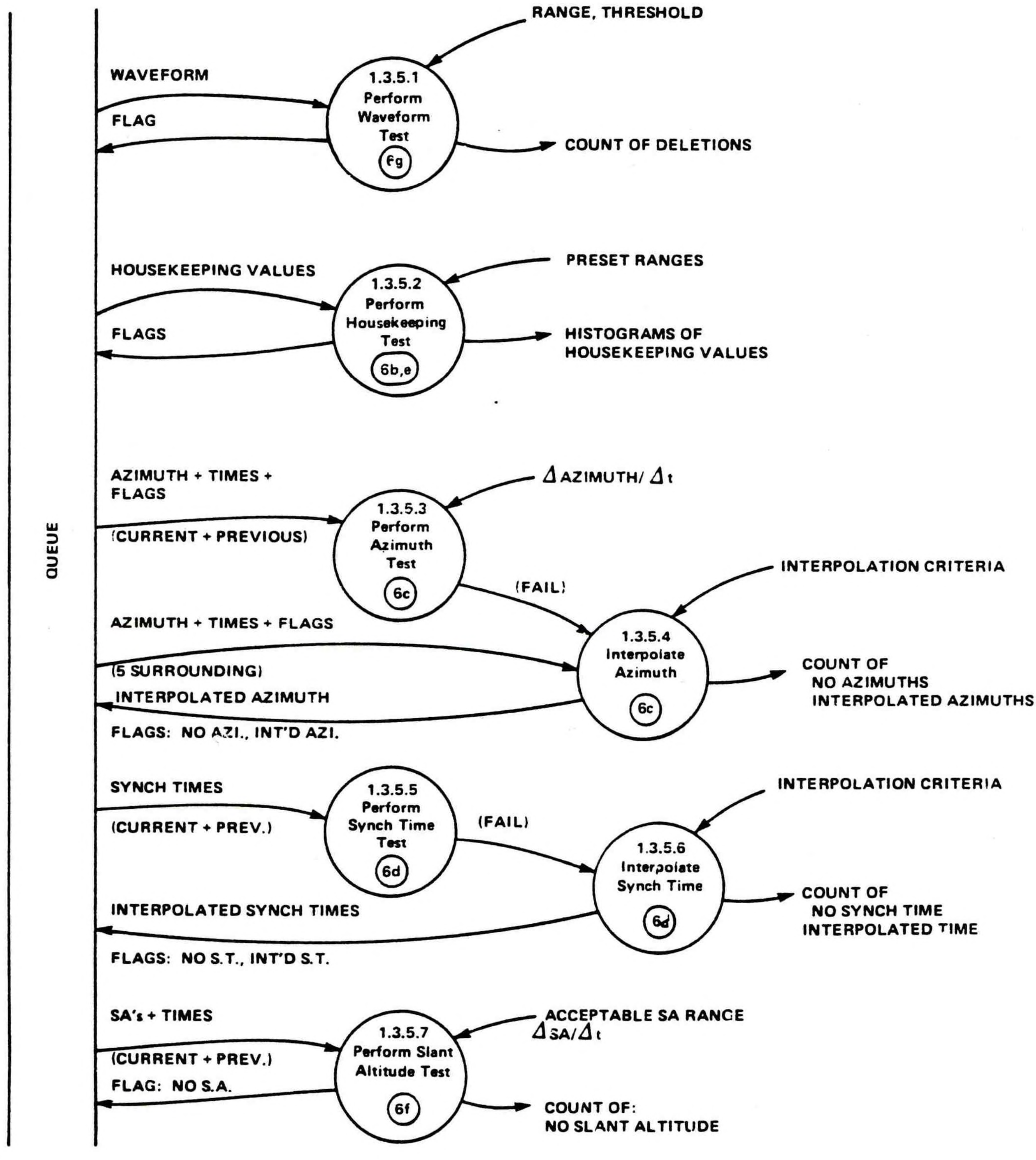
1.3.3 Construct Tide Tables



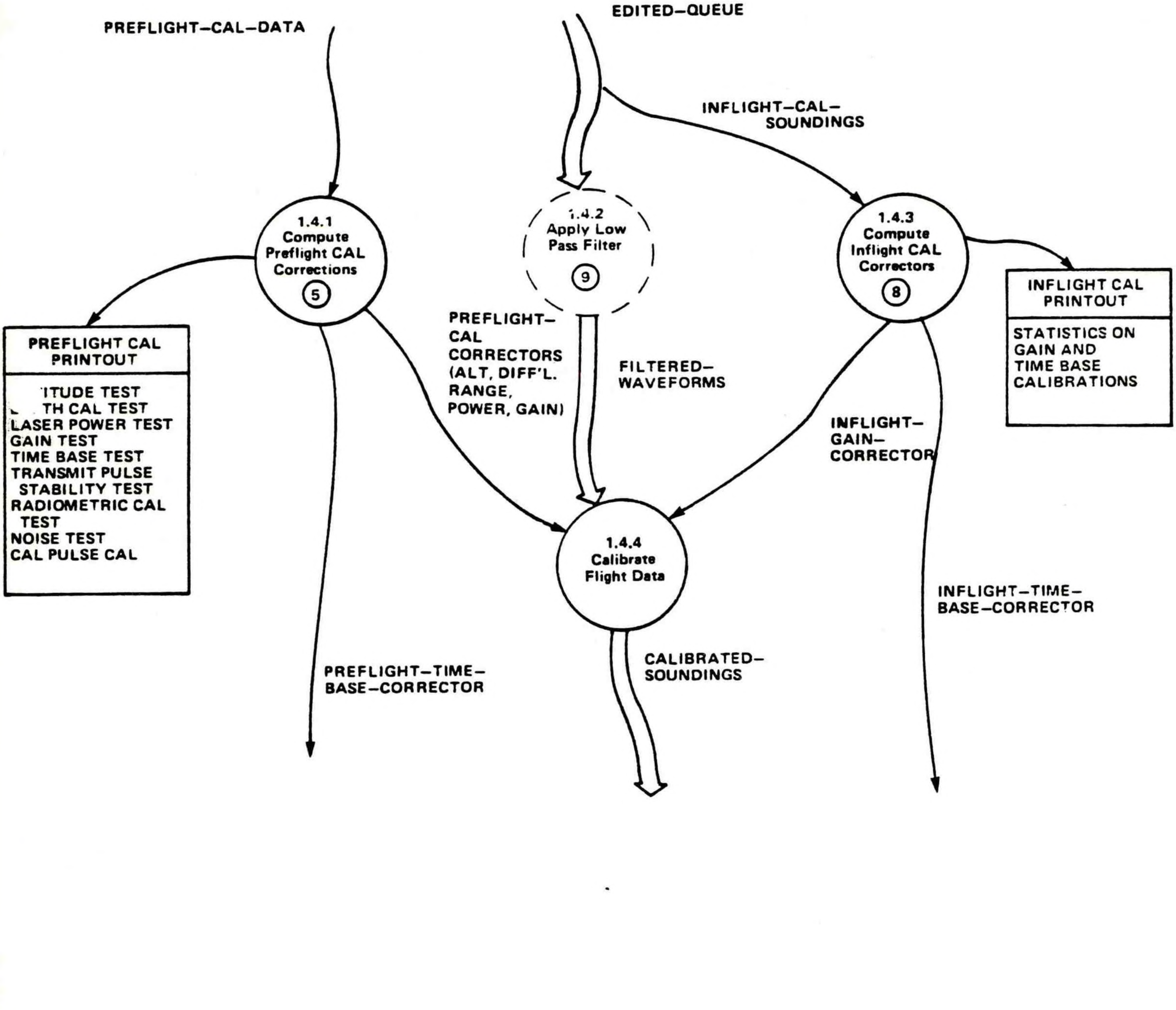
1.3.4 Construct Queue



