NOAA Technical Memorandum OTES 4

FY 1983 ISSUE PAPER - AIRBORNE LASER HYDROGRAPHY

Rockville, Md.
May 1982

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

NOAA TECHNICAL REPORTS

...an Technology and Engineering Services Series

... below are available in both hard copy and microfiche form from the National Technical Information Service, U.S Department of Commerce, Sills Building, 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.

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

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

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

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.

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)

NOAA Technical Memorandum OTES 4

FY 1983 ISSUE PAPER - AIRBORNE LASER HYDROGRAPHY

David B. Enabnit

Rockville, Md.
May 1982

UNITED STATES
DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

National Oceanic and
Atmospheric Administration
John V. Byrne, Administrator

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

CONTENTS

SECTION PAGE

CONTENTS (con't)

C O N T E N T S (con't)

SECTION PAGE

CONTENTS (con't.)

LIST OF FIGURES

Figure Page

LIST OF FIGURES (con't)

LIST OF TABLES

LIST OF TABLES (con't)

Table | Page

FY 1983 ISSUE PAPER
AIRBORNE LASER HYDROGRAPHY

David B. Enabnit
NOAA/Office of Ocean Technology and Engineering Services
Engineering Development Office
Rockville, Md

ABSTRACT. Increases to a government organization's funding level can be requested through the budget initiative process. An Issue Paper is written to support such requests. The Issue Paper provides necessary background information, defines and supports the need for an increase, explains how the funds will be used and what benefits will be derived, and, finally, presents the amount of the increase being requested.

The following Issue Paper was written to request increased funding to build and operate an airborne laser hydrography system. The system would be used by the National Ocean Survey to perform hydrographic surveys in water less than 60 meters deep. It would cost $5,720K to build and a total of $7,632K to operate for 8 years. $29 million and 196 staff years would be saved.

The Issue Paper was reprinted as a NOAA Technical Memorandum because it contains factual information about airborne laser hydrography, its costs and benefits, and its relationship to present surveying systems which is not documented elsewhere.

1.0 EXECUTIVE SUMMARY

1.1 Objectives and Summary

NOAA requests three positions and $1,430K to develop and test an airborne laser hydrography system, transition that system into the National Ocean Survey (NOS) inventory of shallow water hydrographic survey systems, and operate that system for 8 years.

1.2 Program Need

NOAA is the sole agency with legislative responsibility for charting U.S. coastal waters and the Great Lakes. If NOAA cannot start to implement improved, more economical, and higher productivity tools for performing hydrography, the production of hydrographic data will not meet demands and coastal areas where established requirements exist will remain unsurveyed. Due to the present low density of soundings, hazards to navigation may be undetected and human life and property endangered. Without the development and introduction of a laser hydrography system to meet the increased demand for survey data and the increased cost of surveying by launch, NOAA cannot adequately perform its survey mission without drastic increases in manpower and funds.

1.3 Proposed Program

This 12-year program encompasses a Development Phase, a Transition Phase, and an Operational Phase. In the 3-year Development Phase, the Office of Ocean Technology and Engineering Services (OTES) will receive $1,340K annually plus 1 position and NOS will receive $90K annually plus 2 positions of the total +3/$1,430K increase. OTES will use their funds to develop and test one airborne laser hydrography system. NOS will be responsible for developing and testing a data processing capability for handling the additional survey data.

In the 1-year Transition Phase, OTES will receive $1,340K to transition the laser hydrography system to an operational status, and NOS will receive $90K to transition the data handling capability.

At the beginning of the 8-year Operational Phase, the required resources will decrease from the total of $1,430K annually to $954K annually. The $954K will be used by NOS to operate the airborne laser hydrography system and to process the resulting data.

The total program cost is $13,352K.

1.4 Program Result

The airborne laser hydrography system will be used to survey 16,000 square nautical miles (nm^2) during its 8-year design lifetime. Of the 16,000 nm^2, 6,400 nm^2 will be used to supplant existing survey sytems and 9,600 nm^2 will be used to increase the amount of area surveyed by NOS. The proposed program will avoid $29 million of costs and 196 staff years of effort. In addition, the number of soundings gathered per unit area will increase by a factor of 100. The benefit to cost ratio for an airborne laser hydrography system is 7.5 at the planned amount of surveying.

1.5 Resources (Positions/Thousands of Dollars)

FY 1983	FY 1984	FY 1985	FY 1986	FY 1987
+3/$1,430K	0/0	0/0	0/0	0/-$476K

2.0 INTRODUCTION

2.1 Purpose

The purpose of this Issue Paper is to solicit the approval, funds, and positions required to develop and operate an airborne laser hydrography system. The goal is to use airborne laser hydrography to reduce the cost and manpower required for shallow water hydrographic surveys.

The Issue Paper is organized as follows: Section 2.0 provides necessary background information; Section 3.0 describes the present method of performing hydrographic surveys, documents the need for those surveys, and quantifies the cost and manpower requirements of the present technique; Section 4.0 describes the alternative technologies that were considered to reduce the cost and manpower requirements of surveying; Section 5.0 describes the chosen solution -- airborne laser hydrography -- and quantifies the benefits of the technique; Section 6.0 describes the impact of implementing the proposed program; Section 7.0 describes the proposed program to develop and operate an airborne laser hydrography system; the use of program resources and the program schedule are presented in Section 8.0.

2.2 Background

The Department of Commerce Organization Order 25-5B, July 11, 1971, Section 13, describes the current responsibilities of the National Ocean Survey (NOS), NOAA. As part of its mission, NOS is "...to provide the basic maps, charts, surveys, and specialized data required for safe navigation and accurate location." NOS is the sole agency responsible for charting U.S. coastal waters and the Great Lakes.

In fulfilling its responsibilities during FY 1980, NOS will spend $10 million to operate a fleet of hydrographic survey vessels. This fleet will perform hydrographic surveys using launch-based sonar to acquire data for the production of nautical charts. The primary uses of these charts are commercial and recreational navigation, national defense, and environmental and oceanographic studies. For example, the NOS chart of Newark Bay and Kill Van Kull (commercial New York harbor) serves commercial shippers in the world's busiest port. The NOS chart of the Lynnhaven Inlet to the Norfolk Navy base in Virginia is a special chart prepared for the U.S. Navy. The NOS small craft chart of the Annapolis, Maryland, area serves navigators in one of the nation's most heavily used recreational boating areas. The safety of human life and property depends on the accuracy of the 2 million nautical charts distributed annually by NOS.

The cost of the hydrographic surveys needed for nautical charting has increased steadily as a result of inflationary pressures, the increased amount of surveying performed, and the need for more thorough surveys. To counter this trend, NOS aggressively pursues means of reducing the money, manpower, and time required for gathering hydrographic data. Simultaneously, ways to increase productivity are sought in order to help satisfy growing user requirements. Improvements in the economics and productivity of surveying are acceptable only if the resulting data meet the stringent standards for thoroughness and accuracy established by the International Hydrographic Bureau (IHB) and subscribed to by the United States.

NOS and OTES have led the way in developing, testing, and critically evaluating airborne laser hydrography as a new technique for performing low-cost hydrographic surveys in shallow water. This technique has taken 10 years to perfect and was a joint effort with the National Aeronautics and Space Administration (NASA), U.S. Navy, Defense Mapping Agency, private industry, and government scientists in Australia and Canada.

During the 10 years of investigation, it was found that airborne laser hydrography has the potential for performing hydrographic surveys at one-sixth the cost and with one-fifth the manpower of conventional, launch-based sonar systems. It was also demonstrated that airborne laser depth soundings meet the ±0.3 meter accuracy standard of NOS and of the IHB. It was estimated that one laser system should survey annually an amount of area to that now being surveyed by 20 hydrographic launches. Using actual data on the optical properties of water in 10 typical areas, it was determined that a large amount of area where national survey requirements exist could be surveyed by laser. Finally, an airborne laser system would increase by 100-fold the number of soundings made per unit area, making undetected hazards to navigation less likely.

2.3 Proposed Activity

NOS and OTES are proposing to develop and operate an airborne laser hydrography system to reduce the cost and manpower required for shallow-water surveying. NOS is also proposing to use 60 percent of the surveying capacity of the laser system to increase the amount of area surveyed annually in response to increased user requirements.

Three distinct activities will be involved. First, an airborne laser hydrography system will be developed. The development phase will last 3 years, during which a system will be developed, fabricated, and tested. The second phase, a year-long transition period, will follow for user test and evaluation, training, and techniques development. Finally, there will be the operational phase lasting 8 years, during which the system will be routinely used by NOS to gather hydrographic data.

The amount of area surveyed will be a 75 percent expansion of the existing, shallow-water hydrography effort. Over the 8-year operating life of the system, $29 million less will be spent and 196 fewer man-years will be used than if this shallow water were surveyed by conventional means.

3.0 PRESENT METHOD OF HYDROGRAPHIC SURVEYING

This section documents the present method of hydrographic surveying, launch-based sonar, to use as a baseline for evaluating new surveying technologies. A brief description of the requirements for nautical charts and hydrographic surveys and the present surveying technique is presented in Subsections 3.1 and 3.2. Subsections 3.3 and 3.4 quantify the present cost, manpower requirements, and productivity of shallow-water surveying. Subsections 3.5 through 3.7 describe how chart and survey requirements are determined, the present surveying workload, and future requirements for the launch-based sonar surveying method. Subsection 3.8 documents the limitations of launch hydrography, the present surveying technique.

3.1 Nautical Charts and Hydrographic Survey

Nautical charts are published by NOS to serve the navigational requirements of marine transportation. They show the nature and shape of the coast, depths of water, general configuration and character of the bottom, and other items such as prominent landmarks, port facilities, dredged channels, aids to navigation, and marine hazards. Changes brought about by man and nature require frequent updates of the nautical charts.

Hydrography measures and defines the configuration of the bottom and adjacent land areas of oceans, lakes, rivers, and harbors. The principal objective of most hydrographic surveys conducted by NOS is to obtain data for the compilation of nautical charts with emphasis on the features that may affect safe navigation. Other objectives include acquiring the information necessary for related marine navigational products and for coastal zone management, engineering, and science.

The determination of water depth (sounding) is the most tedious and most important part of the hydrographer's duties. An accurate knowledge of the depths and their locations is essential for safe navigation, particularly in harbors and harbor approaches where the draft of many vessels is often nearly as great as the depth that they navigate.

Hydrographic surveys performed by NOS must meet accuracy standards prescribed in the NOS Hydrographic Manual (Ref. 1). Standards exist for both depth measurements and the geographic positions assigned to each depth. These standards are specified in Table 1. The standards of accuracy are established by the IHB and are subscribed to by the United States.

Depth		Position	
Depth Range	Accuracy	Survey Scale	Accuracy
0-20 meters	± 0.3 meters	1:5,000	± 4.6 meters
20-100 meters	± 1.0 meters	1:10,000	± 9.1 meters
Deeper than 100 meters	1% of depth	1:20,000	± 18.2 meters
		1:40,000	± 36.4 meters
		1:80,000	± 72.8 meters

Table 1. Accuracy Standards for Hydrography

3.2 Present Hydrographic Surveying Method

Acoustic echo sounders (sonar) are presently used by NOS to take depth soundings. The NOAA ships MT. MITCHELL and DAVIDSON perform automated sonar surveys in deep or unprotected waters. A variety of launches and small boats are used to survey shallow, inshore, or shoal-water regions. These vessels range from 59-foot high speed launches to 18-foot skiffs used for shoal-water surveying. Data acquisition and processing capabilities vary from full automation aboard the high speed launches to manual recording aboard the skiffs.

The hydrographic survey vessels gather profiles of depth soundings along predetermined survey lines. The fathograms (analog record of the echo sounder, Figure 1) are then manually scanned to ensure accurate digitization and to add soundings when changes in depth greater than 10 percent occur between recorded soundings. A plot of the depths (Figure 2) plus the analog fathograms are then used for a manual evaluation of the completeness and accuracy of the survey. The survey party uses the sounding data plus their experience and judgment to establish that all hazards to navigation were found and that the shoalest depth over these hazards was measured. Further surveying may be done if the hydrographer is not confident in the completeness of the data.

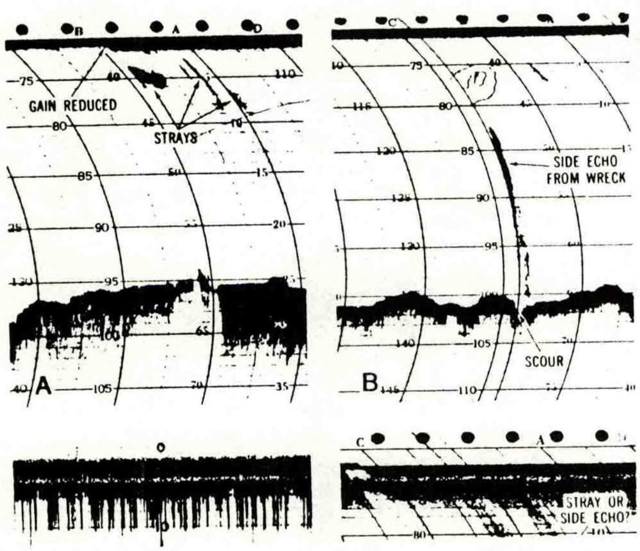

Figure 1. Typical Fathograms

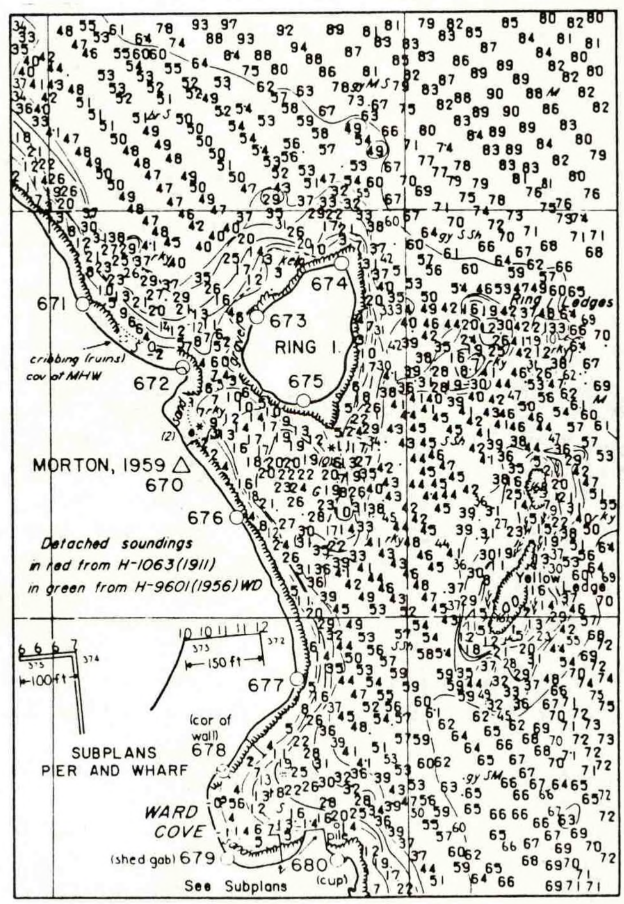

Figure 2. Typical Plot of Sonar Soundings

3.3 Present Surveying Costs

In order to assess the improvements in cost- and manpower-effectiveness of a new surveying tool such as the airborne laser, it is first necessary to quantify the economics of the existing tool. "Economics" is used in a general sense to include cost, manpower, and time. "Shallow water" is defined as water presently surveyed by launches and skiffs, that is, hydrography other than ship hydrography. This definition is consistent with the capabilities of the proposed airborne laser hydrography system.

A composite cost-effectiveness estimate for shallow water hydrography has been developed for this Issue Paper. It was based on five independent estimates. One of the estimates was developed by Cdr. James Collins (NOAA) to use in a cost comparison with photobathymetry (Ref. 2). A second estimate was prepared by Capt. Wayne Mobley (NOAA) for use by NOS as a general baseline. A third estimate was made from the cost of a launch hydrography survey performed as "ground truth" for accuracy tests of an experimental airborne laser system performed by OTES. A fourth, theoretical cost estimate was prepared by GKY & Associates (Ref. 3). Tables showing data and results from these studies are presented in Appendix A.

The final cost study was performed by the Systems Analysis Staff of OTES specifically for comparison with airborne laser hydrography (Ref. 4). This cost estimate was made by accumulating actual costs and productivity for FY 1977 from NOS records. The cost and manpower expended were combined with the amount of area surveyed to calculate cost per square nautical mile (nm^2) and square nautical mile per man-year, as the measures of cost- and manpower-effectiveness. Tables A4 and A5 in Appendix A show examples of data gathered for this study.

In all five estimates, only operating costs were used to establish the cost and manpower effectiveness of launch hydrography. Operating costs associated with launch surveying are for salaries, subsistence and overhead, launch maintenance, fuel, and maintenance of the sonars and data acquisition system. Manpower is required to set up and operate the equipment, maintain quality control, and to perform evaluations of survey data. System acquisition costs were treated as sunk costs. Replacement costs were, for simplicity, assumed to be zero. These operating cost- and manpower-effectiveness figures will later be compared to the total (operating plus annualized acquisition) cost- and manpower-effectiveness of a laser hydrography system. Such an approach will produce a conservative estimate of the economic advantages of laser hydrography.

The results of the inhouse launch hydrography cost study are shown in Table 2 for each of the vessels in the hydrographic fleet.

VESSEL	FY 1977(1)(2)	AREA SURVEYED	$nm/2
HSL #1	$ 146,912	560 nm^2	$ 262/nm^2
HFP #2	$ 119,966	33 nm^2	$3,635/$nm^2$
HFP #3	$ 88,671	89 nm^2	$ 996/nm^2
HSL #4	$ 94,563	115 nm^2	$ 822/nm^2
WHITING launches	$1,037,932	148 nm^2	$7,013/$nm^2$
MT. MITCHELL launches	$ 121,695	32 nm^2	$3,802/$nm^2$
DAVIDSON launches	$1,023,120	283 nm^2	$3,815/$nm^2$
PIERCE(3) launches	$ 229,585	94 nm^2	$2,442/$nm^2$
RANIER(3) launches	$ 134,014	33 nm^2	$4,061/$nm^2$
FAIRWEATHER(3) launches	$1,265,040	220 nm^2	$5,751/$nm^2$
TOTALS	$4,261,498	1607 nm^2	$2,341/$nm^2$

(1) Expressed in FY 1977 dollars.

(2) Includes ship base overhead. Laser cost estimate includes comparable airport and hanger fees.

(3) Cost prorated by fraction of ship plus launch surveying done by launch.

Table 2. Cost and Productivity for FY 1977 Shallow-Water Hydrography Systems

Using the results from the inhouse study plus the four other estimates (Table 3), a composite cost estimate was calculated. The result is that $2,730 per nm^2 (FY 1977 dollars) is the best available estimate of the operating cost-effectiveness of launch hydrography. $2,730 per nm^2 will be compared with the anticipated cost-effectiveness of airborne laser hydrography in a later section.

SOURCE OF ESTIMATE	$/$nm^2$	nm^2
Special Study (ref. 4)	$2,341/$nm^2$	1,607 nm^2
Cdr. Collins's study (ref. 2)	$1,641/$nm^2$	1,322 nm^2
Capt. Mobley's study	$4,801/$nm^2$	977 nm^2
"Groundtruth" survey	$2,714/$nm^2$	122 nm^2
GKY estimate (ref. 10)	$3,059/$nm^2$	122 nm^2
Weighted(1) average cost of launch hydrography	$2,730/$nm^2$ (FY 1977 dollars)	

(1) Each $/$nm^2$ is weighted the number of nm^2 surveyed at that cost

Table 3. Launch Hydrography Cost Estimates

These costs have been achieved as a result of 30 years of world-wide launch hydrography experience. Hardware has undergone continual development to reduce its operating and maintenance costs. Operating procedures have been refined to minimize manpower requirements while maintaining the quality of the surveys. No significant economies are foreseen that will reduce the cost and manpower required for launch hydrography.

3.4 Present Surveying Manpower Requirements

The manpower required for launch-based sonar surveys was quantified using a methodology similar to that used for cost. The manpower study used the same base year as the cost study (FY 1977) and accumulated actual manpower and productivity figures. The amount of area surveyed was divided by the man-years used in order to compute productivity. No other such productivity studies are known to exist.

Table A8 in Appendix A shows an example of the type of manpower information that was developed to compute productivity. Survey manpower is used to plan the missions, to establish and maintain the positioning and tide measuring stations, and for performing the surveys. In performing a survey, skilled manpower is used to man the launches, monitor equipment operation, and evaluate the data.

The amount of area surveyed and the manpower used were combined to compute the productivity of each vessel (Figure 3). The individual estimates were then combined with a weighting factor equal to the amount of surveying performed by each vessel. The resultant, best estimate of the productivity of launch-based sonar hydrography systems is 57.4 nm^2 per man-year.

The productivity estimate is for operating manpower only. No manpower is included for maintenance other than that done in the field by the survey party. No manpower is included for the operation of the ship bases in Norfolk and Seattle. Nonrecurring manpower requirements required to establish launch systems operation are not included. These simplifying assumptions will give a high estimate of launch productivity and thus a conservative estimate of the manpower savings achievable with a laser hydrography system.

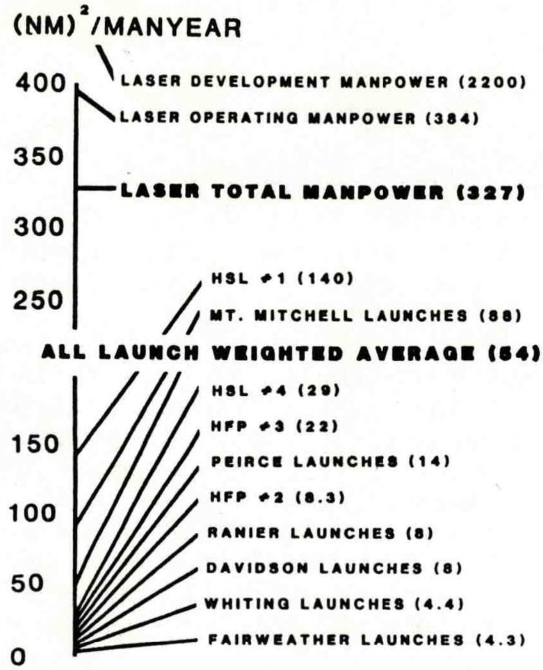

Figure 3. Productivity of Manpower for Launch Hydrography

3.5 Establishing Survey Requirements

This section describes how surveying requirements are determined so that the amount of area to be surveyed by laser will be firmly tied to a national need.

3.5.1 Chart Requirements

The requirement for hydrographic surveys are based on the requirement for marine charts. The Marine Chart Division within NOS is responsible for identifying and justifying the national need for particular charts with the needs of chart users as the fundamental criteria.

User needs are constantly being identified through unsolicited letters from the general public; formal requests from the Defense Mapping Agency and the U.S. Coast Guard; requirements written into international agreements; and requests from land-use planners, oceanographers, and state and federal agencies. For example, completion of the Trans-Alaskan pipeline terminal dictated the need for improved chart coverage of Port Valdez and its approaches in order to accomodate the very large, crude oil carriers. Working in consultation with the American Institute of Merchant Shipping and the U.S. Coast Guard, new chart coverage was agreed upon and is now an issue.

At least annually, chart requests are reviewed, prioritized, and a nautical charting plan is prepared to allow NOS to allocate resources for the orderly and efficient fulfillment of its nautical charting responsibilities (Ref. 5).

3.5.2 Survey Requirements

Raw data for the construction of nautical charts are gathered through hydrographic surveys. Charting requirements are studied to determine if existing hydrographic data are adequate. If adequate data do not exist, a hydrographic survey requirement is identified. Port Valdez is one example of a chart requirement that became a survey requirement. NOS surveyed two wide approaches suitable for very large crude carriers, two anchorage areas, two holding areas, and two containment areas for the Port Valdez charts.

