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Deep-Ocean Search and Inspection: Advanced Unmanned Search System (AUSS) Concept of Operation

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Further information on AUSS is available in related reports that represent NRaD efforts through FY 1992. The bibliography is found at the end of this report.

Released by
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PK

OBJECTIVE

This report describes a new and radically different approach to the task of deep-ocean search. Also discussed are the methods and tactics of AUSS, a system that employs a free-swimming supervisory controlled vehicle to achieve both high-overall search rate and an excellent inspection capability.

RESULTS

This report explains the search tactics and many of the innovative ideas and technologies that are used to perform the AUSS deep search and inspection. These include the acoustic link, the Doppler sonar, the high-quality sonars and optical sensors, and the sophisticated computers and software.

AUSS can perform broad area search and immediate target evaluation interchangeably. The system provides operators nearly realtime high-resolution sonar data at speeds up to five knots. The AUSS vehicle can be commanded to acquire still images from specific locations, as determined from previous sonar or charge-coupled device (CCD) images, or to provide a photomosaic of a prescribed size, orientation, and location. AUSS can resort to purely optical search by using the photomosaic command, or it can use scanning sonar as the primary search sensor. These unique capabilities make significantly different tactics possible.

The greatest strength of AUSS is its versatility. Although years of study, research, and computer modeling preceded the fabrication of AUSS, capabilities and tactics are far better than originally conceived. They have evolved together. AUSS has taught us much about search.

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INTRODUCTION

The Advanced Unmanned Search System (AUSS) finds and inspects objects on the bottom of the deep ocean, 2000 to 20,000 ft down. This mission is accomplished by providing operators on a surface ship essentially realtime communication with an unmanned, untethered, semi-autonomous search vehicle. The vehicle responds to high-level commands to perform complex navigation and search tasks, and transmits images from various sensors along with tracking and status information. The operators do not "drive" the vehicle, they merely supervise it. Supervisory commands can be as simple as instructions to go to a certain location and remain there, or as complex as to perform an entire search pattern while transmitting complete sonar or optical images.

Many innovative ideas and state of the art technologies are incorporated in AUSS, several of which are crucial to the AUSS approach to search. An acoustic link makes untethered communications possible. The vehicle's Doppler sonar enables it to track its position and navigate without interfering with the acoustic link. High-quality sonar and optical sensors are required. Sophisticated computers and software control the vehicle and its sensors, carry out the complex commands, handle the massive amount of information, and provide the surface controls and displays. This report explains how these ideas and technologies are used to perform a unique, versatile, and very rapid form of deep search and inspection.

AUSS hardware, maintenance, and operation were scheduled to be transferred to the Submarine Development Group One in FY 96. This requirement for deep-ocean search and the associated funding were eliminated in FY 92. As a result, search exercises were discontinued in June of that year. There was no 20,000 ft test dive. AUSS has performed 45 dives, the most recent to 12,000 ft. All of these dives were for development related testing and evaluation; search was only part of the mission. Nevertheless, in those searches, AUSS fulfilled its stated goal: an order of magnitude improvement in the rate of deep-ocean search and inspection.

PRIOR PRACTICE OF DEEP-OCEAN SEARCH

The premise of search is that an object is lost on the ocean floor; the location is only known approximately. The objective is to determine the location of that object, or to verify that it is not within a certain area. In the deep ocean, this must be done by moving search sensors along near the bottom.

Only two types of general purpose underwater search sensors exist: sonar and optical. The product of either is images. Purely optical search is sometimes necessary, but the width of sonar images can be hundreds or even thousands of feet, whereas optical sensors are usually limited to a few tens of feet. If vehicle speed is a limitation—and it almost always is—sonar search is much faster than optical.

On the other hand, long range is obtained at the cost of resolution. Unless the object of the search is a nearly intact ship or submarine, sonar is unlikely to distinguish it from worthless objects (false targets). A search system must do more than identify the location of all likely or possible targets; it must verify whether each is the object sought. Generally, a search is not considered finished until a human sees optical images of the real target or of all potential targets.

Because of the conflict between search rate and image resolution, search is usually performed in two phases: broad area search with sonar, and optical contact evaluation for target verification. During contact evaluation, all targets are identified, and the position of the real one is pinpointed. In addition, it might be inspected to determine its condition for future work or recovery.

Theoretically, the vehicle for the search sensors can be towed from the surface by a cable, tethered (i.e., propel itself but use a cable for communication), manned, or totally autonomous. In practice, cost and technology have previously dictated the use of cabled systems. Generally, a towed vehicle (or fish) performs the broad area search. Evaluation is usually performed by a tethered vehicle, either sent out from the fish or separately deployed from the surface, although a manned vehicle or towed fish is sometimes used for this second phase. In any case, the two separate search phases require two or more passes with any combination of one or more vehicles of those types.

In the broad-area-search phase of deep search, the tow fish is a small appendage on the end of the cable and cable handling system. The tow cable forms a long, high-tension catenary with the fish miles behind the surface ship. A modest correction in ship's course might take hours to affect the fish. Any abrupt changes in course would cause slack in the tow cable, and the fish might crash into the bottom; a speed increase might yank the fish upward. Tow speeds much over a knot are unusual, and a 180 degree turn takes unproductive hours. Furthermore, it is difficult to keep the fish on a designated search track, even if it has thrusters and a rudder. The uncertainty of placing the fish where you want it to go is called control error; navigation error is the uncertainty as to where the fish is. To assure full coverage of the search area, successive parallel tracks must overlap each other by an amount equal to or greater than the maximum anticipated control error and navigation error. The tail wags the dog, resulting in a low overall search rate.

If the operators of a towed system see a promising target in a sonar image, they must decide whether to discontinue broad area search and switch to the contact evaluation mode. Even if evaluation is actually done by a different vehicle and ship, it is too dangerous for the towed system to continue searching in the area. If a second vehicle is used, the contact will have to be relocated by that vehicle's sensors, in effect requiring a second small search.

The process of deploying a separate system is extremely time consuming; as is bringing the tow body, with its control problems, close enough to the target to obtain optical images. Special tow techniques have been developed, wherein the tow ship performs a continuous sequence of figure eights or circles. The fish tends toward the center of the pattern, which can then be moved slowly over the target. An alternative approach to towed optical target evaluation is to make a wide turn and a one-shot attempt to pass the tow fish across the target while continuously acquiring pictures. If it misses because of control error, another time-consuming pass must be made.

Interrupting deep towed search for a false target is so costly, so time consuming, that evaluation is generally postponed until broad area search of a large area is completed. Then, all potential targets in the search area are evaluated. While usually the best strategy for deep towed search, delayed contact evaluation is certainly inefficient if the only real target of interest is actually encountered early in a large broad area search.

If the density of false targets is great, or if the search object or search area are unsuited for side-looking sonar (SLS), purely optical search may be necessary. Tethered vehicles, with their relatively smaller control error, are better suited for small-area optical search (i.e., target evaluation) than towed ones; but moving a tethered vehicle around a large area results in the same cable problems as a towed system. With the control errors inherent in deep towed systems, optical search is sometimes done randomly, with no attempt to follow a specific search pattern. If the object is known to be in a certain search area, random optical search will average about twice as long as a perfect search pattern (i.e., one in which the control error is small and a structured path is followed) to find the object. If the object of search is actually not within the area, random optical search will never prove it, since random search can never guarantee 100% coverage.

Generally, all navigation and tracking is done on the ship. Satellite-based Global Positioning System (GPS) or land-based Long Range Aid to Navigation (LORAN) stations may be used to determine ship's location, but the fish must be tracked acoustically. There are two methods of acoustically tracking a tow fish from the surface: short baseline (SBL) and long baseline (LBL). SBL uses an array of hydrophones mounted on the ship to determine the approximate relative direction of the fish. LBL employs an array, or net, of bottom-mounted deep-ocean transponders (DOTs). Occasionally the ship and then the fish interrogates the transponders. From the timing of the replies, the positions of the ship and fish can be calculated within a few tens of feet.

A LBL navigation net only covers a few square miles, and it requires several hours to install and survey the locations of the DOTs. Because of the distances and the speed of sound, deep LBL fixes can only be obtained a few times per minute. Single fixes are not very accurate, although the location of an unmoving vehicle can be determined more accurately by averaging many fixes. But a net can be used again, days or months later, by the same system or a different system, to revisit a target. With the control error of towed systems, the accuracy of LBL is sufficient.

The problems inherent to deep ocean search, as previously practiced, can be summarized as follows:

- major support and handling requirements;
- low search rate;
- imprecise and slowly updated navigation;
- large control error;
- poor maneuverability;
- poor optical search capability;
- inability to stop or hover;
- delayed contact evaluation;
- slow target closure process;
- limited target inspection capability; and
- extremely inflexible tactics.

Shallow search, a few hundred feet down, is done by using similar equipment and methods, a towed SLS, and a tethered vehicle with a camera, yet it is considered routine. Most of the problems of deep search are directly or indirectly related to the need for a long cable between the vehicle and the operators.

SYSTEM OVERVIEW

The Advanced Unmanned Search System was designed from the bottom up specifically for deep search. From the program's inception as a paper study, through concept tradeoffs, computer modeling, subsystem tests, and two working prototypes, the purpose of AUSS has been to eliminate the problems listed above. The result is not just a vehicle, but a system. AUSS significantly advances the state of the art of deep ocean search, primarily by eliminating the long cable.

A deep-ocean-search mission involves extensive mission planning, system mobilization, transit, equipment deployment and retrieval, broad area search, and contact evaluation. This report is concerned primarily with the phases during which sensors collect data which are (at least potentially) about the actual object of search. This is the period during which both navigation data and images, sonar or optical, are gathered.

Nevertheless, it should be noted that AUSS, with no cable or cable-handling system, greatly simplifies mobilization, transport, launch, and recovery. The entire system, consisting of a 2800-lb vehicle, control van, maintenance van, launch and recovery ramp, and a small shallow tow fish, easily fits on an offshore supply boat. For launch, the vehicle simply slides down the launch and recovery ramp, and falls to the bottom on a weighted line. The vehicle is commanded to release from this line to begin the active portion of search. At the end of the mission, the vehicle is commanded to drop an ascent weight; the vehicle floats to the surface, and is recovered by being pulled into the ramp and the ramp is subsequently recovered.

The endurance of the AUSS vehicle, because it is free swimming, is limited by its batteries. Theoretically, it could hover for 24 hours, or it can search 10 hours at its maximum speed of 5 kt. By using the SLS at the 2000 ft range scale (2/3-nmi swath), AUSS could perform broad area search covering over 30 sq nmi on a single dive! Actual overall search rates depend upon many factors, especially target size and number of false targets requiring evaluation; but on one dive, AUSS searched 7.5 sq nmi in 8.5 continuous hours of combined search and evaluation. (That search was a success; it proved the target wasn't there, although several false targets were evaluated.) *With a second set of rechargeable batteries, allowing only* 3-1/2 *hours between* 20,000 ft dives, AUSS could operate continuously.

AUSS provides a method of putting sensors in the right place wherever required. The product of AUSS search is the images. These are computer images preserved as files rather than pages or rolls of paper. Depending on resolution, a new image can be sent every 30 seconds or less, but long-range sonar images take a couple of minutes just to acquire. The greatest number of images collected by AUSS on one dive, thus far, has been 461. Uncompressed, this is approximately 90 Mbytes of sensor images on one dive. The AUSS system takes great care in the handling and the online processing of the collected data, both during and after a dive. Appendix A discusses AUSS data management.

CRITICAL SUBSYSTEMS

The tremendous capability and flexibility of the AUSS is the result of an overall system approach to the problem of search. The AUSS search concept requires the integration and interaction of powerful subsystems. The following sections will describe several critical subsystems and the role each plays in the overall search system.

SENSOR SUITE

AUSS performs broad area search, contact evaluation, and inspection of the object once it has been located. It is able to perform all of these tasks well, and under an extreme range of search scenarios, because it has a full suite of high-quality search sensors configured and controlled by custom AUSS computers and software. The output of these sensors is transformed and transmitted as images for immediate viewing. A brief discussion of each search sensor follows; for a more detailed discussion of the search sensors refer to appendices B and C.

The primary AUSS optical sensor is a state-of-the-art cooled charge-coupled device (CCD) electronic still camera. The still camera is accompanied by a 250 exposure 35-mm film camera for documentation. Both cameras are mounted in the nose section of the vehicle and look straight down. Illumination is provided by two strobe lights that are mounted in the tail section to provide maximum separation from the cameras. The positions of these sensors are shown in figure 1.

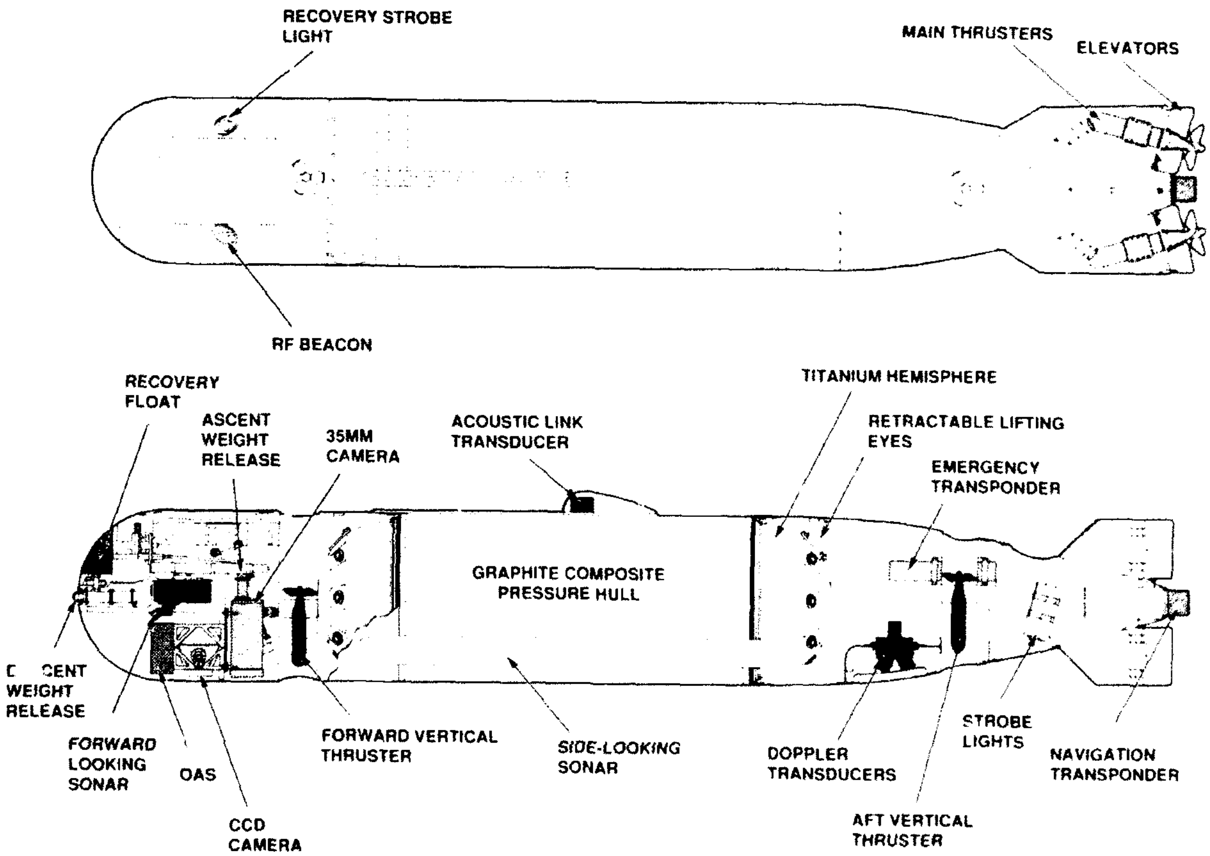

Figure 1. AUSS vehicle.

The operators can choose among algorithms for individual pictures, picture series, photomosaics, and retransmission of prior images. Each image can be acquired as CCD only, 35-mm only, or both simultaneously, and illumination can be from either, both, or none of the strobes. All CCD images are acquired as 14-bit digitized information at spatial resolutions up to 576 by 384 pixels, but AUSS reduces them to a maximum of 512 by 384 at 8 bits. They can be processed by custom AUSS computer hardware and software in a variety of ways, usually including histogram-based linear contrast enhancement and data compression. The system also provides the capability to retransmit CCD images while using different processing or resolution.

The primary AUSS search sensor is an SLS. It consists of two side-mounted transducers and custom AUSS interface and processing electronics. A forward-looking sonar (FLS), also called the scanning sonar, is used primarily for closing in on objects detected with the SLS. The FLS is located on the nose of the vehicle. It consists of a mechanically scanned head assembly and custom AUSS interface and processing electronics. Under computer control, the transducer can be scanned from left to right a full 180 degrees, or any portion thereof, in 1.8-degree steps. This capability to request a scan of a specific sector saves time when the object of interest is known to lie in a particular direction.

Most SLS and FLS operating parameters are computer controlled and under operator selection. These include range scale, resolution, gain and time varied gain. Pulse widths, receiver bandwidths and sampling rates are computer controlled and automatically set to be compatible with other operator configuration selections. All samples are digitized at 12 bits per sample, but each ping of data is converted into an image line with a maximum of 8 bits per pixel. SLS sonar images can be processed as packed or compressed data under various linear, nonlinear, and/or adaptive processing formats.

VEHICLE COMPUTERS

The AUSS vehicle computer architecture is shown in figure 2. It employs both parallel processing and multitasking while using multiple Intel 80386 central processors and two distributed bit-bus controller nodes. The vehicle computers are functionally divided into two major groups: the main vehicle group and vehicle sensor group. Vehicle computers communicate via a common bus or via serial or parallel communication lines to provide a high degree of interaction and data sharing. It is this architecture that makes possible the highly complex and interrelated processing required to meet the search mission requirements.

In the main vehicle group, the main vehicle (MV) processor performs interpretation and parsing of commands from the surface and controls all motion functions on the vehicle. The software includes heading, depth, altitude, pitch, and speed control algorithms for various hover and transit modes. It acquires and handles navigation and control sensor information, monitors emergency functions, and logs vehicle flight recorder data. The MV software is also responsible for the higher level control of the vehicle through maneuvers such as SLS search patterns, hovering over a target, and photomosaic search patterns.

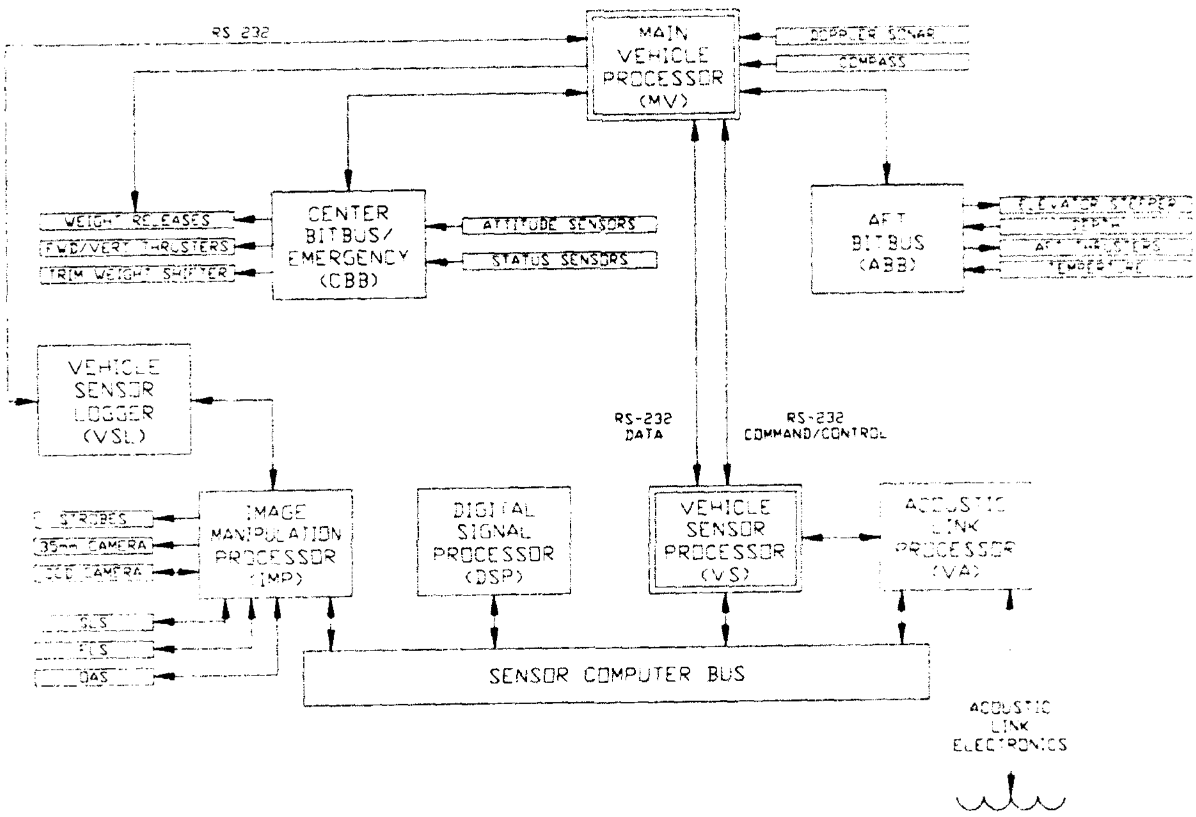

Figure 2. AUSS vehicle computer architecture.

The search sensor group of processors consists of the vehicle sensor (VS) computer, the vehicle acoustic link (VA) computer, the image manipulation (IMP) computer, and the digital signal processor (DSP). The VS computer serves as the master controller for this group. The VA computer controls the vehicle acoustic link electronics, buffers and relays all acoustic link communications, and sets up various acoustic navigation modes for tracking the vehicle from the surface. The primary purpose of the IMP is to serve as the interface and first-level processing node for all vehicle search sensors. The DSP serves as a slave to the IMP to perform secondary data-processing functions for sensor data, including data compression.

SURFACE COMPUTERS

Figure 3 is a block diagram of the AUSS surface computers. The four main components are the Command (CMD), Image (IMG), Navigation (NAV), and Data Logger (LOG). Each of these is an operator work station based on an IBM PC compatible, and has a keyboard and one or more displays for menus, status information, or images. Except for the CMD, these computers are all connected to a local area network (NET) dedicated server for file sharing. The surface acoustic (SA) link computer is analogous to the VA but does not require navigation modes.