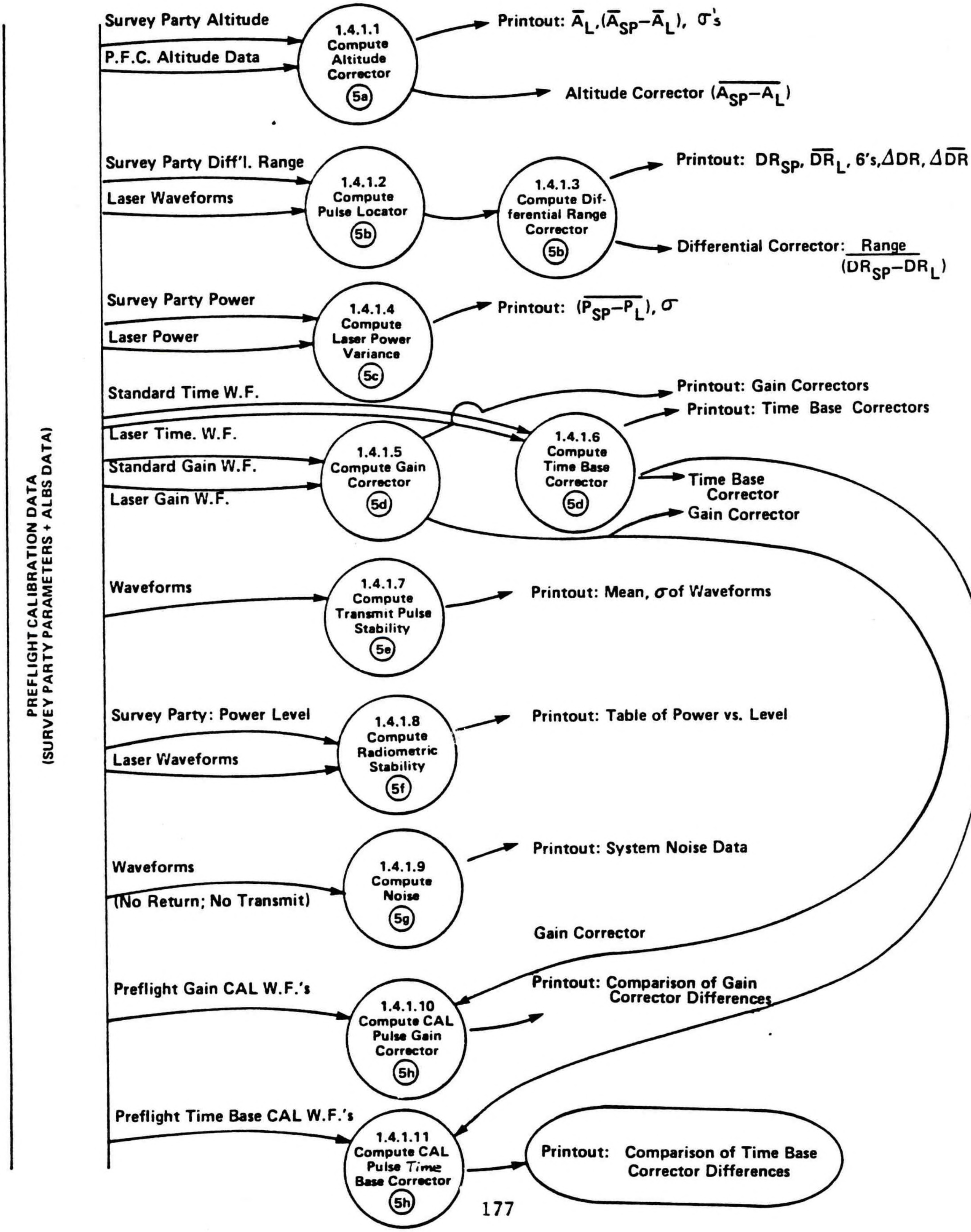
1.3.5 Edit Unacceptable Returns



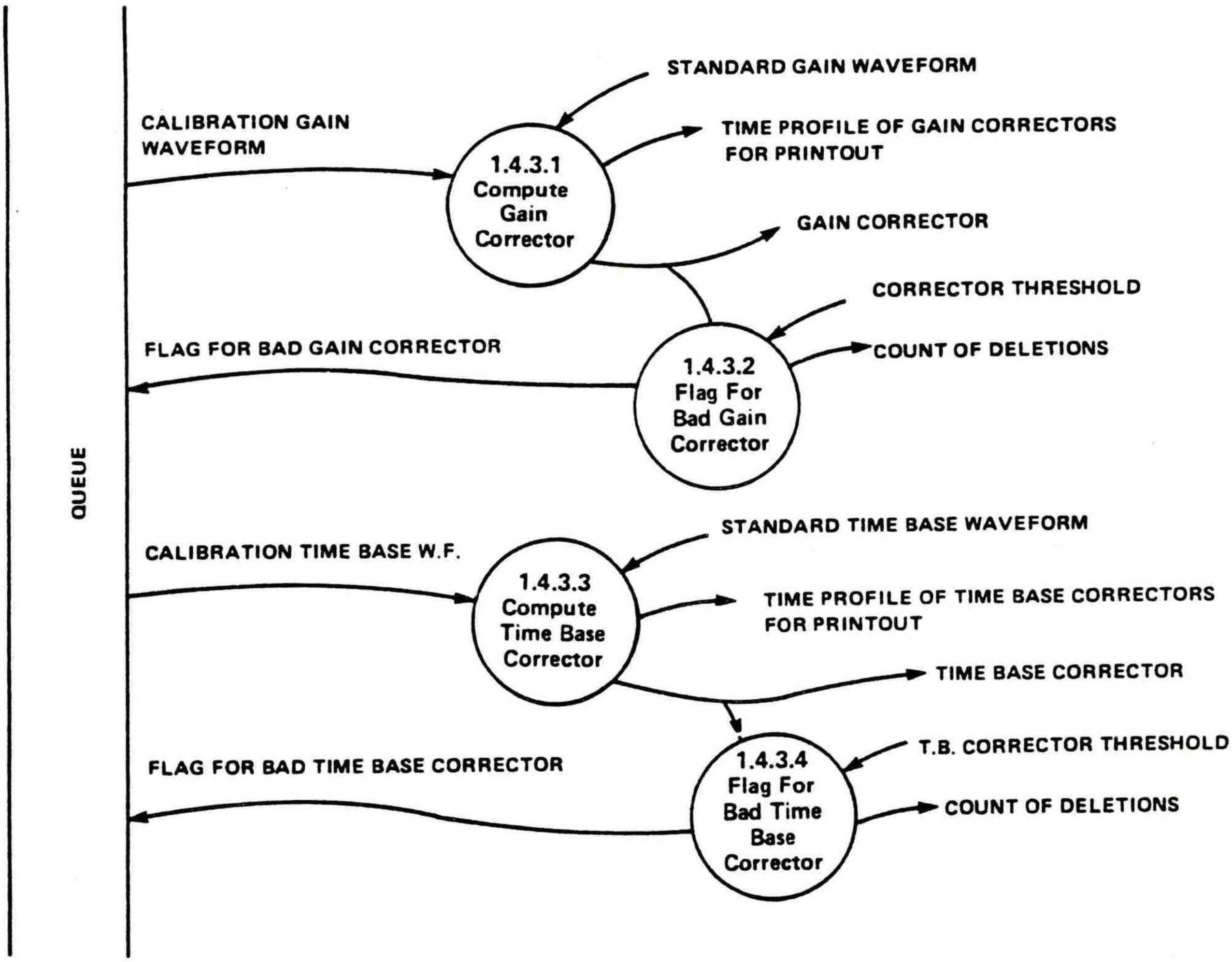
1.4 Calibrate



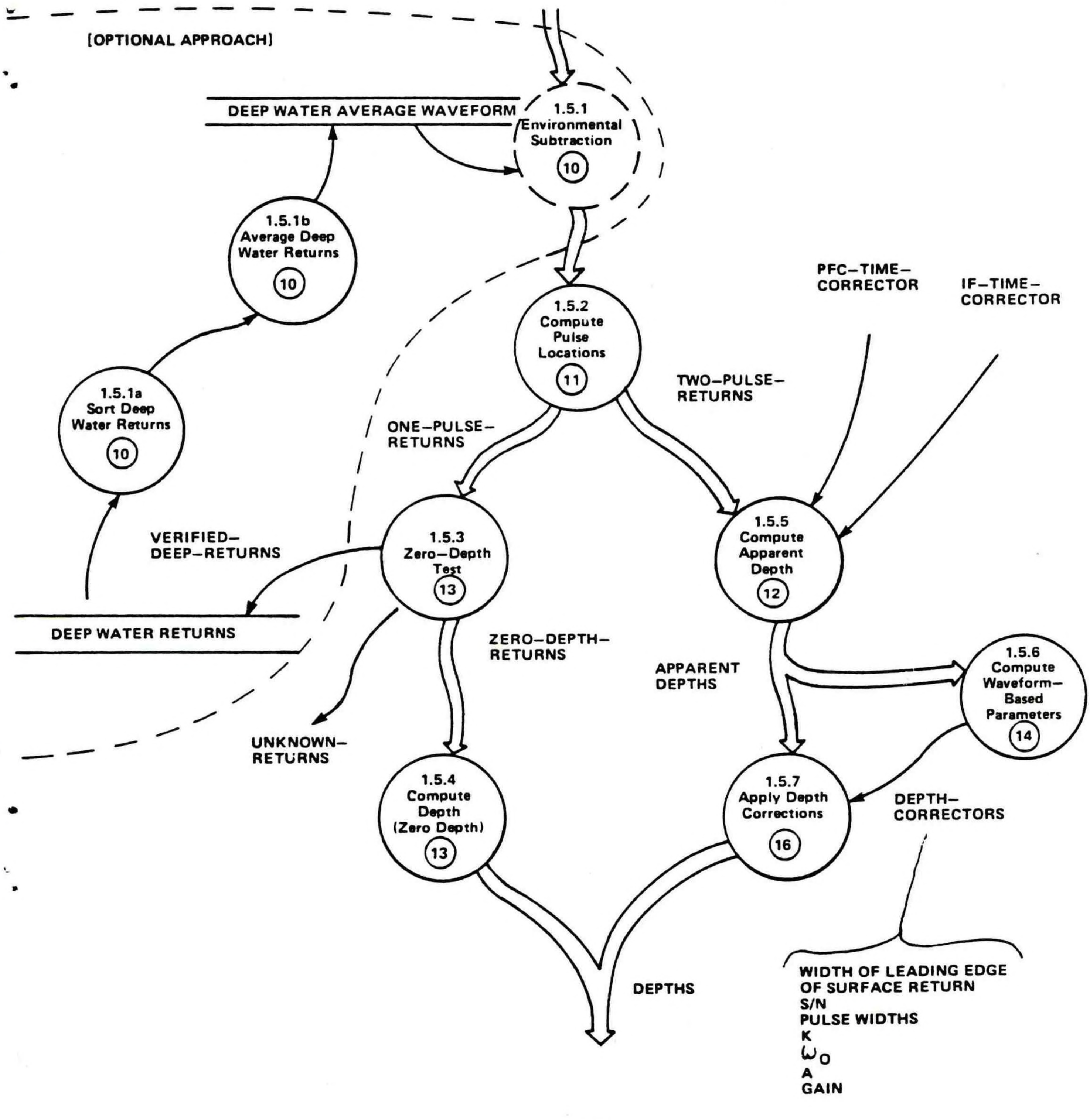