Requirements for hydrographic surveys originating in the NOS Marine Chart Division are compiled by the NOS Hydrographic Survey Division. These requirements are reviewed semi-annually and are prioritized on the basis of the importance and urgency of the user's need. For example, the North Pacific Vessel Owners Association and the Alaska Shrimp Trawlers Association pointed out the need for large-scale charting of Shelikof Strait, Alaska. Loss of life among commercial fishermen has occurred in this area that adequate charting might have prevented.[1] As a result of this request, field surveys for the new Shelikof Strait charts are nearly half completed.

The prioritized list of survey requirements becomes the NOS 5-year survey plan (Ref. 6). Resources are apportioned on the basis of this plan, survey schedules are derived from it, and survey ships and launches are dispatched to perform the work. It is thus seen that the need for hydrographic surveys are derived in a logical manner from documented user requirements.

3.6 Present Surveying Workload

The Nautical Charting Plan (Ref. 5) identifies a need for additional survey data to eliminate or resolve the following chart deficiencies: 26 percent (246 charts) of the published charts contain areas where additional soundings are required to provide an adequate portrayal of the bottom, 12 percent (119 charts) of the charts contain unsurveyed areas, and 18 percent (173 charts) of the charts have other recognized depth deficiencies affecting marine navigation. Portions of many charts are still based on soundings gathered before the turn of the century.

Hydrographic surveys required for these deficiencies are reflected in the 5-year plan for hydrographic surveys (Ref. 6). Survey requirements have been organized into scheduled and unscheduled surveys based on the priority of the survey, the annual surveying capability of the fleet, and the estimated survey duration. Unscheduled surveys are those for which documented, acknowledged

---

1 In 1974 the fishing vessel John Olaf capsized in a storm due to severe icing. The entire crew was lost. A nearby harbor of refuge could have saved the vessel and crew except that it was uncharted and not known to exist.

requirements exist, but for those that NOS does not have adequate vessels and resources. Table 4 gives examples of required surveys that are beyond the capacity of NOS and are classified as unscheduled.

Maine coast, inshore areas (areas from Isle of Shoals to Canadian border, including harbor surveys of Bangor and Bath)
Ablemarle Sound and tributaries (includes harbor survey of Elizabeth City, NC)
Delaware Bay (inshore) (DE, NJ)
Hudson River (NY Harbor to north of Troy, NY; Lake Champlain; and Lake George)
Bogue Inlet (NC)
Florida Intracoastal Waterway (Jacksonville to Miami)
Southwest coast of Florida and Florida Bay
South coast of Long Island (including the bays) and New Jersey coast out to 11-fathom curve
Lake Michigan (Wilmette to Waukeegan, IL)
New York State Barge Canal (Troy to Tonawanda, NY) (including Seneca, Cayuga, and Oneida Lakes)
Raritan Bay and River (NJ)
Rappahannock River (VA)
St. Lawrence River (Lake Ontario to Cornwell, ON)
Gardiners Bay and Peconic Bay (NY)
Vermilion Bay, White Lake, and Grand Lake (LA)
Sabine Lake (TX)
Oshkosh to New London (including Lakes Butte des Morts, Poygan, Winneconne, and Partridge and the Upper Fox and Wolfe Rivers) (WI)
New River to, and including, Jacksonville (NC)

Table 4. Examples of Unscheduled Surveys

It has been estimated that the list of unscheduled surveys contain three times as much work as the list of scheduled surveys. Over a longer period, 100,000 nm^2 of critical hydrography have been identified for surveying during the current decade. The annual average survey rate of 6,000 nm^2 will leave 40,000 nm^2 unsurveyed by 1990. Thus, even at the present level of requirements, there exists sufficient, priority work to effectively use the 75 percent increase in shallow-water surveying to be proposed for the laser hydrography system.

3.7 Future Workload

The 5-year hydrographic surveying plan contains the documented workload for the immediate future. There are, however, anticipated changes in user requirements that will add to that workload, but that are not yet reflected in the plan.

One way to estimate the anticipated growth of the surveying requirement is to examine growth in the user community. Extrapolating the growth can help forecast whether requirements will increase, decrease, or remain constant. The demand for hydrographic surveys has increased along with waterborne commerce, national defense needs, recreational boating, and environmental concerns. There has been a 55 percent increase in U.S. waterborne commerce in the last 10 years. Energy exploration and production in U.S. coastal waters has almost doubled in the last 10 years. More than 100,000 people are employed offshore. More than 114 million people, 53 percent of the U.S. population, live in the coastal zone--a growth of approximately 20 percent in the last 15 years. Almost 54 percent of total U.S. industrial base is in the coastal zone. New offshore oil and gas structures cost more than $7 billion and port and harbor construction exceeds $1 billion annually. These activities make use of NOS marine charts and their growth indicates growth in the hydrographic surveying requirement.

In addition to growth in existing requirements, new user requirements are expected to add to the hydrographic surveying workload. The NOS Institutional Plan, FY 1982 through FY 1987 (Ref. 7), lists the following anticipated changes in user requirements that will increase the required amount of surveying:

- The congressional mandate for Fishing Obstruction Charts must be met.
- The use of deep-draft vessels, particularly supertankers, will increase.
- Recreational boating in fresh water, rivers, and lakes will increase.
- Competition for the use of offshore resources will intensify along with the demand for conserving these resources and protecting the environment.
- The Bureau of Land Management (BLM) and the United States Geological Survey (USGS) needs for managing and evaluating offshore oil and gas resources must be met.
- Demands for up-to-date NOS bathymetric maps and Topographic-Bathymetric maps being produced in cooperation with the USGS will increase.
- The Defense Mapping Agency's demands for surveys outside of U.S. waters will increase.

The surveying demanded by these changes in user requirements is presently not reflected in the 5-year surveying plan.

It is not claimed that the laser system described in this Issue Paper will be appropriate for all new requirements. In some cases, such as data for recreational boating charts, it can directly satisfy a changing survey requirement. Other cases, such as detecting hazards to fishing operations, are outside the technical capability of the laser. The laser, however, could absorb part of the present workload and release existing systems to use on the new requirements.

In summary, the present requirement for hydrographic surveys is beyond the present capabilities of NOS. The identified, future workload is seen to be at least of comparable size and thus will continue to be greater than the available resources. Growth in the user community and new user requirements will increase the backlog of surveys beyond those already identified.

3.8 Other Limitations of Launch Hydrography

3.8.1 Spatial Density of Soundings

It is not practical to measure depth at every point using the existing sonar techniques. Although sonars provide a nearly continuous depth profile, enough bottom profiles must be obtained to permit the detection of hazards to navigation. The possibility of shoals remaining undiscovered between sounding profiles is always present. The greatest responsibility and most difficult task of the hydrographer is to assure that none of these remain undetected. Ideally, the spatial density of soundings should approach 100 percent coverage.

The density of sonar soundings can be increased by increasing the number of profiles collected or by operating at lower launch speeds. Such a tactic would decrease the amount of area surveyed annually or would require more launches to maintain production. Decreasing the area surveyed would worsen the existing production shortfall. Increasing the launch fleet would cost more than implementing the proposed airborne laser system that automatically gives the increased data density.

It has not been possible to establish quantitatively how much denser the soundings must be. It is difficult, therefore, to justify a specific increase in sounding density and to assign an acceptable cost to that capability. The Office of Marine Surveys and Maps (MSM) has, therefore, taken the position that it is desirable to increase the number of soundings per unit area in order to better understand the bathymetry, but that no significant costs should be incurred for this capability alone until the requirement is better quantified.

3.8.2 Speed

A principal limitation of launch-based sonar hydrography is the speed at which an area can be surveyed. The standard 29-foot survey launch can safely perform hydrography at 12 knots. High speed launches can survey at 20 knots if the water is known to be deeper than 10 feet. As the water shoals, or when the bathymetry is unknown, significantly slower speeds are used. Under certain conditions specified in the NOS Hydrographic Manual (Ref. 1), drifting is the standard operating procedure. The cost and manpower impact of present surveying speeds was quantified in preceding sections.

Slow speed also has an effect on the type of vessels in the survey fleet. Many survey sites are too far from port for daily commuting in hydrographic launches. These launches are too small to stay in the field continuously so NOAA operates five large support ships such as the 163-foot WHITING.[1] The cost of maintaining the support ship significantly increases the cost of launch hydrography.

3.9 Summary

The requirements for shallow water hydrographic surveys are based on the requirements for nautical charts. Chart requirements, in turn, are based on user need. In Section 3, documented survey requirements were shown to exist that are far in excess of NOS' ability to satisfy. Growth in the user community and the possibility of new charting responsibilities indicate that eventual survey requirements will be even larger than those presently documented.

The present method of performing hydrography in shallow water uses sonar systems mounted in small boats. The systems cost \$2,730 per nm^2 of surveying (1977 dollars) and produce 57.4 nm^2 of surveying per man-year of effort. No significant cost reduction or productivity increases are anticipated for sonar hydrography.

---

1 The support ships can also perform hydrography. Typically, however, they do not operate at the same time as their launches because there is insufficient manpower.

4.0 ALTERNATE TECHNOLOGIES

Five methods were considered as ways to reduce the cost and increase the productivity of hydrographic surveying. The potential of each method for increasing the total amount of area surveyed and for increasing the number of soundings per unit area was also considered. The five techniques are described in this section (Ref.8 and 9). Reasons are given for the selection of airborne laser hydrography as the preferred technology. A more detailed description of airborne laser hydrography is given to demonstrate that it is feasible and that it can be applied to the NOS survey requirements.

4.1 Launch-Based Sonar

One way to increase the amount of area surveyed annually is to expand the existing fleet of hydrographic launches. This could be done in small increments and with no technological risk. The skills and procedures to use these systems already exist within NOS.

The cost- and manpower-effectiveness of added launches, however, would be the same as for existing ones. They would cost six times as much per unit of area surveyed as laser hydrography, and would require five times as much manpower (Ref. 10 and Section 5 of this paper). There would thus be no savings through increasing the number of launch-based sonar systems either at the present amount of surveying or at an increased amount. New launches would continue to give the present, low spatial density of soundings and would not be as effective a reconnaissance tool as a laser system (Section 7.0).

Added sonar launches would thus continue to be expensive to use in shallow water and would ineffectively use trained manpower. This alternative was rejected as not responsive to the problem.

4.2 Stereo Photobathymetry

Stereo photobathymetry is a technique that was developed by the Photogrammetry Division of NOS (Ref. 11). A series of overlapping, natural color, aerial photographs are taken of a survey area. Where two photographs overlap and the sea bottom can be seen, the photos can be used as a stereoscopic model. The two-photograph models are mounted in a stereocompiler, aligned, and apparent water depths measured using standard photogrammetric procedures.

Stereo photobathymetry offers several advantages. Data collection covers a large area very rapidly. One hundred percent coverage of the bottom is achieved. The technique is available with the skills and equipment in NOS, and a limited amount of photobathymetry is already performed annually.

The technique also has several disadvantages. Principal among these is that it is less cost- and manpower-effective than laser hydrography. Results from an ongoing study (Ref. 12) indicate that photobathymetry will cost three times as much and require three times as much manpower as laser hydrography. Additional equipment and staff would be required if a significant amount of photobathymetry was to be performed. Required equipment would include a digitized, Wild B-8S plotter ($56,000), a high performance twin-engine aircraft such as the Beech KingAir ($750,000), and a Wild RC-10 camera. Because the laser/photo cost study compared laser capital plus operating costs to photo operating costs only, the cost of additional photogrammetry equipment would improve the relative economics of laser hydrography.

In addition to the economic disadvantages, there are technical disadvantages to stereo photobathymetry. First, it cannot penetrate to significant depths except in water as clear as found in the Caribbean. Penetration is limited because only solar illumination is used and photographic film is relatively insensitive. The laser technique can penetrate 10 times deeper for any given water clarity because it actively illuminates the sea bottom and uses sensitive electronic detection techniques.

Second, photobathymetry is intolerant of weather conditions. Acceptable aerial photos can be taken only when the sun is high (10 a.m. to 2 p.m.) with a clear sky and a calm sea. Manpower and equipment are inactive for long periods, sometimes for weeks, waiting for acceptable weather. Laser hydrography, for comparison, can be performed day or night, under any sky condition, and is blocked only by high winds, precipitation, or fog. A study of weather constraints on survey operations (Ref. 13) concluded that laser hydrography could be performed 70 percent of the time versus 5 percent for photobathymetry (Figure 4).

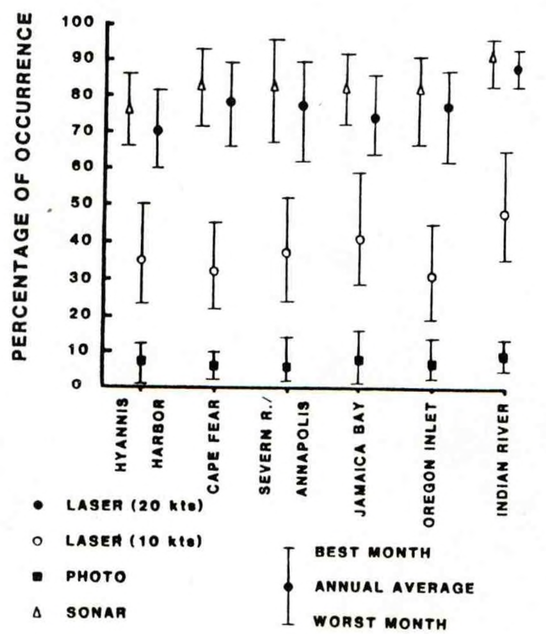

Figure 4. Occurrence of Favorable Weather for Different Survey Techniques

Finally, due to limitations of the stereoscopic technique, photobathymetry cannot be performed in areas of featureless bottom. The bathymetric accuracy of the technique is still open to some dispute. Also, land is required in each photograph in order to align the photomodels and position the soundings. This requirement limits the distance from shore that photobathymetry can be performed.

Photobathymetry is thus seen to be usable with limited applications. The existing capability should continue to be used when equipment and manpower are available. As a production surveying techique, however, it is not competitive economically or performance-wise with airborne laser hydrography.

4.3 Airborne Multispectral Scanner

Another alternative considered was the airborne multispectral scanner (MSS). Feasibility tests with the experimental ERIM M-8 (Figure 5) Active/Passive Multispectral Scanner have shown that a hybrid system consisting of a multispectral scanner calibrated by a pulsed laser can perform bathymetric measurements from an aircraft (Ref. 13).

The MSS (Figure 6) gathers solar illumination reflected from the scene below and decomposes it into discrete spectral components. The spectral component with maximum water penetration is used to infer depth by assuming that more light will return from the sea bottom in shallow water than in deep water. The difference is due to absorption and scattering in the water column. A pulsed laser is necessary to correct for changing bottom reflectivities and optical inhomogeneities in the water.

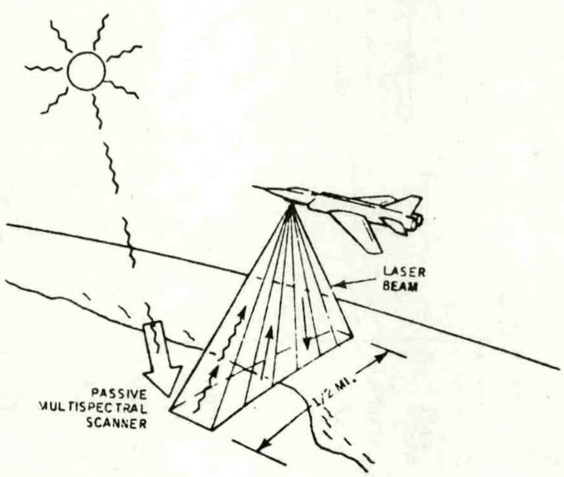

Figure 5. Schematic of ERIM M-8 Multispectral Active/Passive Scanner

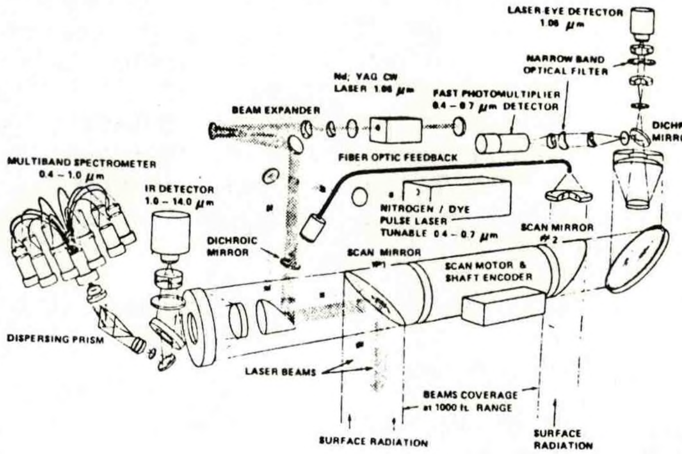

Figure 6. Airborne Multispectral Scanner

There are several technical disadvantages to the MSS. It is a passive technique like photobathymetry, using only solar illumination. The depth of penetration is approximately one-third that of the laser technique. This limits its applicability for U.S. surveying needs. The MSS is less well developed as a bathymetric technique than laser hydrography. Accuracy has not yet been demonstrated. Also, the MSS is a more complicated tool than laser hydrography. MSS requires not only a sophisticated multispectral scanner instrument system, but an airborne laser hydrography system for continuous calibration.

The economics of MSS are not well quantified. Operating costs are expected to be similar to those of laser hydrography due to the similarities in field operation. Acquisition costs would be higher for MSS because both an airborne laser system and a multispectral scanner system are required. The experimental ERIM M-8 system cost $500,000 in FY 1975. This cost is for the depth sounder alone and does not include a positioning subsystem, data processing subsystem, aircraft, training, and other support systems.

The airborne multispectral scanner is thus not being recommended because it offers no advantages over laser hydrography and has several performance disadvantages. Also, the MSS can survey less area than laser hydrography because of its reduced penetration capability, it is a more complicated system, and it is of unproven accuracy. Finally, the lower state of technological development makes MSS a significantly riskier alternative than laser hydrography.

4.4 Satellite Multispectral Scanner

A third advanced technology considered for shallow water surveying was the satellite multispectral scanner (Ref. 15). Bathymetric measurements would be made using the same principal as the airborne multispectral scanner, but without laser calibration. The Defense Mapping Agency is conducting a limited research effort to determine the technical feasibility of satellite MSS.

The advantage of satellite MSS is the large amount of area that can be surveyed rapidly and repeatedly. The disadvantages include enormous acquisition cost, unknown accuracy, inability to resolve small features, and limited depth of penetration because it uses only solar illumination. The technological risk associated with satellite MSS is very high and the potential gains appear to be less than with laser hydrography. For example, assigning accurate geographic coordinates to satellite soundings has never been investigated. The technique is clearly still in the research stage and is not as realistic a competitor as an operational hydrography system.

4.5 Airborne Laser Hydrography

4.5.1 The Laser Hydrography Technique

Airborne laser hydrography uses an aircraft mounted, scanning beam, pulsed laser system to collect swaths of discrete soundings. It measures water depth using the same principal as sonar, but with light instead of sound. For each laser pulse, some energy is reflected from the sea surface and some energy is reflected from the sea bottom (Figure 7).

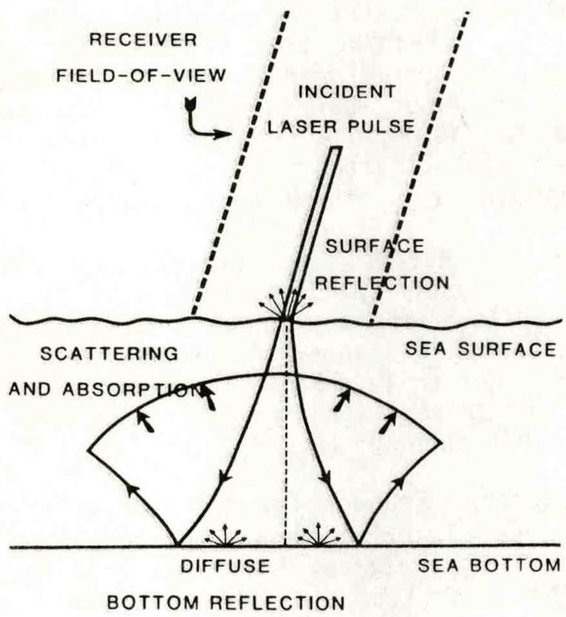

Figure 7. Spatial Representation of a Laser Sounding Pulse

The energy reflected from the sea bottom will be detected at the system receiver later than the sea surface reflection because the bottom-reflected energy travels farther. The amount of time by which the bottom reflection is delayed is proportional to the extra distance it traveled, i.e., the water depth (Figure 8).

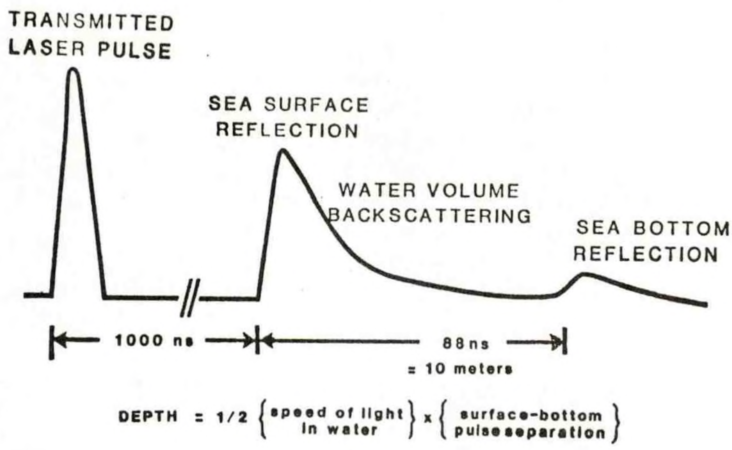

Figure 8. Temporal Representation of a Laser Sounding Pulse

The proposed NOS system will take 600 soundings per second over a 220-meter-wide swath (Figure 9) with an average distribution of one sounding per 25 square meters. The system will operate from a light, twin-engine aircraft flying at an altitude of 300 meters and a speed of 75 meters per second. The laser will use a green wavelength for maximum water penetration and will be totally eye-safe for bystanders in the survey area.

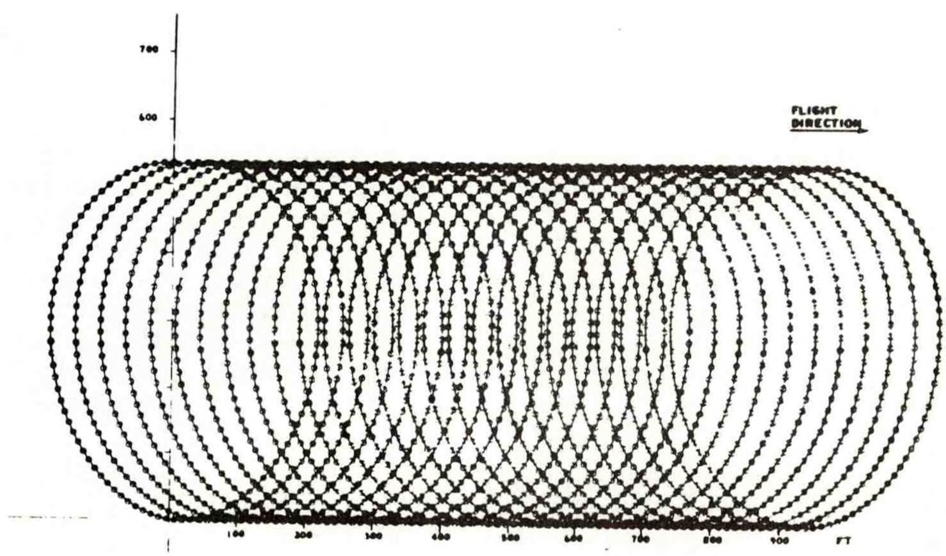

Figure 9. Pattern of Laser Soundings

4.5.2 The Benefits of Airborne Laser Hydrography

A comprehensive evaluation of laser hydrography has been performed by OTES (Ref. 16, 17, and 18, and Sections 5, 6, and 7). As a result of this evaluation, the potential benefits of airborne laser hydrography have been identified and quantified. Principal among these is that it will survey for one-sixth the cost per unit area of the present, launch-based sonar systems (Ref. 10 and 16). Equally important, it requires only one-fifth the manpower per unit of area surveyed that the launches require (Ref. 16 and 18). These potential savings are the result of the high surveying speed of the airborne laser hydrography system, its ability to gather a swath of soundings rather than a single profile, and its high degree of data processing automation. The benefits of cost reduction and increased productivity for hydrographic surveying are the objectives of NOS and OTES in pursuing the laser technology.

