Technical Report 1526
September 1992

The Fast Area Search System (FASS)

A Feasibility Study

D. L. Endicott, Jr.
G. R. Kuhl

Approved for public release; distribution is unlimited.

Technical Report 1526
September 1992

The Fast Area Search System (FASS)

A Feasibility Study

D. L. Endicott, Jr.
G. R. Kuhl

**NAVAL COMMAND, CONTROL AND
OCEAN SURVEILLANCE CENTER
RDT&E DIVISION
San Diego, California 92152-5000**

J. D. FONTANA, CAPT, USN
Commanding Officer

R. T. SHEARER
Executive Director

ADMINISTRATIVE INFORMATION

The work was performed by the Ocean Engineering Division of the Naval Ocean Systems Center (currently known as the RDT&E Division of the Naval Command, Control and Ocean Surveillance Center). Sponsorship was provided by Naval Sea Systems Command, Code 05R, Washington, DC.

This particular report documents the 1984 FASS study and makes no attempt to give the reader an update of the progress made since that time. Approaches to search, concepts of operations, and 1984 technologies in both hardware and software should be reconsidered in terms of present technologies. Related reports are listed under the Bibliography that appears at the end of this report.

Released by
N. B. Estabrook, Head
Ocean Engineering Division

Under authority of
I. P. Lemaire, Head
Engineering and Computer
Sciences Department

ACKNOWLEDGMENTS

The following is a list of those whose contributions made this report possible: L. J. Bodzin, L. Collins, J. T. Durham, D. L. Endicott, Jr., G. D. Gilbert, D. R. Grace, M. H. Higgins, J. L. Held, T. J. Keil, Jr., G. R. Kuhl, J. Mackelburg, H. B. McCracken, M. McCord, D. Rosencrantz, M. R. Solorzano, J. L. Sutton, J. V. Thorn, R. W. Uhrich, S. J. Watson.

PK

OBJECTIVE

This first phase of the FASS project (conducted during 1984) is the initial step of a multiyear effort intended to result in the development of a "next generation" rapid search system.

RESULTS

FASS Concept C, the Autonomous Search Vehicle, is preferred because it has the simplest design and system architecture. Concept C would also be the least expensive to implement and maintain. The number of vehicles that can be deployed is not limited by acoustic bandwidth. The system can be configured with either optical or sonar sensors, or a combination of both. All sensor data for a search vehicle can be stored onboard each vehicle and retrieved at the surface for postdive analysis.

AUSS The deployment of multiple AUSS vehicles with high-resolution sonar will not result in a linearly corresponding increase in search rate. As currently configured, AUSS cannot detect small objects with its sonar sensor suite. The communication channel is bandwidth limited. The addition of a high-performance, high-resolution sonar would limit the AUSS speed to less than one-half knot.

RECOMMENDATIONS

Select the Automonous Search Vehicles as the lead FASS concept. Retain optical sensors and side-looking-sonars (SLSs) as candidate sensors for the system. Experimentally confirm or reject the wide-swath optical performance for conducting broad area search. Pursue automatic target detection and expert system techniques to both FASS and AUSS designs. Participate in at-sea testing of AUSS to evaluate features for FASS. Develop a dynamic draft system specification as a tool for documenting FASS configuration during 1985. Assist the AUSS team in upgrading its sonar and implementing onboard data storage and postdive analysis.

CONTENTS

CONTENTS (continued)

CONTENTS (continued)

CONTENTS (continued)

FIGURES

CONTENTS (continued)

CONTENTS (continued)

CONTENTS (continued)

TABLES

CONTENTS (continued)

INTRODUCTION

This section presents a summary introduction to this report on the Fast Area Search System (FASS) feasibility study and an overview of the FASS project, along with the study's conclusions and recommendations.

GENERAL

Purpose

The purpose of this report is to present the results of the first phase of the FASS project through the completion of the FY 84 assignments. The first phase of the FASS project comprised a multifaceted feasibility study that was the initial step of a multiyear effort intended to result in the development of a "next generation" rapid search system.

Scope

The sections that follow are intended to give the reader an indication of the scope of the feasibility study. The report gives a review of the work actually accomplished during the study; this is done in the text of the report, in the appendices, and in the references noted in the text. While not all the areas of interest were covered as fully as possible, sufficient progress was made so that three FASS candidate systems were selected for further study. This report stands then as a review of work in progress and as an indication of the breadth of the efforts of the FASS project task team.

Organization

This report is divided in to six sections as follows. The appendices are published as Technical Note 1703.*

Section 1. Introduction — This section provides an introduction to this report as well as to the FASS project itself. The conclusions and recommendations made as a result of the feasibility study are also included.

Section 2. Background — This section presents an introduction to search theory, its application to the Advanced Unmanned Search System (AUSS), and an assessment of the AUSS program as it relates to the FASS project. (The performance characteristics of AUSS were used to establish a performance baseline for measuring the effectiveness of the FASS concept.)

---

*Technical Notes are working documents and do not represent an official policy statement.

Section 3. FASS System Analysis — This section presents the status of the FASS analysis model. Included in the section are discussions of methodology (with basic assumptions noted), various search scenarios, and analysis results.

Section 4. Technology Assessment — This section presents the results of the FASS project task team's evaluation of critical areas in key technologies. These technologies were evaluated in terms of application to multiple-vehicle undersea search systems. Eight specific technologies were assessed: information processing, vehicle options, command and control options, applied artificial intelligence (AI), data communications, navigation options, sensor candidates, and specialty engineering.

Section 5. Conceptual Designs — This section briefly introduces the candidate system approach taken by the FASS project task team. It then presents in some detail the three FASS candidates selected as being profitable for further study: the Multiple AUSS, the Dual-Vehicle Search Teams, and the Autonomous Search Vehicles.

Section 6. Proposed Further Studies — This section presents a plan for the FASS project activities during FY 85. (The focus of the year's efforts will be refining a top-level preliminary design.) It also provides descriptions of the FY 85 tasks for the FASS project task team.

Appendices - The following appendices, published as a separate volume, are substantial contributions to this report:

Appendix A — Survey of Candidate FASS Concepts
Appendix B - Measurements of Search Effectiveness
Appendix C — FASS Analysis Flowchart and Program Listings
Appendix D — Navigation for FASS
Appendix E — Specialty Engineering for FASS
Appendix F — FASS Energy Budget Considerations.

FASS OVERVIEW

Objective

The objective of the FASS project is to improve the Navy's deep-ocean search capabilities by substantially improving search-system performance over that achievable with current developmental search systems through the use of multiple free-swimming vehicles. Figure 1 shows a generic FASS concept; however, although the multiple vehicle approach is used in all cases, it has been expressed in a variety of candidate systems. The area search rates for all the candidate FASS search scenarios are anticipated to be 2 to 10 times better than those for the Advanced Unmanned Search System (AUSS).

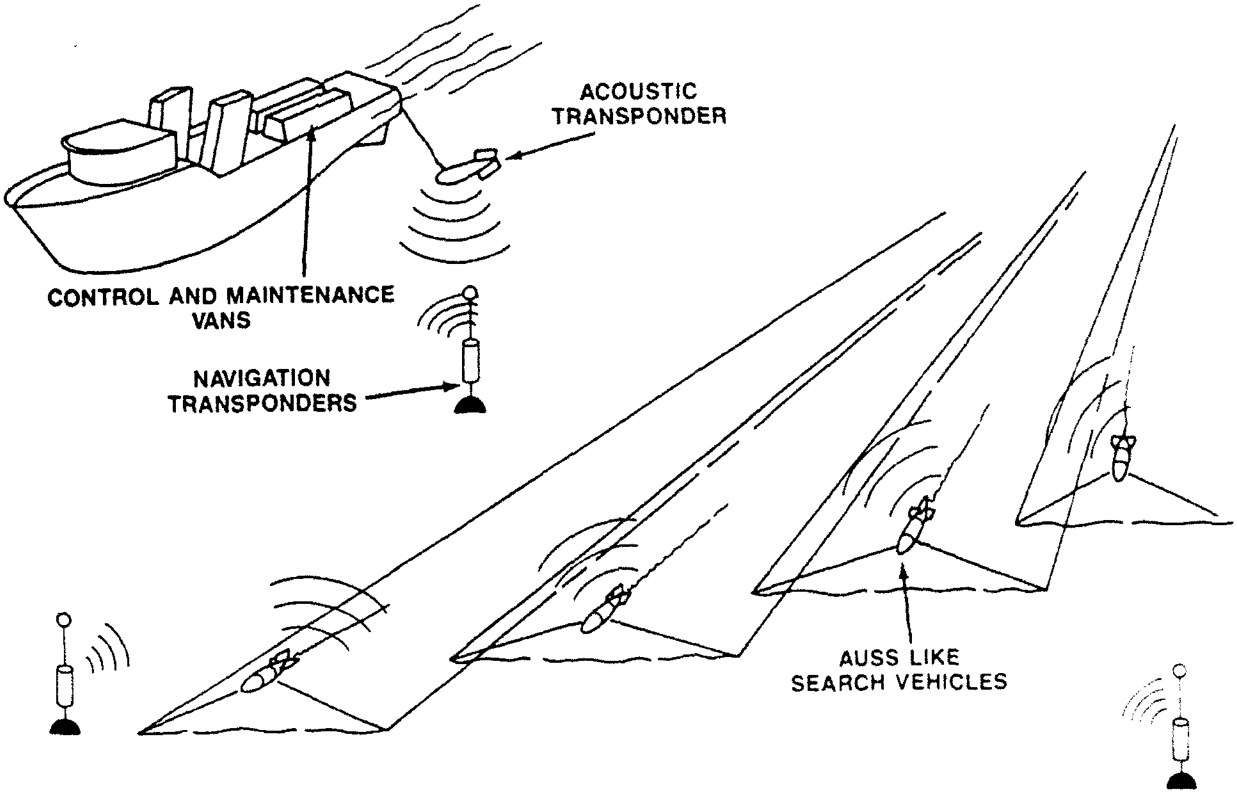


Figure 1. Fast Area Search System (FASS) concept.

The FASS project comprises a series of discrete phases. The feasibility study phase is the first portion of a multiyear effort intended to result in development of a "next generation" system. Following design, fabrication, and testing of the Advanced Development Model (ADM) and the Engineering Development Model (EDM) versions of FASS, an acquisition phase is projected for the FY 95 through the FY 97 time period. The FY 84 FASS project task team organization is shown in figure 2.

The goal of the feasibility phase of the FASS project is to evaluate candidate systems and determine the feasibility of using multiple-vehicle systems to conduct ocean bottom searches. The five major stages of the feasibility study effort are the following:

1. Background assessment
2. System performance analysis
3. Technology assessment
4. Conceptual design
5. System development plans preparation.

FASS Approach and Constraints

The FASS approach is to investigate and assess state-of-the-art search technologies and to perform detailed systems analyses to determine the sensitivity of search performance to a variety of parametric improvements, including the use of multiple vehicles as sensor platforms. Of the various candidate systems, three of them have been developed into conceptual designs that include recommended system architectures, operational procedures, suggested tactics, projected search performance for a number of scenarios, estimated system reliability, and maintenance and support requirements.

The measures of system performance have been determined on the basis of previous AUSS analyses. A series of tutorials on search theory summarized the AUSS studies and provided assistance in the derivation of the FASS analysis approach. A preliminary assessment of the measures of performance includes area search rate, detection probability, search effort, percentage of time devoted to search, navigation error, and control error. Because area search rate is strongly dependent on the search scenario (target size, water depth, and bottom conditions), an initial investigation focused on the principal AUSS scenario of deep ocean, smooth bottom, clear water, and low false target density. Further investigations estimated relative system performance for at least one rough-bottom situation and an intermediate depth situation.

Performance gains over AUSS capabilities are expected to be achieved by increasing effective swath width, effective velocity, and data transmission throughput; improving information processing and display effectiveness; maintaining or improving navigation and control error; and maximizing the percentage of onsite time devoted to search effort.

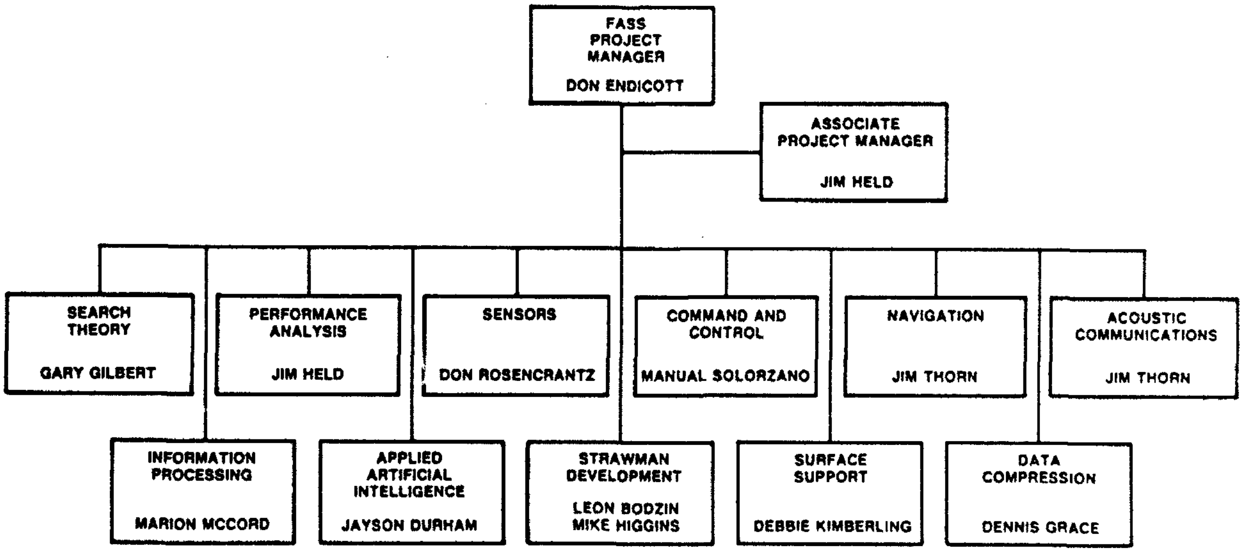


Figure 2. FY-84 FASS project task team organization.

Several top-level design constraints were included in the initial ground rules for designing a AUSS configuration:

1. The vehicles are to be AUSS-like free swimmers to take advantage of the results of the AUSS development efforts;
2. All operations would be conducted from a single surface support vessel;
3. Operation and support should be as simple as possible;
4. The configuration should be capable of being used on ships of opportunity; and
5. The system should be air transportable.

Critical Issues

Operation of multiple vehicles simultaneously will require new approaches for transmission of sensor data to the surface since a single SLS produces enough data to saturate the acoustic transmission channels for all of the vehicles. Approaches to overcome this fundamental limitation include onboard storage of data, target-recognition capabilities, or data relays suspended from the surface vessel to the search area.

The use of multiple vehicles from a single vessel will also require new search tactics and operational and support strategies for coordinating control, navigation, search mission, launch/retrieval, and replenishment. To enable the FASS project team to focus on high-payoff design features, an initial assessment of critical issues was prepared. These issues included the following:

1. Selection and distribution of search sensors;
2. Effective command and control to coordinate the search efforts of multiple-vehicles;
3. Optimal tactics for multiple-vehicle search;
4. Selection of a communication approach for adequate sensor data throughput;
5. Accurate navigation and control;
6. Processing, filtering, and enhancement of sensor data;
7. Effective display, recording, and evaluation of vehicle and target positions;
8. Efficient performance of contact evaluation;
9. Launch, recovery, and support of multiple vehicles from a single surface platform;
10. Minimization of nonsearch time and effort; and
11. Modifications required for effective performance at intermediate depths and/or rough bottom conditions.

The Candidate Systems Approach

A candidate systems approach to the FASS feasibility study was used to provide the FASS project task team engineers with a specific focus as various system and subsystem options were considered. Each candidate system description presented a snapshot of an integrated system configuration that met the FASS objective of substantially improving undersea search system performance.

Each of the candidate systems went through a concept development process. Once the initial idea was proposed, a brief description of the concept was prepared. The concept was then presented to and reviewed by the FASS project task team and a FASS oversight committee (made up primarily of members of the AUSS project task team). Techniques were identified for each of the concept parameters, pros and cons were inventoried, and search-rate performance was analyzed. When all the candidate systems had been put forward, they were given a priority rating according to their likelihood of meeting the FASS objective. Three of the candidate systems were selected for further study:

1. Concept A — Multiple AUSS
2. Concept B — Dual-Vehicle Search Teams
3. Concept C — Autonomous Search Vehicles.

These three systems are discussed in the detail in the Concepts Section 6. All of the candidate systems are discussed in appendix A.

The following system features were considered for each of the FASS concepts: architecture, tactics, operational procedures, contact evaluation, personnel, energy considerations, and mobilization. In addition, numerous subsystem features were also examined: sensors, communications, command and control, navigation, information processing and display, vehicle characteristics, vehicle handling, control van, support van, and surface vessel. Although this information provides a foundation for preliminary design, no design optimization was attempted. And, while all of the features were not addressed in the same depth, the coverage was adequate for the feasibility study goals. During the preliminary design effort all of the pertinent design features will be fully addressed.

CONCLUSIONS AND RECOMMENDATIONS

As the result of the candidate systems approach and the work of the FASS project task team during the feasibility study, the following conclusions and recommendations were made.

Conclusions

The conclusions are presented under two headings: FASS issues and AUSS issues.

FASS Issues. There are 10 conclusions addressing the FASS issues.

1. The autonomous search vehicles configuration (Concept C) is preferred over the other concepts investigated for the following reasons:
   a. It has the simplest vehicle design, system architecture, etc;
   b. It is potentially the least expensive to implement and maintain;
   c. The number of vehicles that can be deployed is not limited by acoustic bandwidth;
   d. The system can be configured with either optical or sonar sensors or a combination of each as the mission dictates; and
   e. All sensor data for a search cycle can be stored onboard each vehicle and retrieved at the surface for postdive analysis.
2. The optical sensor version of Concept C will be the simplest and least expensive, but the assumed swath width used in the performance analysis has not been demonstrated.
3. The SLS version of Concept C is potentially much more expensive and complex due to the sophistication of the sensor required to achieve the desired resolution.
4. A smaller number of vehicles (4 to 6) is probably more realistic than the number considered in the performance analysis (10). Overall system performance will not be seriously degraded and the deployment, operation, maintenance, and data handling may be greatly simplified by using fewer vehicles. Significant performance gains over AUSS will still be achievable.
5. The autonomous search vehicles will significantly outperform a single AUSS even assuming a conservative velocity of 6 to 8 knots.
6. A synchronous pinger navigation system is adequate for the autonomous vehicle configuration as long as each vehicle listens to at least two pingers (range-range mode).
7. The vehicle design for Concept C need not differ radically from that for AUSS, except that it can be considerably smaller (on the order of 0.8 scale) and lighter.
8. The most difficult design challenges are likely to be associated with effective data handling, processing, and postdive analysis.

9. Data-compression techniques can be applied to data storage, handling/manipulation, and communications activities.
10. The most promising artificial-intelligence features, automatic target detection and application of an expert systems approach to mission planning and conduct, will be viable in the 1990s. These features are equally applicable to AUSS and FASS.

AUSS Issues. There are five conclusions addressing the AUSS issues.

1. Deployment of multiple AUSS vehicles with high-resolution sonar will not result in a linearly corresponding increase in search rate due to the severe bandwidth restrictions associated with acoustic telemetry.
2. AUSS, as currently configured, cannot detect small objects with its sonar sensor suite.
3. The AUSS acoustic communications channel is already bandwidth limited. Current efforts to increase the number of gray levels for improving detection performance will aggravate the data throughput situation.
4. Addition of a high-performance, high-resolution sonar to AUSS will not be practical unless onboard storage of sensor data, target-detection capability, and/or postdive analysis techniques are incorporated. The sonar being considered for Concept C, if mounted on AUSS, would limit its speed to less than one-half knot even if a 4:1 data compression is achieved.
5. Although the Dual Vehicle Search Team's candidate system (Concept B) is an attempt to improve the acoustic telemetry situation, it requires an even more complex configuration than the one required for the multiple AUSS (Concept A). Of particular concern is the number of onsite personnel required, the onboard support facilities, and system cost. Concept B still suffers from a severe bandwidth limitation and its search rate performance cannot approach that of a noncommunicating, postdive analysis approach.

Recommendations

After consideration of the results and conclusions of the FASS feasibility study, the following recommendations were made regarding future FASS project task team efforts and the project's relationship with the AUSS program.

1. Select the autonomous search vehicle as the lead FASS concept. All FASS survey and preliminary design activities should focus on this concept.
2. Retain both optical sensors and SLSs as candidate sensors for the system.
3. Develop a means of demonstrating the predicted wide-swath optics performance and experimentally confirm or reject this method for conducting broad area search.

4. Actively pursue applying automatic target detection and expert systems techniques to both the FASS and AUSS designs.
5. Monitor and participate in ongoing at-sea testing of AUSS to evaluate features proposed for FASS.
6. Develop a draft system specification as a tool for documenting all aspects of the FASS configuration determined during FY 85 preliminary design activities. This should be treated as a dynamic document that can be changed to reflect the project team's latest findings.
7. Assist the AUSS team in upgrading its sonar and implementing onboard data storage and postdive analysis to improve overall system performance.

BACKGROUND

This section presents an introduction to search theory and its application to AUSS, and an assessment of the AUSS program as it relates to the FASS project.

SEARCH THEORY

An Important Distinction

First, a distinction must be made between search system design (engineering) and the conduct of a search operation. The former is deterministic in nature, and the latter is probabilistic in nature. When something is lost at sea, the first step in organizing a search is the accumulation of all available information concerning the last known location and condition of the lost object. When this has been done, the organization in charge must select the sensors, navigation, platform, etc., to be used. This step is in essence *search system design and engineering*. For example, assume that a tanker has been lost in an area where the bottom is known to be flat and smooth. The obvious sensor to use is an SLS, which has the greatest swath width of any sensor, and, thus, could provide the best area search rate. This is a simple example of search-system design. Given certain search scenario conditions, specify and fabricate the search system that will optimize chances of finding the target if the search platform gets within sensor range of the lost object. This is the *deterministic* phase of the problem where engineering may be brought into play. Search system design has been the goal of the AUSS program and is the goal of the FASS program.

In contrast to the deterministic design phase is the probabilistic search itself, i.e., what is the roll of nature's dice? Here measures of search effort expended and where that effort is to be located are statistical. This phase is not the concern of this present study, but it is vitally important in actually finding an object once an optimal search system has been selected. The theory describing this area is called "The Theory of

Optimal Search" and involves the mathematics of constrained maxima and Lagrangian multipliers. Though FASS is not directly concerned with this field, awareness of its existence is very important. This approach has been used to evaluate past search operations including searches for the USS *Thresher* and the USS *Scorpion*, the H-bomb off Palomares, Spain, and ordnance during the clearing of the Suez Canal. This approach is supposed to control the planning strategy for present and future search.

Measurements of Search Effectiveness

The following paragraphs are a summary of the material contained in appendix B.

Detection Function as Figure of Merit for Search System Design. A search system's potential performance may be gauged by its detection function. In the selection of sensors for a given search, those producing the largest detection function will give a better search system. The detection function for any system is determined by the specific requirements of the particular search. These include condition of the object lost and the type of bottom terrain to be searched. Thus, there is no "best" search system for all situations. For example, an SLS has a large detection function for a target lost on the flat, featureless abyssal plains of the North Pacific, but a very poor detection function for objects lost in the scarps of the Mid-Atlantic Ridge. An optical imaging sensor has a much better detection function in this case.

Categorization of Operations. A search operation may be broken down into periods of time when searching is actually occurring and times when it is not. Search times may be further divided into broad area search and contact evaluation phases.

Consider times actually engaged in search. The four characteristics of any search system most affecting the system's detection function are area search rate (ASR), sensor swath width, navigation error, and control error.

Maximize Area Search Rate by Maximizing W and V. Faster free-swimming vehicle platforms may greatly increase ASR and improve detection functions for future search systems. Maximum ASR maximizes b(t) and db/dt, which are detection function and the rate of change of the detection function, respectively. A free-swimming system potentially removes this severe upper limit on velocity with a corresponding increase in area search rates. Modern technologies of multibeam, electronic-focused, SLS might then be applied to deep ocean search. This technology has been developed and used in towing shallow multibeam SLS from helicopters at 20-knot speeds. The tow velocity of a typical SLS is approximately 2 knots per beam. Thus, a 3-beam SLS system could move at a 6-knot velocity, a factor of six improvement in ASR.

Caveats exist. Search sensors must be able to operate at a higher velocity. Increased ASR requires increased information channel capacity in the link between the vehicle and the support ship. This requirement will necessitate much study. Additionally, a free-swimming platform will require time for recharging and resupply of onboard resources adding to the cost of nonsearch operations.

Optimizing by Minimizing σ_n Maximizing W. The ratio of navigation error, σ_n, to sensor swath width determines the effectiveness of the system in adequately covering a given area with search passes. At one extreme, with perfect navigation or very large swath width, one complete sweep of the area will find a target, if present, with complete certainty or a detection probability of unity. At the other extreme, with poor navigation or very narrow sensor swath width, one complete sweep-will result, on the average, in 63% of the area being searched and 37% of the area being missed. This necessitates more sweeps with a consequently larger expenditure of resources and a greater cost. Once contacts are made during the broad-area-search phase, they must be evaluated with much narrower swath width optical sensors. The location of the contacts are known to within an uncertainty area proportional to the square of the navigational error. The greater the navigation error the larger the contact evaluation area and more inefficient the evaluation system in searching this area. The Reber curves again give the efficiency of contact evaluation.

Minimize Control Error. Control error, σ_n, the ability to direct the vehicle accurately, strongly affects both broad area search and contact evaluation. In broad area search, control error impairs the ability of the search platform to run given patterns. In contact evaluation, a large control error may mean that many more sweeps of the contact evaluation area are necessary to ensure that the platform has actually passed within sighting range of the contact. Thus, a large control error results in a much greater expenditure of time and resources.

Minimize Uncertainty in Sensor Swath Width. The evaluation of actual sensor swath width at the time of broad area search and contact evaluation is the final concern of a search-system operator. If the sensor is affected by external conditions such as water clarity, water temperature, acoustic reverberation, etc., the operator may be actually searching the sea bottom with a much smaller swath width than believed. Objects may be left undiscovered even though the search operator has expended an effort falsely believed to be sufficient to locate the target. Thus, actual instantaneous sensor swath width at depth is the final important characteristic of a search system that must be known to evaluate a given system's detection function adequately.

Minimize Time of Operations Not Directly Involved in Search. Overhead operations that do not directly change the probability of detection, e.g., turnaround time, transit time, raising and lowering time, recharge and resupply time, etc., affect the overall systems detection function and the related parameter, mean time to detection. Ratio of search to nonsearch time might be called a duty cycle. Cost of a search operation is roughly proportional to the length of time of the operation, i.e., "the meter is always running." A search system that requires a lot of down time, or other non-search time functions, or an inefficient duty' cycle is to be avoided. Thus, minimization of overhead time associated with a search-time design is necessary to achieve an optimal Fast Area Search System (FASS).

SEARCH THEORY AND THE AUSS PROGRAM

AUSS started in early FY 73 with a study of the state-of-search technology and methodology. Early work involved interviewing those few groups in the country with search experience and reviewing the literature of search theory, practice, and past operations extending back to World War II. Early interviews with the few experienced underwater searchers – notably C. L. (Bucky) Buchanan of the Naval Research Laboratory (NRL) and Dr. Fred Spiess of the Scripps Institution of Oceanography Marine Physical Laboratory (MPL) supplied information that substantially influenced the development of a computer model of deep ocean search. Both men had been engaged in the search for the USS *Thresher* lost in 1963, and in many other operations.

They flagged deficiencies of present search systems where improvement could lead to greatly reduced search time. For instance, consider a search to be composed of two classes of operation: first, where the sensors are actually searching and the probability of detection is increasing and, second, where the sensors are not searching and the probability of detection remains unchanged.

A very important member of this second class of operations is vehicle turnaround. All present-day towed search platforms spend a substantial portion of bottom time and, hence, resources engaged in this activity. The deficiencies flagged included vehicle turnaround time, vehicle navigation error, and control capability. Neither MPL's SLS nor NRL's LIBEC photographic system could search as a turn was taking place. After the turn, additional time is spent in getting the subsurface platform back to its appropriate height off the bottom for search. The new direction is generally somewhere near the direction desired, although not always. If the vehicle should inadvertently touch the bottom during the turn, the long length of steel cable towing it from the ship could kink and the whole platform could be subsequently lost. Both Buchanan and Spiess felt that a great improvement in search effectiveness would follow an improve- ment in turning capability. Buchanan had even begun a preliminary study into a free-swimming platform to free search from its cable dependence.

Spiess defined a second problem that greatly impacted MPL search effectiveness. This was vehicle positioning control. The MPL system's main sensor is an SLS. On flat bottoms, this wide-swath sensor can rapidly discriminate potential targets or "contacts" for further investigation. However, contact evaluation must be done with some type of an optical or visual sensor. The mean path of image-forming light in the sea is much less than for image-forming sound. Thus, evaluation must be done with a sensor of greatly reduced swath width on the order of a few tens of meters. It is quite difficult to position a platform from a ship connected to the platform by 4 miles of cable to within a few tens of meters. Spiess told of many frustrating near misses after many hours of turning and lining up.

From these interviews and the literature of search theory, algorithms for a search model were assembled and a computer model of underwater search was developed for the AUSS program. The theoretical method of quantifying search effort used in the model was derived from the work that Reber (1956–57) developed for parallel paths in minefield clearance, and the World War II pioneering effort by the band of top-level scientists led by Koopman (1946) for a wide range of search categories. The 1971 work of Richardson, Stone, and Captain Andrews, USN (Ret) and officer-in-charge of the USS *Thresher* search) was extensively studied and incorporated in the model. Dr. Lawrence Stone was quite helpful in structuring the mathematics of the probability of the general search problem. This probabilistic structure helped to divide the analysis of the general search problem into specific measurable operations. Once broken down into distinct parts, specific operations were evident wherein suboptimization would greatly improve search. The model was first used to simulate performance of existing search systems under the wide range of conditions encountered in deep ocean search. After verifying that model calculations for present-day search systems performance were reasonably accurate when compared with known search operations, the model was used to predict the performance of postulated future search systems as yet unbuilt — including several free-swimming search platforms.

The supposition of Buchanan that an untethered vehicle would improve search capability was validated by the AUSS model in an internal NOSC study conducted by Bryant and Held in 1978. The results of this study indicated that a substantial improvement in search effectiveness would result if the search platform could be freed from the connecting cable constraints. From the results of this effort, development of a free-swimming prototype testbed vehicle was initiated. The AUSS testbed vehicle represents a research development meant to test this concept. The free-swimming system represents a research and development venture into a previously unexplored area of ocean engineering technology. As such, it is realized at the outset that much is to be learned from this venture. While advantages do exist when the search platform is freed from its cable, certain disadvantages will be present, and technologies and methodology must be developed to minimize their effect on overall search. This last set of unknowns still exists for AUSS and will exist for FASS.

AUSS BASELINE DESCRIPTION

Introduction

The goal of the Advanced Unmanned Search System (AUSS) is to provide the Navy the research and development tools for evaluating the acoustically linked free-swimming, deep-sea search system concept under actual dynamic conditions. Although the AUSS is not expected to be used by the Fleet, the AUSS is representative of the next generation of Fleet operational unmanned deep-sea search systems.

This subsection describes the capabilities and performance characteristics of AUSS. (A more detailed description may be found in Brown, 1983). The primary sources of information were unpublished NOSC papers, the AUSS Library, and conversations with members of the AUSS design team. The *performance* characteristics of AUSS will be used to establish a performance baseline for measuring the effectiveness of the FASS concept.

General Description

AUSS is an unmanned, untethered, undersea vehicle system. The major components (figure 3) of AUSS are an untethered underwater vehicle, control equipment, and vehicle handling equipment. The untethered vehicle (figures 4 and 5) provides the mobility, sensors, and telemetry required to conduct an operator-controlled search to locate and classify objects at depths to 20,000 feet. The control equipment (figure 4) provides the capability for an operator to command, communicate with, and navigate the remote untethered vehicle via an acoustic telemetry link. The vehicle handling equipment (figure 6) provides maintenance support and the capability to launch and retrieve the untethered vehicle safely.

Untethered Vehicle

The untethered vehicle component consists of the sensor vehicle, acoustic search sensors, and optical search, documentation, and classification sensors. In its current configuration, the untethered vehicle is equipped with a forward-scanning sonar (FSS) and an SLS for conducting active acoustic search. The vehicle is also equipped with a still photographic and the video camera for optical search and contact classification and documentation.

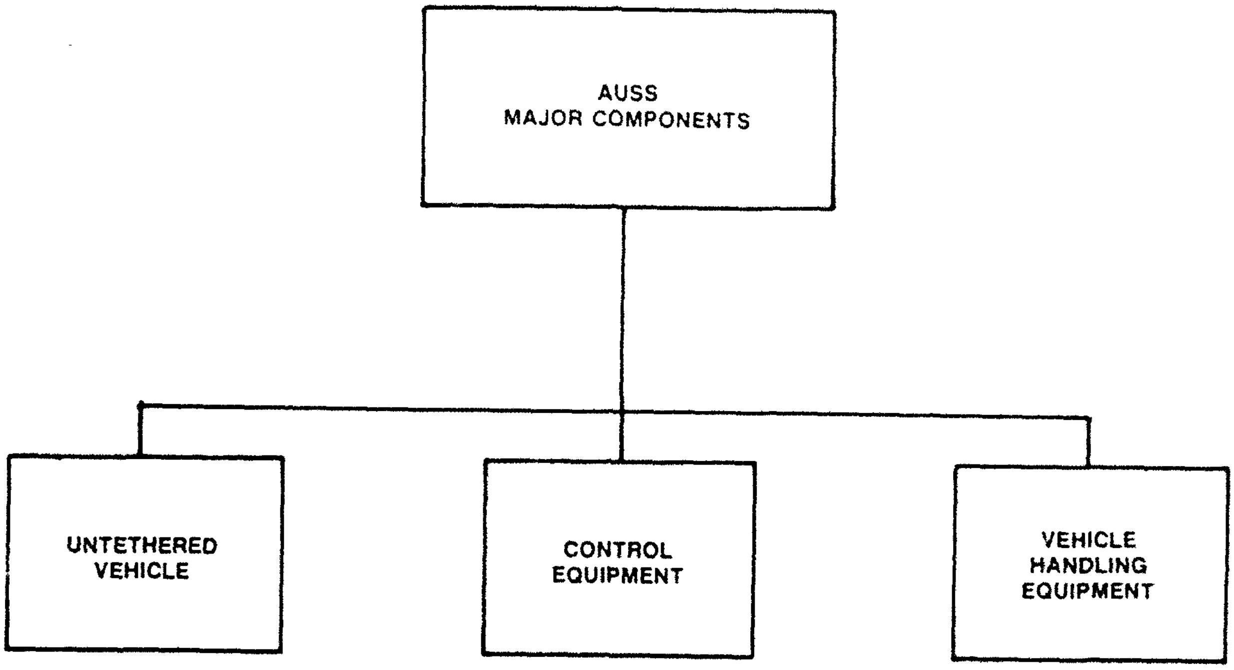


Figure 3. Major components of AUSS.

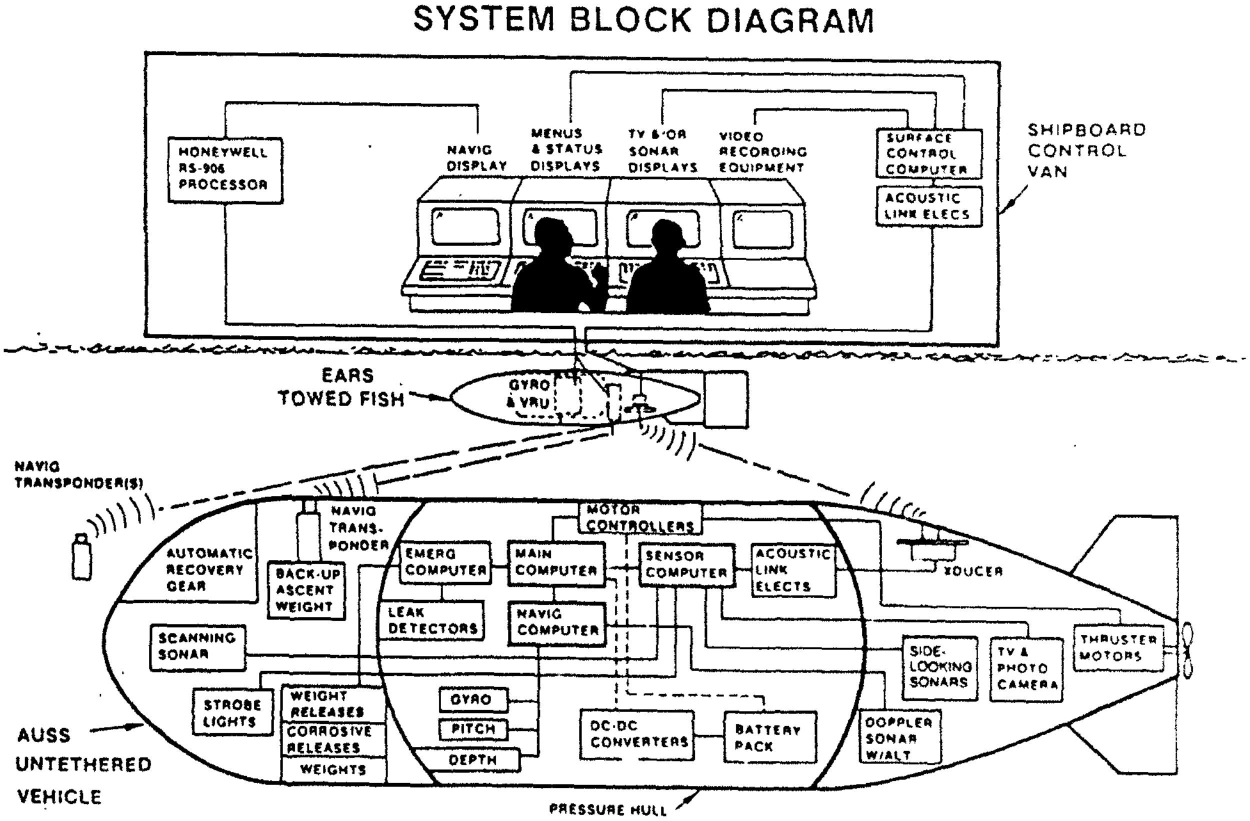


Figure 4. AUSS control equipment and untethered vehicle.

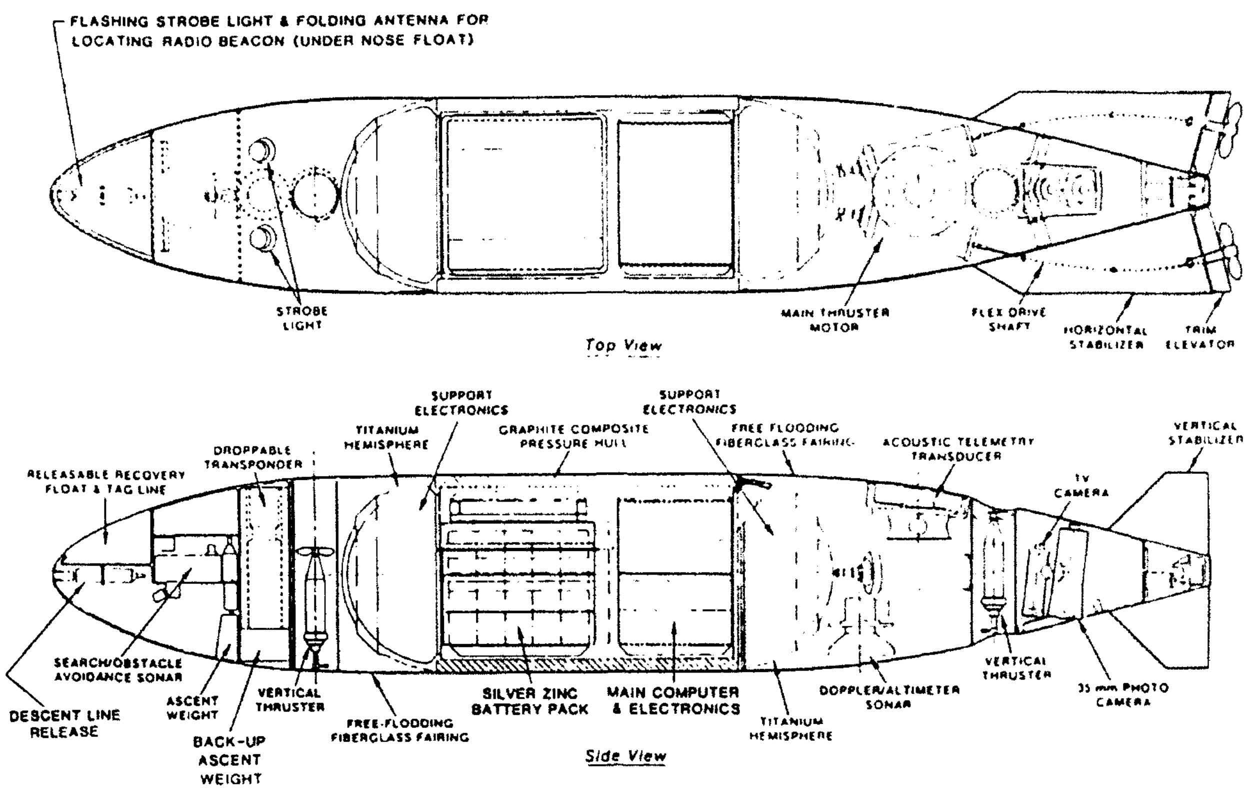


Figure 5. AUSS testbed vehicle layout.

Sensor Vehicle. The sensor vehicle provides the platform for mounting search sensors, sensor mobility, and telemetry. The characteristics and capabilities of the sensor vehicle are presented in table 1. The unique feature of the sensor vehicle is its acoustic telemetry link subsystem. The acoustic telemetry link subsystem is capable of the transmitting binary information from the vehicle to a surface receiver at a rate up to 4,800 bits per second and accepting binary information transmitted from a surface transmitter at a rate up to 1,200 bits per second. The FSS, the SLS, and the video information are transmitted to the surface via this acoustic telemetry subsystem.

Acoustic Search Sensors. Currently, the sensor vehicle is equipped with two acoustic search sensors, an FSS and an SLS. The FSS is an EDO Western model 4059-1 obstacle-avoidance sonar (OAS). The OAS is a high-resolution, mechanically scanned, pulsed sonar with an SLS quality image display in a black-and-white video format. The EDO Western SLS has been custom-designed for operation and control via an acoustic link. The capabilities and specifications for the OAS and the SLS are given in table 2.

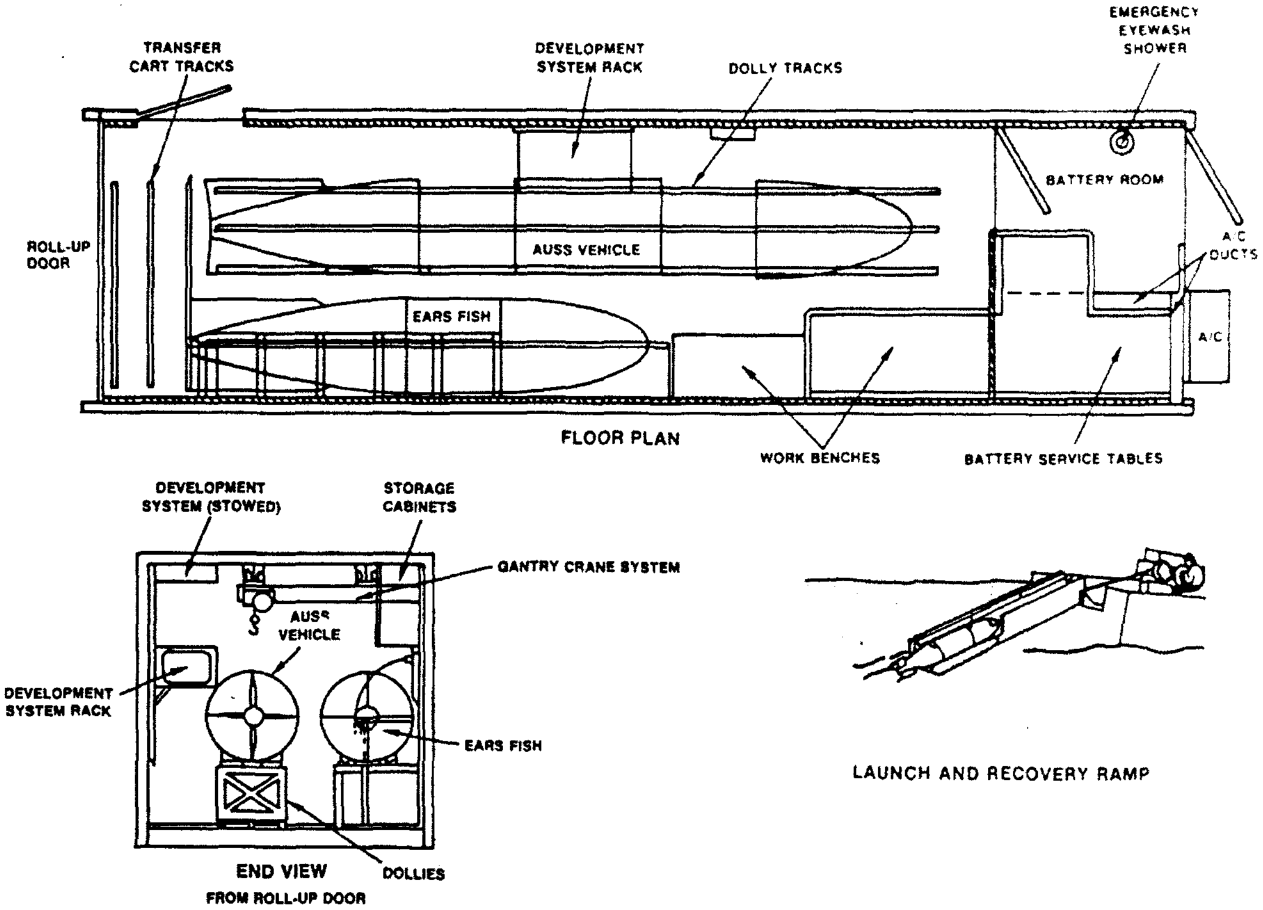


Figure 6. AUSS vehicle handling equipment.

Table 1. AUSS sensor vehicle characteristics.

Configuration	Cylindrical
Length	14 ft
Diameter	30 in
Total Weight	2,700 lb in air
Depth Capability	20,000 ft maximum
Pressure Housing Construction	45-in long by 30-in diameter by 2.125-in-thick graphite-epoxy cylinder capped by titanium end bell
Speed Capability	6.5 kn maximum
Mission Duration	10.0 hrs
Pitch and Roll Stability	Unknown; wait for test results.
Depth Control Stability	Unknown; wait for test results.
Heading Control Stability	Unknown; wait for test results.
Doppler Accuracy	Plus or minus 0.25% of distance traveled plus 60-ft/hr drift
Turn Radius Minimum	Unknown
Main Power Source	Secondary battery
Cell type	Silver-Zinc
Voltage	60 VDC
Energy capacity	350 AHr
Number of cells	40
Full recharge time	20 hr, minimum, following 10-hr mission
Emergency Processors	
Power Source	Secondary battery
Cell type	Nickel-Cadmium
Voltage	TBD VDC
Energy capacity	TBD
Number of cells	4

Table 1. AUSS sensor vehicle characteristics. (continued)

Emergency Weight	
Release Power Source	Primary battery
Cell type	Alkaline
Voltage	63 VDC
Energy capacity	TBD
Number of cells	7
Telemetry Capabilities	Acoustic
Link type	TBD
Communication type	Half duplex; serial
Data rate	Uplink, 4800 bps maximum two independent channels each transmitting at 2400 bps; downlink, 1200 bps maximum
Bit error rate	10^{-6} bps
Carrier frequency	11 kHz
Modulation mode	ISSB; synchronous; DPSK (data)
Output power	100 W maximum 14 W normal

Table 2. AUSS acoustic search sensors characteristics.

FORWARD SCANNING SONAR

Model and Manufacturer	EDO Western model 4059 Obstacle Avoidance Sonar (OAS)
Scan Mechanism	Mechanical
Transmit Frequency	100 kHz
Horizontal Lobe (-3dB)	2 deg
Vertical Lobe (–3dB)	50 deg
Angle of Inclination	0.0 deg
Scan Rate	3.0 deg-sec for 400 m scale
Pulse Length	0. 10 msec
Maximum Source Level	75dB re/µbar @ 1 yd
Minimum Receive Level	–38 dB/µbar
Scan Diameter	800 meters maximum displayable
Display Range Accuracy	Plus or minus 2 deg
Display Type	Video format
Display Dynamic Range	16 gray levels
Display Resolution	512 by 512 picture elements
Weight (subsea units)	64 lb, in air 28.5 lb, in water
Interfaces to Microprocessor	Parallel to customer-specified, microprocessor-based multiplex link
Parallel Data Format	
Baud Rate	Handshake
Level	TTL
Clock	Independent clocks
Word format	8 bytes preamble followed by 512 bytes of data; Checksum
Size of Sound Head	18-in diameter by 8-in long
AUSS System Integration	
Maximum speed of advance while active	0.0 kn; scans while vehicle is stationary.
Maximum 180-deg scan rate	128 sec

Table 2. AUSS acoustic search sensors characteristics. (continued)

Maximum 360 deg scan rate	0.083 hr (consists of two 180-deg scans plus vehicle turn times)
Altitude	200 ft nominal; operator variable
SIDE-LOOKING SONAR	
Model and Manufacturer	EDO Western model 606A modified for operation and control via acoustic telemetry line
Horizontal Lobe (-3dB)	0.75 deg
Vertical Lobe (-3dB)	50 deg
Angle of Inclination	15 deg
Transmit Frequency	100 kHz
Pulse Length	100 μsec
Maximum Source Level	To be supplied
Minimum Receive Level	To be supplied
Display Type	Video format
Display Range Accuracy	To be supplied
Display Resolution	512 by 512 picture elements
Display Dynamic Range	16 gray levels
Weight (subsea units)	25 lb in air
Size (subsea units)	40-in long
Interfaces to Microprocessor	Parallel to customer-specified, microprocessor-based multiplex link
Data Format	Same as Forward-Scanning Sonar
Word format	8 bytes preamble followed by 512 bytes of data; checksum
AUSS System Integration	
Maximum speed of advance while active	Unknown, need test results
Altitude	200 ft nominal; operator variable

Optical Sensors. The sensor vehicle is also equipped with a 35-mm still photographic camera and a black and white video camera. These cameras are intended primarily for contact classification and documentation. However, these cameras can also be used to conduct a limited optical search. The still photographic camera is a Photosea model 1200 35-mm camera. The video camera is a Subsea Systems model CM-8 black and white underwater camera. Lighting for these two cameras is provided by two Photosea model 1500SXD strobes. The capabilities and specifications for these cameras and strobes are given in table 3.

Control Equipment

The major components of the control equipment are the surface control van, external acoustic relay subsystem (EARS), and auxiliary navigation equipment.

Control Van. The control van houses are equipment required to communicate with, navigate, and control the untethered vehicle. The control van also houses the equipment for displaying, storing, and evaluating search sensor data. The physical characteristics and other specifications of the control van are given in table 4.

External Acoustic Relay Subsystem (EARS). The EARs is a towable fish that is about the same size and configuration as the sensor vehicle. EARS contains the surface hydrophones for the acoustic navigation subsystem and the surface end of the acoustic telemetry link equipment. During a mission, EARS is towed behind the support craft at a depth of about 100 feet and 75 feet behind a depressor weight. This configuration minimizes acoustic noise in the acoustic telemetry link and navigation subsystem, and decouples the surface navigation equipment from surface waves. The physical characteristics and capabilities of EARS are listed in table 5.

Auxiliary Navigation Equipment. The auxiliary navigation equipment consists of acoustic transponders, pingers, buoys, and surface navigation equipment that may be required to support a search mission.

Vehicle Handling Equipment

The main components of the vehicle-handling equipment are the launch and recovery ramp and the maintenance van.

Launch and Recovery Ramp. The launch and recovery ramp provides the capability for safely launching and retrieving the untethered vehicle and EARS from the stern of the support craft. During the launch or recovery operation the after end of the ramp floats in the wake of the support craft and the forward end is gimballed at the stern of the support craft. The ramp is hydraulically operated for placing it overboard and for returning it to the deck of the support craft. The physical characteristics and features of the launch and recovery ramp are given in table 6.

Table 3. AUSS optical sensors characteristics.

STILL PHOTO	
Model and Manufacturer	Photosea model 1200 35-mm camera
Field of View	50 deg horizontal by 35 deg vertical; diagonal 60 deg
Maximum Frames per Second	1 frame per three sec
Maximum Number of Frames	250 per cassette
Length	13.5 in
Diameter	5.0 in
Weight	18 lb, in water
Power Source	Self-contained, rechargeable nickel-cadmium 500 frames life
Shutter speed	0.01 sec
Data Recorded	Time, frame number, two-digit alphanumeric
VIDEO	
model and Manufacturer	Subsea Systems model CM-8 black and white
Field of View	(TBD) deg horizontal by (TBD) deg vertical; diagonal 65 deg be supplied)
Resolution	(TBD) vertical (TBD) horizontal (TBD)
Diameter	3.0 in
Length	10.0 in
Weight	3.6 lb, in water
Power Source	Sensor vehicle main power source
Sensitivity	TBD
Vidicon tube	TBD
Lens	8mm @ fl .7 (corrected)
STROBE LIGHT	
Model and Manufacturer	Photosea model 1500 SXD
Intensity	150 W-sec
Charge Time	3 sec to maximum voltage
Power Source	Sensor vehicle main power source (24 VDC at 8 amps peak)
Diameter	4.2 in
Length	9.5 in
Weight	10 lb, in water

Table 4. AUSS control van characteristics.

Length	40 ft (newest version)
Width	8 ft
Height	8 ft
Material	Steel
Weight (ship ready)	15,000 lb
Other Features	Contains storage cabinets and work bench

Table 5. External acoustic relay subsystem (EARS) characteristics.

Configuration	Cylindrical
Length	14 ft
Diameter	30 in
Total Weight	1500 lb in air
Tow Depth	100 ft
Pitch and Roll Stability	To be determined experimentally
Depth Control Stability	To be determined experimentally
Heading Control Stability	To be determined experimentally
In Tow Turn Radius	To be determined experimentally
Power Source	Support craft or dedicated source
Other Features	Requires 500-lb depressor weight during tow

Table 6. Launch and recovery ramp.

Length	20 ft
Width	6 ft, widest point
Height	5 ft
Weight	1000 lb

Maintenance Van. The maintenance van provides the transport and service support for both the untethered vehicle and EARS. Service support consists of replacing the vehicle's expendables and periodic maintenance. The physical characteristics and features of the maintenance van are presented in table 7.

Table 7. AUSS maintenance van characteristics.

Length	30 ft
Width	8 ft
Height	8 ft
Material	Steel
Weight (with EARS and sensor vehicle)	24,000 lb
Transportability	Can be transported by truck, ship, and air; is welded or chained to the afterdeck of host ship; must align with launch and recovery ramp.
Other Features	Storage space for one sensor vehicle, one EARS, and three main battery units equipped with built-in battery charger.

AUSS SEARCH PERFORMANCE ASSESSMENT

Assessing the search performance of AUSS is very difficult. Difficulties range from a lack of a clear-cut definition for the performance of search sensors to a lack of a defined and fixed search scenario. Moreover, predicting the search performance of AUSS is complicated by system design changes effected following the final design configuration decision.

Initially, because the design study concluded that a forward-looking circular scan sonar search was more efficient than a continuous SLS, the AUSS was designed as a "spot-scanning" active sonar search system. This means that the AUSS vehicle is designed to stop and hover while conducting an active 360-degree sonar search. Subsequently, it was decided that a continuous SLS search was superior to the spot scan. Hence, an SLS was retrofitted into the AUSS design. However, whether continuous side-looking is superior to spot scanning and whether retrofitting AUSS with an SLS has proved effective have not been fully demonstrated nor have predictions been made.

REFERENCES/BIBLIOGRAPHY

The following list contains basic and essential references on oceanic search theory.

1. Brown, J. November. 1983. "Technical Descriptive Summary of Advanced Unmanned Search System (AUSS) Testbed." Prepared by ARINC for NOSC.

2. Koopman, B.O. 1986. "Search and Screening," CNO Operations Evaluations Group Report no. 56, Washington, D. C.

   This report laid the background for all search theory to follow. The main subject is search of the sea surface (for the Japanese Fleet in the Pacific Carrier War). However, visual, radar, and sonar search are all considered.

   The overall director of the Operations Evaluation Group, Phillip M. Morse, was the coauthor of *Methods of Mathematical Physics* with Feshbach, and *Methods of Operations Research* with Kimball, which began the field of formal Operation Research. He also coauthored the text *Theoretical Acoustics*. This was a very high-powered group.

3. Reber, R. K. January 1956, June 1957. "A Theoretical Evaluation of Various Search Salvage Procedures for Use with Narrow-Path Locators," in two parts: "Part I — Area and Channel Searching" and "Part II — Locating Objects whose Approximate Presence and Approximate Position are Known," U. S. Navy BuShips reports nos. 117 and 118, Washington, D. C.

   This report presented the impact of navigation error on search.

4. Richardson, H. R. L. D. Stone, and F. A. Andrews. March 1971. "Manual for the Operations Analysis of Deep Ocean Search," NavShips SupSalv report 0994–010–7010, Washington, D. C.

   This manual is an excellent compilation of the operations analysis techniques needed to evaluate a search operation in progress and use statistical and mathematical techniques to allocate search effort, i. e., where to search next. Naval officers had a negative reaction to the manual because few had been prepared to do the mathematics required. Sadly, there has been little change to this day. The appendices contain a discussion of optimal search theory.

5. Stone, L. D. 1976. *Theory of Optimal Search.*

   This book was written by Stone while on sabbatical at the USN PG School in Monterey. It is quite mathematical and contains most of what one needs to know about the subject.

Of more relevance to the FASS project are references to search-system design and engineering. The best of this source material can be found in the AUSS Library at NRaD. When the AUSS program was initiated in 1973, a firm policy was established that everything worthy of investigation was worthy of documentation; thus, a formal system of document preparation and collection was begun. This library contains much of interest to FASS task team personnel. A computer listing of the titles on file has been generated and is available to interested parties. All FASS task team members were strongly encouraged to become familiar with this basic source of relevant material before beginning any further study of a specific area.

FASS ANALYSIS

The purpose of this section is to present the status of the FASS analysis model. The following subsections present discussions of methodology, search scenarios, and analysis results.