1.4.1 Compute Preflight Calibration Correctors



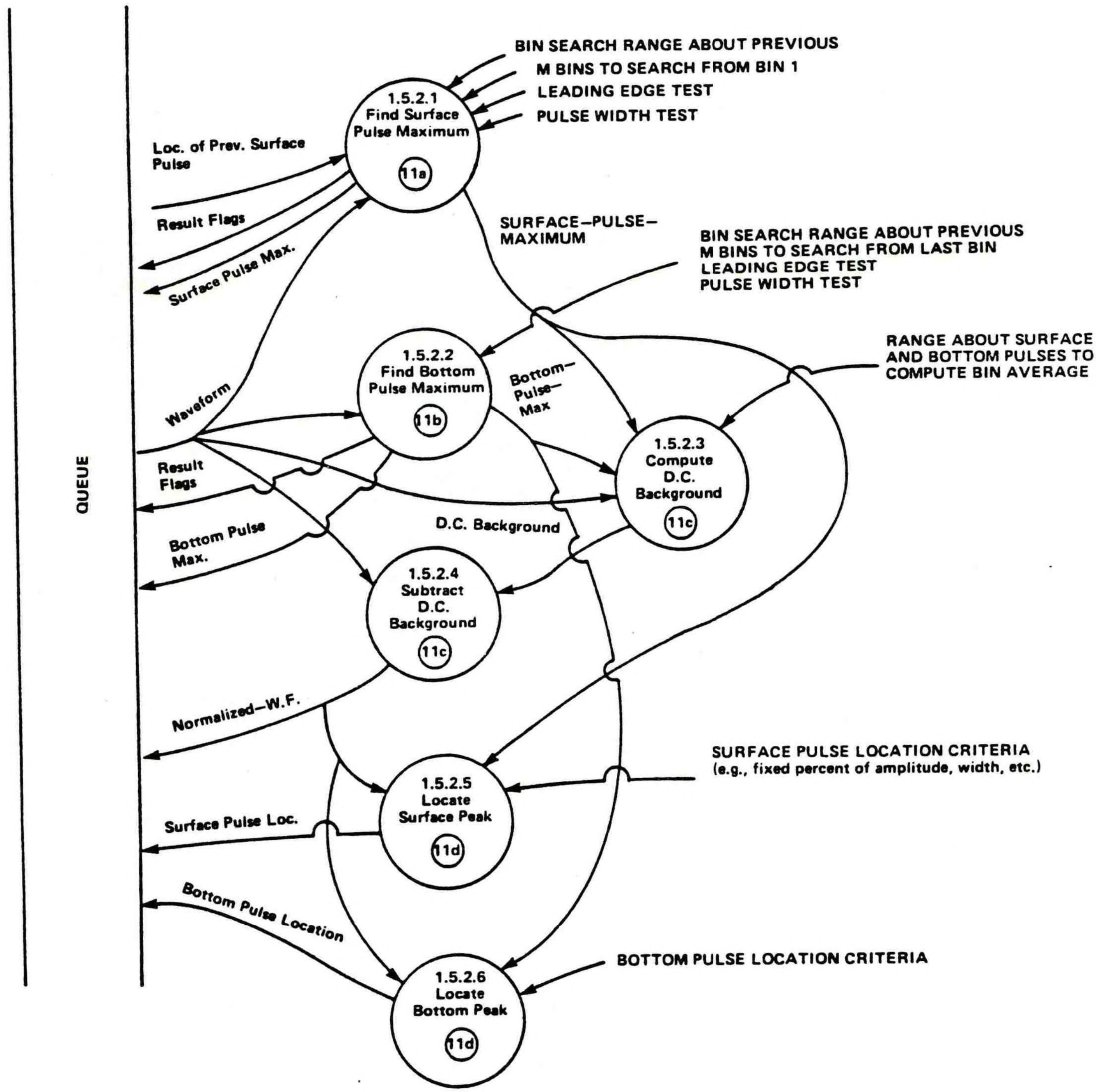
1.4.3 Compute Inflight Calibration Correctors