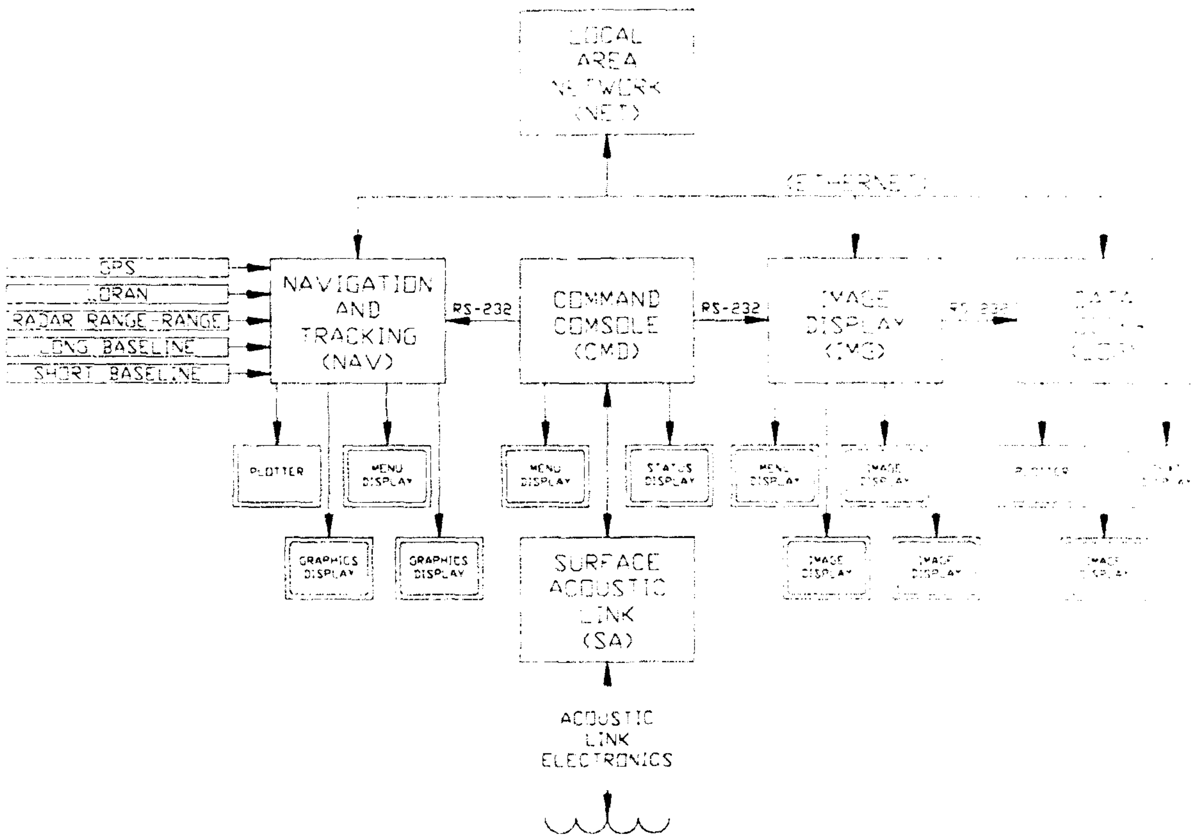

Figure 3. AUSS surface computers.

The CMD is the vehicle-operator interface. It provides command menus and a custom keyboard for assembling and sending high-level vehicle commands, and maintains a vehicle status display showing the latest values of all critical parameters. The CMD controls the SA computer, hands the SA computer the commands to be transmitted to the vehicle, and receives all uplink data from the SA. The CMD also sends a copy of all uplink and downlink communications to the IMG via a serial cable.

The IMG serves as the system's windows. The IMG handles sensor data, decompressing and formatting it, displaying it as images, and automatically saving images as computer files. The IMG operator is able to manipulate, enhance, and zoom these images, and to recall stored images from files for display. The IMG also integrates vehicle navigation and timing data with images, and permits marking of objects within images to determine their locations within the vehicle coordinate system. Appendix D describes the IMG sensor image displays and their interpretation. Nonimage data is forwarded to the LOG.

The LOG computer captures all nonimage data, uplink and downlink, and saves it into files. It also intercepts information about the vehicle's position, the bottom area covered by images, and the locations of targets marked on the IMG. This information is used to maintain a realtime plot containing this information. Transmitted flight-recorder data can be shown as it is received in a formatted text display, and images stored by the IMG can also be recalled and displayed on the LOG. The LOG also has special AUSS data plotting and graphing utilities used mainly for post-dive analysis.

The NAV computer group, actually two computers, integrates the tracking information from several sources to relate the position of the surface vessel, vehicle, bottom transponders, and objects visited by the vehicle, all in one coordinate system, and to display these coordinates on one color display. These functions are discussed next.

SURFACE NAVIGATION SUITE

The AUSS Integrated Navigation System (AINS) performs both surface navigation and vehicle tracking by using inputs from a broad suite of modern navigation systems. Surface sensors include GPS, both standard and differential, shore-based RADAR transponders, and Loran-C. A gyrocompass provides ship's heading information. Tracking of the vehicle is accomplished with either LBL or SBL, as well as by the vehicle Doppler coordinates. NRaD developed software is used for computing and displaying positional fixes of the surface ship and the AUSS vehicle on CRT monitors. Methods of tracking the vehicle in a transponder field include fish cycle, relay, and passive modes of operation. Relay and passive modes employ new algorithms developed for AUSS, which greatly speed and simplify the process of LBL vehicle tracking.

The functions of ship's navigation and surface-based vehicle tracking are often performed essentially independent of search, but they are a critical part of the AUSS concept. During search, the ship must be able to remain within the vicinity of the vehicle, or communications will be lost. After a search, either the location of the found object or the extent of the area searched must be known, either in local fixed LBL coordinates, or in global GPS or Loran-C coordinates.

CRITICAL CONCEPTS

The sections that follow explain certain abstractions, each a marriage of new technologies and techniques. Together, these new technologies and techniques define the AUSS concept of operation.

SUPERVISORY CONTROL AND THE ACOUSTIC LINK

AUSS is untethered and unmanned, yet provides human operators with nearly realtime data and control. This unique capability makes possible the fastest and most versatile deep search and inspection system in the world. From the time it is commanded to release the descent line to begin the active portion of a dive, until it is commanded to drop its ascent weight to terminate the dive and return to the surface, the AUSS vehicle is able to respond to a broad spectrum of commands. The operators evaluate images, status information, and navigation data, and direct the mission. If new information warrants, the operators can make decisions that totally redirect the operation.

The acoustic link makes supervisory control possible in an untethered search vehicle. The link reliably transmits nearly realtime search data to the surface at rates up to 4800 bits per second, and sends high-level commands to the vehicle at 1200 bits per second. With this data rate and the acoustic propagation delays, joystick type control is not possible. However, it is not necessary. All critical control loops are closed on the vehicle. The human operators are kept in the loop as vehicle control supervisors, search data evaluators, and mission decision makers. The vehicle autonomously performs each task until it is completed, or until the vehicle operator interrupts with a different task.

The acoustic channel must be shared for several competing purposes. Since the acoustic link is a half-duplex system and neither end can receive while transmitting, independent time must be provided for uplink and downlink communications. When not transmitting, both ends default to receive mode. The majority of acoustic transmissions are uplink data and images; but downlink transmissions, the supervisory commands from the operators, are of highest priority. Therefore, when transmitting uplink, the vehicle must periodically go silent to listen for preemptive downlink commands. The operators can transmit commands at any time and, if necessary, repeatedly until the vehicle detects the downlink and responds. Silent periods are also required if acoustic tracking of the vehicle from the surface is used.

The vehicle acoustic link has a large set of configurable options, including uplink data rate, maximum continuous transmit intervals, duration, and scheduling of quiet intervals, and support for several surface acoustic tracking options. All data sent over the acoustic link are divided into interleaved, self-contained packets with imbedded synchronization, error sensing, and source/destination information. This provides a flexible means of meeting the competing requirements and priorities of multiple data sources among the vehicle's multitasking multiprocessors.

Images make up most of the data sent over the acoustic link. Image data compression is used to effectively increase the data rate of the acoustic link. The operators can at any time set image resolution and degree of compression, making a tradeoff between effective transmission rate and received image quality. As a result, sonar search can proceed at optimum vehicle speed (up to 5 kt maximum) without significant information loss, and good quality optical images can be transmitted in seconds rather than minutes. (Data compression is available for both the SLS and CCD sensors, but has not been implemented for the FLS.)

COMMAND INTERFACE

Supervisory control provides the operator with powerful capabilities for controlling vehicle functions, without the need for continuous or detailed interaction. It is important however that the operator interface be both flexible and easy to use. Figure 4 is the command selection menu. It illustrates the types and scope of AUSS supervisory commands. The operator selects a command by using a cursor to highlight the command of interest, or by pressing the corresponding function key on the special keyboard. A new menu then appears on the screen to prompt him for entry of the parameter fields, if any, for that command. Once the command has been assembled, it can be placed into the transmit queue for transmission to the vehicle. AUSS supports 32 supervisory commands, ranging from the simple DOP and GYR commands that turn on or off the Doppler or gyro compass, to the MOS or SLS commands that cause the vehicle to perform complicated search functions which can run uninterrupted for hours.

The photomosaic (MOS) command provides a good example of a high-level supervisory command that could be selected from the main menu. This command can be used for optical search, or to acquire full optical coverage of a relatively large area, such as a debris field. The MOS command defines the area to be covered, relative to the vehicle's present location, and the type of optical coverage. All commands begin with a three letter identifier, followed by a list of numerical parameters, if any, separated by commas and ending in a semicolon. The parameters of the MOS command are:

- the heading of the parallel search tracks, or legs, in compass degrees.
- whether to use the 35-mm film camera.
- the resolution and compression options for the transmitted CCD images, if any.

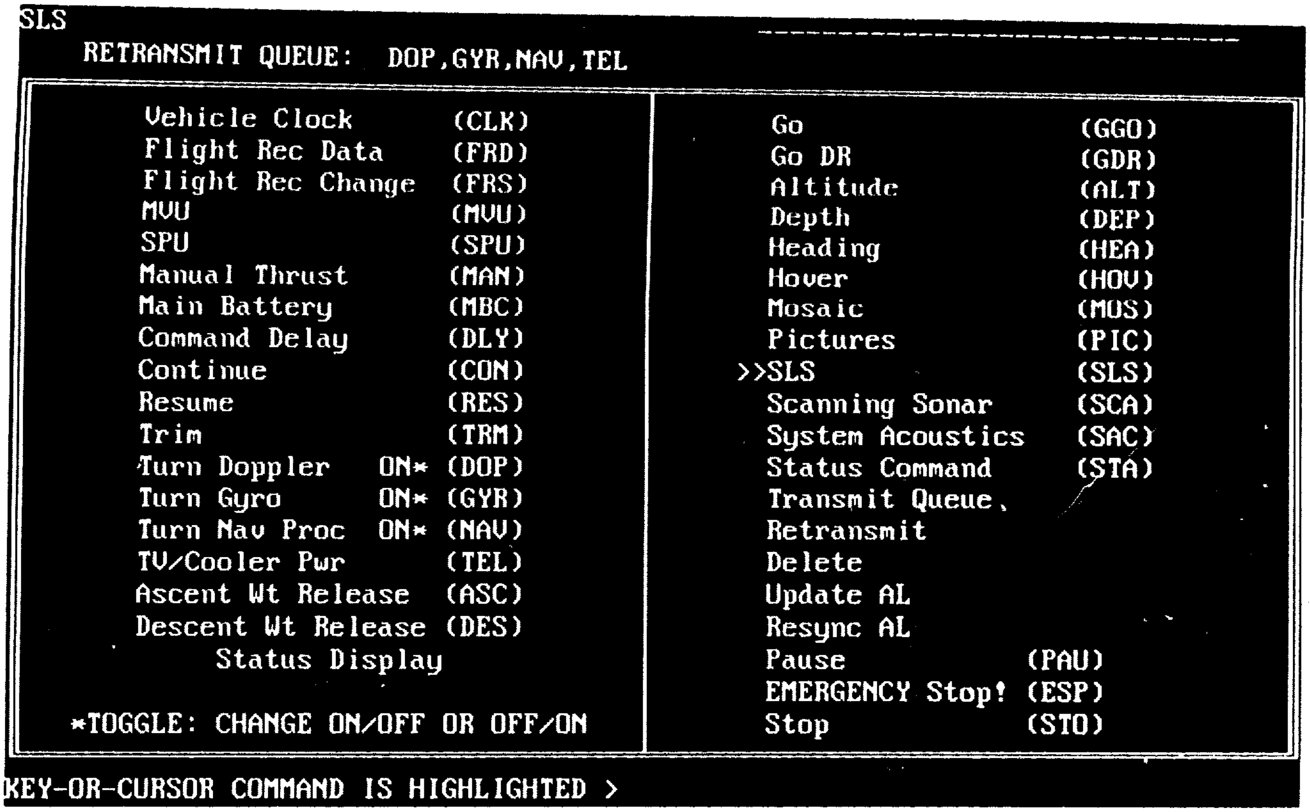

Figure 4. Main menu screen.

- which strobe light or lights to use.
- the length of the legs, in feet.
- the number of legs (a negative number means left turns; positive number means right turns).
- the along-path coverage in percent, 100% meaning no overlap.
- the width coverage in percent (affects leg spacing).
- the altitude at which to perform the task.
- the operating mode of Obstacle Avoidance Sonar.
- the actual velocity to run, or maximum thrust in percent of full.
- whether or not to stop after each leg for surface based navigation fixes.

The MOS command menu is shown in figure 5. The left half of the screen shows the parameters for this command and their present values. The right half of the screen shows context sensitive help for the currently highlighted option, "CCD PACK/COMPRESS." As the operator cursors up or down on the left side of the screen to select parameters for entry, he/she is continually prompted with appropriate help information on the right side. When the menu appears on the screen all parameter fields are filled with values. These values are either commonly used defaults or the values that were selected the last time the menu was invoked. The operator only needs to modify those few parameters, if any, which need to be changed.

The operator has access to an extensive set of control parameters without the need for a time-consuming exhaustive re-entry of values. The operator interface for the AUSS system has proven to be highly efficient and easy to use. New operators have required little training before being able to productively use the system.

```
RETRANSMIT QUEUE:

        MOSAIC                          0: NO CCD

 (ESTIMATED NO. PICTURES: 119)          1: LOW RES, 4-BIT PACKING
                                        2: LOW RES, 6-BIT    "
 HEADING = 45                           3: LOW RES, 8-BIT    "
 PHOTO = 1                              4: HI RES,  4-BIT    "
>>CCD PACK/COMPRESS = 0                 5: HI RES,  6-BIT    "
 STROBE(S) = 0                          6: HI RES,  8-BIT    "
 LENGTH OF LEGS = 100
 NUMBER OF LEGS = 10                    7: LOW RES, MAX COMPRESSION
 PATH COVERAGE = 150                    8: LOW RES, MED      "
 WIDTH COVERAGE = 150                   9: LOW RES, MIN      "
 ALTITUDE = 20                         10: HI RES,  MAX      "
 OBSTACLE DETECT = 200                 11: HI RES,  MED      "
 MAX THRUST = 100*                     12: HI RES,  MIN      "
 NAVIGATION STOPS = 0
                                       NOTE:
                                       HIGH RES PICS TAKE FOUR TIMES
                                       AS LONG TO SEND TO SURFACE

PACK/COMPRESS CODE (0..12) > 7
```

Figure 5. Photomosaic (MOS) command menu.

ONBOARD TRACKING AND SELF NAVIGATION

Under supervisory control, the vehicle must do its own navigating. The half-duplex acoustic link cannot be tied up by continually tracking and steering the vehicle from the surface. If the vehicle is to carry out high-level dynamic tasks such as SLS or MOS, it must "know" where it is, where it should go, and how to get there.

The vehicle's dynamic positioning control loops require essentially continuous position updates consistent within a foot or two. As discussed previously, LBL has a slow update rate and its precision is in tens of feet. Furthermore, the frequencies required by LBL conflict with the AUSS acoustic link; each LBL fix steals up to 10 seconds from data transmission. LBL, by itself, is not adequate for AUSS.

Rapidly updated, self-contained, onboard three-dimensional navigation relative to the bottom is accomplished via a suite of sensors consisting of a Doppler sonar, gyrocompass, depth sensor, pitch and roll sensors, and rate sensors. This suite of sensors solves the control loop problem, and is very well suited to the task of navigation for moderate time periods. But the heart of this subsystem is subject to a long-term accumulation of error called drift. The gyrocompass is rated at 0.5-degree resolution, and the Doppler sonar has a speed resolution of 0.01 knot and a distance accuracy of 0.25%. Assuming the worst case of a straight line course at 5 knots for 10 hours, the compass navigation error could be 2600 ft. The speed error could amount to 600 ft, and the distance error could be 750 ft.

Theoretically, LBL could be used to eliminate drift by continually nudging the Doppler estimates towards fixed reality; in practice, LBL fixes would be required so frequently that the acoustic link would be unable to transmit images. The tactics of AUSS permit a slowly drifting coordinate system, referred to as Doppler coordinates.

To assure complete area coverage during search, the amount of drift can be compensated for by adjusting the commanded degree of track overlap. The surface navigation system tracks the vehicle accurately enough for the ship to follow, and can be used to acquire more accurate fixes, when required. The surface provides long-term repeatability; the Doppler provides short-term consistency.

The vehicle-based and surface-based navigation systems operate essentially independently...until search is completed. Eventually, the real object will be found, or the cell will have been searched, or the batteries will be nearly expended. If it was found, the target's "real" undrifting coordinates, in LBL or global terms, will probably be required. If not, and further search is planned, the "real" area searched must be determined.

The Doppler coordinates of the vehicle are included in periodic status messages, which are sent to the surface every few seconds. This information, as well as other vehicle status parameters, are printed on the formatted status display shown in figure 6. Each such status position update is plotted as a small vector on the realtime Doppler plot. (It is also made available to the surface-based navigation system.) The position vectors are shown in figure 7, which is an edited example of the Doppler plot. The other symbols shown in the Doppler plot will be discussed in the following section.

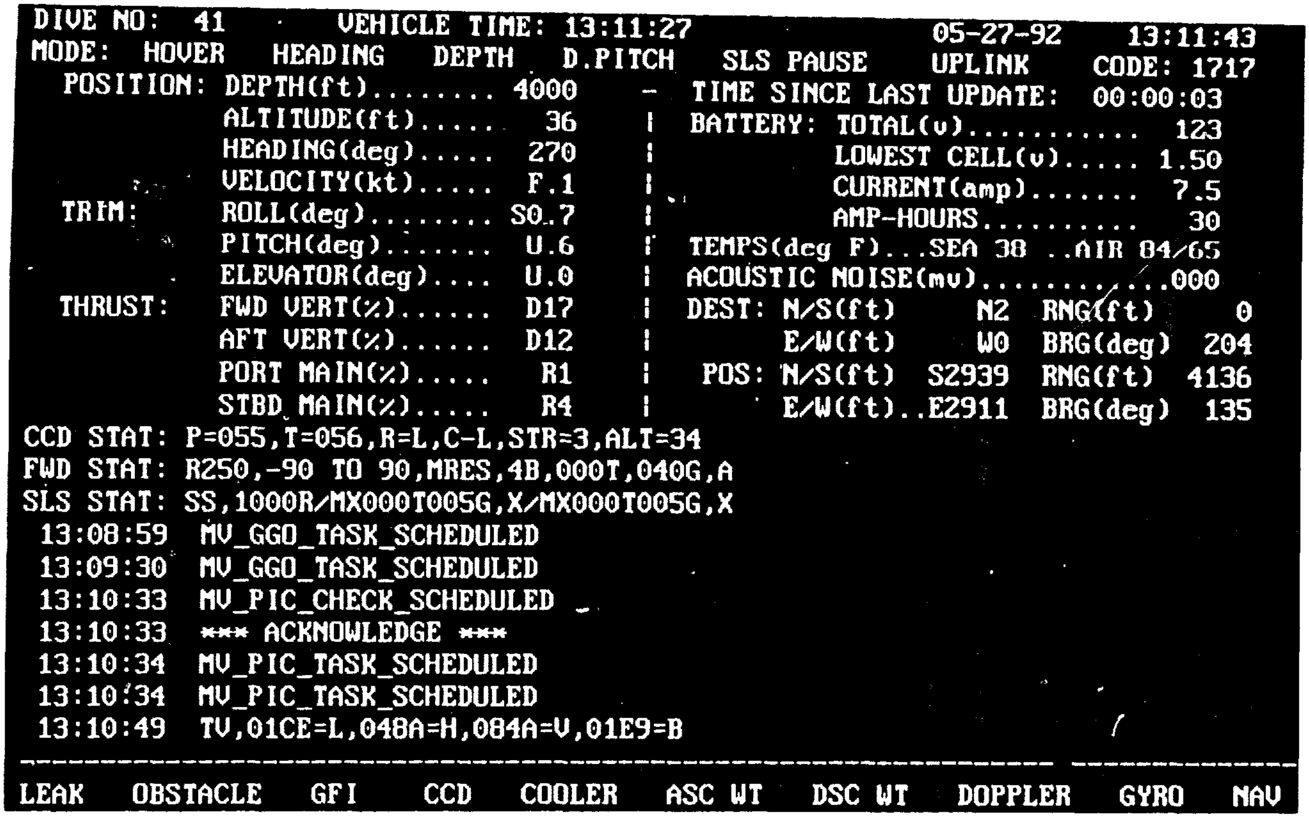

Figure 6. Status display screen.

More frequent Doppler position updates are interleaved with image data. Good images are of little value if the locations of objects therein are unknown. This combination of a realtime Doppler plot and images tagged with Doppler data plays an important role in target evaluation.

TARGET MARKING

Target marking enables the operators to automatically determine the Doppler coordinates of objects within sonar or CCD images. This capability is essential in the process of target closure and inspection as performed by AUSS. It can also be used to determine the size of objects or the orientation of and the distance between objects, even when this distance spans several images. Target marking is possible on images while they are being transmitted, or on images recalled from disk minutes or months later. Each image is saved containing its scale and context in the current Doppler coordinate system. A target is marked by moving a cursor over its location on a sonar or CCD image and pressing a button. The Doppler coordinates appear on the image display, and the location of the mark appears on the realtime Doppler plot. Figure 7 will be used to illustrate the types of marks that follow.