FASS ANALYSIS METHODOLOGY

Methodology Overview

Measure of Performance. The level of performance exhibited by a particular system is measured in terms of time required to perform the search task. This can be expressed in terms of the time required to search a given area to a given probability of detection, or as an area search rate, i.e., so many square nautical miles per hour. Alternatively, the mean time to detection may be used instead of the time required to search to a given probability of detection. Both of these measures of performance are used in this analysis depending on which is most convenient to calculate.

For the purposes of the FASS analysis, the time while on the search site will be the only time considered. Facets of a search such as mobilization, ship transit, and demobilization will not be included in the analysis. It is assumed that one ship of opportunity will be used and that these factors will be common to all of the systems considered.

Purpose of the Analysis. In order to compare one system with another, a consistent measure of performance is required. In addition, system sensitivities to parametric changes can be investigated to determine how performance values can be most easily improved.

Defining the System. Before any analysis can take place, the system to be analyzed must be carefully thought out and completely defined with regard to how it functions and how it will be used. The information requirements noted below will all depend upon this initial definition.

Defining the Scenario. The terrain, the target, the false target density, the area size, and the depth at which the search is to take place all contribute to the definition of the scenario.

The terrain must be determined to be smooth, rough, or scarp. These three choices determine how well a particular sensor, such as an SLS, will perform while looking for a particular target.

The target size will determine the required resolution and, thus, the range of some search sensors. The false target density or number of possible targets per square nautical mile must be determined or estimated to calculate the number of target evaluations that will be required per unit of area searched.

The search area size must be specified to work out a reasonable search strategy as well as to normalize the performance to an area rate if this is desired.

The depth of the water at the search location must be used in the calculations to determine the ascent and descent times for the vehicles and to determine acoustic path characteristics for navigation and communication, if required.

For the purposes of the FASS analysis, three scenarios have been selected for system comparison. All of them are for deep ocean depth (20,000 ft) and for an area 10 nmi by 10 nmi. Each has a different terrain associated with it and a particular false target density. Each is analyzed for a range of targets from 1 to 100 ft in size:

Scenario A: smooth terrain, 1 false target/square nmi
Scenario B: rough terrain, 10 false targets/square nmi
Scenario C: scarp terrain, 100 false targets/square nmi.

Defining the Search Strategy. The search strategy consists of the deployment scheme for using the search system. This includes the geometry of the search patterns used and the sequence of launching, searching, and recovering the search vehicles. This strategy must be carefully thought out since it will affect the calculation of the mission time in a significant way.

Determining the System's Performance Parameters. This category of parameters, although somewhat arbitrarily grouped, consists of the effective sensor swath width, the vehicle's search speed, the bottom time, the sensor probability of detection, the distance traveled between turns, the navigation error, and the desired probability of detection for the system.

The sensor swath width is the width of the path that is searched if the vehicle is proceeding in a straight line. For sonars that search both sides of the vehicle's track, the swath width is twice the range of the sonar. The range of nonbeamformed sonars is calculated by dividing the target size by the product of the number of hits required and the sonar beam angle in radians. This range must be compared to the maximum range of the sonar based on sensitivity quoted by the manufacturer and the lesser of the two values is then used. The number of hits required refers to the number of times the sonar insonifies the target to obtain a given probability of detection. The number of hits to achieve 90% detection probability has been determined through experience to be 6, 10, and 20 for smooth, rough, and scarp terrain, respectively. The range of beamformed sonars is independent of target size since the beam is of constant width over its entire range. Since this type of sonar operates in the acoustic near field, the extent of the near field determines the range. This can be calculated or manufacturers' specifications can be used. Photo systems have swaths that are determined from empirical data or estimated based on calculations involving camera sensitivity, lighting, and water characteristics.

The vehicle search speed is the speed at which the vehicle travels while it is in the search mode. This would be the speed at which side-looking systems or photo systems are traveling while taking data or, in the case of spot-scanning sonar systems, it would be the speed at which the vehicle travels between scans.

The bottom time is that period of time between arriving at the bottom and leaving the bottom. It will generally be determined by battery life and how the scenario affects the battery duty cycle.

The sensor probability of detection is the average over the sensor range of the probability that a target will be detected on one pass given that a target is within range. This value is used to determine how many passes or how much overlap is required to achieve a given system probability of detection.

The distance between turns is the same as the length of a track and is important in calculating the time that is spent turning the vehicle on to new tracks during the search of a given area.

The navigation error is the root mean square error in the measured location of the vehicle. This uncertainty is also used in the calculation of the overlap required to achieve a given system probability of detection.

The desired probability of detection for the system is an arbitrary value determined by what level of confidence one wishes to achieve with one pass over an area. For comparison purposes the value has been fixed at 0.9 throughout this analysis.

Determining Nonsearch Time. In the context of this subsection, the term nonsearch time refers to nonbottom time and consists of launch time, descent time, ascent time, recovery time, and turnaround time (deck time).

Launch time is the time required to get the vehicle into the water once it has been made ready and includes any delay before it starts its descent to the bottom.

Descent time is the time required by the vehicle to go from the surface to the bottom and includes any delay before it begins its run on the bottom.

Ascent time is the time required by the vehicle to go from the bottom to the surface.

Recovery time is the time required to get the vehicle from the surface of the ocean into a position onboard the ship suitable for refurbishment' for the next dive. Turnaround time is the time required to refurbish the vehicle for its next dive such as changing batteries and film packs.

Assumptions. Table 8 lists the assumptions that apply to the FASS analysis as it now stands.

Table 8. FASS analysis assumptions.

A. General assumptions

1. FASS is limited to one ship of opportunity.
2. Only onsite performance is considered in the analysis.
3. The desired system probability of detection is 0.9 after one pass.
4. The system probability of detection is a function of the following:
    a. Sensor probability of detection
    b. Navigation and control error
    c. Track spacing
    d. Sensor swath.

    It is also based on Stone's approximate equations representing the graphical data of Reber.
5. The number of vehicles employed is limited by ship space and personnel limitations
6. For particular systems, time intervals can be estimated for launch, descent, ascent, recovery, and refurbishment.
7. Launch and recovery sequences for *n* vehicles can be scheduled to provide a system that can be analyzed as *n* independent systems.

B. Search conditions

1. Bottom topography can be characterized for the following terrains:
    a. 80-% smooth (abyssal plains, abyssal hills)
    b. 10-% rough (trench zones)
    c. 10-% scarp (oceanic ridge zones).
    (Vought Corporation, 1982)

Table 8. FASS analysis assumptions. (continued)

2. Operational depth affects vehicle structure, acoustics, and navigation.
   a. There is a 20,000-ft requirement from NAVSEA.
   b. Most past searches have been at 1,000- to 5,000-ft depths.
   (Vought Corporation, 1982)

3. False target density can be characterized as follows:
   a. 1 target/square nautical mile on smooth bottom
   b. 10 targets/square nautical mile on rough bottom
   c. 100 targets/sqaure nautical mile in scarp terrain.

4. Target size:
   a. A 1-cubic-meter minimum target size must be detectable.
   b. A 1-cubic-meter target is approximately the 85th to 90th percentile of targets.
   (Vought Corporation, 1982)

5. Search rate calculations are based on 100% system reliability.

6. Weather conditions and sea state do not adversely affect vehicle launch and recovery. An acceptable acoustic environment is also assumed.

C. Sensor performance

1. Sonar sensor probability of detection is 0.9, if the proper number of hits is provided.

2. A free-swimming vehicle provides a more stable sensor platform than does a towed system.

3. Acoustic sensors can be characterized as follows:
   a. Detection on smooth bottom requires six hits.
   b. Detection on rough bottom requires 10 hits.
   c. Swath width is a function of the range specified for each particular sonar.
   d. Speed of advance is a function of sound velocity (assumed to be 4,800 ft/sec).

4. Photographic sensors can be characterized by the following:
   a. They have a 100-% probability of detection.
   b. Average swath width can be estimated to be 40 ft.
   (NAVSHIPS 0994-010-7010)
   c. There is no effective speed limit for photographic sensors if strobe recycle time is properly engineered.

Table 8. FASS analysis assumptions. (continued)

5. Magnetic sensors are not considered in initial performance analysis.
   a. Targets are not generally ferromagnetic. (Vought Corporation, 1982)
   b. Swath width is approximately 100 ft.

D. Contact evaluation

1. Navigation error is smaller than the evaluation sensor's swath (especially if forward-looking sonar is used to close on the target).
2. Control error is negligible for free-swimming vehicles.
3. Evaluation can be achieved in a single pass.
4. For AUSS-like systems, a long baseline system can be used to achieve a maximum root mean square navigation error of 30 ft.
5. For autonomous vehicle systems, a short-range synchronous pinger system can be used to achieve a maximum root mean square navigation error of 10 ft.

Calculations. Using well thought out strategy and performance parameters, one is now in a position to perform the calculations necessary to arrive at a value for the mission time for the desired scenario. The first procedure will be to calculate the amount of overlap required to achieve the desired system probability of detection. This is achieved by inputting the navigation error, the sensor probability of detection, the swath width, and the desired system probability of detection into Stone's equations, which approximate Reber's curves. The required track spacing is computed, that yields the required overlap. This value is saved for later use.

Next, the sonar range is calculated by using the resolution and hit requirements for the specific scenario or the range is simply input in the case of a beamformed sonar of photo system.

In the case of a spot-scanning system, the search speed is calculated based on the mass, hydrodynamic, and thrust characteristics of the vehicle and the distance between scans. This calculation takes into account the fact that acceleration and deceleration times detract from the search speed. For nonscanning systems, a similar calculation is performed to determine average evaluation speeds.

The time to perform an evaluation is then calculated by summing the transit time to the target, the time to take and transmit forward-looking sonar scans, and the time to take and transmit a video image. In the case of a photo system, the evaluation time is taken as zero, since it is performed later and in parallel with the continuing search effort.

The time to turn the vehicle onto a new track is calculated by using the distance between tracks and the time required to turn the vehicle in place. It is calculated by summing the time to make two 90-degree turns and the time to transit between tracks.

The area covered per dive is calculated by equating the bottom time to the sum of the search time, the evaluation time, and the turn time and solving for the search time. The area covered is then the product of the search time, the search speed, and the swath width.

The number of dives required to cover the entire area to the prescribed probability (0.9) is then the total area divided by the area covered per dive (quantity) multiplied by the number of passes required to achieve the overlap previously calculated.

Finally, the total time for the search of the area will be the cycle time for a dive times the number of dives, and the search rate will be this number divided into the total area.

The above is the method used for analyzing one vehicle; but to evaluate more than one vehicle, some additional steps are required. First, one must calculate the increase in probability per unit time per vehicle. This is done by dividing the probability of detection (0.9) by the number of dives (calculated previously for one vehicle) and dividing this by the bottom time for one vehicle. Then, one carefully keeps track of the increase in probability with time as the multiple vehicles are initially launched and cycled. When the probability reaches the prescribed value (0.9), then one pass over the area is complete and the time elapsed to this point is the mission time for one pass for the multiple vehicle system.

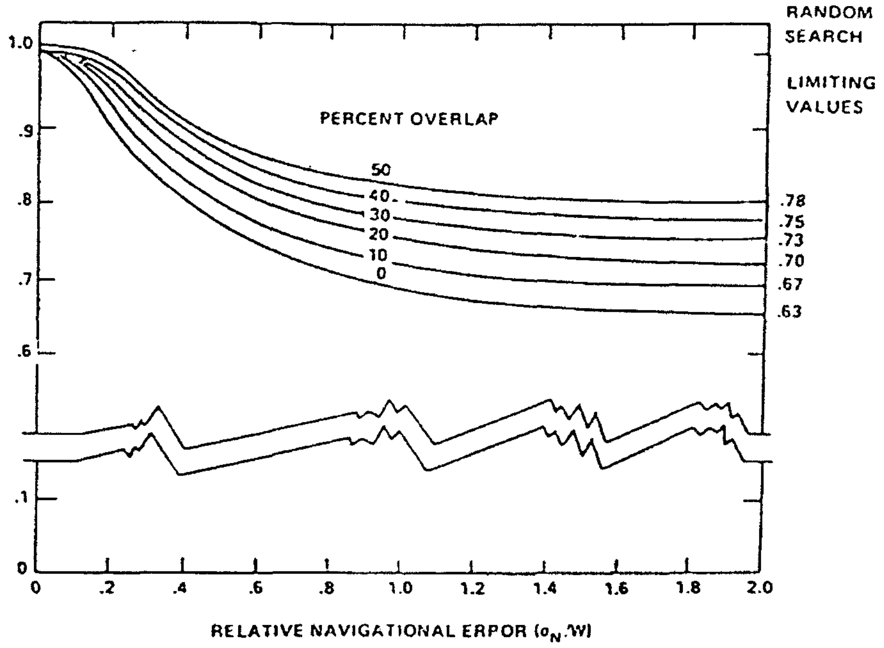
It should be mentioned that if the launching cycles have been well scheduled such that the vehicles can be treated as independent systems and if the initial launching sequence is short compared to the total mission, then the mission time will be very close to the mission time for one vehicle divided by the number of vehicles employed.

Conclusion. The above calculations are actually carried out by using a series of short computer programs that are customized for the particular type of system being analyzed, e.g., side-looking sonar type, spot-scanning system, or photographic system. These programs allow the user to examine the effect of changes in target size, vehicle speed, etc., and help prevent careless errors from causing erroneous conclusions. Even with these tools, one must be careful to exercise clear thinking and logic in the comparative analysis of these search systems.

Inclusion of Navigation Error into FASS Analysis

Navigational error or uncertainty in vehicle location produces holidays or overlaps that lead to less than perfect search area coverage. The net result is that additional search effort (i.e., numbers of passes over the area), must be expended to achieve a particular area coverage or probability of detection.

The pertinent factor in calculating the additional search effort requirements for a given situation is the ratio of the navigational error to the swath width. By the use of this ratio and the desired percentage of coverage (probability of detection), the necessary overlap can be read off of Reber's curves. Figure 7 shows the influence of navigational error on search detection probability. This ratio can then be applied to the computation of the search rate.



NOTES:
1. RECTANGULAR AREA IS COVERED BY SEARCH SYSTEM USING PARALLEL SWEEPS.
2. SWEEP WIDTH AND STANDARD DEVIATION OF THE NAVIGATIONAL ERROR ARE DENOTED BY W AND σ_N, RESPECTIVELY.
3. IF d DENOTES THE DISTANCE BETWEEN SEARCH TRACKS, THE PERCENT OVERLAP δ IS GIVEN BY

$$\delta = 100\left(\frac{W-d}{d}\right).$$

Figure 7. The influence of navigational error on search detection probability.

A short BASIC program was written that uses an approximation for Reber's curve to calculate the required search effort for any particular set of parameters. The output of this program will be used in the FASS analysis. A listing is included as table 9.

It should be noted from Reber's curves that the navigational error becomes significant (greater than a 10% effect) for navigational errors greater than 20% of the search swath width. Therefore, for free swimmers using SLS and long baseline navigational nets, it will only be a factor for targets less than a few feet in size. This is based on a navigational error of 30 feet and a swath width of 600 feet for 2-foot targets on smooth terrain (i.e., the 3-hit criterion). Thus, under most circumstances, the navigational error can be ignored. Note also, this is not true for short baseline systems with errors of approximately 200 feet, unless targets are greater than 20 to 30 feet in size or for photographic systems with small swath widths, unless exceptionally accurate (5- to 10-foot accuracy) navigation systems are employed.

Table 9. Approximation for Reber's curve in BASIC for FASS.

```
10 PRINT "what is nav error/swath width":
20 INPUT E
30 P = 0.632 + 0.33 × EXP(-1.68 × E) + 0.038  EXP(-3 × E)
40 PRINT "what is desired prob of detection";
50 INPUT Q
70 PRINT 60 N = LOG(1-Q)/LOG(1-P) "number of passes required is";N
80 PRINT "this is equivalent to";100× (N -1); "percent overlap"
85 IF N-1 0 THEN PRINT "NOTE: This is actually underlap"
90 PRINT
100 PRINT
110 GOTO 10
```

Side-Looking Sonars (SLSs) versus Spot-Scanning Sonars

Background. Much discussion has taken place regarding the virtues and nonvirtues of side-looking sonars and spot-scanning sonars. In this subsection, the limiting physics of both systems will be pointed out and the practical application shown. In addition, a few words about photographic spot scanning will be mentioned.

Side-Looking Sonar. To prevent holidays, a side-looking system with one beam must not advance more than one resolution element (along the track) before the sound returns from the maximum range. In order to determine the maximum speed, we can equate these two times.

$t = V/e$ and $t = c/2R$

where t = time

V = vehicle speed
e = resolution
c = speed of sound
R = maximum range.

Therefore,

$$V/e = c/2R \text{ or } V = ce/2R.$$

Now, the sensor search rate (SR) is the product of speed and swath ($2R$).

$$SR = 2RV$$

Substituting for V from above,

$$SR = 2Rce/2R$$

or

$$SR = ce.$$

This is the maximum search rate for any single-beam sonar of resolution e.

If we require that in smooth terrain the sonar resolution be one-third the size of the target and we substitute for the speed of sound, we arrive at the following result:

$$SR = 4800(L/3)$$

or

SR 16OOL where L = target length.

Therefore, it can be seen that there is an upper limit to the search rate for side-looking systems with one beam for any given target size. It should be pointed out that multibeam SLSs are capable of increases proportional to the number of beams they employ.

Spot-Scanning Sonars. This analysis employs a scan-within-a-pulse (SWAP) type scanning sonar to determine the limitations of this concept. The time required to search one spot-scanned area will be the sum of the time to get a scan and the time to traverse to the next spot. If the radius of the scanned circle is R, then,

Time to get a scan = $T1 = 2R/c$ and
Time to transit = $T2 = 2R/V$.
SR = area/time = $3.14R \times R/(T1 + T2)$ and
$SR = 3.14\ RcV/2(c + V)$.

If we assume that V is much less than c, then,

$$SR = 3.14\ RV/2.$$

Now, for a spot-scanning sonar, the maximum range (R) is target-size-dependent. That is for smooth terrain, the angular resolution RA, where A is the horizontal beam angle, is required to be one-third the target size ($L/3$). Therefore,

$$R = L/3A.$$

Substituting in the equation for SR,

$$SR = (3.14\ V/6A)L.$$

Compare this result to the result for the SLS. The coefficient on L has no limit as before and is, in fact, directly proportional to the vehicle speed and inversely proportional to the horizontal beam width. It would appear on the surface that the search rate could be increased without limit. In practice, it is obvious that the vehicle speed has limits and so does the horizontal beam width. For comparison, one can calculate that if the ratio of V/A is about 50 feet/second-degree, then the search rate of the two systems will be about the same. For a V/A greater than 50, the spot-scanning sonar will-be superior. This is not easy. For $V = 10$ feet/second, the beam angle can only be 0.2 degrees. Therefore, even though the SLS has inherent limitations and the spot-scanning sonar does not, the SLS will give higher performance in most cases.

Photographic Spot-Scan. It might be noticed that this type of system is similar to the spot-scanning sonar in that it also has no upper limit imposed by physics. The search rate of this sensor is simply the swath times the speed. For a 50-foot swath and 30 feet/second speed (three times faster than AUSS),

$$SR = 2RV = 50 \times 30 = 1500 \text{ ft}^2/\text{sec}.$$

Comparing this to the equation for the SLS ($SR = 1600L$), it is seen that for targets about = 1 foot or less, the photo system could be competitive from a performance point of view. Since it is clearly competitive from the simplicity, reliability, and cost point of view, a system of several photo systems could be competitive overall even for targets of larger size, especially if the terrain is other than smooth or if false targets are significant.

Point-to-Point Speeds for AUSS

While developing a search performance model for the FASS project, it became apparent that a more accurate estimate of vehicle speed was needed when considering acceleration and deceleration. Previously, either the maximum speed or some arbitrary lesser speed was used, but for "short hops" during a spot-scanning search for a small target this value is critical to the accuracy of the calculation.

To analyze the AUSS vehicle in this regard, it was assumed the vehicle could apply plus or minus 50 pounds thrust, its terminal velocity was 10 feet/second, its weight was

2,500 pounds, and full thrust was used for accelerating and decelerating. Solving and plotting the appropriate equations resulted in a relationship between point-to-point distance and average speed between the two points as shown in figure 8.

It should be noted from the graph that the effect of acceleration and deceleration time cannot be ignored, even for relatively large distances. For short distances (e.g., small target searches), the spot-scanning search performance will be severely degraded.

Rather than read the values off the curve, an approximate expression for the curve was developed for incorporation into the FASS analysis of AUSS. This expression is:

$$V = (20/PI) \text{ arcos } (1/(0.0026\ D + 1)) + 0.2,$$

where the arcos is in radians:

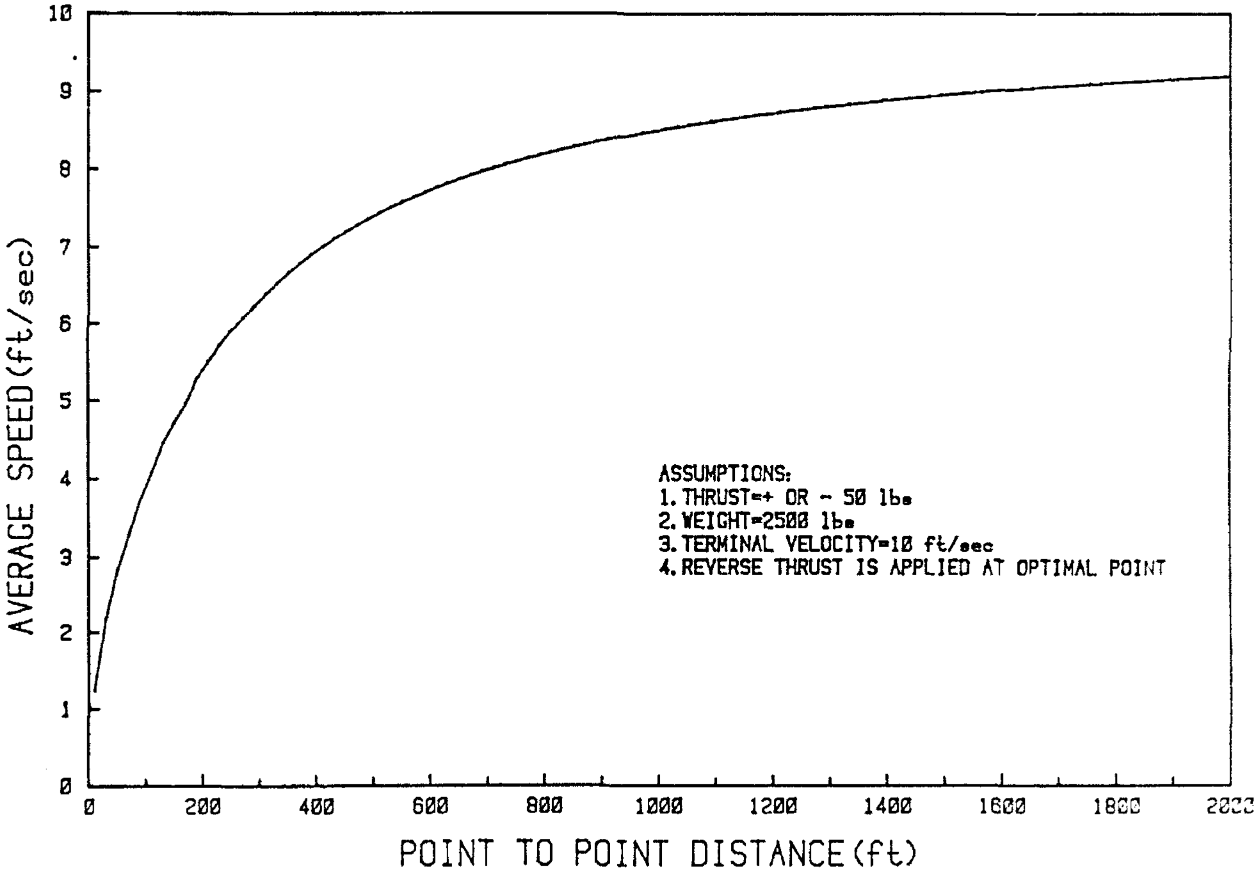


Figure 8. Relationship of average speed to point-to-point distance for AUSS.

Methodology Summary

Table 10 summarizes the FASS analysis approach by reviewing the questions addressed, the analysis approach, and the measures of performance. Figure 9 is a graphic review of the FASS analysis input and output data. A complete computer program listing and flowchart for the FASS analysis is included as appendix C.

Table 10. Summary of FASS analysis methodological approach.

QUESTION ADDRESSED

How is a given system's performance affected by the following parameters?

- Scenario type
- Terrain
- Target size
- False target density
- Number of vehicles employed
- Search strategy
    - Deployment timing schemes
    - Search pattern geometry

How does a given system's performance compare to other systems as a function of scenario?

ANALYSIS APPROACH

- Define system
- Define scenario
    - Terrain
    - Target
    - False target density
    - Area size
    - Depth
- Define search strategy
    - Search geometry
    - Sequence of deployment, bottom time, and recovery

Table 10. Summary of FASS analysis methodological approach (continued).

- Determine performance parameters
  - Swath width
  - Search speed
  - Evaluation speed
  - Bottom time
  - Vehicle speed versus point-to-point distance
  - Sensor probability of detection
  - Scan time
  - Evaluation time
  - Turn time
  - Navigation/control error

- Determine nonsearch time
  - Launch time
  - Descent time
  - Ascent time
  - Recovery time
  - Turnaround time (deck time)
- Calculate
  - Time available to transit on bottom
  - Distance traveled
  - Turns required
  - Adjusted time available and distance traveled
  - Number of dives required
  - Total time
  - Search rate

MEASURES OF PERFORMANCE

Search rate (nm2/hr) for given scenarios (derived from summation of required times only while onsite) Mean time to detection.

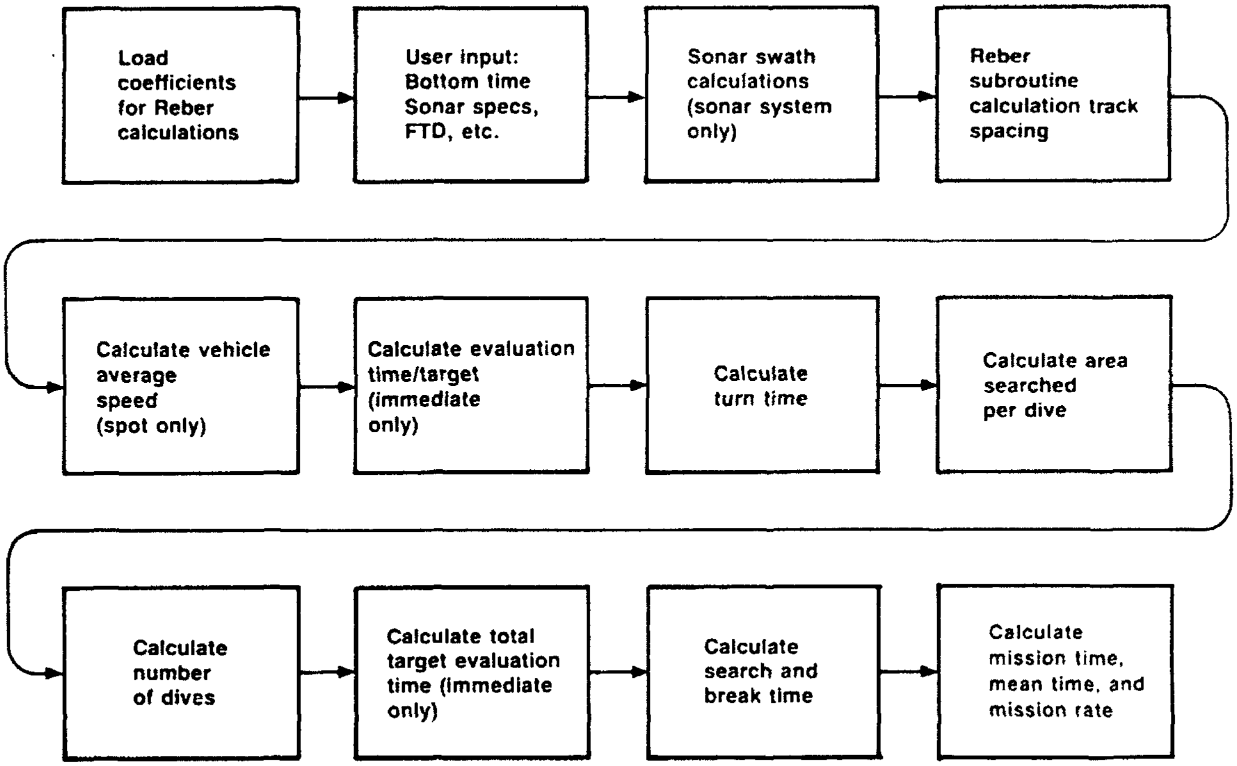


Figure 9. Flowchart for FASS analysis.

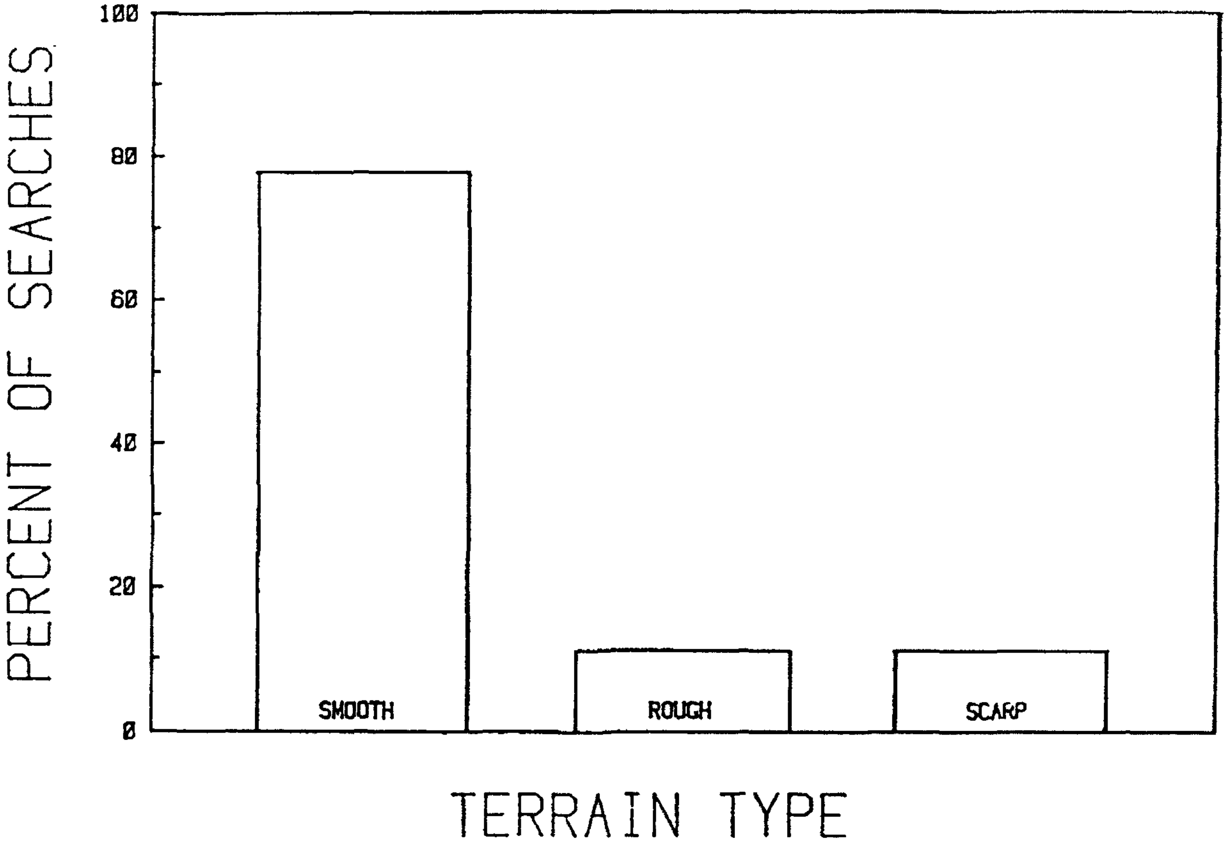
SEARCH SCENARIOS

The following figures were developed as useful aids for formulating analysis procedures, generating new conceptual ideas, and increasing understanding of the FASS search problem.

Targets — Terrain, Depth, and Many Ways to Look at Size

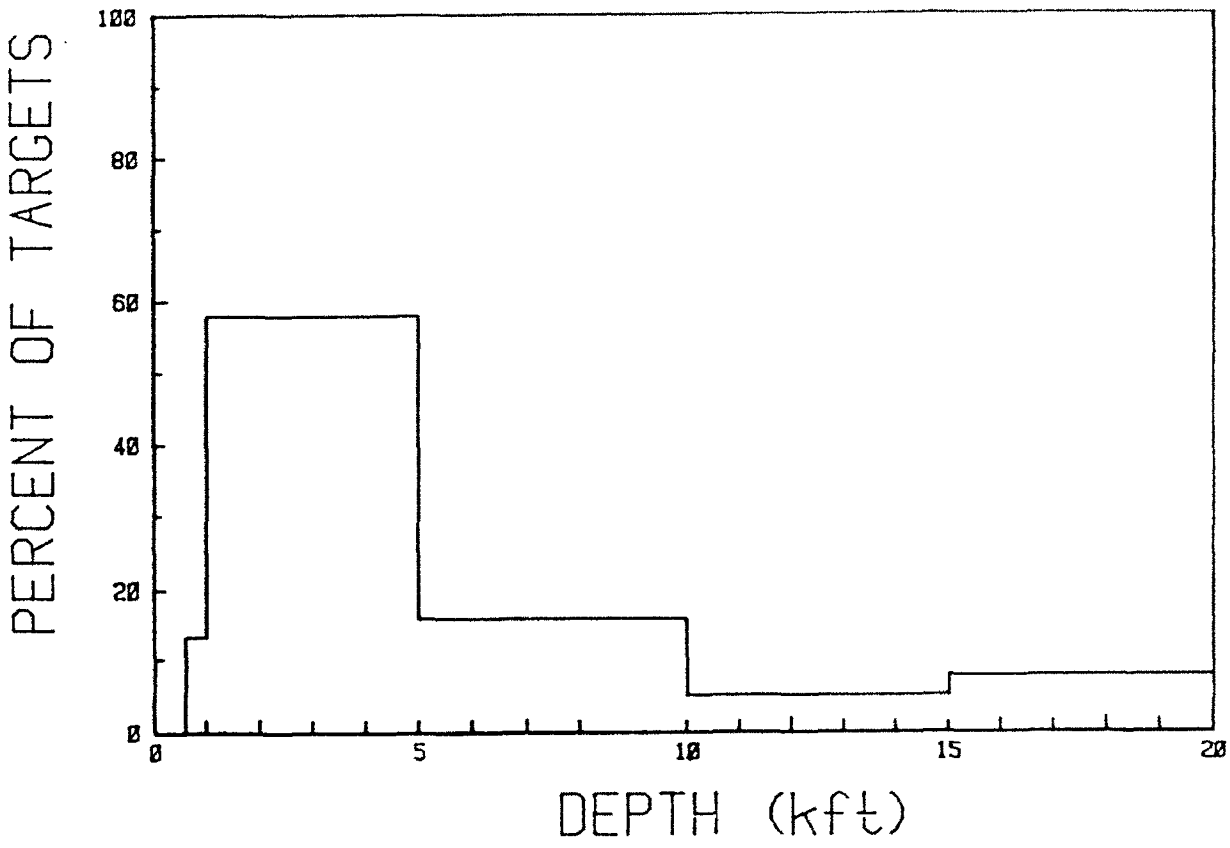
A considerable amount of discussion has taken place in the past as to the nature of the scope of targets and scenarios that make up the search problem facing the FASS project. Target and scenario information was gathered from past searches and non-searches (i.e., where a target was lost, but no search was conducted). Figures 10 through 18 were generated from this information. (Vought Corporation, 1982).

The following brief conclusions were made. Most targets are relatively small compared to a ship or submarine. The median target size is about 20 feet. Most targets are lost in smooth terrain and in depths between 1,000 and 5,000 feet. In order to detect 90% of the targets, one would need to detect targets in the 1- to 2-foot size range. To find them with a sonar would require a sonar resolution in the fractions of a foot. The Surface Towed Search System (STSS) sonar can detect about 80% of the targets in smooth terrain, and the EDO SLS can detect about 70% of the targets. In rough or scarp terrain, both sonars are severely hampered.



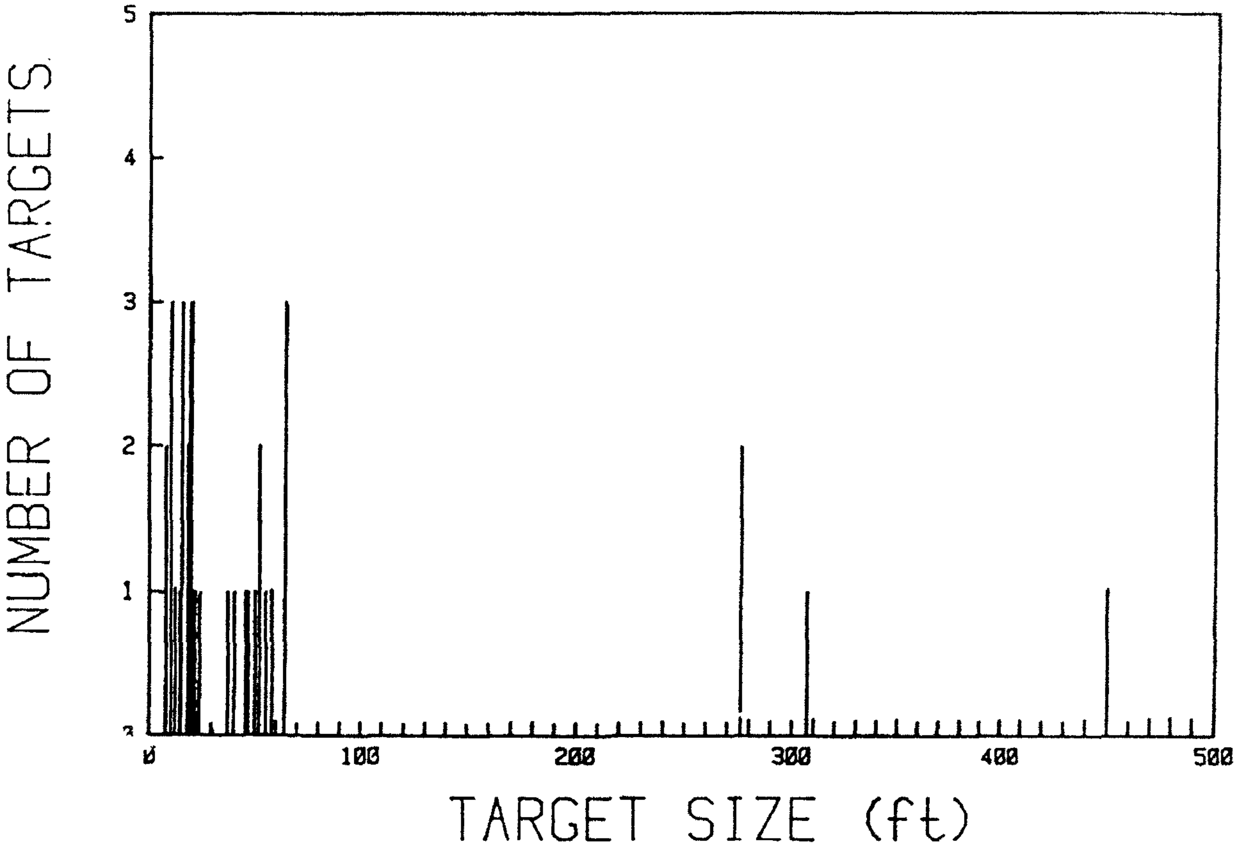
The number of smooth terrain searches, rough terrain searches, and scarp terrain searches were summed and divided by the total number of searches in the sample and converted to a percent to obtain the three bar graphs.

Figure 10. Percentage of searches according to terrain.



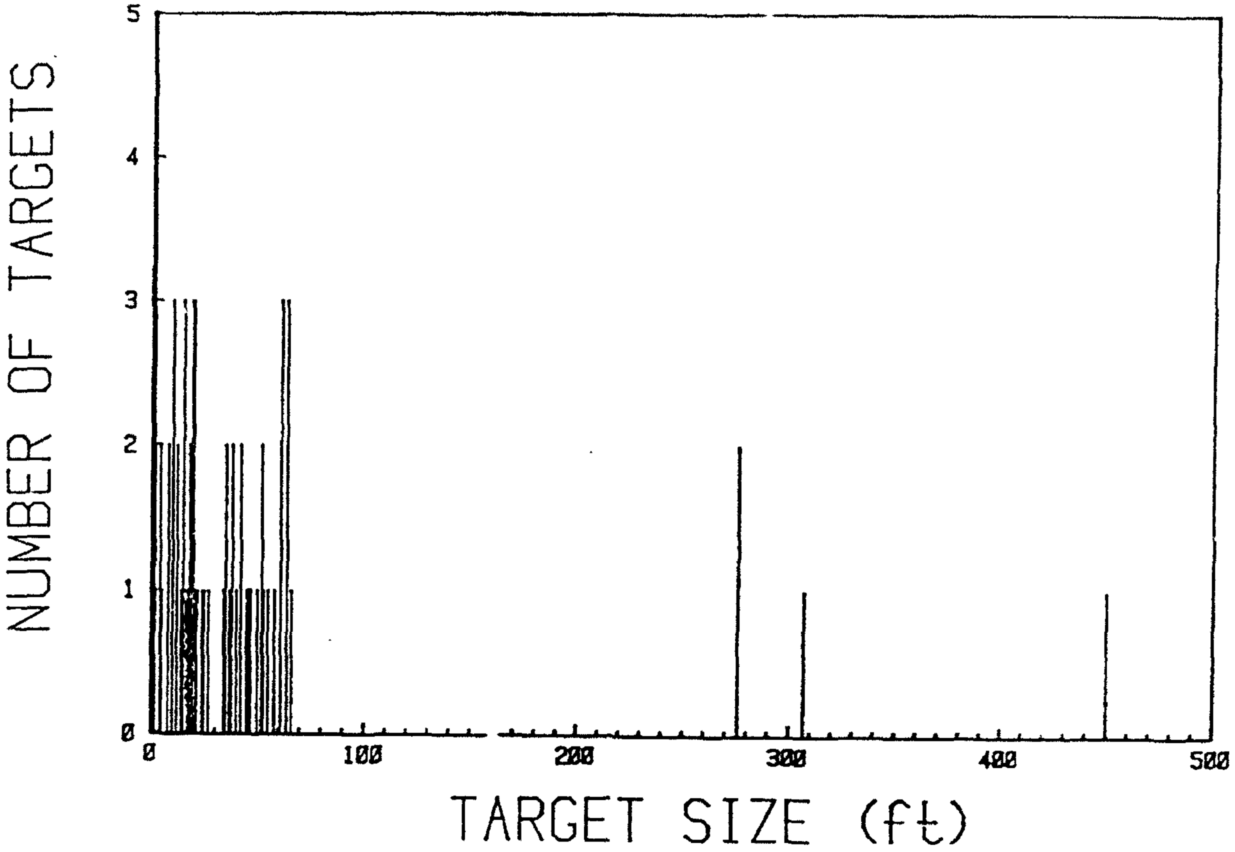
The number of targets lost in depths in each of the depth ranges shown were divided by the total numbers of targets in the sample and converted to a percent to obtain the five depth ranges in this figure.

Figure 11. Percentage of targets according to depth ranges.



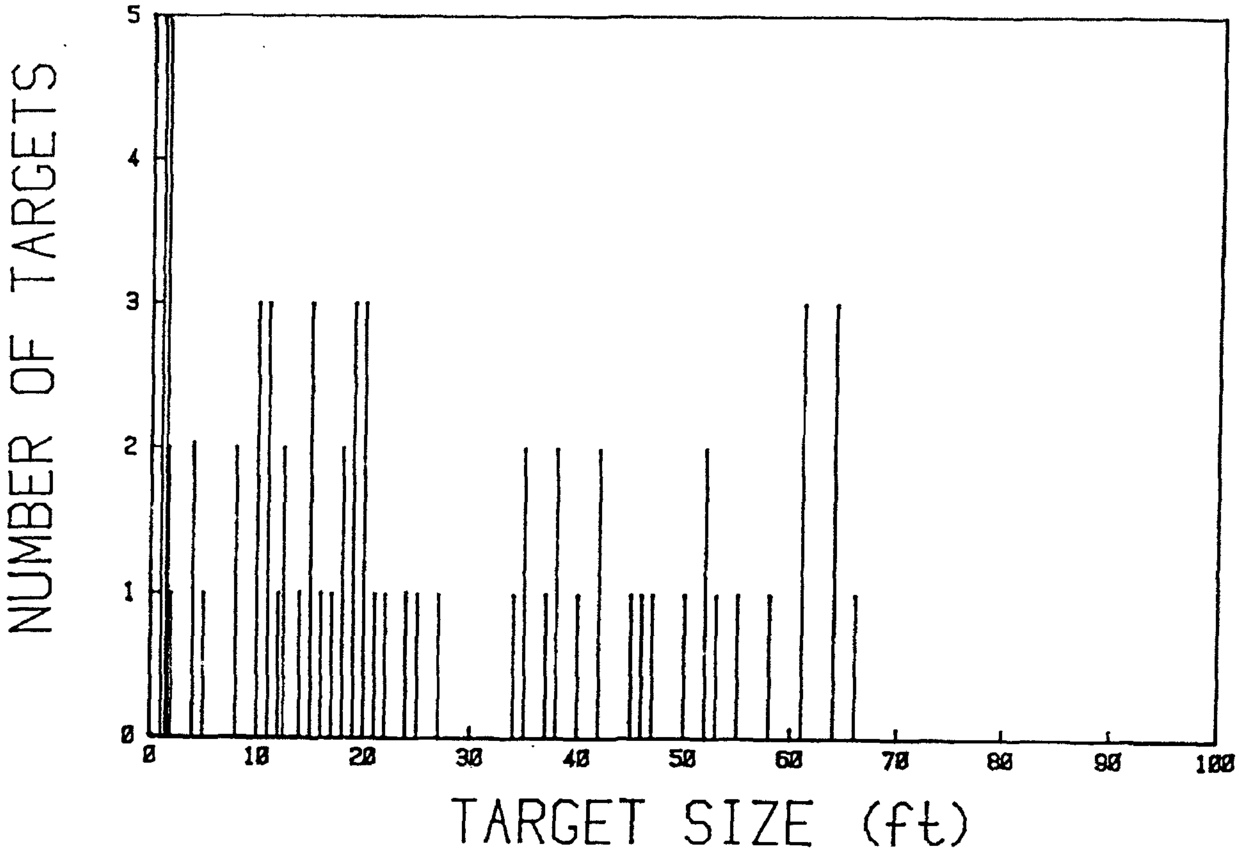
The number of targets of a given length were plotted as a line whose length is proportional to the number of targets of that particular length.

Figure 12. Number of targets according to target length.



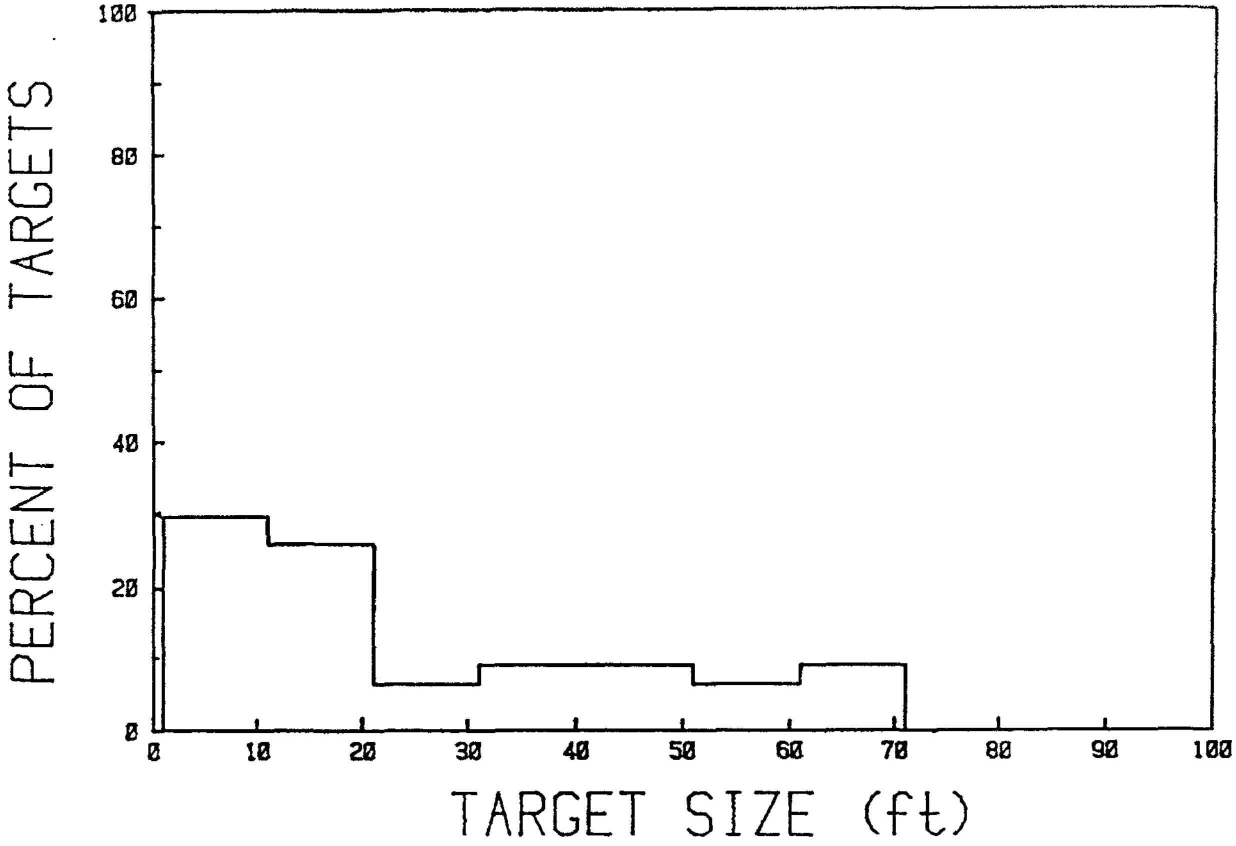
The number of targets of a given length were plotted as a line whose length is proportional to the number of targets of that particular length. The number of targets of a given width were plotted in a like manner in this figure. Target size was 0 to 500 ft.

Figure 13. Number of targets according to target length and width (0 to 500 ft).



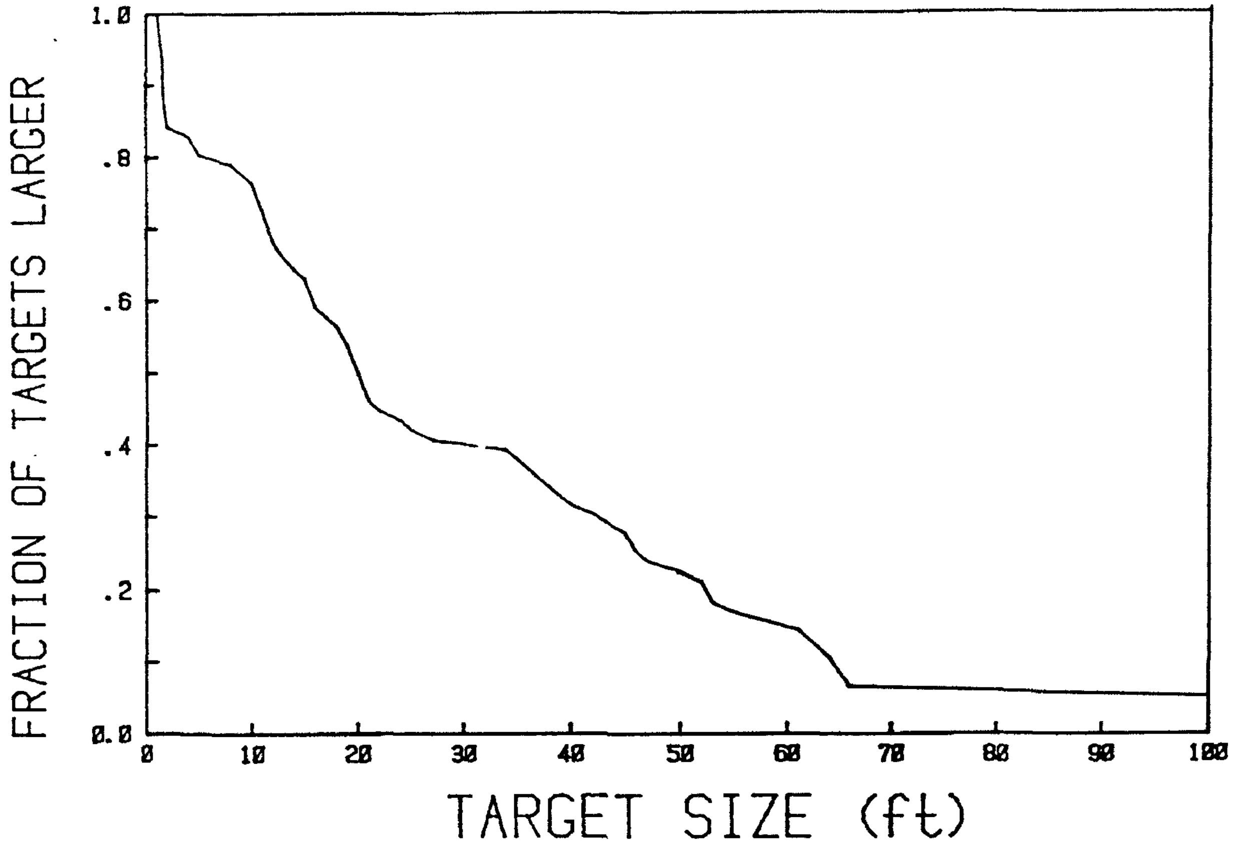
The number of targets of a given length were plotted as a line whose length is proportional to the number of targets of that particular length. The number of targets of a given width were plotted in a like manner in this figure. Target size was 0 to 100 ft.

Figure 14. Number of targets according to target length and width (0 to 100 feet).



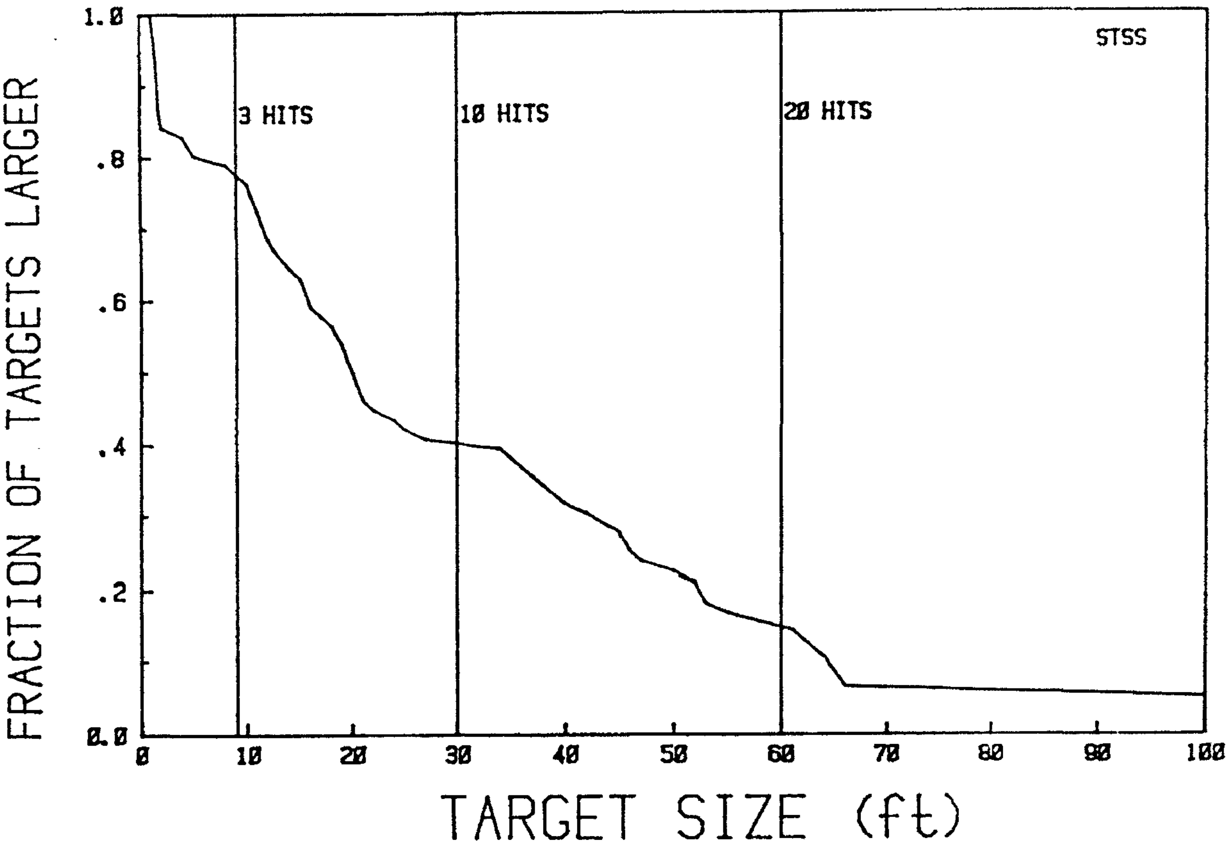
The number of targets in a given size range was divided by the total number of targets to obtain the percent of targets in that size range. This resulted in the seven-step graph (two of the steps are at the same percentage and are adjacent to each other).

Figure 15. Percentage of targets according to size ranges.