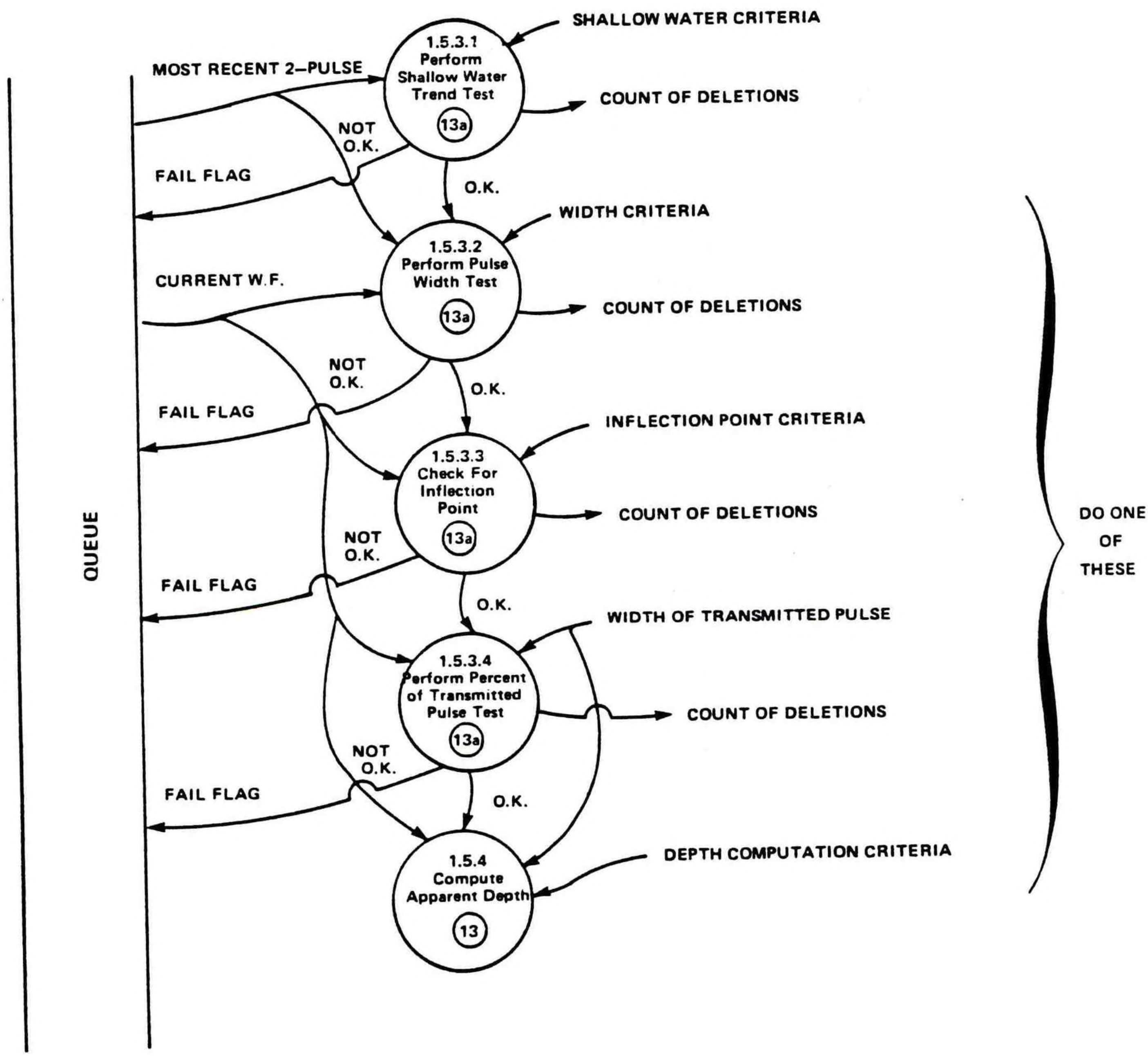
1.5 Compute Depths



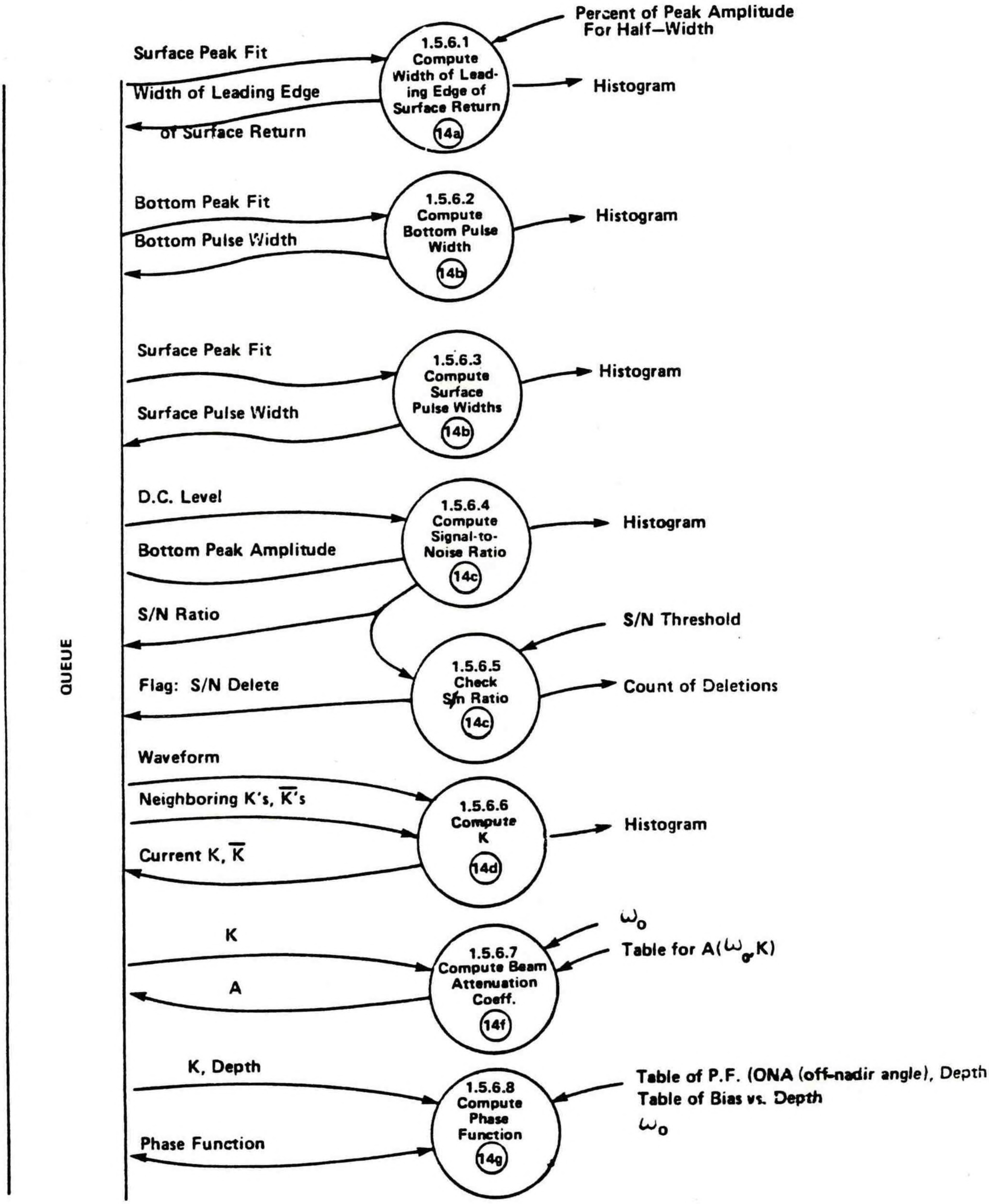
1.5.2 Compute Pulse Locations



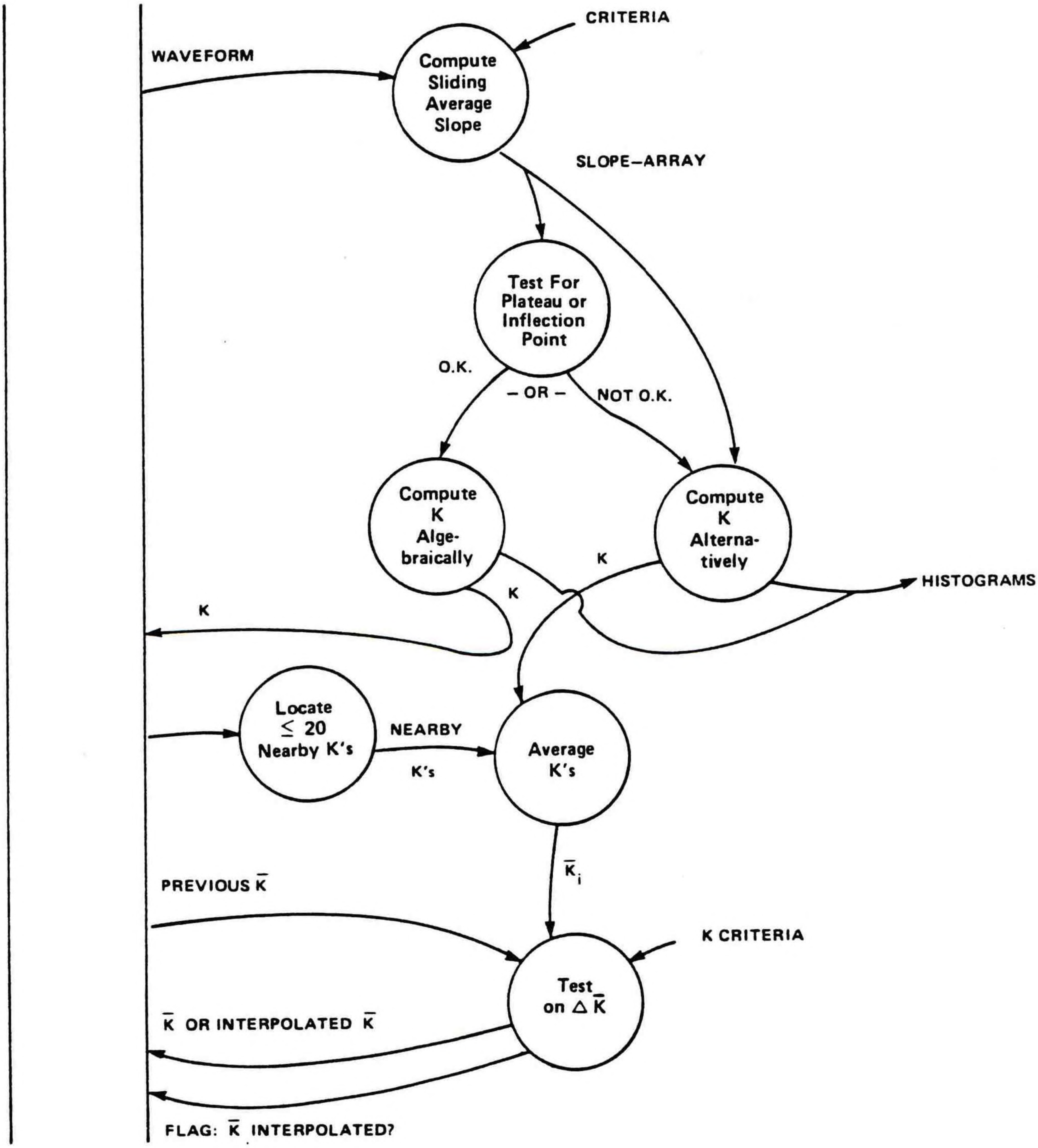
1.5.3 Zero Depth Test