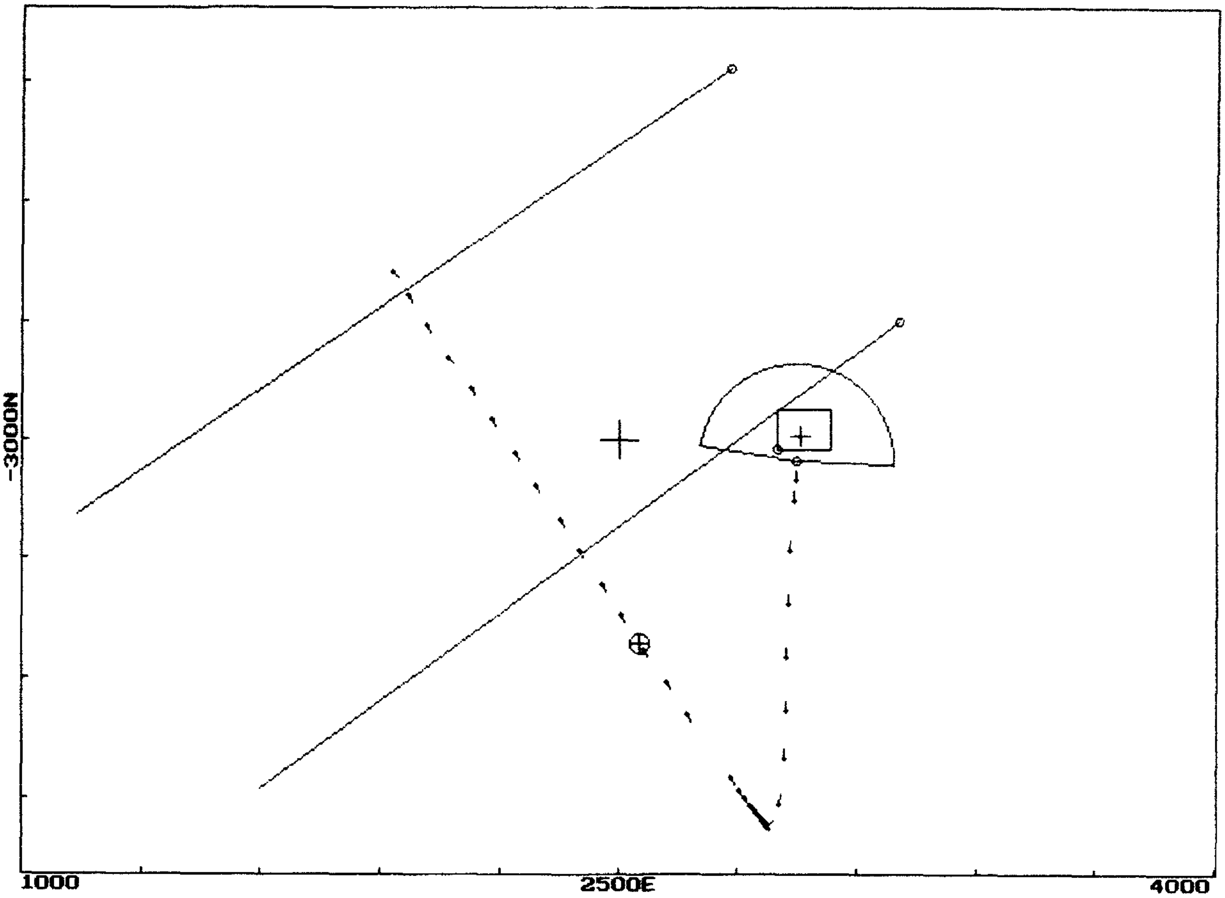

Figure 7. Sample Doppler plot.

Uplink data consist of responses to commands, status messages, images, sensor-related messages, and target-marking data. (Flight recorder information can be transmitted, but this is generally not retrieved until after the vehicle is back in its maintenance van.) The responses and messages are displayed on the status display, and the status information is also used to create the Doppler plot. Image data, like all information sent via the acoustic link, are divided into discrete packets of related data. Each image packet is decompressed or unpacked and placed at the correct location and scale on the appropriate display.

Target-marking data are information about sensor related events and about vehicle onboard navigation fixes. Sensor events include a specific beginning-of-picture (BOP) and end-of-picture (EOP) for each image, and the time and range scale of each 16th sonar ping. Navigation fixes consist of the time, vehicle Doppler coordinates, altitude, heading, and the sensor with which the data are associated. Events and fixes are not synchronized, but both are tagged by time and image type. The surface image computer maintains an independent pair of tables of target marking data for each image.

When an object is marked in a CCD image, the vehicle's coordinates, altitude, and heading are read directiy from the navigation table for that image. The coordinates of the marked object are calculated from the cursor position, the location of the camera with respect to the Doppler, and camera field of view. This information also makes possible the measurement of objects within the image as well as determining their positions within the Doppler coordinate system.

A sonar mark requires more calculation. A minute or more may elapse during the acquisition of a sonar image, during which time the vehicle can move hundreds of feet, change altitude, even change course. During SLS search, the port SLS and starboard SLS images are continually being updated, each new image overwriting the previous image from the bottom up. FLS images are handled similarly, but painted from the top down. Target marking needn't wait until the end of a sonar image. The cursor's position, whether on the old or new image, correlates with a ping number and slant range. The time of that ping and the sonar range scale are found by interpolation or extrapolation in the appropriate sensor event table, and that time is used as an index into the sonar target navigation table. By interpolating or extrapolating again, the image processor can obtain all information needed to calculate target coordinates.

Another type of mark, called a resume mark, is also performed on the SLS image displays (port SLS or starboard SLS). When a likely target is encountered during SLS, the operators mark its position as previously described. If the search is to be temporarily suspended to evaluate the target, they also mark the vehicle's position just prior to interrupting the search, i.e., the location at which the search must later resume. The resume mark is performed by merely placing the image cursor over the last valid SLS image data received before the pause command is sent. The resume vehicle coordinates are calculated from the target marking tables. These are the coordinates at which a search will resume following a contact evaluation.

Target marks, whether on the CCD, FLS, port SLS, or starboard SLS, appear upon the Doppler plot as small plus symbols ('+'). The resume mark appears on the Doppler plot as a circled plus along the search track. Figure 7 contains examples of a target mark and a resume mark. The large plus marks the center of the display. The coordinates of the most recent mark, if any, from each of the four sensors and the most recent resume mark are maintaineu in a small window of the image text display (not shown here).

When an end-of-picture (EOP) is received, the appropriate image is saved to disk, and an outline of the area covered by that image appears on the Doppler plot. CCD sensor area coverage is shown by a scaled rectangle, with a small circle designating the lower left corner of the image. FLS coverage is a pie-shaped sector with a small circle at the vehicle position. For SLS coverage, only a single line is drawr on the plot showing the total swath of the starting ping of the corresponding starboard SLS and port SLS images. A small circle is drawn to indicate the port end of the line. Figure 7 shows the three types of sensor-area-coverage symbols.

When an image is saved, the relevant marking tables are also saved within the image file. If a file is recalled from the disk, the corresponding tables are also reloaded, making possible complete post-dive analysis as well as later image recall and analysis during the dive.

HOVERING, TARGET CLOSURE, AND INSPECTION

A towed fish cannot hover; it cannot remain where it is. For the supervisory controlled AUSS, autonomous hovering is essential to the processes of target closure and target inspection. The vehicle must hover during FLS scans, while CCD images are being evaluated, and at any other time it is not carrying out a dynamic command.

Simply drifting with the current while holding altitude and heading is a poor substitute for true station keeping. Ideally, the vehicle should be able to hover precisely at any commanded location and heading; but this would require side thrusters, which would require additional power, weight, and volume. The vehicle only has two aft main thrusters for steering when underway and for heading control when hovering. (Altitude is controlled by elevators when underway and two vertical thrusters when hovering.)

If this type of vehicle were to be commanded to hover autonomously at a precise point and specific heading, any side component of current or of Doppler drift would eventually force it off station. To return to the target, it would have to circle and reapproach at the desired heading. If the heading were preselected so the vehicle were directly into the current, the hover would be still unstable. Even freeing the heading, allowing the vehicle to always head toward the target, does not result in stability. Computer simulations of AUSS trying to hover at a point show the vehicle constantly buzzing around the target like a bee investigating a flower.

The concept of hovering at a radius is not only a stable solution to the hover problem; it actually has some tactical advantages over the fixed point strategy. The algorithm requires the vehicle to remain a fixed distance R from the target, but maintain a heading toward it. If the vehicle overshoots by approaching closer than R, it merely backs off. Circling back is unnecessary. The effect of side current is to cause the vehicle to slowly weathervane around to a stable position and heading at distance R down current from the target. If R is large or current is small, weathervaning is insignificant; if R is small or current high, downstream stability is achieved rapidly. In either case, the operators can watch the movements on the Doppler plot and initiate a FLS scan command (SCA) or a picture command (PIC) when they judge appropriate.

The command to go to and hover at a radius about a point is perfectly suited for closing in on a target. Although AUSS has successfully gone directly to and taken a CCD image of an object just seen and marked on the SLS, usually a more conservative approach is taken. Typically, at least one FLS scan is performed at a moderate intermediate distance (typically 75 feet) from the suspected target's location. This standoff range and the appropriate heading are achieved automatically by using the command to hover at a radius. Since the FLS scan is done by using a shorter range scale while the vehicle is nearly stationary, the FLS provides a target position mark with better resolution and accuracy than the SLS. If the target still appears worth pursuing, a new mark can be made, this time on the FLS image. Another scan can be taken from a lower altitude, at a different range scale, from lessor or greater radius from the new mark. Or, as is normally the case, the operators can go directly to the derived target location and take a picture.

The CCD and 35-mm film cameras are located approximately 10-ft forward of the Doppler sonar. But it is the location of the Doppler that is used for vehicle positions. If a go (GGO) command is given with R = 10, this is, in affect, a command to hover with the cameras directly over the coordinates. The last step in closure is a GGO to the most recent coordinates obtained from sonar images, at 10-ft range and any desired altitude.

The first step, and usually the last, in contact evaluation is to take and transmit a CCD image. If it shows a false target, search can resume. If the image reveals the object sought, search has been completed. The operators could let the vehicle continue hovering while obtaining a LBL or SBL fix on it from the ship, or they can simply declare the mission over and command the ascent weight dropped.

But with AUSS, when a target evaluation is over, the operators can turn to target inspection. Many exciting options exist at this point. Among the things that can be done, in any order, are:

- retransmit one or more CCD images at higher resolution;
- make another mark and move over it;
- hover higher or hover lower;
- take another CCD image or multiple images;
- use or not use the 35-mm camera;
- take a series of pictures while moving in a certain direction;

- do a full photomosaic area coverage; and
- back off and take a higher resolution or a longer range FLS scan.

Many of these options are further discussed in the SEARCH EXAMPLES section later in this document.

TACTICS, OPTIONS, AND TECHNIQUES

The past sections have discussed the overall problem of deep ocean search and some of the AUSS subsystems. At this point, the discussion will turn to the topic of how AUSS applies all of this into a system level approach to conducting search. The following sections will describe the methodology by which an AUSS search is planned, configured, and conducted.

MISSION PLANNING

For AUSS, as for any search system, before any search mission can begin it is necessary to perform the task of mission planning. This task consists of obtaining as much information as possible about the parameters involved in the search and, based on this information, structuring an orderly approach to the specific search at hand. The environment within which the search will be conducted needs to be defined. What are the characteristics of the target being searched for (size, sonar characteristics, and shape)? Is it likely to be intact or will it be a debris field? What information exists regarding its location? How was this information derived and how reliable and/or accurate is it likely to be? Given the assumed location, what is the water depth, bottom type, and bottom relief likely to be? Will there likely be natural and/or manmade false targets in the area? Will there be conflicts for access to the area such as submarine transit lanes or heavy surface ship traffic? Once as many of these questions as possible have been answered, a synthesis of tactics and mission planning can be performed. It is important to note that the answers to many of these questions must be viewed with some suspicion and may have to be verified on site. The planning phase must maximize flexibility to missing, changing, or inaccurate initial information. As will be shown in the sections that follow, AUSS is an extremely flexible system with a large set of capabilities, most of which can be adjusted and configured as the mission or dive develops. This makes it possible to adapt to virtually any search requirements.

SYSTEM CONFIGURATION

The AUSS vehicle must be ballasted and acoustic link power levels must be configured based on the assumed search depth. The ballasting of the vehicle is important, since the vehicle gains buoyancy with increasing depth and to conserve thruster power it is desirable to have the vehicle near neutrally buoyant at the search depth. Power can also be conserved by not transmitting more acoustic energy into the water than is necessary. These adjustments do not have to be precise but merely within the ballpark. They are the only two critical factors on the vehicle that are not adjustable from the surface during a dive.

NAVIGATION AND TRACKING

The vehicle-based navigation and the surface tracking of the vehicle operate independently. The combination of the two subsystems provides a flexible variety of operational capabilities from which to select. Surface tracking of the vehicle can be accomplished with or without a submerged long-baseline transponder net. If a transponder net has been deployed and surveyed, then all modes of tracking are available. However, deploying and surveying a transponder net requires significant time and effort. A single bottom transponder, such as that deployed on the descent string, can be used in conjunction with short baseline tracking on the surface, or the vehicle can be tracked relative to the surface craft independent of any bottom referenced transponders. The surface craft can navigate using a long baseline transponder net or purely by using GPS.

The decision whether to use a long baseline transponder net could be based on a variety of factors including (1) will the area be used in the future by AUSS or by other systems; (2) are there restrictions to implanting an array; and (3) will there be interference with other systems. If an array is to be deployed, then the altitude and spacing of the transponders within the net must be determined based on the water depth and layout of successive search cells, and the bottom profile and assumed operating altitude of the vehicle. A transponder net is not required by the system, but if it is to be used, time and resources need to be allocated for launching, surveying, and recovering transponders. It is also possible to install and/or survey the transponder net, if desired, after the object of the search has been located.

SENSOR SELECTION AND CONFIGURATION

The assumed bottom type, target characteristics, and false target density will affect the type of primary search sensor used and how each sensor should be configured. In general, the SLS is the broad-area-search sensor of choice because of its large swath width and, therefore, greater area search rate. The longest range scales permit the fastest search rate, but the shorter ranges can be used if higher resolution is needed.

If the target is too small or fragmented, or too poor a sonar target and/or the sonar false target density is too high, it may be necessary to resort to optical sensors for the primary search. AUSS provides this capability with CCD and 35-mm sensors and picture series or photomosaic navigation and control routines. If optical search is required, the altitude of that search and the configuration of the optical sensors will be adjusted "on the fly" based on target characteristics, water clarity, and bottom relief. The CCD and 35 mm have about the same range, so this can literally be done visually. Images have been successfully acquired by AUSS at altitudes up to 70 ft. The size of search cells and the area covered per dive will have to be significantly reduced because of the smaller swath width of the optical sensors.

If optical search is not required, but bottom relief causes the obstacle density to be too high for effective SLS search without significant risk of collision, it may be necessary to resort to the FLS as the primary search sensor. In this case, the vehicle would sprint from point to point, pausing at each point to perform a full FLS scan that overlaps the previous one. Although faster than optical search, FLS search is less effective than the SLS. The FLS tuning, range scale, resolution, and altitude would be configured from the surface based on the bottom type and the target and false target characteristics.

In virtually all searches performed to date by AUSS, the SLS has been used as the broad-area-search sensor. The SLS has been able to detect objects as small as a desk drawer at ranges up to 500 feet, so that target size is not normally a problem. Few search objects are so poor a sonar target that the SLS has not been effective. The extremely efficient target closure algorithms designed into the system have made most false target densities not a problem. The SLS search patterns are performed in a bottom tracking, altitude hold mode, so that bottom slope and reasonable bottom relief are not a problem, unless obstacles exceed the altitude at which the vehicle is flying. Normally, this altitude is chosen as 10% of the range scale selected (e.g., 100-ft altitude for 1000-ft range scale).

All sensor selections and configurations need only be tentative. The AUSS system is designed so that all sensor subsystems as well as all of their operating capabilities are always available to the operator. As a result, total reconfiguration and tactics selections can be remotely modified as needed during a dive or series of dives.

SEARCH TACTICS

When the SLS is used as the primary broad-area-search sensor, a variety of tactical options are available. Many of these options are similar to those available on typical search systems, however the flexibility of the AUSS system and the fact that it does not have a cable makes many of them more viable. In addition, AUSS has the capability to modify tactics and configurations on the fly, if required. In general, tactics are influenced by the target and bottom characteristics and by the desired goal of the particular search.

The size of the target, the uncertainty in its position, the false target density, and the bottom characteristics are critical factors in determining the operating parameters of the SLS. In general, the larger the target the greater the range scale and the lower the resolution in which the sonar will be operated. In addition, for very large targets it is not necessary to have 100% coverage over the bottom. Pings can be spaced farther apart and less lane to lane overlap is required. Given these factors, a much larger area can be searched in a given time. For smaller targets, or for areas of high false-target densities, it may be necessary to reduce the range scale, increase the resolution, and guarantee at least 100% coverage in ping spacing and overlap in lane to lane coverage. Increasing resolution may improve false target discrimination, and shorter range scales reduce the distance the vehicle must travel off the track for contact evaluation.

The length of each sonar leg is influenced by the range scale. In general, the longer the range scale, the longer the legs. Shorter legs decrease the overall search rate at longer range scales since a greater percentage of time is spent sprinting from the end of one leg to the beginning of the next. But longer legs require more lane to lane overlap since the Doppler can drift a greater distance in the increased time required to run the leg. If the location of the object of the search is fairly well known, then the range scale and leg lengths can be reduced to limit the area searched.

The operator must establish criteria for breaking off broad area search to begin immediate contact evaluation. These criteria are based on assumed knowledge of the target and false target characteristics. If the object of the search is known to be intact, then returns indicating significantly smaller physical size can be rejected as potential targets. However, a clustering of returns in a small area, especially if there is a small false target density, may justify the transition to contact evaluation mode. In general, when a new area of unknown characteristics is entered, the operator will tend to pursue targets that do not completely meet the planned target criteria. This will cease as soon as the operator is oriented to typical false target characteristics for the area. Less likely targets are marked and cataloged for later delayed contact evaluation, if required. If the false target density is high, the operator can mark and determine the positions of more than one target before breaking off from broad area search.

The search examples section contains several examples of broad area search and contact evaluation. Search example 1 demonstrates a classic single target, immediate contact evaluation. Search example 2 demonstrates a combination of immediate and delayed contact evaluation in which some targets were not evaluated until after completing the broad area search. Search example 3 demonstrates a high-false-target-density situation in which more than one target was evaluated before resuming broad area search.

INSPECTION TACTICS

Once contact evaluation has located an object, the operator has the option of entering an inspection mode of operation. Many options are available at this point. The choice of options is influenced by how the data (i.e., images) will be used, the characteristics of the object being investigated, and the environment in which it is located.

If the object is largely intact and big enough to extend beyond the area covered in a single CCD image, it can be inspected by marking areas of interest in successive images and commanding the vehicle to move to those points, essentially "stepping" along the object by using the CCD as a viewfinder. Even if the object is broken, this approach can be used provided the spacing of items of interest is such that at least portions of each piece can be simultaneously viewed within an image. A weakness of this technique is that the operator may fail to inspect some portions of a complex object or group of objects.

Large objects and debris fields can also be imaged by commanding the vehicle to hover at a higher altitude to gain a greater area of coverage. This has the advantage of giving a view of the big picture, orienting the operator to candidate areas for detailed inspection. However, image resolution and quality will suffer as a function of altitude. To cover an even greater area, the FLS can be used in high-resolution mode to locate nearby objects of interest.

If the object of interest is highly fragmented, the above approaches may become too tedious, and the risk of missing an object in the overall coverage may become too great. In addition, it may be desired to guarantee total coverage of an area for documentation purposes. In that case, one or more photomosaics may be performed using either CCD or 35 mm as the primary sensor. If CCD serves as the primary sensor then the rate of area coverage is determined by the rate at which images of sufficient quality can be transmitted to the surface. If 35 mm is chosen as the primary sensor, then the area can be covered more rapidly; the CCD will be used only as a viewfinder and can therefore transmit images more rapidly by using higher compression and lower resolution modes.

The search examples section contains several examples of target inspection techniques. Search example 4 describes an inspection in which the operator directs the vehicle to step along an intact item. Search examples 5 and 6 demonstrate the usage of the photomosaic for inspection. In search example 5, the 35 mm served as the primary sensor, and in search example 6, the CCD was the primary sensor.

SEARCH EXAMPLES

The following subsections describe portions of actual AUSS search operations. These examples clarify and expand upon many concepts discussed previously, and they illustrate the flexibility of the system in real-world situations. The first example was a demonstration performed to portray a textbook case of contact evaluation as performed by AUSS. All other examples are unplanned excerpts from normal operations.

SEARCH EXAMPLE 1: IMMEDIATE CONTACT EVALUATION

The concept of immediate contact evaluation and resumption of search will be illustrated by the scenario from a demonstration. The demonstration was performed in 4000 ft of water by using as a target a World War II Dauntless dive bomber. The bomber had actually been found on a previous dive, and its position was now known. The demonstration was set up so that the vehicle would pass about 900 ft from the target. Note however that prior knowledge of the target position, for the purpose of this demonstration, was only used to make sure that the target appeared at a significant range on the SLS. As was the case when originally located, the Dauntless is a clear and unmistakable target. In addition, all subsequent marks, commands and tactics are responses to the actual detection once it occurred and do not rely upon prior knowledge of the target position.

Broad area search was initiated by transmitting an SLS command specifying, among other things, a single 2000-ft run at 100-ft altitude and 1000-ft range scale (2000-ft swath). Figure 8 shows the SLS command menu with the parameters set to the corresponding values. (Previous commands had set various other options, including resolution and compression.) Table 1 lists the SLS command as transmitted, and the subsequent commands and their chronology. This chronology is based on the time evaluation was initiated, not the start of search. During the remainder of this discussion we will refer back to table 1 each time the operator sends a new command to the vehicle. Note as the discussion continues, how few commands were actually required to perform this entire portion of a search and contact evaluation.

At time 0:00 (approximately 2-1/2 minutes into the search), a "suspected" target was seen on the port SLS display, and a series of pause (PAU) commands were sent. Figure 9 is the actual SLS image, which was recalled from disk into the image display and remarked for illustration. The vehicle continued sending data until its next quiet period, when it detected downlink carrier from the pause commands. Accepting the command, the vehicle sent an acknowledgement message to the surface, temporarily stopped searching, and began hovering.