A series of secondary benefits were also identified. The airborne laser hydrography system is able to gather an increased number of soundings per unit area compared to the present technique. The approximate 100-fold increase will help to ensure that hazards to navigation will not go undetected. The high commuting speed of the system makes it an ideal survey reconnaissance tool. Effective reconnaissance will aid in making optimum use of all the surveying systems. Airborne laser surveying was also found to be more fuel efficient than present techniques. Finally, as NOS plans to use the laser system, an increase in the total amount of area surveyed annually can be realized at the same time that total costs are reduced.

The benefits claimed in the preceding paragraph will be substantiated in Section 5 of this Issue Paper. They will also be quantified and compared in detail with the same parameters for launch-based sonar systems.

4.5.3 Laser Hydrography System Performance

Regardless of the potential benefits, a new surveying technique must be able to meet the required standards of accuracy in order to be acceptable (Ref. 1). The bathymetric accuracy of the airborne laser technique has been established by OTES through a theoretical and experimental program. A major experimental effort was mounted by OTES in FY 1977 to determine the bathymetric accuracy, the penetration capability, and the effect of system and environmental parameters on accuracy and penetration. A research laser system belonging to NASA was used to gather 1.5 million airborne laser soundings over 6 months. The experiments culminated in a comparison between laser and sonar measured depths at a test site in Chesapeake Bay. Figure 10 shows laser measured depths gathered during these tests compared to a sonar profile that was gathered at the same time. Table 5 shows the results of several laser/sonar comparisons.

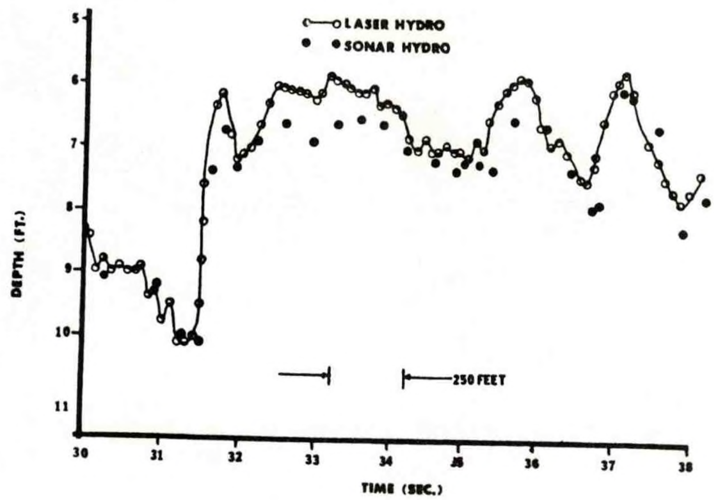

Figure 10. Laser Measured Depths Compared to Sonar Measured Depths

PASS ID	BIAS (INCHES)	BIAS (CENTIMETERS)	BIAS DIRECTION	DEPTH RANGE(FT)	DEPTH RANGE(M)	$\propto$ (M^{-1})
1-7-3 (J)	7.3 IN	18.5 CM	LASER DEEP	5-7.5 FT	1.5-2.3 M	3.15 M^{-1}
2-1-13	12 IN	30 CM	-----	5.5-7 FT	1.7-2.1 M	2.7-4.7 M^{-1}
2-2-4	1 IN	2.5 CM	LASER SHALLOW	5-6.5 FT	1.5-2.0 M	2.9-3.6 M^{-1}
2-2-9 (S)	2.5 IN	6.4 CM	LASER DEEP	5.5-7.25 FT	1.7-2.2 M	2.9-3.6 M^{-1}
2-2-15	12 IN	30 CM	LASER SHALLOW	5.5-8.5 FT	1.7-2.6 M	2.9-3.6 M^{-1}
2-2-23	12 IN	30 CM	-----	5.5-9(?)FT	1.7-2.7 M	2.9-3.6 M^{-1}
2-2-24	15 IN	38 CM	LASER DEEP	5.5-9 FT	1.7-2.7 M	2.9-3.6 M^{-1}
3-2-1XR	4 IN	10 CM	LASER SHALLOW	4.75-9.75FT	1.4-3 M	2.8 M^{-1}

AVERAGE BIAS = 8.2 IN ± 5.2 IN
21 CM ± 13 CM

Table 5. Laser/Sonar Accuracy Comparison

During these experiments, it was determined that the bathymetric acccuracy of the NASA system was 6.4 ±4 inches (Ref. 16 and 19)--well within the ±12-inch NOS accuracy standard. An extensive modeling effort was also mounted to guarantee accuracy under conditions different from those of the experiments and to help explain the experimental results. As a result of this modeling effort, the observed biases have been attributed to stretching of the laser pulse in the water (Ref. 20). These biases (Figure 11) can now be predicted and removed.

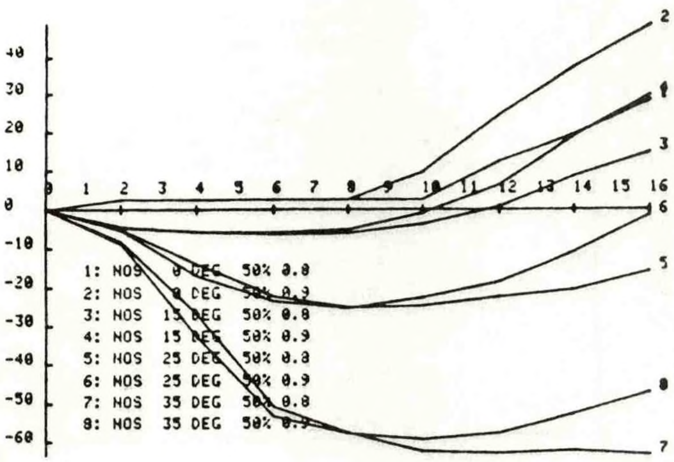

Figure 11. Depth Measurement Bias (centimeters) versus Optical Depth at a Depth of 20 meters

4.5.4 Amount of Laser Surveyable Area

The experimental and theoretical program also produced information on the depth of penetration of the laser system. This information is summarized by the mathematical model $2\ KD + \ln D \leq X$, which relates the water clarity (K), depth (D), and the system extinction coefficient (X).

The model of system penetration was used to estimate how much area should be surveyable at 10 selected U.S. sites (Ref. 21). The estimate was performed using depths from NOS nautical charts, water clarity data from archives of actual oceanographic measurements, aerial photography, and the system extinction coefficient of the proposed laser system (X=7). Figures 12 and 13 show two of the sites examined. Table 6 summarizes the results of the study for all cases.

LOCATION	ESTIMATED %* SURVEYABLE	APPROXIMATE SURVEYABLE AREA	SOURCE OF WATER CLARITY DATA	TYPICAL MAX DEPTH	CONFIDENCE IN ESTIMATE
Chesapeake Bay (North Half)	65%	1,460 km^2	Discrete Measurements	9-10 m	Low
Chesapeake Bay (South Half)	80%	2,850 km^2	Discrete Measurements	9-11 m	Medium
James River (Lower End)	65%	44 km^2	Discrete Measurements	3-4 m	Low
Tampa Bay	100%	926 km^2	Aerial Photography	10-11 m	Medium
Nantucket Sound	90%	1,626 km^2	Aerial Photography	18 m	Medium
Gulf of Mexico (one section north of Tampa Bay)	N/A	6,500 km^2	Aerial Photography	21-30 m	Low
Lake Erie	65%	16,730 km^2	Discrete Measurements	18 m	Low
Lake Ontario	35%	6,830 km^2	Discrete Measurements	8-11 m	Low
Lake Huron	55%	32,700 km^2	Discrete Measurements	35 m	Low
Raritian Bay & Lower Bay N.Y.	70%	57 km^2	Discrete Measurements and Aerial Photography	7 m	Low

* for laser extinction coefficient of $\alpha D = 20$

Table 6. Estimated Area Surveyable by Laser

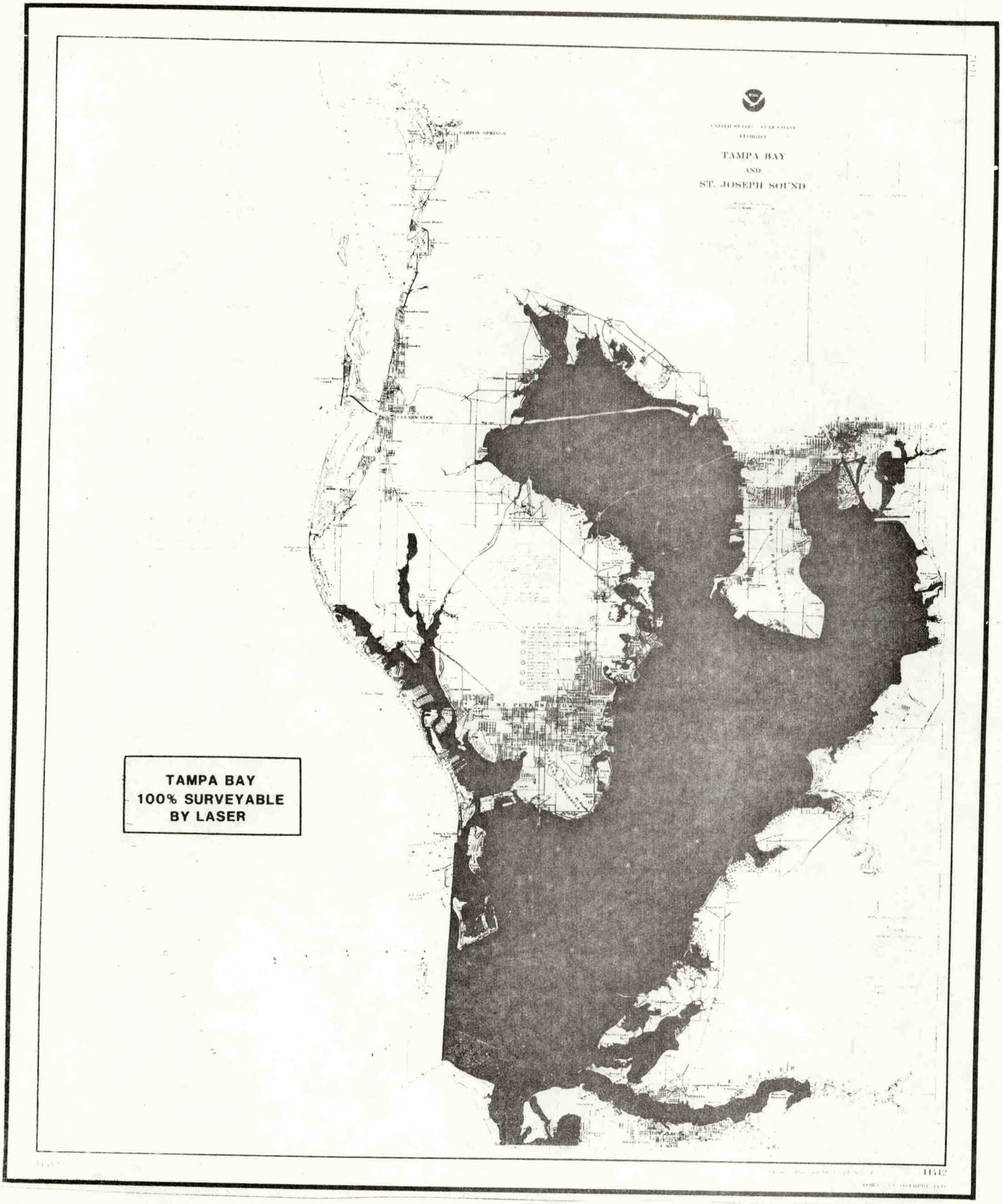

Figure 12. Estimated Laser Surveyable Area in Tampa Bay

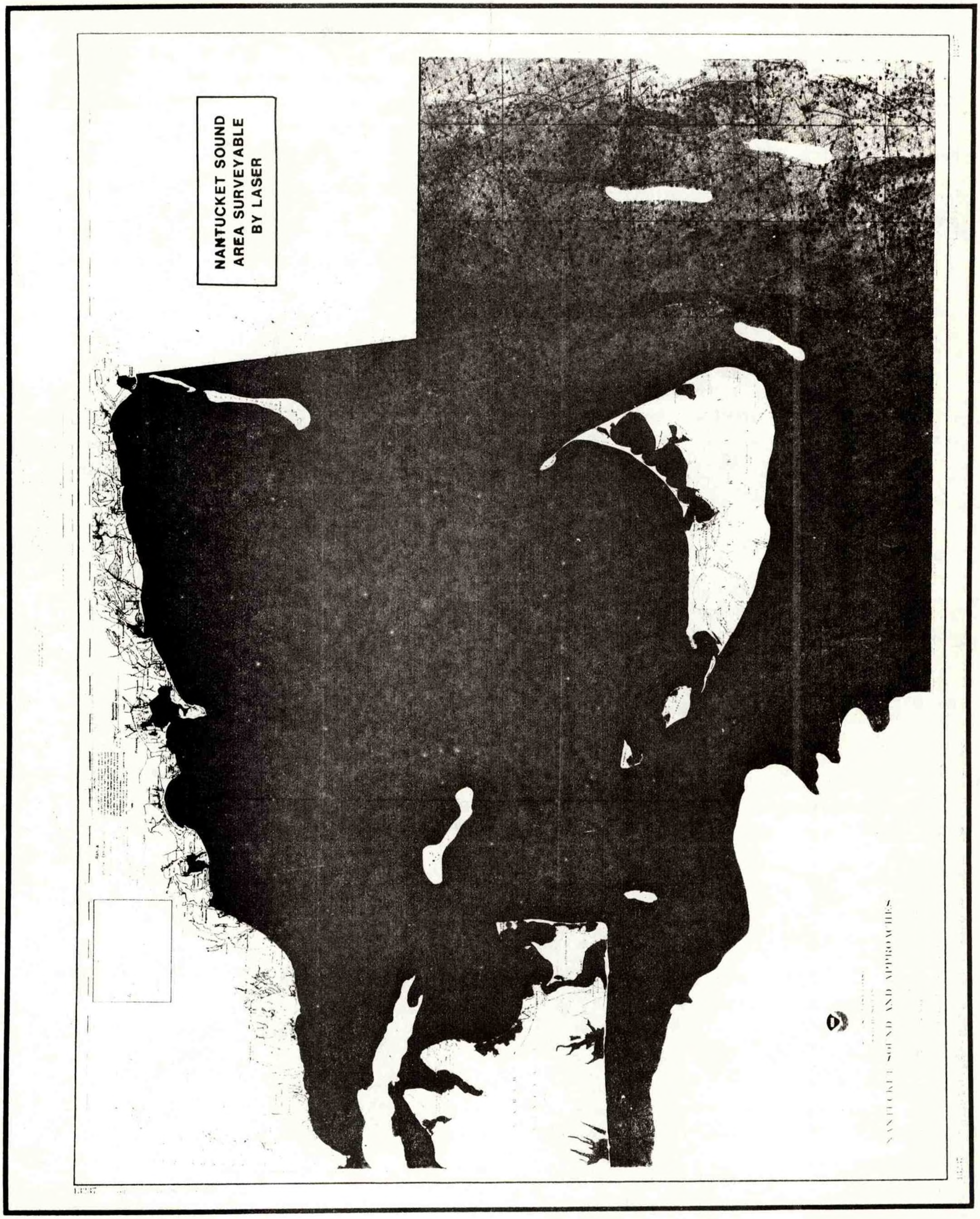

Figure 13. Estimated Laser Surveyable Area in Nantucket Sound

An enormous amount of area was found to be surveyable. Surveyable areas included important locations like lower New York Harbor and Chesapeake Bay. New York Harbor is the busiest commercial port in the world. Chesapeake Bay is one of the most heavily used recreational boating areas in the nation. An important amount of commercial traffic also uses the Bay on its way to the Port of Baltimore and to the liquefied natural gas terminal at Cove Point, Maryland. Consequently, laser hydrography can be done in important areas, and in areas where NOS has responsibility.

4.5.5 Laser Operations

Laser operations were studied to see if the anticipated benefits would remain after the practical aspects of surveying were considered. Two sources of information were used for this study: an operational scenario and the NOS experiences during the 1977 field experiments. It was concluded that the technique is straightforward to use and does not require hard-to-obtain information for operation and management. Several potential techniques were identified, for example, to assess the general water clarity characteristics of an area 1 year in advance. This is information necessary for planning and scheduling. It was also concluded that the cost and manpower benefits would be realizable and would not be degraded through operational compromises.

4.5.6 Impacts on NOS

Potential impacts of airborne laser hydrography were investigated to see if savings during data acquisition would be lost elsewhere in the chart production system. The largest single impact was found to be caused by the increased amount of hydrographic data to be processed, verified, and used. To reduce this potential problem, $700,000 has been budgeted in the development program to create a Hydrographic Software/Data Processing (HS/DP) Subsystem.

The laser system would also impact by requiring training for operations and maintenance personnel. As launches are released from routine surveying, more of their time will be spent in detecting discrete hazards to navigation. This will change the typical duties performed by survey personnel. None of the impacts were found to be unacceptable and most could be minimized through planning.

4.5.7 Conclusions Concerning Airborne Laser Hydrography

Of the five technologies examined, airborne laser hydrography was felt to the best solution for the following reasons:

- It offers the potential of a significant cost and manpower savings over present surveying methods.
- It is expected to be able to survey large amounts of area for which NOS is responsible.
- It has been demonstrated that a laser system can meet the required accuracy standards for hydrography.
- It is technologically mature for implementation without major risks.

- It offers the added potential benefits of an increased number of soundings per unit area, an increased amount of area surveyed annually, and a reduced fuel consumption.

- The potential impacts of laser hydrography on NOS were judged to be acceptable.

No other solution offered as much.

4.6 Summary on Alternate Technologies

Five technologies were examined in an effort to find a way to reduce the cost and manpower required for hydrographic surveying. Those technologies were launch-based sonar, stereo-photobathymetry, airborne multispectral scanners, satellite multispectral scanners, and airborne laser hydrography.

5.0 QUANTIFICATION OF BENEFITS OF AIRBORNE LASER HYDROGRAHY

The NOS and OTES involvement in laser hydrography began in 1970. Since that time, over $600K in money and manpower has been spent in maturing the technology and assessing it as a tool for NOS use. Other U.S. government agencies have recognized the potential of laser hydrography and have joined NOS and OTES in a coordinated, interagency effort. Table 7 shows the participants in laser hydrography development.

Organization	Contribution
Government	
National Ocean Survey	research, funding
Ocean Technology and Engineering Services	research, funding
National Aeronautics and Space Administration	research, funding
Naval Ocean Research and Development Activity	research, funding
Defense Mapping Agency	funding
Naval Coastal System Center	research, funding
Office of Naval Research	funding, technical advice
Naval Air Development Center	research
U.S. Naval Academy	research
Naval Postgraduate School	research
Non-Government	
Avco-Everett Research Laboratories	experimental system fabrication
GKY and Associates	cost-effectiveness analyses
EG&G (Wolf Research)	basic research
Sparcom, Inc.	basic research
Systex, Inc.	software systems analysis
Marine Science Consortium	oceanography
Systems and Applied Sciences Corp.	software design
Vitro Laboratory	specification writing
Foreign Governments	
Weapons Research Establishment, Australia	research, prototype development
Canadian Center for Remote Sensing, Canada	research, prototype development

Table 7. Participants in Airborne Laser Hydrography Development

The motivating factor for the NOS and OTES involvement is the opportunity to reduce the cost and increase the productivity of hydrographic surveying. This section of the Issue Paper will quantify the potential benefits and, by publishing the source data and methodology, substantiate the argument that the potential for significant savings exists.

5.1 Financial Benefit Of Laser Hydrography

The financial benefit of laser hydrography was quantified using an economic analysis. First, a proposed system usage plan was established. The cost of surveying that amount of area with the present launch-sonar method was computed. The cost of surveying the proposed area by airborne laser was then computed using a cost model. The difference between the two costs is the financial benefit.

The laser hydrography cost model (Ref. 10 and 22) categorized expenses as recurring or nonrecurring. The principal recurring costs are salaries and overhead for the five-person survey party, travel, aircraft operating expenses such as fuel and hanger fees, and maintenance for the laser system and the aircraft (Table 8). The recurring costs cover all field work including laser system operation, establishment of a position measuring network, tide control, and the gathering of supporting hydrographic measurements. The estimated annual cost for system operation in FY 1987, the first year of operational use, is $954K.

Laser Crew (3)		$247.8 K
Air Crew (2)		165.2 K
Data Verification Personnel (2)		165.2 K
Scientific Support Personnel (1)		82.6 K
Travel		95.8 K
Laser Maintenance		57.4 K
Aircraft Operation and Maintenance		140.0 K
	TOTAL	$954 .0 K

Table 8. Estimated Laser System Recurring Costs (FY 1987)

Nonrecurring costs associated with laser hydrography are for system development and acquisition. An estimate of this cost was made using the cost of the NASA experimental laser system (Ref. 23), a special design study done for NOS (Ref. 24), and the bid cost of the Navy's operational system (Ref. 25, 26, and 27). Other nonrecurring expenses exist for training, system operation during testing, data quality verification, and a formal system transition between the developer and user. The estimated nonrecurring expenses are $5,720K (Table 9).

	83	84	85	86	TOTAL
Laser subsystem	$515 K	$689 K	$ 0 K	$ 0 K	$1,204 K
Positioning	$347 K	$243 K	$ 0 K	$ 0 K	$ 592 K
Data Processing	$411 K	$334 K	$ 0 K	$ 0 K	$ 745 K
Aircraft	$ 0 K	$ 0 K	$600 K	$ 0 K	$ 600 K
Transition	$ 0 K	$ 0 K	$ 0 K	$572 K	$ 572 K
System operating costs (test, train etc.)	$ 0 K	$ 0 K	$662 K	$675 K	$1,337 K
Other (scientific analysis, studies, test, consumables)	$ 67 K	$ 72 K	$ 78 K	$ 93 K	$ 310 K
Data verification	$ 90 K	$ 90 K	$ 90 K	$ 90 K	$ 360 K
TOTALS	$1,430 K	$1,430 K	$1,430 K	$1,430 K	$5,720 K

Table 9. Nonrecurring Costs for Laser Hydrography

The laser hydrography cost model combines the following recurring and nonrecurring costs: nonrecurring costs are amortized over the useful lifetime of the system, an overtime/difficulty factor is applied to the recurring costs to reflect possible delays or overtime charges, and so forth. The laser cost model and its input parameters are shown in Table 10. The result is that an airborne laser system, when fully utilized, is expected to survey for one-sixth the cost of a launch-based sonar system.