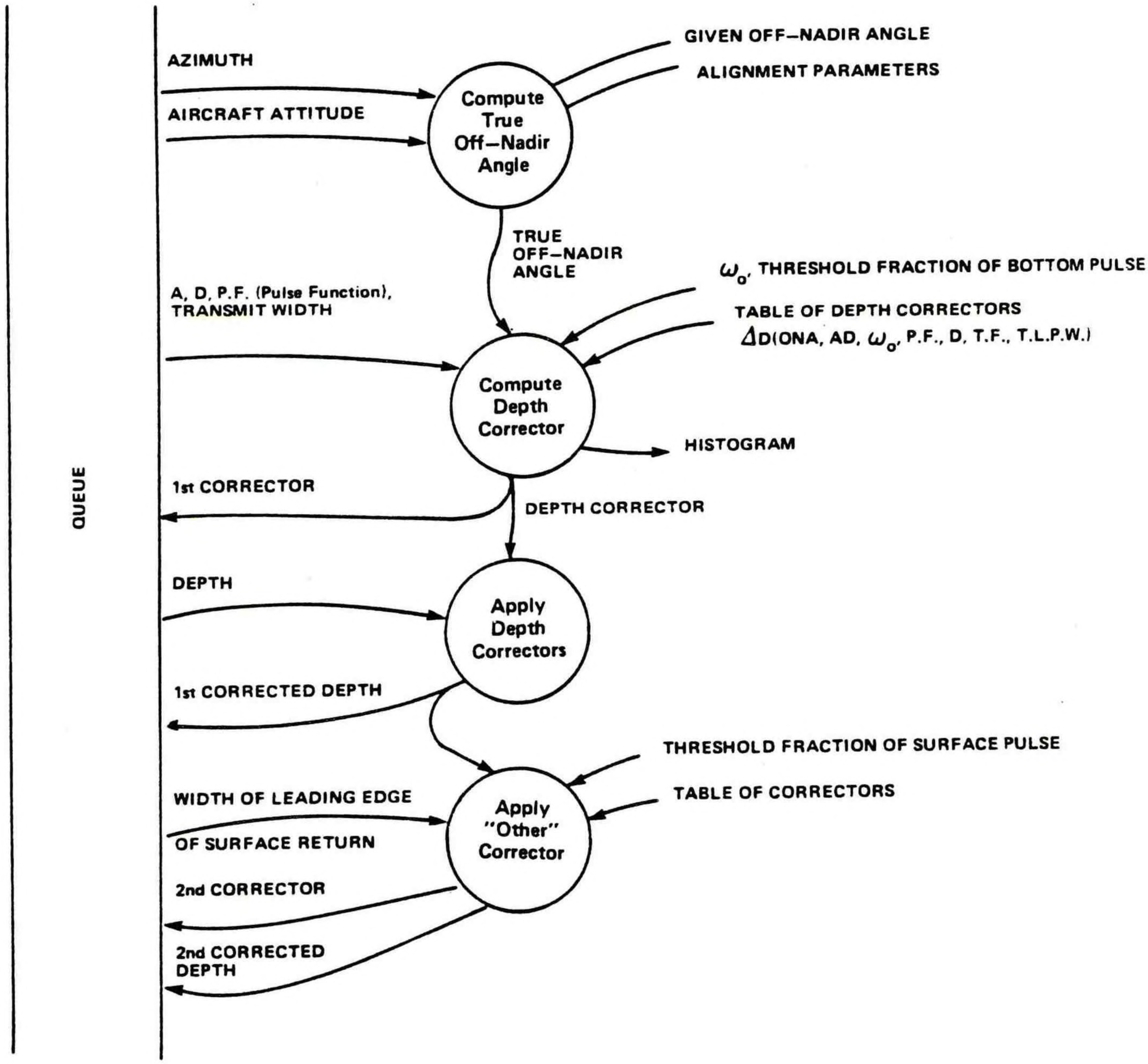
1.5.6 Compute Waveform—Based Parameters



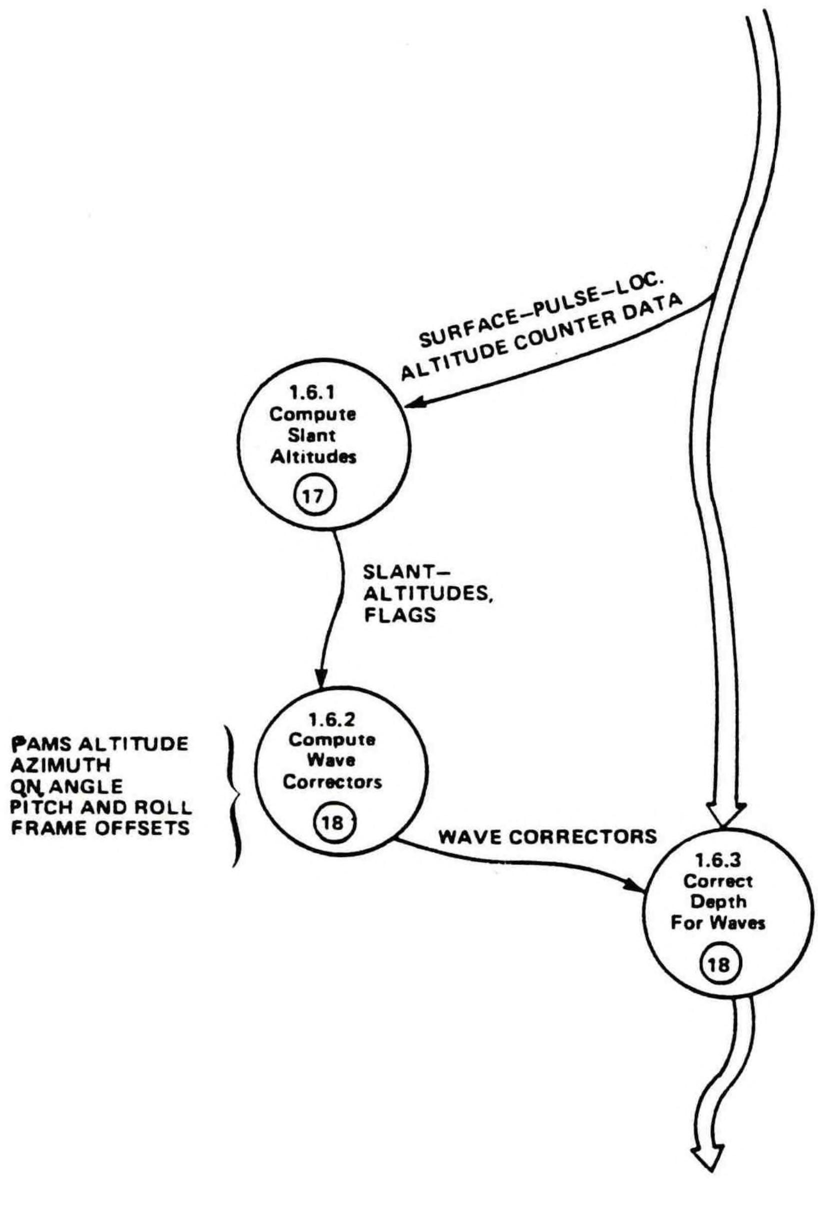
1.5.6.6 Compute K (Effective Diffuse Attenuation Coefficient)