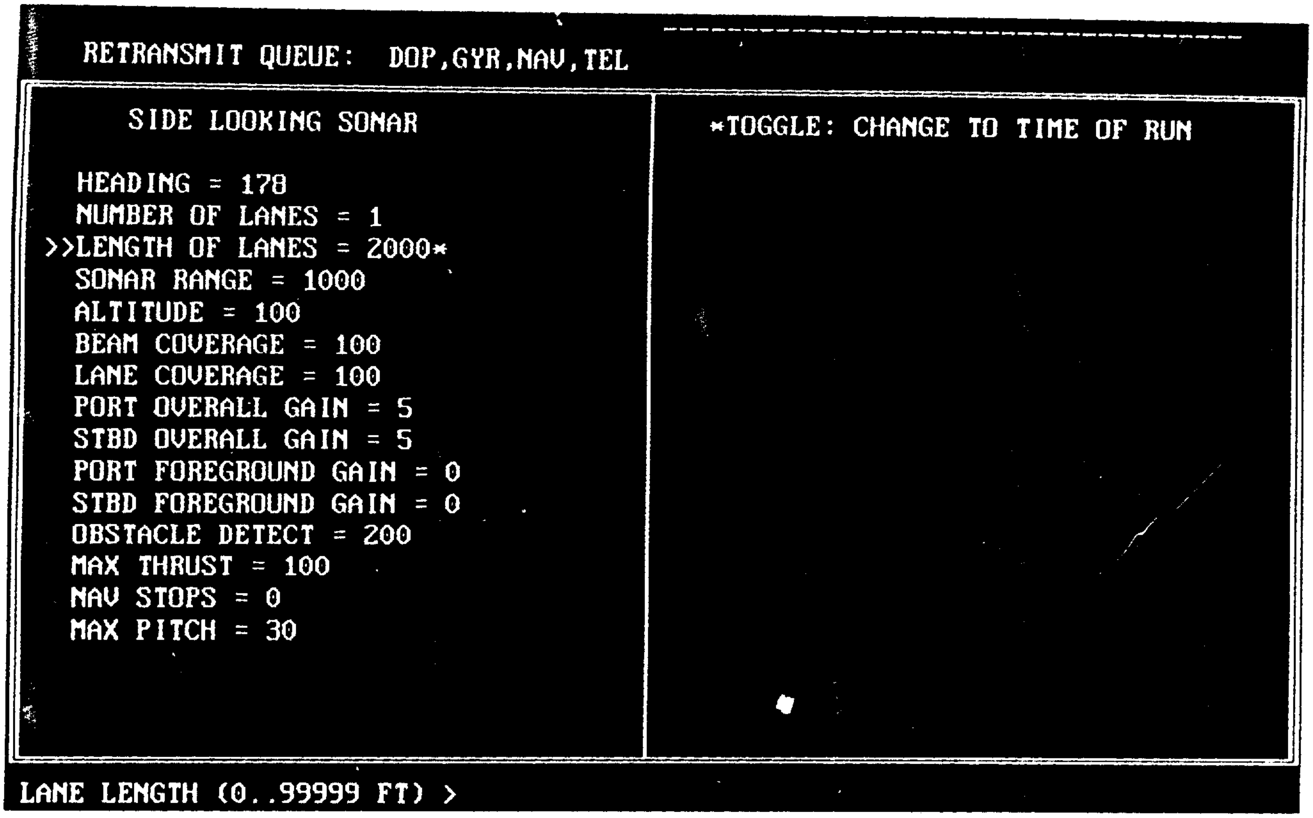

Figure 8. The SLS command menu.

Table 1. Command sequence.

time from start of evaluation (min:sec)	command to vehicle
-2:22	SLS,178,1,2000,1000,100,100,100,5,5,0,0, 200,100,0,30;
0:00	PAU,PAU,PAU;
0:49	GGO,N-2972,E2915,0,A35,0,200,100,30,75;
5:26	SCA,-90,90,250,40,0,1;
7:48	GGO,N-2937,E2902,0,A35,0,200,100,30,9;
9:19	PIC,1,9,3,0,10,1;
11:00	RES,-3090,2047;

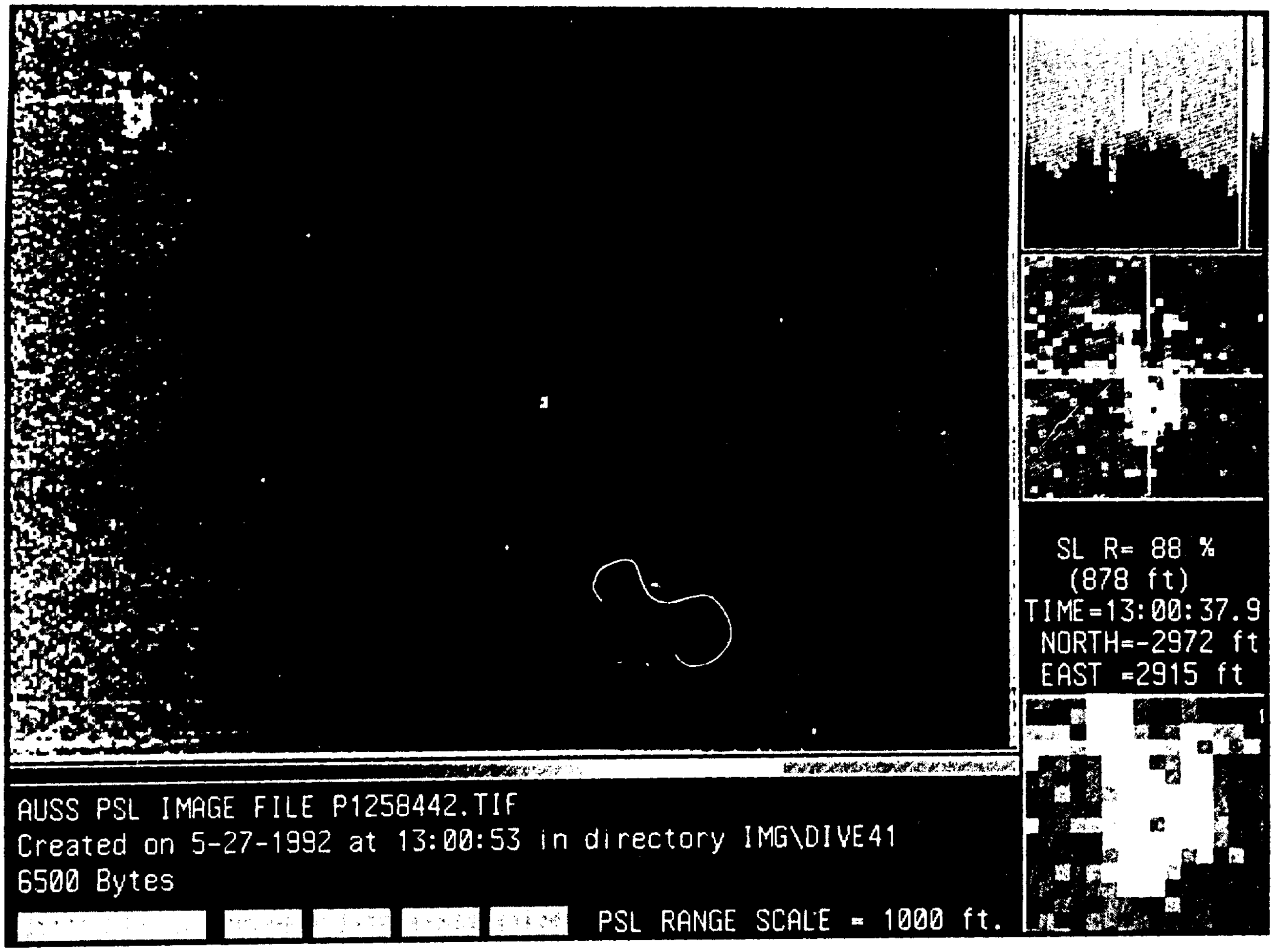

Figure 9. The port SLS image of the Dauntless.

The operators used the cursor on the sonar display to mark both the target and the resume location. The Doppler coordinates of each were calculated and shown on the text display, and the locations appeared on the realtime Doppler plot. These marks can be seen in figure 10, a replot of the entire evaluation process by using the unedited data from the dive.

Forty-nine seconds after the pause command, the operators sent a GGO that told the vehicle to transit to a location 75 ft from the marked coordinates, descend to 35-ft altitude, and hover at that radius. Note that in table 1, the first two parameters of the GGO are the coordinates for the target (N = –2972, E = 2915), which are also shown as the marked coordinates on the port SLS display (figure 9). As the vehicle was transitting, the operators marked the target a second time on the port SLS image, which resulted in two marks a foot apart in figure 11, which is a closer scaled Doppler plot.

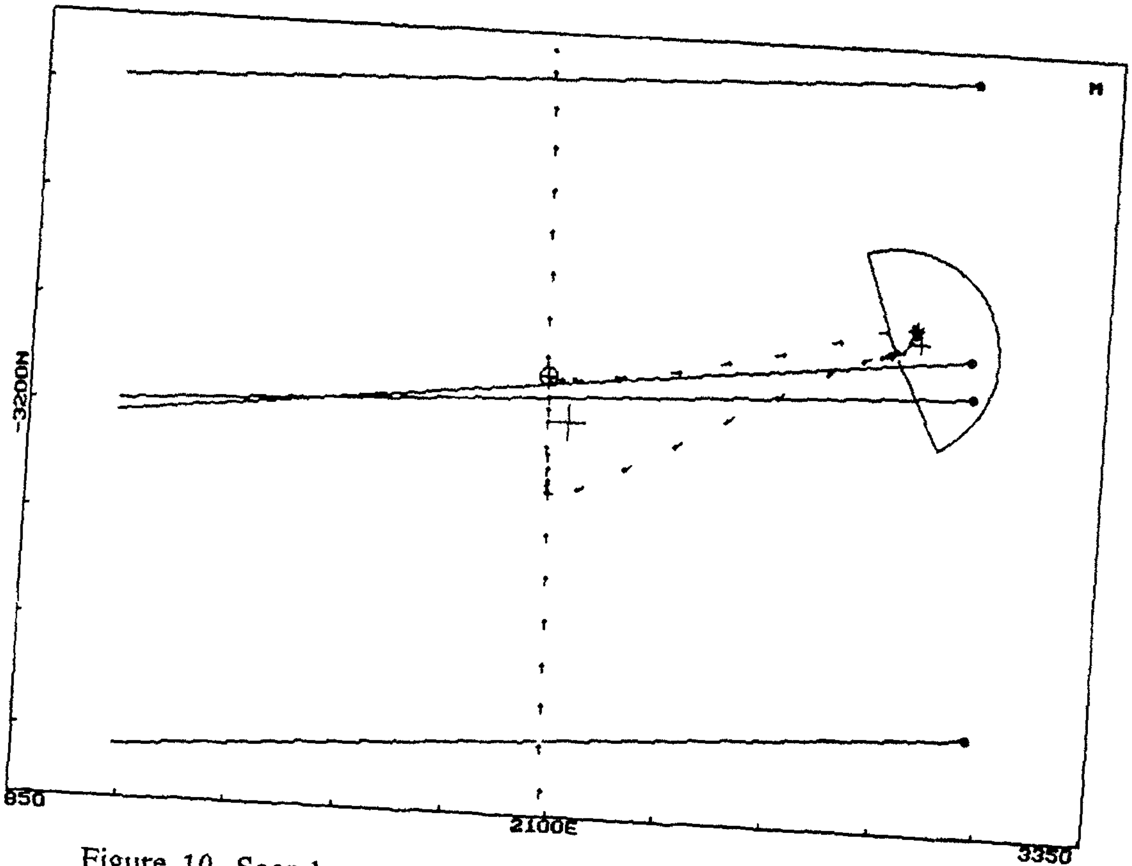

Figure 10. Search example 1: Doppler plot (immediate contact).

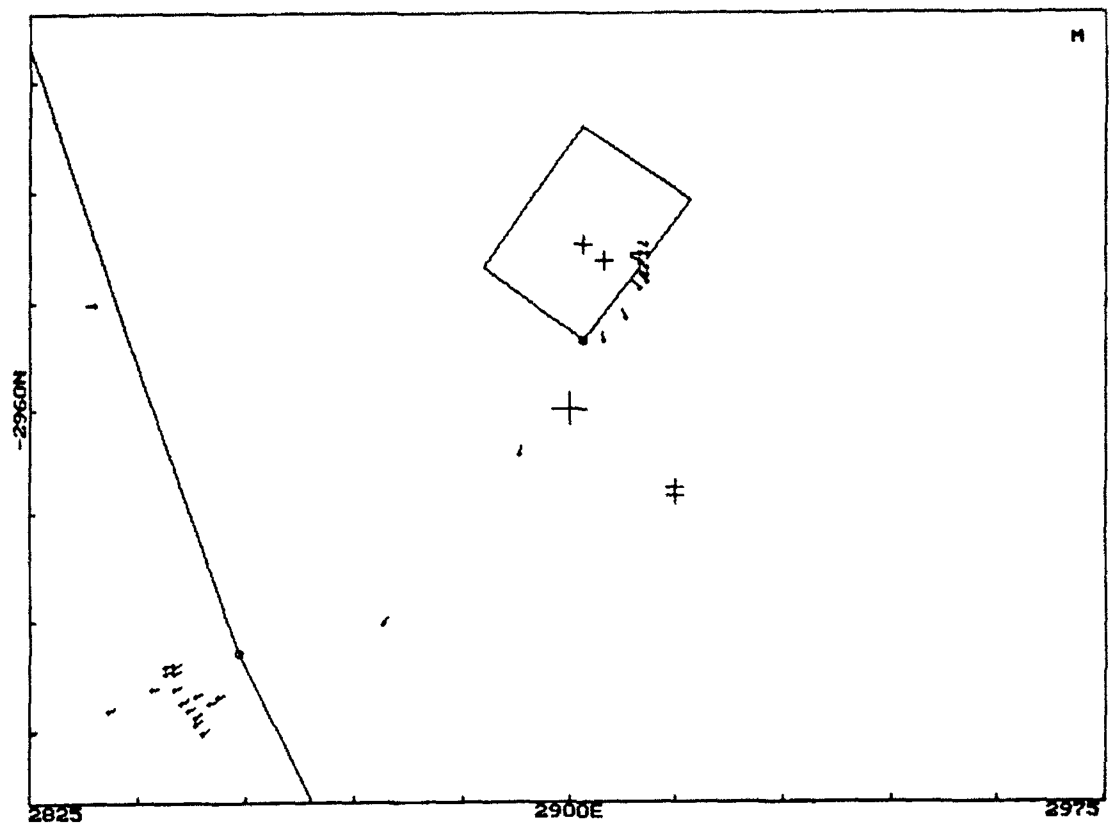

Figure 11. Search example 1: high-resolution Doppler plot.

Five minutes and 26 seconds after the pause, the status display and Doppler plot showed the vehicle was hovering at the commanded radius from the target. A scan command (SCA) was sent telling the vehicle to perform an FLS scan from –90 degrees to +90 degrees on 250-ft range scale. The resulting image, figure 12, not being compressed, required nearly two minutes to send. The operators now marked the target on the FLS image, resulting in more accurate coordinates of the target 37 ft from the original *SLS* mark. The sector covered by the scan was automatically drawn on the Doppler plot, as shown in figures 10 and 11.

At 7:48 into the evaluation, a second GGO was sent with the new coordinates, 35-ft altitude, and 9-ft standoff. Note that the first two parameters of this GGO shown in table 1 are the target position (N = –2937, E = 2902) that the operator obtained from the marked target position in the FLS display (figure 12). The CCD camera is 10-ft forward of the Doppler sonar, so this GGO is, in effect, a directive to place the camera over the target coordinates and keep it there.

At 9:19 the vehicle was holding position, and a picture command (PIC) was sent asking for a single low-resolution CCD image. Figure 13 took about 45 seconds to send. Its coverage is seen in figure 11, but is too small in figure 10. The operators placed a final mark on the target in the CCD image. Note the agreement of this mark (N = –2939.7, E = 2905.7) with the position marked by the FLS (N = –2937, E = 2902).

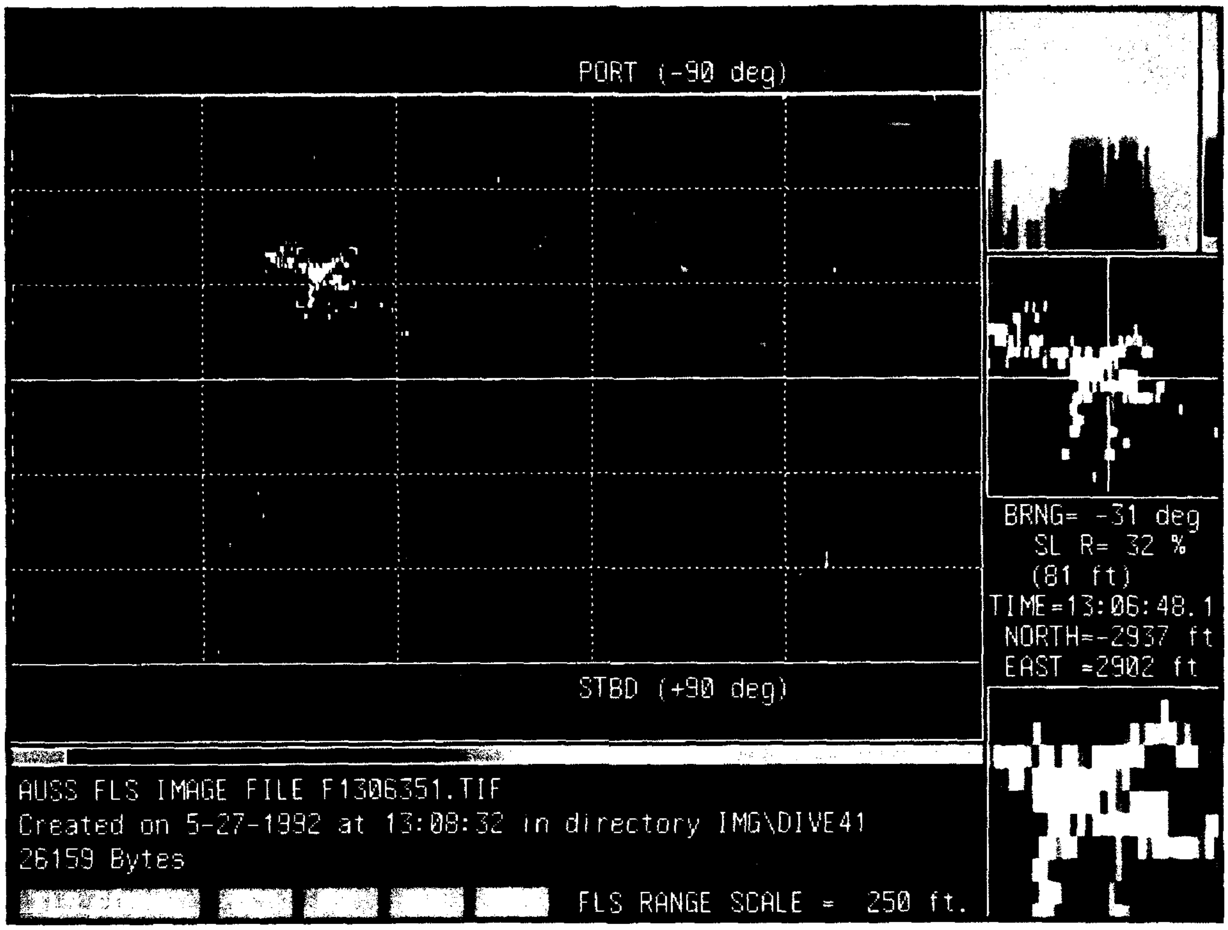

Figure 12. FLS image of the Dauntless.

Had this not been a demonstration, and had the bomber not been explored on a previous dive, the operators would probably have found this object too interesting to pass up...even if they were looking for something else. For the purposes of the demonstration, this was treated as a false target.

Eleven minutes after the pause was sent, a resume command (RES) was transmitted telling the vehicle to return to the search track at the coordinates obtained from the resume mark on the SLS image.

Fourteen minutes after search was paused, SLS images again began to appear on the surface displays. A false target, 900 ft from the search path, had been evaluated, and the vehicle was back on track again performing the broad area search that had been commanded by the original SLS command. As table 1 shows, not including the

SLS command, the operator only needed to send six commands to the vehicle to accomplish this evaluation. The time required (14 minutes) is typical of the 10- to 20-minute range of times usually required by AUSS to perform a contact evaluation. Contrast this time with the times required for other search systems as discussed earlier in this document.

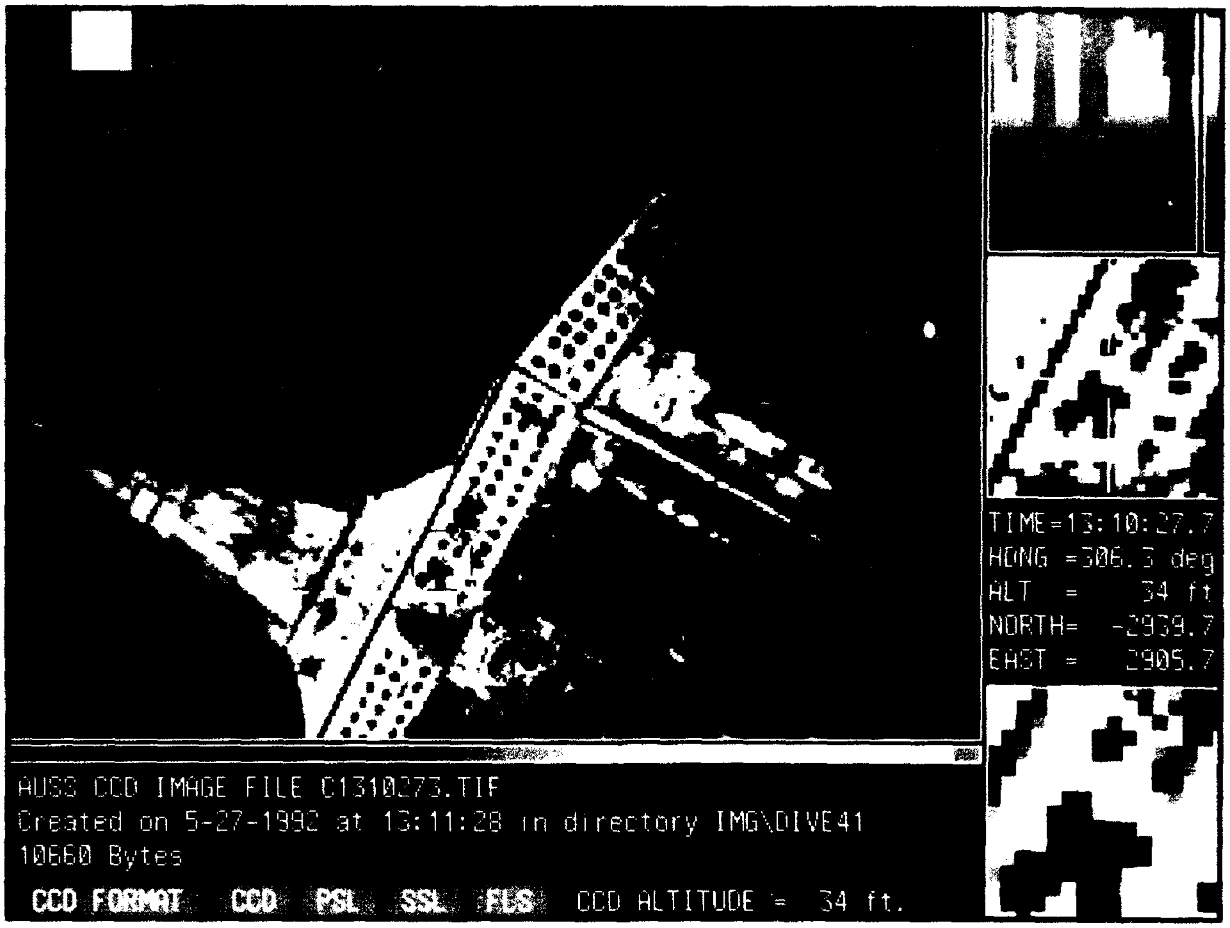

Figure 13. CCD image of the Dauntless.