First Costs (Y_1):

$$Y_1 = (X_1 * X_4) + X_{10} + X_{11} + X_{12}$$

Operating and Maintenance Costs (Y_2)

$$Y_2 = (X_4 * X_5) * [X_6 + (X_6 * X_7) + X_8] + (X_4 * X_9) + (X_{13} * X_5) * [X_{14} + (X_{14} * X_7) + X_{15}] + X_{16}$$

Amortized First Costs (Y_3)

$$Y_3 = (X_1 * X_4)\ (X_2/(1 - (1 + X_2)^{-X_3})) + (X_{10} + X_{11} + X_{12}) * (X_2/1. - (1. + X_2)^{-X_{17}}))$$

Annual Cost (Y_4):

$$Y_4 = Y_3 + Y_2$$

Unit Operating Cost (Y_5):

$$Y_5 = Y_2/(X_{19} * X_{18})$$

Unit Total Cost (Y_6):

$$Y_6 = Y_4/(X_{16} * X_{18})$$

Variable	Definition
X 1	Aircraft Price ($)
X 2	Interest Rate (P.A.)
X 3	Aircraft Time Horizon (YR)
X 4	Aircraft Utilization Factor (Ratio)
X 5	Overtime/Difficulty Factor (Ratio)
X 6	Aircraft Average Salary ($/YR)
X 7	Overhead Factor (Ratio to Salaries)
X 8	Aircraft Travel Per Diem ($/YR)
X 9	Aircraft Maintenance ($/YR)
X 10	Laser Price & Software Development ($)
X 11	Position Fixing System & Interface ($)
X 12	Techniques Development ($)
X 13	Laser Crew Utilization Factor (Ratio)
X 14	Laser Crew Salary ($/YR)
X 15	Laser Travel Per Diem ($/YR)
X 16	Laser Maintenance ($/YR)
X 17	Laser Time Horizon (YR)
X 18	Coverage Rate (S.N.M./HR)
X 19	Aircraft Flight Time (HRS/YR)

Table 10. Laser Hydrography Cost Model

Of greater importance than the relative cost of the two techniques is the total savings realizable, or costs avoidable; an economic analysis was done to determine the amount. The analysis indicates the costs incurred each year for 8 years of laser system usage. It then shows the cost to produce the same amount of surveying using the launch-based sonars. The annual cost differences between the two techniques was discounted back to FY 1983 and totalled to get the financial benefits.

The following facts and assumptions were used in the economic analysis:

a. Approximately 1,600 nm^2 of shallow water hydrography was performed in FY 1977. This will be taken as the annual requirement (Ref. 4).

b. One airborne laser hydrography system can survey 2,000 nm^2 annually (Ref. 10).

c. The airborne laser system will be used as follows: launch hydrography will be decreased 50 percent (1,600 nm^2 to 800 nm^2 annually); laser hydrography will be increased from 0 to 2,000 nm^2 annually; total shallow water hydrography will thus increase 75 percent (1,600 nm^2 to 2,800 nm^2 annually).

d. The laser system operating lifetime is 8 years (Ref. 10 and 22).

e. All development costs are amortized over the life of one system.

f. System acquisition, operating, and personnel costs are charged against laser hydrography regardless of system utilization. If the system is used at less than its maximum rate, then these costs produce no benefits for the purposes of this analysis.

g. The operating cost of launch hydrography was determined to be \$2,730 per nm^2 in FY 1977 (Section 3.3). The 1983 cost is \$5,111 per nm^2 using the following inflation values: 10 percent (1977 actual), 13 percent (1978 actual), 10 percent (1979 actual), 13.5 percent (1980 actual), 11.4 percent (1981 estimated), 8.3 percent (1982 estimated).

h. Only launch-sonar operating costs will be compared to the combined operating plus acquisition costs of laser hydrography. Replacement equipment is assumed unnecessary.

i. The proposed usage plan calls for an increase in the total amount of surveying by 75 percent. It was assumed that zero acquisition cost would be incurred in augmenting the existing launch fleet to perform the added surveying.

j. Inflation is not considered in the project years. All costs are shown in FY 1983 dollars.

Table 11 summarizes the results of the economic analysis. It was found that, over the 8-year system lifetime, it would cost \$29 million less to survey the proposed amount of area by laser than by launch. In addition, an extra 9,600 nm^2 of surveying will be done, and 16,000 nm^2 will be surveyed at an average 100-fold increase in the spatial density of soundings. System payback time is 1 year. Finally, the skilled manpower, vessels, and resources used for the supplanted 800 nm^2 of launch hydrography would be released for other work (Section 7.5.6). Table 12 summarizes the net benefit and productivity of laser hydrography.

Present Value Cost in FY 1983	= \$4,494 K
Present Value Benefit in FY 1983	= \$33,771 K
Present Value Net Benefit in FY 1983	= \$29,277 K ≅ \$29 M
Benefit/Cost Ratio	= 7.5
Payback Time on Investment	= 1 Year
Increased Amount of Surveying	= 1,200 nm^2 annually

Table 11. Summary of Economic Analysis

NOS intends to apply the resources saved by using laser hydrography to perform additional nautical charting work. The $29 million financial benefit should therefore be considered as a cost avoidance rather than a cost savings.

Project Year	Present Method	Proposed Method	Differential	Discounted Differential	Surveying Produced
1 (FY 1983)	$8,178 K (Launch Hydro)	$8,178 K + $1,430 K (Launch Hydro. + Laser Devel.)	-$1,430 K	-$1,300 K	1,600 nm^2
2 (FY 1984)	$8,178 K	$8,178 K + $1,430 K	-$1,430 K	-$1,181 K	1,600 nm^2
3 (FY 1985)	$8,178 K	$8,178 K + $1,430 K	-$1,430 K	-$1,074 K	1,600 nm^2
4 (FY 1986)	$8,178 K	$8,178 K + $1,430 K	-$1,430 K	-$ 977 K	1,600 nm^2
5 (FY 1987)	$14,311 K (2,800 nm^2 of Launch Hydro)	$4,089 K + $954 K (800 nm^2 Launch Hydro + 2,000 nm^2 Laser Hydro)	$9,268 K	$5,755 K	1,600 nm^2
6 (FY 1988)	$14,311 K	$4,089 K + $954 K	$9,268 K	$5,227 K	2,800 nm^2
7 (FY 1989)	$14,311 K	$4,089 K + $954 K	$9,268 K	$4,754 K	2,800 nm^2
8 (FY 1990)	$14,311 K	$4,089 K + $954 K	$9,268 K	$4,328 K	2,800 nm^2
9 (FY 1991)	$14,311 K	$4,089 K + $954 K	$9,268 K	$3,930 K	2,800 nm^2
10 (FY 1992)	$14,311 K	$4,089 K + $954 K	$9,268 K	$3,577 K	2,800 nm^2
11 (FY 1993)	$14,311 K	$4,089 K + $954 K	$9,268 K	$3,244 K	2,800 nm^2
12 (FY 1994)	$14,311 K	$3,483 K + $850 K - $120 K (Aircraft Residual Value)	$9,388 K	$2,995 K	2,800 nm^2
			Present value net benefit computed for FY 1983	$29, 278 K	

Table 12. Net Benefit and Productivity of Laser Hydrography

The costs avoided depend on the amount of area surveyed (assumption c). Analyses were done under different assumptions of system usage to ensure that an acceptable financial benefit would remain if the usage plans changed. Table 13 shows that, for the alternate usage plans considered, a significant benefit remains.

It is believed that the assumptions and methodology used in this economic analysis tend to underestimate the potential cost benefit of laser hydrography. Only launch operating costs were compared to laser acquisition plus operating costs. Ignoring inflation during the project years will not show the growth of personnel costs in launch hydrography--costs to which the laser is less sensitive due to its lower personnel requirements. No launch acquisition cost was charged, yet it was assumed that the launch fleet could survey 75 percent more area when "present method" costs were determined. Even with this conservatism, sufficient benefits remain to make laser hydrography desirable. The consistent underestimating of benefits can be considered as a margin of safety.

	PV Net Benefit FY 1983	Benefit/ Cost Ratio	Comments
1,600 nm^2 surveyed 0 nm^2 by launch 1,600 nm^2 by laser	$22 M	5.9	1. True savings as distinct from some savings and some avoidance 2. Probably not realizable since launches may be needed to fill in gaps in laser surveys
1,600 nm^2 surveyed 800 nm^2 by launch 800 nm^2 by laser	$ 6.9 M	2.5	1. Laser systems is underutilized 2. A major unquantified benefit is the 50% unused portion of the aircraft and personnel
2,400 nm^2 surveyed 400 nm^2 by launch 2,000 nm^2 by laser	$29 M	7.5	1. Potentially realizable
2,800 nm^2 surveyed 800 nm^2 by launch 2,000 nm^2 by laser	$29 M	7.5	1. This is the proposed system usage plan described earlier

Table 13. Laser Hydrography Cost Benefits for Different Amounts of Usage

5.2 Manpower Benefits of Laser Hydrography

The manpower benefits of laser hydrography can be quantified using a methodology similar to that used for cost benefits. The concept of discount rate does not apply. Manpower benefits are computed distinct from their direct cost impact because manpower is regulated independently of cost through "positions". Depending on the constraints in any year, the manpower benefits may be more important than the cost benefit.

The following assumptions and facts were used in the manpower analysis:

a. Approximately 1,600 nm^2 of shallow water hydrography was performed in FY 1977. This will be used as the annual requirement (Ref. 4).

b. One airborne laser hydrography system can survey 2000 nm^2 annually (Ref. 10).

c. The airborne laser system will be used as follows: launch hydrography will be decreased 50 percent (1,600 nm^2 to 800 nm^2 annually); laser hydrography will be increased from 0 to 2,000 nm^2 annually; total shallow water hydrography will thus increase 75 percent (1,600 nm^2 to 2,800 nm^2 annually).

d. The laser system operating lifetime is 8 years (Ref. 10 and 22).

e. All development manpower is amortized over the life of one system.

f. The development and operating manpower is totally charged against laser hydrography regardless of system utilization. If the system is used at less than its maximum rate, then the manpower produces no benefits for the purpose of this analysis.

g. The manpower required for launch hydrography in FY 1977 was 28 man-years to produce 1,600 nm^2 of surveying (Ref. 4). This requirement will be assumed as typical.

h. Only launch sonar operating manpower will be compared to the combined operating plus acquisition manpower requirements of the laser.

Table 14 summarizes the results of the manpower analysis. A total of 196 man-years of labor would be avoided over the life of the system. NOS intends to apply the released manpower to other, priority nautical charting work (Section 7.5.6).

Project Year	Present Method	Proposed Method	Differential	Amount of Surveying
1 (FY 1982)	28 MY(1)	33 MY(2)	-5 MY	1600 nm^2
2 (FY 1983)	28 MY	33 MY	-5 MY	1600 nm^2
3 (FY 1984)	28 MY	33 MY	-5 MY	1600 nm^2
4 (FY 1985)	28 MY	33 MY	-5 MY	1600 nm^2
5 (FY 1986)	49 MY(3)	22 MY(4)	27 MY	2800 nm^2
6 (FY 1987)	49 MY	22 MY	27 MY	2800 nm^2
7 (FY 1988)	49 MY	22 MY	27 MY	2800 nm^2
8 (FY 1989)	49 MY	22 MY	27 MY	2800 nm^2
9 (FY 1990)	49 MY	22 MY	27 MY	2800 nm^2
10 (FY 1991)	49 MY	22 MY	27 MY	2800 nm^2
11 (FY 1992)	49 MY	22 MY	27 MY	2800 nm^2
12 (FY 1993)	49 MY	22 MY	27 MY	2800 nm^2
			196 manyears	

(1) See assumption #7

(2) The 33 manyears are 28 manyears for launch operation plus 5 manyears for laser development. Of the 5 laser manyears, 3 come from the Increase Request and 2 from existing in-house resources.

(3) 49 manyears of launch operating manpower for the increased 2800 nm^2 of surveying.

(4) The 22 manyears are 14 manyears per year for the 800 nm^2 of launch work plus 8 manyears per year for laser work. The 8 positions for laser hydrography are reflected in the Increase request.

Table 14. Manpower Benefits of Laser Hydrography

The potential manpower benefit over the system lifetime are shown in Table 15 for different conditions of system usage.

Usage	Manpower Savings	Comment
1,600 nm^2 surveyed from 0 nm^2 by launch 1,600 nm^2 by laser	140 Manyears	1. True savings a distinct some savings and some avoidance 2. Probably not realizable since launches may be needed to in gaps in laser surveys
1,600 nm^2 surveyed 800 nm^2 by launch 800 nm^2 by laser	28 Manyears	1. Laser system is underutilized
2,400 nm^2 surveyed 400 nm^2 by launch 2,000 nm^2 by laser	196 Manyears	1. Potentially realizable
2,800 nm^2 surveyed 800 nm^2 by launch 2,000 by laser	196 Manyears	1. This is the improved system usage plan studied earlier

Table 15. Laser Hydrography Manpower Benefit with Different Amounts of System Usage

The computed manpower benefit is felt to be a conservative estimate of what could be achieved. No manpower was included in the launch hydrography estimate for operating the ship bases at the Atlantic and Pacific Marine Centers. No development manpower was charged to the present technique. Finally, manpower was included in the laser estimate to cover data verification--a manpower requirement that exists for launch hydrography, but that was not included in the analysis.

5.3 Production Benefits of Laser Hydrography

A single airborne laser system is capable of accurately surveying a great deal of shallow water--2,000 nm^2 annually versus 1,600 nm^2 with the existing launch fleet. This productivity is achievable because of the greater surveying speed (75 meters per second for an aircraft compared to 7.5 meters per second for launches) and because the laser gathers a 220-meter swath of soundings rather than a single profile as with sonar.

It is legitimate to ask whether the nation needs 2,000 nm^2 of shallow water hydrography. In FY 1977 the launch fleet was fully utilized and performed 1600 nm^2 of surveying. Calling 2,000 nm^2 roughly comparable to 1,600 nm^2, it can be said that there is a requirement for the amount of shallow-water hydrography that one laser system could perform.

It is also legitimate to ask whether the nation needs an additional 1,200 nm^2 of shallow water hydrography as proposed. The requirements established in Section 3.5 were estimated to be three times greater than the surveying capacity of the fleet. Anticipated changes in user requirements were described that would further increase the demand for hydrographic surveys. A precise computation of the square nautical miles of surveying that this user growth and new missions would include has not been made. What is important to realize is that whatever the actual amount of this increase, it would be on top of documented requirements that are already three times greater than the available capacity. It is concluded that the extra surveying is needed.

5.4 Intangible Benefits Of Laser Hydrography

5.4.1 Increased Spatial Density Of Soundings

In many areas, more soundings are needed to define adequately the contours of the bottom. Current practice is for launches to run extra profiles when a shoal is suspected. The laser system, however, will automatically give an increase spatial density of soundings and give that increase at the cost and manpower reduction computed in Sections 5.1 and 5.2. Table 16 shows the density of laser soundings compared to the density of sonar soundings.

Technique	Scale	Line Spacing (meters)	Density (meter^2/sounding)(1)
Laser	1: 1,000	Overlapping swaths	25 m^2/sounding
Sonar	1: 2,500	25 m	312 m^2/sounding
Sonar	1: 5,000	50 m	1,250 m^2/sounding
Sonar	1:10,000	100 m	5,000 m^2/sounding
Sonar	1:20,000	200 m	20,000 m^2/sounding
Sonar	1:40,000	400 m	80,000 m^2/sounding

(1) Plotted sonar soundings are 5 mm apart at the scale of the survey

Table 16. Density of Soundings for Laser and Sonar Surveys

In areas where greater density is not needed, the system can be operated at smaller scales, e.g., 1:10,000 or 1:20,000, with a proportionate savings in cost and manpower.

5.4.2 Reconnaissance Capability

The airborne laser system will be an ideal survey reconnaissance tool due to its high survey speed, low cost, and the speed with which it can commute among wide dispersed sites. With a better picture of where changes have occurred, one can accurately schedule basic hydrography into the areas of greatest need. This rapid reconnaissance capability would be useful, for example, in the Gulf of Mexico after a hurricane, in Alaska after an earthquake, and along the East Coast to assess changes resulting from winter storms before the recreational boating season begins in the spring.

5.4.3 Fuel Savings

An analysis was conducted to determine how fuel-efficient the airborne laser system is when compared with existing vessels. The following facts and assumptions were used:

a. All vessel computations are done for a 1:10,000 scale survey with 100-meter line spacing. Fuel consumption per square nautical mile will increase for larger scale surveys and decrease for smaller scale ones.

b. The laser system performs its standard 1:1,000 scale survey, i.e., 220-meter swaths overlapping by 20 percent.

c. 75 percent of launch fuel consumption is assumed to be used running survey lines. The remainder is for other activities such as turns and commuting to and from the survey area.

d. Crosslines (an additional 15 percent of surveying), development, etc., are ignored for launch estimates. The laser system needs no crosslines or development.

e. 20 percent of the aircraft time is assumed to be used running survey lines. The balance is for other activities such as turns, commuting to and from the survey area, and training.

f. The range of aircraft considered are the Piper Navajo C/R PA to the Cessna Titan 404.

The results of the fuel-efficiency analysis are shown in Table 17. The airborne system is comparable to the best survey vessels now operated by NOS. Its productivity is so much higher than any of these vessels (2,000 nm^2 per laser versus 1,600 nm^2 for 20 launches) that the overall fuel-efficiency of the hydrography fleet will improve.

Present Vessels	Max. Survey Speed(1)	Fuel Consumption(1)	Gal/nm^2
MT. Mitchell	12 knots	125 Gal/Hr	256 Gal/nm^2
CLASS III (WHITING, DAVIDSON, PIERCE)	12 knots	80 Gal/Hr	164 Gal/nm^2
High Speed Launch	18 knots	38 Gal/Hr	52 Gal/nm^2
Jensen Launch	13 knots	10 Gal/Hr	19 Gal/nm^2
Turbo Jensen	20 knots	8 Gal/Hr	10 Gal/nm^2
Hydro. Field Party Outboards	20 knots	4 Gal/Hr	5 Gal/nm^2
<u>Proposed</u>			
Airborne Laser	150 knots	28-38 Gal/Hr(2)	8-11 Gal/nm^2

(1) Personnel communication, LCDR Tom Richards (NOAA), Chief, Hydrographic Surveys Branch, Atlantic Marine Center

(2) Business and Commercial Aviation, April 1979.

Table 17. Fuel-Efficiency Analysis

Table 17 shows only fuel savings during surveying. Fuel consumption for commuting to work sites can also be significant. For example, the NOAA ship WHITING is the support ship for two Jensen survey launches. The WHITING and its launches were sent to the Virgin Islands from February 13 to April 26, 1976, to survey. On the 2,500 nm round trip originating in Norfolk, Virginia, the WHITING consumed 16,666 gallons of fuel. The laser aircraft would have burned 633 gallons for the same trip--a savings of 16,033 gallons. Waters in the Virgin Islands are expected ##is proposed that the released manpower, vessels, and resources be applied to other hydrography missions such as detecting discrete hazards to navigation and fishing obstructions. A description and justification for this proposal will be given in Section 7.5.6.

5.5.5 Summary

The benefits of laser hydrography have been quantified to allow comparison of this technique with present surveying techniques. The principal benefits over the lifetime of the system are: a cost avoidance of $29 million; a manpower avoidance of 196 manyears; and an increase of 9,600 nm^2 in the amount of shallow water surveyed. Additionally, the system will gather 100 times more soundings per unit area than the present method, provide an improved survey reconnaissance capability, and save fuel.

6.0 IMPACTS

As with other important services provided by the U.S. Department of Commerce, the prinicipal goal is that of maximum service to users in a reasonable time span at minimum cost. NOS is strongly aware of its responsibilities for nautical chart production and accountability for the optimum use of available resources. Funds and manpower are limited, and this situation is not expected to improve in coming years. In order to satisfy the principal goal of maximum service at minimum cost, reductions must be made in the cost, manpower, and time required for hydrographic surveys.

Airborne laser hydrography provides an opportunity to improve the cost- and manpower-effectiveness of shallow water surveying. Surveying the proposed 22,400 nm^2 over 8 years will cost NOAA $29 million and 196 staff years less if such a system is built and operated.

Maintaining or improving the quality of hydrographic surveys is of equal importance with reducing their cost. Mariners rarely attempt to evaluate a nautical chart; where no dangers are shown, they believe that none exist. As a result, life, safety, and property depend on the accuracy and adequacy of the charts. Faced with growth in existing user requirements and anticipated new requirements, NOS will be less and less able to provide accurate, current, and thorough hydrographic surveys. Consequently, the risk of deaths at sea and the loss of valuable ships and cargo will increase. This also has legal implications because the government is liable for accidents resulting from erroneous charts.

Implementing an airborne laser hydrography system will help maintain or improve the quality of hydrographic surveys in four ways. First, it will allow an additional 1,200 nm^2 to be surveyed annually--9,600 nm^2 over the life of the system. Second, it will survey at a 100-fold increase in the spatial density of soundings compared to existing systems. Third, its use as a reconnaissance tool will help determine where hydrography is most critically needed. Fourth, the launches, skilled manpower, and resources released from existing survey duties will be used to investigate discrete hazards to navigation.

7.0 PROGRAM PLAN BASED ON STRATEGY

The airborne laser hydrography development program is designed to reduce the cost and manpower required for shallow water hydrography. The program plan being followed by NOS and OTES has four phases.

I.	Research and Evaluation Phase	- 1970-1981
II.	Development Phase	- 1983-1985
III.	Transition Phase	- 1986
IV.	Operational Phase	- 1987-1994

Section 7.1 outlines the objectives of the Program Plan. Section 7.2 contains a detailed description of the project management requirements. For those readers who require a more detailed explanation of the Program Plan Phases II through IV, refer to Sections 7.3 through 7.5

The NOS Airborne Laser Hydrography System is illustrated in Figure 14.

7.1 Objectives

7.1.1 Phase I--Research and Evaluation Phase Objectives

Phase I of the project has been completed. Sufficient information was developed to make an informed decision on whether to implement the laser technology. The NOS management carefully considered the information and decided to acquire and operate such a system. More of the Nation's survey requirements would be met, and at a reduced cost and with less manpower. NOS therefore proposes to proceed with Phases II through IV.

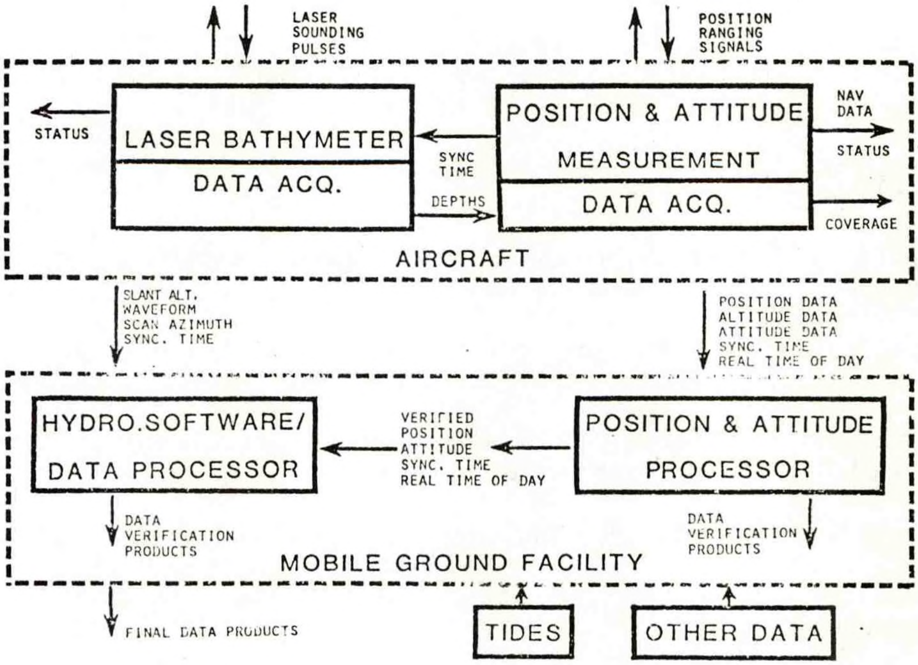

Figure 14. NOS Airborne Laser Hydrography System

7.1.2 Phase II--Development Phase Objectives

The objective of the Development Phase is to develop, fabricate, and test an Airborne Laser Hydrography System suitable for operational use by NOS.