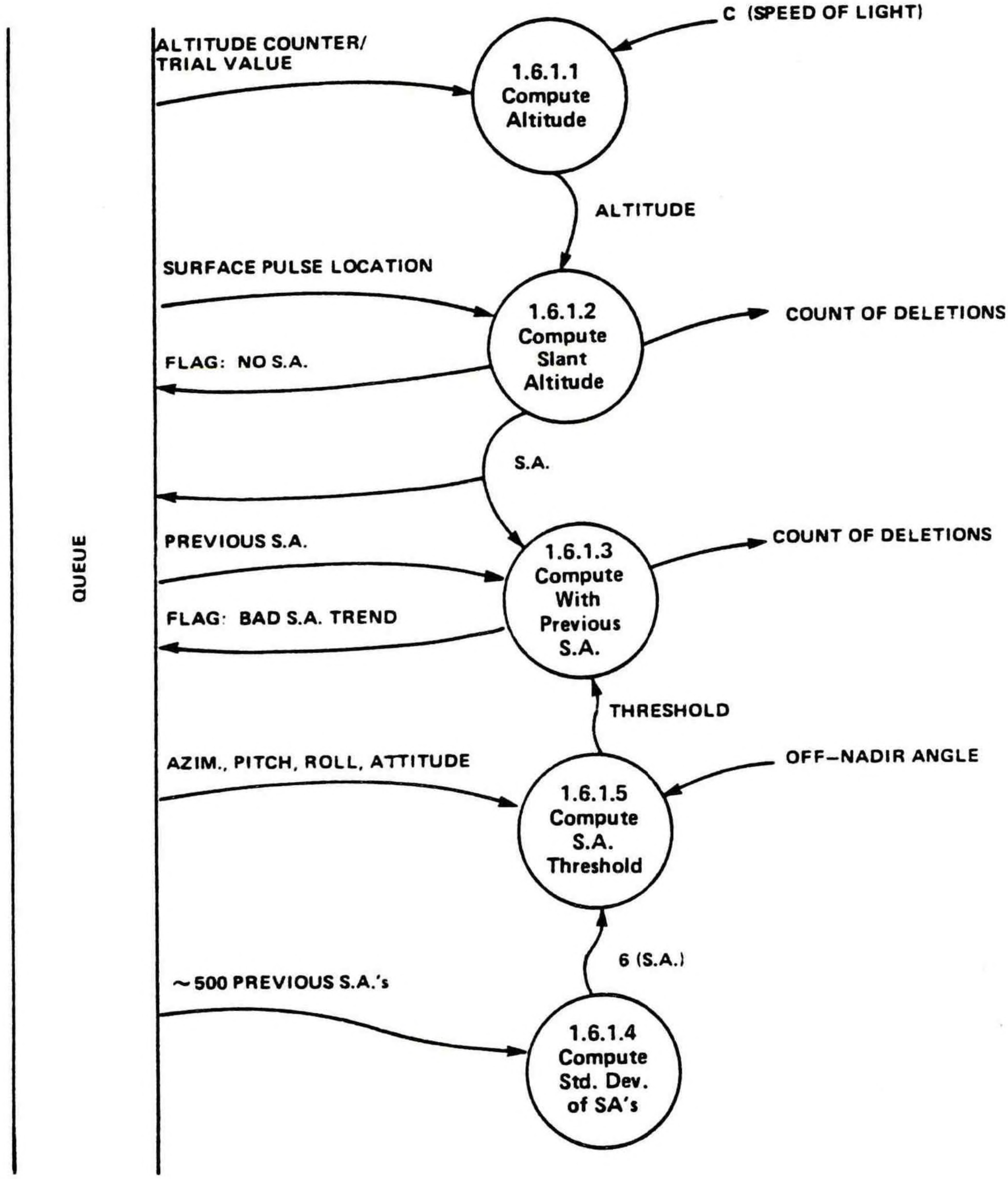
1.5.7 Apply Depth Correctors



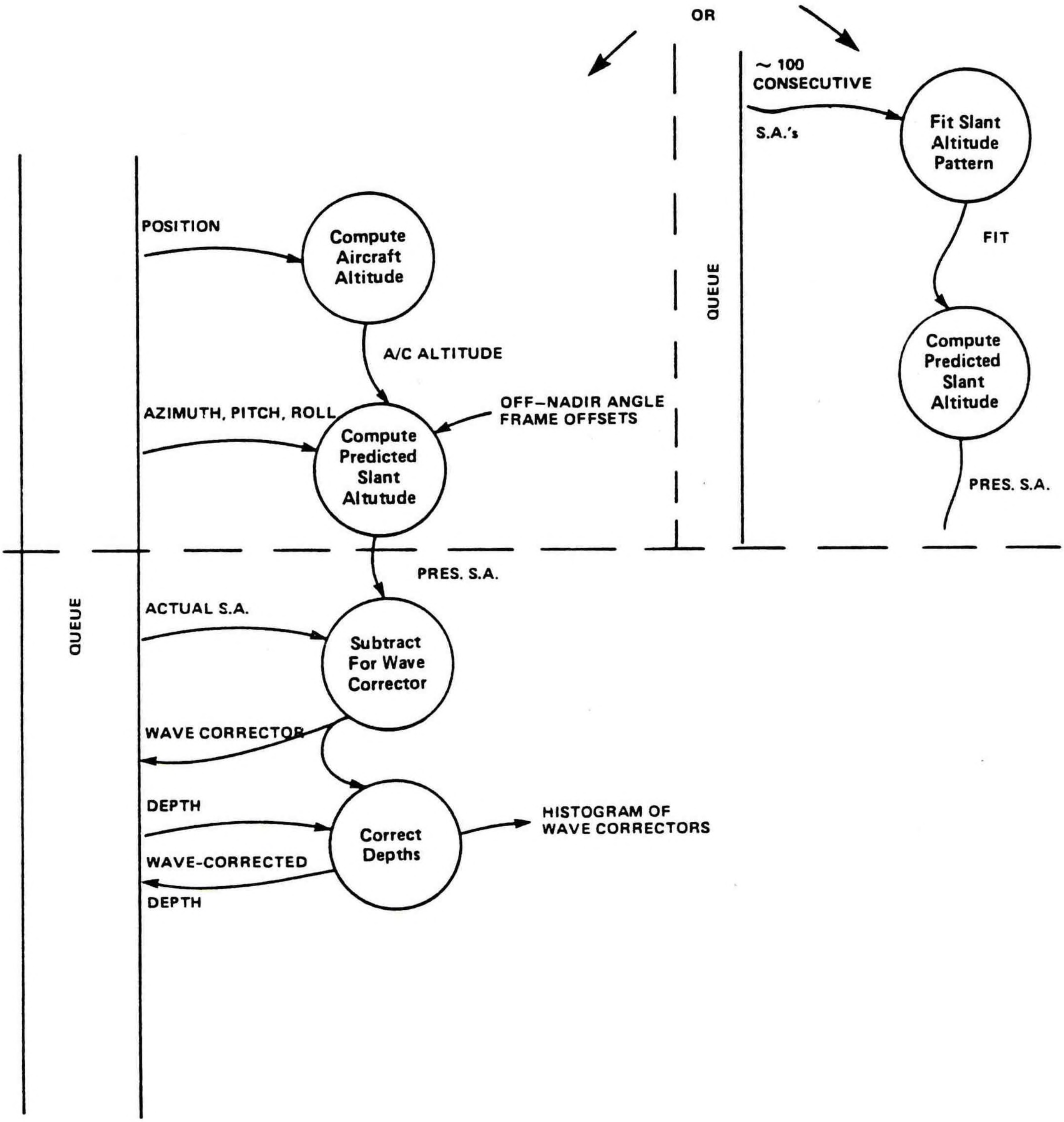
1.6 Correct For Waves



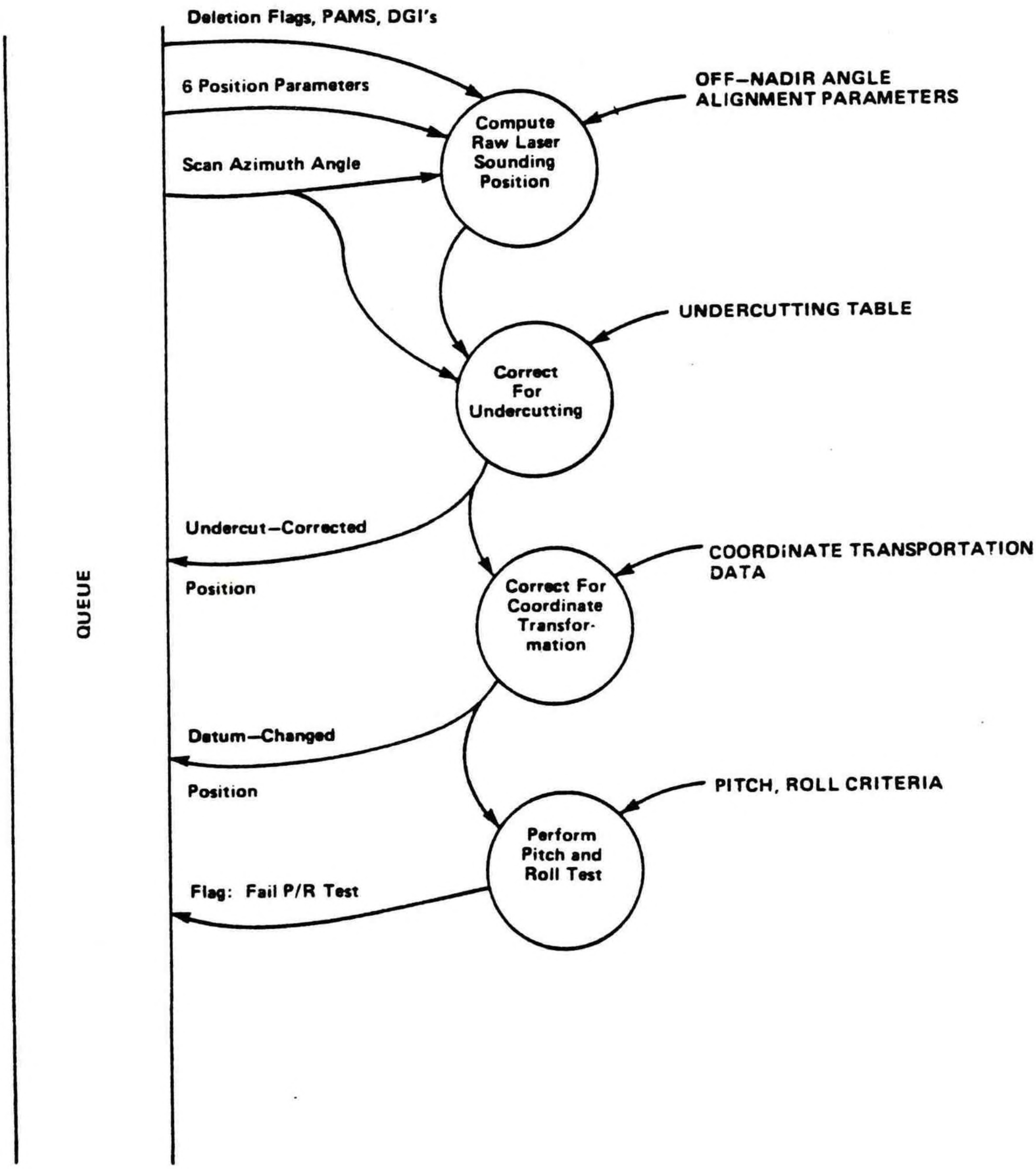
1.6.1 Compute Slant Altitudes (S.A.)