SEARCH EXAMPLE 2: COMBINED IMMEDIATE AND DELAYED CONTACT EVALUATION

Figure 14 shows the Doppler plot of another successful search. This search proved that the target wasn't within the search cell. For clarity, target marks and sensor area coverage are not plotted in figure 14, only the vehicle position vectors. The area was approximately 4000 ft deep. A LBL net had been deployed but was never surveyed or used. (Had the target been found, the net would have been surveyed afterwards.) The area was fairly free of possible targets, although several were marked (figure 14), and a few were immediately investigated. Notably, a debris field was encountered and investigated early into the search. After an hour investigating the debris field, the decision was made to resume search.

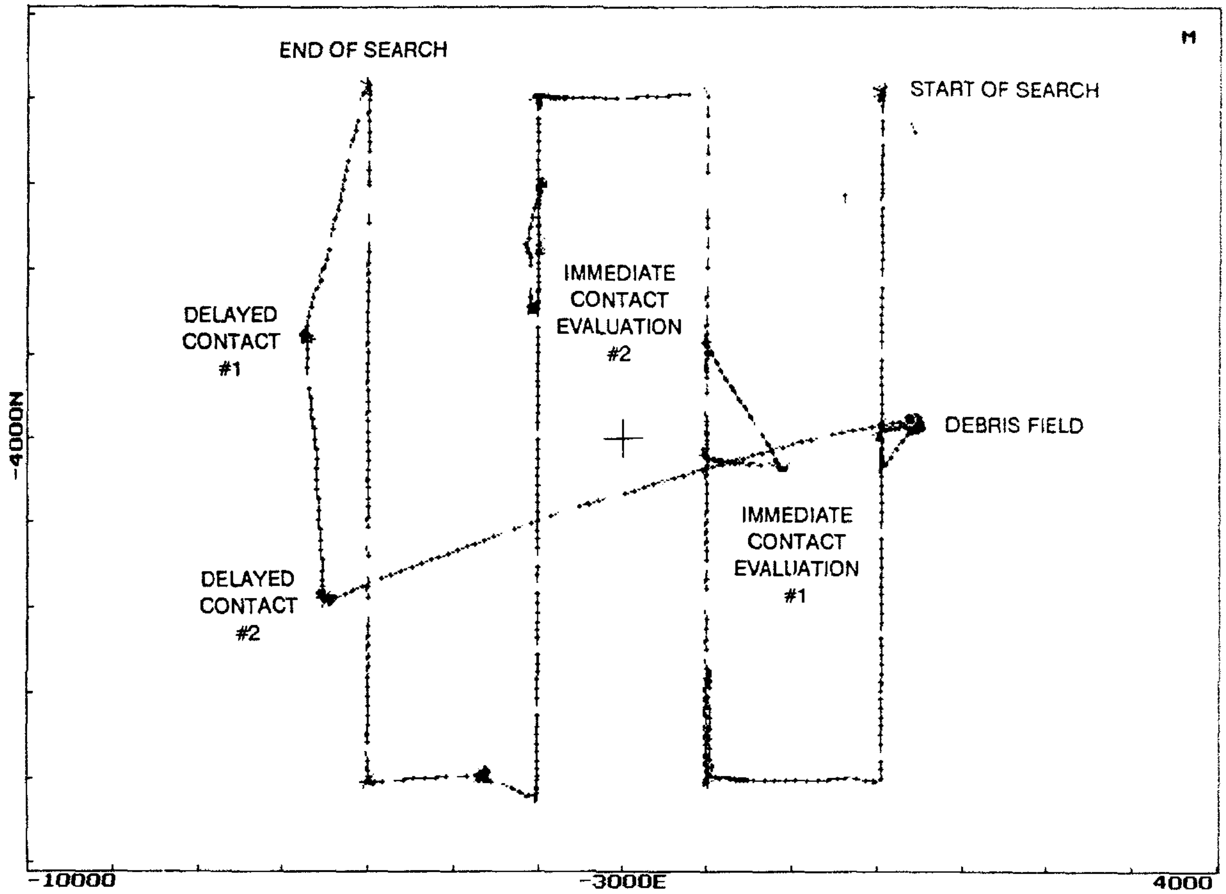

Figure 14. Search example 2: Doppler plot (immediate and delayed contact).

At the end of the SLS search pattern, the entire cell had been searched. The operators decided to go back and evaluate a couple of the marked but unevaluated targets. The sonar returns for these marked targets had indicated that they were not likely to be the target being sought, so they had not been immediately investigated when they were originally detected. They were, however, interesting targets and their position marks had been logged. Contact evaluations on these two marked targets proved that they were indeed false targets. At this point, the search was completed and the operators concluded the target was not in the area. Then, the operators returned to further explore the debris field until the batteries ran down. Over four hours had elapsed since leaving the debris field.

The image of figure 15 was obtained at time 21:23:01.6 while investigating the debris field as part of the original immediate contact evaluation. The image of figure 16 was obtained 4 hours and 28 minutes later as the last part of the delayed contact evaluation just prior to terminating the dive. In each image, the cursor has been positioned to mark the location of a unique feature that is common to both images. Since clearly the vehicle was over the same area when each of these images was taken, the difference in the marked positions of the two figures can only be attributed to Doppler drift in the time interval between their acquisitions. This is calculated to be a drift of 158 ft in 4 hours and 28 minutes. Because the vehicle had returned to the same spot, this error is "closed circuit" navigation error, which cancels out the effects of compass bias and Doppler scaling error. What is important is that the vehicle was able to return after 4 1/2 hours by using only Doppler and CCD.

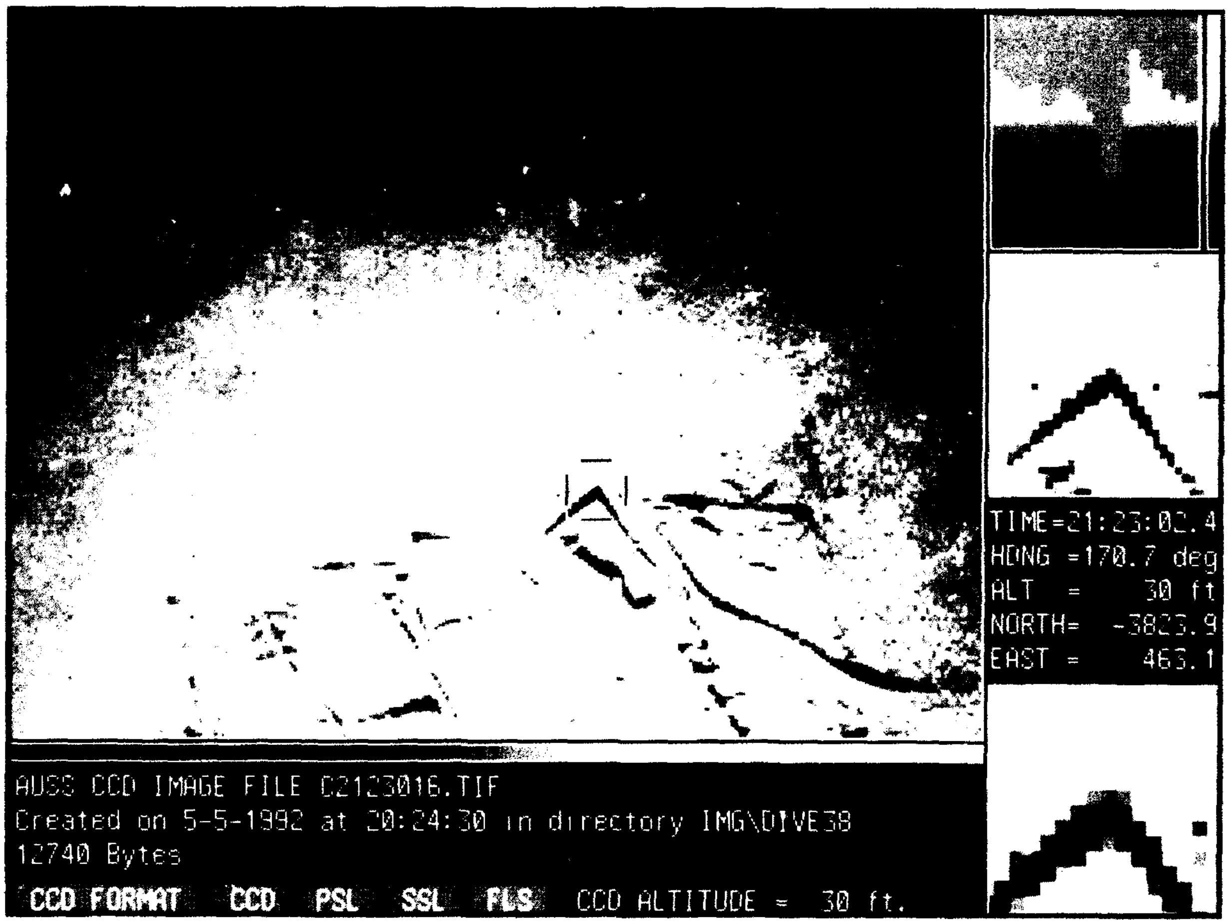

Figure 15. CCD image of debris field (immediate contact).

Figure 16. CCD image of debris field (delayed contact).

SEARCH EXAMPLE 3: MULTIPLE TARGET EVALUATIONS

There is no requirement that only one target be investigated before search resumes. Often a port SLS or starboard SLS image will contain two or more targets, especially in a debris field. Figure 17 is the Doppler plot of an unusual, but not unique, search sequence: the immediate evaluation of two targets spotted nearly simultaneously, one to port and one to starboard. The actual sonar images appear in Appendix D, where they are discussed in detail.

The vehicle vectors start near the bottom center of the Doppler plot. Target 1 was spotted on the port SLS image display, and target 2 on the starboard SLS 25 seconds later. Both were marked, and a resume mark was created. The pause command was sent, and the vehicle stopped. Target 1 was evaluated, then target 2. The resume command was sent, and the vehicle returned to the marked resume coordinates and proceeded with the SLS search. Two targets had been evaluated in 25 minutes.

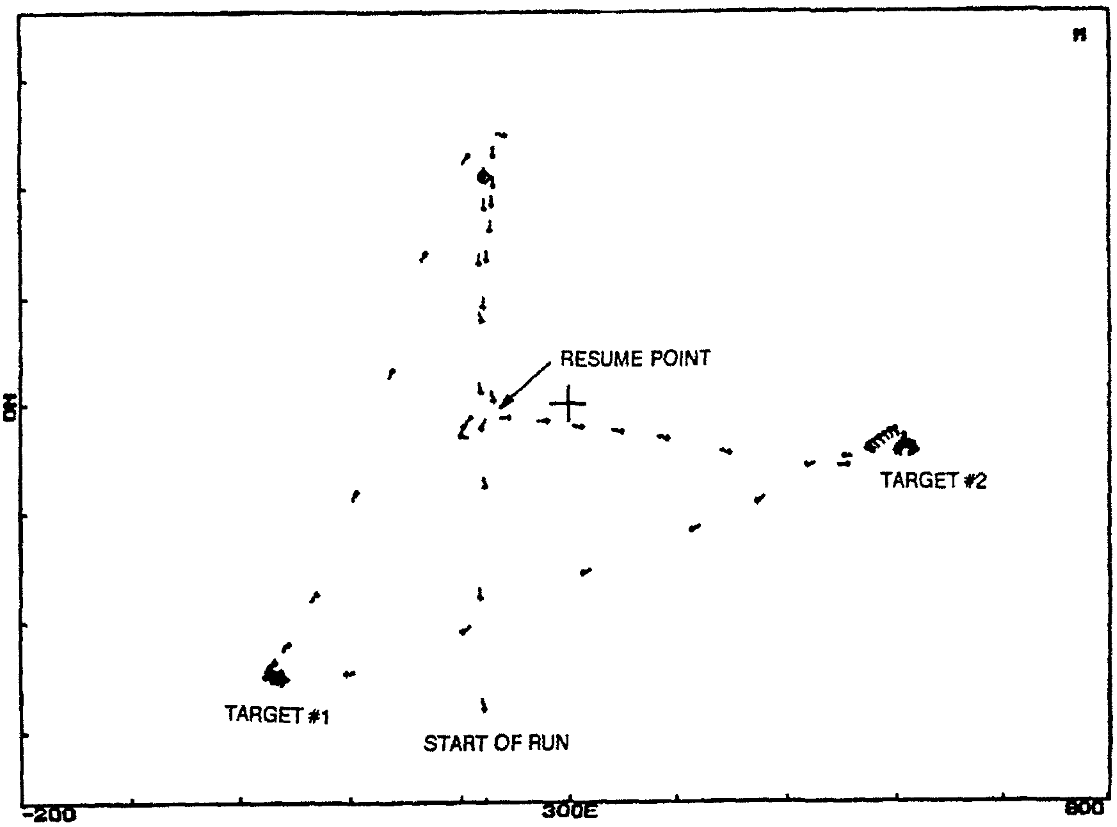

Figure 17. Search example 3: Doppler plot (multiple targets).

SEARCH EXAMPLE 4: INSPECTION

Figure 18 is the Doppler plot of a protracted target inspection. The plot shows four FLS scans and what would appear to be four different clusters of CCD images. In reality, all CCD images were over the same target, a Korean War era Skyraider night fighter. (Coincidentally, the Skyraider was the Navy's replacement for the Dauntless, mentioned previously.) The Skyraider didn't move; the Doppler drifted. Each time a CCD image was transmitted with no target, the vehicle was commanded to literally back off to a larger radius from the latest marked point and perform another FLS scan. Each time, the target was reacquired, marked at new coordinates, closed, and rephotographed

The Doppler drift was about 125 ft in a little more than an hour. During this time, 22 CCD images were taken (4 of which did not contain the target), and there were 6 retransmissions. Figure 19 contains four of the CCD images acquired during the inspection. Successive CCD images were acquired by stepping along the target as described in the tactics section.

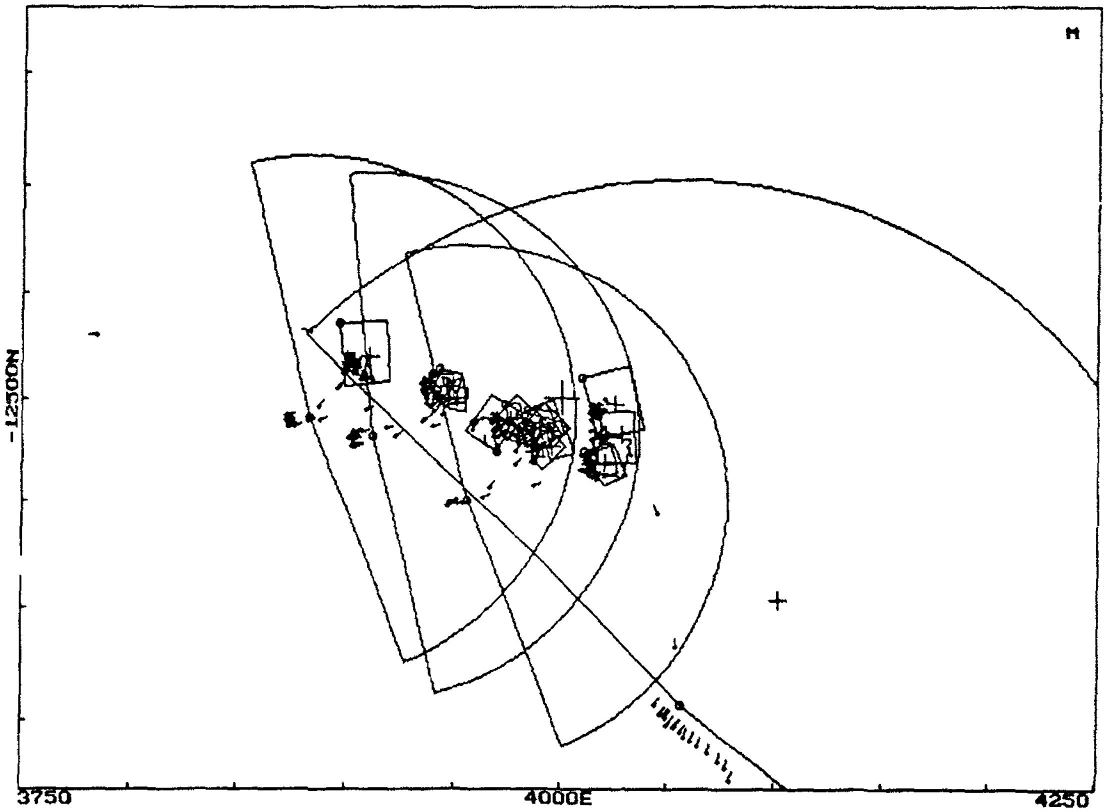

Figure 18. Search example 4: Doppler plot (Skyraider inspection).

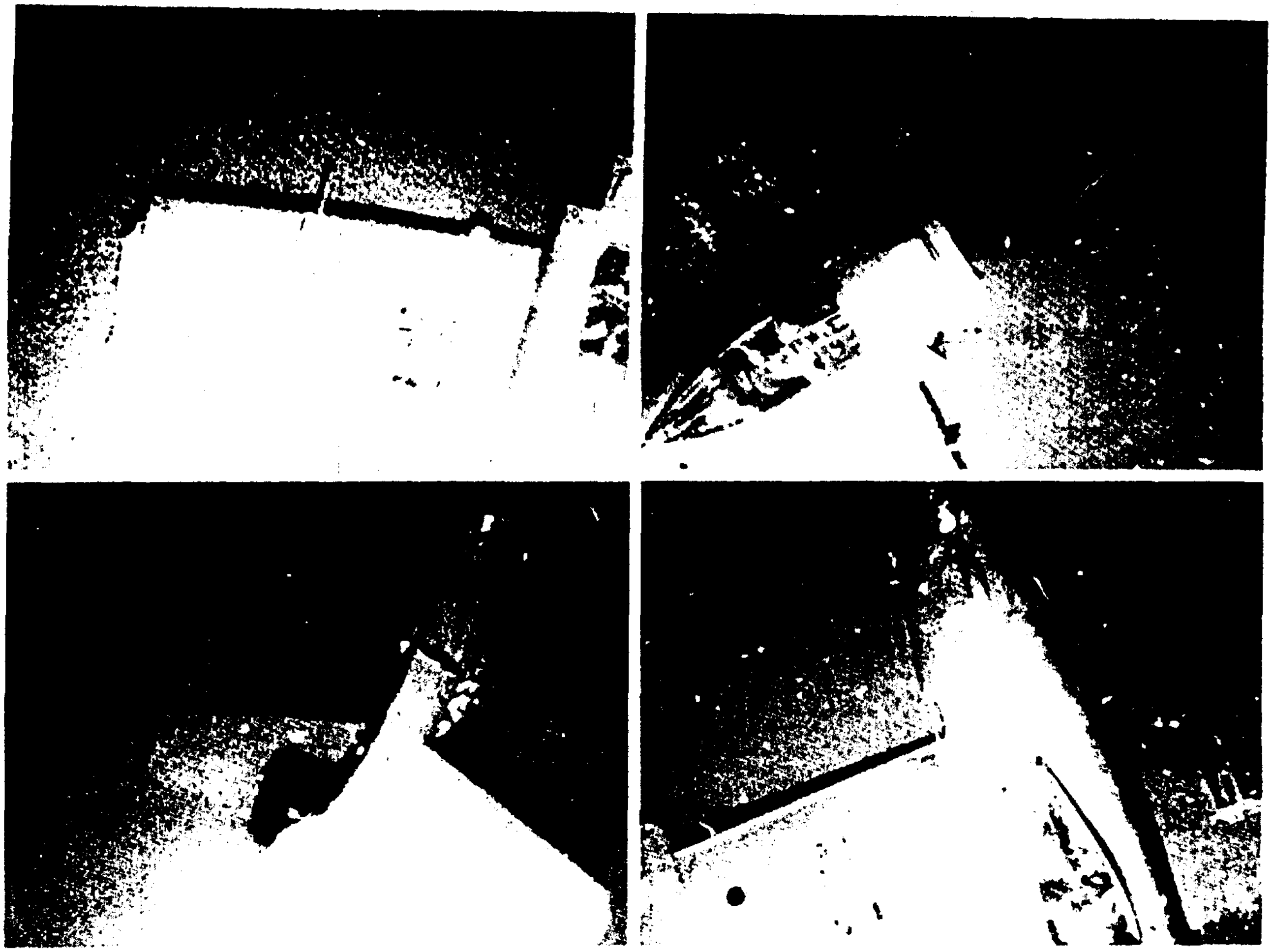

Figure 19. CCD images of the Skyraider inspection.

AUSS found the Dauntless discussed in the first example by searching the areas (more than one) in which it had been reported to lie. The Skyraider was discovered. The AUSS operators had not previously been aware of its existence.

SEARCH EXAMPLE 5: FILM PHOTOMOSAIC

The Dauntless was also revisited to acquire complete photographic coverage of the aircraft using the MOS command. The CCD camera served as a viewfinder so the operators were continuously aware of the photo area coverage.

The vehicle was deployed near the known location of the Dauntless, and, as in the first search example, the Dauntless was first acquired with SLS. Search was paused, and the target was closed with a single 250-ft FLS scan followed by a single CCD image. Having identified the target as the Dauntless, the operators commanded AUSS to back off to a larger radius and take a second FLS scan at 75-ft range scale. Based on the marking of the target in this latest FLS image, they configured a MOS command for a photomosaic area coverage. The command specified four 100-ft legs at a heading of 315 degrees, using both film and CCD.

Figure 20 is a rather daunting Doppler plot of this sequence of events. The large FLS scan is the first one, taken on approach. The first CCD image appears buried under the array of MOS images taken a few minutes later. It is better seen in the closer scaled Doppler plot of figure 21. The second FLS scan nearly fills the plot, and the area coverage of photomosaic images are apparent.