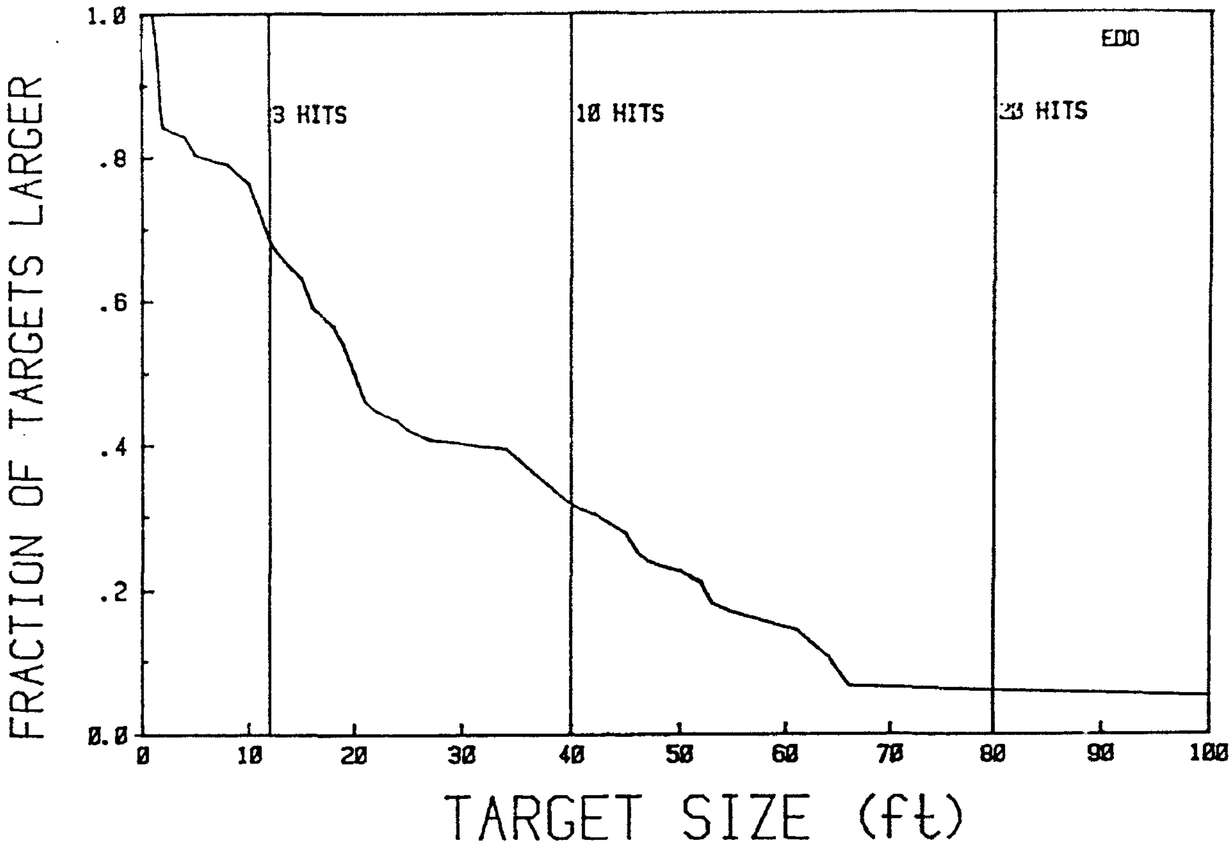
The targets were dealt with individually and sequentially, starting with the largest and concluding with the smallest. The number of targets larger than any given size was divided by the total number of targets. This value was plotted for targets of decreasing size until all were addressed.

Figure 16. Distribution of targets as a function of size.



The targets were dealt with individually and sequentially, starting with the largest and concluding with the smallest. The number of targets larger than any given size was divided by the total number of targets. The value was plotted for targets of decreasing size until all were addressed. The smallest target detectable by the STSS sonar (assuming a 3-ft resolution) in smooth, rough, and scarp terrains is also indicated (by 3, 10, and 20 hits, respectively). Assuming that the distribution of target sizes is relatively independent of terrain, one can infer from the hit indicators what fraction of the number of targets would be detectable in the three terrains for this sonar.

Figure 17. Distribution of targets as a function of size with the smallest target detectable by the STSS sonar in smooth, rough, and scarp terrains indicated.



The targets were dealt with individually and sequentially, starting with the largest and concluding with the smallest. The number of targets larger than any given size was divided by the total number of targets. The value was plotted for targets of decreasing size until all were addressed. The smallest target detectable by the AUSS EDO side-looking sonar (assuming a 4-ft best resolution) in smooth, rough, and scarp terrains is also indicated (by 3, 10, and 20 hits, respectively). Assuming that the distribution of target sizes is relatively independent of terrain, one can infer from the hit indicators what fraction of the number of targets would be detectable in the three terrains for this sonar.

Figure 18. Distribution of targets as a function of size with the smallest target detectable by the AUSS EDO side-looking sonar in smooth, rough, and scarp terrains indicated.

STSS and EDO Side-Looking Sonars

SLSs of particular interest have been the AUSS EDO and the STSS. Figures 19 through 22 give comparative operational characteristics of each of the sonars such as range, maximum speeds, and search rates.

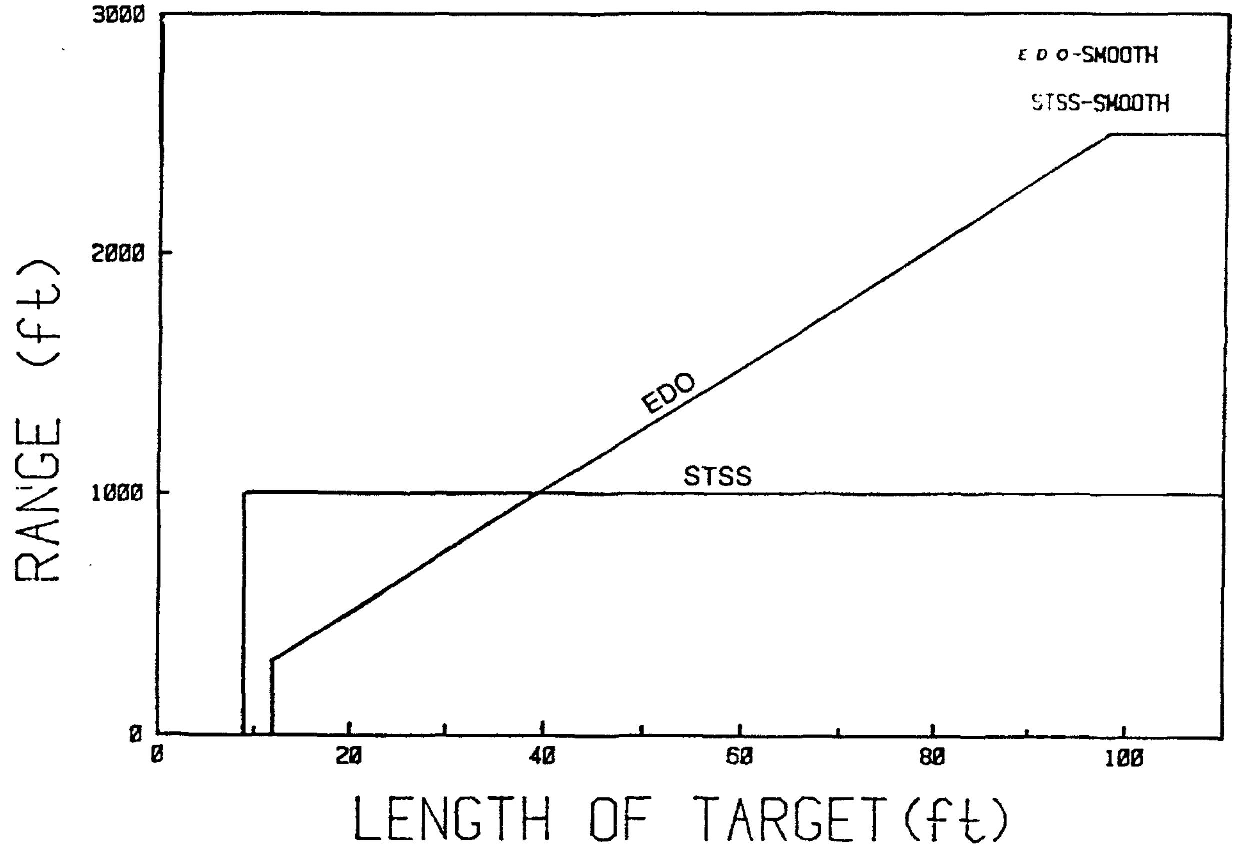
The following brief conclusions were made. Although the STSS sonar is best in theory over the entire range of target size, the STSS sonar in actuality, with a 6-knot speed limit imposed, is only superior up to a 40-foot target size. When the target size is 40 feet or larger, the EDO sonar becomes more effective. This is due to the simple fact that the same speed is employed, but for targets larger than 40 feet the EDO sonar simply has a longer range. Unfortunately, a large fraction of targets falls within the 40-foot and under size range.

Neither sonar performs against targets less than 9 feet in size.

Performance Limits of Electronically Focused Sonars

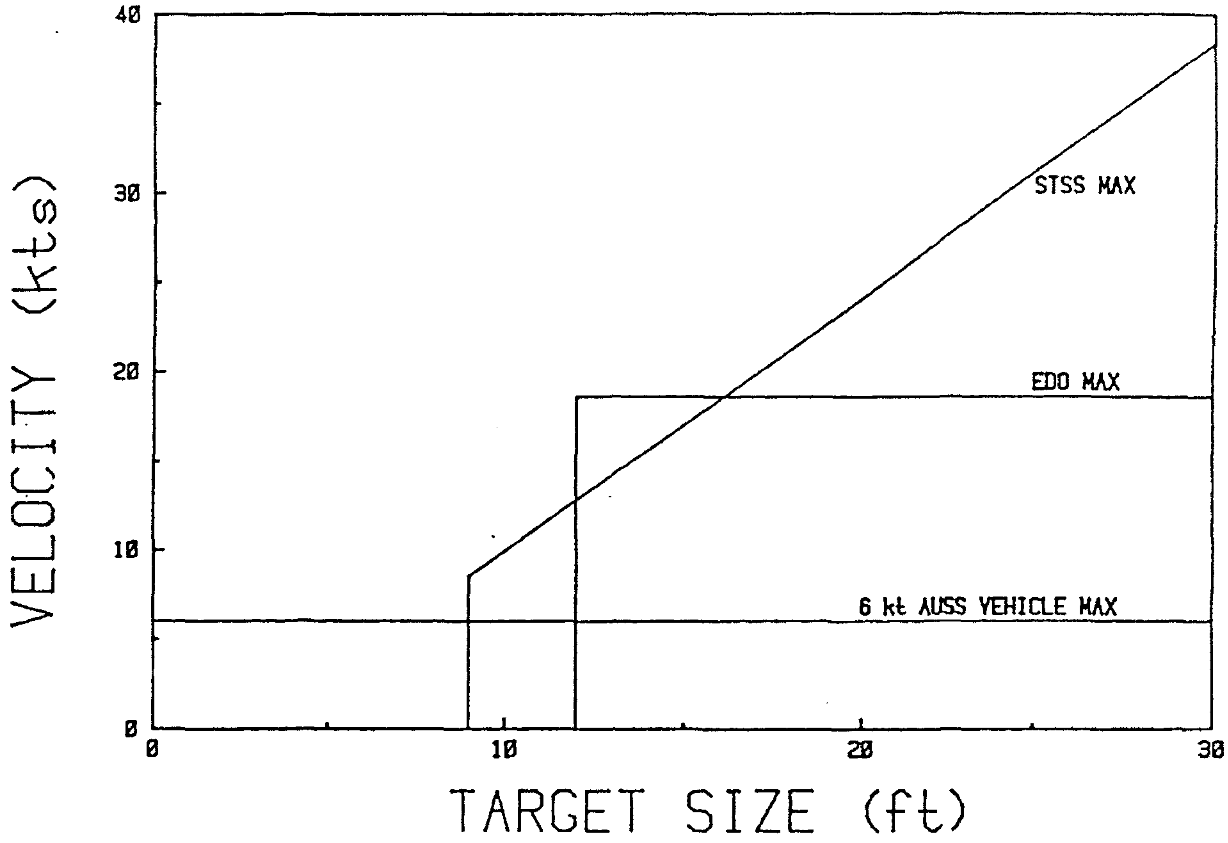
Electronically formed beam sonars in general have also been of interest with regard to maximizing search performance for various target sizes, vehicle sizes, and vehicle speeds. Figures 23 through 25 present the spectrum of multibeam sonars for an AUSS-sized vehicle with a 6-knot maximum speed.

It should be noted that figures 23 and 24 do not depend on vehicle speed and that only the length of the transducer and the resolution required are inputs. In addition to the program that produces the plots as shown, another program will allow a user to design a particular sonar without making any plots. A sample input is shown in figure 26. Resolution and speed are the only inputs on the sample.



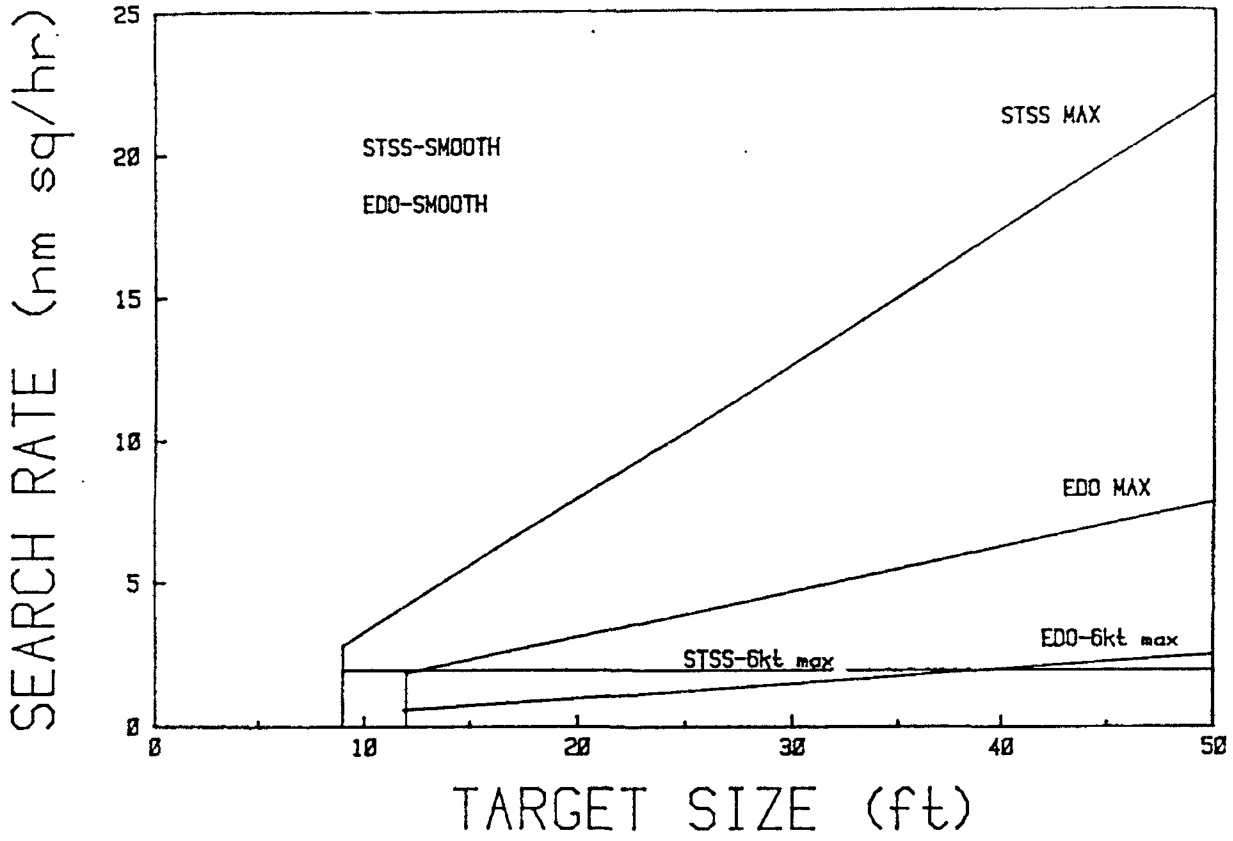
Based on the fact that the STSS sonar has a 3-ft resolution at a range of 0 to 1,000 ft, the minimum target size is 9 ft (using the 3-hit criterion for smooth terrain). Therefore, the STSS sonar can detect any targets larger than 9 feet in the 0- to 1,000-ft range. The EDO sonar is not an electronically formed beam sonar; therefore, its resolution is a function of range, with a minimum of 4 ft. It has a maximum range of 2,500 ft. Therefore, the EDO sonars detection capability decreases linearly from a 12-ft target at short range to about a 95-ft target at the maximum range of 2,500 ft. This graph allows one to select the appropriate range scale for detecting a target of a given size.

Figure 19. Range as a function of target size for the STSS and EDO side-looking sonars.



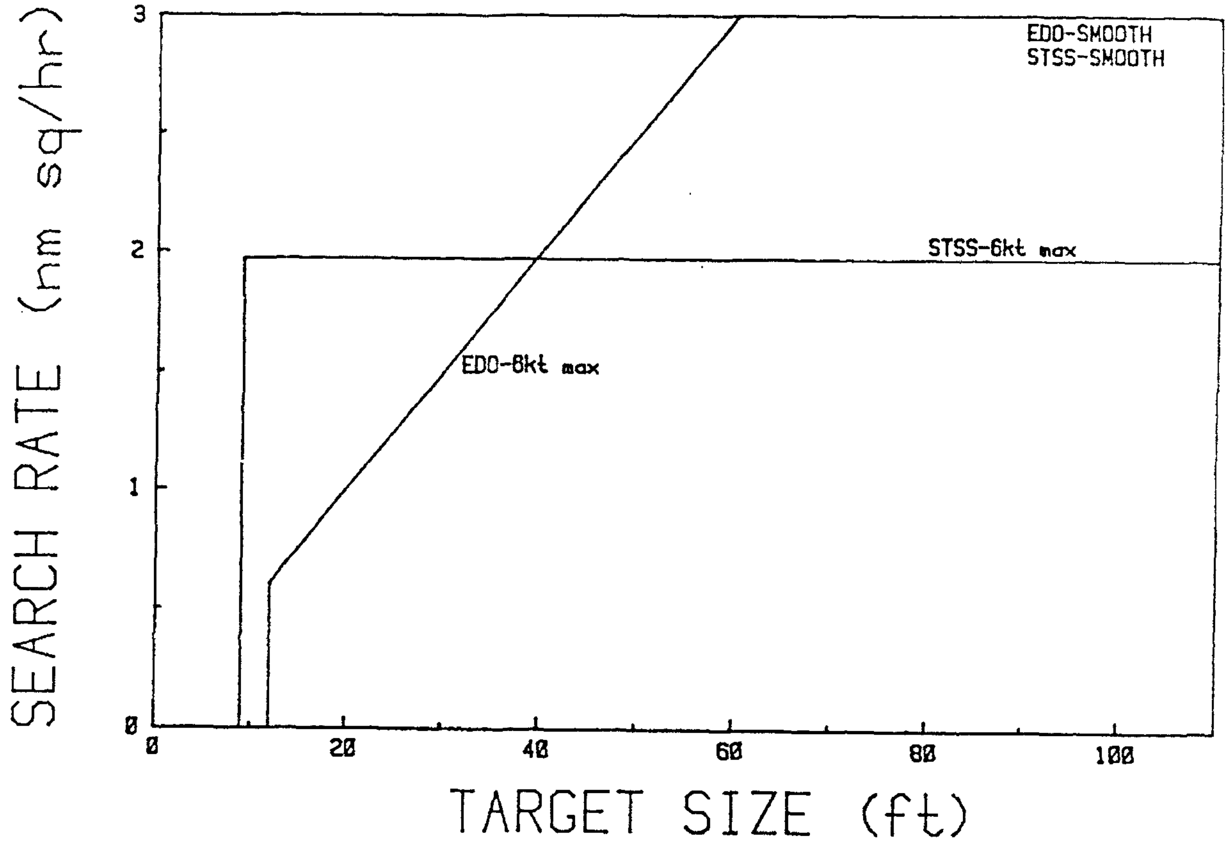
Once the range has been determined from figure 19, a velocity can also be calculated based on the target size. Since three hits must be placed on the target, the distance between pings can be calculated as one-third the target size. Since the range is known from figure 19, the time between pings can also be known because it is twice the range divided by the speed of sound. With these two numbers, the maximum velocity is determined by simply dividing the distance per ping by the time per ping. This value is plotted versus target size in this figure.

Figure 20. Maximum velocities at which STSS and EDO side-looking sonars can be operated as functions of target size.



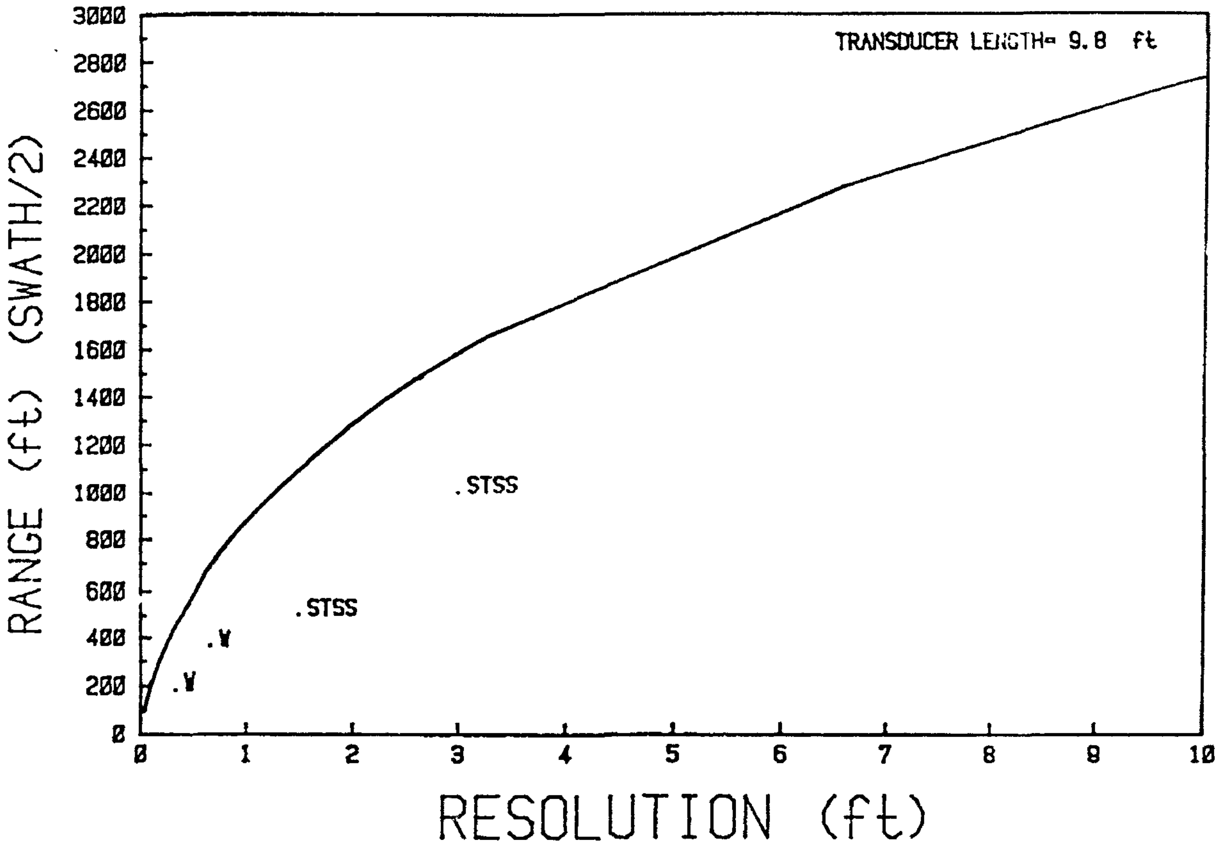
By the use of the ranges shown in figure 19 and the velocities shown in figure 20, the resulting sensor search rates can be calculated. These are plotted in figures 21 and 22. In addition, the search rates are plotted with a 6-knot speed limit imposed. It can be seen that, although the STSS sonar is best in theory over the entire range of target size, the STSS sonar in actuality, with a 6-knot speed limit imposed, is only superior up to a 40-ft target size. When the target size is 40 ft or larger, the EDO sonar becomes more effective. This is due to the simple fact that the same speed is employed, but for targets larger than 40 ft, the EDO sonar simply has a longer range.

Figure 21. Search rates as functions of target size for STSS and EDO side-looking sonars.



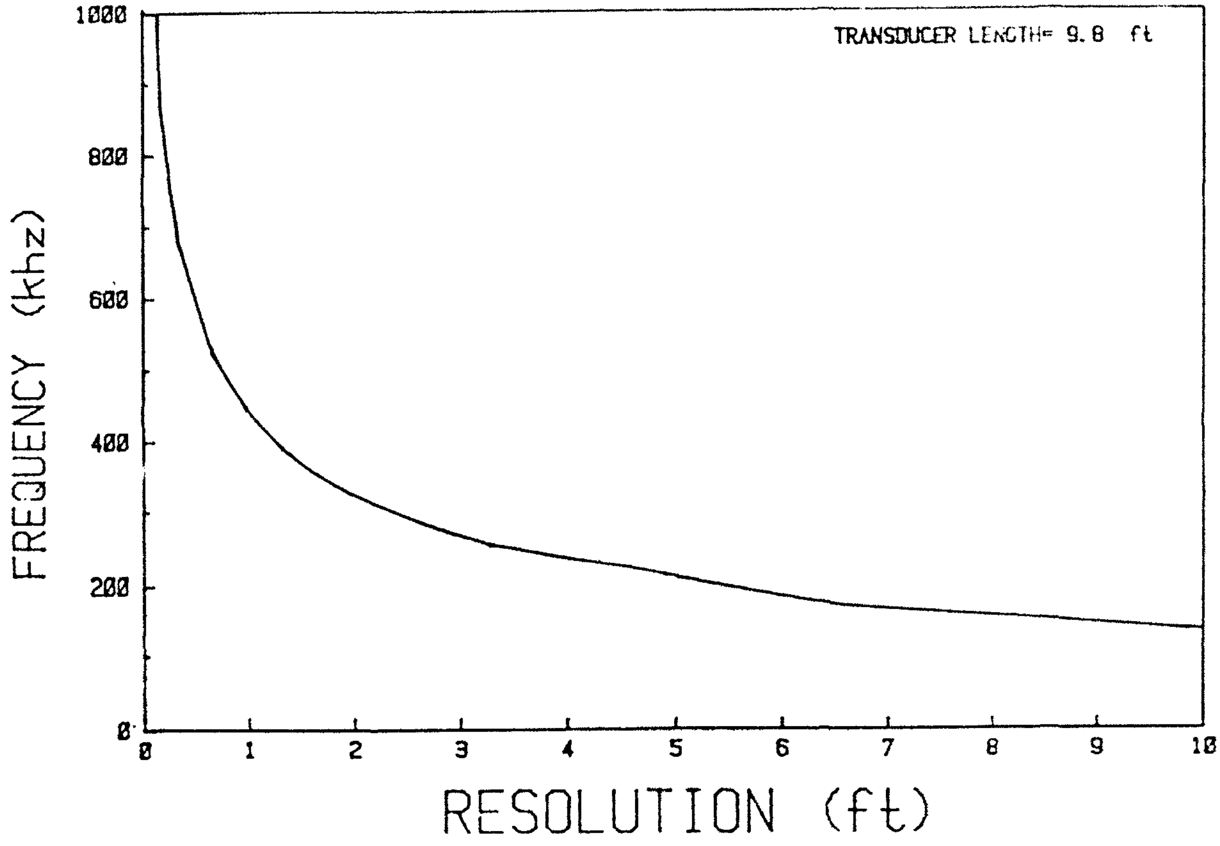
By the use of the ranges shown in figure 19 and the velocities shown in figure 20, the resulting sensor search rates can be calculated. These are plotted in figures 21 and 22. In addition, the search rates are plotted with a 6-knot speed limit imposed. It can be seen that, although the STSS sonar is best in theory over the entire range of target size, the STSS sonar in actuality, with a 6-knot speed limit imposed, is only superior up to a 40-ft target size. When the target size is 40 ft or larger, the EDO sonar becomes more effective. This is due to the simple fact that the same speed is employed, but for targets larger than 40 ft the EDO sonar simply has a longer range.

Figure 22. Search rates as functions of target size (expanded scale).



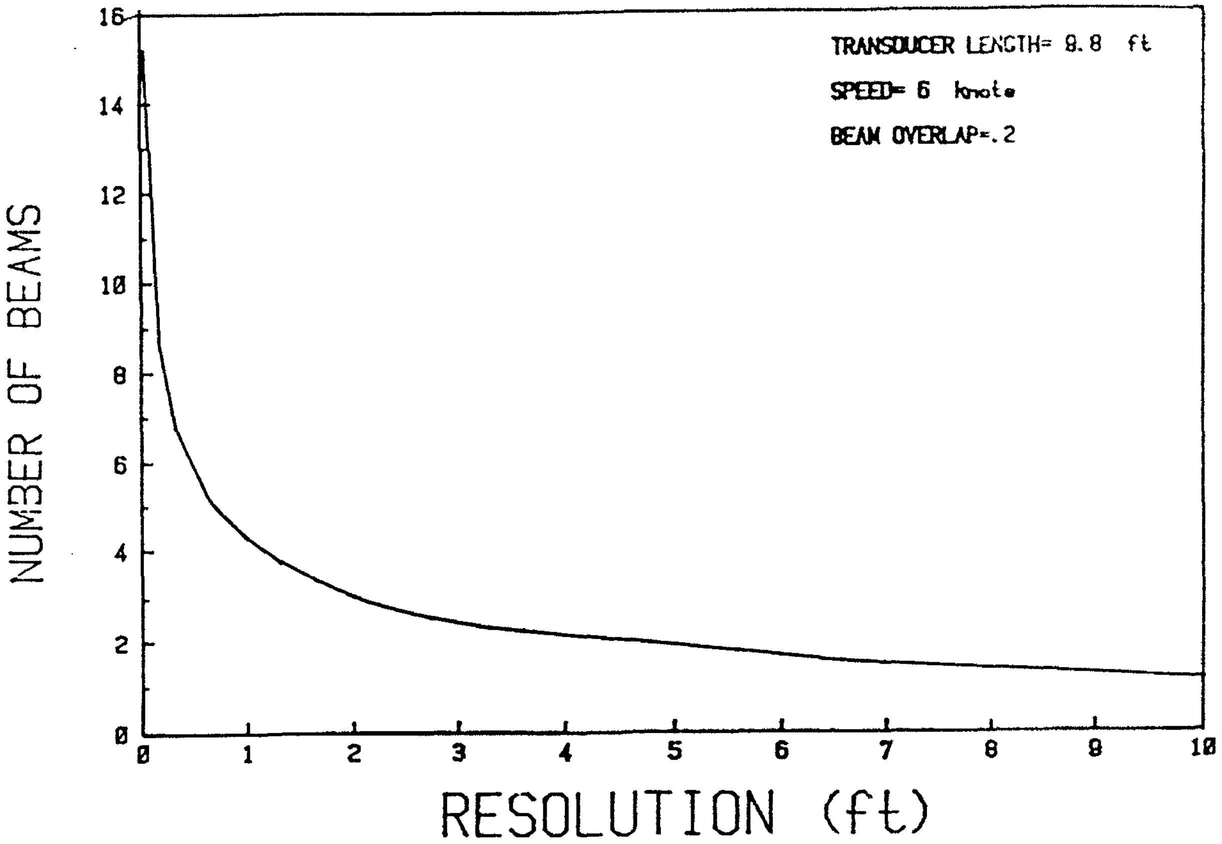
If the equations in the NOSC Contractor Report 141 (September 1982) are solved in great detail, a sonar can be designed for a given resolution requirement. Then a maximum range can be determined. The resolution and maximum range are plotted for a family of sonars with a transducer length of 9.8 ft (a size chosen on the basis of the length of AUSS). This curve is the theoretical maximum performance and all designs must fall beneath it. Four Westinghouse sonar designs are plotted as points of reference. Vehicle speed is not a factor here.

Figure 23. Theoretical maximum sonar performance with a family of Westinghouse sonars noted.



This figure indicates the operating frequencies for the sonar graphically depicted in figure 23. There is no dependency on vehicle speed.

Figure 24. Operating frequencies for the four Westinghouse sonar designs.



If a maximum speed of 6 knots is included as a system parameter, then the required number of beams for the family of sonars depicted in figures 23 and 24 can be computed for a given beam overlap (in this case the overlap = 0.2).

Figure 25. Required number of beams for the Westinghouse family of sonars.

RESOLUTION = 0.05 ft
SPEED = 6 knots
MAX RANGE (SWATH/2) = 131 ft
FREQUENCY = 1333 kHz
NUMBER OF BEAMS = 14 ROUNDED FROM 13.49
MAX SENSOR SEARCH RATE = 0.2596 nmi^2/hr

Figure 26. Sample output from a sonar design program.

FASS ANALYSIS RESULTS

Initial Results

Background. Originally, the FASS analysis was to examine a baseline AUSS and other multiple vehicle FASS conceptions with promise. The baseline AUSS was to have a sensor system that was deemed "best." Consequently, an analysis was carried out first on a single AUSS vehicle with various sensors, the best of that would become the baseline AUSS. The candidate FASS conceptions selected consisted of a system employing two AUSS-like vehicles, a system employing four AUSS-like vehicles, a system employing 10 autonomous photo vehicles, and a system employing 10 autonomous sonar vehicles. These systems were to be analyzed for a range of target sizes and for smooth, rough, and scarp terrain.

Important Characteristics. The most significant characteristics of a search system are the number of vehicles employed, the sensor swath, the system speed, and the resolution or minimum target that can be detected as a target. The systems considered in the first phase of the analysis, i.e., the selection of the baseline AUSS, are listed in table 11 along with these parameters.

Single-Vehicle Performance. The systems listed in table 11 were analyzed for targets ranging from 1 to 100 feet in size and for three false target densities (1, 10, and 100 false targets/square nautical mile). Respectively, this corresponds to smooth, rough, and scarp terrain in the analysis. The dependent variable was mean time to detection or mission time depending on one's preference. The results are plotted on a semilog format in figures 27, 28, and 29. Since the three scenarios do not occur with equal frequency in the field, a weighted average of the three scenarios was also calculated and plotted in figure 30. The weighting was 0.8 for smooth, 0.1 for rough, and 0.1 for scarp, since these were the percentages of searches of each type that the Vought (1982) study found to be historically correct.

Minimum Target Size. Initially, no minimum target detection criterion was established and, consequently, the above systems were all analyzed. Subsequently, a 1-meter (3-foot) target was selected as a minimum detection criterion and those systems unable to detect this size target were rejected. Therefore, the EDO SLS and the STSS SLS have been eliminated. From figures 27 through 30 it can also be seen that the EDO scanning sonar and the Straza SWAP sonar systems should also be eliminated since the mean time to detection is unreasonably high at the small target end of the graphs. That leaves us with a high-resolution sonar referred to as WI (8-inch resolution mode) and W2 (4-inch resolution mode) operating in the W2 mode and the photo system (which is not used on the AUSS vehicle). Consequently, W2 was selected as the AUSS baseline system.

Table 11. Vehicle parameters for AUSS baseline selection process.

NAME	SWATH* (FT)	SPEED (KN)	MINIMUM TARGET SIZE (FT)
EDO SCAN	5,000	6	10
STRAZA SWAP	980	6	15
EDO SLS	5,000	6	40
STSS SLS	2,000	6	30
W1	720	6	7
W2	360	6	3
PHOTO	40	14	0.1
AUTO SLS/PHOTO	360/40	7.5	3

*Maximum

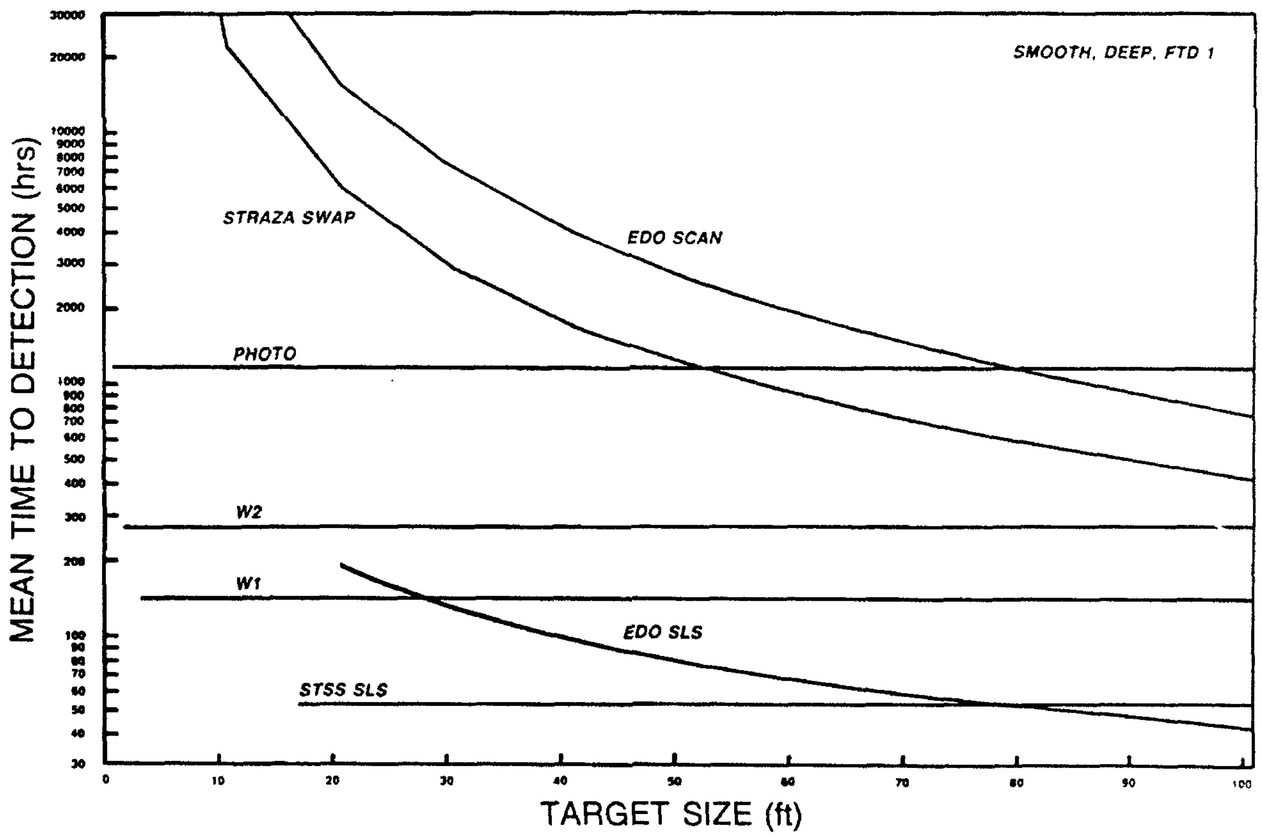

SINGLE VEHICLES

Figure 27. Single-vehicle mean time to detection for smooth terrain. (1 false target per square nautical mile).

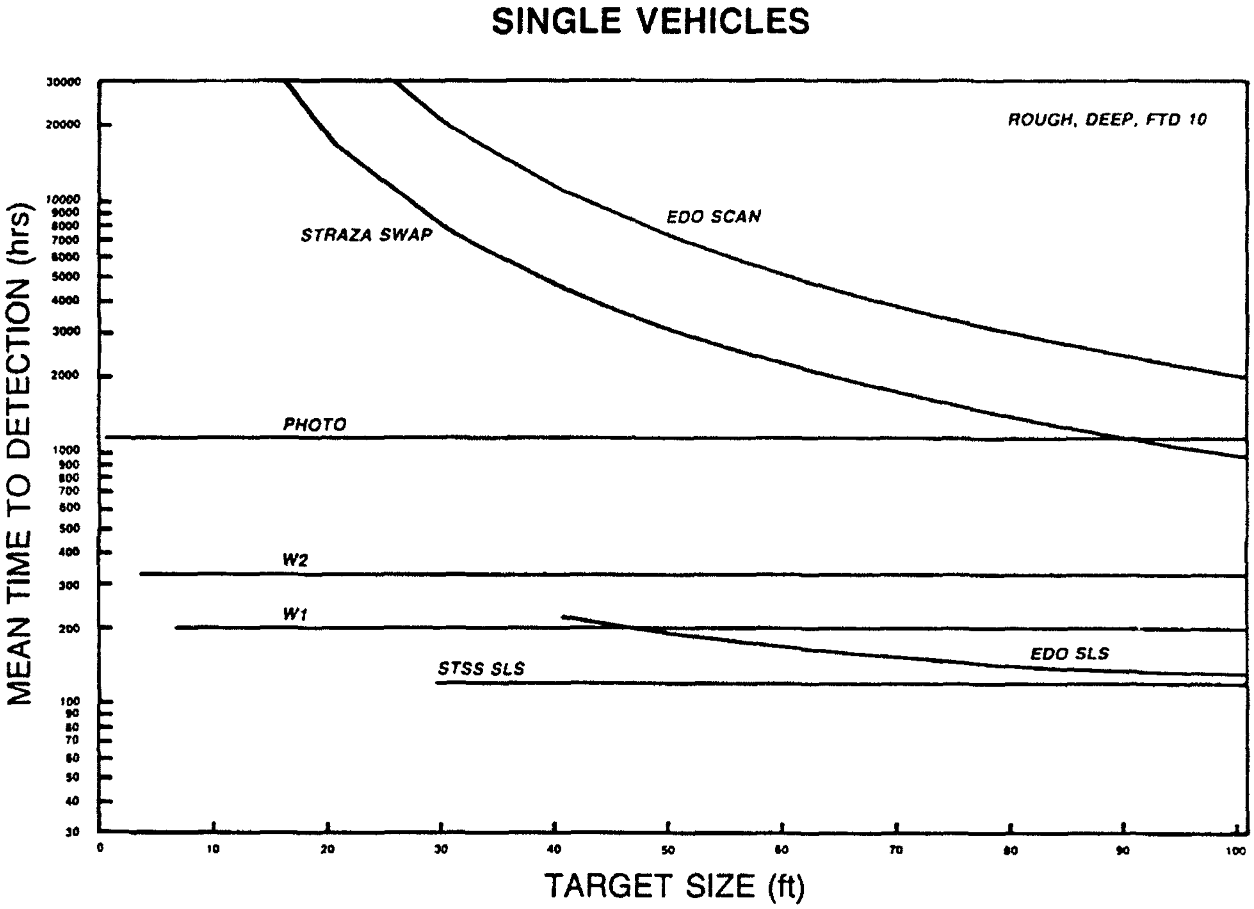


Figure 28. Single-vehicle mean time to detection for rough terrain (10 false targets per square nautical mile).

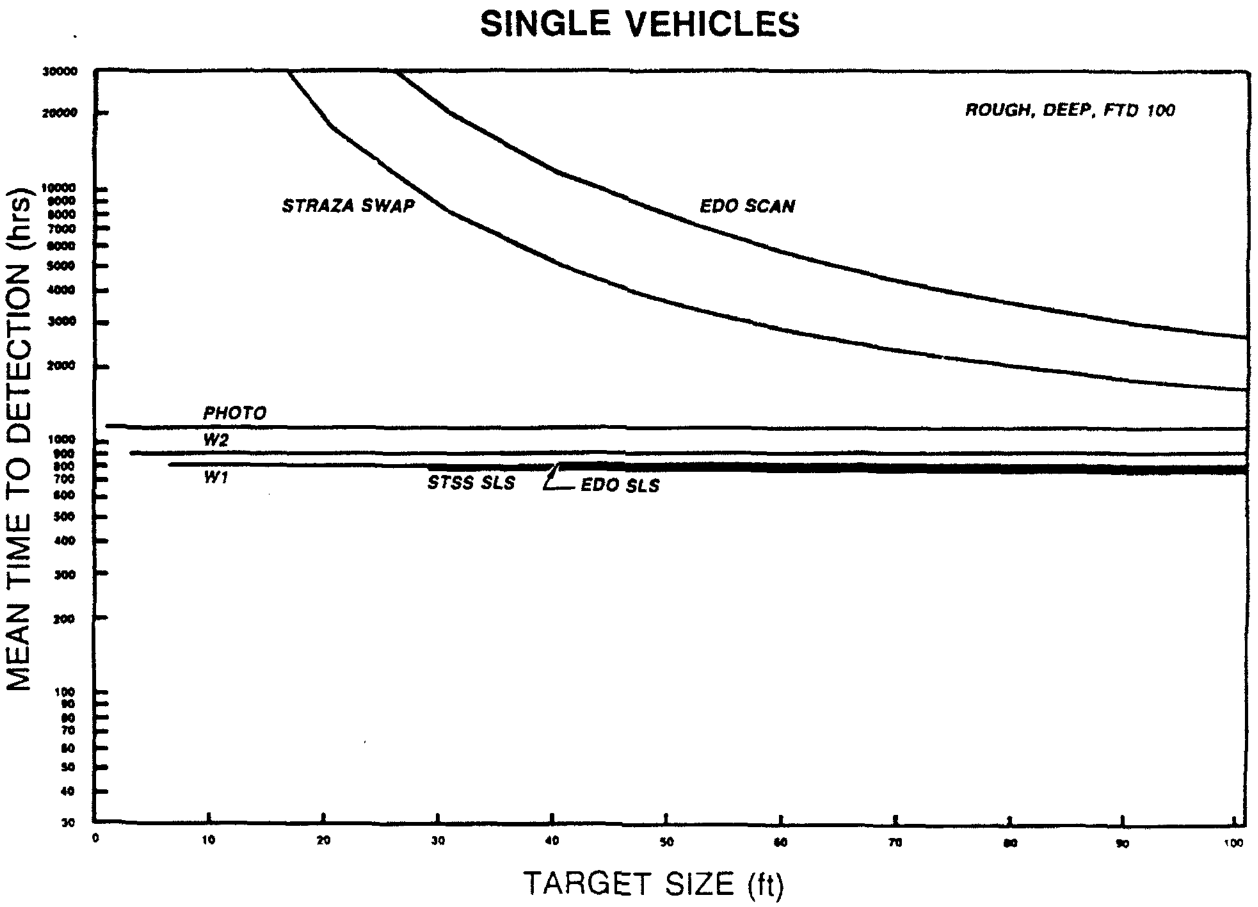


Figure 29. Single-vehicle mean time to detection for scarp terrain (100 false targets per square nautical mile).

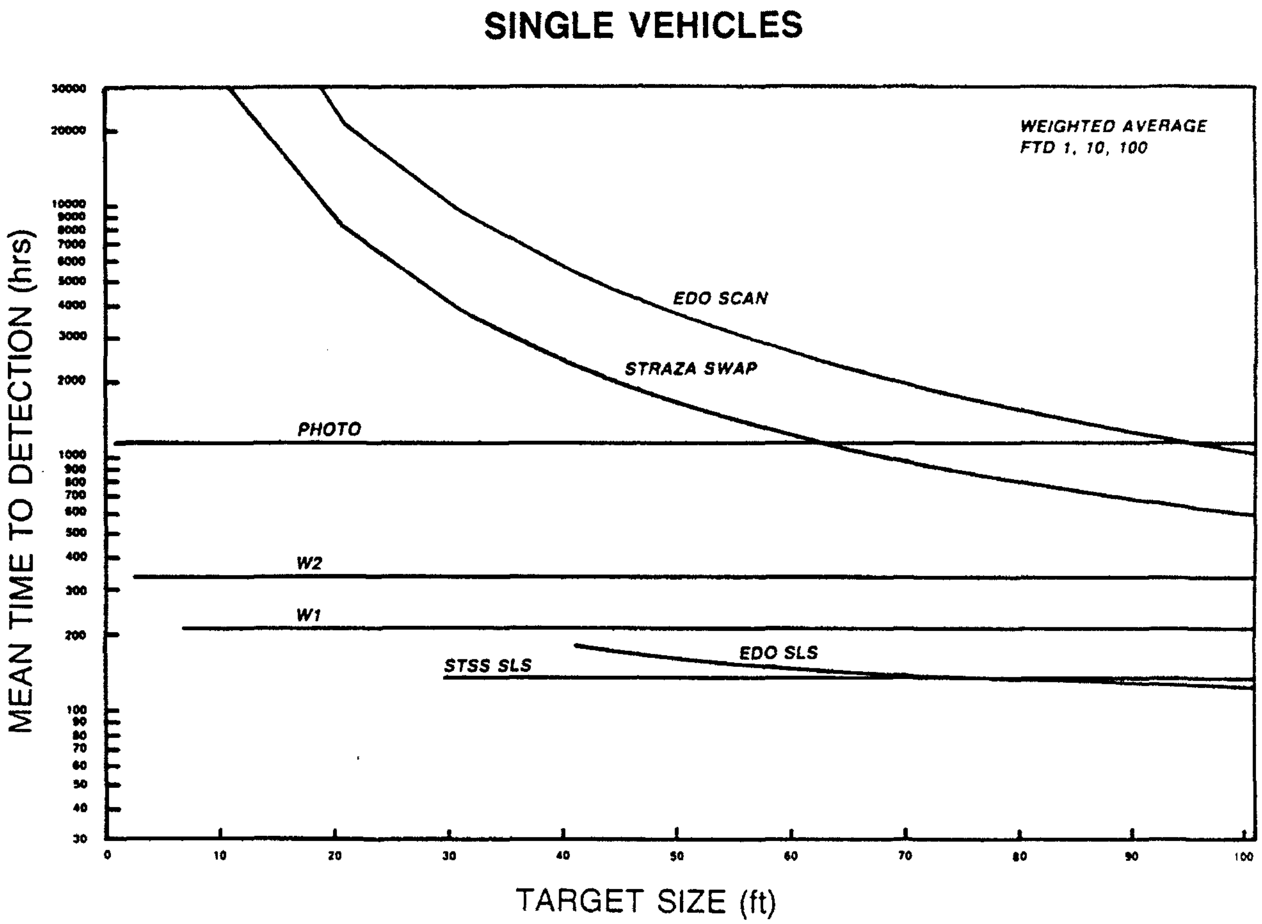


Figure 30. A Weighted average of the three scenarios (smooth, rough, and scarp terrains).

Data Rate Considerations. With W2 established as the baseline, calculations indicate that the data rate is about 54 times the currently available 4,800 bits/second on AUSS (assuming 8 bits/pixel and a vehicle speed of 6 knots). To bring the data rate back down to 4,800 bits/second, the vehicle speed must be slowed down to 0.11 knot. When this speed reduction is incorporated into the calculations, the weighted average performance results in the plot shown in figure 31. The single vehicle photo system is shown for reference.

At this point in the analysis, an additional FASS conception became obvious. This new conception consisted of combining the high-resolution sonar with the idea of the autonomous photo vehicle. The idea here was to eliminate the data rate problem by doing postdive data analysis. In addition, more vehicles of this type can be put aboard the ship.

The final four FASS conceptions and their respective input values to the analysis are listed in table 12.

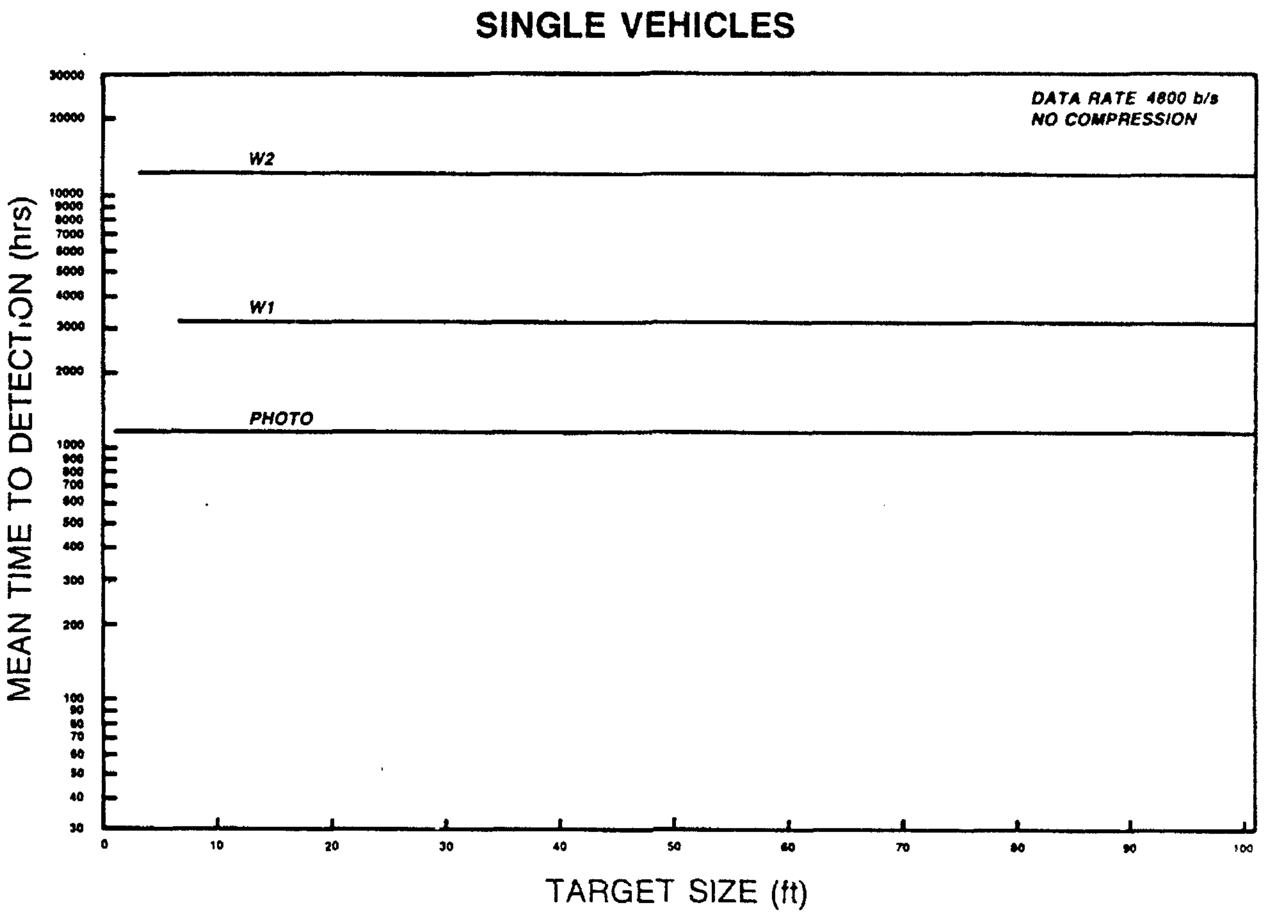


Figure 31. Weighted average performance incorporating a vehicle speed reduction to reduce data rate.

Table 12. Inputs to model.

SYSTEM	BOTTOM TIME (HR)	FALSE TARGET DENSITY #/SQUARE NMI	NAV ERROR (FT)	DESIRED DETECT PROB	SENSOR SWATH (FT)	SEARCH SPEED (KN)	DIST BETWEEN TURN (NMI)	BREAK TIME (HR)	SENSOR DETECT PROB	NUMBER OF VEHICLES
AUTO SLS/PHOTO	6	1,10,100	10	0.9	360	7.5	1.5	1.25	0.9	10
AUTO PHOTO	2.5	1,10,100	10	0.9	40	14.0	NA	1.25	1.0	10
AUSS HIRES SLS	10	1,10,100	30	0.9	360	6.0	10	2.75	0.9	2.4

Effect of Number of Vehicles. If a system of vehicles can be deployed and recovered in a manner such that the vehicles do not affect the operation of each other (i.e., if they can be considered independent systems) and if the initial startup time is small compared to the total mission (i.e., if there are more than two or three launch cycles for the system), then the system performance will be enhanced in direct proportion to the number of vehicles employed. This is the case for the autonomous photo system and the two AUSS-like conceptions as well as the autonomous sonar vehicle, if adjustments are made to include the delayed evaluation cycle. The results of the multiple vehicle analysis are summarized in table 13.

Table 13. Summary of results.

MEAN TIME* SYSTEM	ONE VEHICLE MEAN TIME* (HOURS)	MULTIVEHICLE (HOURS)
AUTO SLS/PHOTO	341	34
AUTO PHTO	1,157	116
AUSS HIRES SLS (2)	12,325	6,162
AUSS HIRES SLS (4)	12,325	3,081

*Weighted average for all scenarios considered.

Conclusions and Recommendations. The highest performance system is the autonomous sonar vehicle system due to its wide swath, high speed, large number of vehicles, and the absence of a data rate limitation. It should be noted that the autonomous photo vehicle system is a less expensive and simpler system concept than the others, and with an improvement in swath it could be competitive. It is suggested that a swath increase to 100 feet or more would bring this system up to par with the autonomous sonar vehicle system due to the aforementioned trade-offs, even though the search times are slightly inferior. Further investigation of photo swath width improvement is highly recommended. In a like manner, data compression should be investigated thoroughly before discounting the multi-AUSS systems since they could, in theory, be brought to within a factor of 2.5 (for the four-vehicle system) of the autonomous vehicle system if data rate were not a limitation.

Analysis of Alternative Autonomous FASS Vehicles

Background. The FASS analysis previously examined the performance of four FASS candidate systems. The two systems involving autonomous vehicles, namely the photo system and the SLS system, were analyzed with a certain set of input parameters. It is the purpose of this subsection to revisit that analysis with certain changes incorporated.

In the case of the SLS system, a change in the overlap from that which corresponds to 0.9 probability of detection (in the previous analysis this was a 14% overlap) to a 50% overlap. The thinking here is to to be sure to compensate for the lower probability of detection found directly beneath the SLS. When this is done, naturally the calculated performance is somewhat degraded in terms of mean time to detection. Specifically, the value for the mean time to detection goes from the previous value of 34 hours to a value of 49 hours. However, it should be noted that the probability of detection is then calculated to be 0.98.

In the case of the photo system, a different parameter was changed, namely the swath width. Some calculations indicated that a swath width of 100 feet is feasible; this value was tried instead of the previous value of 40 feet. The mean time to detection decreased from 116 hours to 36 hours. The resulting probability of detection with no overlap is 0.95.

One last change was tried on the photo system. The speed and endurance were changed from 14 knots and 2.5 hours to 7.5 knots and 6 hours, respectively. These values are somewhat more conservative and would also match the requirements of the SLS under consideration should a combination of sensors be selected. The result was a mean time to detection of 55 hours if the 100-foot swath width was retained with a probability of detection of 0.95.

Conclusions. All of the autonomous vehicle systems perform well and the minor performance variations shown here should not be a large factor in the selection of one or the other. If it can be shown that the photo swath width of 100 feet is realistic, then the simplicity of the system would seem to make it the clear choice. The results are summarized in table 14.

Table 14. Summary of analysis results for the autonomous multivehicle systems.

SYSTEM	CASE 1 (Optimistic Assumptions)		CASE 2 (Conservative Assumptions)	
AUTO SLS/PHOTO	OVERLAP 14%	MTD* 34	OVERLAP 50%	MTD* 49
AUTO PHOTO	SWATH 40 ft	MTD* 116	SWATH 100 ft	MTD 36
AUTO PHOTO	SPEED/ ENDURANCE 14 kt 2.5 hr	MTD 36	SPEED/ ENDURANCE 7.5 kt 6 hr	MTD 55

*Mean Time to Detection in hours

REFERENCE

Vought Corporation. September 1982. "Operational and Logistics Analyses for Candidate Deep Ocean Systems for the Advanced Deep Ocean Search System (AUSS). NOSC Contractor Report 141, AD-B069238L.