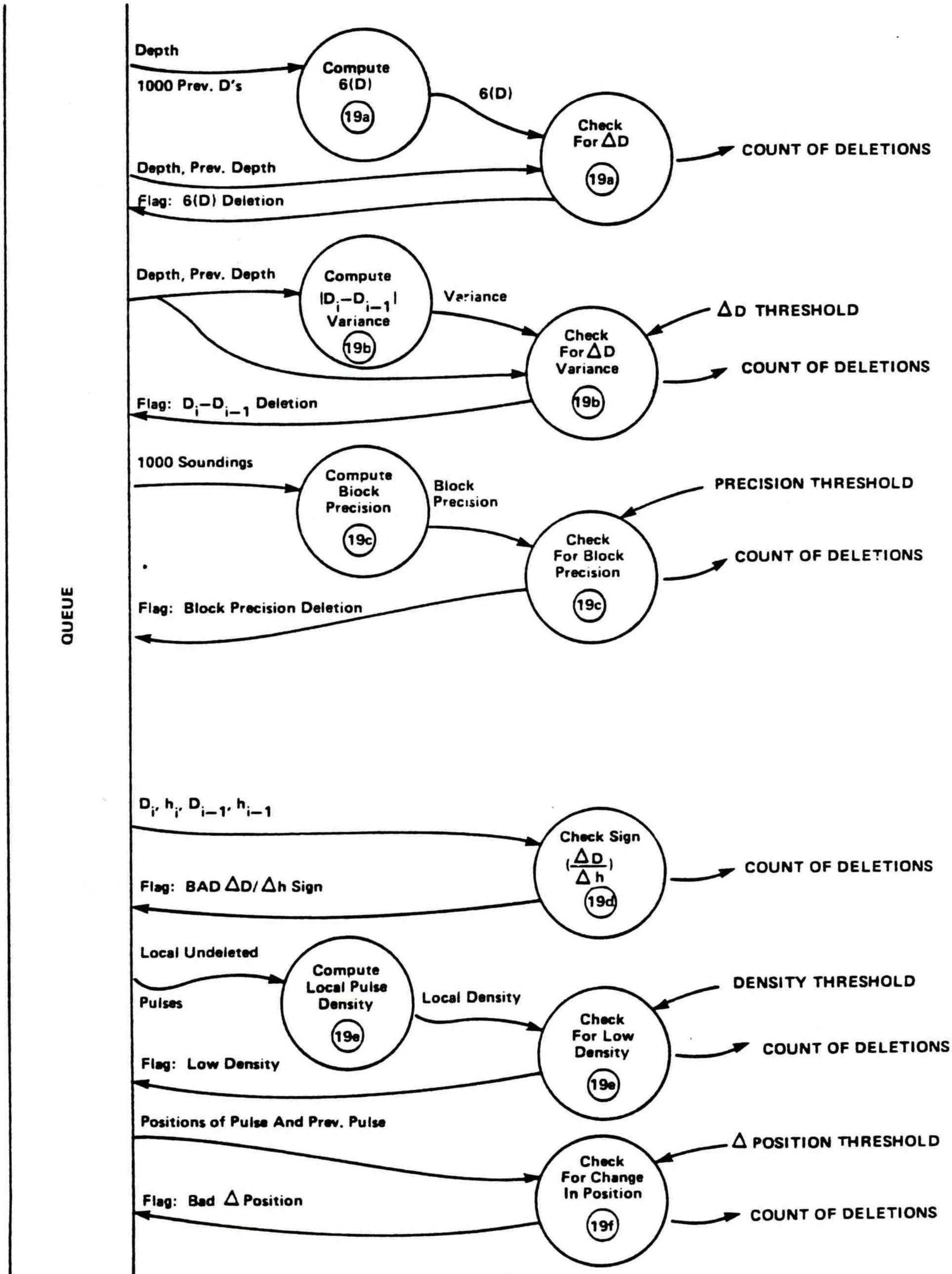
1.6.2 Compute And Apply Wave Correctors



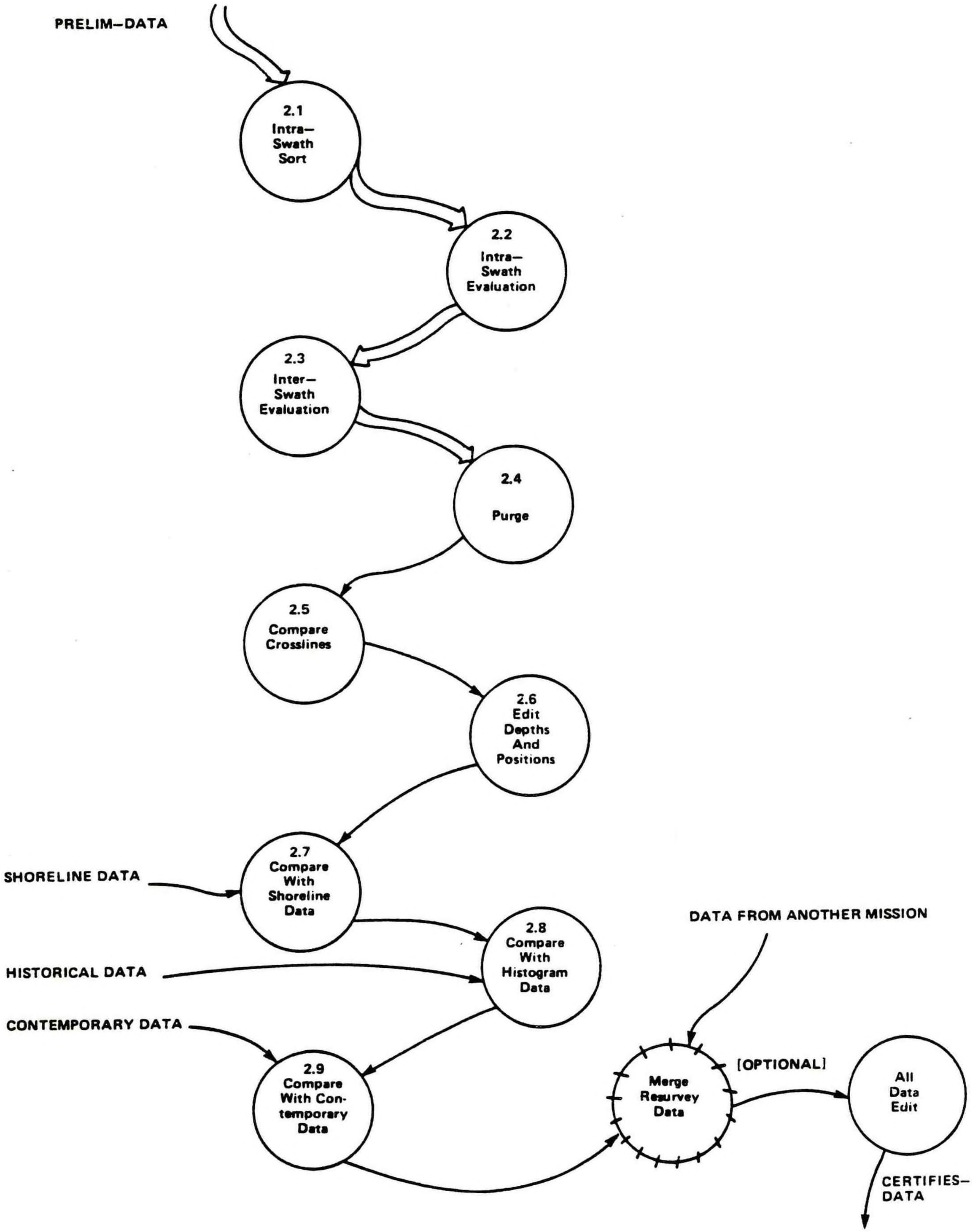
1.7 Compute Laser Sounding Position



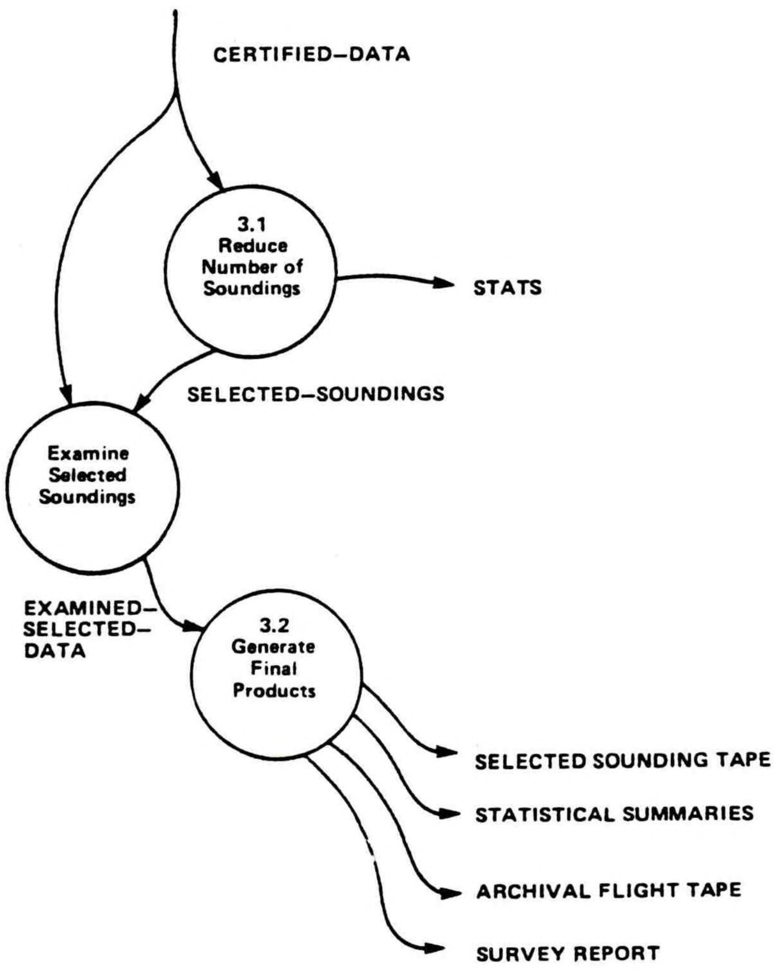
1.8 General Edit



(LEVEL 2) 2. INTERMEDIATE PROCESSING



(LEVEL 2) 3. FINAL PROCESS



APPENDIX D

High Density Tape Drives

The ALH data collection system requires an airborne data recorder which can record 1.4 megabits/sec for a period of up to 6 1/2 hours. Three candidate systems are the Bell and Howell N-141, the Sangemo Sabre V, and the Ampex AR-1700.

The functional specifications of the three units are virtually identical. Each has up to 28 or 32 tracks in a normal configuration, a maximum tape speed of 120 ips with lower speeds available in negative powers of two, and a 14-inch diameter reel which can normally contain up to 9200 feet of tape. For airborne applications, a density of 26.6 Kbits per inch is considered satisfactory for all units.

If four tracks are reserved for markers, at least 24 tracks are available for recording the data. If a 1.4 megabit/sec data stream is fanned out over 24 tracks, the data rate on each track will be 58 Kbits/sec. Using a maximum per track density of 26.6 Kbits per inch, the required tape speed is at least 2.2 ips. At the available speed of 3 3/4 ips, a 9200 foot tape will record for 8.2 hours, easily exceeding the required capacity for a single tape.

It is assumed that the ALH System will require on-board monitoring capability so the operator can check that the data is actually being recorded, but not full on-board reproducing capability. In this configuration, each of the units has a volume of about three cubic feet and weighs between 100 and 125 pounds, depending on mounting arrangements. All three units have identical power requirements: 300 watts at 28 VDC. Delivery for each unit is about six months. The Ampex and Sangemo systems cost about $100,000 each. The Bell and Howell system has a base price of $156,000. ALH shock and vibration requirements may be a determining factor in the choice.