During the 15 minutes required to execute the photomosaic command, 48 images were acquired. The CCD images were transmitted at low resolution and high compression, the fastest to transmit but poorest quality supported by AUSS. (The CCD images only required an average 850 bytes to transmit.) Of the 48, 10 contained portions of the Dauntless. Figure 22 shows the 35-mm images that correspond to those CCD images.

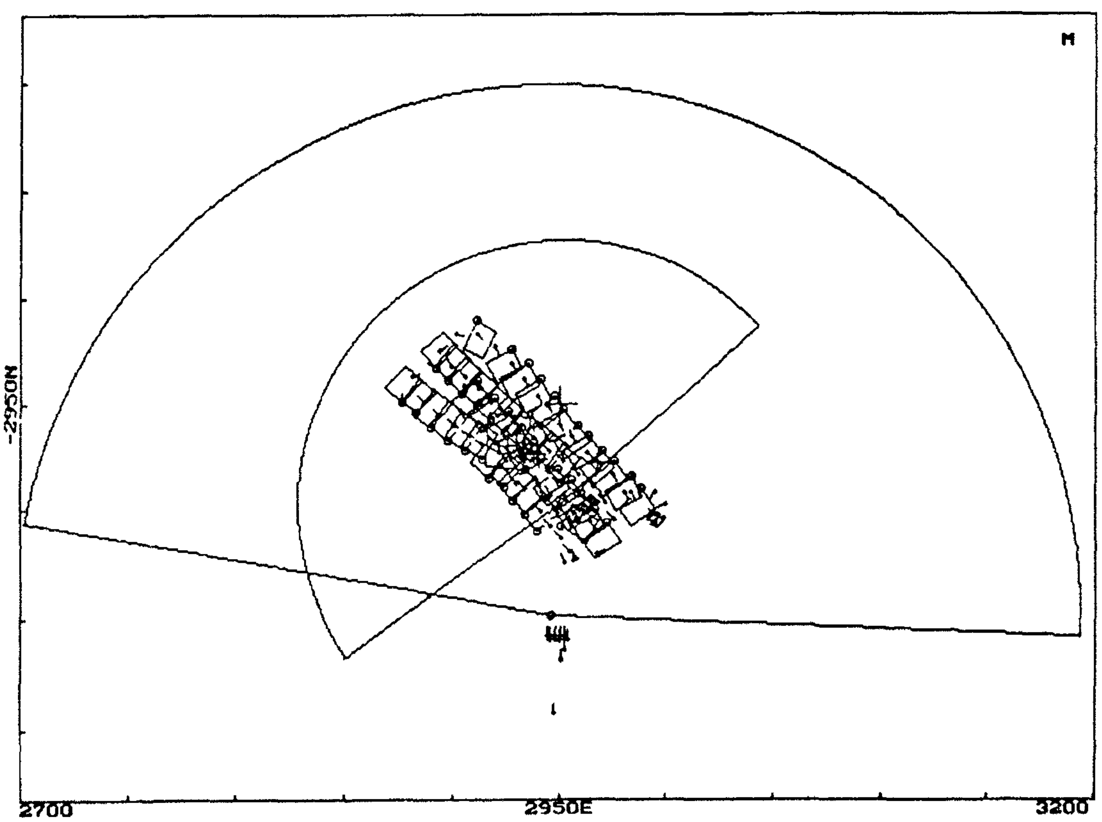

Figure 20. Search example 5: Doppler plot (film photomosaic).

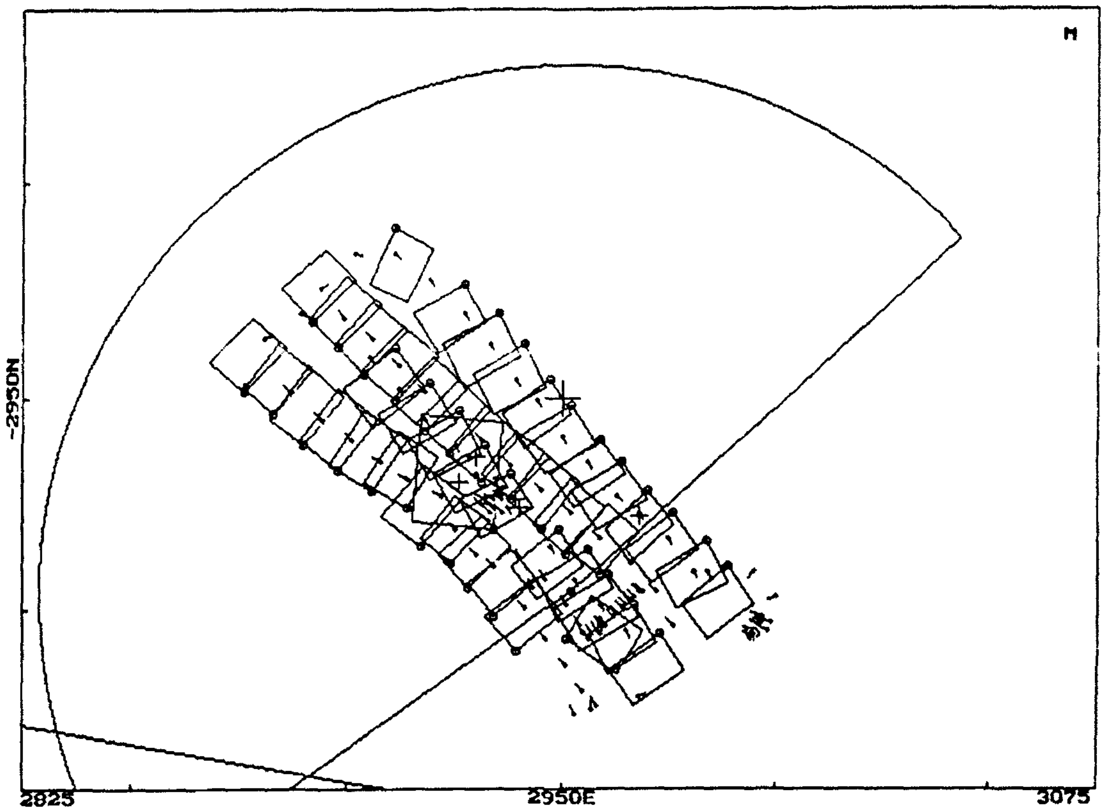

Figure 21. Search example 5: high-resolution Doppler plot.

Prints of these photographs can be cut and pasted to form a collage-type composite image of the Dauntless, but the result is rather nonprofessional. The main problem is scaling: the vehicle's automatic altitude control caused the vehicle to rise and fall as it crossed over the airplane. A better composite can be obtained by using high-resolution CCD images and commercial software. Figure 23 is a composite made from images taken on a previous dive, when the Dauntless was originally found and inspected. During that inspection the technique of stepping along the target was used to obtain this coverage. The lines are purposely added to show how the component images are fitted to form the composite; the upper right corner of the display was not imaged at low altitude.

SEARCH EXAMPLE 6: CCD PHOTOMOSAIC

As of this writing, the last dive performed by AUSS was to 12,000-ft water depth. The purpose of the 12,000-ft dive was to test and demonstrate the system at that depth by searching for a previously deployed target that had been dumped overboard several months earlier for this purpose. AUSS found and inspected the target. In the CCD

Figure 22. Photomosaic images of the Dauntless.

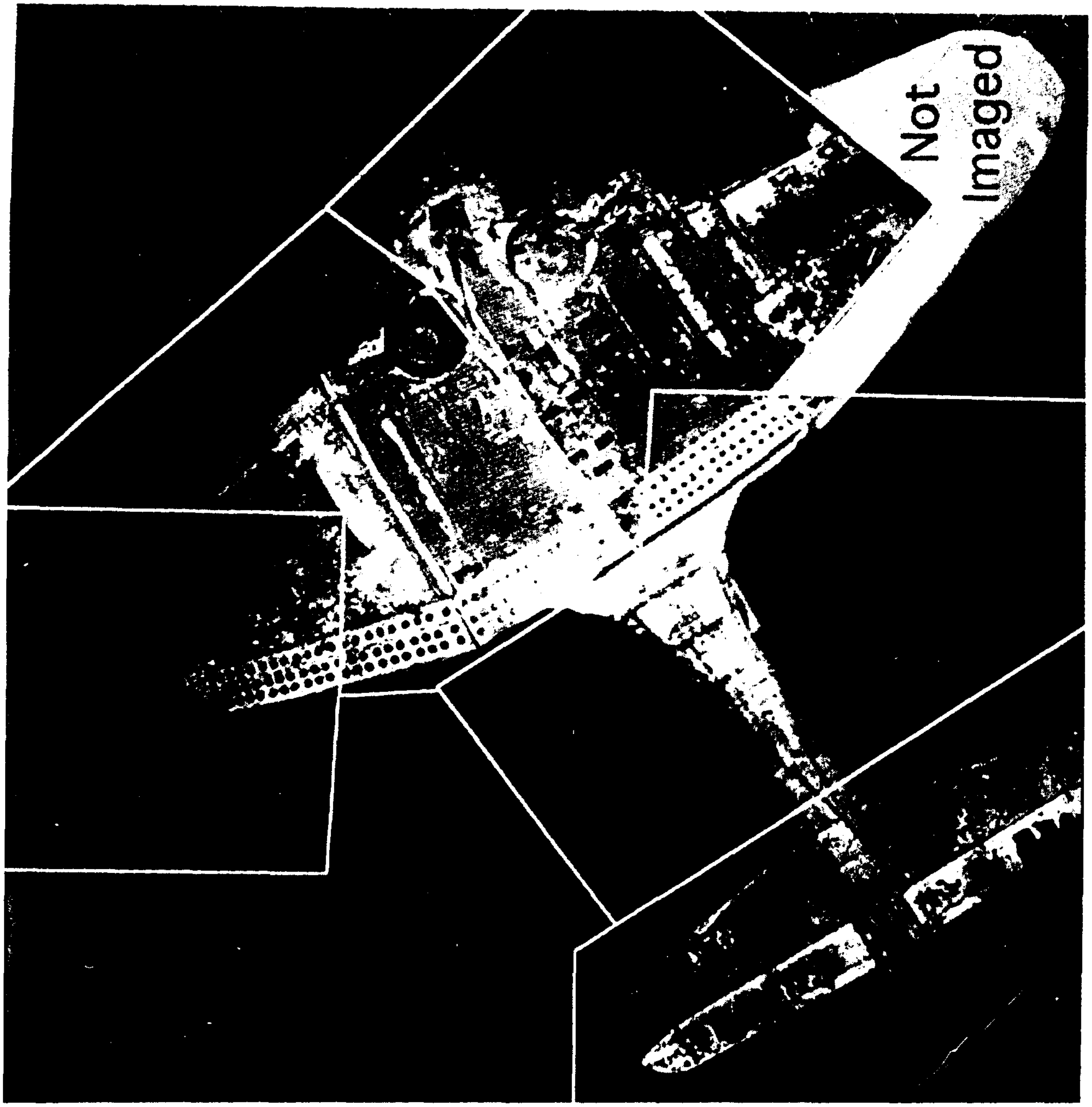

Figure 23. Composite of the Dauntless CCD images.

images, the operators noticed the car had been dragged some distance, leaving skid marks along the silty bottom. (The dragging is attributed to another system, the Advanced Tethered Vehicle, which also used the target as an exercise tool.)

The operators decided to perform a photomosaic coverage to inspect the extent of the skid marks. The MOS command was configured to run three legs parallel to the marks. This photomosaic was at low resolution, medium compression, and the film camera was not used. The CCD images revealed that the first leg happened to run right down the skid marks. Figure 24 is a composite image of that first leg of the photomosaic run. This composite was created from the AUSS images by using commercial image-manipulation software. As can be seen, there was a gap between two of the mosaic images. This gap has been filled with a portion of another image of the car. More overlap in the MOS command would have prevented the gap.

Figure 24. Composite of photomosaic CCD images.

Of course, the composite images were not available during the photomosaic run and would not necessarily have been useful during the search. Its value is as a post-dive tool for visualizing and explaining the geometric relationship of items that exceed the borders of single images. The capability to create such composite images is only one example of the possibilities of post-dive computer image manipulation.

VEHICLE ONBOARD DATA STORAGE

AUSS development is not completed. Among the few capabilities not fully implemented are the Obstacle Avoidance Sonar (OAS), FLS image compression, and VSL vehicle onboard data storage. Of these, the VSL will have the greatest effect on the concept of operation. The VSL is now used only for storage of flight recorder data, but its original purpose was to preserve search sensor data in raw form, unprocessed for transmission as images.

As valuable as it is, the acoustic link is a bottleneck. AUSS incorporates sonar oversampling, CCD low-resolution mode, various image preprocessing techniques, and image compression. All of these reduce the amount of transmitted data, but they also reduce image quality. Potentially valuable image data are lost.

VSL storage will preserve raw image data for post-dive access, permitting extraction of images of the highest quality possible from the sensors. These images will be valuable for archiving and documentation. The raw image data will also be used to evaluate image processing techniques for sonar noise reduction and alternate compression techniques for possible incorporation in the vehicle.

Perhaps the biggest benefit of onboard data storage will be the almost total elimination of CCD retransmissions, except as needed operationally. Low-resolution, medium-compression CCD images require only 20 or 30 seconds to transmit, and are of adequate quality for target evaluation and inspection. But images are the only product of search, and they are valuable. The most recent four CCD images are retained in onboard computer memory; if another image is acquired the oldest is overwritten. To insure quality archiving, interesting CCD image are generally retransmitted at high resolution, low compression, and reduced data rate. If an acoustic error occurs, an image may be sent a third time. Twenty minutes or more can be required, during the critical part of an inspection, merely to insure the archival quality of the last four images.

The term Doppler drift has been used frequently in this report. For reasons yet undetermined, the drift increases when the vehicle is not moving and the uplink acoustic link is being used heavily. These are precisely the conditions during CCD image retransmissions. A side benefit of eliminating retransmissions will be to minimize the problem of Doppler drift during hover.

Despite onboard data storage, the AUSS concept will remain supervisory, with operators evaluating near realtime images. But one more option will be available: autonomous search with post-dive analysis.

SUMMARY

We have described a new and radically different approach to the task of deep-ocean search: a system that employs a free-swimming supervisory controlled vehicle to achieve both high overall search rate and an excellent inspection capability.

AUSS can perform broad area search and immediate target evaluation interchangeably. The system provides operators nearly realtime high-resolution sonar data at speeds up to five knots. The AUSS vehicle can be commanded to acquire still images from specific locations, as determined from previous sonar or CCD images, or it can provide a photomosaic of a prescribed size, orientation, and location. AUSS can resort to purely optical search by using the photomosaic command, or it can use scanning sonar as the primary search sensor. These unique capabilities make significantly different tactics possible.

The greatest strength of AUSS is its versatility. Although years of study, research, and computer modeling preceded the fabrication of AUSS, capabilities and tactics are far better than originally conceived. They have evolved together. AUSS has taught us much about search.

GLOSSARY

AINS	AUSS Integrated Navigation System
BOP	Beginning-of-Picture
CCD	Charge-Coupled Device
CMD	Command Processor
DOT	Deep-Ocean Transponder
DSP	Digital Signal Processor
EOP	End-of-Picture
FLS	Forward-Looking Sonar
GGO	The "Go" Command
GPS	Global Positioning System
IMG	Image Display Processor
IMP	Image Manipulation Processor
LBL	Long Baseline
LOG	Surface Data Logger Computer
LORAN	Long Range Aid to Navigation
MOS	The "Photomosaic" Command
MV	Main Vehicle Processor
NAV	Navigation Computer
NET	Network Computer
OAS	Obstacle Avoidance Sonar
PAU	The "Pause" Command
PIC	The "Picture" Command
PPI	Plan Position Indicator
RES	The "Resume" Command

SA	Surface Acoustic Link Processor
SBL	Short Baseline
SCA	The "Scan" Command
SLS	Side-Looking Sonar
TIFF	Tagged Image File Format
VA	Vehicle Acoustic Link Processor
VS	Vehicle Sensor Processor

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APPENDIX A

DATA MANAGEMENT

INTRODUCTION

One of the most critical but often overlooked requirements of a search system is that of data management. Massive amounts of data are generated during a search. If not stored in some form, this highly valuable data would be lost forever. Without a well structured data storage and retrieval system, this mass of data can rapidly become unmanageable and almost useless during a search operation. In addition, post-dive analysis would be difficult at best.

The AUSS system has been designed to treat data as a critical product of all search and development dives. This is accomplished not only by data logging hardware and software, located both in the vehicle and on the surface in the control van, but also as an orderly process of data maintenance and analysis.

The data that are stored consists of the following:

- vehicle flight-recorder information;
- analog recording of all vehicle communications;
- video recording of selected displays;
- digital logging of all uplink and downlink communications;
- digital logging of received images with critical data;
- digital logging of all Doppler data with target marks;
- digital logging of all surface navigation fixes; and
- handwritten operator logs.

FLIGHT-RECORDER DATA

The vehicle flight recorder is a region of nonvolatile computer memory for the storage of information about the vehicle's status and performance. Up to 34 parameters can be measured as frequently as twice a second, and the data can be stored in the flight recorder. During early AUSS tests, the flight recorder was very valuable in evaluating control algorithms and tracing problems. The flight recorder was designed to be retrievable after the vehicle was recovered, but the memory was small (approximately 2 Mbytes). The data were routinely transmitted to the surface, either because it was needed immediately or just to prevent it from being overwritten. In later dives, flight-recorder data were stored on the vehicle sensor data logger disk as well as in the flight-recorder memory. With no urgent need for the data and with the ability to store large amounts of data on board, flight-recorder dumps were no longer necessary during a dive. Following every dive, the flight-recorder information is dumped from the vehicle sensor logger disk and captured to a disk file on another computer for archival storage and for post-dive analysis. Post-dive analysis is facilitated by a comprehensive set of analysis and plotting software. In addition, the flight-recorder data have been used directly with general-purpose, three-dimensional simulation software to generate realtime video tapes that facilitate visualization of vehicle dynamics.

SURFACE ANALOG AND VIDEO RECORDING

Video switch and scan conversion electronics permit video recording of selected operator displays on the video track of a video recorder. In addition, a tap is provided in the acoustic link transmit and receive path for the purpose of analog recording of acoustic information. This information is provided to the audio track of the video recorder and to a reel-to-reel recorder where it is recorded along with a time code and other system information. The analog recordings contain a reproduction of the acoustic channel during the dive. They can be played back into the front end of the acoustic link receivers so that a total dive can be replayed through the surface computers.

DIGITAL LOGGING OF COMMUNICATIONS

All nonimage uplink and downlink communications are transmitted as ASCII printable characters and are digitally logged as text onto a single disk file. This file serves as a total log for a dive, but its utility is mostly for post-dive reconstruction. Messages that are logged maintain their sequence of occurrence, and many contain clock information so that times of events can be reconstructed with reasonable accuracy. One of the advantages of these files is that they can be searched on key words in text and, with moderate familiarity with the system, an analyst can interpret the information directly from text screens. These files are also used for post-dive computer analysis and plotting.

IMAGE STORAGE AND RETRIEVAL

All images received at the surface are automatically stored as independent digital files. These images are stored in a format compatible with Tagged Image File Format (TIFF) version 5.0, a joint specification by Aldus and Microsoft Corporations. TIFF was chosen for AUSS images because it is widely supported by commercial applications, yet permits imbedded non-TIFF data. This allows AUSS image files to contain target marking tables and other image related data while remaining 100% compatible with popular desktop publishing, image viewing, and image-format-conversion software.

TIFF also permits a simple uncompressed image format, which is ideal for rapid screen dump, image storage, and recall. These images are uniquely named based on source sensor and time of generation by using messages generated by the vehicle. In addition, every image contains all information required to evaluate its context based on vehicle time and position along with other critical data. Individual images can be recalled on the fly during a search as well as for post-dive analysis. Using these images, target marking and measurement capabilities are retained and virtually all real-time image operations are possible.

DOPPLER AND TARGET MARKING LOGS

All Doppler information received at the surface is logged into a vehicle navigation file. This file contains not only vehicle position information, but also sensor coverage and target marks. While being received, these data are used to generate realtime Doppler plots for viewing by the vehicle operators. These plots can be regenerated, either during the dive for changing areas of interest or changing resolution, or after the dive for post-dive analysis. The plots are highly useful for visualizing areas searched as well as the relative positions of marked targets.

SURFACE NAVIGATION LOGS

All surface navigation fixes are logged into a series of time-stamped files. These files contain both raw and processed navigation information regarding surface craft and vehicle positions for an entire dive. They are useful mostly for post-dive analysis and reconstruction, including the capability of replaying files into the original navigation computers.

HANDWRITTEN OPERATOR LOGS

Handwritten logs are maintained for all dives. These logs are especially useful for noting operator observations that would not necessarily be evident from the digitally stored files. The logs also serve as redundant storage of all critical events.

APPENDIX B

OPTICAL SENSORS

INTRODUCTION

The AUSS optical sensor suite consists of a cooled CCD electronic still camera and a 35-mm camera, both of which look straight down and are mounted in the nose section of the vehicle; two strobes that are mounted in the AUSS tail section and point forward and down to provide illumination with good source receiver separation; and processing software for enhancement, data compression, and retransmission. Control algorithms exist in the vehicle for providing individual picture and picture series acquisition, photomosaics, and retransmission of prior images. Each image can be acquired as 35 mm only or CCD only or simultaneous acquisition from both cameras. Illumination can be from either, both, or none of the strobes.

CCD CAMERA

The CCD camera hardware consists of a Marine Imaging Systems MKII cooled CCD camera head and control electronics mated to custom AUSS computer hardware. The camera electronics, under computer control, can provide diagnostic, bias current, and dark current images as well as optical images. All images are provided as 14-bit digitized information at spatial resolutions up to 576 by 384.

CCD Specifications:

• Horizontal field of view	45 degrees*
• Vertical field of view	31 degrees
• Lens f number	3.5
• Image quantization	14 bits*
• Image resolution	576x384*
• Time to acquire image	~10 sec.

*These numbers are modified by processing. (see text)

IMAGE SOURCE SELECTION

The images for processing can be obtained either from the CCD camera or from a selected (one of four) digital image buffer. When an image is obtained from the CCD, it is placed, along with critical data about the image, into one of four digital image buffers in the memory of the Image Manipulation Processor (IMP). This makes it possible to later retransmit images once they have been acquired. Images obtained from the CCD can be selected from any of the following: normal image, bias image, dark image, or test image. Standard usage of the CCD dictates selection of the normal image. Other selections are used for diagnostics and measurement.

IMAGE PROCESSING

Once the image has been acquired (either from a buffer for retransmission or from the CCD), it can undergo several optional processing functions. The image data were originally obtained as an array of 576 x 384 picture elements (pixels) that were digitized to 14 bits. Before being submitted to the software for further processing and formatting, this data must be reduced to 512 x 384 at 8 bits per pixel. The image modification is separated into two stages.