Subobjective 1: Develop, fabricate, and test an Airborne Laser Bathymeter (ALB) subsystem capable of making depth soundings accurate to within ±0.3 meter RMS for water 0 to 20 meters deep and accurate to within ±1.0 meter for water 20 to 100 meters deep. The subsystem should penetrate to depths characterized by the expression $2\ KD + \ln D \leq 7$ for $0.1\ \text{meter}^{-1} \leq K \leq 0.5\ \text{meter}^{-1}$. The subsystem should take 600 such soundings per second, spread uniformly over an approximately 220-meter wide swath when operated from a light, twin engine aircraft travelling at a speed of 75 meters per second and an altitude of 300 meters.

Subobjective 2: Develop, fabricate, and test an aircraft Position and Attitude Measuring Subsystem (PAMS) capable of assigning geographic coordinates to each laser sounding. The positions must be accurate to ±4.6 meters RMS between 0 and 15 kilometers from shore, accurate to ±9.2 meters RMS between 15 and 30 kilometers from shore, and accurate to ±18.4 meters RMS between 30 and 60 kilometers from shore. The subsystem must also provide real-time navigational information to the aircraft pilot that is accurate to ±10 meters RMS between 0 and 30 kilometers from shore, and accurate to ±18.4 meters RMS between 30 and 60 kilometers from shore. The subsystem must operate in a light, twin-engine aircraft travelling at a speed of 75 meters per second and an altitude of 300 meters. The subsystem must be capable of operating both in a stand-alone mode and as an integrated part of the Airborne Laser Hydrography System.

Subobjective 3: Develop, implement, and test a Hydrographic Software/Data Processing Subsystems (HS/DP) that includes the hardware and software capable of performing the following operations:

- o Accept raw data from the ALB Subsystem, PAMS, Tides Subsystem, and manual input by the operators.
- o Compute the water depth and a quantitative measure of confidence in the accuracy of each depth measurement.
- o Compute the geographic position of each laser sounding and a quantitative measure of confidence in the accuracy of each position.
- o Allow for manipulation, evaluation, and modification of the data set in the field by experienced hydrographers.
- o Eliminate anomalous, erroneous, and low confidence soundings or positions.
- o Select that subset of the acceptable soundings that best represents the bathymetry.
- o Prepare final survey products including a magnetic tape of the selected soundings, an archive copy of the raw data, and written reports as specified in the NOS Hydrographic Manual (Ref. 1).

Subobjective 4: Develop, fabricate, and test a Tide Measurement Subsystem (TMS) with a gage/recording accuracy of 0.1 inch or better that makes a measurement at least every 6 minutes. As many as 12 gages may need to operate concurrently and the subsystem must be deployable and maintainable by the laser hydrography survey party.

Subobjective 5: Develop, fabricate, and test a Mobile Ground Facility (MGF) suitable for housing the PAMS and HS/DP data processing hardware. The MGF must also be usable by the survey party as a data processing facility, a mission planning facility, and an equipment maintenance facility.

Subobjective 6: Procure and modify light, twin-engine aircraft suitable for airborne laser hydrography.

Subobjective 7: Integrate the subsystems, install in the aircraft, and test as a system.

Subobjective 8: Prepare a logistics support package to include maintenance procedures, maintenance manuals, spare parts and consumables for 12 months, system operating manuals, training manuals, support and test equipment, storage and shipping containers, and system documentation.

7.1.3 Phase III--Transition Phase Objectives

The objective of the Transition Phase is to transition the system from the developer to the user by performing the following:

Subobjective 1: Training in system operation and maintenance.

Subobjective 2: Developmental testing of system readiness for transition to the user, evaluate technical aspects of support equipment, assure continued performance in the aircraft environment, and determine required modifications based on technical performance.

Subobjective 3: Operational testing to evaluate the worth of the system to the user, test effectiveness in the operating environment; test operational suitability in a realistic environment; generate reliability, availability, and maintainability statistics; and determine required modifications based on human engineering factors.

Subobjective 4: Techniques development to test the adequacy of the employment and supportability concepts and develop procedures for the details of performing a mission.

Subobjective 5: System modification and finalization based on the results of the developmental and operational testing.

Subobjective 6: System certification and user acceptance.

At the conclusion of Phase III, the Office of Marine Surveys and Maps (MSM) of NOS will accept responsibility for the Airborne Laser Hydrography System from the developing organization, OTES.

7.1.4 Phase IV--Operational Phase Objective

The objective of the Operational Phase is to operate the system for 8 years to gather large quantities of accurate, cost-effective bathymetric soundings suitable for use in preparation of nautical charts.

A more detailed discussion of the Program Plan Phases is presented in Section 7.3.

7.2 Project Management and Control

Project management will be established so that control will reside with the organization responsible for meeting the project objectives. During the Development and Transition Phases, the responsible organization will be NOAA/OTES. OTES will directly receive one position and $1,340K of the $1,430K increase for each of 4 years to develop, test, and transition an Airborne Laser Hydrography System. During the Operational Phase, the responsible organization will be NOAA/NOS. NOS will directly receive $864K of the increase (reduced from $1,430K to $954K in FY 1987) for each of 8 years to operate the system. In addition, $90K and 2 positions wil be received directly by NOS for the entire 12 years of the project to develop and operate an expanded data handling capability made necessary by the increased amount of data being gathered.

An Airborne Laser Hydrography Development Project will be established in the Instrument System Development Division, Engineering Development Office, OTES, to manage the Development and Transition Phases. This Division has successfully developed major hardware systems for NOS in the past, for example, the Water Level Telemetry System, and has maintained the necessary skills and experience to manage the laser hydrography development.

The anticipated organization of the project reflects the system concept and phases of work. Figure 15 shows this organization. The systems engineer is responsible for producing an integrated system that has passed acceptance testing. The transition manager will take that system and meet the objectives of the Transition Phase. An aircraft manager is identified to coordinate aircraft usage with existing NOS air operations and to identify the aircraft or range of aircraft parameters that the systems engineer must design to. Between 3 and 4 man-years per year will be furnished by OTES to staff the project during the Development and Transition Phases.

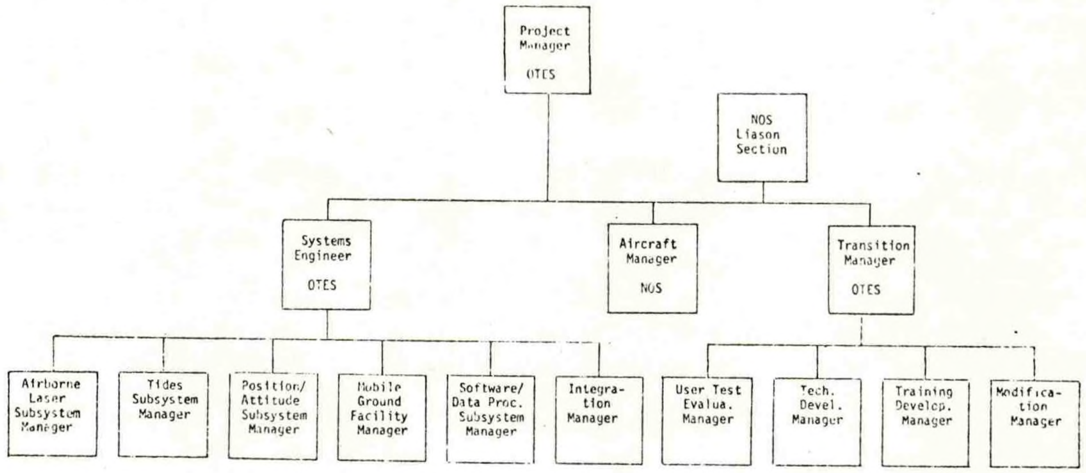

Figure 15. Laser Project Organization During Development

A high degree of interaction between developer and user is essential for three reasons. First, because the laser is a revolutionary technique of gathering bathymetric data, existing organizational policies and procedures will have to be modified, waivers obtained, or new policies written. Regular interaction between the user and the developer will allow early identification and resolution of such conflicts. In cases where organizational policy might affect system design, early resolution is essential. Second, the HS/DP Subsystem is an implementation of the specialized hydrographic knowledge and experience diffused throughout NOS. Required interaction between the developer and user should help the effective transfer of this information. Third, the operability (and ultimately the productivity) of the system will be strongly influenced by input from the user.

The required user/developer interaction will be provided through two means: a NOS liaison section that will be an integral part of the project; and a NOS Laser Hydrography Board. The liaison section will be led by the Technical Assistant, Applied Technology Group, Office of Marine Surveys and Maps of NOS. It will provide input with respect to operational constraints on system design and will identify and resolve conflicts between the proposed design or operations and existing NOS policies and procedures. The Laser Board will be an advisory group that represents the interests of NOS as a whole. The Board will also deal with required changes in policy and procedures. The Deputy Associate Director, Office of Marine Surveys and Maps, will chair the Laser Board and membership will include representatives from the Director's office, Office of Fleet Operations, Atlantic Marine Center, and Office of Program Development and Management.

Management of the Operational Phase will lie in NOS. The laser system will be operated as an independent survey party in a manner similar to the independent survey launches (hydrographic field parties) presently operated by NOS. The laser hydrography survey party will be under the administrative control of the Photogrammetry Division of MSM, NOS. The Photogrammetry Division has experience in aircraft operations and the base of experience in airborne hydrography lies within MSM. When conducting operations in the field, the management of the system, the conduct of the survey, and the supervision of the survey party personnel will be the responsiblity of the Officer-in-Charge.

7.3 Description Of Proposed Development Phase (Phase II)

As outlined in Section 7.1.2, the objective of the Development Phase, Phase II, is to develop, fabricate, and test an airborne laser hydrography system suitable for use by NOS. OTES will act as systems engineer. The systems engineer will establish the performance requirements for the system, define the major subsystems and their performance requirements, establish the interface specifications between subsystems, and apportion the engineering parameters such as power, weight, size, error, reliability, etc., among the subsystems.

In its role as systems engineer, OTES has already defined the major subsystems (Figure 14). OTES will prepare a set of Technical Specifications (TS), a Statement of Work (SOW), and a Contractor's Data Requirements List (CDRL) for each subsystem. MIL-STD-490, Specification Practices and MIL-HDBK-24SA (Navy) Preparation of Statement of Work will be adapted to this purpose.

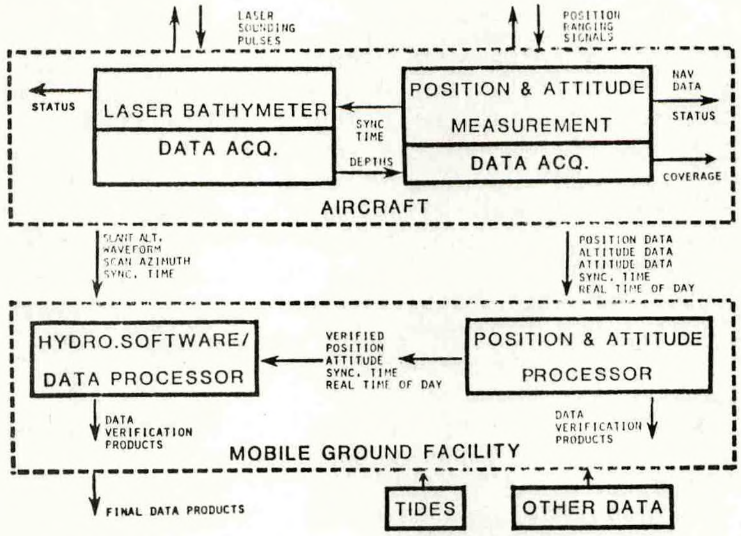

Figure 16. NOS Airborne Laser Hydrography System

The various subsystems will then be contracted for separately. This approach will allow the major subsystems to be procured from different vendors because it has been found, for example, that companies proficient in airborne laser systems have no experience in aircraft position and attitude measuring systems. The development of each subsystem will be discussed briefly in the following sections.

7.3.1 Airborne Laser Bathymeter (ALB) Subsystem Development (Subobjective 1)

7.3.1.1 Subsystem Description. ALB (Figure 17) produces the laser sounding pulses, transmits them to the water, receives the return signal, and digitizes and records that signal. It must also monitor and display its own status for use by the system operator, although actual operation should occur without operator intervention.

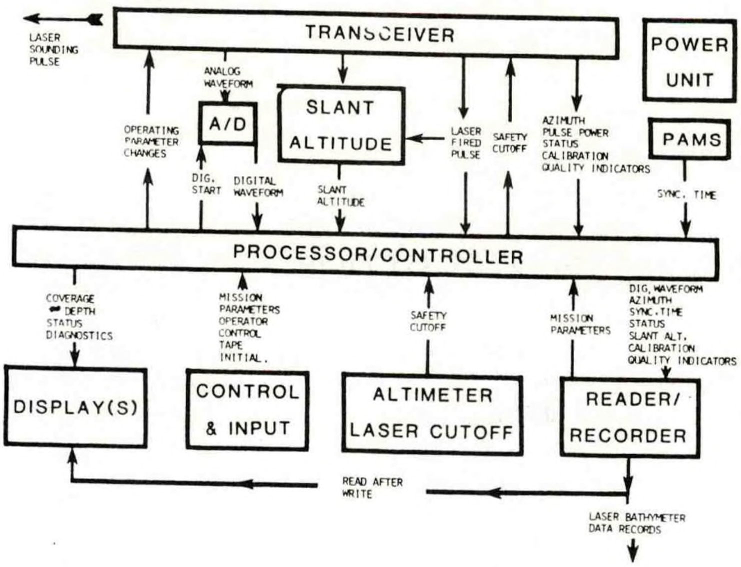

Figure 17. ALB Subsystem

The design goal performance parameters have been established for this subsystem (Table 18).

Wavelength	540 nanoseconds
Laser bandwidth	0.1 nanometers
Laser pulse rate	600 per second
Laser pulse width	5 nanoseconds
Probability of bottom detection	99%
Probability of false alarms	10^{-6}
Scan angle	variable to ±20° from nadir
Scan rate	5 per second
Beam divergence	5 milliradians
Receiver field of view	80 milliradians
Receiver temporal resolution	1 nanosecond
Receiver dynamic range	10^{7}
Waveform amplitude resolution	10 bits
Laser pulse peak power	800 kilowatts
Power	3.5 kilowatts
Weight	≤ 800 pounds
Size	to be determined
Platform	light, twin engine aircraft
Mission Endurance	4 hours

Table 18. ALB Design Goals

The ALB consists of a transceiver assembly (Figure 16), subsystem electronics, and the data recorder. Within the transceiver, pulses of the desired 540 nanometer wavelength will be generated by a solid state, frequency doubled, Nd:YAG laser. The laser is followed by a series of optical components that shape the beam and a scanner that produces the swath of soundings. A telescope in the aircraft receives the returning laser light. The optical signal is converted to an electrical signal, amplified several times, digitized, and recorded. Depth will later be computed from this digitized waveform. As Figure 18 shows, the laser subsystem has significant mechanical aspects such as the mounting cradle, vibration isolators, and the continuously rotating scanner. Power supplies, packaging, logistics support and testing are also to be provided.

TRANSCEIVER ASSEMBLY

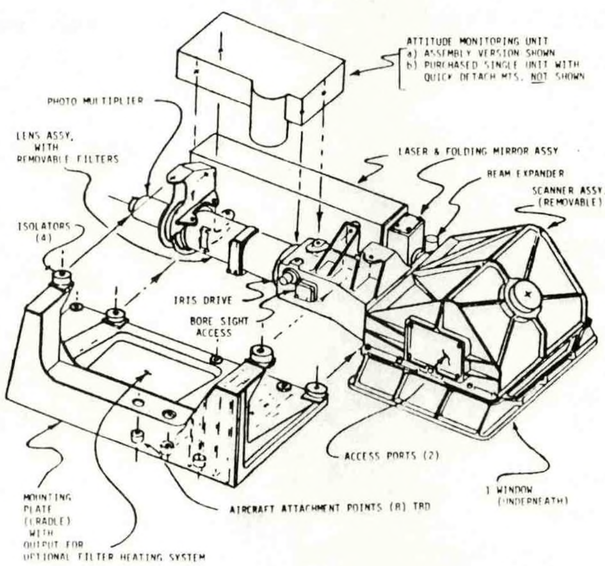

Figure 18. Sample ALB Transceiver

7.3.1.2 ALB Procurement Strategy. The ALB Subsystem will be procured on contract with private industry. The contract will be cost-plus-fixed-fee to recognize the developmental nature of the work. Preparation of the TS, SOW, and CDRL has begun and will be completed by September 30, 1981.

The Laser Bathymeter Subsystem contract will be phased with the satisfactory completion of one phase being required before proceeding to the succeeding phase. The major phases will be the design and error analysis, transceiver fabrication and test, subsystem completion, and test phase.

OTES will provide the required technical personnel to prepare the RFP, to evaluate responses, and to act as the Contracting Officer's Technical Representative. Expertise to fulfill these responsibilities has been developed within OTES through three mechanisms. First, OTES has been performing research and analysis on laser hydrography for 11 years, and has successfully operated the NASA experimental system for 2 years. Second, OTES is a participant in the U.S. Navy's procurement of an operational Hydrographic Airborne Laser Sounder (HALS). OTES personnel helped write the specifications for HALS, provided one member of the source evaluation board, are members of the design review board, and expect to participate in the testing and acceptance phases of HALS. Third, formal training in project management has been provided to the proposed project team. As additional technical support, members of the Navy HALS project will be asked to participate in the NOAA development.

7.3.1.3 Areas Of Risk In Laser Bathymeter Subsystem. The NOS ALB Subsystem will be largely a state-of-the-art instrument using commercially available components. The development effort will be to build an integrated, reliable subsystem using those components. Five similar subsystems will have been built before the NOS instrument: the NASA Airborne Oceanographic Lidar (AOL); the Australian laser depth sounders WRELADS I and II; a bathymeter/terrain mapper (BTM) built for demonstration to the Mexican government; and the Navy's HALS. None of these systems is immediately suitable for NOS. For example, the AOL laser transmits only one-thousandth of the power required by NOS and the BTM pulses at 10 pulses per second instead of 600. Each will provide design and performance data that will reduce the technological risk for NOS.

Two components, however, are not known to exist commercially: An analog-to-digital converter (A/D) and a suitable data recorder. The analog-to-digital converter digitizes the returning laser waveform. The design requirement calls for digitizing a waveform at 200 points, 1 nanosecond apart, with 10 bits of resolution. New waveforms arrive at a rate of 600 per second. A study was performed in FY 1979 to identify potential A/D technologies. Three possibilities were discovered digitizing the waveform from an oscilloscope screen using a light sensing diode array; a Charge Coupled Device (CCD) digitizer being developed for the Office of Naval Research; and a modification of an existing A/D converter (ADC 1108-50). The recorder must record 4 hours of data on one or two recording media, such as magnetic tapes. Approximately 10^{10} bits of data are gathered in 4 hours (Table 19).

Data Item	Frequency Per Second	Bits Per Item	Bits Per Second
Sounding Waveform	600	2,000	1,200,000
Scanner Azimuth	600	12	7,200
Laser Pulse Power	600	10	6,000
Synchronization Time	600	≤ 27	16,200
Slant Altitude	600	≤ 23	13,800
System Failure Messages	Infrequently	10	---------
Diagnostic Messages	Infrequently	10	---------
Approximate Depth	5	9	45
System Temperatures (3)	1 (each)	7 (each)	21
Flashlamp Outlet	600	10	6,000
System Power	1	7	7
Other Housekeeping	1	10	10
TOTAL			1,249,283

Table 19. ALB Data Set

7.3.2 Position and Attitude Measurement Subsystem (PAMS) (Subobjective 2)

7.3.2.1 Subsystem Description. The PAMS is used to establish the geographic coordinates of each laser sounding and to navigate the aircraft during a survey. Each sounding must have a geographic position associated with it to be useful for charting. To determine the coordinates of soundings, this subsystem measures the aircraft location with respect to geodetic control points on the shore, measures aircraft attitude (which affects laser pointed direction), and measures the angle at which the scanner is deflecting the laser pulse. These seven parameters are then combined to compute the location of the pulse on the sea surface (Figure 19).

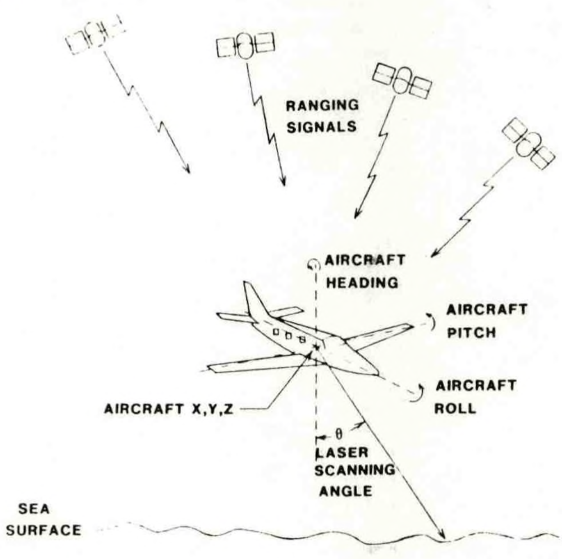

Figure 19. Sounding Position Parameters

The positioning subsystem must also provide navigation information to the aircraft pilot. It must accept as input the boundaries of the survey area, the desired flight lines, and the required altitude. The subsystem must then provide the pilot with directional information (Figure 20).

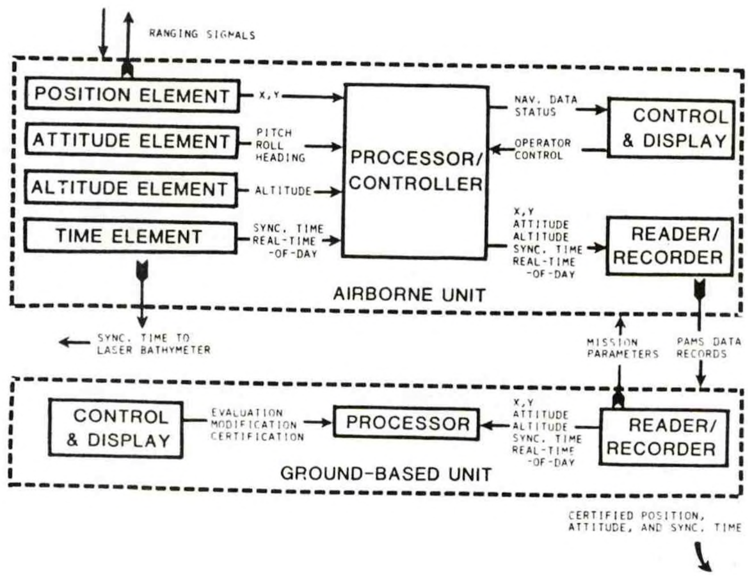

Figure 20. PAM Subsystem

Tables 20 and 21 contain performance parameters for the positioning subsystem. Table 22 is an error budget for the parameters from which the position is computed. The positioning subsystem also includes the power supplies, mechanical support and packaging, logistics support package, and testing required to measure accurate positions.