TECHNOLOGY ASSESSMENT

One of major stages of the feasibility phase of the FASS project was technology assessment. In this stage, critical areas of key technologies were evaluated in terms of application to multiple vehicle undersea search systems. Eight specific technologies were assessed:

1. Information Processing
2. Vehicle Options
3. Command and Control Options
4. Applied Artificial Intelligence (AI)
5. Data Communications
6. Navigation Options
7. Sensor Candidates
8. Specialty Engineering.

For each of the technologies, the following items will be addressed:

1. The scope of the task
2. A summary of results and/or conclusions as well as selected illustrations
3. References to appropriate memoranda.

INFORMATION PROCESSING

Information Processing Task

In assessing what information processing options will meet project requirements, the sensor, navigation, system status, and other information that the FASS operator will need was inventoried. The characteristics of these data were determined and a preliminary assessment of the amounts and types of processing likely to be required was accomplished. Particular attention was paid to how the amount of data actually transmitted from the undersea search area to the surface can be reduced (at the surface and/or on the vehicles) through time sampling, operator selection, or other acceptable methods. Alternative methods of displaying and recording the information were reviewed for both realtime monitoring and postoperation mission analysis. Methods for enhancing the displayed data, specifically that produced by SLS and sector-scanning sonars, were investigated to explore potential benefits for FASS operation. Finally, system architectures that incorporate the recommended information processing and display features were proposed.

FASS Information Processing: Design Constraints, Issues, and Goals

Acoustic Telemetry Bandwidth Constraint. Telemetry concepts ranging from a fiber-optic cable link to an acoustically coupled heavy clump cable link have been proposed for FASS underwater telemetry. However, one of the goals of FASS (and AUSS) is to delete the cable. The most attractive solution to the cableless underwater telemetry problem is acoustic telemetry. The advantages and disadvantages of underwater acoustic telemetry systems are well documented and will not be repeated in this subsection. It shall be assumed that any FASS concept that requires a near realtime communication capability shall use acoustic telemetry. The most advanced acoustic telemetry equipment available is the AUSS (or BUMP) unit. These units provide the capability for half-duplex communication at data rates up to 4,800 bits per second. It is assumed that FASS will use similar or identical units. As such, a limited amount of data may be transmitted per unit of time between the vehicle and the surface command control console. This limitation imposes the most severe constraint on the transmission of video and sonar data (uplink channel). Other vehicle sensors' (housekeeping and search) data and command data to the vehicle (downlink channel) do not require a significant portion of the available communication channel bandwidth and thus are not as severely constrained.

Digital versus Analog Processing Issue. Digital information processing in general offers several advantages over analog. First, and most important, digital techniques offer schemes that use the available bandwidth more efficiently in bandwidth-limited communication systems. Second, data handling is done more efficiently with digital techniques and there are fewer calibration problems with digital circuits. Moreover, digital techniques can handle complex signal processing and system control algorithms with greater ease. With these advantages in mind, it is a logical conclusion that information processing for FASS should be performed by using digital processors and techniques. However, a problem arises in that acoustic and optical sensors are analog and therefore require A/D conversion prior to interface with a digital processor. Also, human operators prefer analog information displays (over memoryless digital displays) so as to observe trends and patterns. Complicating this problem is the fact that off-the-shelf search sensors (of the type used on AUSS) are designed for realtime analog operation and control, not near realtime via a digital control processor (as found in robotic systems).

Software versus Hardware Interface Issue. Interfacing microprocessors to external data sources ink-controllers is a primary FASS information processing task. Direct connection between the microprocessors and external sources is desirable. Even more desirable is to be able to design from the beginning the external sources and their microprocessor control systems (hardware and software). However, this is not always possible.

There is a notion, held particularly by the inexperienced designer, that interfaces are best accomplished via software using "cheap hardware." Hardware is inexpensive, but more than one design effort has met with failure due to software that cost more (much more) than expected. Before embarking on the path of custom-software-dependent interfaces, alternative approaches should be considered.

One possible interface design approach that offers the advantages of both inexpensive hardware and a reduction in software development risks is the intelligent interface. An intelligent interface has its own microcomputer and onboard machine language programs in ROM. These intelligent interfaces can be assigned the repetitious control and processing tasks thereby relieving the operating system of these time-consuming and complex tasks. A side benefit of using intelligent interfaces is that the required custom system software can often be written in a high-level language.

Design Goals. The primary FASS information processing design goal is to make best use of the available channel bandwidth. This goal will be accomplished by the following:

1. Ordering the data produced by sources in accordance with the importance of the data at the destination
2. Either deleting or compacting the less significant data prior to transmission.
3. Provide a flexible data format for video and sonar data to allow for configuration changes based on specific mission requirements.
4. Separate the information-processing functions into modules with defined interfaces (software and hardware) to allow for the rational inclusion of enhancements.
5. Perform as many as possible information processing tasks using digital processors.
6. Use intelligent interfaces to connect external sources to the main system processor.

Summary of Results

Figures 32 through 39 summarize video, sonar, and 35-mm photographic data. Tables 15 through 17 summarize characteristics of FASS search sensor options, external communications options, and data-storage options.

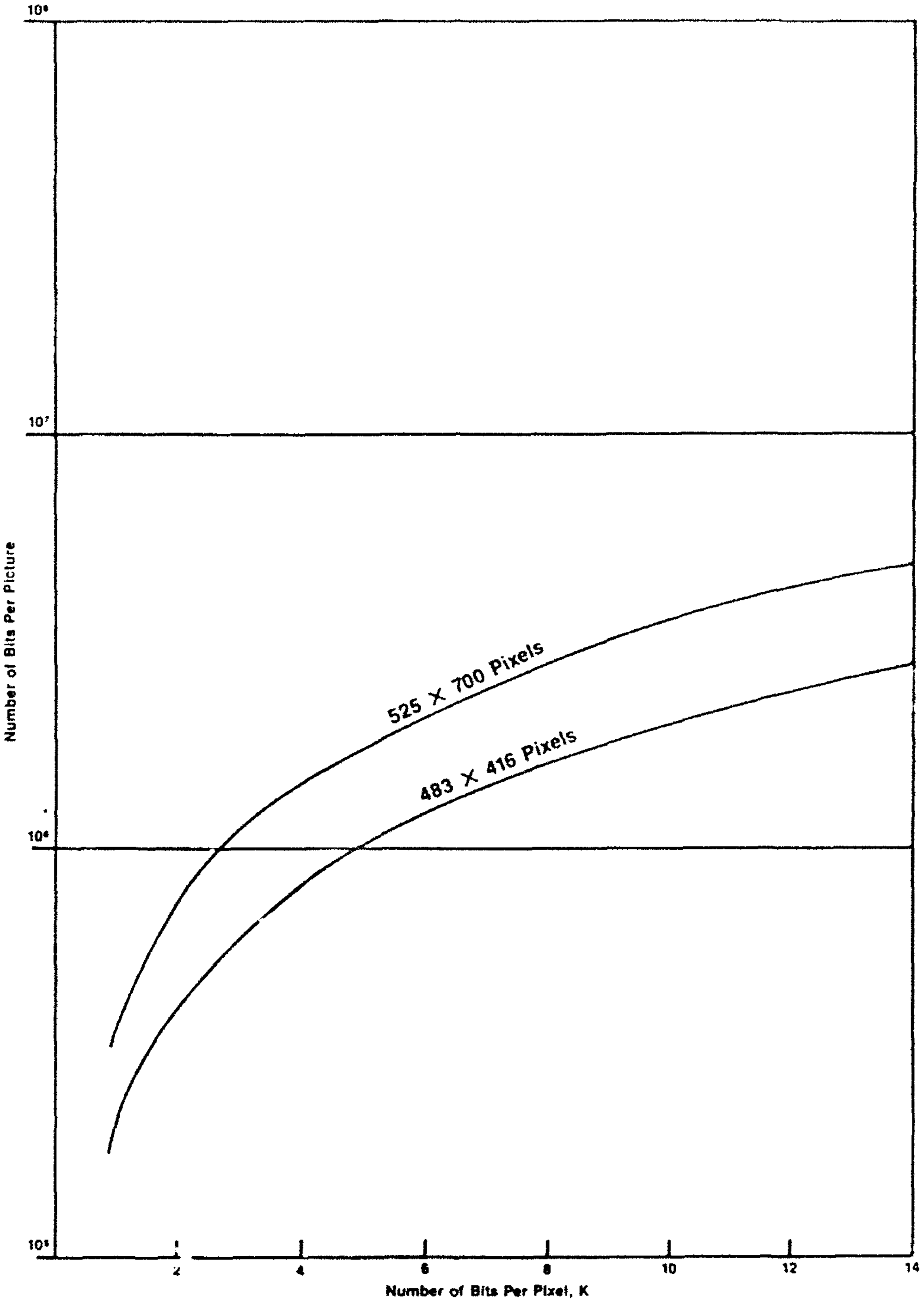


Figure 32. Bits per picture as a function of bits per pixel for video imagery.

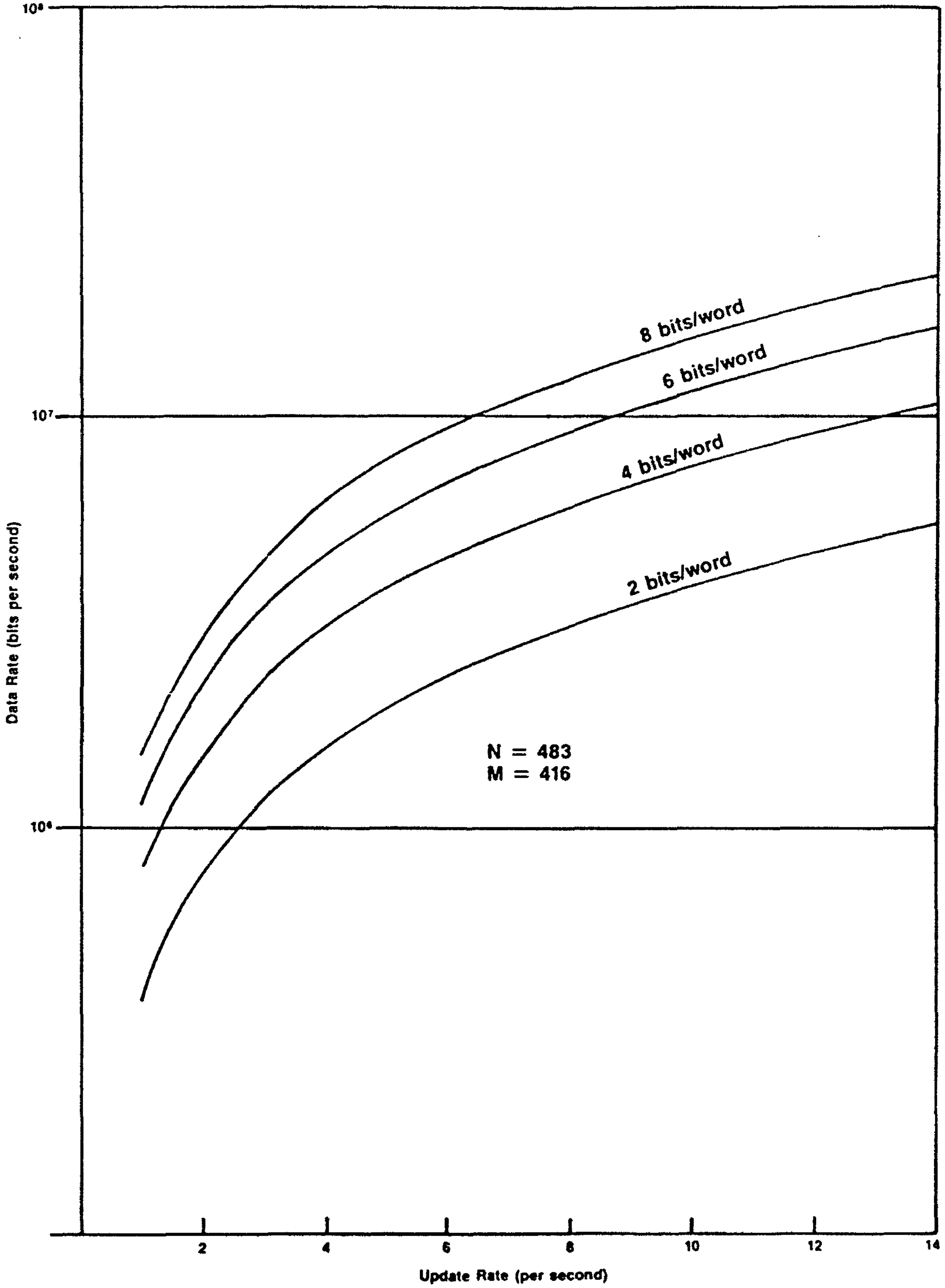


Figure 33. Data rate for video transmission as a function of update rate.

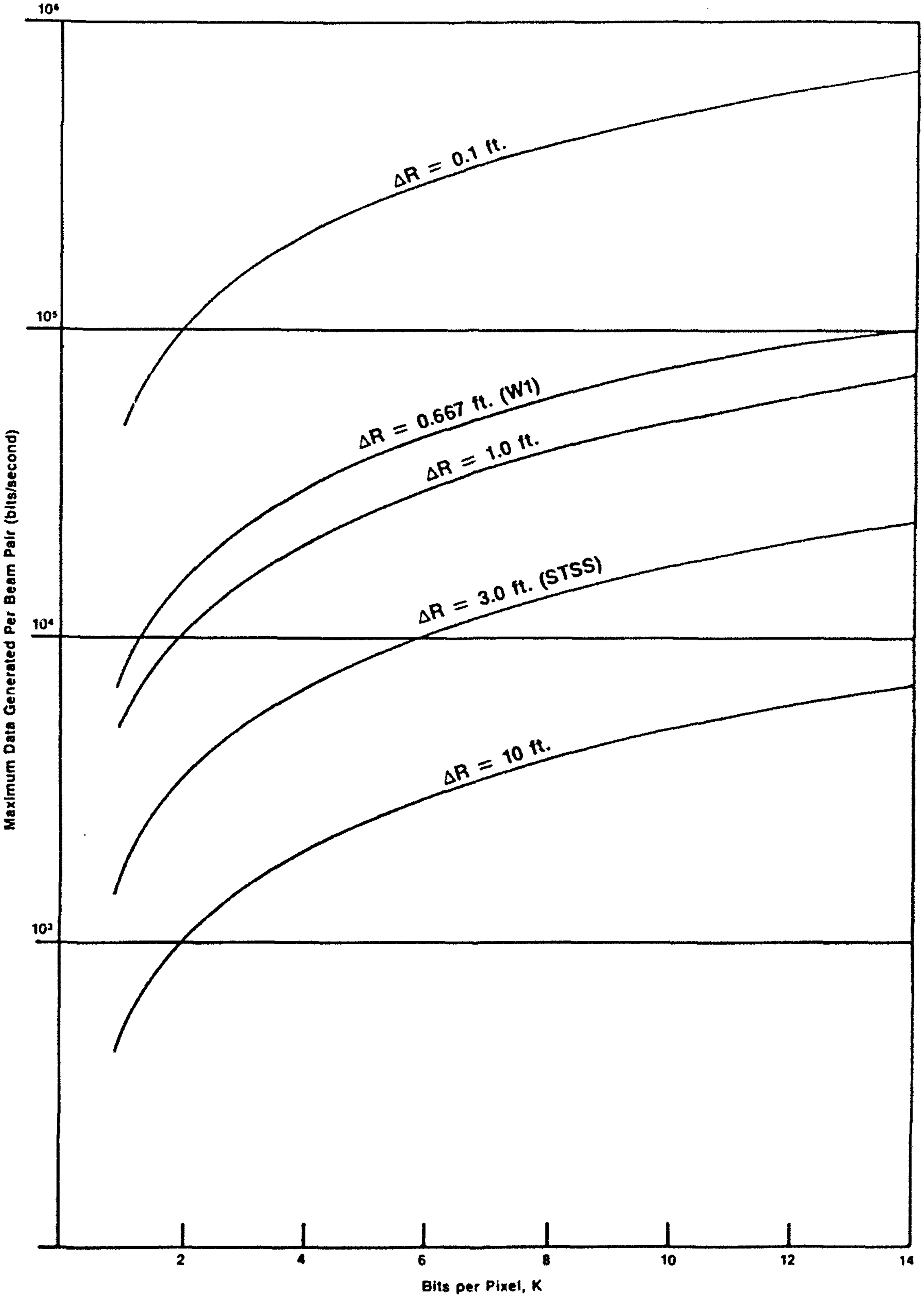


Figure 34. Maximum data generation rate for side-looking sonars.

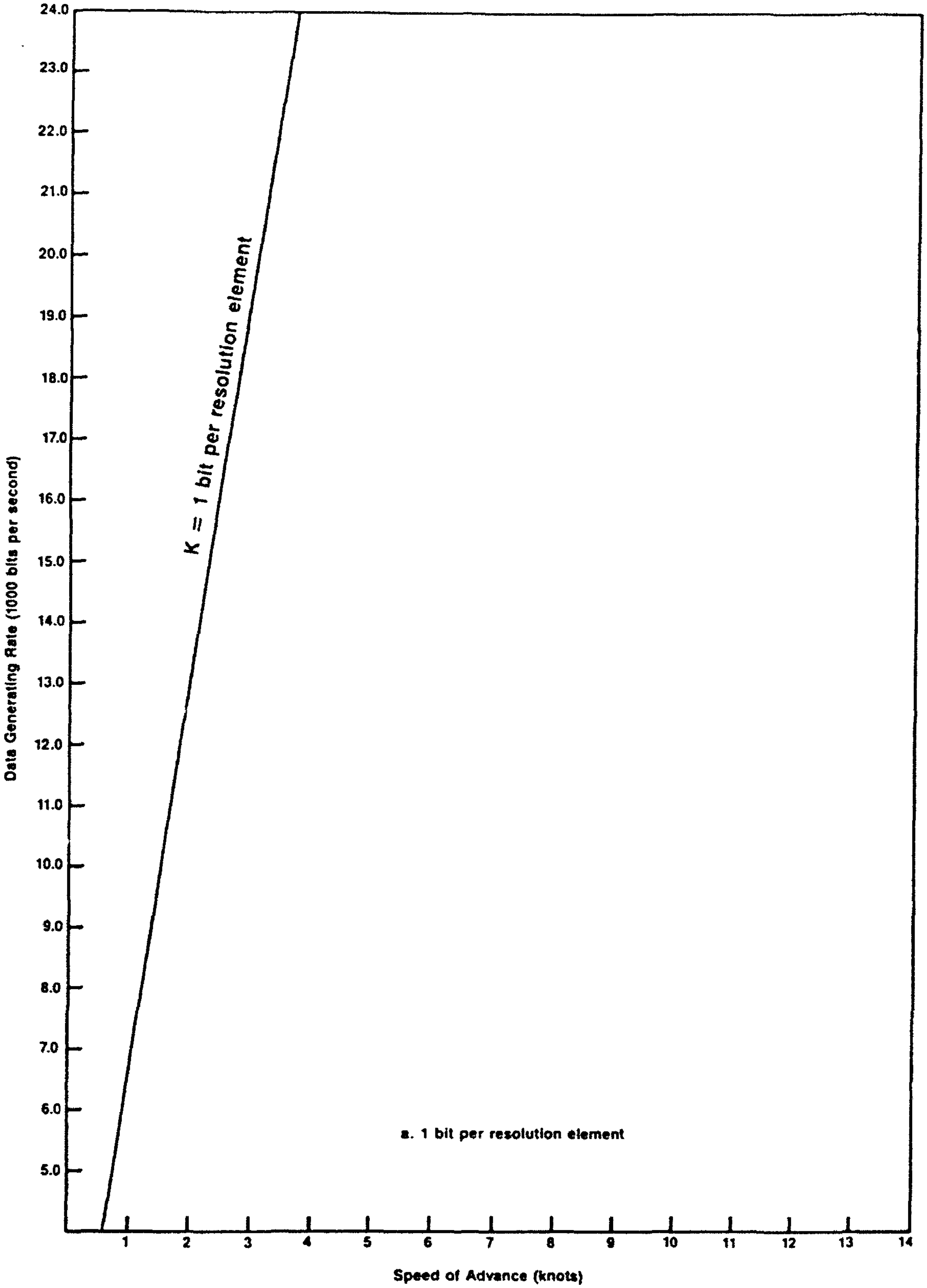


Figure 35(a). Data generation rate as a function of speed of advance for the Westinghouse W1 sonar.

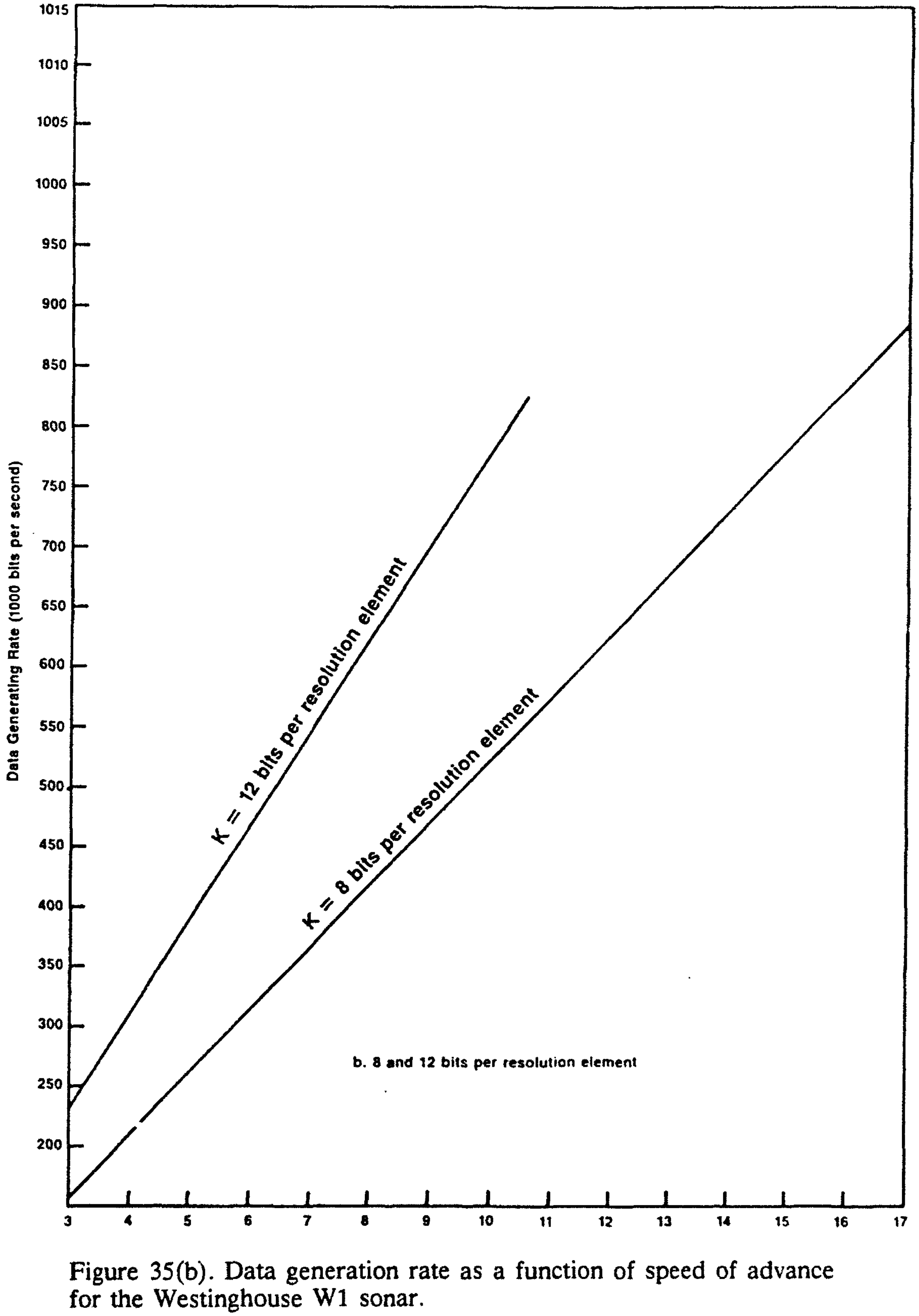


Figure 35(b). Data generation rate as a function of speed of advance for the Westinghouse W1 sonar.

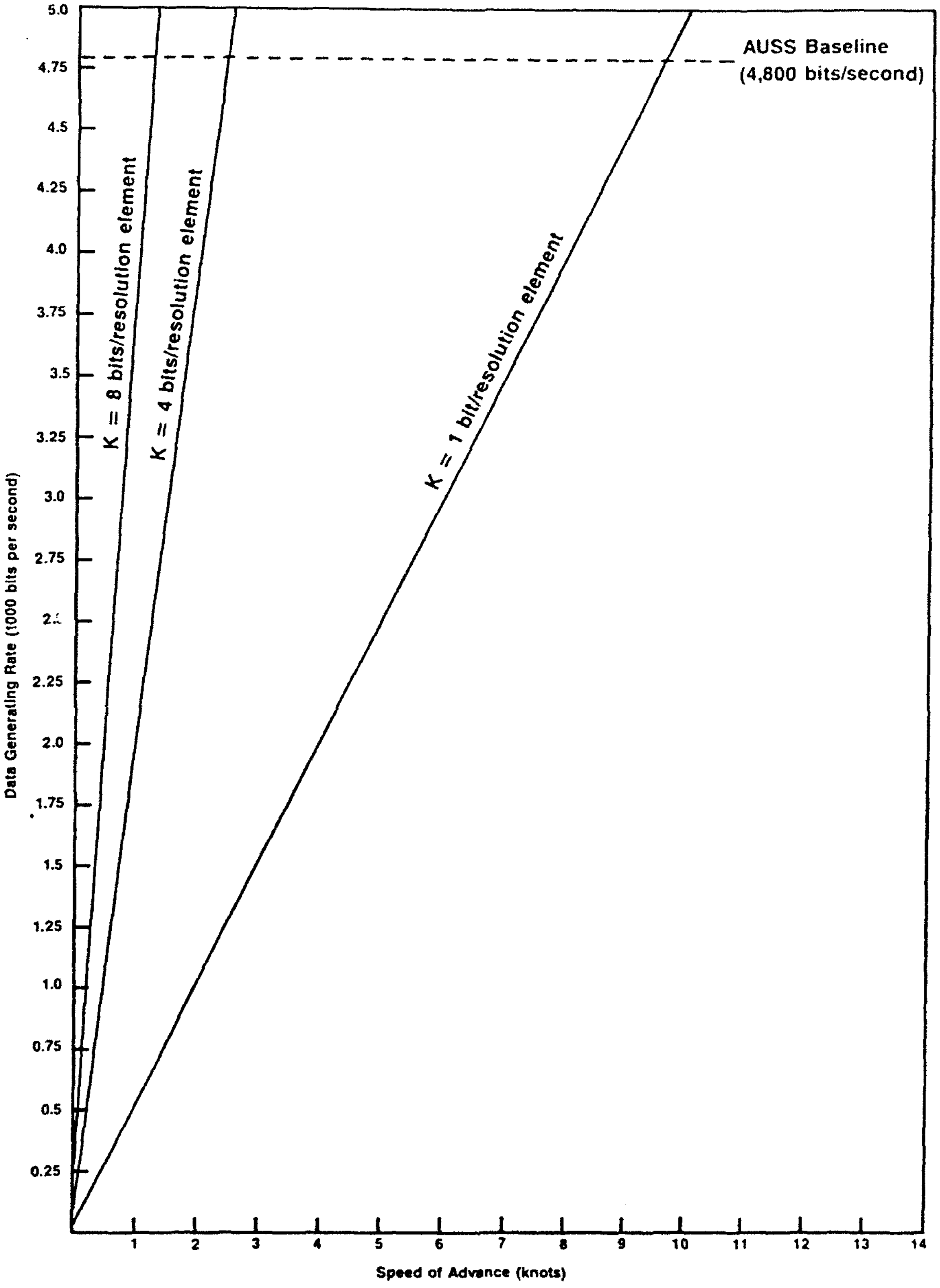


Figure 36. Data generation rate as a function of speed of advance for the Westinghouse STSS sonar.

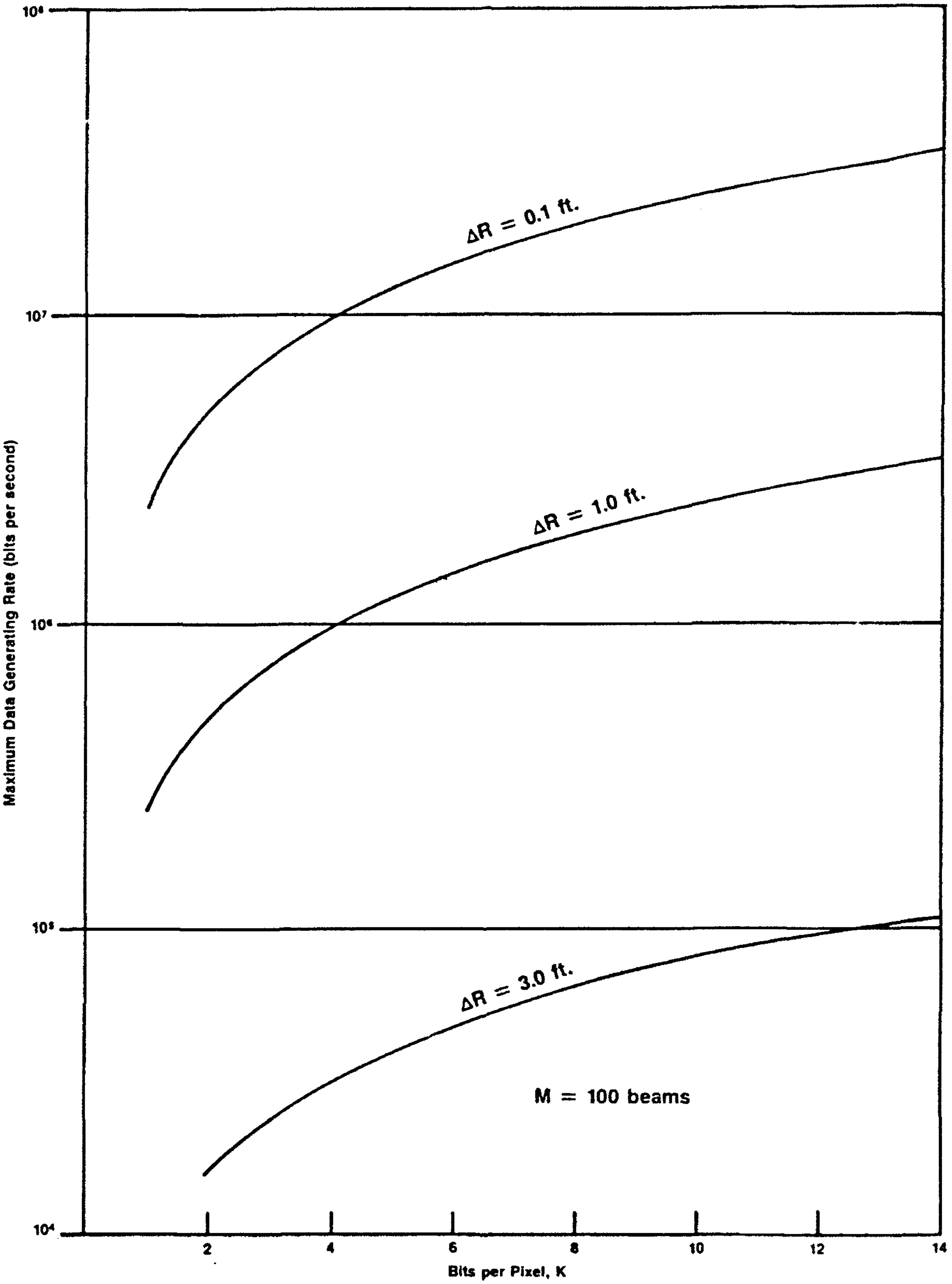


Figure 37. Maximum data generation rate for scan-within-a-pulse (SWAP) sector scan sonars.

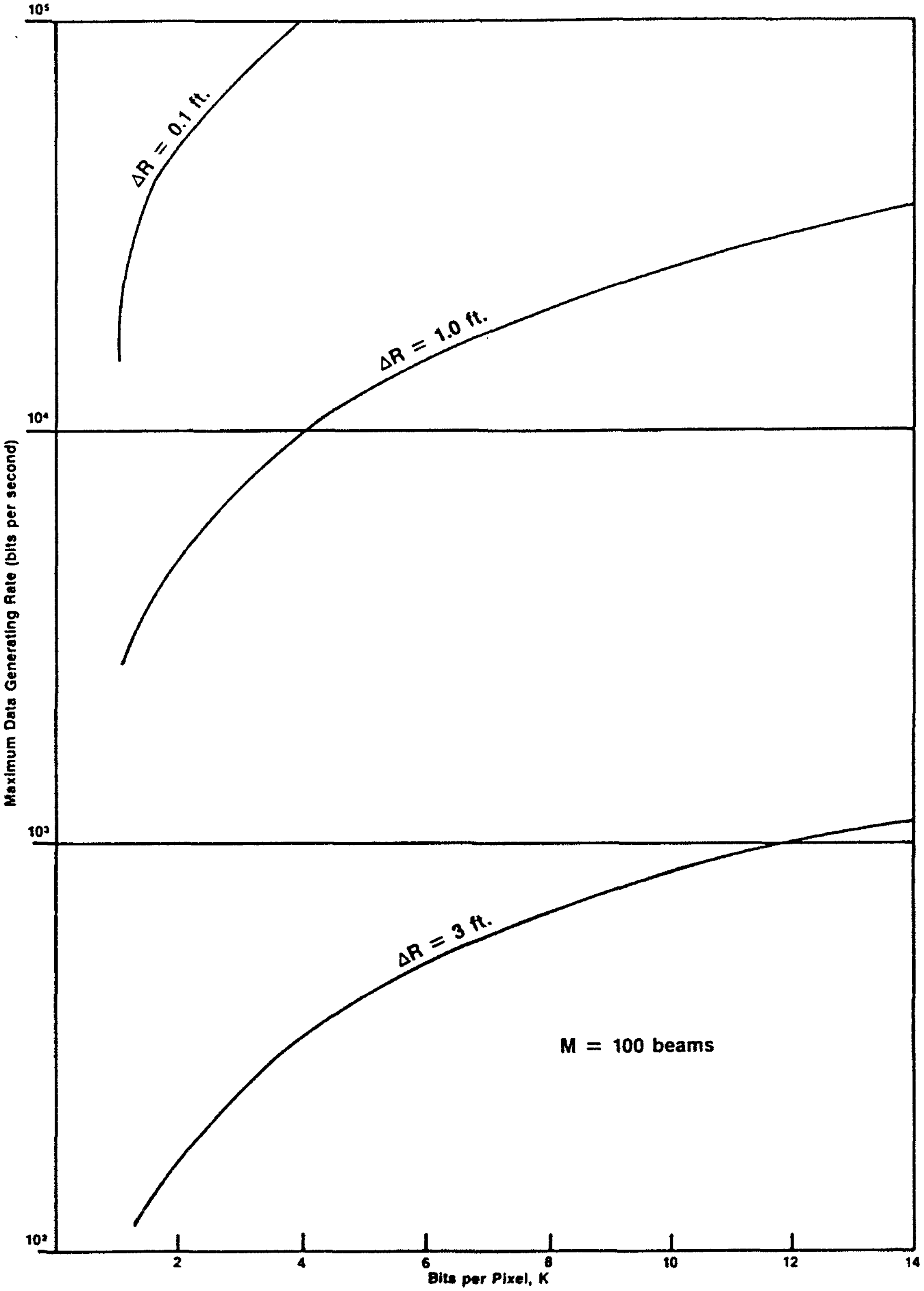


Figure 38. Maximum data generation rate for pulsed sector scan sonars (mechanically or electronically scanned).

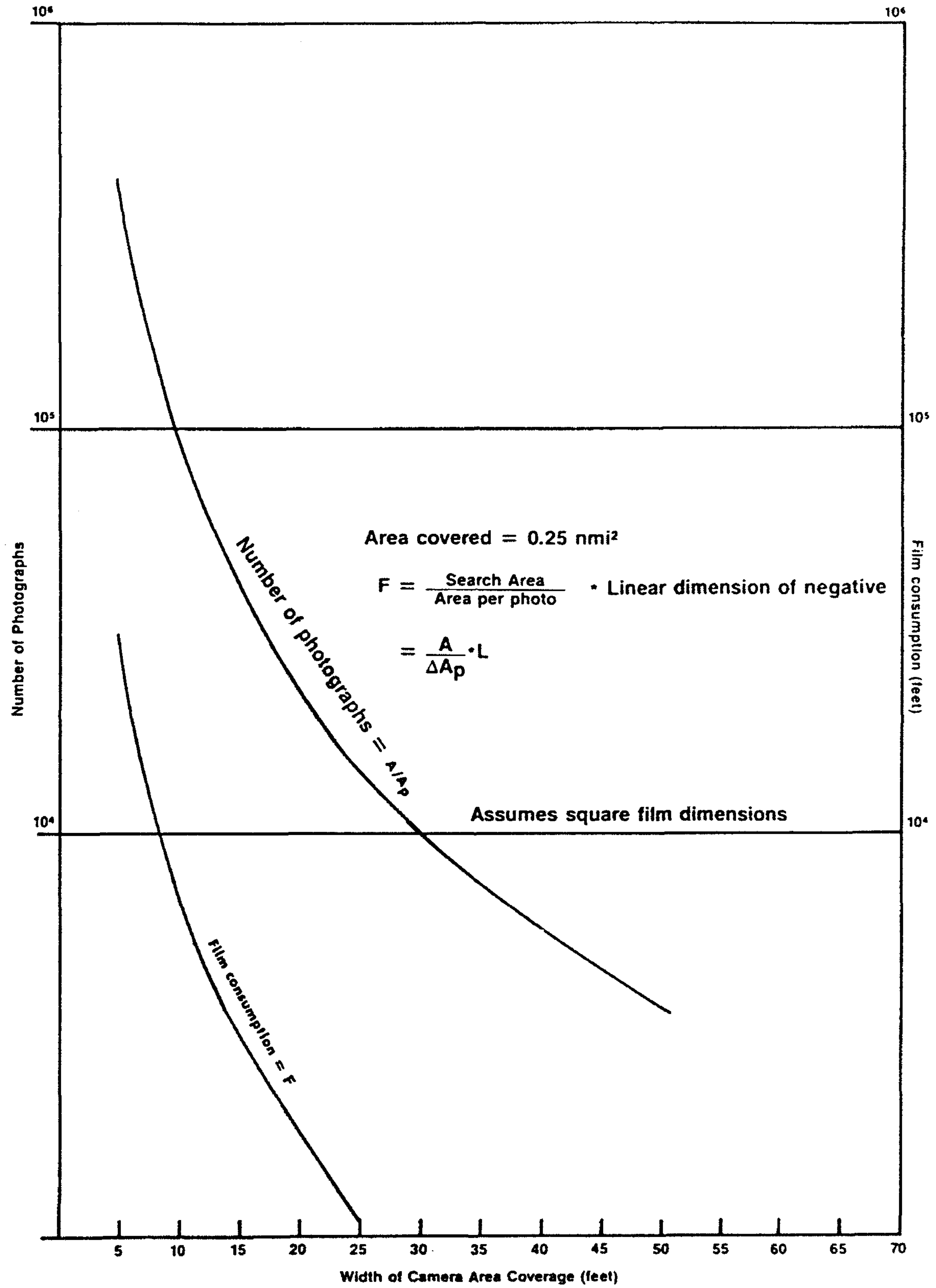


Figure 39. Data rate for 35-mm photographic system.

Table 15. Characteristics of search sensor options.

Search Senor	Required Channel Data Capacity	Required Secondary Storage Capacity for 6-hour Mission	Display Medium
1. Acoustic Sensors Focused SLS	2 $\times 10^5$ bits/second @ 12-bits per pixel and 3 ft resolution	5.4 $\times 10^8$ bytes	CRT or dry paper
Unfocused SLS	2 $\times 10^5$ bits/second @ 12-bits per pixel and 3 ft range resolution	5.4 $\times 10^8$ bytes	CRT or dry paper
Mechanical pulse sector scan sonar	1 $\times 10^3$ bits/second ($\pm$45 deg. sector) @ 12-bits per pixel and 3 ft. range resolution	2.7 $\times 10^6$ bytes	CRT
Electronic pulse sector scan sector	1 $\times 10^3$ bits/second ($\pm$45 deg sector) @ 12-bits per pixel and 3 ft. range resolution	2.7 $\times 10^8$ bytes	CRT
Electronic Sector Scan-Within-a-Pulse (SWAP) sonar	1 × 105 bits/second ($\pm$45 deg sector)	2.7 $\times 10^8$ bytes	CRT
2. Magnetic Sensors Total field magnetometer	72 bits/second	1.94 $\times 10^5$ bytes	CRT, dry paper or discrete digital displays
3. Optical Sensors Still photographic system	2.2 $\times 10^3$ 35-mm photographs (for 0.25 nmi^2 coverage and 20 × 20 ft coverage per photograph)	1.8 $\times 10^3$ ft of 35-mm film and 2 ×104 35-mm photographs	Dry paper
Video System	2.1 $\times 10^6$ bits per second @ 1/2 frame per second and 12-bits per pixel	5.6 $\times 10^9$ bytes	CRT or dry paper

Table 16. Characteristics of external communications options.

Conduits	Data Transfer Rates
1. Hardwire (metal or fiber optics)	
Serial	3. 3×10^6 bits per second
Parallel	40 to 80×10^6 bytes per second
2. Acoustic	
AUSS acoutic link	4.8×10^3 bits per second, maximum
ASI Sonarlink	4.8×10^3 bits per second, maximum
3. Removable Storage Mediums	
Floppy disk	2.5×10^5 bits per second
Winchester disk	5×10^5 bytes per second
Optical disk	3.5×10^6 bytes per second
Magnetic card	2.5×10^5 bytes per second
Magnetic tape (digital and video)	8.75×10^6 bytes per second for video (equivalent) 3×10^5 bits per second for digital tape
Solid-state memory (including bubble)	8×10^5 bits per second for bubble
Photographic film	5- to 15-seconds processing time per negative or slide using dip-dump semifinish process (equates to 1 to 3 hours per 100 feet).

Table 17. Characteristics of high-density data storage options.

Storage Medium	Storage Density	Typical Storage Capacity	Type of Access	Access Time	Power Estimate
1. Magnetic Tape • Casette (1/4", 4 tracks)	1,600 bpi per channel	2×10^7 bits per 300 ft	Sequential	12 to 30 ips	5-100 watts
• Cartridge (1/4", start/stop)	1,600 bpi per channel	9 to 15 $\times 10^6$ bytes per 450 ft	Sequential	10 to 40 ips	
• Cartridge (1/2", start/stop)	6,250 bpi per channel	15 to 160 $\times 10^6$ bytes per 2,400 ft	Sequential	75 ips	
• Multichannel 1/2"	1,000 to 1,600 bpi per channel	2.5×10^8 bits per 2,400 ft	Sequential	200 to 300 ips (300,000 bits/sec)	
• Video (3/4" Umatic)	2.3×10^6 bytes/inch	30×10^9 bytes per 1,00 ft	Sequential	3.5 ips	
2. Floppy Disk					
• 5 1/4"		1 to 2 $\times 10^6$ bytes	Random	0.25×10^6 bps	
• 8"		4×10^5-10^7 bytes	Random	2.5×10^5 bps	
3. Winchester Disk	6M bytes per square inch of surface				
• 5 1/2"	2-150 $\times 10^6$ bytes per surface	30×10^6 bytes	Random	5×10^6 bytes per second	
• 8"	5-200 $\times 10^6$ bytes per surface	100×10^6 bytes	Random	10^7 bps	
• 14"	5-10^6-5×10^9 bytes per surface	600×10^6 bytes	Random	1.4 5×10^6 bps	

Table 17. Characteristics of high-density data storage options. continued

Storage Medium	Storage Density	Typical Storage Capacity	Type of Access	Transfer Rate	Power Estimate
4. Optical (write once)					
• 5 1/4" disk	10^8 bits/cm^2	2 $\times 10^8$ bytes	Random	3 $\times$ 10^6 bytes per second	Device dependent
• 12" disk	10^8 bits/cm^2	1 $\times 10^9$ bytes	Random	3 $\times 10^6$ bytes per second	Device dependent
• 14" disk	10^8 bits/cm^2	4 $\times 10^9$ bytes	Random	3 $\times 10^6$ bytes per second	Device dependent
5. Solid State Memories	—	32K per device	Random	—	53 MW active 5.3 MV standby

Conclusions

The conclusions regarding information processing made as a result of the FASS project feasibility study are listed below.

1. The information processing requirements for FASS are strongly system configuration-dependent.
    a. Specific information processing concepts cannot be identified until FASS specifications are determined.
    b. Generic FASS information processing functions consists of signal processing, data handling, and display operations.
2. The requirement that the FASS increase the search rate and effectiveness for large area search requires a corresponding increase in the rate of data generation and accumulation.
    a. The required high-resolution search sensors generate raw data at a high rate.
    b. Large-area search operations generate a large volume of data.
    c. Identically equipped multiple sensor vehicles generate a larger quantity of data than a single sensor vehicle.
3. The system data throughput bottlenecks for FASS are the external communication link and search data analysis.
    a. The data-generating rates of candidate acoustic and video search sensors exceed the channel capacity of existing acoustic data links and the storage capacity of existing storage devices.
    b. The search sensor vehicle speed of advance is limited by, in order of importance, the channel capacity of the realtime telemetry link and data collection rate of the search sensors.
    c. The ability of the data analyst (human, machine, or both) to evaluate and abstract good assessments from large data streams can cause variations in system effectiveness.
    d. The characteristics and configuration of the display subsystem will influence the performance of a human data analyst.
4. The hardware and software, within limits, required for the design of either an autonomous vehicle system or a supervisory-controlled vehicle system does exist.

   a. Advancements in VLSI, solid-state memory, and microcomputer technologies have eliminated computing hardware resources limitations.

   b. Recent advancements in realtime data processing technology are reducing the economic, engineering, and space constraints on automatic near realtime information processing subsystems.

Recommendations

The following recommendations are offered as a result of the FASS project feasibility study.

1. Select either a system using supervisory-controlled vehicles or a system by using autonomous vehicles for the FASS project.
2. Determine existing specific hardware and software support for FASS concepts:
   a. System development software
   b. Operating systems
   c. Local data link structures
   d. Intelligent I/O interfaces
   e. Smart software packages
   f. Data storage and retrieval resources.
3. Investigate high payoff areas and means for incorporating computer-controlled automation in the system to help eliminate human cognitive problems:
   a. Automated target detection, classification, mapping, and contouring aids
   b. Data handling and display systems to integrate, merge, and enhance relevant graphic and video data collectively
   c. Image processing and enhancement.

4\. Investigate data compression and quantity-reduction techniques for optical and sonar sensors:

   a. Data compression codes and algorithms
   b. Order data produced by source in accordance with its importance to user.

5. Direct the thrust of the FY 85 FASS information processing investigations towards supporting an autonomous search system. The rationale for this

recommendation is that information processing techniques and designs developed for the autonomous system can enhance the capabilities of the supervisory-controlled system.

VEHICLE OPTIONS

Vehicle Characteristics Task

The conceptual designs for each of the candidate systems were refined, and the preliminary descriptions of each of the major vehicle features were prepared. These features included power source, propulsion, ballast, and consumables as well as body shape, size, and weight. In lieu of investigating a large number of options for each of these features for each vehicle, one practical configuration (at least) that addressed all the issues was proposed for each vehicle. However, where alternatives were readily apparent and equally acceptable, they were identified. As part of the vehicle design documentation, functional block diagrams, artistic renditions, summaries of major characteristics, and performance estimates were prepared.

Vehicle Design Options

Background. Three candidate system concepts were selected for further study during the ongoing FASS project: the Multiple AUSS concept, the Dual-Vehicle Search Teams concept, and the Autonomous Vehicles concept. The first two concepts, it is assumed, will be very similar in terms of vehicle design to the present AUSS vehicle and, consequently, will not be the topic of this subsection. The third system concept, which can incorporate either to autonomous photo or SLS vehicles, is the topic of this subsection.

Vehicle Structure. AUSS has demonstrated the feasibility of using graphite-fiber-composite material for high-pressure hull construction. The combination of hull and buoyancy in one efficient structure cannot be improved upon and would be used in any future FASS development. It is anticipated that further development will only serve to refine the concept.

Weight and Size. AUSS serves as an excellent model of real-world component weights and as such, is extremely useful in extrapolating to determine weights and sizes of similarly designed systems. A list of AUSS components and their associated weights is presented in table 18. If these components are divided into the categories of structure and buoyancy, electronics and sensors, and energy and propulsion, the results are that about 60% of the weight is structure and buoyancy, 20% is electronics and sensors, and 20% is energy and propulsion (table 19). If a similar weight budget is made for the FASS autonomous concept, one can calculate an estimate for the weight of structure and buoyancy as well as the vehicle total weight. The results of this tabulation and calculation are shown in table 20. It can be seen that simplification of the sensor and electronics packages has the net result of reducing the vehicle displacement to approximately 1/2 that of AUSS. Since scale or size is proportional to the cube root of displacement (volume) the resulting system is about 0.8 scale relative to AUSS. The relative size can be seen in the outlines shown in figure 40.

Table 18. AUSS component weights.

Item	Weight in Pounds
Pressure housing	1,015
Electronics	198
Motors	99
Additional buoyancy	215
Fairings/fins/actuator	163
Ascent weight/actuator	77
Brackets	22
Battery and shifter	316
Connectors and cables	52
Transponder assembly	132
Side-looking sonar	50
Doppler sonar	24
Scanning sonar	32
Photo camera	25
TV camera	12
Strobe lights	36
Acoustic link transducer	23
Pressure transducer	4
SAR equipment	14
Total	2,509

Table 19. AUSS weights by category.

Category	Weight In Pounds	Percent
Structure and buoyancy	1,492	59
Sensors and electronics	456	18
Battery and propulsion	415	17
Other	146	6
Total	2,509	

Table 20. FASS components weights.

Item	Weight in Pounds
Ascent weight	35
Strobes	36
RF transmitter	5
Flasher	3
Ascent release	3
Descent release	3
Connectors/cables	10
Battery	150
Electronics/navigation	80
Side-looking sonar	50
Motor (1)	40
TV camera	15
Pressure transducer	4
Data recorder (optical disc)	70
Payload total	504
Structure/buoyancy = 504 × 1.5 =	756
Vehicle total	1,260

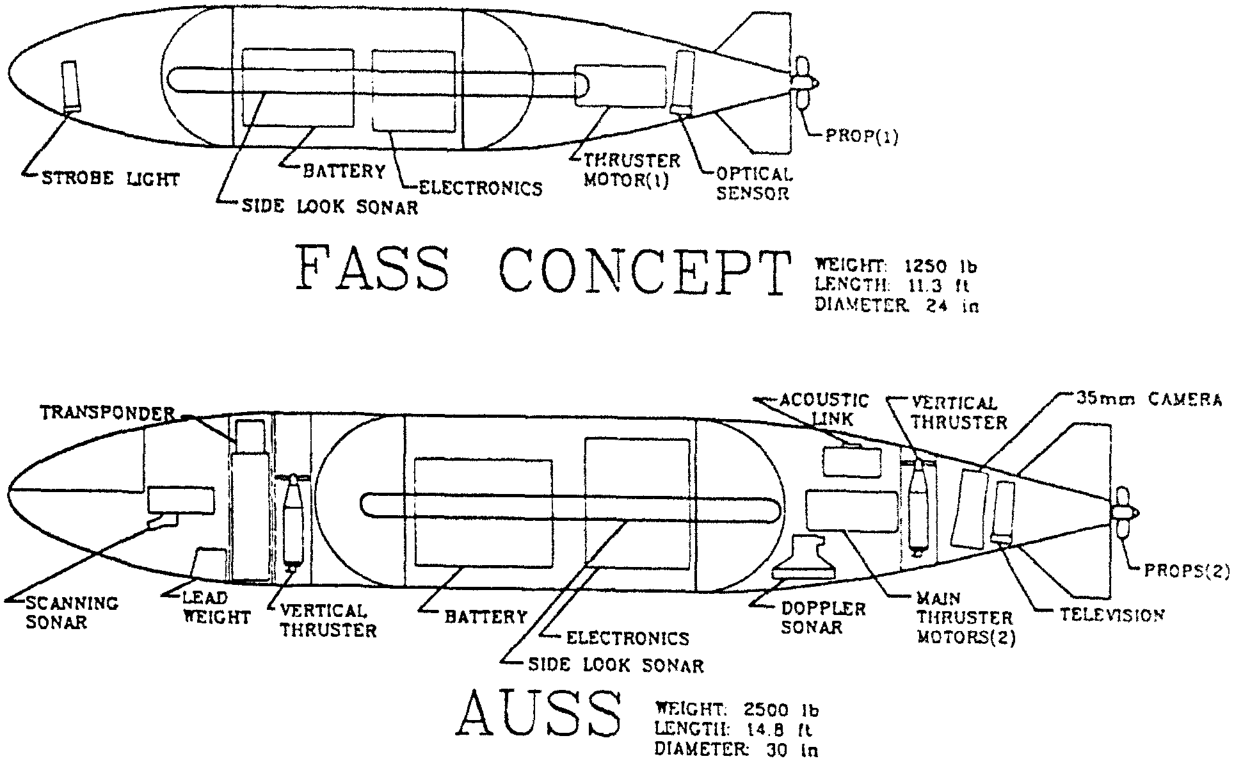
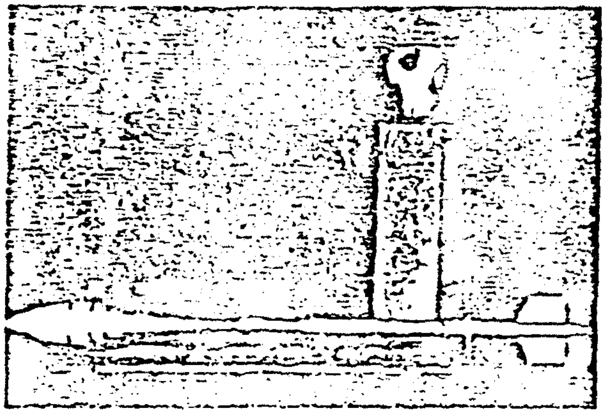


Figure 40. AUSS and FASS concept design layouts.

Hydrodynamic Shape Options. Since this concept involves significant reductions in acoustic windows and fairing perturbations (i.e., no vertical thruster tubes for hovering), consideration was given to the use of a laminar flow shape instead of the standard torpedo-like turbulent flow shape. It was anticipated that, since this type of shape has roughly 50% of the drag of a turbulent body, a significant reduction in energy requirements would result in an associated reduction in vehicle weight and size. As it turns out, this is not the case due to the fact that the energy and propulsion with its associated structure and buoyancy comprise about 50% for the vehicle weight in the first place. If the energy and propulsion portion were reduced by a factor of two, the vehicle weight would consequently be reduced only by about 25%. This is a relatively small benefit considering that the overall bulk of the vehicle would increase due to the noncylindrical shape of such vehicles (figure 41). In addition, the costs to produce and maintain the high-quality surface finish must be taken into account. From an overall tradeoff standpoint, the laminar flow vehicle shape does not appear to be worth the effort.



Hypep-2 mounted on the carriage bridge at the Naval Ship Research and Development Center. (Figure unclassified.)

Hypep-2 all-metal configuration for test at the Naval Ship Research and Development Center. (Figure unclassified.)

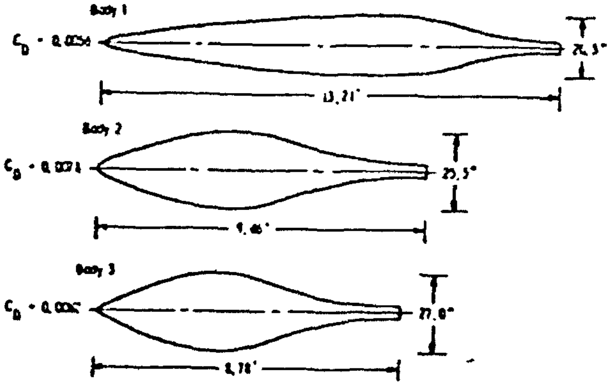


Figure 41. Comparison of laminar flow body test shapes.

Energy Options. After examining several previous studies on the subject of energy sources for undersea vehicles, four types of sources appeared to be feasible, at least logistically: batteries, fuel cells, thermal energy, and flywheels. One by one, all but the batteries were eliminated as possible candidates.

Flywheels were initially intriguing since recharging and cycle life seem so advantageous, but unfortunately the energy density is prohibitively low. A flywheel of equivalent energy would weigh 10 to 15 times the weight of a silver-zinc battery in the size range appropriate for FASS.

Thermal energy is heat that is stored in a block of material of high-heat capacity (in this case, carbon) and then converted to mechanical energy through the use of a closed-cycle machine, such as a Brayton or Stirling engine. In large sizes, these systems can compete with and even surpass the performance of silver-zinc batteries but, when scaled to the size appropriate for FASS, they are at best about two times the weight of a silver-zinc battery and about 10 times the volume.

Fuel cells suffer from the same problems of scale as the thermal energy source, that is, at larger energy values they are competitive but not at the level of FASS which is about 10 kWh. A family of curves demonstrates this point and indicates an energy density about half that of silver-zinc batteries at the FASS level (i.e., 1 kW for about 10 hours).

Batteries are currently headed by the silver-zinc battery, that is the highest energy density, rechargeable battery presently available. This is the energy source presently employed by the AUSS vehicle and is the recommended choice for FASS. Eventually, superior batteries are expected to replace the silver-zinc type. For example, a type of rechargeable lithium cell that employs a solid polymer electrolyte (currently under development in Europe), promises to double the energy density of the silver-zinc cell. Obviously, the choice of a battery-type energy source lends itself to retrofitting with a superior device for future performance improvement.

Conclusions. In summary, it is recommended that the FASS autonomous vehicle systems be configured as a simplified AUSS vehicle of about one-half the displacement and using a similar energy source and similar hydrodynamic shape.

COMMAND AND CONTROL OPTIONS

Command and Control Options Task

The first step in assessing the FASS command and control options was to inventory the control and status functions likely to be required of the FASS undersea vehicles, the surface platform, and the search sensors. The research also included determining how these functions are controlled for the AUSS vehicle, including the command approach and how status information is processed and routed. Furthermore, the AUSS command and control architecture was reviewed and its summary description was prepared. Then, it was necessary to identify any new functions that resulted from the use of multiple vehicles, such as the need to coordinate activities. Finally, any probable command and control design constraints for selected combinations of vehicle autonomy and data communications throughput were identified.

AUSS Vehicle Command and Control Summary

Solorzano (June/July 1984) made a brief report on the command, control, and computer-level communications abilities of the AUSS vehicle. It begins with the shipboard operators' control of the deployed system, reviews the digital/acoustic communications scheme, and examines the vehicle internal command and control reactions. A summary of the system commands and status reports is appended. The reference also includes these AUSS data:

1. AUSS block diagram
2. AUSS console keyboard
3. AUSS status keyboard
4. AUSS console menus
5. AUSS vehicle computer architecture.