The reduction in spatial resolution (i.e., from 576 x 384 to 512 x 384) is required so that the format of the transmitted CCD images will be compatible with that of all other sensors. The reduction to 512 x 384 is accomplished by discarding 32 columns of pixels on both the left- and right-hand edges of the image. This effectively reduces the horizontal field of view of the CCD from 45 degrees to approximately 40 degrees.

The reduction from 14 bits per pixel to 8 bits per pixel is required so as not to exceed the dynamic range of post processing and display software. The operator can select one of two processes by which this reduction is performed (i.e., linear range selection or linear contrast enhancement). Linear range selection shifts the original 14 bit pixels, an operator selected number of bits, so that only 8 contiguous bits are retained. In essence, this is equivalent to scaling the original image information and retaining only the top 8 bits. This can be visualized much like setting a manual exposure control on a camera. Using this option the system does not perform any automatic adaptive processes and the image information retains its exact relative levels. This process is only selected for diagnostics or when the operator desires exact exposure information.

The second, and most often selected option, is linear contrast enhancement. The main benefit of this selection is that the image is automatically processed to maximize the contrast and in essence provides a perfectly exposed image (i.e., the 14 bits of raw image data are optimally mapped into 8 bits) based on the image's global statistics. In this manner, the system adapts to changing light levels without the requirement for operator intervention.

The linear-contrast-enhancement process is performed in three steps. First, a histogram for the entire image is generated so that the number of pixels at each level of brightness are known. The next step is to determine the brightness levels that define the boundaries of the histogram tails. The low tail is defined to be that area under the histogram curve that contains a given percentage of the total pixels in the image, all of which will be forced to zero. The high tail is a similar area corresponding to those pixels that will be forced to full scale (i.e., 255). The brightness level that bounds the low tail will be the floor and the brightness level that bounds the high tail will be the ceiling. The final step is to subtract the value of the floor from all pixels and set all negative valued pixels to zero, then multiply all pixels by full scale divided by the ceiling, setting all pixels that exceed full scale equal to full scale. The percentage values that individually define the low and high tails can be adjusted by the operator.

CCD IMAGE FORMATTING

The image must be formatted before being transmitted over the acoustic link. The operator can select from twelve different formatting options, six of which involve data compression. Noncompressed image data are referred to as packed data since they merely involve packing the pixel data into a packet for transmission. Packed data can be low resolution (128 x 96) or high resolution (256 x 192) and be sent at 4, 6, or 8 bits per pixel. A unique header byte and a line number are inserted as part of the transmission packet so that the surface computers can determine how to process the packet of data and where to place it on the display screen.

Data compression is based on custom AUSS application of adaptive discrete cosine transform algorithms. This approach provides six data compression options. These options are: low resolution (256 x 192) or high resolution (512 x 384); at high, medium, or low compression. The compressed data are formatted as packets of compressed blocks of data. A unique header byte, beginning block number and error recovery information are inserted as part of the transmission packet so that the surface computers can determine how to process the packet of data and where to place it on the appropriate display screen.

CCD CONFIGURATION AND MODE SELECTION

Faced with the wealth of configuration and operational choices that are available, it would appear that the operator's task would be difficult. Such is not the case. The configuration options rarely need to be changed, unless unusual circumstances dictate nonstandard modes of operation. All configurable options are initialized to standard values when power is first applied to the vehicle. In general, the operator only needs to select whether to take a new picture or retransmit an old one, and how to format the data for transmission. If a new picture is commanded, the operator selects how many strobes to use and whether to simultaneously acquire a 35-mm picture.

Most CCD images are transmitted as compressed data. The packed transmission of images is retained mainly for diagnostics and unusual circumstances. Figure B-1 is a laboratory simulation showing image data of a helicopter provided to AUSS by Marine Imaging Systems. This figure consists of four subimages and provides a comparison of a partially processed (i.e., 512 x 512 linear contrast enhanced to 8 bits) original image at the top, and the quality of images transmitted in high-resolution (256 x 256) 6-bit packed, low-resolution (128 x 128) 4-bit packed, and high-resolution (512 x 512) high-compressed mode. The window in the upper right corner of each subimage is an expanded view of the corresponding area in the image outlined by the small white block. Note the relative pixel size and image quality shown in these windows. The legend area in each subimage shows the format and a time in minutes and seconds. The times shown are approximately how long it would take to transmit a full image in that format over the acoustic link if it were operating continuously at 4800 bits per second. Clearly the compressed mode would be selected, based on image quality and transmission time.

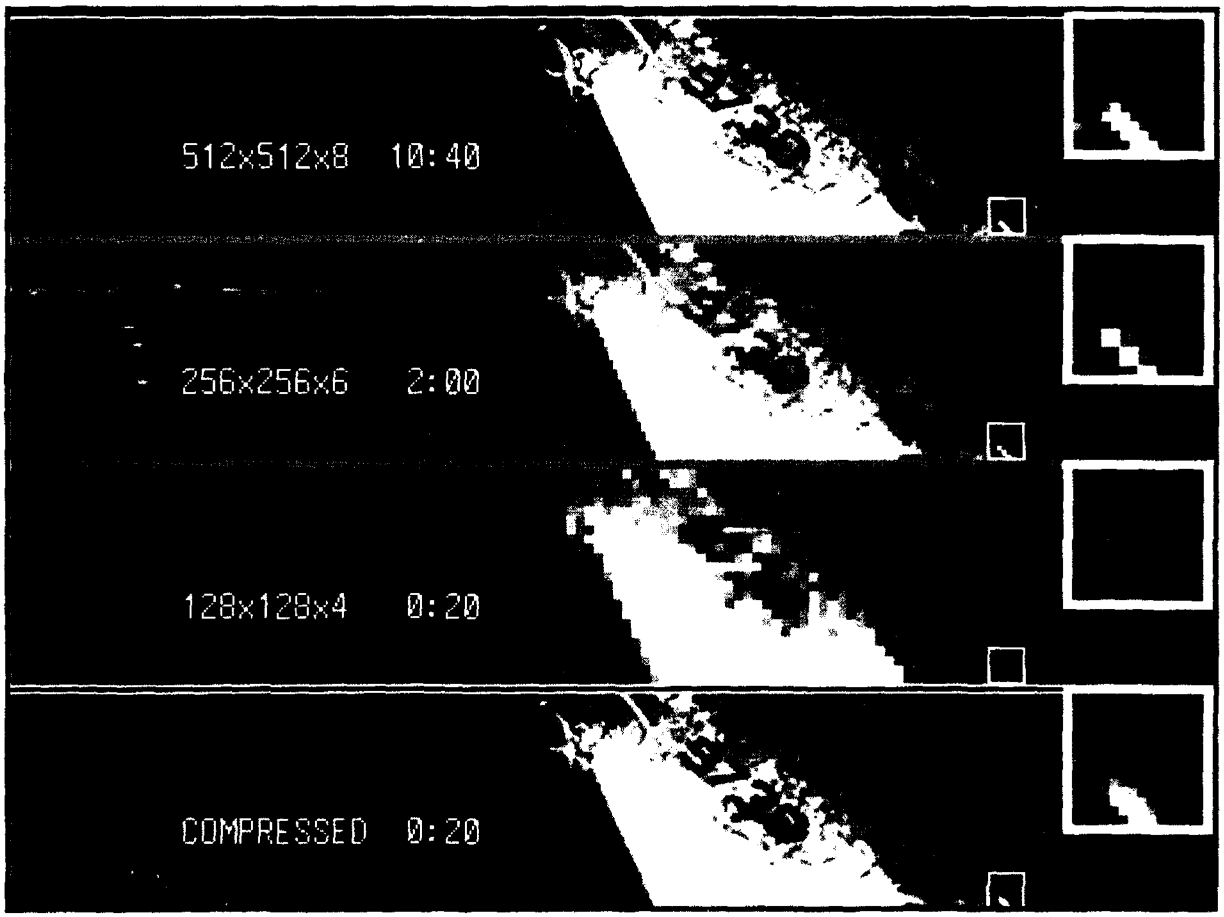

Figure B-1. Comparison of image processing techniques.

The selection of which compression mode to use is based upon the desired image quality and how long it will take to transmit. Since the compression algorithms adapt to the content of the image being processed, it is impossible to predict exactly how long it will take to transmit the image; typical compression ratios range from 6 to 1 to over 30 to 1. The higher the resolution and the lower the level of compression the longer it will take to transmit the image. However, the more detail contained within the image, the less it will be compressed and, therefore, the longer it will take to transmit regardless of which mode is selected. Generally, images are originally sent at low resolution (256 x 192) and medium compression. This is a good compromise between image quality and transmission time. If a higher quality version of the image is later required, it can be retransmitted at high resolution (512 x 384) and low compression. This is the highest quality image transmission presently available on the system. Figures B-2 and B-3 provide a comparison of the quality of these two compressed data modes. Figure B-2 is the originally acquired image, transmitted at low resolution and medium compression. Figure B-3 is the retransmission of that image at high resolution and low compression.

35-MM CAMERA

The 35-mm camera, a modified Photosea model 1000 camera powered directly from the vehicle, has a 50-degree horizontal and 35-degree vertical field of view. The camera has a bulk film magazine that can handle up to 250 exposures per load. A data chamber provides a time stamp option on each frame as it is exposed. The camera is triggered to take a picture directly under computer control. The 35-mm camera is generally used only for documentation purposes, while the CCD camera is used for search and evaluation. When a 35-mm image is taken, the CCD camera serves as an electronic viewfinder so that the operator on the surface can visualize the area covered. The 35-mm and CCD cameras' fields of view are aligned to make this possible. Figure B-4 and figure B-5 are CCD and 35-mm images respectively that were simultaneously acquired in this manner.

STROBES

Illumination is provided by two modified Photosea model 1500SX, 150 Joule strobes that are powered directly from the vehicle. The strobes are independently fired by trigger lines provided by the computers and synchronized with CCD and 35-mm-camera image acquisition.

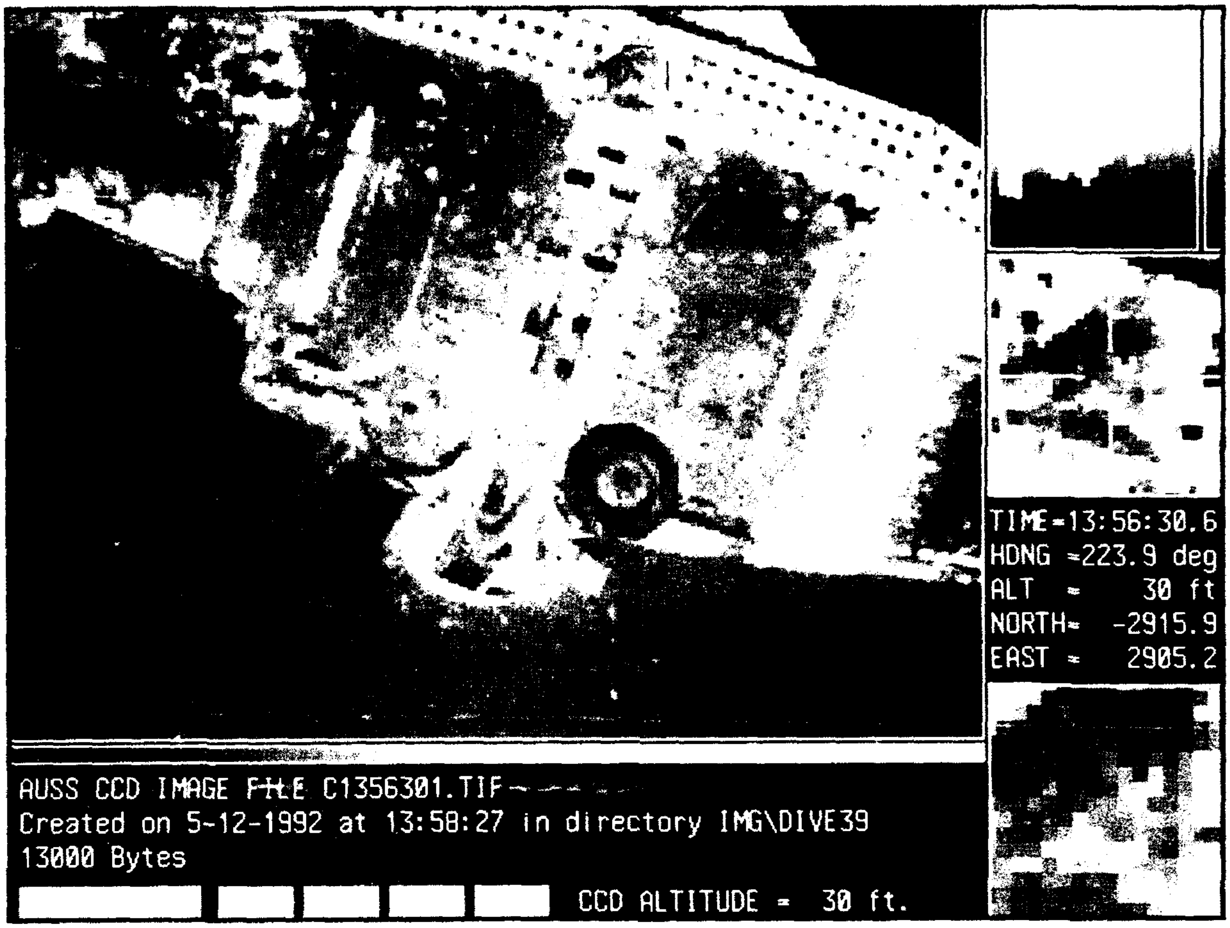

Figure B-2. The originally acquired image transmitted at low resolution and medium compression.

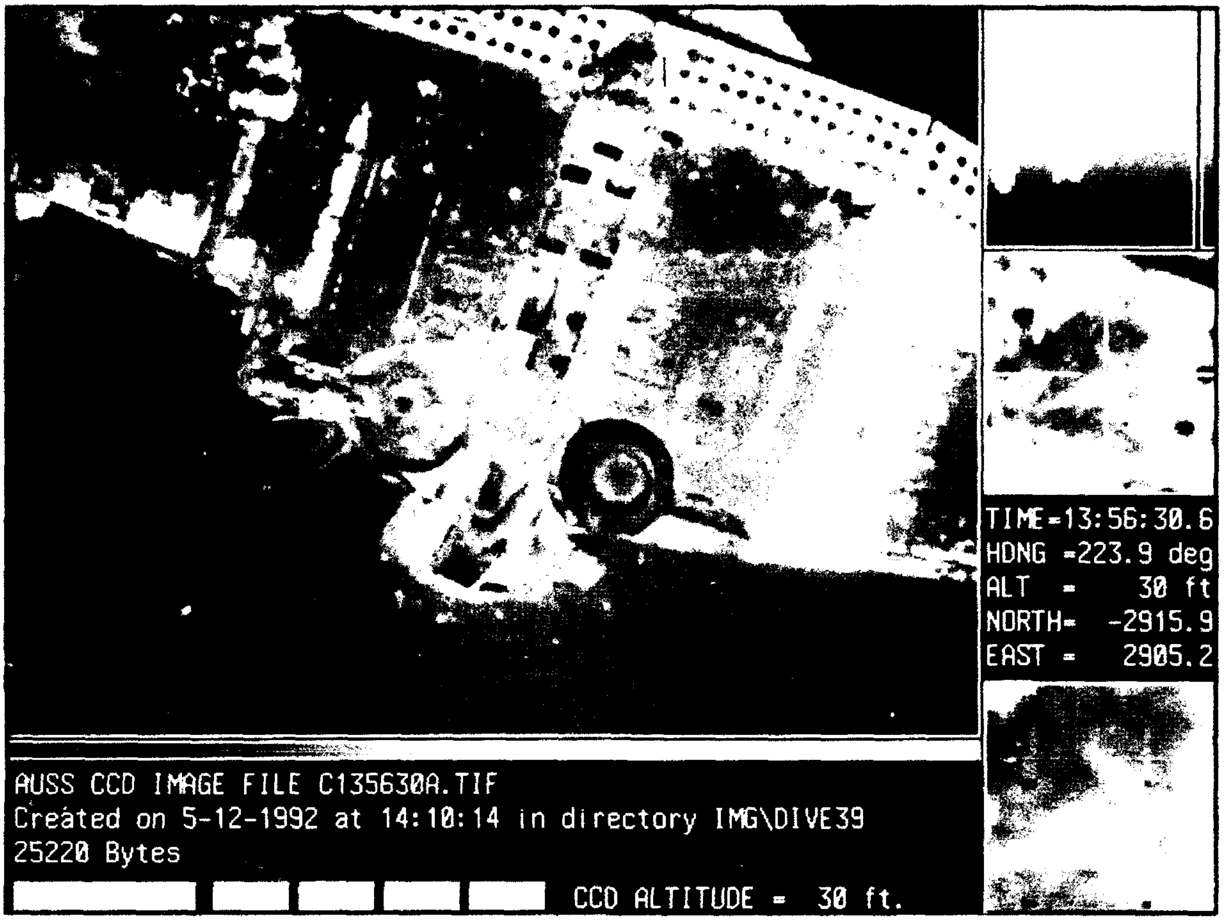

Figure B-3. Retransmission at high resolution and low compression.

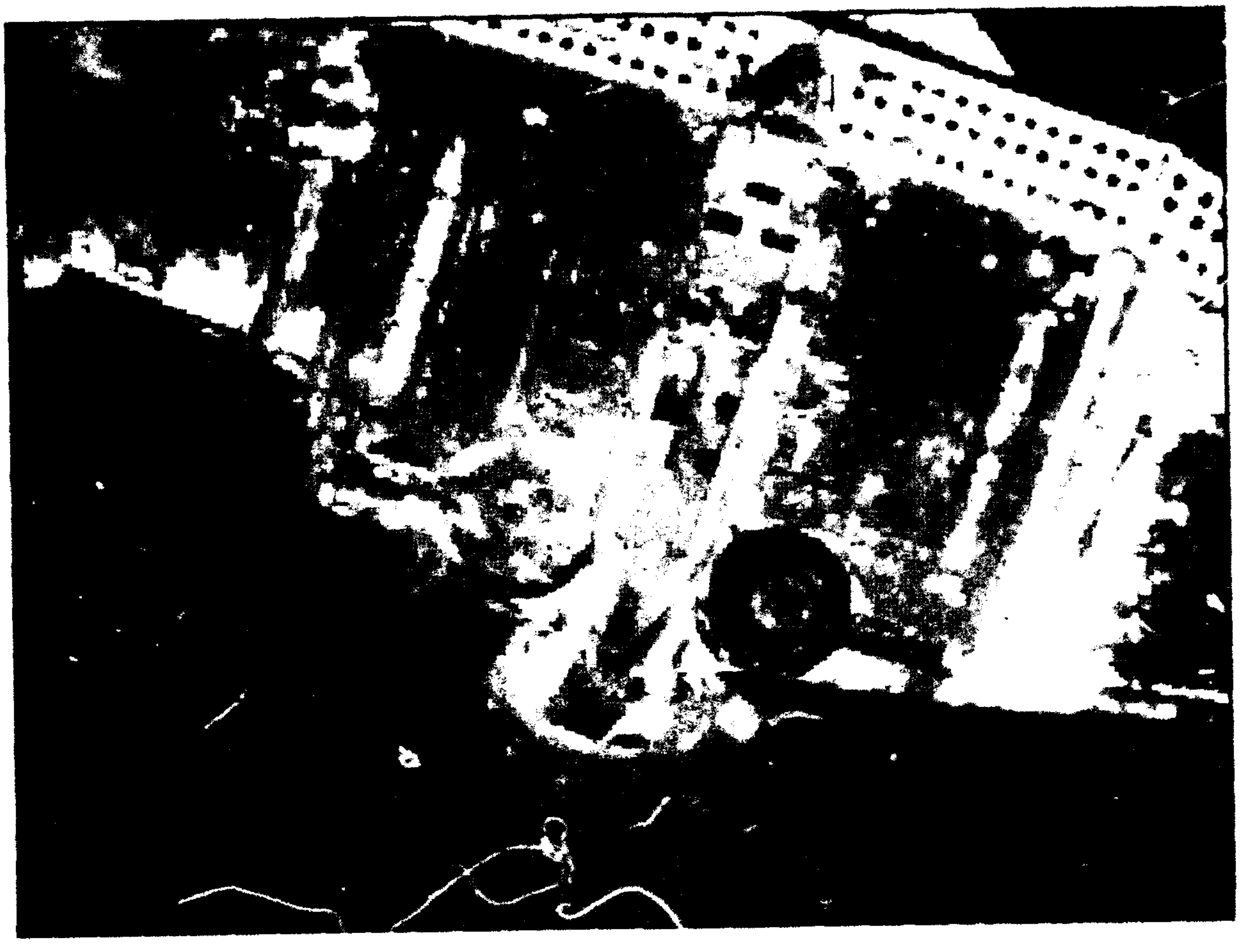

Figure B-4. CCD image.

Figure B-5. 35-mm image

APPENDIX C

SONAR SENSORS

INTRODUCTION

The AUSS sonar search sensor suite consists of an obstacle avoidance sonar (OAS); a forward-looking mechanically scanned sonar (FLS); a side-looking sonar (SLS); and data processing for compression and/or formatting of the data for transmission.

The AUSS search sonars have many characteristics in common. Table C-1 provides a summary of common specifications. All operating parameters are computer controlled and under operator selection or configuration. Although the operator has control of virtually every critical sonar operating parameter, the majority of these are configured prior to starting a search and often do not need to be changed. All parameters are initialized to the most commonly used defaults. Once a sonar is configured either by the operator or as defaults by the computers, the operator need only select the range scale, gain and time varied gain and a limited number of other parameters, depending on the specific sonar.

Table C-1. Common sonar characteristics.

Range Scale—selectable @ 125, 250, 500, 1000, 2000 feet

Resolution—selectable @ low, medium, high

Pulse Width—selectable @ 0.1, 0.2, 0.4, 0.8, 1.6 mSec.

Receiver Bandwidth
  pre-detection—fixed @ 10 kHz.
  post detection—selectable @ 312.5, 625, 1250, 2500, 5000 Hz.

Samples per ping—selectable @ 64, 128, 256, 512

Gain—selectable @ 0 to 100% in 1% steps

Time Varied Gain - selectable @ 0 to 100% in 1% steps calibrated to cancel absorption loss, where

$$0\% = 11 \text{ dB/kyd}$$

$$100\% = 60 \text{ dB/kyd}$$

The number of samples per ping, the sample rate, transmitted pulse widths and receiver bandwidths for all sonars are all automatically adjusted to be compatible with the associated, operator-selected range scale and resolution, and the speed of sound in water. The speed of sound that is used is obtained under operator selection as either a default value, a value that was commanded from the surface, or by a value determined by the Main Vehicle Computer using its depth and temperature sensors.