The above analysis of high density tapes recorders follows requirements analysis for the Multispectral Data Processing System prepared by W.W. Gaertner Research, Inc. for the Rome Air Development Center (ref. 10).

NOAA SCIENTIFIC AND TECHNICAL PUBLICATIONS

The National Oceanic and Atmospheric Administration was established as part of the Department of Commerce on October 3, 1970. The mission responsibilities of NOAA are to assess the socioeconomic impact of natural and technological changes in the environment and to monitor and predict the state of the solid Earth, the oceans and their living resources, the atmosphere, and the space environment of the Earth.

The major components of NOAA regularly produce various types of scientific and technical information in the following kinds of publications:

PROFESSIONAL PAPERS—Important definitive research results, major techniques, and special investigations.

CONTRACT AND GRANT REPORTS—Reports prepared by contractors or grantees under NOAA sponsorship.

ATLAS—Presentation of analyzed data generally in the form of maps showing distribution of rainfall, chemical and physical conditions of oceans and atmosphere, distribution of fishes and marine mammals, ionospheric conditions, etc.

TECHNICAL SERVICE PUBLICATIONS—Reports containing data, observations, instructions, etc. A partial listing includes data serials; prediction and outlook periodicals; technical manuals, training papers, planning reports, and information serials; and miscellaneous technical publications.

TECHNICAL REPORTS—Journal quality with extensive details, mathematical developments, or data listings.

TECHNICAL MEMORANDUMS—Reports of preliminary, partial, or negative research or technology results, interim instructions, and the like.

Information on availability of NOAA publications can be obtained from:

PUBLICATION SERVICES BRANCH (E/AI13)
NATIONAL ENVIRONMENTAL SATELLITE, DATA, AND INFORMATION SERVICE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

Washington, DC 20235

NOAA--S/T 83-142