The following paragraphs present the system summary and observation subsection from this reference.

The Advanced Unmanned Search System is a supervisory-controlled untethered deep-ocean search vehicle. It has a well-defined set of primitives for vehicle operations with one complex search command (the MOSAIC). The surface operation of the vehicle is designed via a menu-driven console and limited trajectory planning to require human supervision of every new orientation of the vehicle as well as that of the sensor suite. This shifts the reliability problem in both software and hardware, as well as in mission, from the ocean below to the surface above.

The acoustic communications technique meets the free-swimming requirement for the vehicle, while imposing severe restrictions on the data rate as well as requiring a broad beam for ease of link alignment. For raw transmission rates it may even pose a vehicle search-rate-limiting factor.

The vehicle itself contains an expandable, hierarchically configured multiprocessor computer set with sensors and peripherals attached through various interface cards.

The major computer system responds to a command string by parsing and decomposing the commands and exercising stored instructions to comply. Some of the required sensor data are acquired by interfaces, which relieve the computational load.

Some observations made by AUSS team members regarding multiple AUSS-like vehicle deployment concerned the navigation of ship and vehicle, the command set, data processing and routing, and the instrumentation suite.

With time sharing, the currently planned shipboard navigation system could easily accommodate multiple vehicles. Some of the required modifications include channel time sharing and vehicle identification, minimum vehicle spacing to prevent intervehicle sensor interference, and vehicle screen identification. Vertical channel time sharing could be profitably used in horizontal plane navigation among multiple vehicles.

Easily, one of the most significant advances in computer architecture for an advanced, highly capable search vehicle, multiple or not, is the design of a generic interprocessor communications scheme. The current method of communication between processors in different card cages is arguably sufficient for the purpose, particularly in the view of minimizing the software-development effort and building a working vehicle in the near future. However, with any expansion of capability requiring more card cages or separation of the card cage in the current AUSS configuration into multiple smaller cages (for reasons of bus contention, added processor(s) bus dedication, etc.), custom communications software tailored to each processor would be required. This may not be a minor task.

The physical means of interprocessor communications would also have to be changed, as the present technique cannot support more than a single communications link between two processors, i.e., three processors could not communicate to each other with their onboard parallel and serial ports as in the present AUSS.

The command set of the individual vehicle could be expanded to include standard maneuvers such as turning with conditionals for immediate contact evaluation. This does not mean that the vehicle would itself initiate a contact evaluation. Extension of the internal vehicle queue would allow an entire search pattern to be downloaded, which would reduce the opportunity of operator error due to fatigue or boredom. It must be observed that the mosaic instruction constitutes a much more complex or higher level instruction that approaches this extended queue capability in providing for a rectangular serpentine-synchronized photographic reconnaissance path of known length and duration.

Data processing was favorably proposed both as a means of reducing data transmissions and of decreasing operator fatigue. Simple data processing already exists in the form of sensor interfaces and the flight recorder function. Routing much of the raw data to mass storage was repeatedly expressed.

Higher resolution systems and greater search rates imply higher data rates, thus, requiring data compression or lower level evaluation of the data in realtime.

The following figures (42 through 45) and tables (21 and 22) summarize some aspects of the AUSS vehicle command and control study and present information useful to the FASS project for evaluating command and control options.

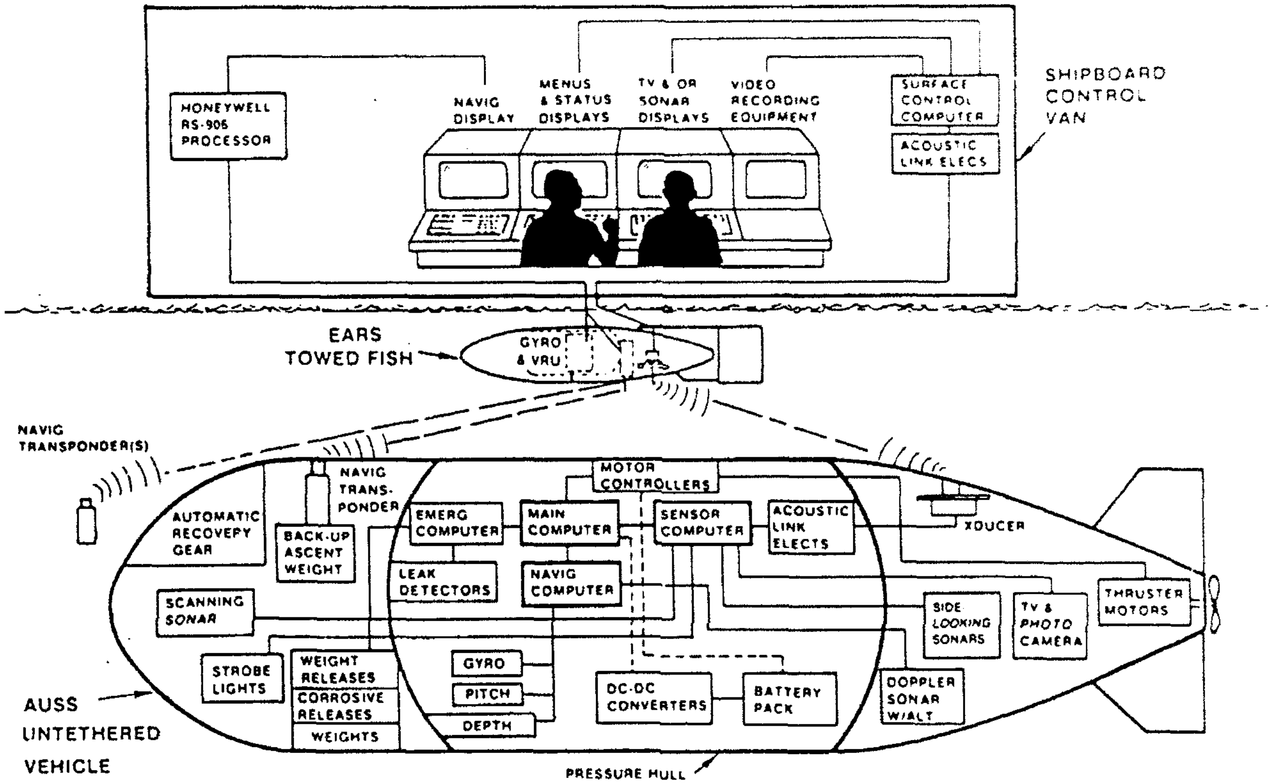
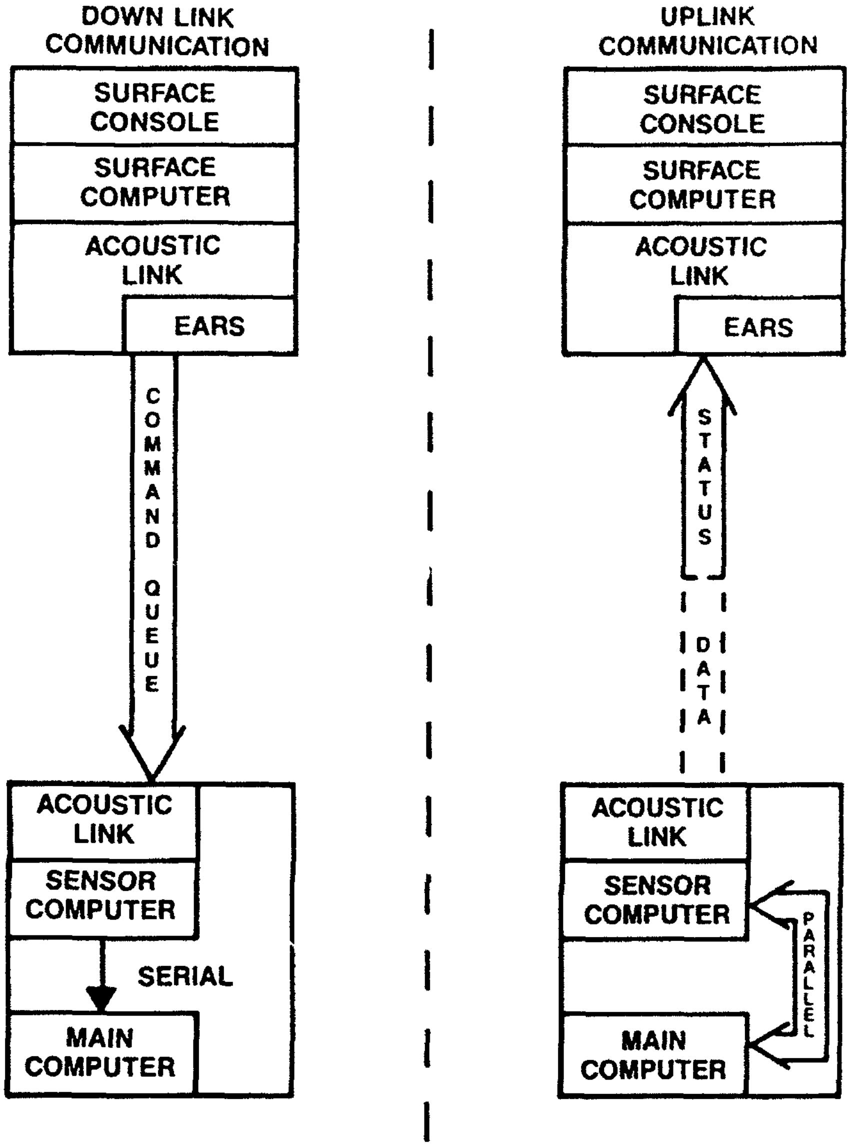


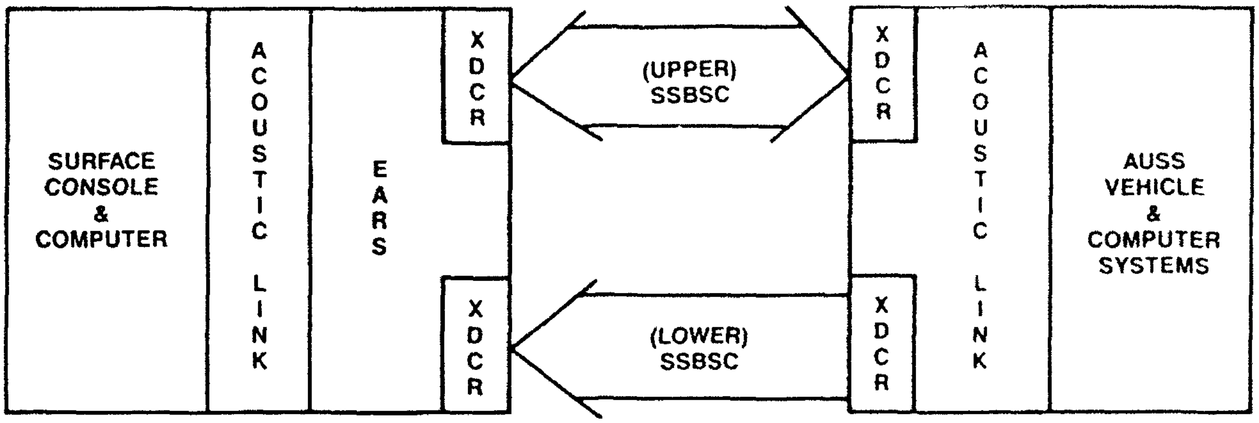
Figure 42. AUSS block diagram.



Notes:

1. **Transmission of a command queue requires a status message returning a confirmation.**
2. **Status reports may be appended to data transmission.**

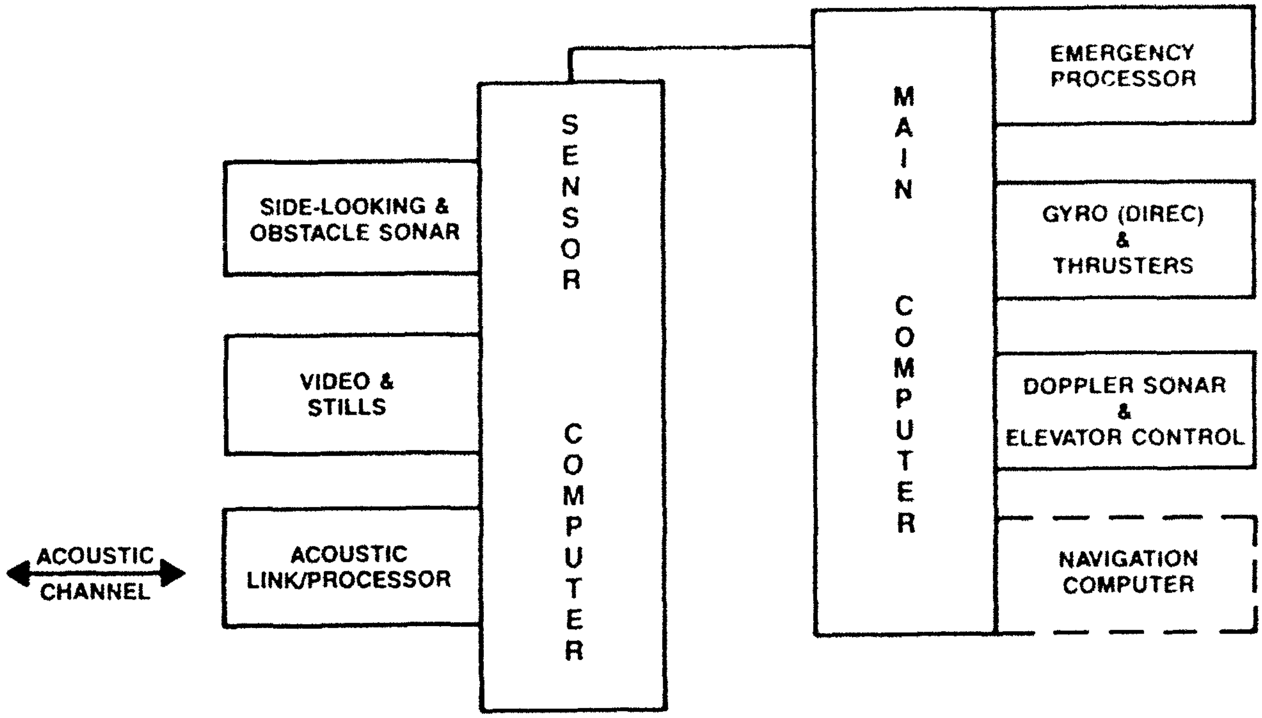
Figure 43. AUSS communications diagram.



Notes:

1. **Channel assignation may be full duplex as illustrated or both channels assigned during uplink operations to data transmissions for effective half duplex.**
2. **XDCR is transducer, i.e., hydrophone.**
3. **Carrier of 11 kHz is intermittently broadcast for synchronization.**
4. **SSBSC is Single Side Band Suppressed Carrier.**

Figure 44. AUSS electroacoustic communication diagram.



NOTES:
1. Functional blocks vertically arranged in order of control hierarchy.
2. Navigation computer may not be implemented.
3. Horizontal blocks share BUS with associated computer.

Figure 45. AUSS internal control diagram.

Table 21. FASS command and control options.

COMMAND AND CONTROL POSSIBILITIES ARE DEPENDENT UPON

1. Operations, Both System and Field
2. Level of Surface Control
    - A. Fully remote control
    - B. Semiautomatic control
    - C. Preprogrammed or supervised control
3. Nature of the Communications Channel
    - A. Partitioning the communication channel
        - i. Parallel channels
        - ii. Multiplexing: time and frequency
    - B. Bandwidth
    - C. Noise
    - D. Reliability
    - E. Propagation characteristics; delay and divergence
4. Vehicular Sophistication
    - A. *Automation of process controller(s)*
    - B. Communications processing
    - C. Computer architecture
    - D. Redundancy and reliability
5. Data Reduction and Analysis
    - A. Raw-data generation rates
    - B. Data compression
    - C. Data reduction site
        - i. Vehicular
        - ii. Shipboard
        - iii. Remote site
    - D. Data storage
        - i. Mass storage (optical, magnetic, film)
        - ii. Data transmitted vs data stored

Table 21. FASS command and control options. (continued)

6. Sensor Complement(s)
    - A. Raw-data transmission requirements
    - B. Timeliness of analysis
    - C. Sensor servicing
    - D. Intersensor functioning interference
    - E. Sensor data correlation
    - F. Sensor interchangeability or upgrades

7. System Deployment
    - A. Number of vehicles
    - B. Density of vehicles
        - i. Size and geography of search area
        - ii. Sensor interference
        - iii. Navigation sensors and vehicle coordination

8. Intervehicle Coordination
    - A. Search plan
    - B. Individual vehicle path planning
    - C. Vehicle alignment (not only linear in time-or space)
    - D. Vehicle assignment (automatic, failsafe, or operator)

9. Software Design
    - A. Display and command requirements
    - B. Communications protocol
    - C. Communications packeting
    - D. Sensor processing requirements
    - E. Shipboard computer architecture
    - F. Vehicular computer architecture
    - G. Intravehicular communications
    - H. Intervehicular communications
    - I. System monitoring
        - i. Vehicle status
        - ii. Sensor status
        - iii. Computer status
        - iv. Execution monitoring (procedure, communications)
        - v. Communications channel status and test
        - vi. Shipboard status and mode
        - vii. Remote site status
    - J. Design for Expansion

Table 21. FASS command and control options. (continued)

i. Modularization of sensor device drives
ii. Standardization of sensor I/O formats
iii. Field dependent control and pointers
iv. Built-in test equipment and software (BITES)
v. Parallel processing
vi. Parallel access of vehicular computers to external communications
vii. Generalized and loosely coupled vehicular processors.

Table 22. Command and control design constraints.

TYPE OF CONTROL IS NOT A CONSTRAINT UPON ACTUAL COMMAND AND CONTROL SET:

> SOFTWARE DESIGN AND COMPUTER ARCHITECTURE IS READILY DESIGNED TO ALLOW DIFFERENT LEVELS OF CONTROL AND MONITORING GIVEN ANY MEANS OF REMOTE COMMUNICATIONS.

Actual Constraints Are Dependent Upon:

- Sophistication of vehicle computer and software design
- Realtime control requirements
- Symbol level of communications
  - Water column (in the communications channel)
  - Internal to vehicle
- Intervehicle coordination
  - Passive coordination
  - Active coordination
  - Frequency of surface interaction
- Communications channel characteristics
  - Bandwidth
  - Multiplexing
  - Duplexing
  - Processed level of transmitted data, if any

APPLIED ARTIFICIAL INTELLIGENCE

Since FASS is expected to be fully developed and implemented in the 1990s, there is a corollary expectation that artificial intelligence (AI) technology will be incorporated in the final system design. As a result of the feasibility study, three particular areas of AI appear to offer significant potential for application to future systems:

1. Target discrimination (this is a potential AI solution to the bandwidth problem)
2. Expert systems
3. System monitor.

Table 23 summarizes possible approaches to the implementation of AI for FASS. These approaches are more thoroughly discussed by Durham (16 July 1984).

Table 23. Perspectives on AI applications for FASS.

Types of AI Approaches
- AI as "smart machine"
- AI as operator emulator
- AI as goal directed behavior

Implementation Techniques
- Completely in-house developed system
- Tailored commercial system
- Tailored in-use demonstration system
- Tailored research system
- Integrated systems system

Design Considerations
- Advancing technology
- System manageability
- Level of supported effort

Target Detection or Recognition

Introduction. Target detection or recognition is the area in which AI technology offers the greatest possibility of beneficial applications to the FASS project. The application of AI to target detection could significantly reduce the amount of data to be communicated, processed, or stored. In addition, the techniques may be applicable to both realtime onboard processing and postdive processing on the surface ship. Durham (8 August 1984; 13 August 1984; 15 August 1984; 27 August 1984) further develops the application of AI to target detection.

The purpose of the rest of this subsection is to outline an approach that is recommended for implementing a target recognition system for FASS. Because of the payoff that such a system would have, the following recommendations are made for developing such a system.

Use An Incremental Approach. The recommendation is that FASS build up its image-processing capability in a number of small highly beneficial steps that will greatly enhance search capability at each step. Besides being an end in itself, each step is designed to be a foundation for the next step. The eventual goal is a target recognition system but the immediate payoff of enhancing search is always a short-term high priority that drives the overall design effort. With an incremental approach, the risk of developing target recognition capability is eliminated because the problem is broken down into a continuum of capabilities that can be developed one step at a time.

Isolate Critical Parameters. The first step is to isolate the critical parameters related to sonar search. For any sonar search system, the stability of the sensor platform (i.e., the AUSS-like vehicle) is a critical parameter at some point. Also, the signal-to-noise ratio is another critical parameter for any sonar search system. The first and most valuable step is to list all the possible parameters related to sonar search and then investigate all possible relationships between those parameters. This listing of parameters establishes a domain of variables that affect the performance of a sonar search sensor. The integrity and accuracy of the sensor data are a major concern and knowing the values of the variables that affect that sensor helps to optimize the integrity and accuracy of that sensor data.

For the critical sonar parameters the following list is proposed. At the top level, four separate categories are set forth. These categories are transducer system parameters, sensor platform parameters, enviromental parameters, and finally the data storage parameters. Enclosure 1 of Durham (27 August 1984) lists the specific elements of each category that has been identified thus far. Admittedly, some parameters may have a negligible effect during normal operation, but it may be wise to monitor those parameters to ensure they have a negligible effect and then correct the errors introduced if abnormal operation is ever detected. Salinity, temperature, and depth (STD) is an example of such parameters. The speed of sound in water is known to be a function of STD; therefore, a more accurate range value can be calculated if the speed of sound is computed in terms of the recorded STD during sonar operation.

Acquire Signal- and Image-Processing Capability. Purchase an image-processing workstation that can be repackaged and embedded on an AUSS-like vehicle. This will allow FASS to have a standardized image-processing system. With this image-processing workstation, ensure that both the signal-processing software library and the image-processing library are as complete as possible. The object is to buy as much processing capability as possible with as many software utilities as possible. Debugging tools should be considered as high-priority items since new software will be generated.

Not, all image-analysis systems are designed and built as "board component" systems that do not require a disk drive for operation. For an image-analysis system to be embeddable into an AUSS-like vehicle, it needs to be made up of single board components that do not need a disk drive for operation. Enclosure 1 of Durham's memorandum of 13 August 1984 is such a system. The first page of that enclosure shows a block diagram of the system and the last page shows the prices for the board components and assorted libraries.

Develop Restoration, Enhancement, and Analysis Capability. After the workstation has been configured so that an operator can page through raw sonar images, provide easy access to the signal- and image-processing utilities provided with the workstation. A function key for each primitive would be ideal. Put all the supplied processing capability at the fingertips of the operator. Another feature to add for the operator would be process command chaining and automatic image preprocessing. An operator may know that he/she does not want to inspect raw sonar data, but rather only look at the images output from a multiple chain of image commands with only the initial image being raw data. Also, develop signal-processing capability so that an operator can manipulate and graph any row of a sonar image. There can be a lot of information in the shape of the returned pulse.

Emulate Operator Capability. Once an operator has all the processing capability at his/her fingertips, he/she will be using particular commands under particular conditions. There should be an ongoing task of implementing a system that emulates an expert operator. When you have an expert operator who can use the system to its full power for detecting features, you have an opportunity to implement a rule-based system that will emulate what the operator does.

Utilize Image-Analysis Software Library. Develop algorithms that will sample images and from the sample determine which processing primitives would best enhance a sonar image for an edge and region detection algorithm. This algorithm could then be used to filter out all regions that were not within a given size range of the target. The size of the target is known and the resolution of the sonar is known so, therefore, the approximate area of the target's sonar reflection is known. Why not only look at regions whose area very roughly corresponds to the expected area of the target's reflection?

Develop Analytical 1-D Feature Detection Capability. In parallel with implementing a system that emulates an expert operator, analytical feature detection algorithms should be developed, implemented, and tested. Statistical pattern recognition techniques seem to fit this kind of approach well. The very first feature detector should be an algorithm that detects any deviations from the background noise of the echo. This algorithm will filter out all echoes that cannot possibly contain information about the target because, by definition, the target will cause a deviation from the background noise.

Sonar search is based on this principle. Only the echoes that are not filtered out by this initial feature detector are echoes of interest. The next step would probably be to try to filter out natural objects. Much promising work has been done on the features of echos from manmade objects.

Develop Analytical 2-D Feature Detection Capability. 2-D analysis is considered to be an extension of l-D analysis. Therefore, only the echoes that have deviations from background noise are still the echoes of interest in a plane. 2-D analysis is looking at multiple echoes of interest in a plane. The spatial clustering of hits (i.e., deviations from background noise) will probably be one of many possible feature detection algorithms.

Conclusion. An approach to implementing a target discrimination system was presented in order to give an outline of how one could be developed. An emphasis was placed on adopting an incremental approach that always added capability to the system. Each step is intended to provide immediate payoff as well as providing a foundation for the next step. This is intended as an aid for the conceptual design of such a system and, at that time, the actual developmental steps should be decided upon.

Expert Systems

The following paragraphs were taken from Durham (15 August 1984), which presents "A Mission Planning Expert System For FASS."

Introduction. Expert systems have been receiving much attention as high-potential, high-payoff computer applications. Among the many applications of expert systems, planning has been a very fruitful area. The structure of the most common commercially available expert systems, rule-based systems, is well suited to the problem of creating plans. For the problem of planning search missions, a rule-based expert system seems to be a well-suited solution. Planning is not always a trivial task and the best expert planners usually use rules-of-thumb that they have acquired through experience. Commercial sources are presently available for FASS to create a rule-based search mission planner that can incorporate such rules-of-thumb as well as performing the basic planning.

The Rationale for an Expert System. Planning a mission for a multiple-vehicle search system will probably be a very laborious and time-consuming task. With the added number of vehicles, support vans, and personnel, mission planning becomes a rather complex operation. What further complicates this task is that the success of a mission plan is very dependent on the level of expertise of the planner. Rule-based expert systems were developed for the purpose of implementing a computer system that can incorporate the often used rules-of-thumb of the experts and the structure of those systems lends itself to the problem of planning.

Commercial Utilities Available for Building Expert Systems. Within the last two years, a number of commercial products have become available for building expert systems. The most significant development has probably been the introduction of standalone AI workstations (commonly called Lisp Machines). An additional development has been the introduction of software packages designed to guide the building of a particular expert system application. These two products together provide an optimized environment for developing generic expert system applications. An added feature is that many of the expert-system development packages do not assume previous experience of building expert-systems.

Necessary Requirement for Building a Generic Expert System. From the reports that have been discovered, there seems to be four basic requirements for implementing a straightforward generic expert system application. Those four requirements are at least one expert, at least one software specialist familiar with contemporary software development practices, adequate development tools, and a fair amount of time for developing the system. The ins and outs of building a particular expert-system are reportedly in the development packages that were mentioned earlier and supposedly this is a major feature of these packages.

Recommendations for Implementing an Expert Mission Planner. Since commercial products are available for developing an application that has high-payoff potential for a multiple vehicle search system and since these products are designed for developing applications such as the expert mission planner that we have been considering, the following recommendations are made. First, determine who the expert search mission planners presently are and query them about actual search planning. In other words, find out how experts plan out particular search missions. Second, investigate the commercial expert system development tools and determine exactly how applicable they are to developing a search mission planner. Finally, determine if the degree of effort actually required for developing such a system is feasible for the FASS project.

Conclusion. Expert systems have been receiving much publicity as high-payoff applications for particular kinds of problems. This publicity has spurred an initial feasibility investigation for applying this technology to FASS. From information about the recently released commercial products that are available, it seems that the FASS project has the opportunity of possibly developing an expert search mission planner with very low risk. From this initial information, recommendations were made for determining whether or not such an application is actually feasible.

Conceptual Design of a System Monitor

The following paragraphs were taken from Durham (11 July 1984).

As a computer system becomes more and more complex, the more and more difficult it becomes to know the actual internal operation of that system. When a system is small and there are only a few possible operations, a person can usually keep track of this system. When a system is not small and it is tightly coupled to realtime events that will invoke any number of different system operations, a person has a very difficult time keeping track of this more complex computer system. An intelligent system monitor becomes a much needed utility for these larger more complex systems. Its use is twofold. First, it is a testing and debugging tool for the engineers who build the prototype system. Second, when the system is operational, it is a tool that will help operators to understand fully the operational characteristics of the system they are using. The value of the system monitor is in the fact that it provides these people with as much knowledge as possible about the internal workings of the given computer system.

In the case of mobile robot design, the system is invariably complex and tightly bound to realtime events. Hence, there is a need for a system monitor. There are three different types of monitoring activities that can be pursued. These activities are application software monitoring through in-line subroutine calls, through the operating system debugger, and hardware monitoring, through the use of a programmable logic analyzer. These three activities can "passively" monitor a given computer system, signal an operator when an irregularity occurs, and then provide an operator with valuable information that is relevant to that irregularity. This is the value and purpose of using a system monitor for a mobile robot computer system.

In terms of the conceptual design of an intelligent monitoring system, each of the three activities are recognized as the independent activities that they are, and they are developed as such. As an outgrowth of the development of these three separate monitoring systems, a fourth very high-level monitoring system is created. This fourth system is a system that integrates the capability of the previous three and provides a very comprehensive monitoring capability. Each of the four systems will be sketched out in the future.

Keep in mind that this system may be a rather sophisticated computer system. Intelligent 'passive' monitoring is an involved process, and the structure of the monitoring system will reflect that fact. This is especially true since the monitor will be monitoring the given system in realtime.

The internal organization of the monitoring subsystems will be as similar as possible. The only major differences will be the interfaces to the different sources of data (in-line subroutine calls, operating system debugger, and programmable logic analyzer). The subsystems will operate on different data from different sources; but, nevertheless, they will operate on all data the same way.

The monitor will be designed and implemented to be as intelligent as possible, but AI methodologies will not be stressed. Designing and implementing the monitor will, for the most part, be a systems programming task. The main purpose of the monitoring system, as it has been discussed thus far, is to provide the basis or foundation for a rule-based expert monitoring system. Within the given time frame, knowledge engineering companies will have canned software packages available for building such an expert system (see enclosure 1 of Durham, 11 July 1984). The problem is that the expert system can only be as good as the basis from which it is built. The monitor system is intended to provide an optimal foundation for that canned expert system.

The AI system will interface with the system monitor at the human interface layer and use the monitor in the same way that a human operator does. This will decouple the AI system from the actual system monitoring problems and allow it to be what it is intended to be. The AI system is intended to be a computer system that emulates a human expert. Ideally, this computer system will be a storehouse of the system monitoring knowledge of all the experts. The AI system will provide a mechanism for keeping the experts' knowledge with the search system so that when the experts leave, all the expertise does not leave with them.

The monitoring activity is to be transparent to all the other activities within the search system. A "system monitor guru" is responsible for maintaining the monitor system and configuring it for any given computer system that meets the specifications required by the monitoring system. The monitor is to be designed so that nobody needs to know about the monitoring activity but the monitor guru. The guru simply takes any computer system, "plugs" his monitor into that system, and then trains people how to use the monitor to monitor their computer systems. With this capability, they can then gain specific information about how their computer works in actual operation. Keeping the monitor transparent allows the monitor users to do their work and use the monitor as the tool it is intended to be.

Figure 46 is a block diagram of the conceptual design of the system. Each block is a stand-alone processing module, and the arrows between the blocks designate communication channels between each module.

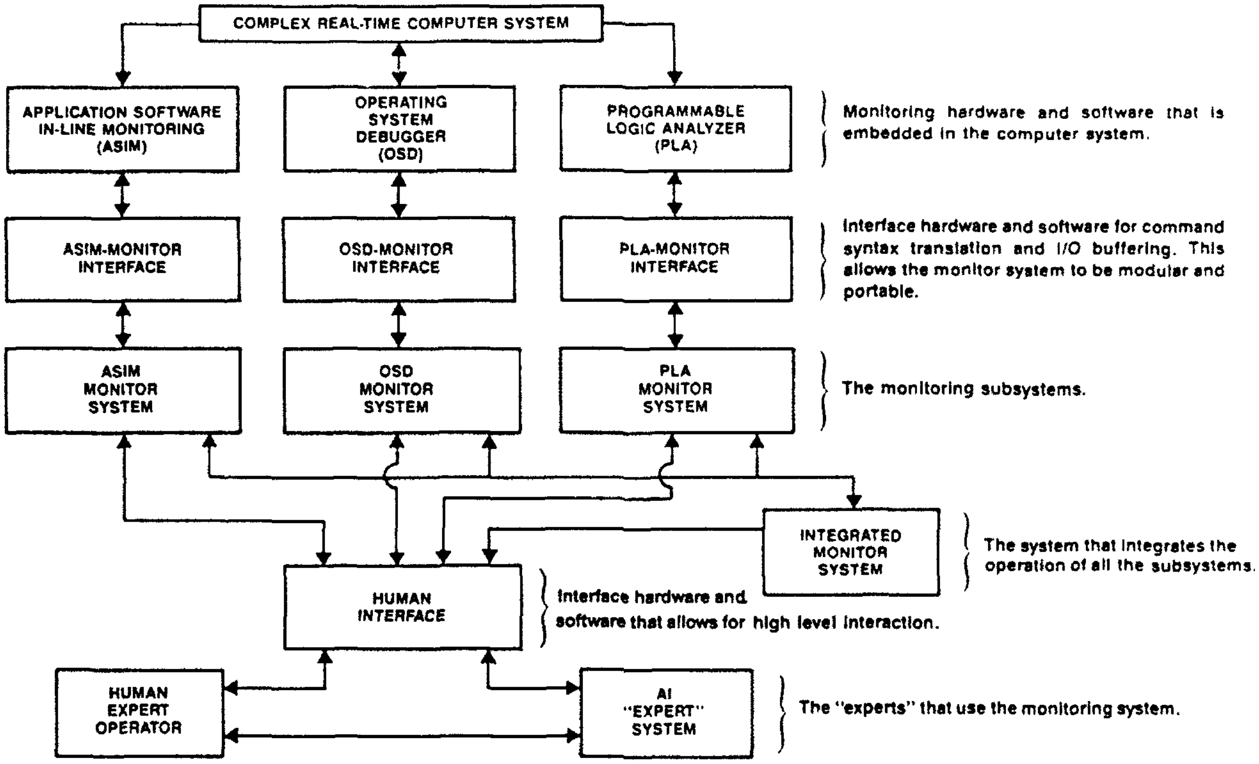


Figure 46. Conceptual block diagram of the system monitor.

DATA COMMUNICATIONS

Data communication technology considerations are presented under two headings. Acoustic telemetry is discussed first, and then data compression is addressed.

Acoustic Telemetry

The Data Communications Task. The data storage and communications task was extensive, and it began with a review of the technical literature and a "walking-talking" survey of the acoustic communications community. There was an effort to identify and understand the physics associated with undersea acoustic communications. Current capabilities were assessed and limitations, including physical constraints, that cannot be overcome by technological improvements were identified. The acoustic bandwidth of the in-water communication path was determined and then compared with the typical bandwidth required for the principal AUSS sensors. Estimates for transponder range and the envelope associated with reliable acoustic transmission were prepared. Also, alternative approaches for improving the bandwidth and for maintaining noninterfering communications with multiple vehicles were investigated. In addition, the problems that result from the simultaneous acoustical communication of multiple vehicles were identified and characterized.

Acoustic Telemetry Surveys. A brief acoustic telemetry survey was conducted at the inception of the FASS project. AUSS uses a fairly high data-rate system; and the people at Acoustic Systems Inc., having come to NOSC and obtained data concerning the design of our system, subsequently built their own version. Within the last two months, they have tested it successfully off the coast of Santa Barbara and are now trying to find customers who wish to buy it.

Acoustic Systems Inc. is not the only company in the business. Honeywell in Seattle has a system with model number MT–300, and International Submarine Technology Ltd., also in Seattle, has a system as well. However, the systems marketed by these two companies are designed primarily for shallow water applications where there is a severe multipath problem. The systems use multiple redundant frequency coding schemes to assure the data get through. Typically, they are happy to be able to get data rates as high as 50 baud. Clearly, such systems are of little use to the FASS concept.

One of the best acoustic systems is indeed the one invented here at NOSC and being built by Acoustic Systems Inc. Even though Acoustic Systems Inc. started with NOSC's ideas, they have implemented a large number of improvements over the NOSC design. The NOSC goal had been to develop something, to go out and prove a concept, and to make it work on the AUSS to prove the feasibility of that system. Acoustic Systems Inc.'s goal was to build a system that was reliable and saleable in the marketplace to satisfy a variety of customer's needs, used minimal power, and was easily engineered into different customer's hardware.

FASS has a real bandwidth limitation even if all it were trying to do was send up the data from one SLS, equivalent in resolution and quality to the Westinghouse SLS used on the Surface Towed Search System (STSS), in the single-beam mode. The problem is compounded if a multibeam sonar is used. The Westinghouse SLS in its simplest mode is a two-beam sonar (one beam to each side). If one considers a SWAP sonar that views a full circle of 360 degrees with 2-degree beams, it has 180 beams and data rate that is 90 times as fast as the Westinghouse sonar. This assumes that the pulse length is the same for both sonars. This is a data rate of approximately 1.2 megabits per second. If one wished to telemeter the data from one SWAP sonar to the surface in realtime, it follows that 250 data links of the kind used on AUSS (working at 4,800 baud each) would have to be used in parallel to do the job. If we had four FASS vehicles in the water at the same time, it would take 1000 systems. When one considers that an optimized telemetry system from Acoustic Systems Inc. uses 35 watts to transmit 4,800 baud from a depth of 20,000 feet, it could take 35 × 250 = 8,750 watts per vehicle.

The foregoing exercise clearly demonstrates how futile it could be to try and send all the data from a high-performance SWAP sonar.

However, it is instructive to examine whether the 4,800 baud achieved by AUSS really is all that can be accomplished. Fortunately, the situation is not quite that bleak.

A proprietary document from Acoustic Systems Inc., which may not be copied or given to their competition, is available to the FASS team. Its title is **DEEPSCAN - A Deep Ocean High Data Rate Acoustic Telemetry System** and it describes the Acoustic Systems Inc. acoustic telemetry system. There is also a very thorough analysis of the constraints that must be considered in order to build an optimal system. Several major points results from the analysis by Acoustic Systems Inc.'s Volberg:

1. The principal problem that affects system performance is signal-to-noise ratio. Signals arriving via the direct path are the desired ones. Those arriving by multipath due to scattering or reflections from the bottom or surface are noise and cause the direct path signal to deteriorate. This problem cannot be eliminated by increasing the source level, as the reverberated noise also increases along with it.

2. A second source of noise is the ambient noise level in the sea. This is caused by sea state, thermal conditions, ships, marine life, etc. The effects of this problem can be overcome by increasing the source level of the transmitter.

3. Single-bounce signals (off the surface or bottom) can usually be handled by proper design of the transducer to eliminate receipt of signals from behind.

4. A high-data-rate system requires that direct paths between the vehicle and the near surface receiver use sound rays that subtend angles that are not much greater than 45 degrees with respect to the vertical. This is because it becomes impractical to build transducers with the right beam pattern that can eliminate multipath noise from single-bounce paths.

5. Double-bounce signals are the ones that cause problems, even with a good transducer design with proper beam patterns.

6. Double-bounce, multipath signals have roughly three times the signal path as the direct path. Therefore, high-transmission frequencies help to eliminate this problem and improve signal-to-noise ratio. This is because high-frequency sound attenuates faster in seawater than low-frequency sound. Unfortunately, the direct path desired signal also attenuates, thus requiring increased source power levels in the transmitter as the frequency goes up.

Volberg has demonstrated that an optimal system, if it is designed to work at ranges from 3,000 feet to 30,000 feet, would have the following features:

1. Once an operational range has been established, the usable bandwidth must be determined. Good design dictates that the bandwidth be limited to the region

where transmitter power requirements across the band do not vary by more than a factor of two.

2. Center carrier frequency must be varied with range and should operate between 11 kHz and 28 kHz. The overall band used stretches from 4 to 41 kHz. Different portions of the band are used at different ranges.
3. Bandwidths available for data transmission get larger as the range gets smaller. The bandwidth at 30,000 feet is about 9 kHz, while at 3,000 feet it is 27 kHz.
4. A rough estimate of the power required on the vehicle to transmit a 4,800-baud signal is 35 watts.

Discussions with Volberg and his analysis are the basis for the following observations:

1. A slant range at 45 degrees is approximately 1.414 times the vertical distance between the vehicle and the surface transducer. If this number is simplified and a factor of 1.5 is used, then 30,000 feet corresponds to a depth of 20,000 feet and 3,000 feet corresponds to a depth of 2,000 feet; and these are broad limits of the FASS problem.
2. The NOSC/Acoustic System Inc. telemetry concept employs a design approach that uses pairs of data carrying sidebands spaced about a carrier. Each sideband has a bandwidth of 2 kHz. There needs to be some spacing between the sidebands and the carrier that uses up some of the total bandwidth. However, it should be possible to have a total of four sidebands at a range of 30,000 feet. Each sideband can carry 2,400 baud of data, thus giving a total capacity of 9,600 baud. The range of 3,000 feet offers even greater possibilities. It should be able to carry 12 sets of sidebands, which corresponds to 28,800 baud.
3. Power required on the vehicle for data transmission would be 70 watts at 30,000 feet and 210 watts at 3,000 feet, if maximum data transmission is employed.

None of the above observations have considered the fact that for the FASS concept, multiple vehicles would be running around and would all need to use the same set of acoustic frequencies to handle the data. It may be possible to handle this problem by using the "field of sonobuoys" concept. When this scheme is used, both the surface and vehicle transducers would be built with narrow-angle beam patterns. This requires that the vehicles always have a sonobuoy in view almost directly overhead.

This approach would probably improve other aspects of the telemetry problem as well. The narrower beam pattern would reduce the effects of ocean noise. The reduced angle would limit the slant range to less than 1.5 times the depth. However, while these effects will probably not greatly affect the overall signal bandwidth very much, they will improve the signal-to-noise ratio. This benefit can be used to improve signal reliability, or maintain the same reliability and reduce the transmission power requirements.

In addition, an independent assessment of how to handle FASS communications was solicited from the AUSS team (Mackelburg, August 1984). The conclusions from that assessment are as follows.

Many of the same communications and navigation techniques developed for AUSS could be adapted for use on FASS. Operation of up to four vehicles should be possible provided each remains within a vertical cone of approximately 90 degrees originating from its surface vessel. Low error rate (1 × 10-5) communications at 2,400/1,200 bps should be possible for each vehicle from depths of 2,000 to 20,000 feet with less than 100 watts of power. Each vehicle should employ synchronous independent single-side band modulation to enable the transmission of the output of standard modems over a 3-kHz frequency band. The frequency band from 8 through 20 kHz should be used. A subset of the existing acoustic link hardware and software would be adequate to perform the task. (New transducers would also have to be purchased for the higher frequencies.)

Although only 8 through 11 kHz and 11 through 14 kHz channels have been tested, analysis indicates that the 14 through 17 kHz and 17 through 20 kHz channels should also be adequate. It appears that there would be sufficient signal-to-noise ratio at these frequencies in spite of the higher absorption losses these frequencies incur. (Early BUMP tests indicated that 2,400-bps transmission was possible from 4,000 feet by using 40 through 43 kHz, so there should be no hidden pitfalls.) It is recommended that sea tests be conducted to verify these predictions.

Data Compression

The Data Compression Task. The investigation of data compression alternatives was of particular interest. A survey of the technical literature on data compression theory and the most effective approaches to become familiar with data compression terminology, techniques, and measures of performance were performed. The current efforts to implement a compression technique for the AUSS acoustic telemetry link were reviewed. This review provided background for the objectives, characteristics, and design trade-offs associated with data compression for an undersea search system. A review of the FASS project files was then conducted to understand the terms of the characteristics and increased quantities of data that may have to be transmitted from the multiple, sensor vehicles. Appropriate compression schemes for matching this data with the available bandwidth were proposed. Finally, an analysis of the expected compressibility of the data for the proposed techniques was performed.

Data Compression Conclusions and Recommendations. The following conclusions and recommendations regarding data compression were taken from Grace (January 1985). This reference presents the data compression approaches considered for FASS.

1. The channel capacities of all relevant sensors should be established. Knowing these capacities will provide a means of ensuring that data generation rates do not exceed the rates at which the sensors can provide information. The established channel capacities will also allow estimates of system performance to be expressed in terms of information transfer rates rather than data rates.
2. The high-resolution SLS data examined thus far can be separated into various categories. The analytical form of the functions that accomplished this separation suggests that information preserving techniques will not provide significant compression. Some means of selecting and processing sensor data image enhancement, pattern recognition, target detection, etc., will have to be employed.
3. A database of sensor data should either be established or located. Data processing and compression schemes must be developed relative to a representative sample of data since their specific form is dictated by the characteristics of the data. Likewise, a database is clearly required for any serious, informed estimate of system performance.

NAVIGATION OPTIONS

Navigation Options Task

The AUSS approach to surface vessel and sensor platform navigation was reviewed. The AUSS method for determining the positions of detected targets was also reviewed. Navigation accuracies relative to sensor swath width as inputs to the FASS performance analysis were determined in light of the candidate conceptual designs. Long baseline, short baseline, and ultrashort baseline products and capabilities were also identified. A market survey was conducted to identify a selection of products that could be used for the proposed navigation approaches.

Navigation Options Summary

The scope of the navigation task is shown in the summary of the report on navigation that is included as appendix D. This summary is presented below.

Many kinds of navigation errors are tolerable in a search system, so extra effort to improve navigation accuracy does not necessarily pay off in extra search performance.

The information rate from a navigation system is very small compared with typical rates from other search system sensors. Size, weight, acoustic bandwidth, and power consumption do not present problems for an underwater search vehicle.

Surface navigation can currently be done accurately to 10 feet near shore-based pingers; but it is hundreds of times less accurate than this, far from shore. New satellite systems should solve this problem within ten years.

Underwater navigation can soon be done with self-contained inertial systems accurate to a few tens of feet of drift per day. Presently, the most accurate underwater navigation is done with various types of acoustic pingers. Noise generated by the underwater vehicle itself is the factor limiting navigation accuracy, so best results are obtained when the navigator and searcher are designed together as a single system.

Bottom-mounted synchronous pingers used in a range-range mode theoretically offer navigation accuracies of a few feet at ranges to a few miles, although this performance has not been conclusively demonstrated.

The stability of the ocean's sound velocity profile over both time and space plays an important part in underwater navigation accuracy, and should be more closely examined.

SENSOR CANDIDATES

AUSS Sensors

The Sensor Candidates Task. To assess the AUSS sensors, the sensors currently employed on the developmental AUSS were reviewed and inventoried. A list that includes type of sensor, a manufacturer, major performance specifications, and cost was also prepared. In addition, it was noted whether there are improved versions of these particular sensors that have become available since the AUSS purchases were made. A survey was conducted of sensors that were not included in the AUSS configuration, especially those that have been developed since the AUSS design was fixed. Then, a list, similar to the one noted above, was compiled for use in evaluating potential AUSS performance and for characterizing the sensors to be used in the FASS performance analysis.

AUSS Sensor Information. While figure 47 presents the relationship of the AUSS vehicle sensor suit to the "on-vehicle" electronics, table 24 lists the AUSS search sensors and their manufacturers. For more complete descriptions of the search sensors and appropriate product literature see Kimberling (1984).

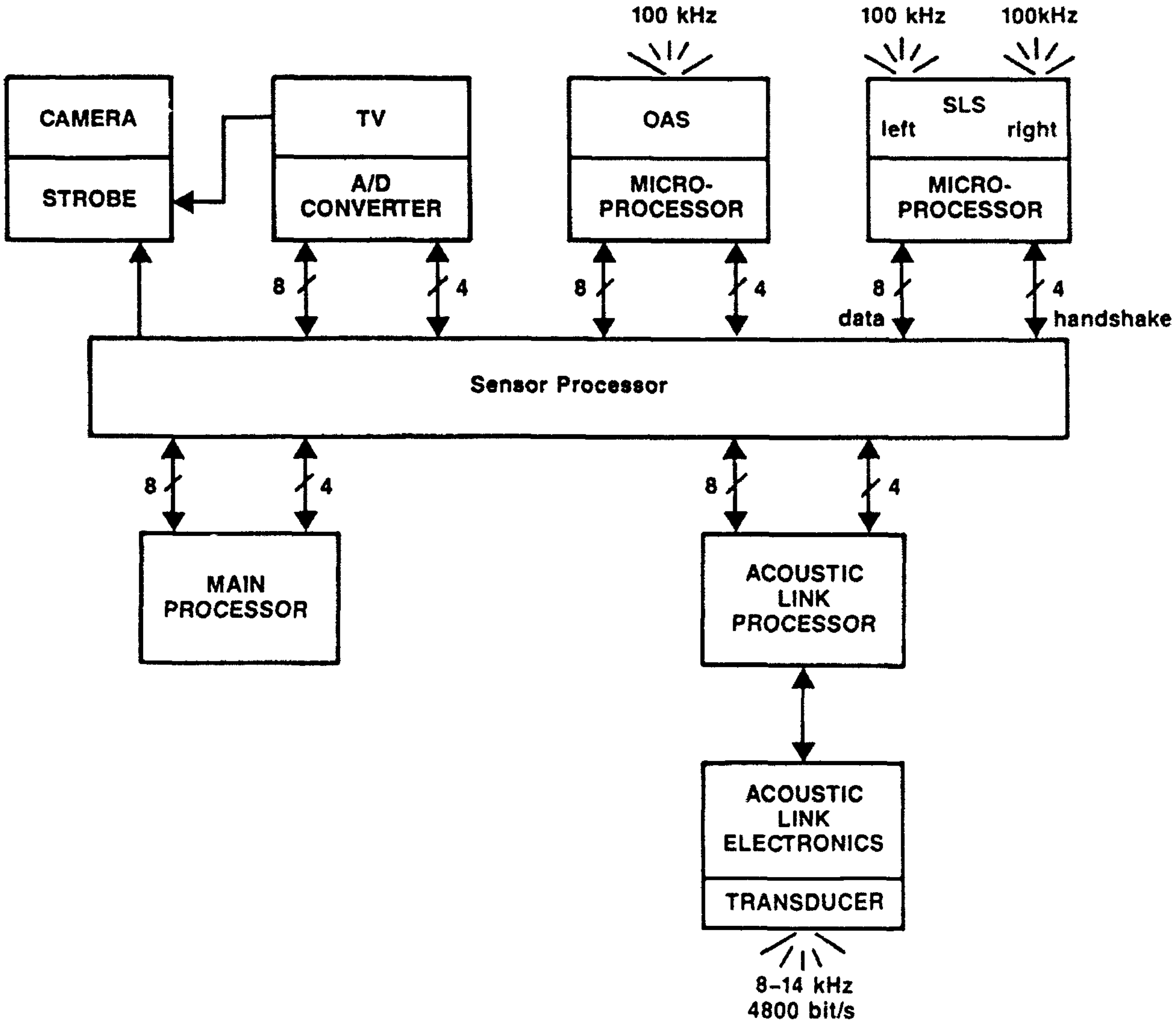


Figure 47. The relationship of the AUSS vehicle sensor suit to the "on-vehicle" electronics.

Table 24. AUSS search sensors.

Sensor	Manufacturer
Photographic Camera	Photosea Model 1200
Television Camera	Subsea Systems Model CM-8
Forward-Scanning Sonar	Edo Western Model 4059 Obstacle Avoidance Sonar (OAS)
Side-Looking Sonar (SLS)	Edo Western (custom-made for compatibility with sensor processor)

FASS Sensors

The FASS Sensor Candidates Task. Sensor complements for the contending FASS concepts were selected. These choices were then optimized for the search scenarios previously identified by working in conjunction with the analysis efforts. As a result, performance characteristics as inputs to the refined analyses were determined. Also, the data rate estimates were updated to assist in refining the telecommunications design. The market survey made in reference to the AUSS sensors was updated as well. Finally, recommendations were made regarding the type of sensors and candidate vendors and/or products most suitable for each FASS concept.

Optical Sensors. The focus of the investigation into this technology was on increasing the optical sensor swath width; it was not to do a market survey on possible sensors. The final choice of an optical sensor for FASS can be made part of the preliminary design once the final concept is established.

The following paragraphs of this subsection will address the question of increasing the optical sensor swath width.

Two versions of the Autonomous Search Vehicles candidate system are still being considered: an optical search vehicle and a sonar vehicle. Either will acquire data at a rate much higher than can be sent without degradation over an acoustic link, so the basic tradeoffs are the higher search rate of sonar versus the zero rate of false targets for optical sensors. The resolution required is highly dependent on the target, and the definitions of sonar and optical resolution are different. However, if the search rate of an optical sensor could be made nearly that of a sonar of adequate and comparable resolution, the optical sensor would be chosen.

Search rate can be improved by increasing vehicle velocity or sensor swath. Thrust power is proportional to the cube of velocity, which is why the sonar's 300-foot swath is so attractive compared to the 40-foot swath for a camera. Optical swath improvements require a combination of increased altitude and field of view. The former has exponential effects on lighting power (or receiver sensitivity), while the latter is limited by sensor dynamic range (i.e., picture too bright in the middle or too dark on the edges). In any case, the fog created by lighted particles in suspension must not eliminate the contrast between the target and background.

The availability of very-low-light level imaging devices enables us to reduce the required light intensities by orders of magnitude. An SIT camera has an effective ASA rating of 200,000 whereas ASA 400 film was assumed for AUSS. Such cameras would make it possible for the AUSS to see from a height of approximately 100 feet, instead of 39 feet. Unfortunately, with the present conventional lighting geometry, backscatter would reduce target contrast to undetectable levels.

Underwater illumination consists of direct unscattered light, subject to r-squared losses and exponential attenuation, and indirect scattered light, with a much more complex function. This latter component, ignored in the original AUSS design calculations, actually dominates at larger ranges. The light returning to the camera from a target or from the bottom will also be attenuated and its image will be clouded by the backscatter. (The image will also be blurred by forward scattering, but this effect is ignored in this analysis.) Whether a target is discernible depends on its image contrasting sufficiently with the bottom.

W. L. Mertens (1970) presents semiempirical equations for calculating the illumination at any distance from an underwater light source and the attenuation that will occur to the camera image of any object at that location. Also, by using equations from Mertens (1970) and numerical integration techniques, it is possible to determine the total backscatter contribution along any optical ray between the bottom and camera. The focal plane images of the bottom and any target thereupon will both be brightened by that contribution, thus reducing the contrast. Although details are not given, B. L. Patterson (1971) used a similar technique in investigating the LIBEC concept.

We have developed a BASIC program that permits us to compare different cameras and lighting geometries, including LIBEC and ROMS (figure 48). We have found that LIBEC would significantly reduce the AUSS backscatter, but the ROMS technique could totally eliminate it: there would be no "common volume," no water lighted by the source and seen by the camera. LIBEC geometry is incompatible with a single free-swimmer, and ROMS's synchronously scanned spot source and receiver are too large and complex. But ROMS is merely the ultimate in source-receiver separation. Our approach has been to evaluate approximations to this ideal, using more conventional sources and imaging receivers.

```
10 REM        Program to determine the contrast of an in-water photograph.
20 REM        Target  contrast  must exceed  0.02 to  be visable.  Program
30 REM        also calculates the watt seconds of light needed to illumin-
40 REM        ate a given area.
50 REM
60 REM                  Most equations were obtained from IN-WATER
70 REM                  PHOTOGRAPHY by MERTENS,pages 101 thru 104.
80 REM
90 REM *****************************************************************
100 REM *    ALPHA ....................... ATTENUATION COEFFICIENT (PER FT)    *
110 REM *    ALT ........................... VEHICLE'S ALTITUDE FROM BOTTOM    *
120 REM *    BETA ................................. BEAM WIDTH IN RADIANS    *
130 REM *    BOTTOM ........................ APPARENT BRIGHTNESS OF BOTTOM    *
140 REM *    C1 AND C2 ........................... CONSTANTS FROM PAGE 103    *
150 REM *    CAMH ......................... CAMERA'S HORIZONTAL FIELD OF VIEW    *
160 REM *    CAMV ........................... CAMERA'S VERTICAL FIELD OF VIEW    *
170 REM *    DIST ............................. SOURCE RECIEVER SEPARATION    *
180 REM *    E ....................................... ILLUMINATION AT TARGET    *
190 REM *    EF .......................... ILLUMINATION AT CORNERS OF PHOTO    *
200 REM *    KAPPA ................................ BACKSCATTER COEFFICIENT    *
210 REM *    I ..................................... NORMALIZED SOURCE INTENSITY    *
220 REM *    INT1, INT2 AND INT3 ........ INTEGRALS FROM PAGE 104 COLUMN 1    *
230 REM *    L ................................................ LIGHT AT DISTANCE R    *
240 REM *    LF ...................................... LIGHT AT CORNERS OF PHOTO    *
250 REM *    R ................... RANGE FROM CAMERA, INTEGRATION VARIABLE    *
260 REM *    R1 ............... DISTANCE FROM CAMERA TO FIRST RAY OF LIGHT    *
270 REM *    RT .................. DISTANCE FROM CAMERA TO CORNER OF PHOTO    *
280 REM *    SCATTER ....... BRIGHTNESS OF BACKSCATTER AT CORNERS OF PHOTO    *
290 REM *    SIGMA .......................... SCATTERING FUNCTION (pg. 38)    *
300 REM *    TARGET ........................ APPARENT BRIGHTNESS OF TARGET    *
310 REM *    WSAIR ................WATT SECONDS IF PHOTO WERE TAKEN IN AIR    *
320 REM *    WSWATER ................................ WATT SECONDS IN WATER    *
330 REM *****************************************************************
340 REM
350 REM
360 CLS : KEY OFF
370 ASA = 200000!
380 FSTOP = 3.5
390 ALPHA = 1/36
400 BETA = 1.5
410 KAPPA = ALPHA/2.5
420 SIGMA = ALPHA/200
430 I = 1
440 PI = 4 * ATN(1)
450 INPUT "INPUT SOURCE-RECEIVER DISTANCE":DIST
460 INPUT "INPUT CAMERA'S FIELD OF VIEW (eg. 62,82)": CAMV,CAMH
470 INPUT "VEHICLE'S ALTITUDE FROM BOTTOM": ALT
480 CAMV = (CAMV/57.29)/2 : CAMH = (CAMH/57.29)/2
490 R = ALT/COS(CAMH
500 RT = R/COS(CAMV)
510 GAMMA = ATN((DIST-R*TAN(CAMV))/R)
520 THETA = 90/57.29 - (GAMMA + CAMV)
530 R1 = DIST * COS(CAMV) * TAN(THETA) + DIST * SIN(CAMV)
540 INT1 = 0 : INT2 = 0 : INT3 = 0
550 TEMP1 = DIST * SIN(CAMV) : TEMP2 = (DIST * COS(CAMV))^2
560 FOR R = R1 TO RT STEP .1
570       L = SQR((R - TEMP1)^2 + TEMP2)
580       INT1 = INT1 + EXP(-(ALPHA * (L + R)))/(L * L)
590       INT2 = INT2 + EXP(-(KAPPA * L) - ALPHA * R)/L
```

Figure 48. Listing of a program to determine the contrast of an in-water photograph.