	OVER LAND	DURING TURNS	DISTANCE TO NEAREST LAND 0-8NM	8-16NM	16-32NM	32NM
AIRCRAFT REL. HORIZONTAL (X,Y) REAL TIME	25M	25M	10M	10M	10M	10M
AIRCRAFT ABS. HORIZONTAL (X,Y) REAL TIME	460M	460M	460M	460M	460M	460M
AIRCRAFT ABS. VERTICAL (Z) REAL TIME	NO REQ.	NO REQ.	15M	15M	15M	15M
LASER ABS. HORIZONTAL POST-PROCESSING	NO REQ.	NO REQ.	4.5M	9.1M	18.2M	36.5M

Table 20. Positioning Subsystem Accuracy Design Goals

Number of positions required	1 per sounding (600 per second)
Post-processing time allowed	2 hours per hour of data collection
Operating environment	Light, twin engine aircraft 75 m/sec aircraft speed 300 meters altitude
Off-nadir scan angle	20°
Mission length	4 hours
Time tagging	1 μs accuracy
Weight	To be determined
Power	To be determined
Size	To be determined
Other	Stand-alone capability (without laser subsystems) Day/night operation All geometries of shoreline

Table 21. Positioning Subsystem Design Goals

PARAMETER	ACCURACY
HORIZONTAL POSITION (X, Y)	3.9 M RMS
VERTICAL (Z)	1 M RMS
OFF-NADIR ERROR (PITCH AND ROLL)	0.25°
HEADING ERROR (LASER POINTING PLUS AIRCRAFT HEADING)	0.5°
AZIMUTH	0.3°

Table 22. Positioning Subsystem Error Budget

Two candidate positioning subsystems have been identified: an inertially aided microwave ranging instrument, and an inertially aided satellite Global Positioning System (GPS) used in the differential mode (Ref. 28 and 29). The microwave alternative determines aircraft location by measuring the distance to three shore-based, microwave transponders. The CR-100 Precision Ranging System manufactured by Cubic Corporation is typical of such systems. The satellite alternative determines aircraft location by measuring the distances to four satellites in the GPS network (Ref. 30). Both alternatives required an inertial measurement unit to determine aircraft attitude and to "bridge" the period between ranging fixes. Strapdown inertial measurement units such as the Litton LR-80 seem suitable for this application.

7.3.2.2 PAMS Procurement Strategy. The Positioning and Attitude Measuring Subsystem will be procured under contract with private industry. The contract will be cost-plus-fixed-fee to recognize the developmental nature of the work. The TS, SOW, and CDRL have been written and circulated to private industry for comments.

OTES will provide the required technical personnel to evaluate the responses to the RFP, and act as Contracting Officer's Technical Representative. OTES has had experience in writing specifications for postioning systems (such as ARGO), and in testing microwave positioning systems (Del Norte and Motorola).

7.3.2.3 Areas of Risk In The Positioning Subsystem. A microwave ranging instrument, a GPS receiver, and inertial measurement units are expected to be commercially available in the required time frame. The contractor will integrate these instruments into a subsystem suitable for laser hydrography, develop the required software, and provide the required input and output interfaces.

The greatest risk with the microwave ranging technique is in achieving the required accuracy over an entire survey area. When the microwave transponders are properly located, the microwave/inertial combination can meet the specification. This was demonstrated at Holloman Air Force Base, New Mexico, where a modified Cubic CR-100 microwave ranger and Litton LN-15 inertial measurement unit achieved 4 meters of accuracy. When the microwave transponders are arrayed in an unfavorable geometry, accuracy is degraded through a geometric dilution of precision (GDOP). For laser hydrography, the constraint imposed by the location of the land, shape of the shoreline, and length of the flight lines may cause large GDOP in portions of a survey area giving regions of inaccurate positioning.

The government would require the risk of microwave positioning to be reduced in three ways if the successful bidder proposed this technology. First, an extensive error analysis would be part of the subsystem design to ensure that the contractor has identified all sources of error and that the proposed solution has the potential of working. Second, the work would be phased to test the major potential error sources before the total system is built. For example, if the contractor proposes "bridging" areas of large GDOP by using the inertial measurement unit, it must be demonstrated that the drift of the inertial unit over the bridging time remains within the error budget. Third, extensive acceptance testing will be performed.

Use of the GPS for aircraft location also poses a risk. Commercial receivers are being developed by four companies, but they are not yet commercially available. The final cost of these receivers is therefore unknown. Estimates range from \$30K to \$500K and pose a cost risk. There is also an availability risk. Operational satellites are still being built and launched. The launch schedule has been extended once and the planned number of satellites reduced from 24 to 18. Further reductions in that program could limit the availability of the GPS for laser hydrography positioning. OTES will review this situation at the time of proposal evaluation but can take no risk reducing actions.

7.3.3 Hydrographic Software/Data Processing (HS/DP) Subsystem (Subobjective 3)

7.3.3.1 HS/DP Subsystem Description. The third major subsystem of the Airborne Laser Hydrography System is the HS/DP Subsystem (Figure 21). Laser hydrography is an intensive signal processing and data management problem. The ability to compute depths accurately will determine the acceptability of laser data. The effectiveness of the data management software will determine the ability to maintain quality control and to use the data. The HS/DP is a ground-based, trailered subsystem that will provide the necessary hardware and software to process raw survey data through to final, certified, survey results.

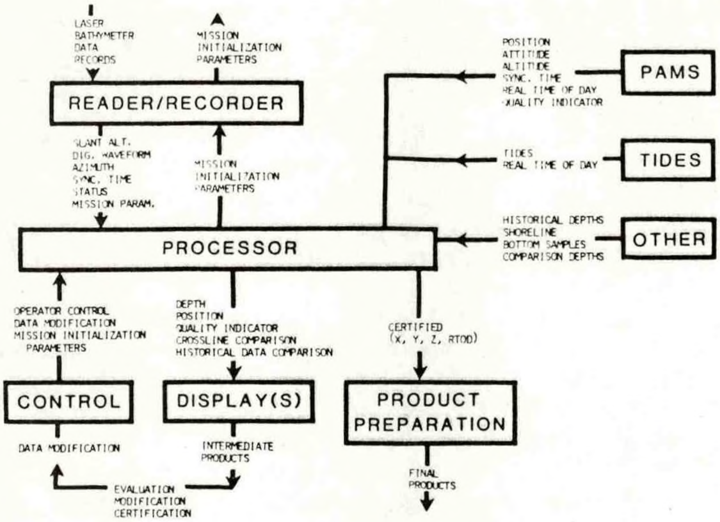

Figure 21. HS/DP Subsystem

The HSDP Subsystem (Ref. 31 and 32) has been separated into three configuration items that are capable of being developed simultaneously. Those configuration items are the preliminary, intermediate, and final processing (Table 23). Preliminary processing will start with the digitized laser return waveforms, compute depth and depth correctors, merge depth and position, and perform some quality control functions. The preliminary processing will be fully automated and will operate using only properties of the data set itself. The intermediate processing is a quality control phase in which the survey party examines the data for completeness and accuracy. Intermediate processing is interactive and takes advantage of the hydrographer's experience. Final processing prepares the output products of the survey.

STEP	FUNCTIONS	OUTPUT
PRELIMINARY PROCESSING	• UNPACK • COMPUTE DEPTH • MERGE XYD • COMPUTE Q_i	• ALL (X, Y, D, T, Q_i) • ANOMALIES • REFLY DECISION
INTERMEDIATE PROCESSING	• SORT • EDIT • INTERMEDIATE PRODUCTS • HYDROGRAPHIC EVALUATION • PRIOR SURVEY COMPARISON	• ALL ACCEPTABLE (XYDTQ_i) • ANOMOLIES
FINAL PROCESSING	• REDUCE NUMBER OF SOUNDINGS • CERTIFICATION • PREPARE OUTPUTS • PREPARE REPORTS	• SELECTED (XYDT) • ALL ACCEPTABLE (XYDT)

Table 23. Hydrographic Software Functions

The HS/DP Subsystem need not operate in real time. It only has to process data at a rate of 2.2 hours of processing per 1 hour of data collection. Both software and ADP hardware will be required. At the minimum, a mini-computer and magnetic tape recorder will be required. The HS/DP Subsystem also includes power supplies, mechnical support and packaging, integrated logistics support, and testing.

7.3.3.2 HS/DP Procurement Strategy. The HS/DP Subsystem will be procured on contract(s) with private industry. Software will be procured using a cost-plus-fixed-fee contract to recognize the developmental nature of the work. Hardware will be procured using a firm fixed-price contract because only commercially available equipment is desired. A detailed draft set of user's requirements (Ref. 33) has already been prepared for this subsystem and a high level subsystem design will be completed in FY 1981. Work will then stop until a funding initiative is approved.

The Computer Applications Division (CAD) of OTES will be responsible to the project manager for the development of this subsystem. CAD will prepare the procurement specifications, monitor the software development and hardware procurement, and deliver a completed subsystem to the project engineer. CAD has had significant previous experience in the design, development, and procurement of data processing systems. Examples include the off-line processing for the Bathymetric Swath Survey System and the management and display software for the Analog-to-Digital Recorder used for tide measurements.

7.3.3.3 Areas of Risk in the HS/DP Subsystem. Data throughput is expected to be the area of greatest risk in the HS/DP Subsystem. The 10^6 to 10^7 soundings gathered permission must be processed and evaluated such that the data processing and data gathering are accomplished at comparable rates. A large amount of data must be held in computer memory simultaneously in order to calculate many of the required pieces of information. To reduce the risk, a data throughput analysis will be conducted in conjunction with the high level, HS/DP Subsystem design. The subsystem user requirements will then be reviewed and revised based on the result of throughput analysis.

A second area of difficulty in the HS/DP will be in selecting the small subset of all the soundings that best represents the bathymetry. This sounding selection is necessary to avoid inundating the chart compilers and their data processing systems with data. Sounding selection as done by cartographers, like data verification, has years of tradition that will affect the acceptability of proposed sounding selection procedures. Work will be needed on sounding selection prior to the approval of this initiative.

7.3.4 Tide Measurement Subsystem (TMS) (Subobjective 4)

The Tide Measurement Subsystem (TMS) must record the level of the tides during an airborne laser hydrographic survey so that all water depths can be converted to the depth at Mean Lower Low Water (MLLW) for use on a nautical chart. Sufficient gages must be deployed to allow the water level to be estimated at any point within the survey area. This means that as many as 10 to 12 gages must be deployed and operating simulataneously in highly irregular areas where flight lines cross many tide zones.

The TMS is seen as a low risk subsystem. NOS has many years experience in measuring tides, making tide corrections for hydrography, and in operating and monitoring tide measuring systems. No work to date has been done on the TMS because the risk is felt to be so low. NOS will be responsible for providing a TMS to the project manager. It is anticipated that equipment will be allocated to laser hydrography from the stockage that will exist in 1987. The reassignment of some hydrographic launches to item investigation (Section 7.5.6) should make such equipment available. No funds are included in the Initiative for the procurement of tide measuring equipment.

7.3.5 Mobile Ground Facility (Subobjective 5)

The ground-based portion of the Airborne Laser Hydrography System is planned as a trailered, data processing center that will accept the recorded raw survey data from the airborne suite and produce the survey results. This Mobile Ground Facility (MGF) will contain two separate processing systems, one from the PAMS for computing aircraft position and attitude, and one from the HS/DP subsystem which computes depth, merges depth and position, and then allows manual verification and certification of the survey results. A 20-foot trailer is anticipated to contain the HS/DP hardware, the PAMS ground based suite, and a power supply, in addition to equipment and space for maintenance, calibration, mission planning, data evaluation, and the storage of spare parts.

The MGF is seen as a low risk subsystem. The Ocean Engineering Division (OED) of OTES will be responsible to the project manager for the specification and procurement of this subsystem. OED has developed two similar shelters in the past, a chemistry van and a personnel shelter that were environmentally controlled, outfitted, and deployed aboard the NOAA ship KELEZ. No work will occur on this subsystem until after a laser hydrography initiative has been approved.

7.3.6 Aircraft (Subobjective 6)

An aircraft will be procured as part of this initiative. It is anticipated that the aircraft will be fully utilized performing airborne laser hydrography. The airborne equipment is being sized to operate in a light, twin-engine, low performance aircraft (Ref. 34). The Cessna Titan represents the largest such aircraft considered suitable. Most technical problems with the aircraft, such as disposal of waste heat, are expected to be small compared with the difficulty of procuring a plane within the Federal Government. It is impossible to specify in advance the type of aircraft that will actually be purchased. This, in turn, makes specification of the airborne suite size, weight, and fit difficult.

The Coordinator for NOS Aircraft Operations will be responsible to the project manager for the procurement and modification of the aircraft. The project manager will provide funds from this initiative and requirements to the Coordinator for the procurement. No work will occur on the aircraft specification or procurement until after a laser hydrography initiative is approved.

7.3.7 System Integration and Test (Subobjective 7)

7.3.7.1 Description. In order to have the subsystems operate together, interfaces among subsystems must be defined and built, the subsystems must be installed and interconnected, and system tests must be performed. The following interfaces are of concern:

- o Mechanical-size and physical fit, mechanical interconnection among subsystems (e.g., inertial measurement unit to optical platform), mechanical connection to aircraft vibration isolation, total weight
- o Power-total power, power distribution, power conditioning, RF noise shielding
- o Thermal-heat dissipation from electronics, disposal of heat from aircraft cabin
- o Data-data formats, interrupt structure, electronic status, diagnostics, environmental
- o Human- accessibility, system status indicators, diagnostics, environmental

7.3.7.2 Integration Strategy. Two interfacing strategies exist, the first, to buy subsystems "as manufactured" and then build interfaces based on what is delivered, or the second, to specify the interfaces during subsystem procurement and buy the interfaces as part of their respective subsystems. The second alternative will be used for the Airborne Laser Hydrography System. This approach will allow the contractor most familiar with a subsystem to design and build the interfaces and will require the least government manpower.

OTES will provide technical personnel to specify subsystem interfaces. The responsible individual on the project staff will be the systems engineer. Through minimization of interfaces, actual system integration should consist of the mechanical installation of the subsystems and making power corrections. OTES will be responsible for this integration.

7.3.7.3 Areas of Risk in System Integration. Successful integration requires advanced specification of interfaces. This may not be possible. For example, the laser aircraft must be chosen in FY 1982 in order to specify size, weight, and mechanical mounting requirements in subsystem purchase descriptions. NOS is not able to make such an early aircraft selection. In addition, the reality of procuring an aircraft in the Federal Government may prohibit the acquisition of that chosen aircraft. Interfaces not specified in the original purchase descriptions will be handled through contract modifications. The impact of these modifications will be delay and added cost.

7.3.8 Logistics Support Package (Subobjective 8)

7.3.8.1 Description. The logistics support package is the information and materials required to operate the Airborne Laser Hydrography System. It includes maintenance procedures, maintenance manuals, spare parts and consumables for 12 months, system operating manuals, training manuals, support and test equipment, storage and shipping containers, and system documentation.

7.3.8.2 Procurement Strategy. A logistics support package will be procured as part of each subsystem from the subsystem contractor. No other logistics support materials are expected to be required.

OTES will provide the technical expertise to specify the logistics support package. OTES has had previous experience in providing integrated logistic support (ILS) and maintains this capability as a standard engineering service. For example, an ILS package was prepared for the NOS Water Level Measurement System and included general maintenance procedures, maintenance support kits, preventive maintenance procedures, maintenance data collection and analysis, a spare parts list, list of parts suppliers, and qualification standards for field repairmen.

7.3.8.3 Areas of Risk in Logistics Support. There are no apparent risk factors in the logistics support package.

7.4 Description of Proposed Transition Phase (Phase III)

7.4.1 Strategy

The objective of Phase III, the Transition Phase, as outlined in Section 7.1.3, is to develop proficiency in system operation and maintenance within the using organization, and to certify the accuracy of the airborne laser system. The phase will last one year during which the developer and user together will perform training, test and certify the system under operational conditions, develop techniques for system use, and make necessary system modifications.

Training in system operation and maintenance (Subobjective 1) will be provided to an initial, five-person survey party by the subsystem vendors. The requirement for this training will be specified in the subsystem purchase descriptions. Training beyond the initial five-person survey party will be the responsibility of NOS and is not part of this project. One person from OTES will also be trained in system operation in order to operate the system during selected tests and to provide technical support during the operational years.

Developmental and operational testing (Subobjectives 2 and 3) will be performed jointly by the laser project staff and MSM. Contractor help will be used for data analysis during the certification tests. Certification criteria will be established by MSM during FY 1984. Planning for the tests will be performed in FY 1985. Two hundred hours of developmental and operational testing will be performed in FY 1986.

Techniques development (Subobjective 4) will be performed by MSM to develop operating and utilization procedures that maximize the cost and manpower savings and minimize the risk of erroneous data. One hundred hours of techniques development surveying will be performed. The results will be documented as a chapter in the NOS Hydrographic Manual (Ref. 1) on procedures for airborne laser hydrography.

Two sites have been tentatively selected for much of the developmental and operational testing: Winter Quarter shoal in the Atlantic Ocean off Assateague Island (near the Maryland--Virginia border), and Tangier Sound on the Eastern Shore of the Chesapeake Bay. These sites are logistically accessible for the proposed work. They are also areas that have been used for laser hydrography testing in the past and so are well characterized. Two more sites will be needed - one north of Cape Cod and one off southern Florida - in order to conduct testing over a representative set of water types.

System modifications (Subobjective 5) will be performed to correct those deficiencies identified during the operational and developmental testing, and during the techniques development. System modification will be the responsiblity of the laser project staff. Technical personnel will be provided by OTES. The actual modifications will be performed on contracts with the appropriate subsystem vendors.

7.4.2 Areas of Risk in the Transition Phase

Certification is an area of potential risk. System certification (Subobjective 6) is presently not practiced by NOS hydrographers. New systems are operated until obvious shortcomings are removed and the organization becomes accustomed to the new hardware. In an attempt to improve this situation, it is proposed that airborne laser hydrography be submitted to controlled, quantitative, certification procedures of three types. First, the PAMS will be certified as measuring accurately the aircraft's 6 degrees of freedom. This will be done in an aircraft, using a simultaneous photogrammetric measurement of the six parameters as ground truth. The photogrammetric technique is claimed to be able to measure aircraft position with mean errors of less than 1 meter and attitude within .02 degree when flying at 4,000 meters. Accuracies improve at lower altitudes.

The second certification procedure will be of the ALB in a static environment. The subsystem will be mounted either on an appropriate fixed platform or on a helicoptor and used to measure depth over a small, instrumented area. A range of environmental conditions will be experienced at each of several sites.

The final certification will be an operational certification during which the entire system will be certified with its operators. Ground truth is expected to be launch-sonar measured depths where an intercomparison among launches is performed first. This intercomparison among launches will establish the distribution of "true" values. The result of the laser/sonar intercomparison would thus be a measure of whether the laser is "as good as" the standard accepted technique in a hypothesis testing sense.

The potential exists for long delays in acceptance by NOS of this scheme of certification. The impact of such delay would be increased expense and lack of system utilization.

7.5 Description of Proposed Operational Phase (Phase IV)

The NOS airborne laser hydrography system has an 8-year design lifetime. During those 8 years, the system will be used as an operational hydrographic tool to gather large quantities of accurate, inexpensive, bathymetric soundings.

7.5.1 Areas of Operation

The principal areas of system utilization will be the Gulf of Mexico, the U.S. East Coast, and the Great Lakes. Harbors, rivers, bays, and estuaries adjacent to these areas will also be surveyed. The Gulf, East Coast, and Great Lakes were selected as the primary survey areas for two reasons: the majority of the high priority, shallow-water surveying requirements are there; and the large amount of contiguous shallow water will make the laser system highly efficient.

For example, on the gulf coast of Florida, it is estimated that the laser system could survey as far as 40 to 60 nautical miles from shore and reach depths of 120 feet. Operating in these areas will allow the laser system to be used on important surveys such as the deep water oil terminals in the Gulf of Mexico (Louisiana Offshore Oil Port and Texas Deepwater Port), and for the Great Lakes confluence charts being prepared under an international agreement with Canada.

The specific sites to be surveyed during the 8 years of system operation have not yet been selected. This is for two reasons: work is still continuing on understanding which areas will be surveyable by laser (e.g., Ref. 21); and because the 5-year list of survey priorities (Ref. 6) does not yet reach to the first year of laser system operation.

7.5.2 Characteristics of Areas to be Surveyed

The areas selected for surveying by laser will be characterized by being surveyable with long, straight flight lines; having a period of time when the bottom is nearly vegetation free; and where the clarity/depth relationship of a significant portion of the water is characterized by $2\ KD + \ln D \leq 7$ with $0.1\ \text{meter}^{-1} \leq K \leq 0.5\ \text{meter}^{-1}$ and D being the depth.

A suitably long flight line is 50 kilometers. This length keeps the unproductive aircraft turning time below 20 percent of the total air time. The length of the vegetation-free period depends on the size of the area. Since the laser surveys at approximately 6.4 nm^2 per hour (Ref. 10), that period need not be long--certainly shorter than a normal 3-month winter season (Ref. 35). The relationship $2\ KD + \ln D \leq 7$ requires that the water be shallow enough and/or clear enough for the laser to penetrate. It is estimated that this relationship will allow surveying, for example, up to 35 feet in the Chesapeake Bay, up to 90 feet in the Atlantic Ocean off Cape Cod, and up to 120 feet off the Gulf Coast of Florida.

Highly irregular areas are not excluded as laser survey sites. Winding rivers and irregular harbors may be surveyed with long, straight lines by overflying a good deal of land in the process. The cost-effectiveness of laser hydrography allows such a tactic to be acceptable.

7.5.3 Selecting and Scheduling Survey Sites

Selecting and scheduling a specific area to be surveyed will be accomplished by the Requirements Branch, Hydrographic Surveys Division, Office of Marine Surveys and Maps of NOS. This branch presently performs a similar function for NOAA by maintaining the surveys priority list, scheduling survey resources, and preparing survey mission plans. Mission area selection will be performed 9 to 12 months in advance of a survey. It will be based on the priority of the survey requirement and the capabilities of the laser system.

An example survey site has been chosen to illustrate the data acquisition and field work program. The selected site is Tangier and Pocomoke Sounds in Chesapeake Bay near Crisfield, Maryland. The area was chosen because it is expected to be surveyed during the operational life of the NOS laser system. Its first use will be to demonstrate the survey site selection process.

Pocomoke and Tangier Sounds were last surveyed in the 1940's and 1950's and will be considered for resurvey around 1990. Meanwhile, Crisfield is being considered for development as a deep draft seaport. It would be an oil import terminal and an export site for the Delmarva peninsula's agricultural products. This intense development would stimulate requests for up-to-date charts and surveys, from the U.S. Army Corps of Engineers (channel dredging and maintenance), the Coast Guard (aids to navigation), the State of Maryland (development planning), private industry interested in development (environmental impact), and from the marine transport industry (navigation). Because the development of such a seaport impacts two national priorities--energy and the balance of trade - Pocomoke and Tangier Sounds would probably be scheduled for survey.

Twelve months before the planned survey date, the Requirements Branch would assess the area to determine its suitability for a laser survey. The assessment considers water clarity, vegetation, bottom composition, and the availability of support facilities such as airports. An assessment was done for the Crisfield site. Figure 22 shows the estimated "surveyability" of the southern Chesapeake Bay including Pocomoke Sound and Tangier Sound. Water clarity data for this estimate was available from existing data archives (Ref. 30). Vegetation coverage was determined to be 15 percent and it disappeared from October to April (Ref. 35); NOS charts indicate that the bottom is hard sand. The reflectivity is known to be approximately 15 percent (Ref. 37). Facilities suitable for supporting the laser system were found in Crisfield and nearby Salisbury. For example, the Salisbury Wicomico county airport has a 5,000-foot asphalt runway, sells Grades 100 and Jet A fuel, has facilities for major airframe and power plant repairs, and has medium intensity runway lights suitable for night operations (Ref. 38). The town of Crisfield has adequate lodging, restaurants, and a marina where small boats can be rented for gathering bottom samples in the survey area or for performing spot checks of laser accuracy.