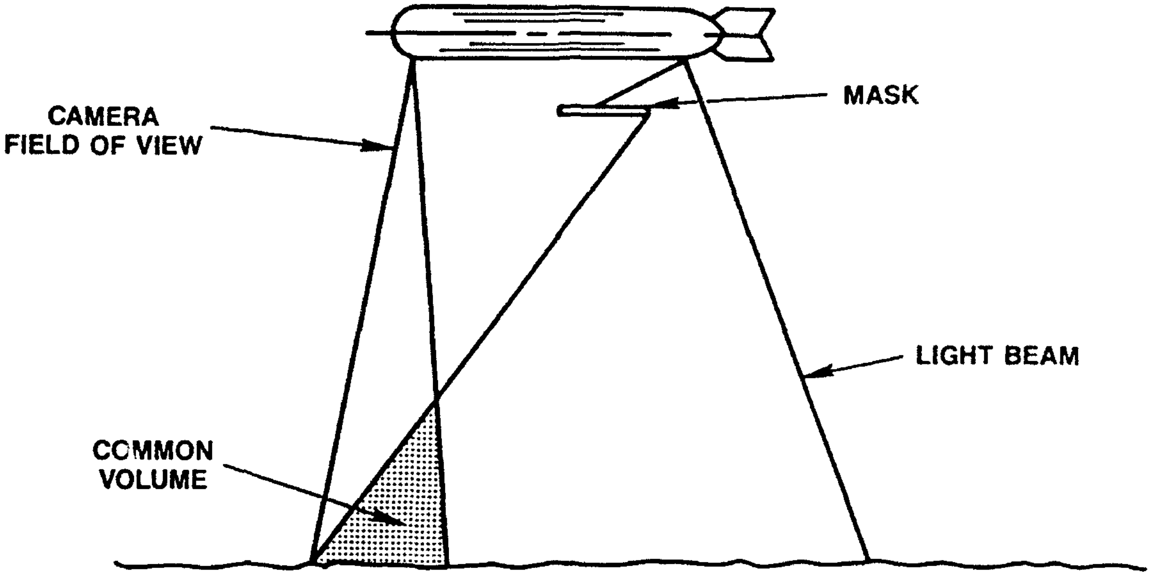
```
600       INT3 = INT3 + EXP(-(2 * KAPPA * L) - ALPHA * R)/L
610 NEXT R
620 C1 = (2.5 - 1.5 * LOG(2 * PI/BETA)/LOG(10)) / (4 * PI)
630 C2 = C1 * 7 * SQR(2 * PI/BETA)
640 E = I/(L*L)*(EXP(-(ALPHA*L))+C1*KAPPA*L*EXP(-(KAPPA*L))+C2*KAPPA*L*EXP(-(2*K
APPA*L)))
650 SCATTER = SIGMA * I * (INT1 + C1 * KAPPA * INT2 + C2 * KAPPA * INT3)
660 TARGET = (.18/PI) * E * EXP(-ALPHA*RT)+SCATTER    '.18 ASSUMED REF. OF TAR.
670 BOTTOM = (.036/PI) * E * EXP(-ALPHA*RT)+SCATTER  '.036 ASSUMED REF. OF BTM.
680 LF = P/COS(GAMMA)
690 EF = I/(LF*LF)*(EXP(-(ALPHA*LF))+C1*KAPPA*LF*EXP(-(KAPPA*LF))+C2*KAPPA*LF*EX
P(-(2*KAPPA*LF)))
700 WSAIR = 2 * FSTOP^2 * LF^2/ASA
710 WSWATER = WSAIR / (EF * EXP(-ALPHA * RT) * LF * LF)
720 PRINT : PRINT USING "TARGET CONTRAST = #.###"; (TARGET-BOTTOM)/BOTTOM
730 PRINT "WATT SECONDS WATER =";WSWATER
740 INPUT "AGAIN (Y OR N)"; CH$
750 IF CH$ = "Y" THEN PRINT : GOTO 450
760 END

B>
```

Figure 48. Listing of a program to determine the contrast of an in-water photograph. (continued)

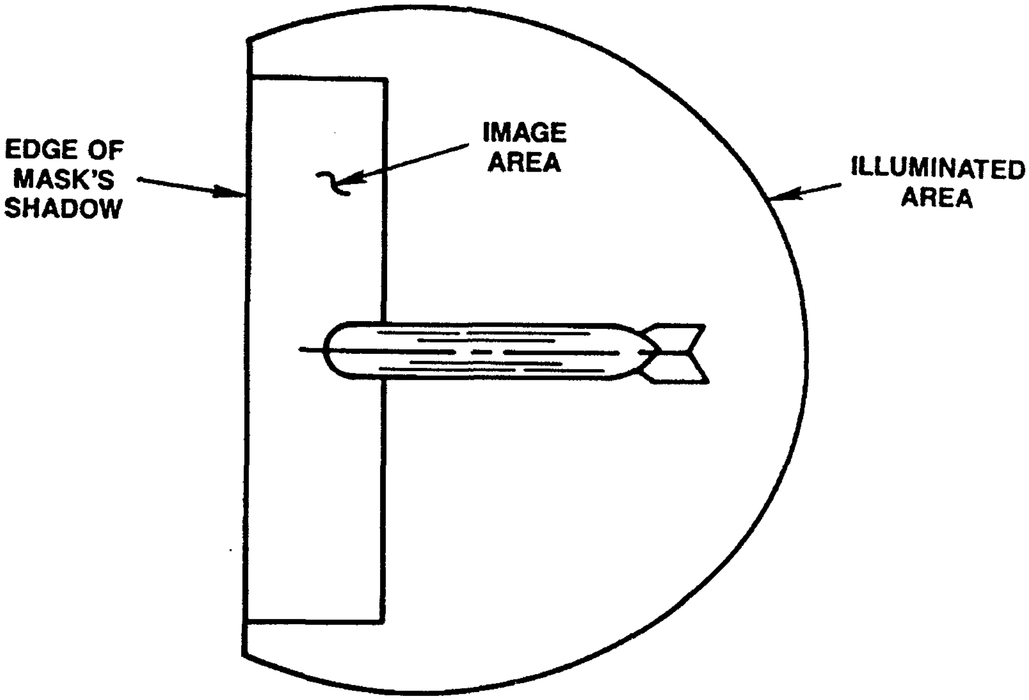
We have assumed a torpedo-shaped body with an SIT camera looking straight down from its nose, and a light source in its tail. The geometry is shown in figure 49. The most important feature of the system is that light not be projected beyond the forward edge of the camera's field of view. (For the sake of discussion, we will assume this is accomplished with a conventional strobe and a dark mask that casts a shadow right at the edge.) As a result, the common volume is reduced to the absolute minimum required to illuminate the entire field.

If the port-starboard field is the horizontal camera aspect, then the fore-aft angle is the vertical field of view. Notice that, as the camera's vertical field of view decreases, so does the common volume. In the limit, the camera has an infinitesimal vertical field; the system is effectively a ROMS with no moving parts.

Figures 50 through 53 show the strobe requirements and the maximum possible vertical field of view, both plotted as a function of swath width. These are done for all four combinations of 60-degree and 90-degree camera horizontal field of view and for 12-foot and 24-foot source/receiver separation. In each case, as the vehicle's altitude increases and the swath widens, the strobe must be brighter to illuminate the upper (forward) corners of the image; and the vertical field of view must decrease to preserve minimum contrast at the lower (aft) corners.



a. Side view.



b. Top view.

Figure 49. Optical geometry model.

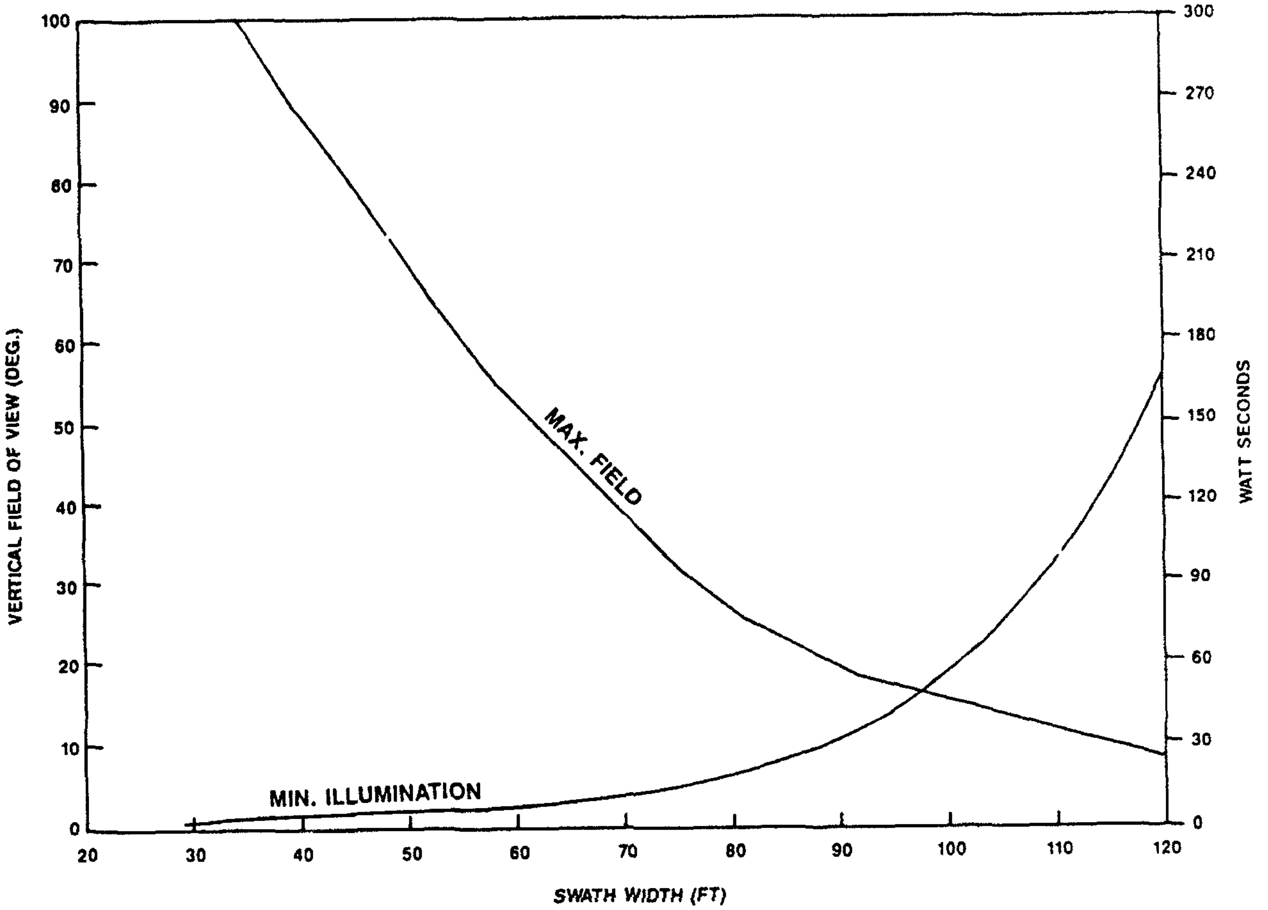


Figure 50. Optical geometry model: 60-deg horizontal field and 12-ft separation.

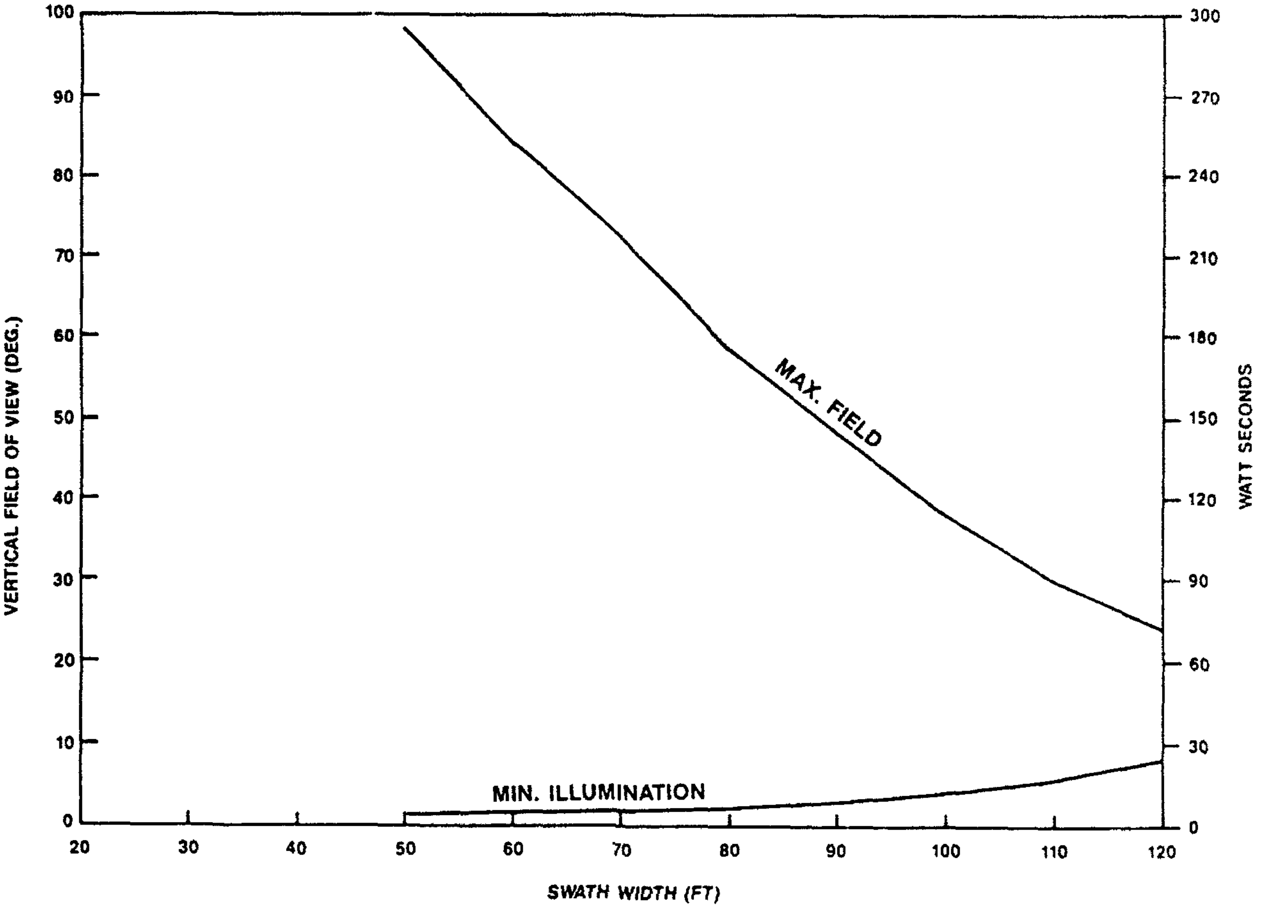


Figure 51. Optical geometry model: 90-deg horizontal field and 12-ft separation.

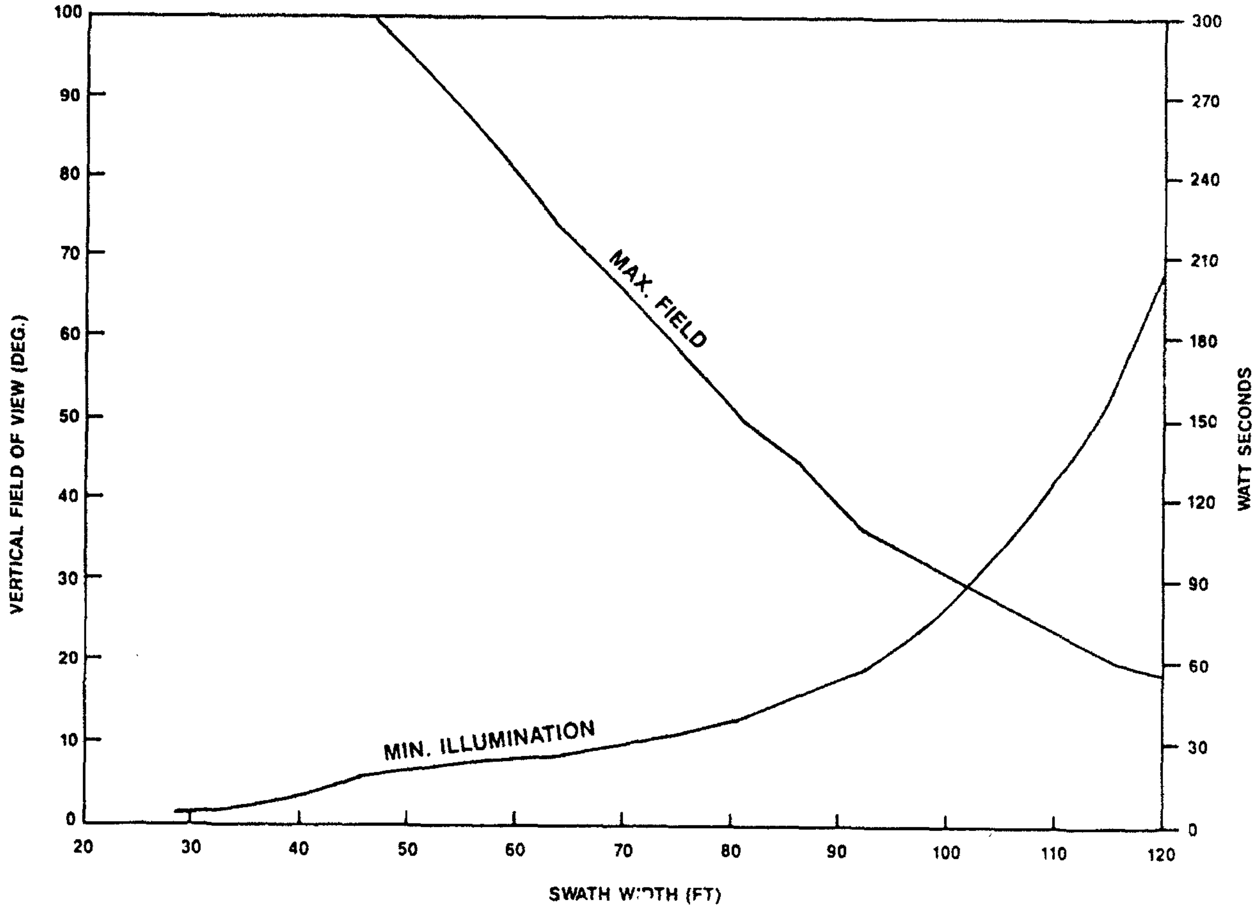


Figure 52. Optical geometry model: 60-deg horizontal field and 24-ft separation.

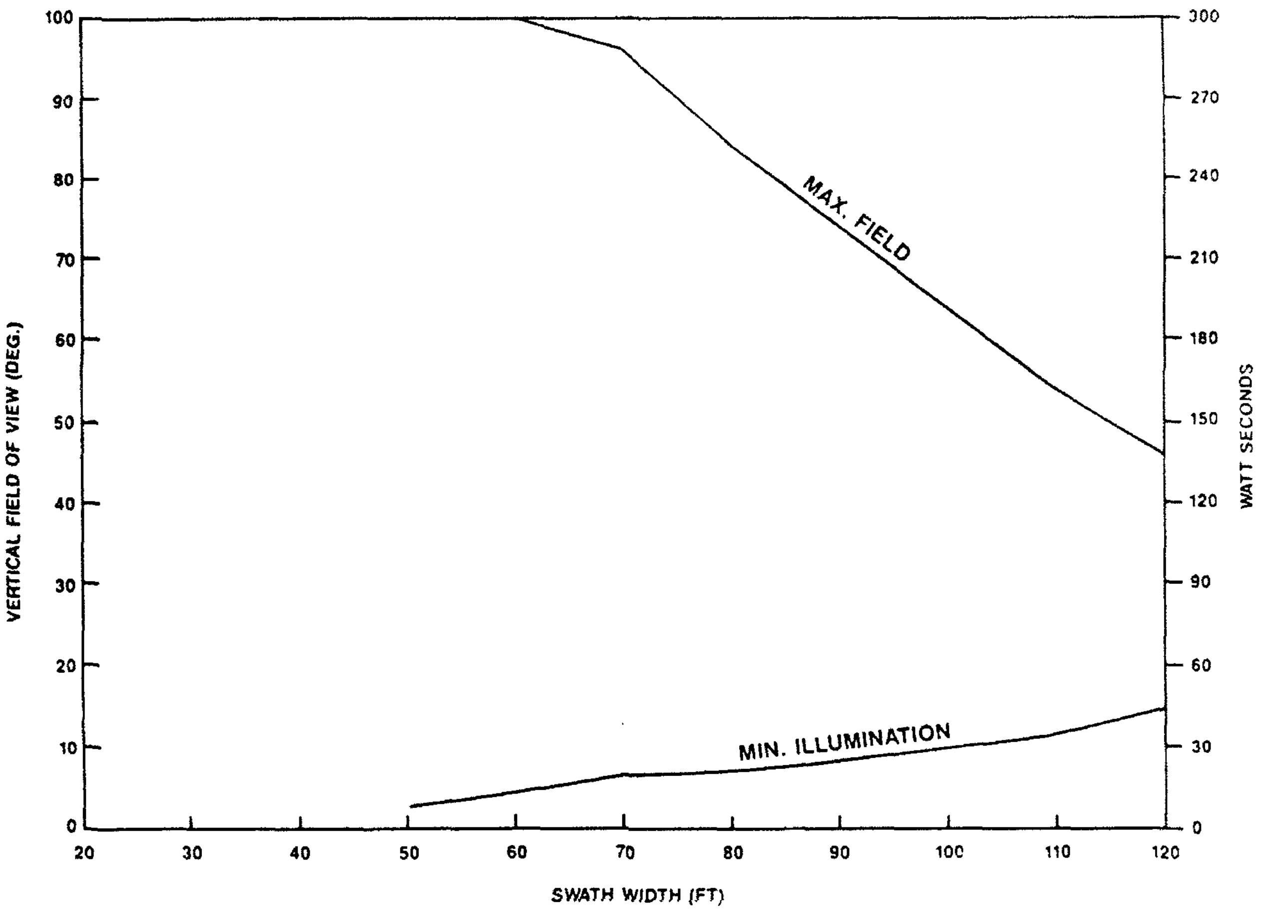


Figure 53. Optical geometry model: 90-deg horizontal field and 24-ft separation.

Whereas these illustrations may seem to contain far too much data and too little information, the following important observations can be made:

1. Bigger horizontal angles are better, for both minimum light and maximum vertical field of view. This is because the vehicle flies lower to get a given swath width.

2. Maximum separation between source and sensor is also desirable. But it is a less important factor than is horizontal angle.

3. Power is so low that it is not a major factor. And with an ISIT, it would be only a tenth the values plotted.

Figure 51 represents a 90-degree camera horizontal field of view and a 12-foot source receiver separation. This is probably an achievable geometry. The ANGUS film camera is only 82 degrees, but if necessary we could use two 45-degree SIT's side-by-side. And a separation beyond 12 feet implies a towed or spar-mounted light, that would involve special alignment, masking, and deployment problems. At a 100-foot swath (50-foot altitude), figure 51 implies we could have up to a 35-degree vertical field of view before becoming contrast limited. This means a single frame (or two, if twin cameras are used) would cover an area 30 by 100 feet. The strobe would be only 30 watt-seconds, and at 10 feet/second would strobe every 3.0 seconds. The single-vehicle area search rate would be 0.1 square nautical miles per hour, 2.5 times that of the AUSS photo system and about half that of the high resolution sonar.

Even at this swath there is concern over the dynamic range. The required illumination range is only six to one, from the dim upper corners of the image to the brightly lit lower center. But the image of the bottom at lower center contains 165 times as much scatter as actual bottom reflected light. This region actually appears 250 times brighter than the upper corner. With 8-bit digital coding, that is our entire range. But, if we digitize to 12 bits, we can substract off the backscatter and then store six bits per pixel.

These calculations are based on various rules of thumb and assumptions, most of which are listed in table 25 along with their sources. The analysis is simplistic when compared to B.L. McGlamery's (1975) work — that will serve as the Woods Hole Oceanographic Institution (WHOI) basis for analysis — and we would hesitate to extrapolate the results much beyond the 100-foot swath width. Therefore, it would be naive to put a great deal of faith in the accuracy of the numbers plotted. Nevertheless, the trends are clear and they lead to the following conclusion:

> We can achieve significantly wider optical swath than AUSS by using a fan-shaped beam of light carefully matched to a low-light camera having a very short but wide field of view.

This technique could double (or more) the optical search rate of free swimmers, and/or cut the requirements for navigation accuracy during sonar target evaluation. Nevertheless, sonar's swath will not be approached by an optical system. We will proceed with a search for sources of fan-shaped light beam and, regardless of which candidate system is selected, it is recommended that the FASS program include plans to test the geometry described herein.

Table 25. Assumptions used in the analyses.

Rules of Thumb and Assumptions	Source
1. The attenuation length of clear seawater is 12 meters (38 feet).	Woods Hole Oceanographic Institution (WHOI)
2. A SIT camera has an effective ASA of 200,000.	WHOI
3. The scatter coefficient of clear seawater is about equal to the attenuation coefficient divided by 2.5.	Mertens, 1970, p. 108 (see text)
4. The scatter function for angles up to 90 degrees from the light source is about 1/200 the attenuation coefficient.	Mertens, 1970, p. 108 (see text)
5. The reflectivity of the bottom is assumed to be 0.0036; a target is five times that. These are rather arbitrary assumptions, but probably as good as any.	Pattern, 1971 (see text)
6. Minimum detectable contrast is 0.02.	Patterson, 1971 (see text)

Acoustic Sensors. Potential acoustic sensors for FASS were evaluated, but the evaluation has not as yet been fully documented. However, Thorn (1984) does present some data on focused versus unfocused SLS; especially interesting are the design rules of thumb drawn from George A. Gilmour's syllabus on **High Resolution Sonar**.

SPECIALTY ENGINEERING

Specialty Engineering Task

A review, based on the lessons learned from previous development projects (e.g., the Precise Integrated Navigation System [PINS]), was made of the significance of and the approaches for accommodating reliability, maintainability, and life-cycle issues in the context of FASS development. The relative importance of generic features and how they are likely to impact system performance, operational efficiency, and system availability were assessed. Reliability features, maintenance procedures and staffing, spares (subsystems, components, and parts), and cost and storage of consumables were also considered. Finally, some specific specialty engineering recommendations regarding the FASS design were offered.

Introduction to Specialty Engineering

Appendix E presents a thorough introductory discussion on specialty engineering. It is a distillation of the knowledge and experience gained (often painfully) during the time the author was leading the PINS Technical Design Agent (TDA) team at NOSC. The real-world requirements of a system design are many, important, and often too long ignored or inadequately addressed by system designers. As mundane and technically uninteresting as they may be to most design engineers and scientists, the subjects addressed under the heading of specialty engineering probably have the biggest impact on system cost, amount of work to be done, and ultimate success of the system. And like it or not, they ultimately receive the most attention and time from everyone involved in the project.

This appendix particularly addresses the impact of specialty engineering on early system design efforts.

Specialty Engineering Recommendations For FASS

Introduction. Appendix E lays the groundwork for why specialty engineering aspects of design should be considered during conceptual design. This subsection will address a set of specialty engineering recommendations for the Fast Area Search System (FASS) design, based on some assumptions about the probable nature of its deployment and usage.

Assumptions About FASS Future. The following assumptions are postulated as a basis from which to derive recommendations for future development strategies for FASS. They are also expected to impact the present conceptual design details to some extent.

1. Number of Systems: 1 or 2
2. Location: SUBDEVGRU ONE and possibly the East Coast
3. Operational Staff: Military, augmented by ISEA for unique operations
4. Support Staff: Navy Techs, Contractor, ISEA
5. Design Stability: Evolutionary
6. Usage: Dedicated ship for routine operations. Fly-away rapid deploy and ships of opportunity. Changing conditions may require onsite modification.

Probable Support Environment. It follows from the above assumptions that a relatively small, dedicated support environment will be required for FASS, much as is presently provided from other SUBDEVGRU ONE systems, such as the Deep Submergence Rescue Vehicle (DSRV). The support environment would have the following features.

Training. Given so few systems, no formal Navy schools will be set up to address FASS. At most some vendor-provided courses might be used to train operators or maintainers on specific subsystems of FASS, such as the navigation subsystem or specific sensors. The remainder of the system training will probably be acquired by self-guided study of the technical manual and tutored on-the-job training. It may include training aids such as video tapes and simulator-driven use of the system.

Engineering Support. The design is expected to change with the state of the art, to solve problems, to adapt to special or changing search requirements, and to adapt to changes in availability of spares. Such a small number of systems will carry no-clout with vendors, so it is expected that some subsystem designs will change in uncontrollable ways. Some form of engineering support will be necessary to determine fixes, find alternate sources, or make system alterations to accommodate the changes. The support for these efforts would most likely come from a combination of NOSC engineers acting as the In-Service Engineering Agent (ISEA), Navy technicians working as system maintainers, and support contractor technicians operating a maintenance depot at SUBDEVGRU ONE.

Spares Procurement. Normally spares would be purchased through either regular Navy Supply channels or through the depot contractor's commercial purchasing methods. In either case, the spares would be inspected and tested for acceptability upon their receipt before being put on the shelf (or in the hold). Those spares that require fabrication from purchased parts or modification of purchased subsystems would probably be worked on by the Navy or depot technicians. For rapid deployment and high availability at sea, the system would probably maintain a fairly large stock of spares.

Recommended Specialty Engineering Features. Recommendations, for each of tl specialty engineering disciplines, are made below. They will address features of system design that might be affected soon or the ways in which future work should be accomplished. All of this assumes that the system is being designed so that the final design matches the task it will be called on to perform.

Reliability. Although not a combat system, the FASS will be an important Navy asset for use at sea. Hence, it still requires high-operational availability. Since a feature of FASS is the use of multiple vehicles and parallel signal/data processing channels, the overall system reliability will be impacted strongly by redundancy and graceful degradation of capabilities as failures occur. System simplicity would contribute greatly to reliability.

Maintainability. The critical factor here is the presence of dedicated and trained maintainers. This requirement is critically interdependent on the presence of good, detailed documentation, manuals, training aids, and adequate test equipment. If these conditions hold, specially developed test sets can be avoided. Circuit-level repair might be possible, given such technicians, but possible, board level or even box level replacement is more desirable, with later offline repair of circuits. To support board level replacement, Automatic Fault Indication (AFI) to the board level should be included in the FASS design. To facilitate system checkout prior to launch of vehicles, some form of end-to-end system test capability should be built in. This might include simulators that could also aid in operator training ashore, in-port or in-transit. The biggest contributor to maintainabitity, however, would be overall system simplicity.

Safety. The assumption of well-trained maintainers allows for much of the safety of the system to be derived from proper procedures, rather than extensive designed-in features. It does place more requirements on the technical manuals and training aids. Air shipment may place some design constraints, such as the batteries used.

Environmental Testing. Given that the system could be required to operate almost anywhere and in any season, a full set of environmental requirements should be assumed, and hence tested. Air-borne shipment should also be considered. Designs and tests for ruggedness would also contribute to overall system reliability.

Human Engineering. FASS will undoubtedly place a heavy load on its operators and data analysts. Some of it can be automated. Past experience in the search mission, however, indicates that modifications will be required to meet special circumstances. To make modifications to a highly automated, highly integrated system is very difficult and requires extensive regression testing following such changes to assure proper system operation. Hence, the goal in FASS should be to implement automation aids where feasible, but to also maintain overall system simplicity. This means that human engineering efforts should be aimed at improving man-machine interactions for the most tedious and error-prone functions (e.g., image analysis and maintaining vehicle track). Command and control functions should remain in the hands of skilled operators so that operations can be customized and refined to meet special situations. If command and control aids are to be used, they must also be readily adaptable. Once again, the key to good human engineering will be system conceptual simplicity.

Packaging, Handling, Shipping, and Transportation (PHS&T). The prime requirement here will be for air shipment. Another is to assure that adequate space is allocated in system designs and layouts for spares storage.

Technical Manuals. Given the staffing and training predictions made above, the quality of the technical manuals and supplementary documentation is extremely important.

Technical Documentation Package. Since FASS is expected to be essentially user-maintained and evolutionary in its design stability, the drawing package needs to be designed for ease of configuration management. A relatively flat tree of technical drawings would help this process. By this is meant a set of drawings consisting primarily of top-level assembly drawings and detailed design drawings. Changes should then appear on only one or the other, but not on several intermediate documents. Care should be taken to eliminate duplicate information. Besides the technical descriptions, the documentation package should include purchase documents and acceptance test specifications for present spares. These documents should then be kept up to date by support engineering as changes occur in the spares available.

Software Support and Quality Assurance. The anticipated need to make system alterations to meet special circumstances requires that the maintenance staff have the ability to modify software as well. To do this properly implies that an adequate Software Support Activity (55A) be established at the user's facility. It also means that any software developed for FASS be done so according to MIL-STD-1679 methodologies to support software maintenance activities. Likewise, the project must provide an adequate software support environment including:

1. Computer
2. Compilers
3. Debuggers
4. Simulations
5. Software configuration management tools and controls.

Quality Assurance, Configuration Management, and Integrated Logistics. These specialty engineering subjects have been included under other discussions. All three will be procedures followed by user, ISEA, and depot staff. Policing of the procedures will have to be by the user, SUBDEVGRU.

Disclaimer. The recommendations detailed above are based on the assumptions presented at the beginning of the subsection. Should any of those assumptions be changed, the recommendations will have to be reexamined.

REFERENCES

Durham J. NOSC Memorandum Ser 943/59–84 dated 11 July 1984, Conceptual Design of a System Monitor.

Durham J. NOSC Memorandum Ser 943/63–84 dated 16 July 1984, Prelude to Discussion of AI Applications for FASS.

Durham J. NOSC Memorandum Ser 943/71–84 dated 8 August 1984, Investigation of Target Discrimination for FASS.

Durham J. NOSC Memorandum Ser 943/76–84 dated 13 August 1984, Automatic Target Detection for FASS.

Durham J. NOSC Memorandum Ser 943/79–84 dated 15 August 1984, A Mission Planning Expert System For FASS.

Durham J. NOSC Memorandum Ser 943/82–84 dated 15 August 1984, Response to Question About Automatic Target Detection.

Durham J. NOSC Memorandum Ser 943/86–84 dated 27 August 1984, Response to Questions Concerning NOSC Memo 943/83-84.

Grace, D. NOSC Memorandum Ser 945/171–84 dated January 1985, NP Tour Report (Data Compression).

Kimberling, D. A. NOSC Memorandum Ser 942/58–84 dated 12 June 1984, Search Sensors.

Mackelburg, J. NOSC Memorandum Ser 943/69–84 dated 8 August 1984, Adaptability of the AUSS Acoustic Link to Potential FASS Requirements.

McCord, M. NOSC Memorandum Ser 941/87–84 dated 25 July 1984, FASS Information Processing.

McCord, M. NOSC Memorandum Ser 941/119–84 dated 27 September 1984, FASS Information Processing Design Concepts.

McGlamery, B. L. January 1975. *In Computer Analysis and Simulation of Underwater Camera System Performance*. Scripps Institution of Oceanography (SIO), San Diego, CA.

Mertens, W. L. 1970. *In-Water Photography Theory and Practice.*

Patterson, B. L. March 1971. "Increased Ranges for Conventional Underwater Cameras," *Proceedings of the SPIE*, vol. 24, p. 143.

Solorzano, M. R. NOSC Memorandum Ser FASS 01 dated 18 June and 5 July 1984, AUSS Vehicle Command and Control Summary.

Thorn, J. NOSC Memorandum Ser 945/98–84 dated 23 July 1984, Focused versus Unfocused Side-looking Sonars.

CONCEPTUAL DESIGNS

INTRODUCTION

A candidate systems approach to the FASS feasibility study was used to provide first the engineer and then the reader with a specific focus as various system and subsystem options were considered. Each system description presented a snapshot of an integrated system configuration to meet the FASS objective of substantially improving undersea search-system performance.

Each of the candidate systems went through a development process. Once the initial idea was proposed, a brief description of the concept was prepared. The concept was then presented to and reviewed by the FASS task team and the oversight committee. While the process was proceeding, techniques were identified for each of the concept parameters, pros and cons were inventoried, and search rate performance was analyzed. When all the candidate systems had been put forward, they were given a priority according to their likelihood of meeting the FASS objective. Three of the candidate systems were selected for further study:

1. Concept A — Multiple AUSS

2. Concept B — Dual-Vehicle Search Teams

3. Concept C — Autonomous Search Vehicles.

These three systems are discussed in detail below. All of the candidate systems are discussed in Appendix A.

The following system features were considered for each of the FASS concepts: architecture, tactics, operational procedures, contact evaluation, personnel, energy considerations (the FASS energy budget is discussed in appendix F), and mobilization. In addition, numerous subsystem features were also examined: sensors, communications, command and control, navigation, information processing and display, vehicle characteristics, vehicle handling, control van, support van, and surface vessel. Although this information provides a foundation for preliminary design, no design optimization was achieved. And, while all of the features were not addressed in the same depth, the coverage was adequate for the feasibility study goals. During the preliminary design effort all of the pertinent design features will be fully addressed. The references provided at the end of the section present more detailed information on the topics noted above.

MULTIPLE AUSS CONCEPT

Introduction

The multiple AUSS concept is based on the existing AUSS technology and tactics. It will incorporate two or three AUSS-like vehicles, with AUSS-like sensors, communications, and control computers. The vehicles will be deployed with an AUSS-like launch/recovery ramp and will be acoustically linked with the control van using an EARS-like towed transducer. Since this FASS concept is using the technology and search techniques being developed for the single AUSS project, there will be a minimum of technology development and risk.

The specifics of the multiple AUSS concept are summarized below.

1. The support ship will deploy two or three free–swimming search vehicles.
2. Sonar (side-looking or spot-scanning) will be the primary search sensor with optical sensors providing target identification data.
3. Communications and search data telemetry will take place over a time-shared acoustic link (a two-to-one or three-to-one data compression will be required over the baseline AUSS information rate).
4. Search data will be analyzed in near real time.
5. One acoustic transducer fish will be towed on a short cable behind the support ship for low-noise acoustic communications.
6. One large control van will contain the equipment and personnel for the control, navigation, and data analysis of the two or three vehicles.
7. The two or three vehicles will be deployed together and always stay within the acoustic cone of the ship.
8. The vehicles will swim in parallel and optically investigate suspected sonar targets as they are detected.

Figures 54 and 55 illustrate the deployed system with different sonars.

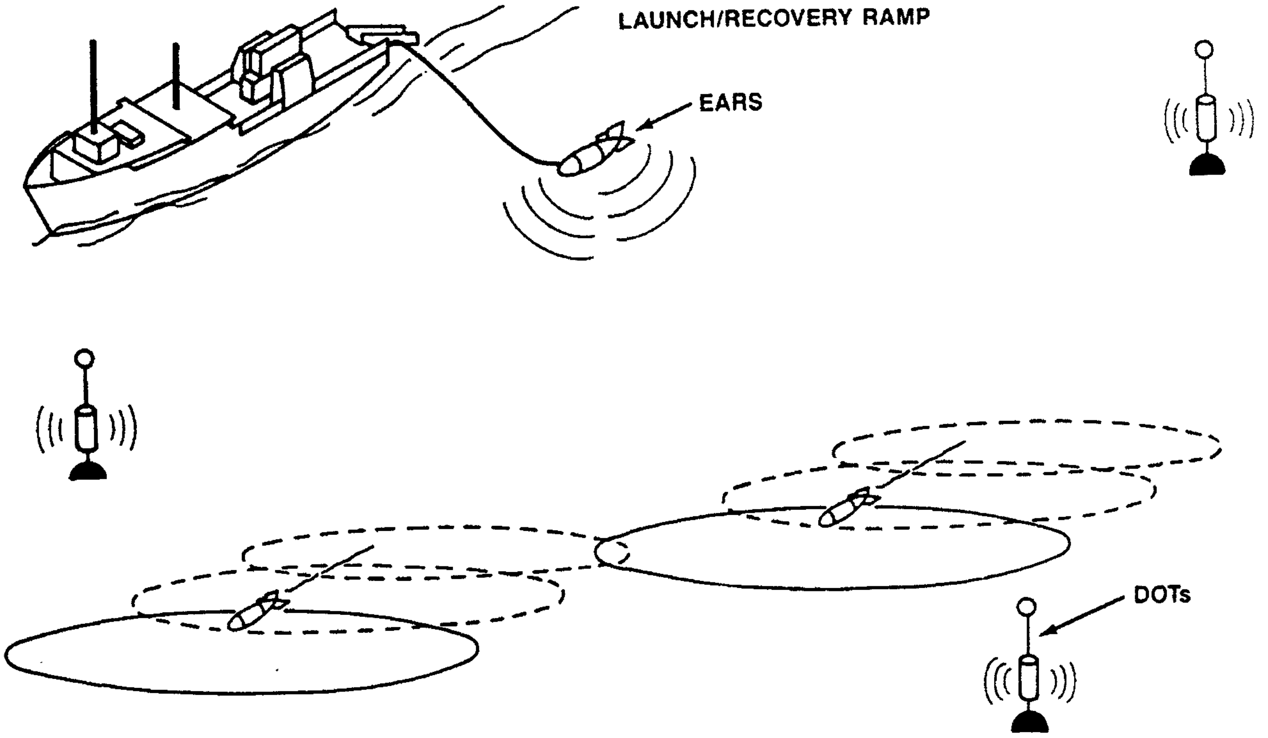


Figure 54. Multiple AUSS using spot-scanning sonar.

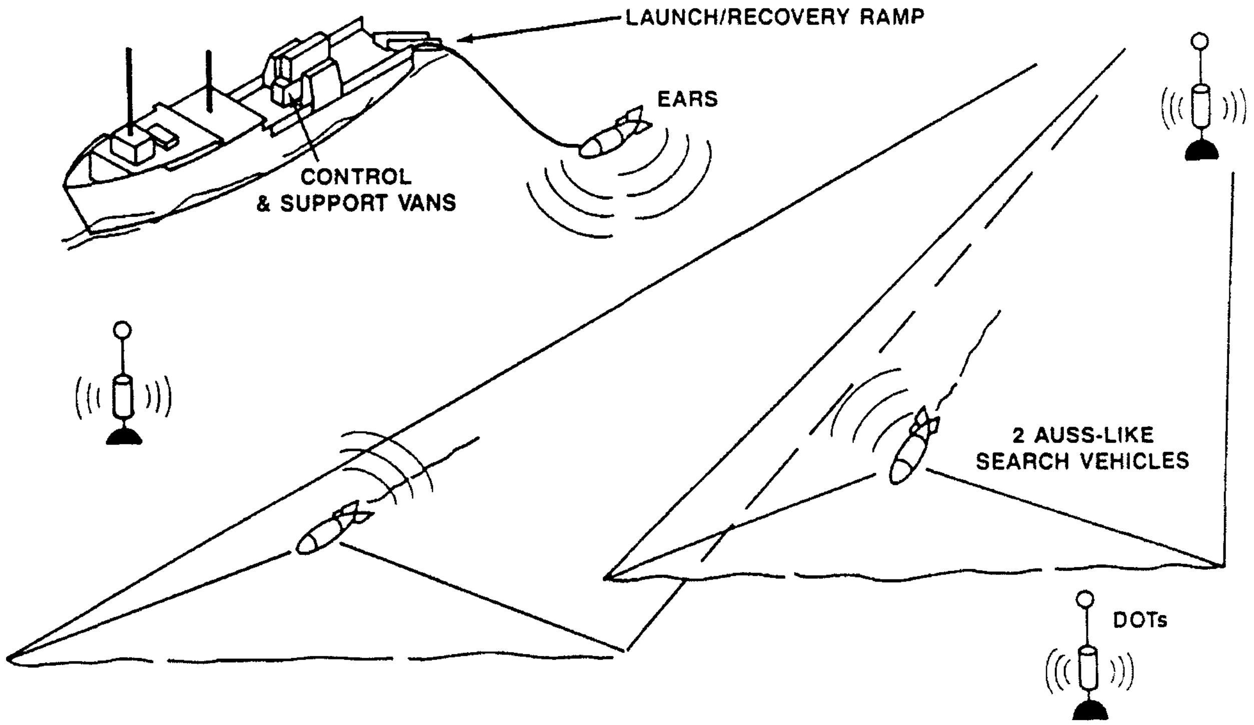


Figure 55. Multiple AUSS using side-looking sonar.

The following is a possible operational scenario for the multiple AUSS. The support ship arrives at the search site with the FASS. The area of highest probable detection is determined and a long baseline acoustic navigation system is deployed and surveyed. By deploying about six to eight deep-ocean transponders (DOTs) a 20-square mile area of the seafloor can be covered. As the calibration of the navigation grid takes place, other parameters of the search area are investigated with the shipboard sensors. The current, wind, bathymetric, and other data are collected and used to formulate a search tactic given the probability distribution of detection and the target characteristics. The search tactic will address the number of vehicles to deploy, the type of sonar to use, the search path, etc. When the FASS is ready, the support ship moves to the site to begin the search. The vehicles are deployed sequentially, within minutes of each other. As soon as one vehicle is launched, it begins its descent and, when at the bottom, waits for the second and possibly third vehicles to arrive. When all vehicles are at the bottom and stabilized, the search begins. The vehicles will swim in parallel paths. If side-looking sonar is used, a staggered formation will be maintained to prevent sonar interference. If the vehicles use a spot-scanning technique to detect targets, the sonar scans will be timed so that while one vehicle is scanning, the other is transiting. When one vehicle detects a suspected target, the vehicle transits to the target, homing in on it with the SLS, and investigates it optically. The other vehicle continues on its transit-scan investigation cycle. If one vehicle gets too far ahead of the other, it stops and waits. The vehicle convoy continues on in this search mode, swimming either parallel paths or a square spiral pattern, until the power is depleted. The vehicles are then recovered sequentially, refurbished, and redeployed to continue the search.

An alternative search technique would be to swim the search vehicles through an area and collect sonar data only, while logging (though not investigating) suspected target sites. After the sonar search, the vehicles would then go back and optically investigate the most promising targets. Figure 56 illustrates such a technique.

A third technique would use one dedicated optical sensor vehicle to follow the one or two sonar search vehicles and investigate promising sonar targets. Further investigations will be required to determine the best of these three alternatives.

When the area in the acoustic navigation net is satisfactorily covered, the DOTs are recovered and FASS moves to a new search area and the process begins again.

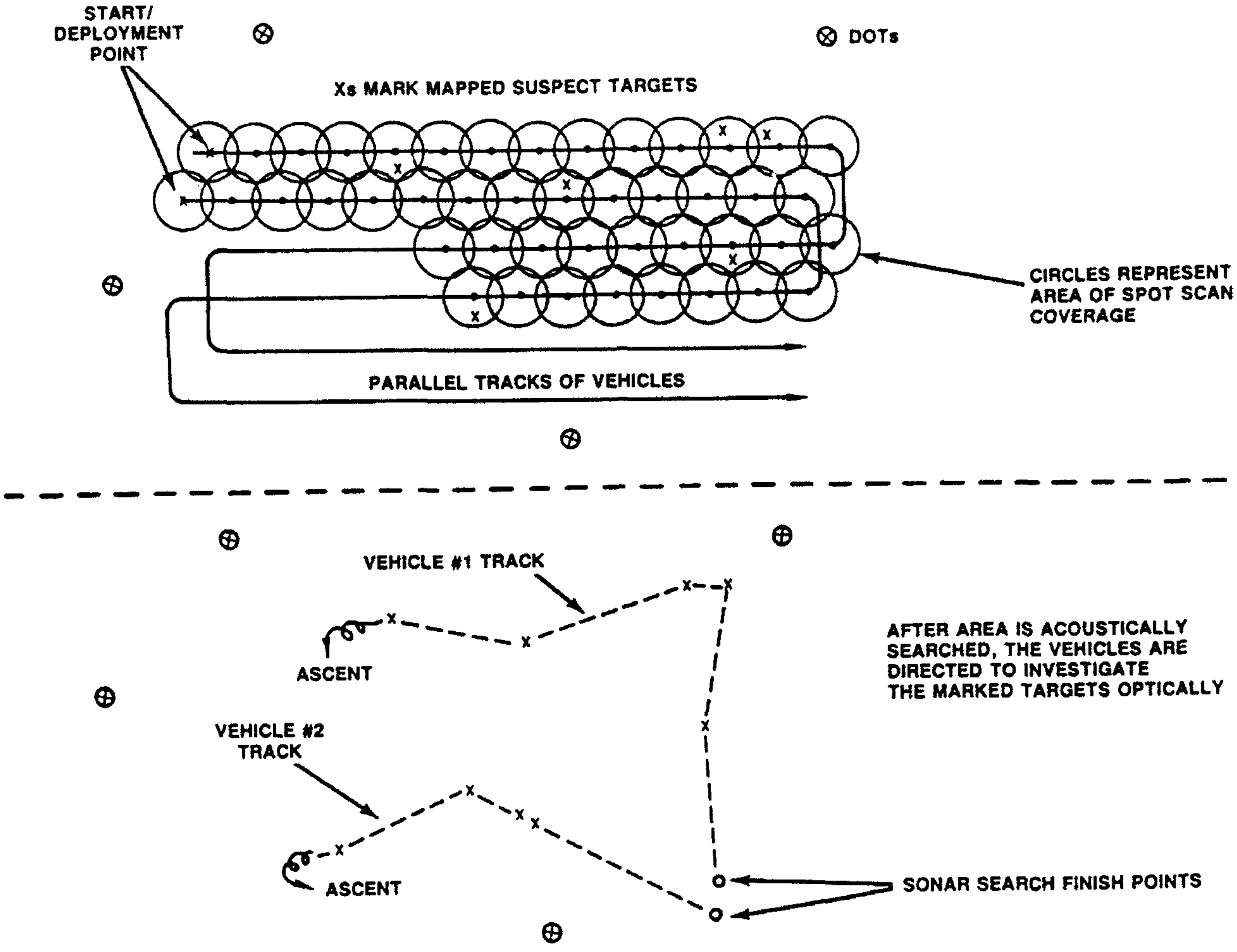


Figure 56. Multiple AUSS search technique.

Multiple AUSS Subsystem Description

The following paragraphs present, in an introductory way, the subsystem descriptions for the multiple AUSS. System features were also addressed for the multiple AUSS. Table 26 indicates some of the particular inputs to system feature considerations. However, the major effort was expended on the subsystem descriptions.

Sensors. The sensor suit is AUSS-like. A spot-scanning or SLS is the primary search device, coupled with optic sensors for target evaluation. Other specialized sensors could be used for supplementing search and target discrimination efforts. The supplemental information will be displayed simultaneously with the acoustic data to enhance the operator's ability to locate possible targets.

Table 26. Inputs to multiple AUSS system feature considerations.

ARCHITECTURE

1. Multiple AUSS-like search vehicles (acoustic search sensor)
2. Ship-towed acoustic telemetry transducer (EARS fish)
3. 1 to 4 search vehicles share acoustic telemetry cone (time-share)
4. Parallel search pattern (side-looking sonar/spot scanning sonar)
5. Near realtime data telemetry link (acoustic-link)
6. Immediate target contact evaluation (optical-imaging sensor)

TACTICS

1. Establish location of base port.
2. Mobilize FASS to search area base port facility.
3. Analyze probability distribution of target location.
4. Configure long-baseline navigation system (LBNS).
5. Deploy search vehicles in high-probability region.
6. Collect sonar data while performing parallel search patterns.
7. Locate potential targets in near real time.
8. Conduct immediate target evaluation using optical sensor.
9. Redistribute target location probability curves.
10. Optimally redeploy search teams through completion.

OPERATIONAL PROCEDURES

1. Mobilize personnel and equipment to search area.
2. Conduct preoperational Oeanographic/topographic survey.
3. Deploy deep-ocean transponder (DOT) array for LBNS.
4. Survey LBNS array using surface support vessel.
5. Transit to search site and maintain small headway.
6. Sequentially launch search vehicles.
7. Maintain acoustic communications with each vehicle.
8. Stabilize multivehicle search configuration.
10. Recover search vehicles at end of first search operation.
11. Refurbish search vehicles for redeployment.
12. Recover/redeploy DOTs as needed throughout search area.
13. Redeploy search vehicles through completion.
14. Recover FASS and demobilize.

CONTACT EVALUATION

1. Identify potential targets from acoustic data in near real time.
2. Immediately contact potential targets with search vehicle.

Table 26. Inputs to multiple AUSS system feature considerations (continued).

3. Maintain all search vehicles in acoustic telemetry cone.
4. Acquire optical images from location of possible target.
5. Evaluate optical information from potential target.
6. Tag positively identified target.
7. Continue parallel search pattern after contact evaluation.

PERSONNEL

1. FASS operations coordinator
2. Supervisor of control operations
3. Supervisor of deck operations
4. Search sensor specialist
5. Search vehicle controller
6. Navigator
7. Electrical/electronic engineer/technician
8. Mechanical engineer/technician
9. Material/vehicle handler

ENERGY CONSIDERATIONS

1. Search vehicle hotel energy
2. Search vehicle propulsion energy
3. Search vehicle sensor energy
4. Search vehicle telemetry link energy

MOBILIZATION

1. Identify and assemble required personnel.
2. Locate coastal seaport for logistic support.
3. Identify and mobilize surface support vessel.
4. Transport FASS to support base.
5. Configure surface support vessel with FASS.
6. Transit to search area.

The acoustic sensor will perform spot-scans in a pattern so that it overlaps an adjacent spot that was scanned by the other vehicle. To prevent holidays between adjacent spot-scans an overlap of no less than 6 % of the area of a single spot-scan must be maintained. This can be accomplished by assuring that the centers of adjacent spot-scans are separated by no more than 1.7 times the spot-scan radius. Even if it is determined that SLS will be used instead of spot-scanning sonar, the search tactics will remain the same. Spot-scanning which requires a stop-and-go procedure may be less efficient than side-looking in terms of search rate, vehicle power consumption rate, and system logistics. It is expected that, at some point, the benefits of one sensor suit will outweigh those of the other. This FASS concept can use spot-scanning or side-looking acoustic sensors without changing the concept significantly.

After a circular bottom (one scan circle) has been scanned and the acoustic data analyzed, the AUSS-like vehicles are commanded to transit to the targets and collect optical data using a still-frame low-light or CCD-type camera. The sensor data will be analyzed while the vehicles await further instructions. After all the targets in the scan circle have been looked at, the vehicles transit to the next scan site.

Communications. Communications are AUSS-like, accomplished via the acoustic telemetry link. Two vehicles and possibly a third will share the link, each sending acoustic data as it is collected. It is envisioned that, while one vehicle is sending data, the other is making transit to its next position. When either spot-scanning sonar or side-scanning sonar is used, a staggered store and send technique can also be used, or possibly simultaneous transmission can be developed and used. Tactics will necessarily be constrained by the need to keep the vehicles in the communication cone. Figure 57 shows the geometry of the acoustic link for 2,000 and 20,000 feet of water. As the figure shows, the size of the acoustic cone in shallow water limits the vehicle separation and results in either overlap of long range sonars or the use of shorter range sonars.

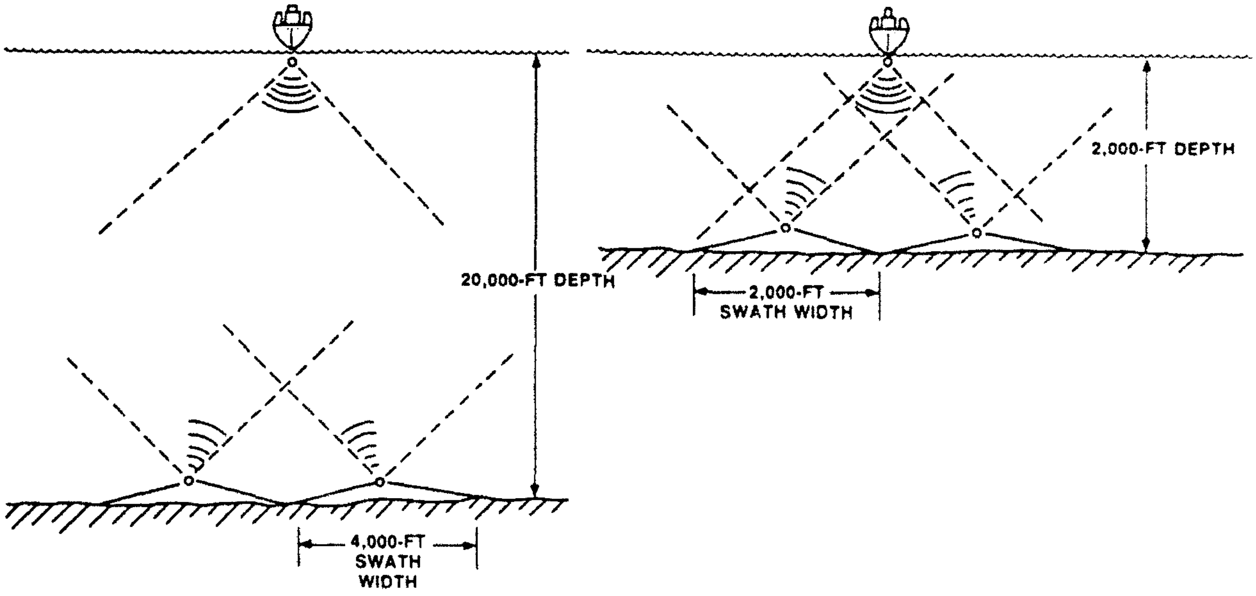


Figure 57. Multiple AUSS acoustic telemetry and search sensor geometry for 2,000-ft and 20,000-ft depths.

Each vehicle will report system status before and after data transmission. While a track of spot-scanning or side-looking data is being produced, it is also being viewed and marked for possible targets. If immediate contact evaluation is desired at the time, then commands to perform the evaluation would be sent. Otherwise, its next position would be commanded and the other vehicle would begin communication.

Command and Control. Command and control is AUSS-like, i.e., operations are performed on a supervisory level basis. Commands are sent to the vehicles via the acoustic communications channel by using a time-sharing technique over the telemetry link developed for AUSS. Two vehicles, or possibly three depending on the water depth and sensors used, will be self-controlled with regard to maintaining their own stability and self-monitoring with regard to their onboard systems. Commands and data will be coded to distinguish between one vehicle and another. The proposed software and computer architecture for multiple AUSS is listed in table 27.

While searching, the multiple vehicles must remain in proper geometric configuration with the surface to ensure communications. The resulting geometry will be one of the factors in selecting the sensor suit for the required resolution of the search area.