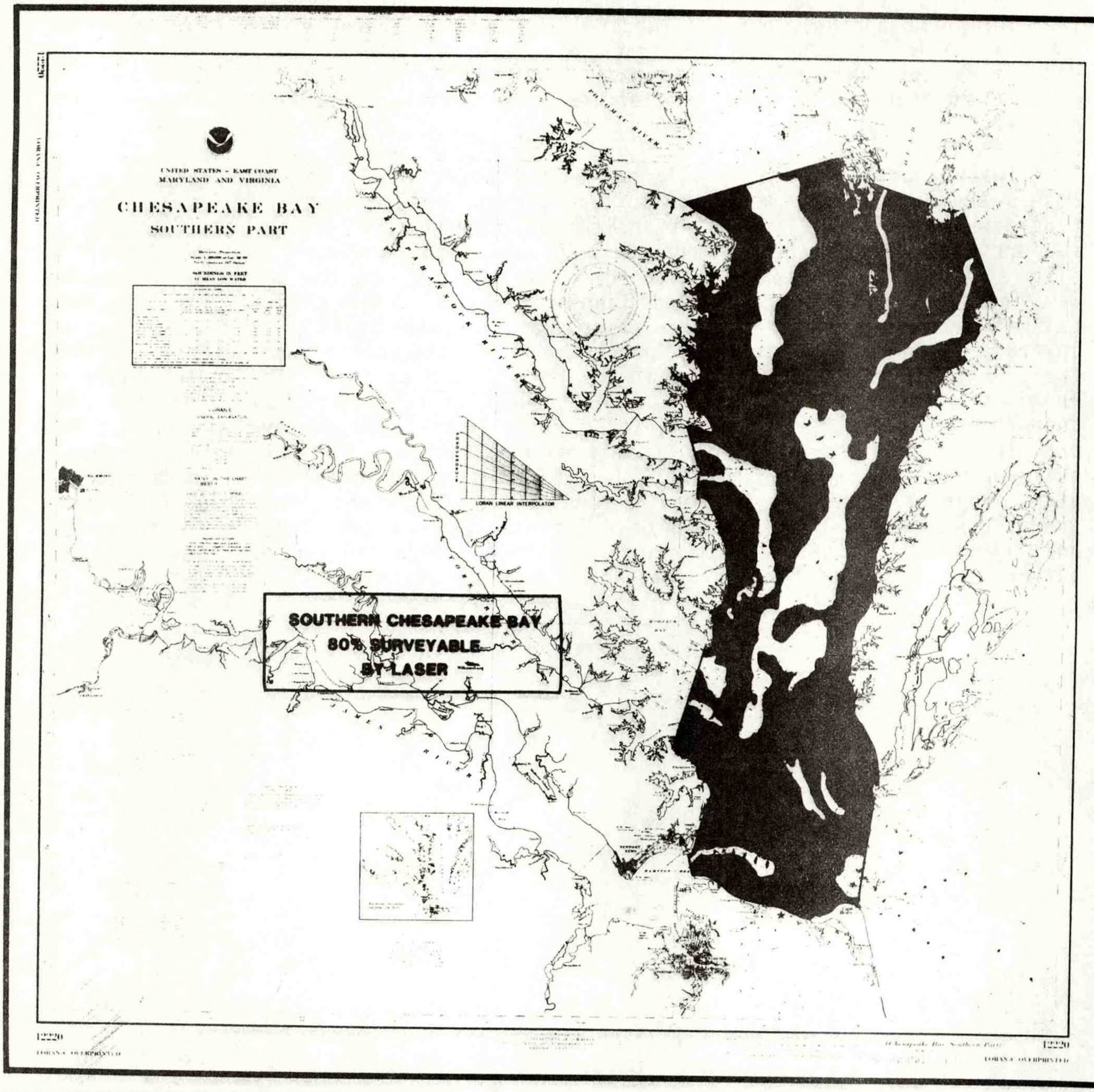

Figure 22. Estimated Surveyable Area in Southern Chesapeake Bay

These characteristics make the example site eminently surveyable by laser and show October to December to be the optimum time for laser hydrography. The combination of a priority requirement and suitability of the area would probably cause the site to be scheduled for an airborne laser hydrography survey.

7.5.4 Laser System Usage

The proposed airborne laser system will be mounted in its own aircraft. That aircraft will be flown 600 hours per year for the 8 years of the laser system's lifetime (Table 24). Both day and night operations are anticipated. Of those 600 air hours, 300 air hours will be spent over survey areas taking bathymetric soundings. This is an average of 6 hours per week of data collection. The remaining 300 hours have been allocated for overhead costs and include commuting between sites and to maintenance sites, pilot training, maintenance, and failed missions. The total number of air hours and its allocation were established using the historical performance of NOAA aircraft. This system utilization plan was used in Section 5 to determine the economic benefits of laser hydrography.

AREA SURVEYED ANNUALLY	6800 KM^2
FLIGHT HOURS PER YEAR	600 HOURS
SURVEY HOURS PER YEAR	300 HOURS
SURVEY LINE LENGTH DESIRED	70 KM
SURVEY RATE	22 KM^2/HOUR
NUMBER OF SURVEY SITES PER YEAR	4 - 10
TYPES OF SURVEYS PERFORMED	BASIC RECONNAISSANCE
SOUNDINGS PER YEAR	650 MILLION
MONEY SAVED (1982 VALUE)	U.S. $25 MILLION
MANPOWER SAVED	196 MANYEARS
SURVEY SITE	GULF OF MEXICO
	EAST COAST
	U.S. GREAT LAKES

Table 24. System Usage

The 600 aircraft hours/300 survey hours is the design utilization. Up to 650 million soundings will be gathered each year. Two thousand nm^2 will be surveyed annually at an approximate scale of 1:1,000. Shallow-water areas on the NOS survey priority list were divided into subareas appropriate for laser surveying. The average size of these subareas was determined to be 200 nm^2. The 2,000 nm^2 of laser system productivity will thus be distributed among an average of 10 sites, as compared with the 1 or 2 sites that launch-sonar parties survey each year. During the techniques development portion of the Transition Phase, efficient techniques of setting up at new survey sites will be developed to minimize unproductive time in the survey area. Tables 25 and 26 show mission and environmental characteristics during laser surveying.

ALTITUDE	150 M - 650 M 300 M NOMINAL
SPEED	75 M/S
SWATH WIDTH	220 M
SWATH OVERLAP	10%
SURVEY SITE AREA	150 KM^2 TO 3500 KM^2
AVERAGE SOUNDING SPACING	1 PER 25 M^2
SURVEY SCALE	1:1,000
MISSION DURATION	4 HOURS
SURVEY PATTERN	SLIDING RACETRACK PREFERRED
TURN RATE	3^o PER SEC.
DISTANCE TO AIRPORT	30 KM AVERAGE
SURVEY PARTY	5 PERSONS - 2 PERSON AIR PARTY, 3 PERSON GROUND PARTY
SEASON OF OPERATION	DURING MINIMUMS IN PLANKTON AND BOTTOM VEGETATION
OTHER	DAY AND NIGHT OPERATIONS ANTICIPATED
OPERATOR ACTIVITIES	SYSTEM OPERATES UNATTENDED
ADDITIONAL DATA GATHERED	COMPARISON DEPTHS BOTTOM SAMPLES TIDE WATER CLARITY ? FIELD EDIT DATA COAST PILOT DATA

Table 25. Mission Characteristics

PARAMETER	RANGE
RANGE OF WATER CLARITIES	$\alpha = .4M^{-1}$ TO $3.5M^{-1}$
WAVES	0 - 1.5M
WIND (SEA SURFACE)	0 - 5M/S
WIND (AIRCRAFT ALTITUDE)	0 - 15M/S
BOTTOM REFLECTIVITIES	4 - 15%
WEATHER	NO PRECIPITATION OR FOG
TIDES	ARBITRARY

Table 26. Mission Environmental Conditions

7.5.5 Application of Laser System Productivity

The 2,000 nm^2 surveyed annually with one laser system will be applied to the Nation's survey requirement as follows: launch hydrography will be decreased from the present 1,600 nm^2 annually to 800 nm^2 and 2,000 nm^2 of laser hydrography will be performed--800 nm^2 to replace launch surveys and 1,200 nm^2 of additional surveying. Total annual shallow water surveying will then be 2,800 nm^2, an increase of 75 percent. This 75 percent increase in the amount of area surveyed will yield 9,600 nm^2 of additional surveying over the lifetime of the system. The need for additional surveying was established in Section 3. Sixteen thousand nm^2 will be surveyed over 8 years at a 100-fold increase in the number of soundings per unit area. This surveying will be performed for $29 million and 196 man-years less than if it were performed by conventional methods.

7.5.6 Use of Released Hydrographic Launches, Manpower, and Resources

The proposed laser system usage plan would reduce launch hydrography from 1,600 nm^2 to 800 nm^2 annually. The launches, skilled manpower, and resources no longer used for launch hydrography will be applied to other national marine charting needs. One such important need is the detection of discrete hazards to navigation. Discrete hazards such as sunken wrecks, submerged pilings, and rocks are not part of the general bathymetry. The investigation of these hazards is a slow, expensive operation with an extremely low productivity. The primary investigation technique uses two 90-foot vessels towing a submerged wire between them. When the wire snags on a potential hazard, a diver goes into the water to describe the obstruction and measure the shoalest depth over it. Productivity for the pair of wire drag ships is 12 items per year. New suspected obstructions are being reported five times faster than they are being disposed of. Because discrete hazards are anomalies in the general bathymetry, they are extremely dangerous to marine navigation. The application of resources made available by the implementation of an airborne laser system would allow an increased number of suspected obstructions to be investigated annually.

A second important use of the launch hydrography resources made available by the implementation of a laser system could be the detection of fishing obstructions as mandated by Section 407, Title IV, PL95-372. Commercial fishermen would use fishing obstruction charts. They annually suffer millions of dollars in damage to their trawl equipment and boats as a result of snagging on uncharted obstructions. These losses would be reduced by the detection and charting of the obstructions.

A third planned use of the resources is intensified investigations for the United States Coast Pilot. The nine Coast Pilots are published by NOS pursuant to the Act of August 6, 1947 (33 U.S.C. 883a and b), and to the Act of July 2, 1958 (PL85-480; 72 Stat. 279). They supplement the navigational information illustrated on nautical charts and are based on field inspections conducted by NOS and other sources. Coast Pilot subjects include outstanding landmarks, channel and anchorage pecularities, dangers, pilotage, port facilities, and other information. Presently, most of the Coast Pilot investigations are done by automobile from the landward side. An intensified effort using launches would, for example, examine navigational landmarks from the seaward side to establish their visibility and decription for inclusion in the Coast Pilot.

7.5.7 Operational Staffing

A five-man survey party will be required for the laser system. Table 27 shows the expected composition of the survey party, their principal responsibilities, and the proposed grade levels. Senior level personnel are indicated due to the technological sophistication of the system and the maturity required to operate a novel, first-of-a-kind tool where detailed procedures are not available.

Personnel	Responsiblity
Officer-in Charge LCDR, GS-13	o mission planning o supervision of mission execution o chief hydrographer - responsible for post flight data review, edit, and quality control o alternate shore party member
	SHORE PARTY
Chief of Shore Party LT, GS-12	o mission logistics excluding air logistics o lead or perform support operations, e.g., tides, bottom samples, water clarity measurements, verfication soundings, establish positioning net, ... o assistant hydrographer
Electronics Technician GS-11	o maintenance and operability of all systems o system calibration excluding preflight calibrations o shore party member
	AIR PARTY
Chief of Air Party LCDR, GS-13	o pilot and aircraft commander o air operation planning o air operation execution o assistant hydrographer
Air Party Member LT, GS-12	o copilot o laser system operator o air logistics o alternate shore party member

Table 27. Survey Party Personnel

The survey party will be responsible for planning and executing the survey, for performing an evaluation of the survey data, for preparing the final results of the survey, and for transmitting those results to the Atlantic Marine Center (AMC). No other supporting personnel or field parties are expected to be required. One exception might be assistance in establishing tide measuring stations in the survey area. The tides party of the AMC provides such support on an "as available" basis. This support might be requested for laser surveys as it is for launch surveys.

7.5.8 Types of Laser Surveys

The laser system will be used for two types of surveys--reconnaissance surveys and basic surveys. Reconnaissance surveys are used to determine the extent of change in the bathymetry or the inadequacy of existing data. The high speed and low cost with which the airborne laser can commute among widely dispersed sites will allow NOS to mount a thorough reconnaissance effort. The knowledge of where significant changes have occurred in the bathymetry will then be used to schedule basic surveys efficiently. The reconnaissance capability will also be used for frequent checks of the bathymetry in critical areas such as New York harbor. Specific operating parameters for laser reconnaissance surveys have not been established. Swath spacing, sounding density, positioning accuracy, etc., will be determined during Techniques Development.

The second type of survey, the basic survey, obtains all the detailed information needed to map submarine topography and to compile nautical charts. The information to be gathered is documented in the NOS Hydrographic Manual (Ref. 1). The basic survey for the airborne laser will be at a scale of 1:1,000. Soundings will be taken with an average distribution of one per 25 m^2 within a swath, i.e., approximately 5 meters apart in any direction. Swaths will be 220 meters wide and adjacent swaths will overlap by 20 percent. Swath overlap was established so that there would be a minimum number of gaps in coverage and was based on a pilot's ability to follow a preestablished flight line.

Basic and reconnaissance surveys are not new to NOS. Policies and procedures have been evolving since 1807 and are documented in the NOS Hydrographic Manual (Ref. 1). The airborne laser system will comply with the manual except where the nature of the laser system requires an exception. A chapter on laser hydrography will be written by the MSM, NOS before the end of the Transition Phase in FY 1986. Examples of required changes to traditional operating techniques include: the lack of crosslines; flight lines will not be perpendicular to bathymetric contours; sheets of plotted soundings are impractical due to the number of soundings; and "development" of a subarea is no longer necessary.

7.5.9 Fate of the Gathered Data

Bathymetric soundings gathered by the airborne laser hydrography system will be processed and evaluated by the laser survey party. All soundings that remain after the automated and manual quality control steps (Ref. 31 and 33) will be considered as "accuracy certified". The laser party will then reduce the total number of certified soundings through a hydrographic sounding selection process. Sounding selection picks the subset of soundings that best represents the bathymetry and provides a spatial density of soundings usable by cartographers.

The selected soundings and the survey party's report will be submitted to the AMC for a procedural review. After acceptance by the AMC, the data will be forwarded to the NOS headquarters in Rockville for inclusion in the Automated Information System (AIS). The AIS is the computerized data base of all the current nautical charting data. It is from the data in this data base that the NOS cartographers compile nautical charts.

7.5.10 System Operation and Maintenance

The airborne laser hydrography system will be operated by the five-man survey party. System operation will involve: calibration, initialization, flying the survey, post-flight data reduction, examination and acceptance of the reduced data, and preparation and transmittal of the survey results. During the actual survey flights, the laser hydrography system is expected to operate unattended except for possible changes of the data recording medium and a change in system operating parameters.

The most time-consuming functions of system operation will be the post-flight data reduction and the data examination and acceptance. Approximately two people in the survey party will be working full time on these steps in order not to develop a backlog of survey data each year.

System maintanence during the Operational Phase will be performed at the field level and the factor level. Field level repairs will be performed by the five-man survey party and covers preventive maintenance and corrective maintenance. Preventive maintenance includes items such as a visual inspection, cleaning filters, replacing life-limited components, and preflight grooming. Corrective maintenance is that which can typically be performed in 1 hour including both diagnosis and repair. Repairs of this type are characterized by emplugging, removing and replacing modules, circuit boards, or major components. The second level of repair, the factory level, is performed by the subsystem vendors. It covers all repairs, refurbishments, and replacements that are not part of the preventive or corrective maintenance.

Training in system operation and maintenance will be provided to the initial five-man survey party by the subsystem vendors (Section 7.4.1). Subsequent personnel will be trained by existing survey party personnel and using training manuals and materials provided by the subsystem vendors.

7.6 Summary

The program proposed in this FY 1983 Initiative is for the development and operation of an airborne laser hydrography system. Section 7.0 has presented objectives for the program, established the management structure, and provided detailed descriptions of the Development, Transition, and Operational Phases of the effort.

8.0 PROGRAM COST

8.1 Program Cost

The following, time-phased cost charts have been prepared to show the planned expenditure of funds.

	83	84	85	86	TOTAL
Laser subsystem	$515 K	$689 K	$ 0 K	$ 0 K	$1,204 K
Positioning	$347 K	$243 K	$ 0 K	$ 0 K	$ 592 K
Data Processing	$411 K	$334 K	$ 0 K	$ 0 K	$ 745 K
Aircraft	$ 0 K	$ 0 K	$600 K	$ 0 K	$ 600 K
Transition	$ 0 K	$ 0 K	$ 0 K	$572 K	$ 572 K
System operating costs (test, train etc.)	$ 0 K	$ 0 K	$662 K	$675 K	$1,337 K
Other (scientific analysis, studies, test, consumables)	$ 67 K	$ 72 K	$ 78 K	$ 93 K	$ 310 K
Data verification	$ 90 K	$ 90 K	$ 90 K	$ 90 K	$ 360 K
TOTALS	$1,430 K	$1,430 K	$1,430 K	$1,430 K	$5,720 K

Table 28. Use of Program Funds During Development and Transition Phases

Laser Crew (3)	$247.8 K
Air Crew (2)	165.2 K
Data Verification Personnel (2)	165.2 K
Scientific Support Personnel (1)	82.6 K
Travel	95.8 K
Laser Maintenance	57.4 K
Aircraft Operation and Maintenance	140.0 K
TOTAL	$954 .0 K

Table 29. Use of Program Funds During Operational Phase (Annual Costs)

8.2 Program Schedules

The following schedules have been prepared to show the activities taking place during the Development and Transition Phases. Activity during each of the 8 operating years is the same: "Conduct 2,000 nm^2 of airborne laser hydrography surveys."

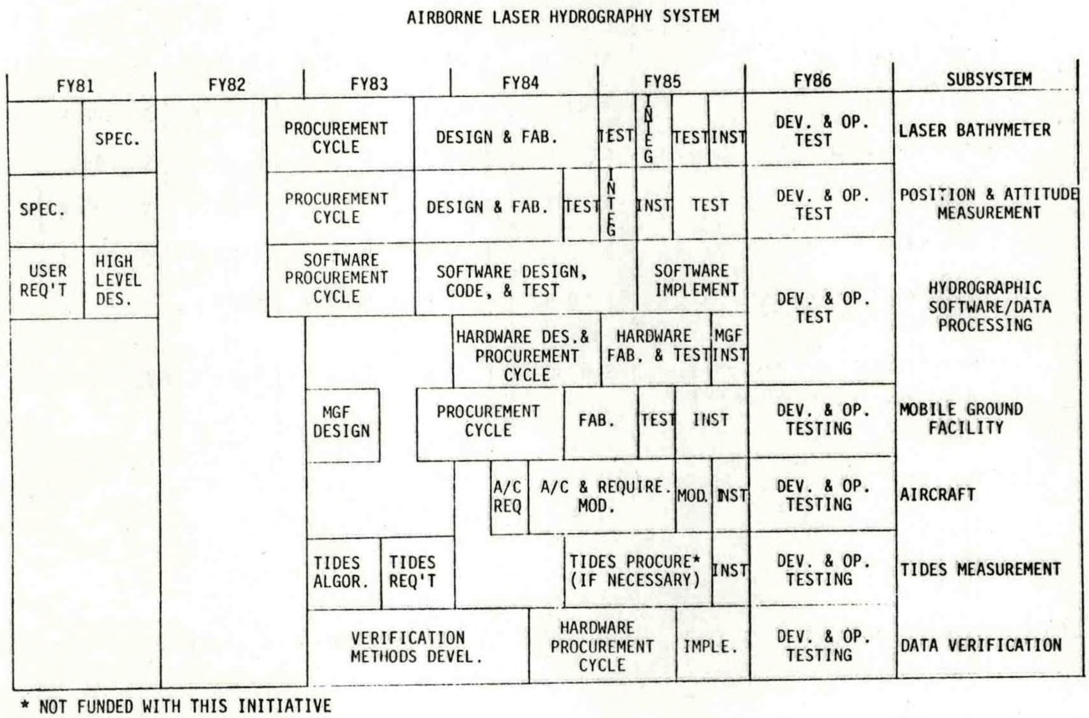

Figure 23. Airborne Laser Hydrography System Development Schedule

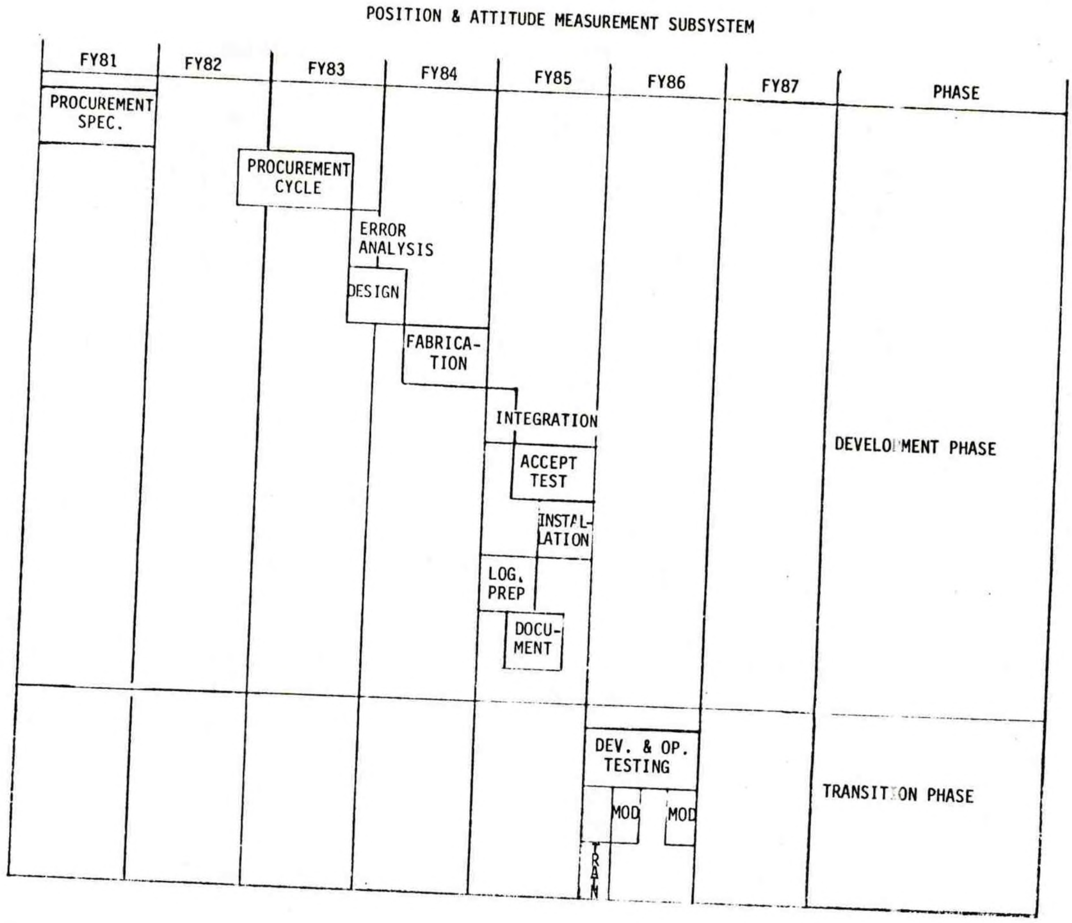

Figure 24. Airborne Laser Bathymeter Subsystem Development Schedule

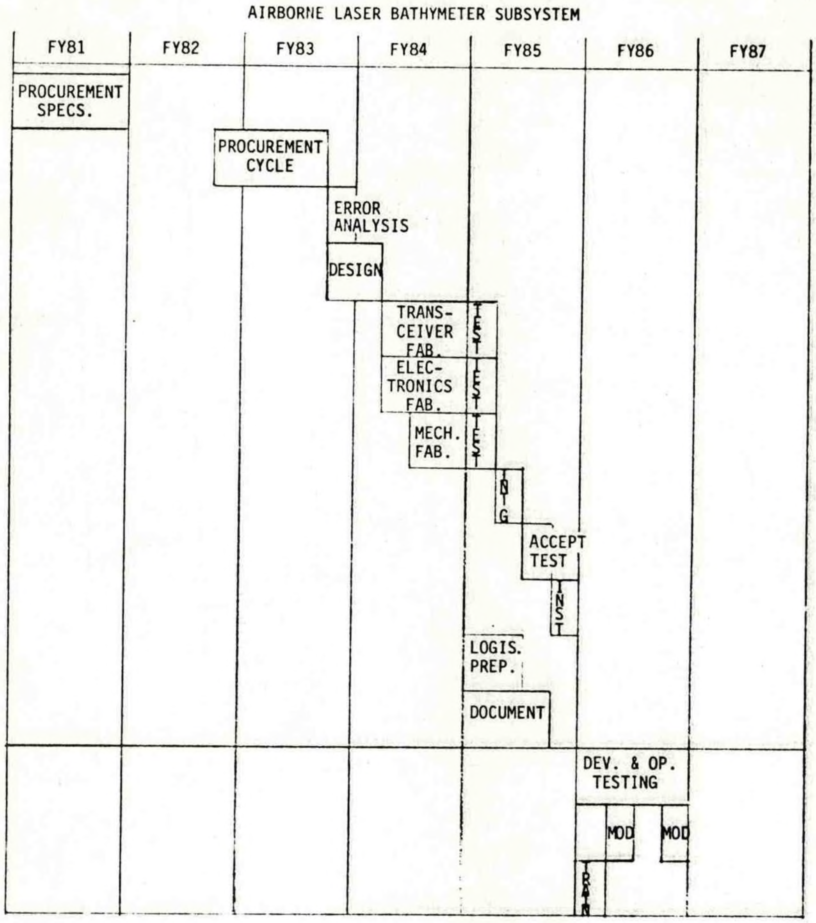

Figure 25. Position and Attitude Measurement Subsystem Development Schedule

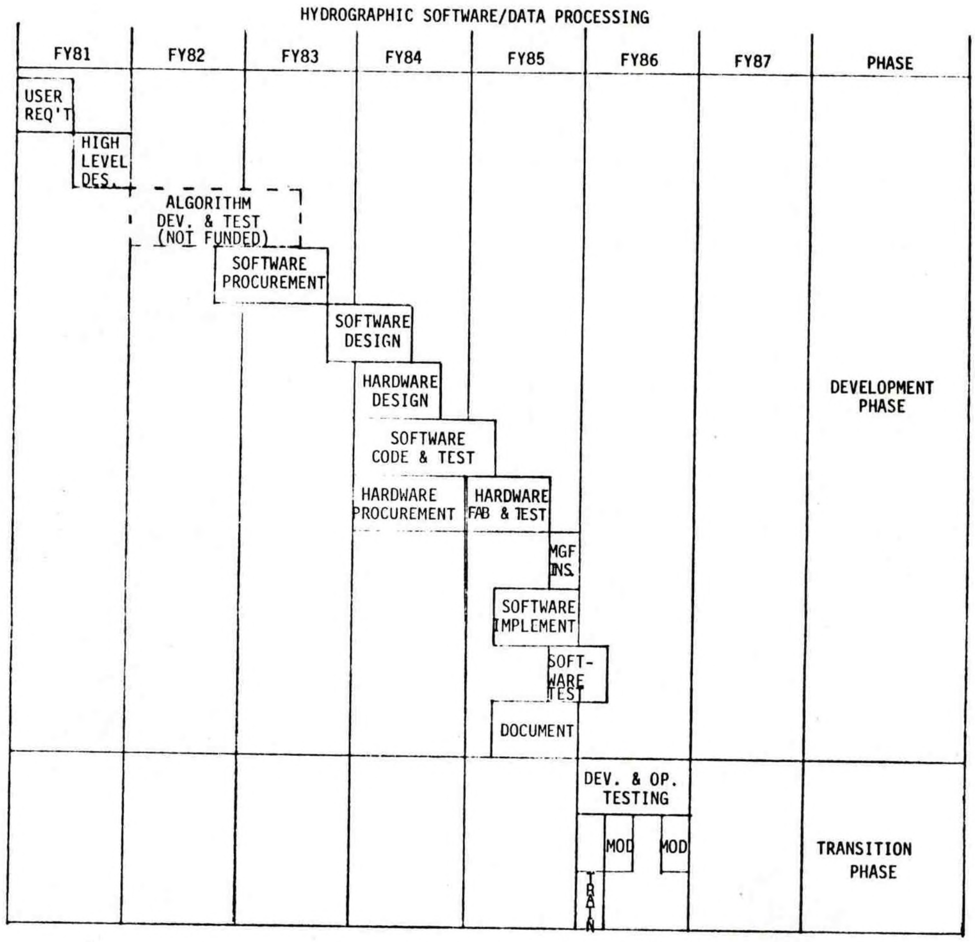

Figure 26. Hydrographic Software/Data Processing Subsystem Development Schedule

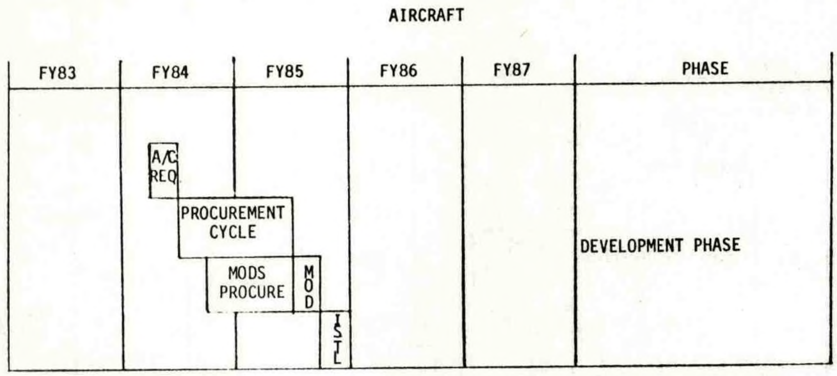

Figure 27. Aircraft Acquisition and Modification Schedule

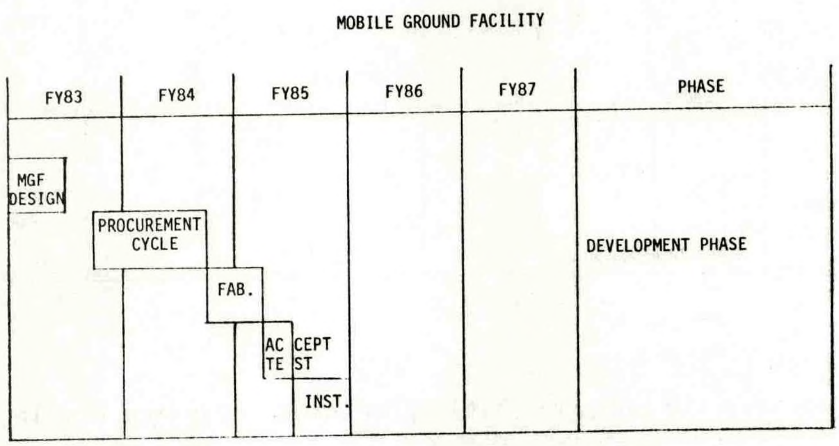

Figure 28. Mobile Ground Facility Development Schedule

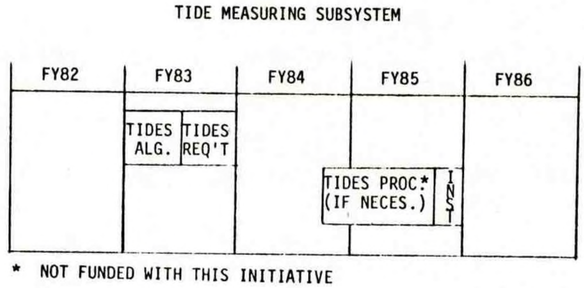

Figure 29. Tide Measuring Subsystem Development Schedule

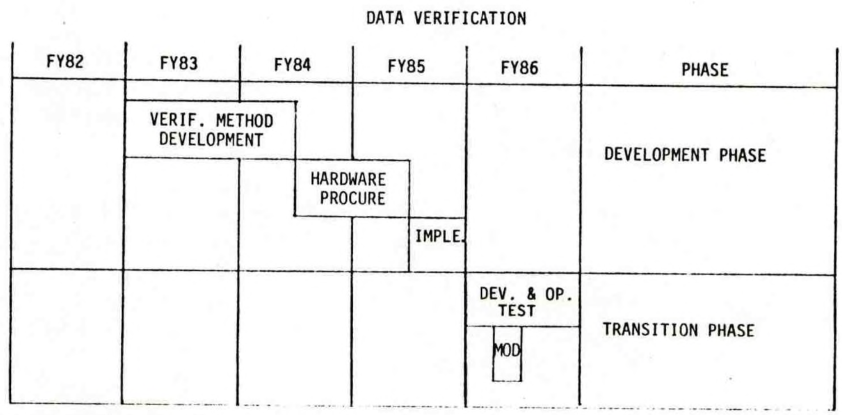

Figure 30. Data Verification Development Schedule

REFERENCES

1. NOS Hydrographic Manual, Fourth Edition, July 1976.

2. Collins, James, "Cost Benefits of Photobathymetry," proceedings of the Coastal Mapping Symposium, prepared by the Potomac Region of the American Society of Photogrammetry, p. 98, August 14 to 16, 1978.

3. Young, G.E., J. Lott, J.T. Phillippe, "Laser Hydrography Analysis (A Cost Comparison Study for the National Ocean Survey)," final report prepared by GKY & Associates, January 1977.

4. Gatzoulis, Juliani, "Economic Analysis of NOS Launch-Sonar Bathymetric Systems," draft report prepared by the Systems Analysis Division, NOS, November 1978.

5. "Nautical Charting Plan", National Ocean Survey, NOAA, November 1978.

6. Memorandum from OA/C3, Roger F. Lanier, "Memorandum of Survey Priorities," October 24, 1980.

7. "National Ocean Survey Institution Plan, Directions for FY 1982-87," 1979 (Draft).

8. Giannotti & Buck Associates, Inc., "Candidate Bathymetric System Configurations for Use in Shallow Water Bathymetry, Volume I - Executive Summary," Giannotti & Buck Report No. 77-027-01, prepared for NOS under contract 7-35286, September 1977.

9. Gatzoulis, J., "Summary Report of Alternative Shallow Water Bathymetric Systems," prepared by the System Analysis Division, NOS, April 1978.

10. Enabnit, D.B., L.R. Goodman, G.K. Young, W.J. Shaughnessy, "The Cost Effectiveness of Airborne Laser Hydrography," NOAA Technical Memorandum NOS 26, December 1978.

11. Keller, M., "A Study of Applied Photogrammetric Photobathymetry in the National Oceanic and Atmospheric Administration," Proceedings of the Coastal Mapping Symposium, prepared by the Potomac Region of the American Society of Photogrammetry, p. 45, August 14 to 16, 1978.

12. Enabnit, D.B., "A Comparison of the Cost Effectiveness of Airborne Laser Bathymetry with Photobathymetry," draft report prepared for the National Ocean Survey, January 1979.

13. Scott, R., "Weather Constraints on Airborne Laser Hydrography Operations," draft report prepared for the National Ocean Survey, March 1979.

14. Cooper, M.T., "Airborne Hydrography Survey During READEX 1A-79," Naval Coastal Systems Center Technical Note TN 498, June 1979.

15. Kasischke, E.S., R.A. Shuchman, J.D. Lyden, "Detection of Bathymetric Features Using Seasat Synthetic Aperture Radar - A Feasibility Study," prepared by the Defense Mapping Agency, Hydrographic/Topographic Center, April 1980.

16. "Airborne Laser Hydrography - A Briefing Prepared for the Director of the National Ocean Survey," prepared by the Engineering Development Laboratory, Office of Marine Technology, NOS, May 11, 1979.

17. Enabnit, D.B., "An Evaluation of Airborne Laser Hydrography," Proceedings of the International Symposium on Airborne Laser Hydrography, Adelaide, Australia, September 30 to October 3 1980, in press.

18. Enabnit, D.B., "Airborne Laser Hydrography, FY 1982 Issue Paper," internal report, May 1, 1980.

19. Guenther, G.C., L.R. Goodman, D.B. Enabnit, R.W.L. Thomas, R.N. Swift, "Technical Papers on Airborne Laser Hydrography (March - December 1978)," NOAA Technical Memorandum NOS 25, February 1979.

20. Guenther, G.C., R.W.L. Thomas, "Monte Carlo Simulation of the Effects of Underwater Propogation on the Penetration and Depth, Measurement Bias of an Airborne Laser Bathymeter," NOAA Technical Memorandum OTES 01, March 1981.

21. Enabnit, D.B., "An Examination of 10 U.S. Sites to Determine Their Surveyability Using an Airborne Laser Hydrography System," in preparation as a NOAA Technical Memorandum.

22. Young, G.E., J. Lott, J.T. Phillippe, "Laser Hydrography Analysis (A Cost Comparison Study for the National Ocean Survey)," final report prepared by GKY & Associates, January 1977.

23. AVCO Everett Research Laboratory, Inc., "Airborne Oceanographic Lidar System," NASA Contractor Report, NASA CR-141407, October 1975.

24. AVCO Everett Research Laboratory, Inc., "Airborne Hydrography System Limited Design Report," NOAA Technical Memorandum NOS 27, January 1978.

25. Naval Ocean Research and Development Activity, "Hydrographic Airborne Laser Sounder (HALS), "Purchase Description for Office of Naval Research RFP Number: N00014-79-R-0015, March 30, 1979.

26. Naval Ocean Research and Development Activity, "Hydrographic Airborne Laser Sounder (HALS)," Example response to purchase description prepared for the Defense Mapping Agency, October 15, 1978.

27. AVCO Everett Research Laboratory, Inc., "Proposal for Hydrographic Airborne Laser Sounder, Part I - Technical," response AERLP 269 to Office of Naval Research RFO Number N00014-79-R-0015, June 1979.

28. Rulon, T. Lt(jg), "Test Results of a Differential GPS Receiver," Proceedings of the National Ocean Survey Hydrographic Survey Conference, January 1981, in press.

29. Teasley, S.P., W.M. Hoover, C.R. Johnson, "Differential GPS Navigation," proceedings of the IEEE 1980 Position, Location, and Navigation Symposium, December 8 to 11, 1980, p.9.

30. Navigation, Journal of the Institute of Navigation, Vol. 25, Number 2, Summer 1978.

31. Enabnit, D.B., "The Hydrographic Software/Data Processing Subsystem of the NOS Airborne Laser Hydrography System," Proceedings of the International Symposium on Airborne Laser Hydrography, Adelaide, Australia, September 30 to October 3 1980, in press.

32. Systex, Inc., "Data Processing System Requirements and Functional System Description of the NOS Laser Hydrography System," draft report, February 1980.

33. Enabnit, D.B., "User Requirements for the Hydrographic Software/Data Processing Subsystem," memo to file, March 13, 1981.

34. Enabnit, D.B., M. Grunthal, "Required Aircraft Capabilities for Airborne Laser Hydrography," draft report prepared for the National Ocean Survey, March 1979.

35. Lippson, Alice Jane, The Chesapeake Bay - An Atlas of Natural Resources, prepared for the Natural Resources Institute of the University of Maryland, John Hopkins Press, 1973.

36. Borman, Kurt L., "Chesapeake Bay Oceanographic Data Base," Final Report, prepared by Wolf Research and Development Corporation for the Maryland Power Plant Siting Program, Maryland Department of Natural Resources, October 15, 1974.

37. Swift, R.N., "Preliminary Report on Preflight Seatruthing for the Airborne Oceanographic Lidar," a Marine Science Consortium report, February 1977, p.15.

38. Airport/Facility Directory, Northeast U.S., U.S. Government Flight Information Publication, November 2, 1978.

BIBLIOGRAPHY

Brown, Clinton E., and Stephen J. Daugard, "A Study of the Near- and Long-Term Shallow Water Bathymetric Plans of the National Ocean Survey," Hydronautics Inc., final report TR-7788-1, prepared for the Systems Analysis Division, Office of Marine Technology, NOS, under contract 7-35285, September 28, 1977.

Guenther, G.C., "Calculation of Accuracy Degradation Due to Logarithmic and Difference Processing for Airborne Laser Hydrographic Systems," Memorandum for File, National Ocean Survey, March 14, 1980.

SYSTEX, Inc., "Data Acquisition, Recording, and Front End Processing Requirement for the NOS Laser Hydrography System," draft report, December 1979.

APPENDIX A

ADDITIONAL TABLES

Launch hydro for launches based on 2-launch ships costs = $\$3488/nm^2$

Launch hydro for shore based launches (HFP's & HSL's) = $\$1037/nm^2$

2 Launch Ships	Area Surveyed in FY'77
PIERCE	94 nm^2
WHITING	148 nm^2
DAVIDSON	283 nm^2
Total	525 nm^2

Shore Based Launches	Area Surveyed in FY'77
HSL #1	560 nm^2
HFP #2	33 nm^2
HFP #3	89 nm^2
HSL #4	115 nm^2
Total	797 nm^2

Combined Estimate $\frac{(525 \times 3488) + (797 \times 1037)}{525 + 797} = \$1641/nm^2$ for 1322 nm^2

Table A1. Cost and Productivity for FY 1977 as per Cdr. J. Collins for Shallow Water Hydrography

VESSEL	FY'73 COST(1)	AREA SURVEYED IN FY'77 (2)	$/nm^2$
MT. MITCHELL (inshore)	$ 178,080	32 nm^2	$\$5565/nm^2$
WHITING (inshore)	$ 690,270	148 nm^2	$\$4664/nm^2$
ALL HFP & HSL (inshore)	$3,822,400	797 nm^2	$\$4796/nm^2$
TOTALS	$4,690,750	977 nm^2	$\$4801/nm^2$

(1) Inflated to FY'77 dollars at 7% per annum

(2) Mobley provided no productivity figures so those of FY'77 were used.

Table A2. Cost for FY 1973 and FY 1977 as per Captain Mobley for Shallow Water Hydrography

Ground truth sonar survey for laser accuracy experiments:

$3800 for 1.4 nm^2 → $2714/nm^2

Theoretical estimate (ref 8): $3059/nm^2 for HFP's only

Table A3. Other Cost and Productivity Estimates for Shallow Water Hydrography

Parameter Value in Thousands

VARIABLE	DEFINITION	ALT. "A" HFP	AMC ALT. "B" HSL	ALT. "C" CES	WHITING	EAST COAST PEIRCE	MT. MITCHELL
V_{1jk}	Civilian personnel services	$ 71.7	$ 53.2	$29.8	$352.2	$355.8	$ 619.7
V_{2jk}	NOAA Corps officer personnel services	$ 28.9	$ 28.9	$14.5	$101.0	$ 94.7	$ 110.4
V_{3jk}	Other personnel costs	$ 48.2	$ 38.1	$17.9	$107.1	$ 85.8	$ 170.5
V_{4jk}	Material, supplies, utilities, other services	$ 28.5	$ 60.4	$ 9.3	$130.9	$ 95.6	$ 314.9
V_{5jk}	Fuel costs	$ 8.4	$ 20.9	$ 1.7	$ 41.4	$ 58.3	$ 128.1
V_{6jk}	Maintenance & repair costs	$ 1.5	$ 8.4	$ 2.6	$ 93.5	$ 95.2	$ 153.7
V_{7jk}	Capital equip. costs	$ 15.7	$ 1.2	$ 3.0	$ 64.2	$ 48.3	$ 131.3
V_{9jk}	Other costs	-0-	-0-	-0-	-0-	-0-	$ 0.1
C_{jk}	Total costs	$202.9K	$211.1K	$78.8K	$890.3K	$833.7K	$1,628.6K
		$492.8K +162.6 (33% overhead $655.4K AMC)			$3,352.6K +1,106.4 (33% overhead $4,459.0K AMC)		

Table A4. Data for Inhouse Estimates of Launch Hydrography Costs

Operating and Maintenance (O&M) Costs and Coverage Rate

HSL #4

FY 77

MONTH	O&M COSTS ($)	LNM	SNM
October	$ 5,948.89	-0-	-0-
November	4,842.74	184	19.2
December	5,765.82	340.2	28.4
January	4,132.47	-0-	-0-
February	6,010.81	-0-	-0-
March	5,956.88	-0-	-0-
April	14,915.75	-0-	-0-
May	5,497.49	-0-	-0-
June	4,404.28	675	45.8
July	4,791.09	166	N/A
August	4,510.69	93	10.7
September	4,345.53	188.7	11.2
Total/year	$71,122.44	1,646.9	115.3

Source:
Performance: Cdr. Suloff, Requirements Division, NOS
O&M Costs: Cdr. Richards, Atlantic Marine Center, NOS.

Table A5. Data for Inhouse Estimate of Launch Hydrography Costs

Project Year	Cost	Discount Rate	Discounted Cost
1 (FY 1982)	$1275 K	.909	$1159 K
2 (FY 1983)	1275 K	.826	1053 K
3 (FY 1984)	1275 K	.751	958 K
4 (FY 1985)	1275 K	.683	841 K
		Total Discounted Cost	$4041 K

Aircraft Residual Value $536 K x 20% x .319 = 34 K

Present Value Cost = 4041 - 34 = $4007 K in FY 1982

Table A6. Cost of Laser Hydrography

Project Year	Present Method	Proposed Method	Differential	Discount Rate	Discounted Differential
5 (FY 1986)	$12191 K	$4333 K	$7858 K	.621	$4880 K
6 (FY 1987)	12191 K	4333 K	7858 K	.564	4432 K
7 (FY 1988)	12191 K	4333 K	7858 K	.513	4031 K
8 (FY 1989)	12191 K	4333 K	7858 K	.467	3670 K
9 (FY 1990)	12191 K	4333 K	7858 K	.424	3332 K
10 (FY 1991)	12191 K	4333 K	7858 K	.386	3033 K
11 (FY 1992)	12191 K	4333 K	7858 K	.350	2750 K
12 (FY 1993)	12191 K	4333 K	7858 K	.319	2507 K
			Total Discounted Benefit		$28635 K

Present value benefit = $28,635 K in FY 1982

Table A7. Benefit of Laser Hydrography

SHIP	OFFICERS		WAGE MARINE				TOTAL	
			PERM.		OTHER			
	AUTH.	FILLED	AUTH	FILLED	AUTH.	FILLED	AUTH.	FILLED
MT. MITCHELL	10	10	44	43	23	11	77	64
PEIRCE	8	8	20	19	9	8	37	35
WHITING	7	7	20	18	10	9	37	34
FERRELL	5	5	13	13	2	2	20	20
RUDE/HECK	5	5	15	13	2	1	22	19
RESEARCHER	11	11	45	45	15	11	71	67
ALBATROSS IV	0	0	19	18	11	4	30	22
DELAWARE II	0	0	13	10	8	5	21	15
OREGON II	0	0	17	14	3	1	20	15
BOWERS	0	0	0	0	0	0	0	0
KELEZ	6	6	11	11	7	7	24	24
TOTAL	52	52	217	204	90	59	359	315

Table A8. Vessel Manpower Requirements--Atlantic Marine Center

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:

ENVIRONMENTAL SCIENCE INFORMATION CENTER (OA/D812)
ENVIRONMENTAL DATA AND INFORMATION SERVICE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

Rockville, MD 20852

NOAA--S/T 82-170