Table 27. Proposed software and computer architecture.

1. Proposed Generalized Computer Architecture

   Easily reorganized to support unforeseen hardware developments.

2. Proposed Expandable Communications Protocol

   External communications format may be fixed, with generalized addressed fields to support undetermined number of vehicles.

   Internal communications format, interpreted-from external communication, by using control and pointer fields to activate different levels of control as well as reassigning tasks to individual computers.

3. Parallel Processing

   Allows higher speed internal processing as well as allowing a dedicated processor for external communications. Relieves a possible constraint posed by the present AUSS configuration of routing all data through the sensor computer, or at least its bus.

4. Parallel Access to Internal and External Communications Nets

5. Dedicated External Communications Computer

   Allows the parallel accessing above.

6. Modularized Device (Sensor and Control) Drivers

7. Standardized Format for Accessing any Device or Task

Navigation. System navigation is AUSS-like. The surface ship references the Earth via the Global Positioning System (GPS), that is assumed to be operational in the 1990s, although other systems such as SatNav or Loran may be used. The sensor vehicles reference the Earth via a long-baseline navigation network which is deployed and calibrated during the preoperations period.

Target locations are stored in a navigation computer for use by the routines that develop the vehicle command structures. When the vehicles are sent to a likely target to collect optical data, they are actually sent to a small region of the search area. A sensor vehicle in pursuit of a target must perform a small search of the target area until it can converge on the object. Once the object has been precisely located, its exact coordinates can be used to improve the navigational accuracy for the subsequent target investigations, possibly reducing the amount of time for convergence.

Information Processing. Information processing is AUSS-like. All search data will be available for inspection soon after it is collected. If spot-scan sonar is used, the data will be telemetered just after it is collected; and if SLS is used, the data will be sent in a staggered fashion (on a time-share basis). In either case, the general principle of acoustically searching until a likely target is found and then immediately optically investigated remains unchanged.

Sonar data will be collected at the surface and displayed to the analysts. They can then locate and mark the likely targets with a light-pen, storing the information in the navigation computer. As the search path is followed, the vehicles will be commanded to transit to the targets and gather the optical data that will immediately be telemetered to the surface. The optical data may be displayed on the same monitor as the acoustic data. After a period of search effort, the vehicles either drop ballast and surface for refurbishment or continue on to the next track of the search area. McCord (1984) presents the FASS information processing design concepts study.

Vehicle. Each of the vehicles will be AUSS–like. They will be about 14 feet long, displace about 2,700 pounds, transit at 6 knots, and have about a 10-hour duration. The onboard computer system will be based on the supervisory control technique now used by AUSS.

Vehicle Handling. A launch/recovery ramp, much like the existing AUSS design, will be used to deploy and retrieve the vehicles. When the vehicles are onboard the ship, they will be moved around the deck on a cart and track system. The vehicles will be housed and transported in the vans. FASS vehicle handling is discussed in more detail in Higgins (1984).

Control Van. The control van will be AUSS-like in design, but will be more efficiently arranged to accommodate the dual-vehicle control and sonar stations. The van will be 40 feet long, 8 feet wide, and 8 feet high and will be mounted on top of the 40-foot long support van.

Support Van. The support van will be the same size and configuration as the existing AUSS support van. The van will house the vehicle service area, tools, spares, and the batteries and their charging equipment. This support van will also store the EARS fish during preoperation and postoperation transit. The two or three search vehicles will be stored in a separate, smaller van. This storage van will be welded to the deck along side the support van and will be about 20 feet long, 8 feet wide, and 8 feet high. Figure 58 shows the deck arrangement on the *PAUL LANGEVIN III* (PL III), a typical civilian supply boat and the vessel used for testing the AUSS prototype.

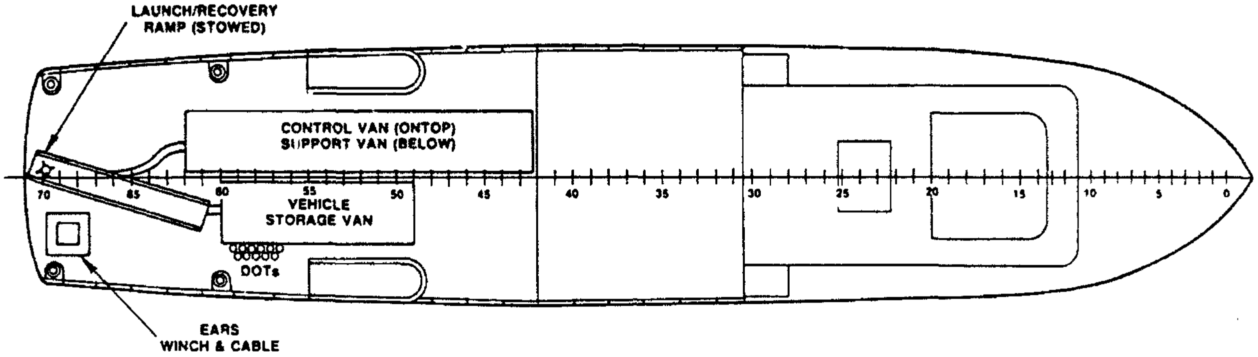


Figure 58. Multiple AUSS installed on the PL III.

Surface Vessel Requirements. All FASS concepts will, by direction, use a "ship of opportunity." The FASS project will require a large open deck area (for vans, EARS winch, DOTs, and other equipment), a shallow freeboard height (8 feet or less for the 20-foot launch/recovery ramp), enough berthing (for crew and FASS personnel), and a worldwide availability. For fast and safe vehicle recoveries, the vessel should also have a bow thruster and a rear-facing helm station. Many vessels will accommodate FASS ranging from auxiliary Fleet ocean tugs to civilian mud or supply boats and tug/supply boats. Jane's (1982–1983) lists seven TATF owned by the U.S. Navy. Figure 59 presents basic information for the TATFs, which are the leading candidates for the FASS surface vessel. Providing the need exists, a Navy vessel could be pressed into service. The civilian supply and tug/supply boats do exist in greater numbers and can be rented or leased worldwide. However, these vessels are often leased on a long-term basis, and it may be difficult to find a vessel available or between jobs. The **Fleet Data Service** (1980) outlines a complete list of these offshore surface vessels; both small (60 through 149 feet) and large (greater than 150 feet) are included. Kimberling (July 1984; August 1984) provide more detailed information on FASS surface vessel support.

TATF INFORMATION

OVERALL LENGTH:	226 X 42 FEET
OPEN DECK AREA:	82 X 30 FEET
FREEBOARD:	4.44 to 8.88 FEET
DECK CARGO CAPACITY:	300 TONS
RANGE:	10,000 NAUTICAL MILES AT 13 KNOTS
BERTHING:	20 CREW/MILITARY PERSONNEL 20 TRANSIENTS
REGULATIONS:	USCG

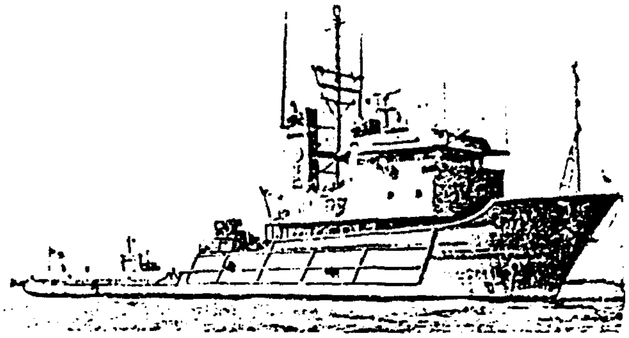


Figure 59. TATF information.

Personnel. The required personnel for around-the-clock operations (two alternating watches) will be as follows:

1. Four vehicle controllers (two for each watch, one for each vehicle)
2. Four sonar operators (two for each watch, one for each vehicle)
3. Two watch supervisors
4. Two deck hands/vehicle handlers.

Since the vehicles will be recovered, refurbished, and launched only once every 12 hours or so, the single watch of two deck hands, with the aid of the vehicle pilot, will be sufficient for most conditions. A total of 12 FASS crewmen will be required.

DUAL-VEHICLE SEARCH TEAMS

Introduction

This concept centers around using a number of independent search teams to conduct a methodical search of the seafloor. Each team consists of two bottom search vehicles and one remotely piloted surface vehicle (RPSV). Figure 60 shows a system of two teams deployed and searching. The support ship is in continuous radio contact with each RPSV, and each RPSV is in acoustic contact with the two sensor vehicles below it. The RPSV receives the search data from the search vehicles and continuously sends it back to the support ship over an RF link for processing. The commands to the sensor vehicles are likewise sent from the support ship to the RPSV and are then acoustically sent down to the search vehicles. The RSPVs were added to the system so that the search vehicles can operate out of acoustic telemetry range of the main support ship. Rather than many vehicles having to remain within the 90-degree acoustic cone of the support ship, the search vehicles are free to spread out over the seafloor and reduce acoustic interference problems (especially in shallow water). A selected number of these three-vehicle teams could be deployed by the support ship. The capacity of the support ship as well as the search scenario will dictate the optimal number. For most searches, two teams would work well. Two search vehicles were selected for each search team for the following reasons:

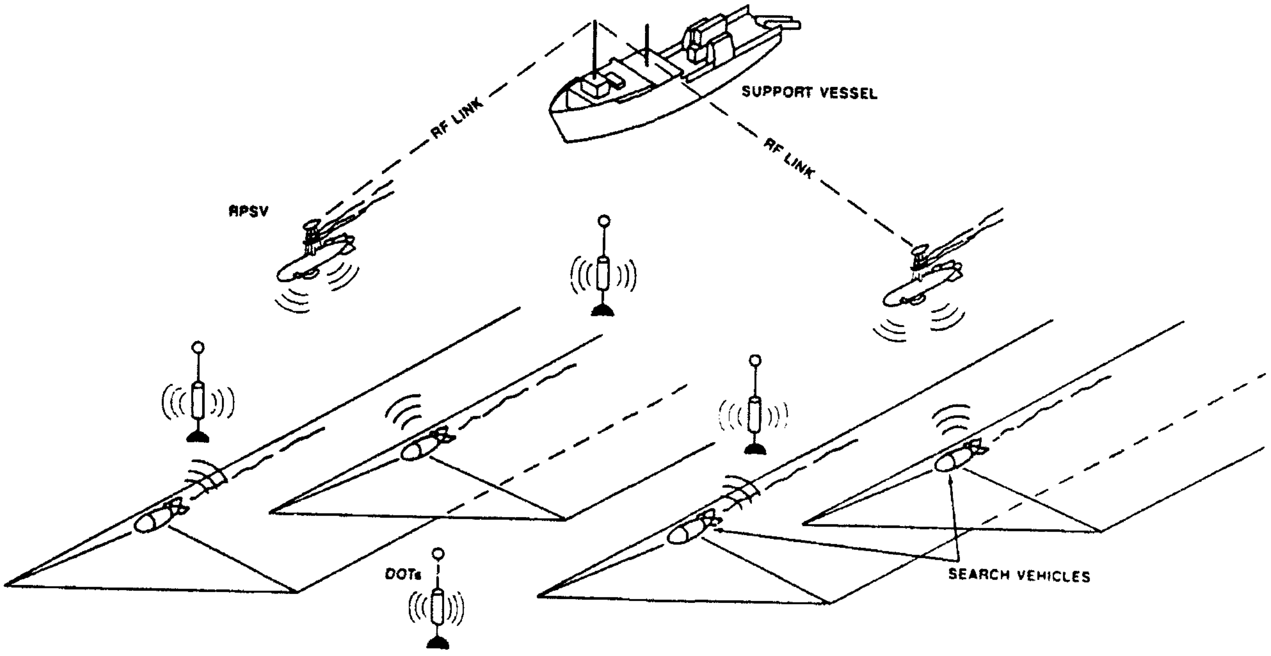


Figure 60. Two search teams using the spot-scanning technique.

1. A two-to-one data compression is feasible and would allow two search vehicles to share a common acoustic telemetry link.
2. If it is assumed that an individual search vehicle has about a 2,000-foot wide swath, two vehicles would fly parallel paths about 2,000 feet apart. In shallow water, no more than two bottom vehicles could easily fit into the acoustic telemetry cone (figure 61).

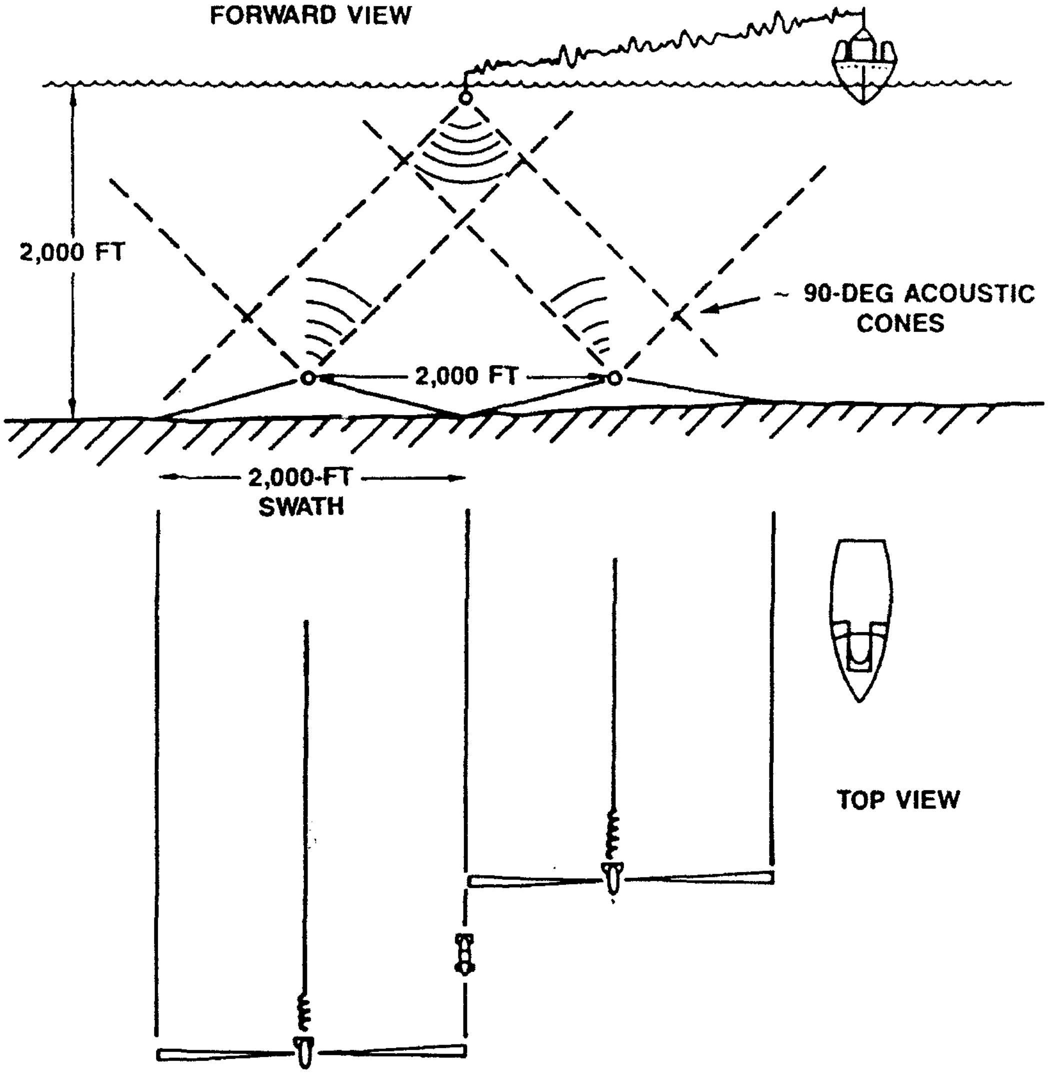


Figure 61. One search team using side-looking sonar at 2,000-ft depths.

In deep water, more than two vehicles could fit into the acoustic cone of the RPSV, but this would require greater data compression techniques if all the vehicles were to share the same acoustic telemetry link. Figure 62 shows the system operating in 20,000 feet of water.

An operational scenario could include the following. The support ship arrives at the search area. If a local long-baseline navigation system is not set up yet, the ship drops a set of deep ocean transponders (DOTs) and calibrates them. (A field of about 15 DOTs would cover an area of approximately 50 square nautical miles.) After the navigation net is in place, the support ship moves to a high-probability area of the search grid. The first search team is deployed by first launching the two search vehicles and then launching the RPSV. Both the bottom and surface vehicles use an AUSS-like launch ramp for launch and recovery. While the search vehicles are descending to the bottom, the support ship with the other search team is transiting to another launch site.

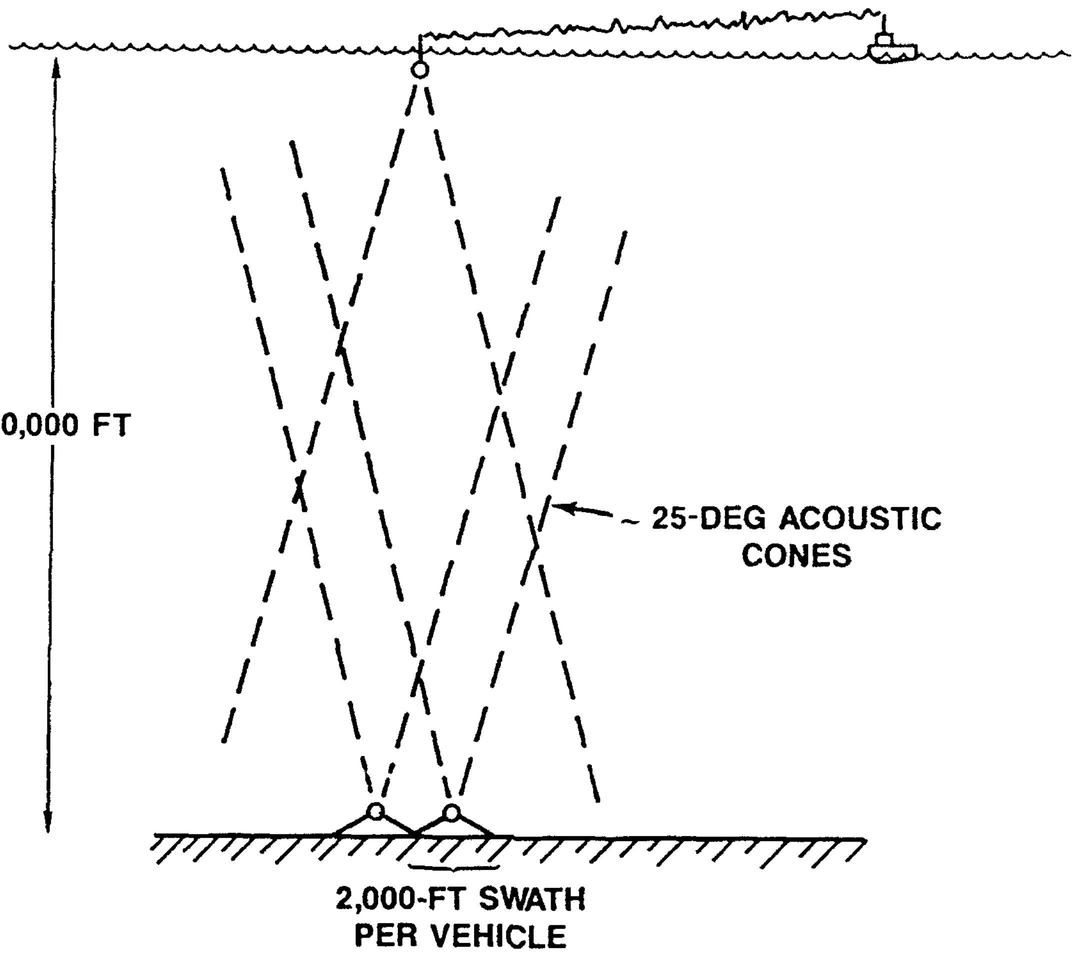


Figure 62. One search team using side-looking sonar at 20,000-ft depths.

As soon as the first team of search vehicles is positioned on the seafloor and the RPSV is ready above them, the team begins a predetermined search path of the bottom. The second search team, deployed after the support vessel reaches the second search area, also begins its search routine when ready. The vehicles could use either SLS or spot-scanning sonar as the main search sensor. Sonar targets are investigated with an AUSS-like optical sensor suit. While the two (or more) vehicle search teams are conducting their searches, the surface support ship with the vehicle control personnel and search data analysts are maintaining station in a central location. When a team is through searching (by finding the object or running low on power), the bottom search vehicles are ordered to ascend and the support vessel transits over to the surfacing site. The support ship recovers the two search vehicles, and, if the search needs to be continued, transits to a new site, refurbishes the vehicles, and relaunches the vehicles. The vehicles again descend to the bottom and begin the search process. The support ship then transits to the next vehicle team needing servicing. If the launch and ascent of the vehicle search teams are properly timed, only one vehicle search team will need servicing at a time.

During the search vehicle recovery, refurbishment, and launch cycle, the RPSV will be standing by. The RPSV will be diesel-powered and have enough fuel onboard to run 3 days at 6 knots. Thus, the RPSV can remain in the water for the entire time it takes to search an area 10 nautical miles by 10 nautical miles.

The launch-search-recover-refurbish-launch cycle continues until the entire search area within the navigation net has been covered the proper number of times and/or the target found. The size of the search area is limited by the practical size of the long-baseline navigation net. If the search teams are to be spread out over great distances, separate acoustic navigation nets will have to be installed.

The system can be more fully described by looking at the various subsystems.

Dual-Vehicle Search Teams Subsystem Descriptions

The following paragraphs present, in an introductory way, the subsystem descriptions for the Dual Vehicle Search Teams. System features were also addressed for the Dual Vehicle Search Teams; table 28 indicates some of the particular inputs to system feature considerations. However, the major effort was expended on the subsystem descriptions.

Table 28. Inputs to the Dual-Vehicle Search Team's system feature considerations.

ARCHITECTURE

1. Modular independent search teams (1 to 4 search vehicles/team)
2. Multiple AUSS-like search vehicles (acoustic search sensor)
3. Remotely piloted surface vehicles (RPSV) (RF-link)
4. Unrestrained surface support vessel (line-of-sight/relay)
5 Near realtime data telemetry link (acoustic-link/RF)
6. Immediate contact evaluation (optical sensor).

TACTICS

1. Establish location of base port.
2. Mobilize FASS to search area base port facility.
3. Analyze probability distribution of target location.
4. Configure long-baseline navigation system (LBNS).
5. Deploy individual search teams in high-probability regions.
6. Locate potential targets in near real time.
7. Conduct immediate target evaluation with optical sensor.
8. Redistribute target location probability curves.
9. Optimally redeploy search teams through completion.

OPERATIONAL PROCEDURES

1. Mobilize personnel and equipment to search area.
2. Conduct preoperational oceanographic/topographic survey.
3. Deploy deep-ocean transponder (DOT) array for LBNS.
4. Deploy RPSV and establish RF-link.
5. Survey LBNS array using RPSVs.
6. Transit to search site -1 and maintain small headway.
7. Sequentially launch first team of search vehicles.
8. Stabilize search team configuration.
9. Commence search operation over site -1.
10. Transit to search site -2 maintaining RF link with RPSV -1.
11. Deploy search team at site -2.
12. Commence search operation over site -2.
13. Return to site -1 for recovery of search vehicles.
14. Refurbish search vehicles for redeployment.
15. Transit to search site -3 with RPSV under power alongside.
16. Redeploy refurbished search team at site -3.
17. Commence search operation over site -3.

Table 28. Inputs to the Dual-Vehicle Search Team's system feature considerations (continued).

18. Return to site -2 for recovery of search vehicles.
19. Continue redeployment of search teams to completion.
20. Recover RPSVs and sensor vehicles for postoperational procedures.
21. Recover DOTs and redeploy FASS or demobilize.

CONTACT EVALUATION

1. Identify possible targets from acoustic data in near time.
2. Immediately proceed to potential targets with search vehicle.
3. Acquire optical image from target area.
4. Evaluate optical information from potential target.
5. Tag positively identified target.

PERSONNEL

1. FASS operations coordinator
2. Supervisor of control operations
3. Supervisor of deck operations
4. Search sensor specialist
5. RPSV controller
6. Search vehicle controller
7. Navigator
8. Electrical/electronic engineer/technician
9. Mechanical engineer/technician
10. Material/vehicle handler

ENERGY CONSIDERATIONS

1. RPSV hotel and propulsion energy
2. Search vehicle hotel energy
3. Search vehicle propulsion energy
4. Search vehicle sensor energy

MOBILIZATION

1. Identify and assemble required personnel.
2. Locate coastal seaport for logistic support.
3. Identify surface support vessel.
4. Transport FASS to support base.
5. Configure surface support vessel with FASS:
6. Transit to search area.

Sensors. SLS or spot-scanning sonar is the primary search sensor. The SLS will probably have a dynamically focused beam and a 1,000-foot range (STSS-like). The scanning sonar will probably be a SWAP-type. These sonars could be supplemented by magnetometers, bottom profilers, and other sensors as required. After the acoustic search is complete, the suspect targets will be investigated with AUSS-like optical sensors (still frame TV and 70-mm photo camera). The TV optical images will be acoustically sent to the RPSV and then to the control van aboard the support ship by RF link.

Communications. The two search vehicles will continuously communicate acoustically with the RPSV, and the data are then RF-linked to the support ship. Each vehicle will have 2,400 bps on the uplink side. Since the SLS, after digitization, creates 4,800 bps, a 2:1 data compression will be required onboard the vehicle before transmission. The slow-scan TV data will be sent up sequentially by the vehicle pairs on a time-share basis. When the SLS is being used, the acoustic telemetry channel is continuously used on the uplink side for transmitting the sonar data. This prevents commands from being sent down to the vehicles while on the SLS run. The AUSS vehicle, while using SLS, navigates with dead reckoning until the sonar run is complete. Since the Dual Vehicle Search Teams must have closely integrated navigation (tc prevent excessive holidays and overlaps), there must be some method of sending the vehicles position data. One method would be to break the SLS data transmission periodically long enough for the RPSV to relay down position data. The sonar data transmission could be broken for about 10 seconds every minute if the data generated during that time is stored in a RAM (10 sec × 4,800 bps = 48,000 bits = 6 Kbytes). The stored data would then be sent up when the uplink acoustic transmission resumed again. This would require only a small increase in the data compression. As long as the vehicles were on a SLS run, this telemetry and data storage/transmission cycle would continue.

The RPSV will be configured as shown in figure 63. Figure 62 shows the geometry of the acoustic link at 20,000-foot depths. The acoustic transducers illustrated in the drawing have a narrow conical beam with an enclosed angle of about 20 to 30 degrees. This narrower beam (the existing AUSS acoustic transducer beam is about 90 to 100 degrees) allows the search teams to operate closer together without interfering with each other's acoustic link. The narrower conical beam can be achieved by using a different transducer and baffle design. The transducers and baffles will be modular, so the narrow beam can be used for deep depths and the wide beam used for shallow depths. The point where the transducers should be switched is a function of the depth, the angle of the acoustic cones, and the separation distance of the vehicles on the bottom.

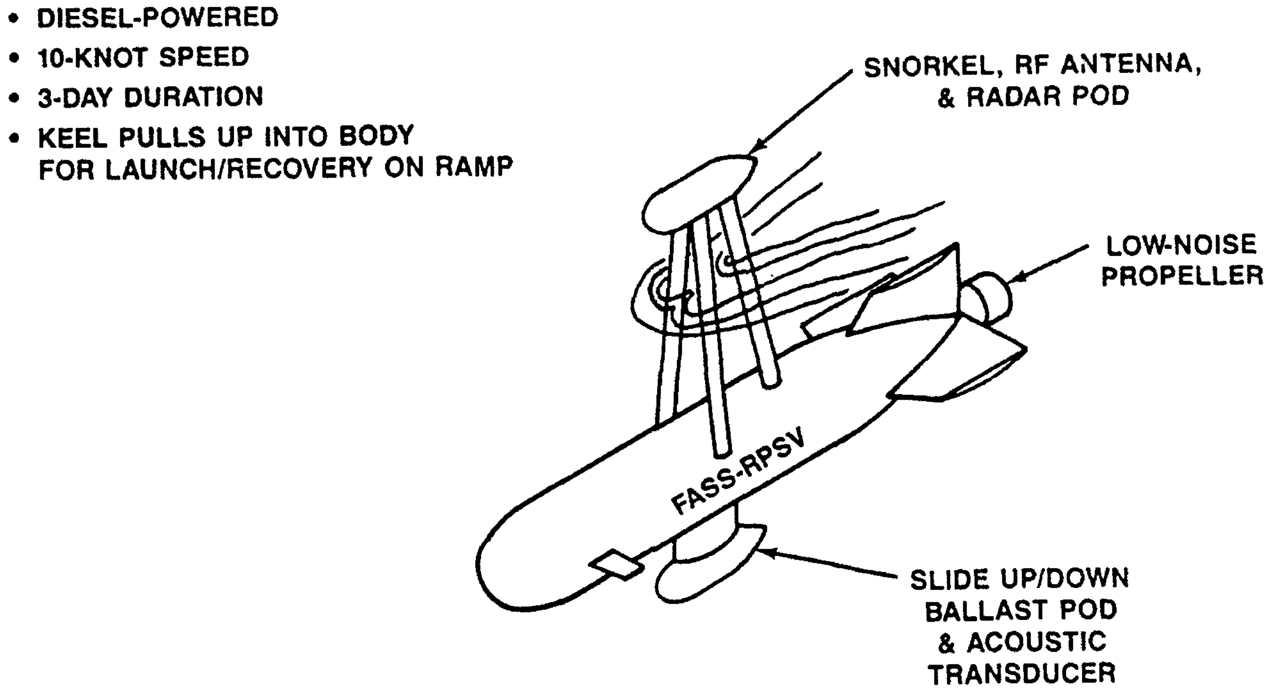


Figure 63. FASS Remotely Piloted Surface Vehicle (RPSV).

Command and Control. The bottom search vehicles will be piloted with onboard computers that fly the vehicle at the proper altitude and along the proper course. The vehicles receive bottom position data periodically from the control van's navigation computer (through the RPSV link). If the vehicles are not flying along the proper search paths, the surface operators send down commands altering the course routines. The status of the onboard systems and the bottom position are monitored on an intermittent basis. One vehicle operator monitors and controls all four search vehicles with a single-vehicle control station. This supervisory control system allows the vehicles to follow the predetermined search routine automatically, with the vehicle pilot monitoring status and sending down commands when unforeseen situations arise. The RPSVs will each have a dedicated controller/pilot. This pilot will monitor the RPSV's radar, its position with respect to the bottom vehicles, and its onboard systems status.

Navigation. The vehicles will be referenced to the seafloor with a long-baseline acoustic navigation system. An array of DOTs will be laid over the search area and the system calibrated. A spread of about 15 DOTs will cover an area about 5 by 10 nautical miles. Each vehicle will be commanded to ping when its position is desired. All the vehicles will ping at the same frequency, but at different times (a time-shared acoustic navigation net). When the DOTs are interrogated by the vehicle, their replies are picked up by the RPSV and radioed to the support ship. The vehicle position is then calculated by the central navigation computer in the FASS control van. Each vehicle's position is then relayed back through the RPSV and back to the search vehicle for onboard navigation. The computer stores the vehicle tracks and the suspected target positions for later investigations. The RPSV also periodically interrogates the DOTs and their positions are computed. The RPSV and the two search vehicles bottom tracks are displayed in the control van.

Information Processing. The sonar search data will be available for processing on a near realtime, continuous basis. One sonar operator/interpreter will monitor two SLS displays (one sonar operator will be required for each search team). If an SLS is being used when a suspected target is found, the operator uses a light-pen to mark the spot on the CRT display. This spot will then be registered in the navigation computer memory for later investigation. If the spot-scanning sonar is being used, the operator will investigate the sonar targets immediately by closing in on them with the sonar. Realtime computer processing and video enhancement can be used to help the sonar operator discriminate targets. All data will be recorded in the control van for later processing, if desired. (FASS information processing is discussed in more detail in McCord, 1984.)

Vehicle. The four search vehicles will be similar to the AUSS search vehicles in design and configuration. They will operate at depths of 20,000 feet and travel at a maximum speed of 6 knots for 10 hours. The vehicles will have an onboard computer control system similar to the existing AUSS. The diesel-powered RPSVs are configured for simplicity; other characteristics include high-power density and long-range capability. Figure 63 illustrates an RPSV and gives the specifics.

Vehicle Handling. The vehicles will be launched and recovered sequentially using an AUSS-like ramp on the stern of the support boat. The RPSV will be launched and recovered with the keel pulled up into the body, so it can be accommodated in the launch/recovery ramp. (FASS vehicle handling is discussed in more detail in Higgins, 1984.)

Control Van. Each search team will have a control van that will accommodate the vehicle controller, the RPSV pilot, and the sonar operator. The major difference from the AUSS van will be the addition of the RPSV station and the expanded sonar station. There will also be room for two observers. The control van will be approximately 40 feet in length and can be accommodated next to the maintenance storage van (figures 64 and 65). The secondary control van will be approximately 20 feet long.

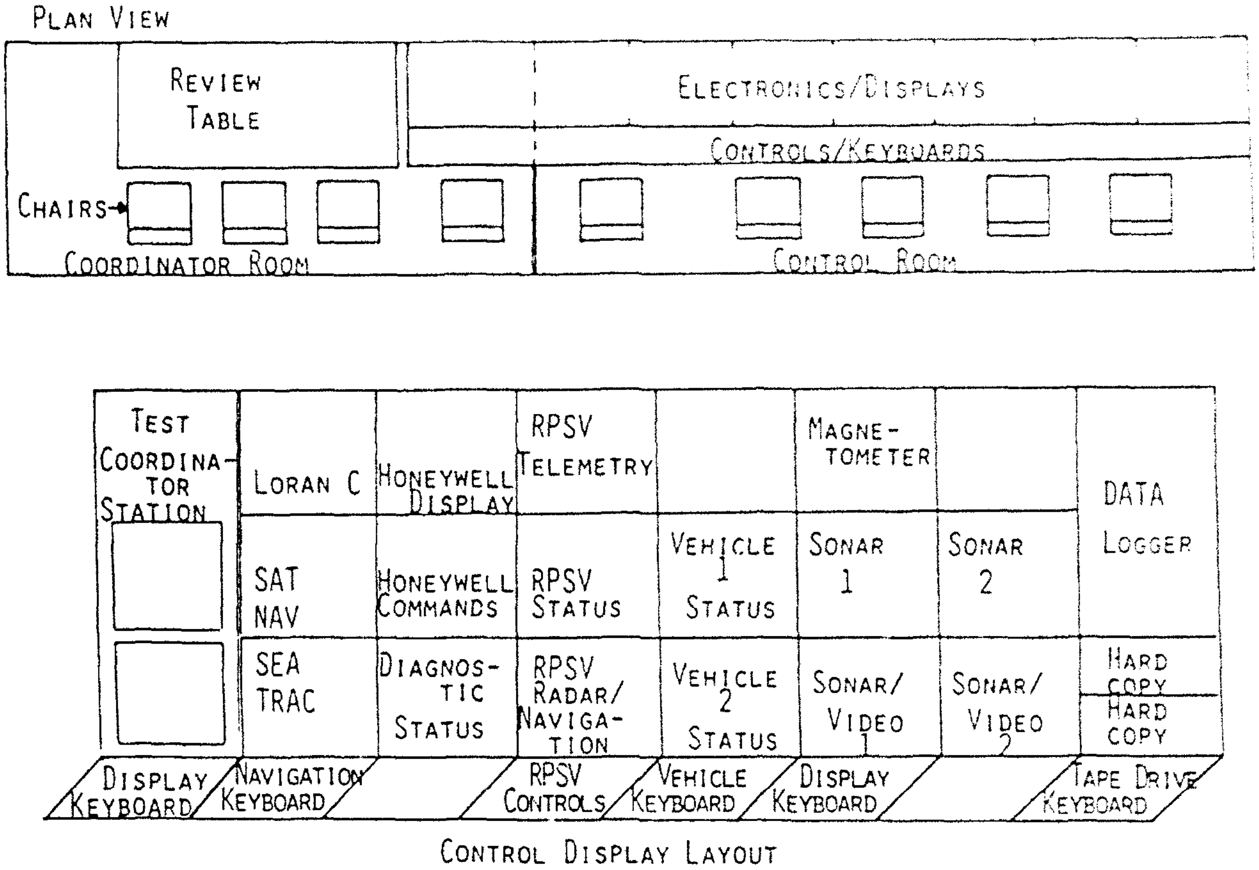
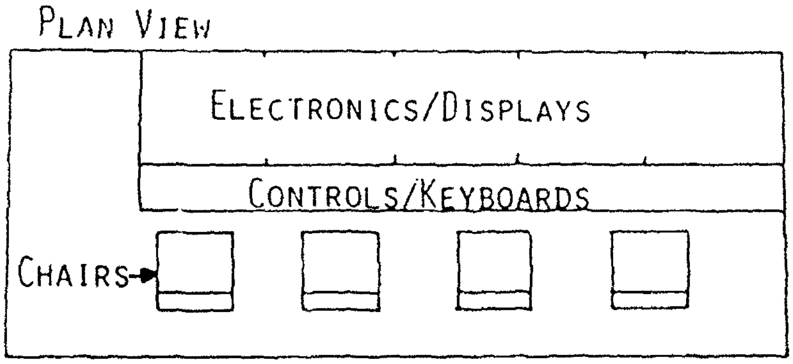
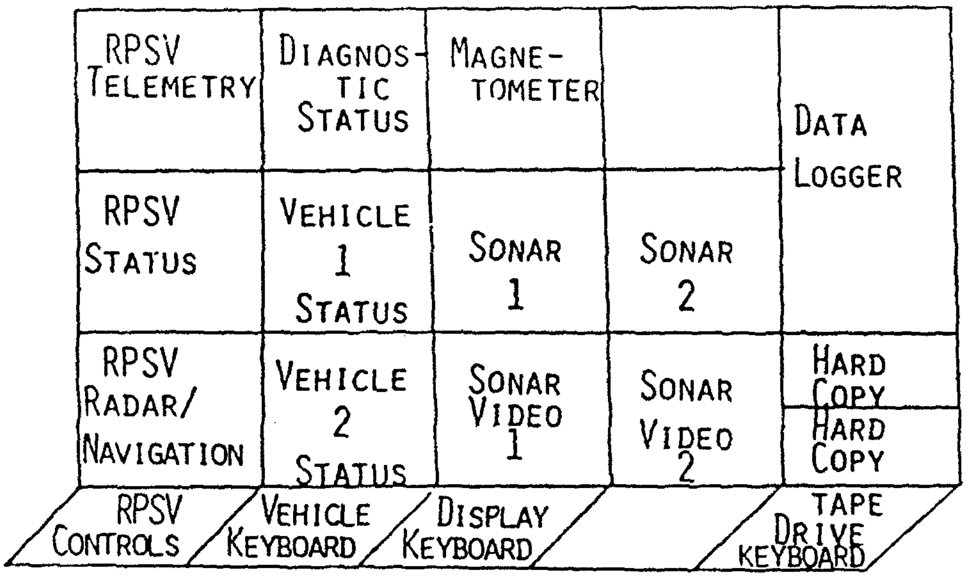


Figure 64. Dual-Vehicle Search Team primary control van.





CONTROL DISPLAY LAYOUT

Figure 65. Dual-Vehicle Search Team secondary control van.

Support Van. There will be one maintenance/storage van for each search team. The two search vehicles, spare batteries, spare parts, tools, battery recharging equipment, and other miscellaneous support equipment will be housed in the van. The van will be 40 feet long and will be welded to the deck of the support ship (figure 66). The RPSVs will be stored on deck as shown in figure 67.

Surface Vessel Requirements. The support vessel must have adequate deck space to support two vans per team, a portable diesel generator, the launch/recovery ramp, and the RPSV with its stand. The ship should also have a bow thruster and a rear-facing bridge station for safe and fast vehicle handling (figure 67). (For further information please see the discussion on Surface Vessel Requirements in the Multiple AUSS subsection above and Kimberling, July 1984 & August 1984.)

Personnel. The personnel requirements for the operation of the Dual-Vehicle Search Teams are detailed in table 29.

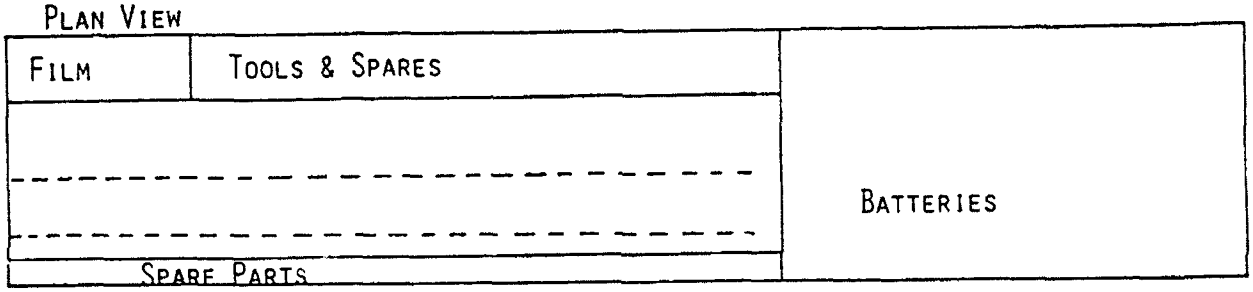


Figure 66. Dual-Vehicle Search Team support van.

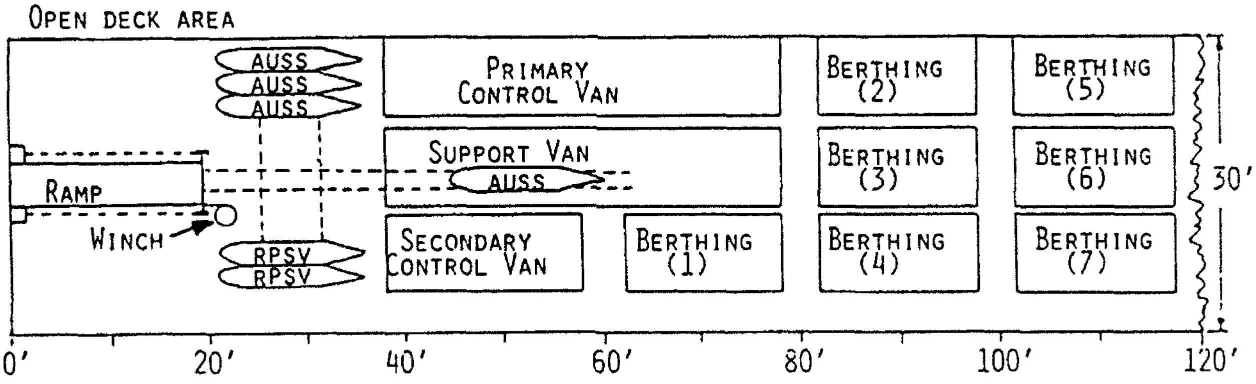


Figure 67. Dual-Vehicle Search Team deck layout.

Table 29. Dual-Vehicle Search Team personnel requirements.

FASS OPERATOR	VAN LOCATION PRIMARY	VAN LOCATION SECONDARY	SUPPORT	24-HOUR OPS 12-HOUR SHIFT
Test Coordinator	*			1
Navigation	*			2
RPSV	*	*		4
Vehicle	*	*		4
Search Sensors	*	*		4
Control Supervisor	*	*		4
Deck Supervisor			*	2
Vehicle Handlers			2	4
Mechanical Technician			*	1
Electronic Technician	*	*	*	1
			FASS CREW:	27

Summary of Pros and Cons for the Dual-Vehicle Search Teams Concept

The advantages of this concept include the following:

1. This concept uses AUSS-proven technology.
2. All aspects of the concept appear feasible. There is very little technological risk, only engineering development.
3. The modular architecture of the system is appealing. The number of teams deployed can be optimized to a given situation and complete independency assures that if one team fails, there will be others operating to complete the mission.
4. Sensors can be modular and optimized for a given search and situation.
5. This concept has the capability of performing immediate contact evaluation.
6. It has potential for near realtime communications that permit the operators to be aware of the current status of the search teams.

The disadvantages of this concept include the following:

1. Putting highly directive (- 25-degree enclosed angle) acoustic cones on the vehicles is difficult and may not really be necessary. Since the downlink has a

much lower data rate, more vehicles can share the same link. The downlinks could be frequency-coded so that, although the search vehicle may hear more than its RPSV, it can pick out the signal it wants.

2. The system is large. The RPSVs and their support equipment will occupy a great deal of deck space.
3. The system could have ungraceful degradation. If the RPSV fails, two search vehicles will also be inoperative.
4. The acoustic navigation net is large and complex and will take much time to set up.
5. The navigation net interrogation technique will take excessive time in deep water. If the search vehicle must stop sending search data while it interrogates and waits for the RPSV to pick up the ping, compute the position on the support ship, and send the data back down, this time will be excessive. Some other ways of generating vehicle position should be designed: perhaps a Loran-type acoustic navigation net (with continuous sing-a-round DOTs) or a synchronous pinger system. Or, if the vehicle could interrogate the DOTs, pick up the reply, and compute its position alone, this could take the lag out of the up and down time to the support ship navigation computer (but still, the surface controllers would want to know where the vehicles are periodically).
6. The noise from the RPSV's drive system and the sea-generated surface noise may cause too much acoustic interference with the telemetry receiver.
7. Suspected targets found on sonar will be difficult to investigate because two vehicles will have to be coordinated. This may result in one vehicle standing still much of the time while the other is transiting to a target. The difficulty will vary as the terrain and false target density varies.
8. Sonification of the water in the search area is excessive. With the combined energy of sonars, of navigation pings, and of telemetry, interference and crosstalk will be a possible problem when many vehicles are in the water.

AUTONOMOUS SEARCH VEHICLES CONCEPT

Introduction

This concept proposes to simplify the operational and hardware aspects of a FASS by employing a large number of single purpose, autonomous optical sensor vehicles. The general idea is to deploy a large number of optical sensor vehicles that perform parallel flight paths among synchronous pingers to collect pictures for postdive analysis. Figure 68 depicts the system after a number of vehicle/pinger teams have been launched. After the last unit has been deployed, the ship transits to the point where the first vehicle is due to surface. The timing is such that the vehicle arrives at the surface just prior to the ship's arrival. Multiple vehicles are staggered in time by an amount equal to the transit time between launches. At each deployment location, a search unit is launched from a magazine on the ship while underway. Each unit includes a clock-synchronized vehicle and pinger, strung together so that the pinger and its flotation stem lead the vehicle to the seafloor during a high-speed free descent (figure 69). The descent weight lands first and the slightly positive buoyant vehicle quickly decelerates to a halt. After stabilization, the vehicle detaches itself and begins its parallel-path search pattern.

The flight path is performed autonomously by each sensor vehicle. Two widely spaced transducers on the vehicle are used to extract range and bearing information from the synchronous pinger. Time differences are measured between the synchronous clock and ping reception at each transducer. As discussed in appendix D, more accurate navigation is possible if each vehicle derives its position information from the two nearest pingers.

Triangulation is used to calculate the vehicle's position and orientation with respect to the pinger. When an accurate measure of the speed of sound is used, absolute ranging can be done. Otherwise, relative positions can be determined from the time differences. The system has the following fundamental characteristics.

1. Each sensor vehicle is clock-synchronized with an acoustic pinger, and they are deployed together as a unit.

2. Each sensor vehicle conducts a parallel path search pattern in relation to its pinger without any intervention from the surface.

3. All sensor data are optical, providing target location and identification simultaneously. (An SLS option is also possible as discussed below.)

4. All sensor data are stored onboard the sensor vehicle in the form of photographic film or other high-density storage medium.

5. The system operates on the principle that a large number of simple, single-function vehicles can work more efficiently than a few complex ones.

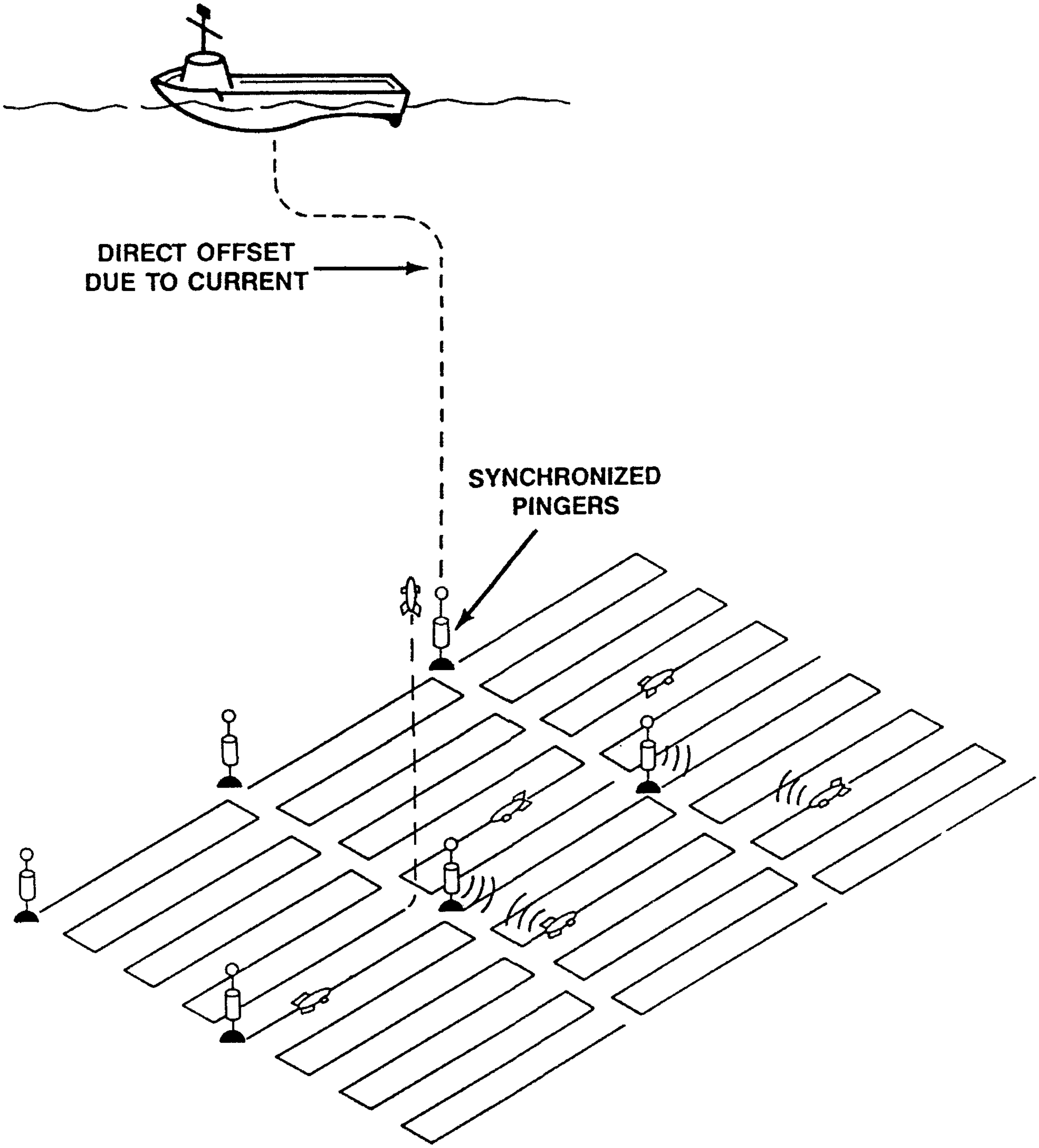


Figure 68. Overlapping search cells.

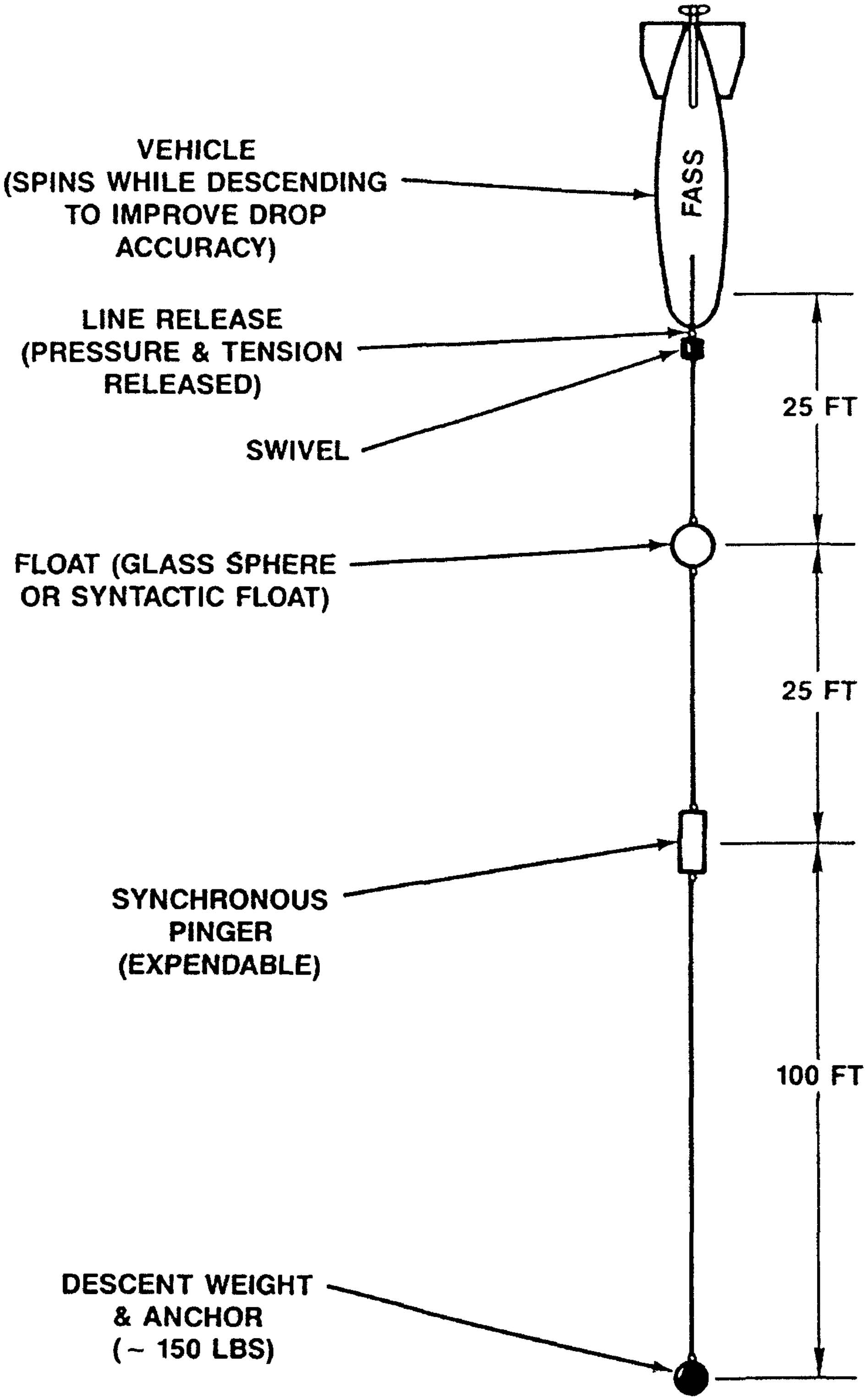


Figure 69. Autonomous vehicle with its pinger and flotation stem.

An operational plan might develop as follows. After the search area has been surveyed for depth and water clarity information, a logistics plan is devised for deploying the search units. The deployment plan will be a function of many parameters, including the probability of detection distribution over the search area, the depth, the required overlap between cells to assure full coverage, and the accuracy of the ship's position at launch. The plan will specifically address the exact position where each unit will be deployed taking into consideration the offset produced by prevailing ocean currents in the region (figure 70). Also, the sequencing of operational events so that the search rate is maintained at an optimum level must be considered at all times. Events will be sequenced so the amount of time each vehicle swims is equal to twice the time it does not swim. This assures that each vehicle contributes to maximizing the system search rate for a given energy source and dive time. There are numerous operations that must be closely coordinated to prevent accumulation of one task or another. Timing for operations such as descent/ascent, search, data retrieval, postdive analysis, refurbishment, and transit between deployments must be planned carefully to assure a smooth flow of events.

As an example, figure 71 presents a timing chart for a system that uses nine vehicle-pinger search units. Each unit is deployed for a total of 3 hours: 10 minutes for descent, 2.5 hours for search, and 20 minutes for ascent. Deployment time is about 5 minutes, but may be considered insignificant because the units are dropped while underway. Upon recovery (10 minutes), refurbishment involves replacing the storage medium (film, tape, disk, bubble memory, etc.) and installing freshly charged batteries. Refurbishment is assumed to take about 30 minutes. Four analysts are available for data interpretation. It is assumed that each analyst can interpret 2.5 hours of data in 1 hour, meaning that each analyst can interpret almost three times as fast as the data were collected. It can be seen from the diagram that the system is staggered in time by 17 minutes between unit deployments. This is figured by dividing the endurance of a single vehicle (2.5 hours or 150 minutes) by the number of times the ship has to transit between points to complete a closed path, i.e., the number of vehicles (nine) to be deployed. Two possible deployment schemes are illustrated in figure 72.

Autonomous Search Vehicles Concept Subsystems Descriptions

The following paragraphs present, in an introductory way, the subsystem descriptions for the autonomous search vehicles concept. System features were also addressed for the autonomous search vehicles concept; table 30 indicates some of the particular inputs to system feature considerations. However, the major effort was expended on the subsystem descriptions.

Table 30. Inputs to the autonomous search vehicles concept system feature considerations.

ARCHITECTURE

1. Individual vehicle and navigation units (10 units)
2. Automated vehicle deployment mechanisms (magazines)
3. High-speed vehicle deployment scheme (free descent)
4. Clock-synchronized pinger/vehicle navigation (range/ bearing)
5. Antonomous parallel-path search pattern
6. Operator-independent vehicle control (no telemetry link)
7. Onboard mass data storage medium (film, magnetic)
8. Postdive data analysis (computerized data processing)
9. Optical evaluation of possible targets (first pass or revisit)

Side-Looking Sonar Sensor Option

1. Autonomous acoustic sensor vehicles (high resolution)
2. Target site revisitation (evaluation vehicle deployment)
3. Optical verification (second postdive data analysis).

Optical Sensor Option

1. Autonomous optical sensor vehicles (photographic, low-light)
2. Simultaneous target location and identification (single pass)

TACTICS

1. Establish location of base port.
2. Mobilize FASS to search area base port facility.
3. Analyze probability distribution of target location.
4. Deploy vehicle-pinger units in highest probability region.
5. Recover search vehicle units containing stored data.
6. Conduct postdive analysis using computer enhancement.
7. Redistribute target location probability curves.
8. Optimally redeploy vehicle/navigation units to completion.

Side-Looking Sonar Sensor Option

1. Locate possible targets from high resolution SLS information.
2. Optimally deploy optical evaluation vehicles.
3. Recover evaluation vehicles containing stored optical data.
4. Perform postdive evaluation of optical information.

Table 30. Inputs to the autonomous search vehicles concept system feature considerations (continued).

Optical Sensor Option

1. Evaluate optical information from first pass deployment.
2. Simultaneously locate and identify potential targets.

OPERATIONAL PROCEDURES

1. Mobilize personnel and equipment to search area.
2. Conduct preoperational oceanographic/topographic survey.
3. Transit to search site –1.
4. Deploy vehicle-pinger units while underway.
5. Transit to first vehicle recovery point.
6. Recover all search vehicles in order of deployment.
7. Recover and process mass storage medium.
8. Analyze data for possible targets.
9. Redeploy entire system to completion.
10. Demobilize.

Side-Looking Sonar Sensor (SLS) Option

1. Collect acoustic data.
2. Analyze SLS data.
3. Deploy optical evaluators.
4. Recover optical evaluators.

Optical Sensor Option

1. Collect optical data.

CONTACT EVALUATION

1. Collect optical data from target area.
2. Recover and process optical data.
3. Evaluate optical information.
4. Identify targets.

SLS Sensor Option

1. Identify possible targets from SLS sensor data.
2. Optimally deploy optical evaluation vehicles.
3. Perform target-to-target optical data acquisition.

Table 30. Inputs to the autonomous search vehicles concept system feature considerations (continued).

PERSONNEL

1. FASS operations coordinator
2. Supervisor of deck operations
3. Data analyst
4. Navigator
5. Electrical/Electronic engineer/technician
6. Mechanical engineer/technician
7. Material/Vehicle handler

ENERGY CONSIDERATIONS

1. Search-vehicle hotel energy
2. Search-vehicle propulsion energy
3. Search-vehicle sensor energy

MOBILIZATION

1. Identify and assemble required personnel.
2. Locate coastal seaport for logistic support.
3. Identify surface support vessel.
4. Transport FASS to support base.
5. Configure surface support vessel with FASS.
6. Transit to search area.

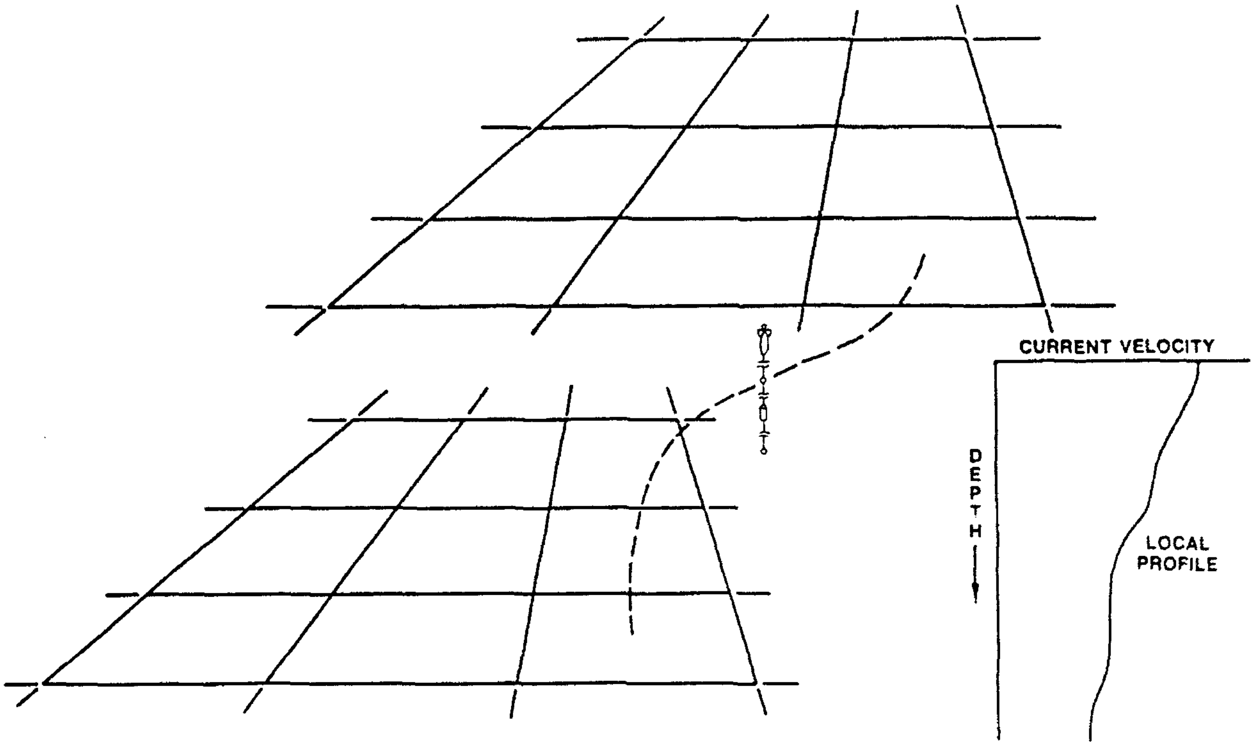


Figure 70. Grid shift as a result of current velocity distribution during vehicle-pinger deployment.

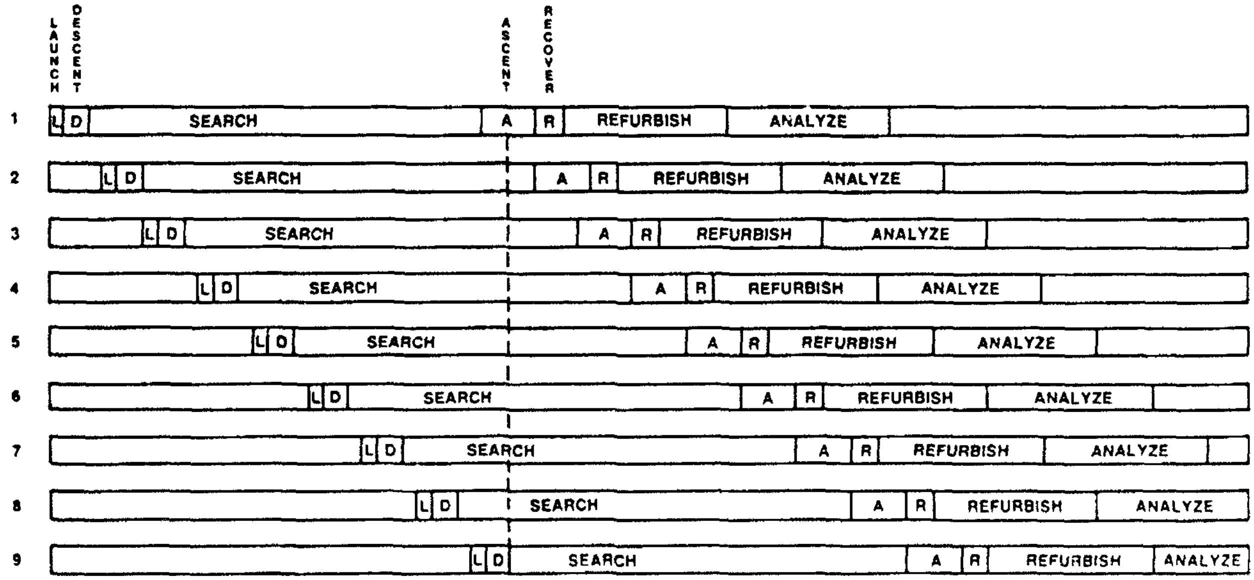


Figure 71. Timing chart for the use of nine autonomous vehicles.

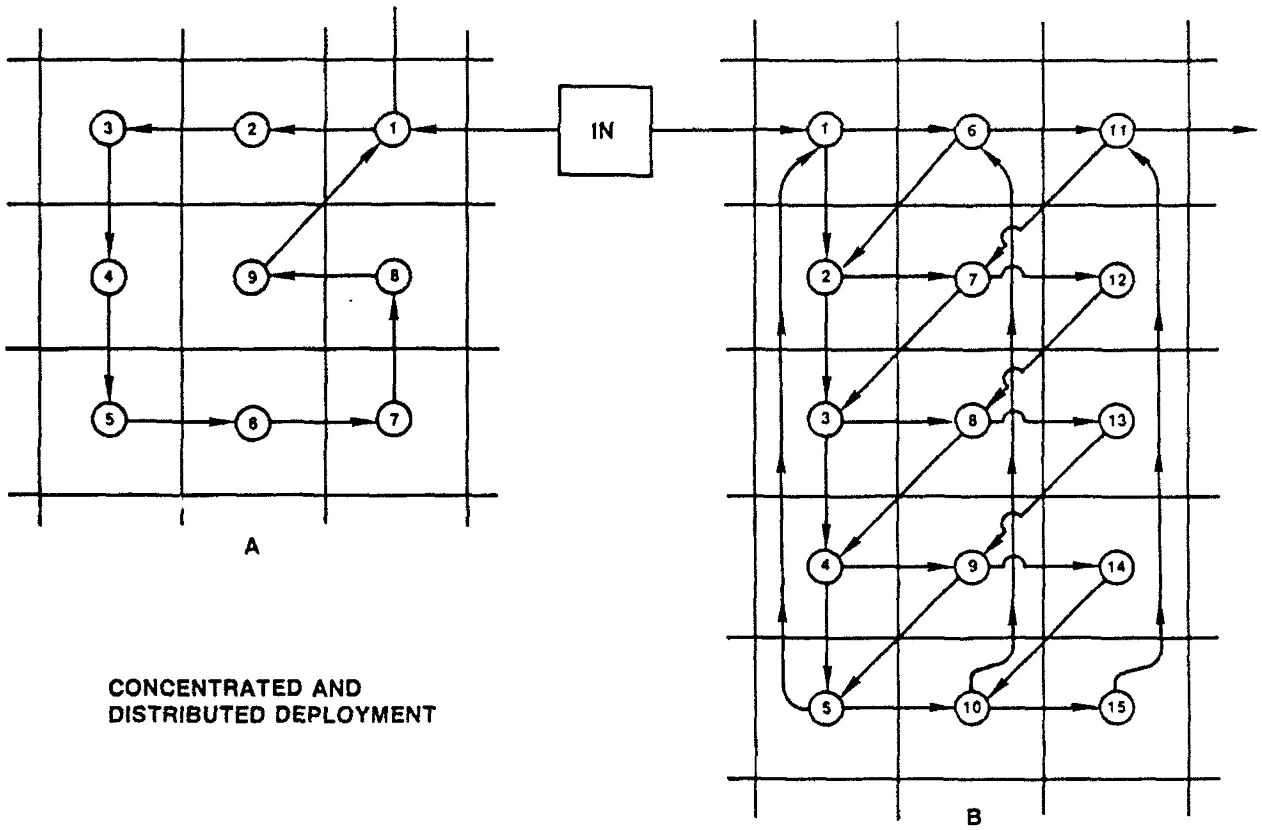


Figure 72. Concentrated and distributed deployment of autonomous vehicles.

Sensors. Optical sensors will be the primary search device, although magnetometers or other specialized sensors could be used for supplementing the optical search if the mission demands it. The supplemental sensor data could be annotated on the optical frames, eliminating the need for separate storage devices. Two types of optical sensors could be used on the vehicle:

1. Photographic camera - with film as the data storage medium
2. TV camera (low light level or CCD type) - with still-frame video tape or digital mass storage as the storage medium.

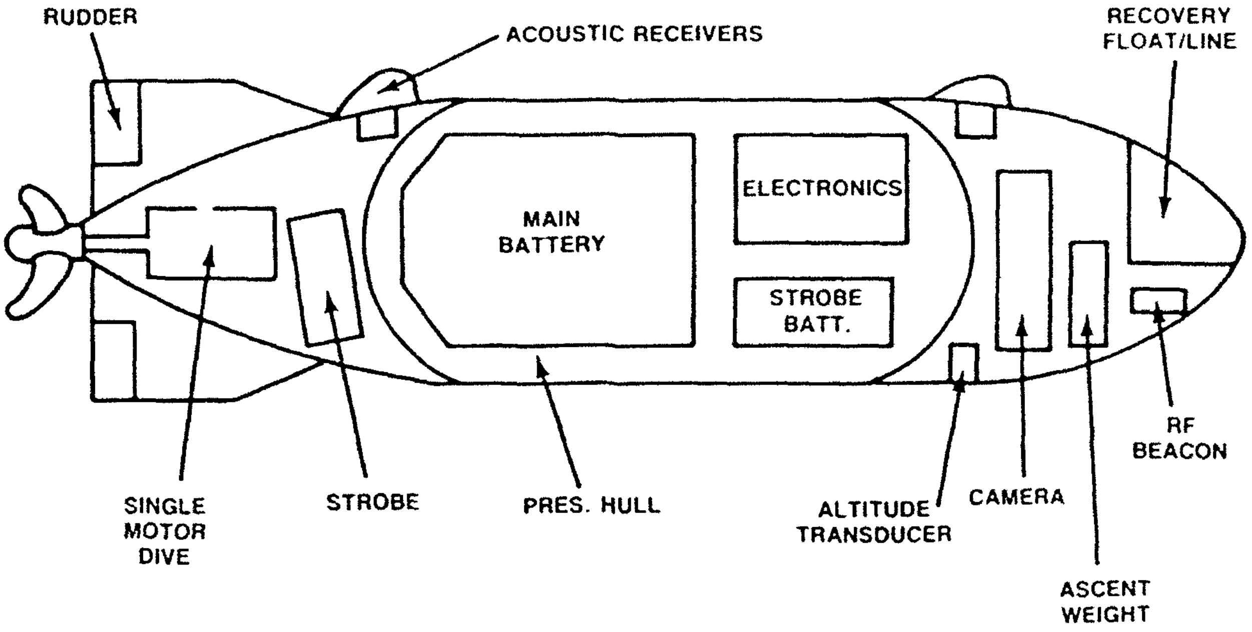
Acoustic search sensors could be considered for this system. However, there are difficulties associated with using them on an autonomous vehicle. For example, sonar data must be efficiently interpreted so that followup optical inspection can be performed. With optical sensors, search and target investigation take place simultaneously. Acoustic sensor options will be further explored as part of the preliminary design.

A preliminary list of pros and cons for each sensor is shown below. The sensors for this FASS concept will be selected during the conceptual design phase of the project. It may be determined that the sensor suit should be modular, allowing the best sensor to be installed for a particular search. In this case, both of the above sensors could be developed to work in the system.

The optical sensor will also require a device to illuminate the seafloor. A high efficiency, directed strobe would probably be best. The position and light pattern of this strobe, along with the position and field of the optical sensor, is shown in figure 73. The power requirement of the strobe will be determined by the sensor sensitivity, water clarity, the height of the vehicle off the seafloor, the field of view, the field of illumination, and the strobe's efficiency.

If a photographic camera is used as the optical sensor and a strobe is used as the illuminator, a 30-foot swath width would be a realistic attainment, while a 50-foot swath width is a possibility. The actual swath will depend on the water characteristics, the strobe power and efficiency, and the source-receiver geometry.

To optimize the vehicle's altitude above the seafloor for maximum picture quality and swath width, a transmissometer could be used for measuring the water clarity prior to the deployment of the search vehicles. This device could be expendable, and the data could be sent to the surface over a fine wire (much like an expendable bathythermograph [XBT]). As determined by the water clarity, the vehicle's controls are set to fly at the optimal altitude to maximize the photo coverage. The strobe and camera intercept angle would also be adjusted at the surface for the proper illumination. When adjusting the sensor altitude and the swath width, the vehicle's bottom track program will also need to be adjusted to ensure total and efficient bottom coverage.



- DISPLACEMENT ~ 1000 LBS.
- LENGTH ~ 10 FT.
- DIAMETER ~ 2FT.
- TRANSIT SPEED ~ 14 KTS.
- ENDURANCE ~ 2.5 HRS.
- RANGE ~ 35 NM
- SEARCH AREA (40-FT SWATH) ~ .23 NM^2
- DESCENT CONFIGURATION:

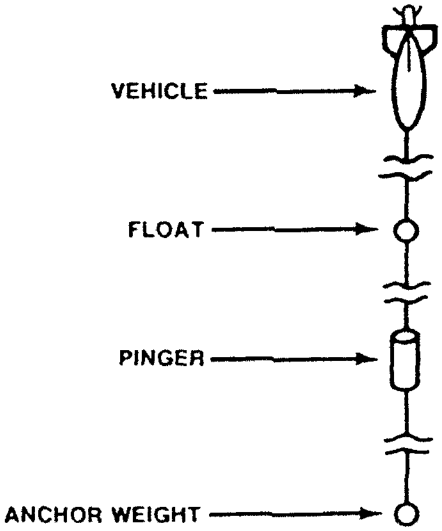


Figure 73. Autonomous search vehicle configuration.

Communications. The vehicles, once deployed, will not communicate with the surface. Each vehicle will listen for the acoustic signal from its synchronous pinger (for navigation purposes), but no other form of input or communication will be required. The vehicle will operate on the bottom as a truly autonomous system. The option exists to include an acoustic receiver onboard the vehicle to pick up an "abort dive" command from the surface. A properly designed transducer could be used for both navigation and command reception. The added complexity of such a device may not be worth the ability to recall the vehicles, since the vehicles will routinely surface after the 2- to 4-hour dive. In the event that the vehicle loses all power or completely malfunctions, a mechanically timed or corrosive link will ensure that the vehicle rises to the surface. Once on the surface, an RF beacon and a strobe will be automatically activated to assist location and recovery of the vehicle.

When the vehicle is recovered and search data are retrievable, the data could be digitized (if not already digitized) and communicated via satellite back to a shore-based computer processing center. Again, the costs versus benefits of this more complex system will have to be addressed.

Command and Control. The sensor vehicles are completely autonomous, being entirely decoupled from surface support while operating. The vehicles are much like AUSS in that they are self-monitoring, but differ in that no acoustic link is used to permit man-in-the-loop control. Also, the vehicles are not as programmable as AUSS. They essentially have a single function: to drive a parallel path relative to a synchronized acoustic pinger. All commands that would typically be sent via the acoustic link are eliminated by reprogramming the flight plan and providing close-range, high-accuracy navigation. An onboard processor takes in data from a synchronous clock and compares them with the time of arrival of an acoustic ping. Two widely spaced transducers on the vehicle provide enough information for the vehicle to always know its range and bearing with respect to the pinger. Since the range is small and the clocks are highly accurate, control error is very small. By knowing its range, the vehicle should always know its proper bearing; thus, a control algorithm can be designed to steer the vehicle along its proper path. During its search pattern, optical sensor data are collected at a steady rate, triggered as a function of speed. Once it has completed its search pattern, it commands itself to drop ballast and to begin transmitting an RF ping once it arrives at the surface.

Navigation. Ship navigation is provided by SatNav and other locally available means. A long-baseline acoustic navigation system will not be required, thus reducing preoperation time significantly. An ultrashort-baseline acoustic system will be used for locating the sensor vehicles with respect to the ship, although accuracies are only about 1% of the depth with current systems. This accuracy should be adequate for confirming the pinger position and ensuring proper search overlap of adjacent vehicles. This

1% of depth accuracy is also the limiting factor on knowing where the vehicles, pingers, and targets are with respect to earth. It is assumed that knowing target position to within 1% of the water depth will be adequate for this system.

Vehicles navigate their way through a parallel path search pattern by sensing time differences between a synchronous clock and its associated pinger and neighboring pingers to obtain highly accurate range and bearing information. The position of the vehicle relative to the pingers, along with other log information, will be recorded in a corner of the picture frame. A built-in algorithm relating range and bearing for a given size search cell will control the vehicle, forcing it to follow the path prescribed for it. An altitude sonar will be used to maintain a constant height above the bottom. Obstacle-avoidance sonar is not used in order to keep the vehicles simple and relatively inexpensive.

The navigation pingers could be expendable, eliminating the need to recover them.

Information Processing. All search data are stored on the vehicle during the dive, and then dumped when recovered. The storage medium will be either photographic film, magnetic tape or disk, or some other mass data storage device. Immediately after the vehicle is recovered, the film is removed or the magnetic data transferred to the data processing/navigation van. If film is being used, a short delay will take place while the film is processed. Once the data are prepared, a data analyst will view the frames at an accelerated rate. By speeding up the frame display rate about 3 to 1, the analyst can process one vehicle's 3-hour dive in about an hour. If the bottom is smooth and uncluttered, the analysis speed may be faster, but, if the bottom is rough and cluttered, the processing may take longer.

The data analysis process may be assisted by computer processing. The data would be fed into a computer to look for possible targets automatically or to assist the analyst by enhancing poor pictures (the film or analog video picture would first have to be digitized). If something interesting is located on a frame, the frame is displayed to the operator. All of the raw search data would be saved for later viewing or more elaborate automatic processing.

As the operation time line indicates, the search data will be processed at an accelerated rate with a lag time equal to the vehicle dive time plus ascent and recovery time. (FASS information processing is discussed in more detail in McCord, 1984)

Vehicle. The vehicles are small and simple. The simplicity comes from the following characteristics:

1. Only one propulsion motor, with a single speed
2. No acoustic communication link

3. No sonar search system

4. A very limited intelligence onboard command/control computer.

The vehicles are small enough so that a relatively large number (approximately 10) of them can be maintained and deployed by FASS and so that they can be recovered quickly and easily from the ocean.

The search time should be twice that required for the combined vehicle ascent time, recovery and deck time, and the descent time in order to achieve maximum area search rate. Given the search time, the size of the vehicle (and, therefore, the energy source) will dictate the vehicle's transit velocity. Based on broad assumptions, the vehicles should be very small (displacing about 300 pounds) and a great many used. However, a realistic limit must be placed on how many vehicles FASS could deploy and maintain and on the collective weight of the fleet of vehicles. Those limits would probably be around 10 vehicles and about 10,000 pounds. Given these limits and the suggested vehicle configuration, the vehicle would have the following characteristics:

1. Transit speed - 14 knots

2. Displacement - 1,000 pounds

3. Propulsion energy source - 15 kilowatt hours

4. Length and diameter - about 8 feet by 2 feet.

Figure 73 illustrates a possible vehicle configuration. The camera and strobe are separated as far as possible to improve the picture quality. The two acoustic navigation receivers are also separated as far as possible to improve the range and bearing data from the synchronous pinger. A separate battery could be used to supply high-voltage power to the strobe (this would improve efficiency by eliminating the DC-DC voltage converter). The vehicle is positioned by a simple rudder and elevator system. This implies that the vehicle must always maintain forward motion for altitude and position control.

Vehicle Handling. The vehicles will be launched out of a rack (or magazine) over the side of the ship (figure 74). Since the vehicles are small and robust, this form of high speed water entry should be acceptable. The vehicle, pinger, anchor, and float will be tied together and will descend to the seafloor at about 20 knots. This high speed descent will result in the pinger being anchored almost directly under the launch point. In 20,000 feet of water and with a typical current profile the vehicle-pinger will drift no more than 200 feet during descent. The support ship will use a GPS navigation receiver and display in combination with its propulsion system to position the vehicle launcher precisely. After one vehicle is deployed, the ship transits to the next launch site and again precisely positions itself for a launch.

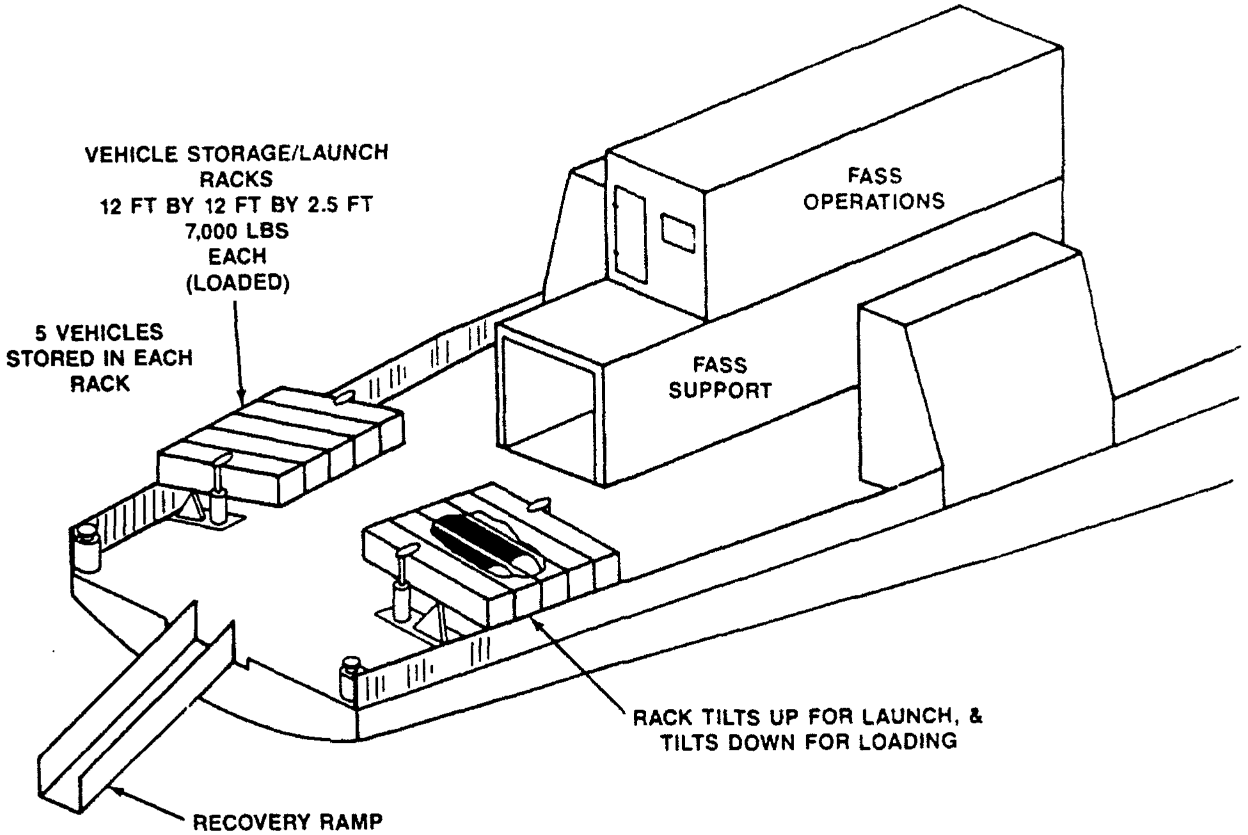


Figure 74. Autonomous vehicle launch and recovery configuration.

The recovery process involves transiting to the location where the ascending vehicle is expected to surface and wait. When the vehicle surfaces, it will float in a spar mode with an RF beacon and strobe light indicating its position. The vehicle will also automatically deploy a 50-foot long buoyant recovery line with a float at the end. The ship will position itself alongside the float and pick up the line with a hook. The vehicle will then be winched to the ship's transom and hauled up a ramp and into a rack for refurbishment. From there it will be again hooked onto a pinger and loaded into the ilaunch rack. (FASS vehicle handling is discussed in more detail in Higgins, 1984.)

Control/Operations Van. Since the vehicle operates autonomously, there will be no control van. However, there will be an operations van that will house the navigation and search data processing equipment (figure 75). This van will act as the command and control center for the search operations. The navigation displays will consist of a large X-Y plotter showing the location of the pingers and the support ship with respect to the seafloor. The dive times and expected surfacing times of each vehicle will also be displayed. The watch supervisor will monitor the navigation displays and work with the helmsman on the bridge and the vehicle handlers on the stern to coordinate the vehicle launch and recoveries.

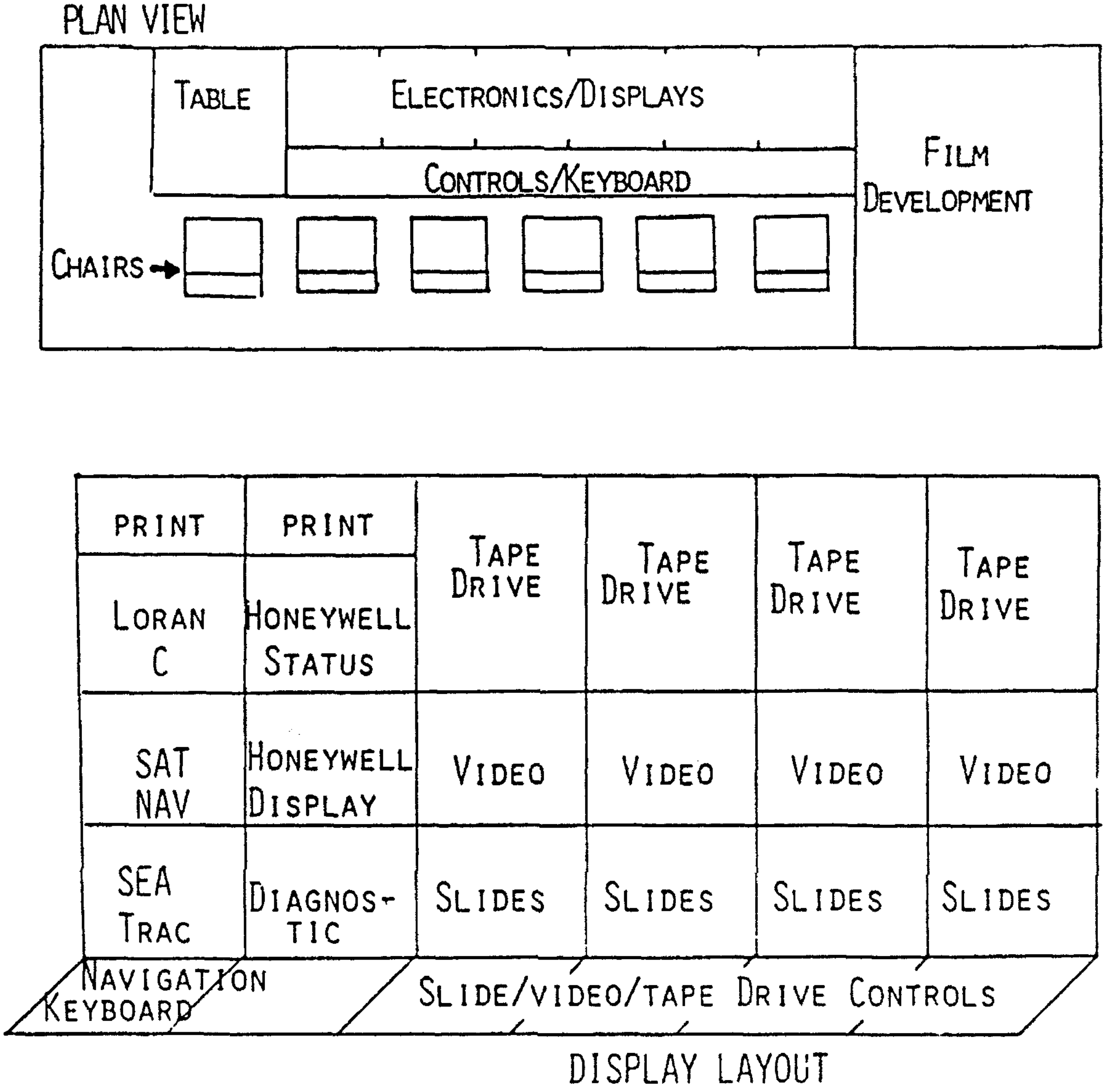


Figure 75. Autonomous search vehicles concept operation van.

The search data processing will also take place in this van. If film is used as the data-storage medium, an automatic film processing machine will be part of the van's equipment. When the film is ready to be viewed, it will be loaded into viewers and displayed to data analysts. The analysts will watch the frames at an accelerated rate, stopping or slowing down when interesting scenes appear. If the data are stored on the vehicles in an analog or digital format, the raw data, after vehicle recovery, will be immediately viewed by the data analysts. If computer processing of the raw search data is desirable, the computer and its controls will also be located in this van.

The operations van will be about 30 feet long, 8 feet wide, and 8 feet high. (For further information see Kimberling, July 1984.)

Support Van. A separate vehicle maintenance and service van will be located on the afterdeck of the ship near where the vehicles will be recovered and launched. This van will house tools, spare vehicle batteries, battery charging equipment, spare equipment, and a vehicle servicing area. The van will not store the vehicles. The vehicles will be stored in the launch racks and brought into the support van only for servicing. A track with carts will allow the vehicles to be moved about the deck between the launch rack, the service van, and the recovery crane or ramp. Figure 76 shows the launch rack and vehicle track system.

The support van will be about 40 feet long, 8 feet wide, and 8 feet high. (For further information see Kimberling, July 1984.)

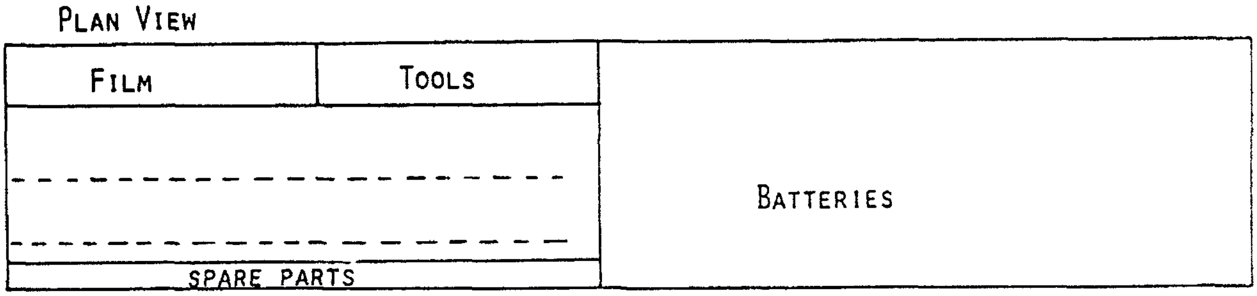


Figure 76. Autonomous search vehicles concept support van.

Surface Vessel Requirements. The support ship must have sufficient deck space for the control/operations van, the support van, and the launch and recovery devices. Figure 77 shows the deck arrangement.

The ship must have adequate control for positioning the launch rack to within a few yards of the desired launch site. Preferably, the ship will have an automatically controlled dynamic station keeping system that can be served off the GPS. If this advanced control system is not available, the ship must have an experienced helmsman who can maneuver the ship to the launch site by watching an X-Y tracking display. (For further information please see the discussion of Surface Vessel Requirements in the Multiple AUSS subsection above and Kimberling, July and August 1984.)

Personnel. Based on the assumption that 10 vehicles will be deployed and maintained by one crew on a continuous around the clock operation, the crew requirements will be as follows (based on two rotating watches):

1. Eight data analysts (four for each watch)
2. Eight vehicle handlers and maintainers (four for each watch)
3. Two watch supervisors (one for each watch)
4. One test coordinator.

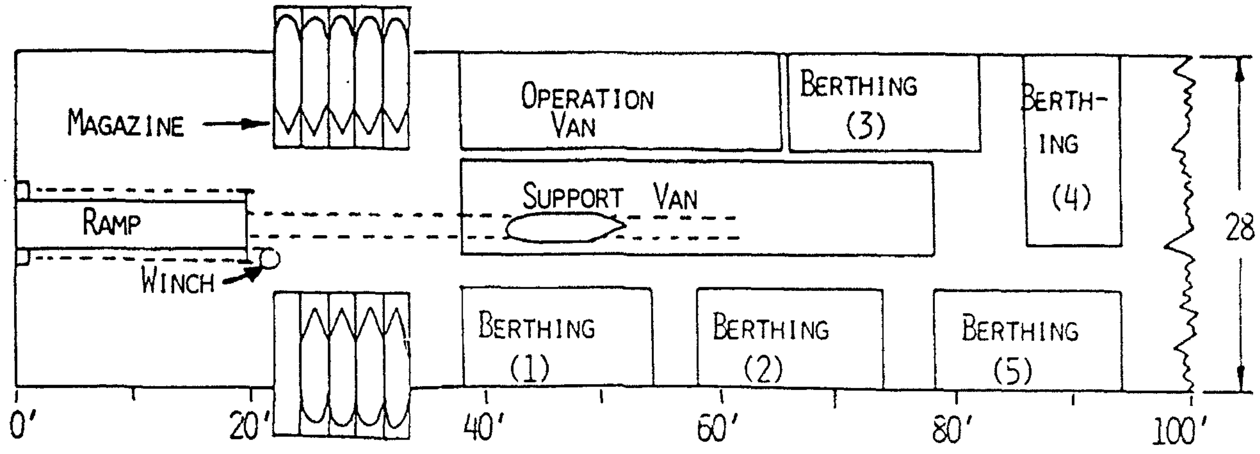


Figure 77. Autonomous search vehicles concept deck layout.

If lengthy search operations are planned (more than a few days), one more watch (nine more personnel) should be added so that three watches are rotating, not just two. Therefore, the FASS crew will number about 19 for short operations and 28 for longer operations.

The personnel requirements are also noted in table 31. (For further information, see Kimberling, July 1984.)

Table 31. Autonomous search vehicles concept personnel requirments.

FASS OPERATOR	EACH SHIFT	24-HOUR OPS 12-HOUR SHIFT
Test Coordinator	1	1
Navigation	1	2
Data Analyzers	4	8
Deck Supervisor	1	2
Vehicle Handlers	2	4
Mechanical Technician	1	1
Electronic Technician	1	1
	FASS CREW:	19

Summary of Pros and Cons for the Autonomous Search Vehicles Concept

The following advantages of the concept have been noted.

1. A long-baseline navigation network is not required. The purpose of a long-baseline navigation net is to attach a bottom frame of reference (or grid) to the

surface ship. The surface vessel is only concerned with the point at which the vehicle-pinger team is deployed, and, since the sensor vehicles only reference their respective pingers, a continuous connection between the ship and bottom is not required.

2. Immediate contact evaluation is performed simultaneously during search effort by using an optical sensor, although postoperation analysis is required. Optical search performed in a precisely navigated pattern produces negligible uncertainty in the search area. Unlike the case of acoustic sensors, a search area would not be visited more than once.

3. This concept eliminates man-in-the-loop control problems associated with nonrealtime, two-way acoustic communications in depths of 20,000 feet. Each vehicle is autonomous with respect to the surface, but remains in contact with a pinger which provides range and bearing information.

4. Many simple vehicles, deployed and recovered on a compressed time schedule, perform the search effort of fewer complex vehicles. Using many, low-endurance vehicles while incorporating simpler design will pay off by the following: reduction of cost per vehicle; operational simplicity; system expendability, modularity, and transportability; reduction in maintenance; and graceful degradation if the system fails.

5. The concept minimizes support personnel and hardware requirements due to the autonomous nature of the system. A control van and all the associated hardware of two-way acoustic communications is eliminated, therefore impacting on the number of personnel which would normally be required for operations.

The following disadvantages of the concept have been noted.

1. Initial location of the vehicle-pinger combination would be difficult to pinpoint without a navigation grid firmly established on the seafloor. Although short-baseline navigation is accurate enough for shallow-water applications, accuracies in the deep ocean cannot be considered precise (SBL is accurate to 1% of the depth: + 200 feet at 20,000-foot depths).

2. Producing a 50-foot swath may be unrealistic for a free-swimming low-endurance sensor vehicle. Since the vehicle must remain small and "expendable", the available power will limit the output of a light source to something less than that required for a 50-foot swath.

REFERENCES

Fleet Data Service. 1980. *Guide to American Offshsore Fleets; Offshore Service Vessels.* Fleet Data Service, Houston, TX.

Higgins, M. NOSC Memorandum Ser 944/79–84 dated 14 August 1984, FASS; Vehicle Handling.

Jane's Fighting Ships, 1982–1983, Publishing Co., Ltd, London, England.

Kimberling, D. A. NOSC Memorandum Ser 942/89–84 dated 13 July 1984, FASS Surface Vessel Support.

Kimberling, D. A. NOSC Memorandum Ser 942/122–84 dated 16 August 1984, FASS TATF Vessel of Opportunity.

McCord, M. NOSC Memorandum Ser 941/116–84 dated 25 September 1984, FASS Information Processing Design Concepts Study.

PROPOSED FURTHER STUDIES

INTRODUCTION

A new plan has been prepared for the Fast Area Search System (FASS) project activities for FY 85. This year's activities will be focused on refining a top-level preliminary design. It will be based on the preferred conceptual design selected from those proposed in FY 84. The major milestones for the coming year include the following:

Select Lead Concept	1 Nov 1984
Complete Subsystem/Component Tradeoffs	1 May 1985
Complete Top-Level Preliminary Design	1 Aug 1985
Complete In-House System "Specification"	1 Oct 1985

The program plan for FY 85 is presented in figure 78 and described in the next subsection. One notable feature of this plan is a proposed new initiative to establish an image-processing capability for exploring target detection, image enhancement, and data-compression alternatives.

TASK DESCRIPTIONS

Preliminary Design

Select Lead Concept. Taking the results of the FY 84 Final Project Review into account, select a lead concept from the three candidates. The balance of the FY 85 activities will focus on his/her concept.

Perform In-Depth Subsystems and Components Tradeoffs. Building on the findings of the technology survey conducted in FY 84, continue to investigate alternatives for subsystem and component features. These efforts can now be concentrated on those features that are compatible with the lead FASS concept. Options will at least be explored for the following system attributes: sensors, vehicle design, command and control, navigation, data storage, communication, and information processing techniques.

Perform "Lessons Learned" Software Analysis. Review the AUSS software design and its performance as demonstrated by the at-sea trials. Also review other software designs and experiences for similar types of systems. In conformance with recognized software design practices, use these "lessons learned" to formulate a software design approach and goals for the lead FASS concept.

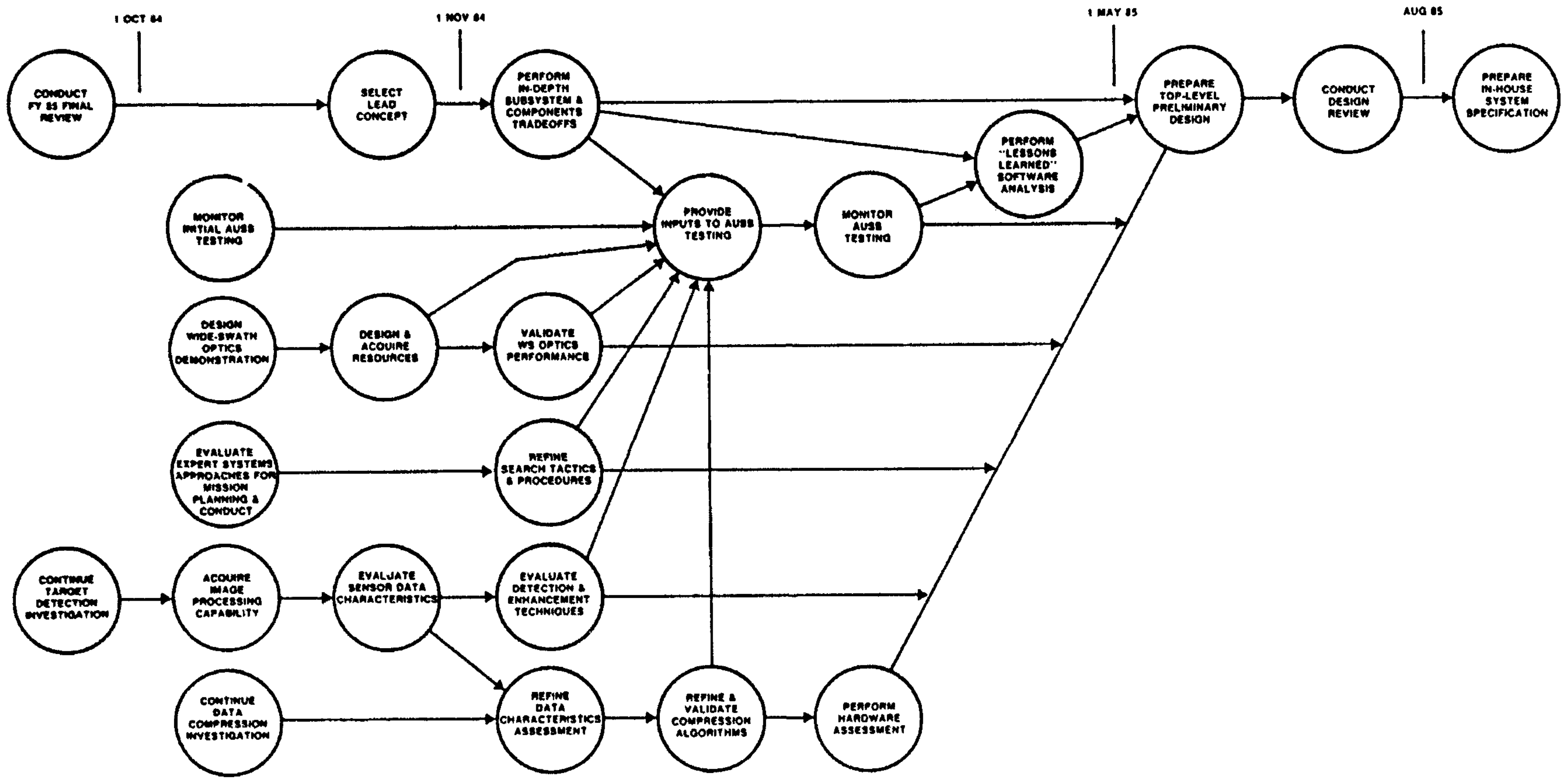


Figure 78. Fast Area Search System (FASS) project FY 85 task sequence.

Prepare Top-Level Preliminary Design. Develop a system design for the lead concept. This is to be a top-level design that emphasizes functional architecture. A first cut at major subsystem and component choices (including software) is to be included. The design document will also provide preliminary descriptions of search tactics, operating procedures, refurbishment requirements, and refinements of all other aspects of the system configuration which were addressed in the FY 84 concept study. Estimates of system performance will be updated.

Conduct Formal Design Review. A major design review will be conducted following completion of the preliminary design document. This review will at least include participation by the FASS and AUSS project teams, the FASS sponsor, NOSC quality assurance personnel, and NOSC management.

Prepare In-House System Specification. To document the preliminary design explicitly and to provide a future aid for implementing the FASS concept, an in-house specification will be prepared. Although this document will not be used for procurement of a system, it will be organized according to accepted specification guidelines. This will become the baseline document for the design and fabrication of any prototype configurations. It will be revised as required during the future course of this project.

Monitor AUSS Testing and System Performance

Monitor Initial AUSS Testing. Participate in and observe the initial series of AUSS at-sea trials. This will be a primarily passive activity in that the object of interest is AUSS's as-designed performance. Of particular interest are free-swimming vehicle behavior, command and control behavior, communications performance, navigation performance, sensor performance, and the suitability of operational and refurbishment procedures.

Provide FASS-Specific Inputs to AUSS Testing. Suggest and assist in performing experiments in conjunction with continuing AUSS sea-trials that demonstrate or invalidate aspects of the FASS concept and its design features. These tests may include exercising alternative sensors (e.g., wide-swath optics), conducting searches using alternative tactics, and acquiring sensor data for use in evaluating target detection, image enhancement, and data compression techniques.

Monitor Ongoing AUSS Testing for FASS Validation. Continue to monitor AUSS testing during the fiscal year. The emphasis here will be on validating FASS design choices so some of these tests may be conducted under the auspices of the FASS project.

Investigate and Demonstrate the Wide-Swath Optics Concept

Design Wide-Swath Optics Demonstration. Design an experiment or series of experiments to validate the concept and performance of the proposed wide-swath optics configuration. It may be possible to perform this experiment in conjunction with AUSS sea trials. Identify the objectives, technical approach, optics configuration, expected performance, experimental procedures, and method of evaluating the results. If possible, the test plan will be submitted for review by other investigators to ensure that previous work has not been duplicated and that all of the factors necessary for a controlled experiment have been considered.

Design and Acquire Resources. Design and fabricate or procure the components necessary for the optics demonstration. If feasible, install the equipment on AUSS or another available platform. Also acquire any special test or support equipment required by the experiments.

Validate Wide-Swath Optics Performance. Conduct the wide-swath optics demonstration and report on the results. Incorporate the design of the preferred sensor configuration in the FASS preliminary design, if appropriate.

Evaluate Expert Systems Approaches for Mission Planning and Conduct. Investigate the current procedures for planning and conducting searches of the ocean floor. Through a review of the technical literature and commercial products, evaluate the potential of expert systems software for streamlining and enhancing conventional procedures. Identify where expert procedures are likely to be most beneficial as decision aids. Inventory the likely sources and characteristics of the requisite expert knowledge.

Refine Search Tactics and Procedures. Based on the results of the expert systems investigation, determine an appropriate set of search tactics and procedures for the lead FASS concept. This information will also be used for refining the system performance predictions.

Evaluate Image Enhancement/Target Detection Options

Continue Target-Detection-Techniques Survey. Continue the literature and product survey for target detection and image enhancement techniques. These may be applied to processing onboard the vehicle as well as postdive processing on the surface support vessel. Identify the leading contender techniques and determine a technical plan for evaluating their suitability for the FASS application.

Acquire Image-Processing Capability. Determine the functional and performance requirements for an image-processing facility that can be used to evaluate the most promising detection and enhancement techniques. Survey existing in-house capabilities and commercially available products. Acquire access to or procure an image processing workstation that is compatible with FASS objectives (e.g., appropriate processing utilities, user programmability, etc.). As with the wide-swath optics investigation, define the objectives of the detection and enhancement study, develop an analytical and experimental approach, and determine the procedures and measures of performance prior to acquiring the necessary resources.

Characterize Sensor-Generated Image Data. Acquire a variety of sensor data in media and format suitable for the image-processing facility. Use the workstation to characterize the data and use this information to determine the most likely candidate processing techniques.

Evaluate Alternative Detection and Enhancement Techniques. Evaluate and demonstrate detection and enhancement algorithms through "hands on" processing of actual search sensor data. This investigation should include SLS, video, and still photographic data. Identify the best performing techniques and algorithms. Provide inputs to the FASS preliminary design efforts based on the experimental results and the state-of-the-art in hardware and software implementations.

Determine Optimal Data Compression Approach

Continue Data Compression Investigation. Continue the data-compression investigation started in FY 84. Extend the study to cover video and photographic data (in addition to SLS data).

Refine Data Characteristics Assessment. Use the results of the image-processing efforts described earlier to improve characterizations of the search sensor data. Refine and validate compression algorithms. Propose and experimentally test compression algorithms operating on the "real" sensor data used for the image processing tasks. Demonstrate compression performance on unprocessed and processed data to assist the preliminary design team in assessing information processing and communications requirements.

Perform Hardware Assessment. Survey and identify hardware implementations or potential for hardware implementations of the preferred algorithms. If hardware is not available or seems unlikely in the FASS time frame (1990), identify software availability and computational resource requirements. These results will be reflected in the preliminary design.

GLOSSARY

ADM	Advanced Development Model
AFI	Automatic Fault Indicator
AI	Artificial Intelligence
ASR	Area Search Rate
AUSS	Advanced Unmanned Search System
CCD	Charge Coupled Device
DOT	Deep-Ocean Transponder
DSRV	Deep Submergence Rescue Vehicle
EARS	External Acoustic Relay Subsystem
EDM	Engineering Development Model
FASS	Fast Area Search System
FSS	Forward-Scanning Sonar
GPS	Global Positioning System
ISEA	In-Service Engineering Agent
LBNS	Long-Baseline Navigation System
OAS	Obstacle-Avoidance Sonar
PHS&T	Packaging, Handling, Shipping, and Transportation
PINS	Precise Integrated Navigation Sonar
ROM	Read Only Memory
RPSV	Remotely Piloted Surface Vehicle
SLS	Side-Looking Sonar
SSA	Software Support Activity
STD	Salinity, Temperature, Depth
STSS	Surface Towed Search System
SWAP	Scan-Within-A-Pulse
TATF	Auxiliary Fleet Ocean Tug
TDA	Technical Design Agent
VLSI	Very Large Scale Integrated circuits
XBT	Expendable Bathythermography

BIBLIOGRAPHY

Acoustic Systems, Inc. 1992. "Definition of the Advanced Unmanned Search System (AUSS) Sonar Characteristics." NRaD TN 1704 (Sep). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.*

Bryant, S. B. 1979. "Advanced Unmanned Search System (AUSS) Performance Analysis." NOSC TR 437 (Jul). Naval Ocean Systems Center, San Diego, CA.

Cooke, M. W. 1992. "Advanced Unmanned Search System (AUSS)." NRaD TD 2348 (Dec). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

Endicott, D. L. Jr., and G. R. Kuhl. 1992. "Fast Area Search System (FASS): Feasibility Study Appendices." NRaD TN 1703 (Sep). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.*

Endicott, D. L. Jr., and G. R. Kuhl. 1992. "The Fast Area Search System (FASS): A Feasibility Study." NRaD TR 1526 (Sep). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

Grace, D. R. 1992. "Brownian Reber Search Theory for the Advanced Unmanned Search System." NRaD TR 1534 (Oct). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

Gunderson, C. R. 1978. "Advanced Unmanned Search System (AUSS), Preliminary Search Systems Analysis." NOSC TR 375 (Dec). Naval Ocean Systems Center, San Diego, CA.

Held, J. L. 1992. "Automatic Hovering Algorithms for the Advanced Unmanned Search System." NRaD TR 1535 (Sep). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

Held, J. L. and H. B. McCracken. 1993. "Automatic Transit Algorithms for the Advanced Unmanned Search System (AUSS)." NRaD TR 1536 (Jan). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

Jones, H. V. 1992. "Advanced Unmanned Search System (AUSS) Description." NRaD TR 1528 (Nov). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

---

* NRaD Technical Notes (TNs) are working documents and do not represent an official policy statement of the Naval Command, Control and Ocean Surveillance Center (NCCOSC), RDT&E Division (NRaD). For further information, contact the author(s).

Keil, T. J. 1992. "Advanced Unmanned Search System (AUSS) Deep Ocean Floor Search Performance Computer Model: Executive Summary." NRaD TN 1702 (Sep). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.*

Kono, M. E. 1992. "Surface Computer System Architecture for the Advanced Unmanned Search System (AUSS)." NRaD TR 1538 (Dec). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

Mackelburg, G. R., S. J. Watson, and W. D. Bryan. 1992. "Advanced Unmanned Search System (AUSS) Acoustic Communication Link Development." NRaD TR 1531 (Nov). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

McCracken, H. B. 1992. "Advanced Unmanned Search System (AUSS) Supervisory Command, Control and Navigation." NRaD TR 1533 (Nov). Naval Command, Control, and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

Osborne, P. D., and C. C. Geurin. 1992. "Advanced Unmanned Search System (AUSS) Surface Navigation, Underwater Tracking, and Transponder Network Calibration." NRaD TR 1532 (Oct). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

Rasmussen, M. E. 1992. "Advanced Unmanned Search System (AUSS) Battery Monitor/Charging Systems." NRaD TR 1539 (Sep). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

Schwager, M., and J. Stangle (SAIC). 1992. "Advanced Unmanned Search System (AUSS) Software Description: Vol I Surface SW/Vol II Vehicle SW." NRaD TN 1705 (Dec). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.*

SEACO, Inc. 1992. "Development of the Acoustic Telemetry System." NRaD TD 2336 (Sep). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

Stachiw J. D. 1984. "Graphite-Reinforced Plastic Pressure Hull for the Advanced Unmanned Search System (AUSS) (U)." NOSC TR 999 (Oct). Naval Ocean Systems Center, San Diego, CA.

Stachiw J. D. 1986. "Graphite-Fiber-Reinforced Plastic Pressure Hull Mod 1 for the Advanced Unmanned Search System (AUSS)." NOSC TR 1182 (Dec). Naval Ocean Systems Center, San Diego, CA.

---

* NRaD Technical Notes (TNs) are working documents and do not represent an official policy statement of the Naval Command, Control and Ocean Surveillance Center (NCCOSC), RDT&E Division (NRaD). For further information, contact the author(s).

Stachiw J. D. 1988. "Graphite-Fiber-Reinforced Plastic Pressure Hull Mod 2 for the Advanced Unmanned Search System (AUSS)." NOSC TR 1245 (Aug). Naval Ocean Systems Center, San Diego, CA.

Uhrich, R. W., J. Walton, and S. J. Watson. 1978. "Portable Test Range and its Application to Side-Looking Sonar." NOSC TR 258 (Jan). Naval Ocean Systems Center, San Diego, CA.

Uhrich, R. W., and S. J. Watson. 1992. "Deep-Ocean Search and Inspection: Advanced Unmanned Search System (AUSS) Concept of Operation." NRaD TR 1530 (Nov). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

Uhrich, R. W., S. J. Watson, and G. R. Mackelburg (Eds.). 1992. "Advanced Unmanned Search System (AUSS) Surface Acoustic Link Description." NRaD TN 1706 (Oct). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.*

Vought Corporation. 1992. "Design Analysis and Operations Research for the Advanced Unmanned Search System (AUSS)." NRaD TD 2337 (Sep). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

Walton, J. 1992. "Advanced Unmanned Search System (AUSS) At-Sea Development Test Report." NRaD TR 1537 (Dec). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

Walton, J. 1992. "Advanced Unmanned Search System (AUSS) Testbed: FY 1987 Development Testing." NRaD TR 1525 (Nov). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

Walton, J. 1992. "Advanced Unmanned Search System (AUSS) Testbed: Search Demonstration Testing." NRaD TR 1527 (Nov). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

Walton, J. 1992. "Evolution of a Search System: Lessons Learned with the Advanced Unmanned Search System." NRaD TR 1529 (Nov). Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA.

---

* NRaD Technical Notes (TNs) are working documents and do not represent an official policy statement of the Naval Command, Control and Ocean Surveillance Center (NCCOSC), RDT&E Division (NRaD). For further information, contact the author(s).

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE September 1992	3. REPORT TYPE AND DATES COVERED Final: FY 1984

4. TITLE AND SUBTITLE
THE FAST AREA SEARCH SYSTEM (FASS)
A Feasibility Study

5. FUNDING NUMBERS
PE: 0603713
WU: DN588521

6. AUTHOR(S)
D. L. Endicott, Jr
G. R. Kuhl

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Command, Control and Ocean Surveillance Center (NCCOSC)
RDT&E Division (NRaD)
San Diego, CA 92152–5000

8. PERFORMING ORGANIZATION REPORT NUMBER
NRaD TR 1526

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Naval Sea Systems Command
Code 05R
Washington, DC 20362–5101

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report presents the results of the first phase of the FASS project, during FY 84. The first phase of the FASS project comprised a multifaceted feasibility study that was the initial step of a multiyear effort intended to result in the development of a "next generation" rapid search system.

14. SUBJECT TERMS

AUSS	multiple vehicle
single vehicle	target size
dual vehicle	

15. NUMBER OF PAGES
200

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAME AS REPORT

NSN 7540-01-280-5500

Standard form 298 (FRONT)

UNCLASSIFIED

21a. NAME OF RESPONSIBLE INDIVIDUAL Michael Cooke	21b TELEPHONE *(Include Area Code)* (619) 553-1881	21c OFFICE SYMBOL 941

NSN 7540-01-280-5500

Standard form 298 (BACK)

UNCLASSIFIED