OAS

The OAS consists of a ITC model 3355 transducer and custom AUSS interface and processing electronics. The transducer operates at 267 kHz and has a narrow (5 degree) vertical beam and a wide (60 degree) horizontal beam. This beam pattern makes it possible for the vehicle to discriminate between bottom returns and reflections of sonar energy from an object in the water column in the path of the vehicle, even if the vehicle is turning. If an obstacle is detected, the main vehicle computer receives an interrupt and immediately initiates avoidance maneuvers. At this writing, although the obstacle avoidance system has been installed and undergone initial testing, it is not fully implemented.

FLS

The FLS consists of a EDO model 764 mechanically scanned head assembly and custom AUSS interface and processing electronics. The transducer is mechanically scanned from minus 90 degrees (i.e., looking to port) to plus 90 degrees (i.e., looking to starboard) relative to the nose of the vehicle in 100 steps of 1.8 degree resolution. The transducer operates at 100 kHz and has a horizontal beam of 1.8 degrees and a vertical beam of 60 degrees. The positioning and stepping of the sonar head are directly under computer control so that partial scans from and to any head position can be performed as desired by the operator. This makes it possible to concentrate on specific sectors without spending time transmitting unimportant data. In particular, this can be useful during target closure when the object of interest is known to be directly ahead of the vehicle.

All samples are digitized at 12 bits per sample but the operator can select from various linear, nonlinear, and/or adaptive processing formats yielding image data at 4, 6, or 8 bits per pixel. Once the FLS is configured, either by the operator or as defaults by the computer, the operator need only select the range scale, gain and time varied gain, and define the limits of a scan and how many scans to acquire.

When FLS data are transmitted to the surface, they are sent as packets that are assembled together to form images. Prior to every image, a beginning-of-picture message is sent, and following every image, an end-of-picture message is sent. These messages are used on the surface to identify and store the image data. In addition, after every 16th ping, time marks and vehicle position information are sent to the surface. This information is used by surface computers for measurement and target position determination and marking.

SLS

The SLS consists of two side-mounted Edo model 6645 transducers and custom AUSS interface and processing electronics. The transducers have fixed horizontal and vertical beams of 3/4 degrees and 60 degrees respectively. The port SLS operates at 100 kHz and the starboard SLS operates at 105 kHz. All samples are digitized at 12 bits per sample but can be processed as packed or compressed data. If packed formatting is selected, then various linear, nonlinear, and/or adaptive processing formats are available yielding image data at 4, 6, or 8 bits per pixel. If compression is selected, it can be configured for low, medium, or high levels of compression.

Once the SLS is configured, either by the operator or as defaults by the computer, the operator need only select the range scale, time varied gain, and gain values to control the sonar sensor operation. Additional sonar related parameters deal mainly with how the vehicle is driven to follow the sonar search patterns. These include length of legs, number of legs, lane to lane overlap, along-track coverage, and altitude.

To assure complete bottom coverage during an SLS search, the forward velocity of the vehicle must be established and controlled closely coupled to the operation of the SLS sensor. The SLS ping rate is determined by the commanded range scale and along track coverage, and the velocity of the vehicle. This assures that a ping is fired every time the vehicle moves the appropriate distance over the bottom. However, the sonar data must be processed and transmitted to the surface over the acoustic link. Therein lies a problem. Normal operation of the SLS makes use of the medium resolution, medium compression post-processing algorithms. The data compression algorithms automatically adapt to the information content of the images being compressed. It is impossible to predict what the compression rate will be for any given series of returns. Clearly the sonar cannot continue to ping and acquire sonar data at a rate faster than it processes and transmits it without eventually beginning to lose data.

The AUSS system can compensate for the speed of advance problem by operating in one of two modes: fixed velocity mode, or automatic velocity mode. In fixed velocity mode, the operator commands the vehicle to advance at a constant velocity, and the ping rate of the SLS automatically adjusts to this velocity. If the operator's selection was appropriate, no data are lost. However, if the selected vehicle velocity is too high then eventually transmission of data will fall behind, buffers will overflow, and data will be lost. When this begins to happen, messages are sent to the surface warning the operator of an impending problem so that a new velocity can be commanded. If the commanded velocity is too slow, no data are lost but the speed of advance and therefore the search rate is slower than necessary.

The automatic velocity mode eliminates the requirement for the operator to guess an appropriate vehicle velocity. In this mode, the sonar ping rate is adjusted based on vehicle velocity just as in the fixed velocity mode, however new vehicle velocity requests are continually fed back into the control loops by onboard computers instead of via the operator. The new velocity requests are calculated based on the status of internal buffers in the vehicle. As a result, as the buffers begin to fill, indicating that the present vehicle velocity cannot be maintained without data loss, a slower vehicle velocity is requested. Likewise, if the buffers remain underfilled, an increased vehicle velocity is requested. By using this approach, the vehicle velocity and the sonar ping rate are mutually adjusted to yield a continuously updated, optimum search rate based on changing conditions. The dynamics of the automatic velocity mode often produce higher energy consumption than the fixed velocity mode due to the accelerations and decelerations caused by the new velocity requests. Often the automatic mode is used only to obtain a good estimate for the appropriate vehicle velocity, and then the fixed velocity mode is commanded to conserve energy.

When SLS data are transmitted to the surface, they are sent as packets of data that are grouped together to form images. Each image fills a surface display screen. The packets contain header information that informs the surface computers how to process the contained data, and position information so that the resultant image data can be properly placed on surface displays. Prior to every image, a beginning-of-picture message is sent, and following every image, an end-of-picture message is sent. These messages are used on the surface to identify and store the image data. In addition, time marks and vehicle position information are sent to the surface after every 16th ping. This information is used for measurement and target position determination and marking.

APPENDIX D

SENSOR DISPLAY AND INTERPRETATION

INTRODUCTION

An important product of the AUSS search system is the search sensor images that it generates. Many important features of the AUSS system relate directly to the images themselves or to the operations that can be performed by using these images in conjunction with other sensor related information provided by the AUSS vehicle. Many tools are provided to the sensor operator to aid in the task of sensor data management, interpretation, and target marking. This appendix will discuss the tools provided to the operator as well as the format and presentation of the sensor displays. This will aid the reader in interpreting the sensor information provided in this document.

The sensor operator is provided with a total of four displays, three of which are image displays. The fourth is the text display and provides menus and sensor related text information to the operator.

SENSOR TEXT DISPLAY

The sensor text display can be operated in two modes: with or without the help menu. When the help menu is disabled, the entire screen provides a scrolling text window for the display of sensor messages. However, when the help menu is selected, a help window overlays the top half of the sensor text display. Figure D-1 shows the sensor text display with the help function enabled. The bottom half of the text screen shows the uncovered portion of the text scrolling area. The text displayed in this figure shows the results of an analysis session relating to the images discussed under SLS image interpretation.

The help menu is divided into three regions: display selection, active display, and miscellaneous. Each of these regions provides the sensor operator with a reference to available commands as well as selected feedback relating to the image display configurations and active files.

The sensor operator has access to three image displays but must be able to handle image data from four vehicle sensors. In addition, operations can only be performed on one image display at a time. The display selection region in the upper left corner of the help menu is dedicated to the direction of sensor data to specific image displays as well as the selection of the presently active display (i.e., that image display with which the operator is presently interacting).

The direction of a specific sensor's image data to one of the three image displays is accomplished by pressing the appropriate function key (i.e., F1 through F4) for that sensor. Each time the function key is pressed, the specified sensor data steps to the

```
HELP MENU:
─────── DISPLAY SELECTION: ───────          ─────── ACTIVE DISPLAY: ───────
  F1: increment CCD display [0]               F6: increment display format
  F2: increment PSL display [2]               F7: clear image
  F3: increment SSL display [1]               F8: redraw entire display
  F4: increment FLS display [0]              '+': mark cursor location
  F5: increment active display [0]           '-': set LUT to local histogram
─────── MISCELLANEOUS: ───────               'H': mark FLS "Horizon"
SHIFT-F5: recall image                       'O': toggle FLS Overlay ON/OFF
SHIFT-F6: change directory                   'R': mark SLS Resume coordinates
SHIFT-F7: change file mask                  PgUP/PgDN: incr/decr saturation
                     \IMG\*.tif             HOME/END: incr/decr threshold
'A': Auto save toggle ON/OFF [OFF]          INS: toggle color ON/OFF
'M': Menu toggle ON/OFF                     DEL: restore default LUT

File   1 of   4 in Directory 'USR\UHRICH\LOG\DIVE37':  'P191203-.TIF' recalled.
SLS mark: 19:09:14.6; 199 Range, 268 Bearing; -248 North, 19 East
(delta=248.7 ft at 175.6 deg True)
File   2 of   4 in Directory 'USR\UHRICH\LOG\DIVE37':  'S191208-.TIF' recalled.
SLS mark: 19:09:39.7; 401 Range, 88 Bearing; -61 North, 622 East
(delta=631.3 ft at 72.8 deg True)
RESUME AUSS VEHICLE POSITION AT 19:09:42.7:
                  -56 ft NORTH
                  222 ft EAST
```

Figure D-1. Sensor text display with the help function enabled.

next image display, the number of the present image display selection is shown to the operator, and any incoming image data of that type is directed to that display. In a similar manner, the operator selects the active image display by pressing the F5 function key and steps to the desired display. In figure D-1, the port SLS is directed to display [2], the starboard SLS to display [1], and the CCD and FLS are both directed to display [0]. Display [0] is also the active display.

The active Display region in the right half of the help menu is a reference to the functions available on the presently active display. Pressing the F6 function key causes the format of the active display to step through selection of forward-looking (scanning) sonar (FLS), Port SLS, Starboard SLS, or charge-coupled device (CCD) electronic still camera formats. A description of each of these formats will be provided in following sections. Pressing the F7 function key clears only the image portion of the active display, whereas pressing the F8 function key clears and redraws the entire display. The remainder of the functions shown in the active display region will be discussed in the context of the image display descriptions that follow.

The miscellaneous region in the lower left corner of the help menu is used mainly for the storage and retrieval of image data to and from computer files. The SHIFT-F6 function key permits the operator to define the name of the computer directory into which images files will be stored and from which they will be retrieved. By convention, the name of this directory contains the number of the dive in which the images are acquired. Pressing the SHIFT-F5 function key provides the operator with a directory of image files available for recall into the active image display. To select the desired image, the operator moves the cursor over the file name in the display and presses the enter key. Recall of images is done often both during a dive and during post-dive analysis. Pressing the SHIFT-F7 key permits the operator to select whether all stored images or only images for specific sensors will be available at that time for recall.

The automatic saving of image data can be toggled on or off by pressing the A key. In figure D-1, auto save is toggled off. The help menu can also be toggled on or off by pressing the M key.

SENSOR IMAGE DISPLAY

Figure D-2 shows the display of a CCD image as it would be viewed by an operator on the surface. This image is of a sunken 55-ft boat that was discovered by AUSS at 4000 foot depth. It will serve as a sample image for the explanation of the standard AUSS sensor display format and how the operator interacts with the sensor display subsystem.

The standard AUSS sensor image display is divided into eight distinct regions:

- Image Display Region
- Color Bar Region
- Message Region
- Format Region
- A-Scan Region
- Stored Zoom Region
- Position Mark Region
- Cursor Zoom Region

The major portion of the sensor display is the image display region. It is the upper left corner of the display and is where received sensor images appear. The interpretation of the images varies depending upon the sensor that was the image source. Figure D-2 shows a CCD image, that has a straightforward interpretation, but other sensors (i.e., FLS, and the port and starboard SLS) have a less intuitive presentation. Interpretation of all sensor image display formats will be discussed in following sections.

Figure D-2. CCD image as viewed by operator on the surface.

The operator can move a cursor within the image display region. In figure D-2, the cursor is positioned over the windows in the forward cabin of the boat. As the cursor is moved within the image display region, a zoomed expansion of the area covered by the cursor is provided in the lower right corner of the display. This region is the cursor zoom region and provides the operator with the ability to roam within the image and get an expanded view of image information.

Next to target recognition, target marking is the most important function performed by the sensor operator. The operator accomplishes this by moving the cursor over the target in the image display region and pressing the plus key. This initiates several computer-controlled actions, the most important of which is the calculation of the target position within the Doppler coordinate system of the vehicle. The resultant Doppler coordinate information is placed in the target mark region. This region is the second block from the bottom on the right edge of the display.

In addition to target marking, pressing the plus key transfers a copy of the image information contained in the cursor zoom region into the stored zoom region. This region, the second block down from the top on the right side of the display, provides the operator with a stored, zoomed portion of the image with a cross-hair showing the exact position of the target mark within the image. In addition, this region can be used to store zoomed information while the cursor zoom region actively tracks the cursor. Note that in figure D-2, the area in the stored zoom region was transferred while the cursor was over the forward hatch at the bow of the boat. The cursor has since been moved to the area above one of the cabin windows. The information in the target mark region reflects the coordinates of the forward hatch.

The upper right corner of the display is the A-scan region. This region provides an A-scan, or amplitude plot of the portion of the image covered by the horizontal cross-hair in the stored zoom region. The A-scan region is particularly useful when viewing the relative signal strength of sonar returns. Examples of this will be shown in the SLS display interpretation section.

Directly beneath the image display region is the color bar. A second vertical color bar appears to the right of the A-scan. These color bars reflect the present threshold and saturation settings used to display the image data. The scale of the color bar is from zero intensity on the left to 255 (i.e., full scale) on the right. Pixel values in the original image below the threshold will be shown as black and values above the saturation level will be shown as white, with values between the two points linearly scaled between black and white. The operator can adjust those settings, effectively controlling the contrast and brightness of the displayed image, in two ways (i.e., manually or automatically). Manual adjustment of threshold, the left end of the color bar, and saturation, the right end of the color bar, are accomplished by using keys specified in the help menu.

Automatic adjustment of image contrast is initiated by pressing the minus key. This directs the computer to automatically perform a linear contrast enhancement on the entire image, based on the local statistics of the stored zoom region. An example of color-bar manipulation by using the automatic mode is provided in the CCD display interpretation section. The settings can be restored to defaults by pressing the delete key, and the image display can be toggled between gray scale and false color using the insert key.

Below the color bar region is the message region. During a dive, this area would display special sensor messages sent by the vehicle. When an image has been recalled from disk, as is the case for figure D-2, this area displays the name of the image file, along with related information such as creation date and the number of bytes that were originally used to transmit the image.

All images are stored as separate files into the presently active directory. File names for images consist of a first letter designating the sensor type (i.e., C for CCD, F for FLS, P for port SLS, and S for starboard SLS) and the time at which the image was generated in hours, minutes, and tenths of seconds. All stored image names have a TIF extension. If the image is from the CCD and was retransmitted, then the last digit of the time is overwritten by an alpha character signifying the specific retransmission (i.e., A for the first retransmission, B for the second, etc.). The image of figure D-2 was taken at 17:29:43.6 and the letter "A" signifies that it is the first retransmission of that image. The time that the disk file for this image was created is shown as 17:38:06, indicating that the image was retransmitted approximately 8 minutes and 30 seconds after the original image was taken. If the image was manually saved then the time used to generate the file name is the time at which the image was saved rather than the time at which it was acquired in the vehicle, and a "-" is appended to the last digit of time. An example of this is shown in the SLS interpretation section.

Below the message region is the image format region. This region shows what specific sensor format is presently being displayed and what sensors are being directed to that display. In figure D-2, the format is CCD and all sensors are being directed to the same display.

CCD DISPLAY INTERPRETATION

The interpretation of CCD images is straightforward so their discussion here will be brief. The center of the image display shows the area directly beneath the camera. The top of the image display region is straight ahead on the vehicle. Left and right on the display are similarly left and right relative to the vehicle. The CCD camera is located in the nose of the vehicle while the strobes are located in the tail. This causes shadows to be cast toward the top of the image since lighting comes from behind. In CCD format, the target mark region shows the heading and altitude of the vehicle when the picture was taken. This is in contrast to the sonar formats that substitute percent of full range scale and slant range values in this region.

Figure D-2 is an example of a CCD image display. Figure D-3 is of the same boat image, however automatic local-area contrast enhancement has been used to bring out the bowsprit. Note the color bar region in figure D-3, which indicates that saturation (i.e., the right edge of the color bar) has been set to drive low light levels in the original image to full scale in the display. The forward projection of the shadow due to lighting from behind is also more evident in figure D-3 than in figure D-2. Note also the parquet floor appearance of the muddy bottom in figure D-3. This is an artifact of the data-compression algorithms used to send this picture. This artifacting is most evident in areas of little information content, such as the muddy bottom, especially when the contrast of the image is heavily overdriven as is the case here. The degree of artifacting is also affected by how heavily the image data were compressed. Some artifacting such as this may be noticeable in any image that was sent by using data compression. These would include CCD and SLS images but not FLS images.

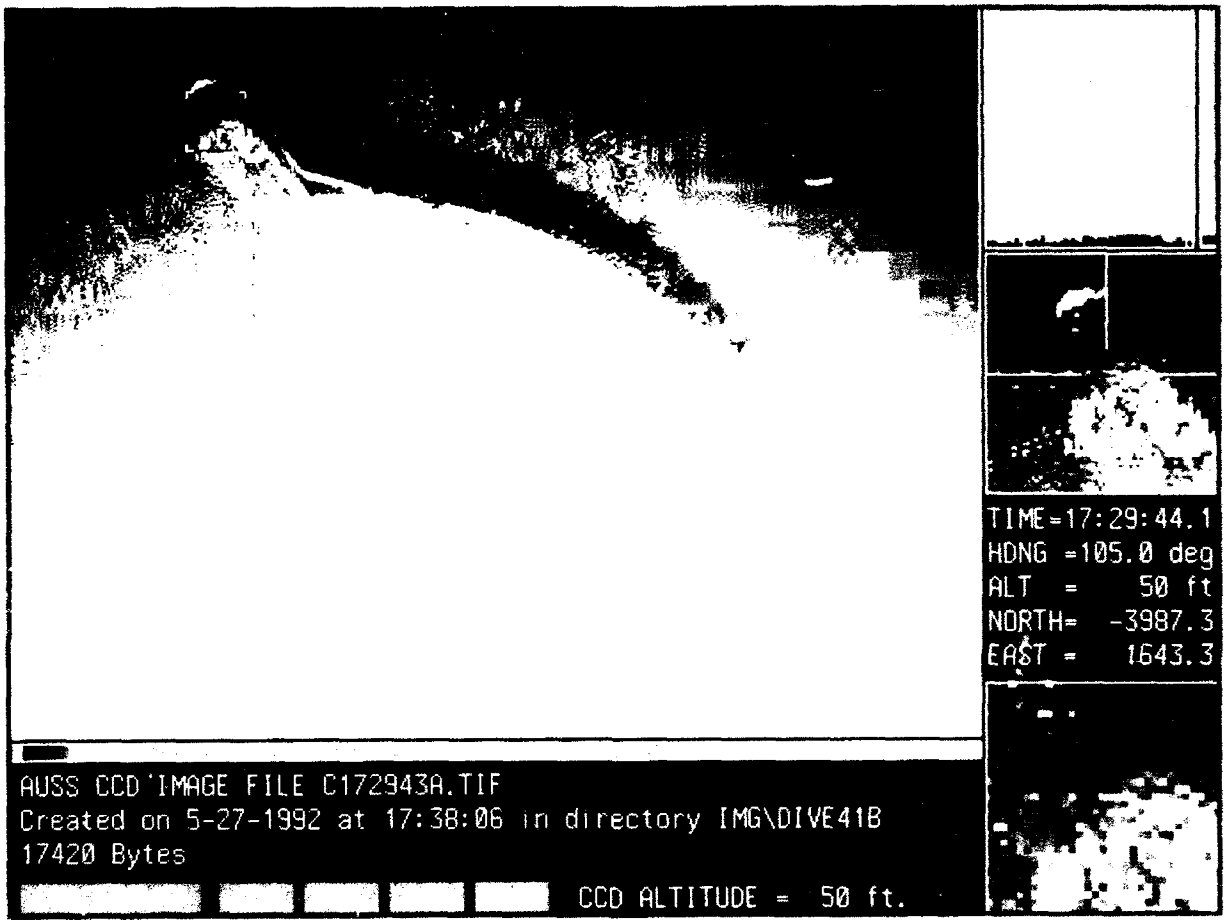

Figure D-3. Local-area contrast enhancement is used to bring out the bowsprit.

FLS DISPLAY INTERPRETATION

The interpretation of FLS image displays is perhaps the most counterintuitive of all the AUSS sensors. Before discussing the details of the FLS image display format, some background information is useful.

After each ping, the FLS head is stepped 1.8 degrees before the next ping is fired. This is continued until the entire scan is completed. As a result, the area covered by a single scan approximates a fan shape. Each ping making up that fan covers a small pie-shaped wedge, increasing in width as a function of slant range, much like spokes emanating from a central hub. The natural way to visualize this coverage would be to use the classic plan position indicator (PPI) style display, as is used for radar systems.

Figure D-4 shows a PPI style display with the image of an airplane shown at close range. This image was obtained by post-processing FLS sonar information from an AUSS dive. Such a display, while not free of distortion, provides an intuitively easy to interpret presentation of the sonar information, since it is almost a direct mapping into the physical position of objects. It is extremely useful when used with joystick controlled systems that require the operator to make immediate and continuous corrections in vehicle attitude. The PPI display format does however require substantial processing and extremely high display resolution to adequately present the information obtained by the FLS.

The AUSS system is supervisory controlled and, therefore, does not require the operator to continuously maneuver the vehicle based on visual feedback from the sonar display. Instead, the operator utilizes the FLS display to detect a target and then marks that target to obtain its position. As a result, the intuitively simple interpretation of the PPI style display is not critical for AUSS. The AUSS system instead uses a B-scan format for the FLS. Figure D-5 shows this format displaying the same information from which figure D-4 was derived. Objects at close range, such as the airplane shown here, suffer a distortion due to this style of presentation. Real-world lines map to arcs in this display, but objects are recognizable and just as easily detected as in the PPI display. Processing is simple and resolution is retained without the need for exotic and nonstandard display equipment.

Figure D-5 shows the FLS display format for a full 180 degree scan (i.e., minus 90 to plus 90) with the overlays option enabled. This option is available only on the FLS display and can be toggled on or off by pressing the "O" key. In the FLS display format, zero range (i.e., closest to the vehicle) is the left edge of the image display region with increasing range toward the right. The right edge of the image region is full scale, which is 125 ft in this image. Port of the vehicle is displayed to the top of the region and starboard toward the bottom. The range increments on the overlay represent 20% of full-scale slant range and the angle scale uses 30-degree increments.

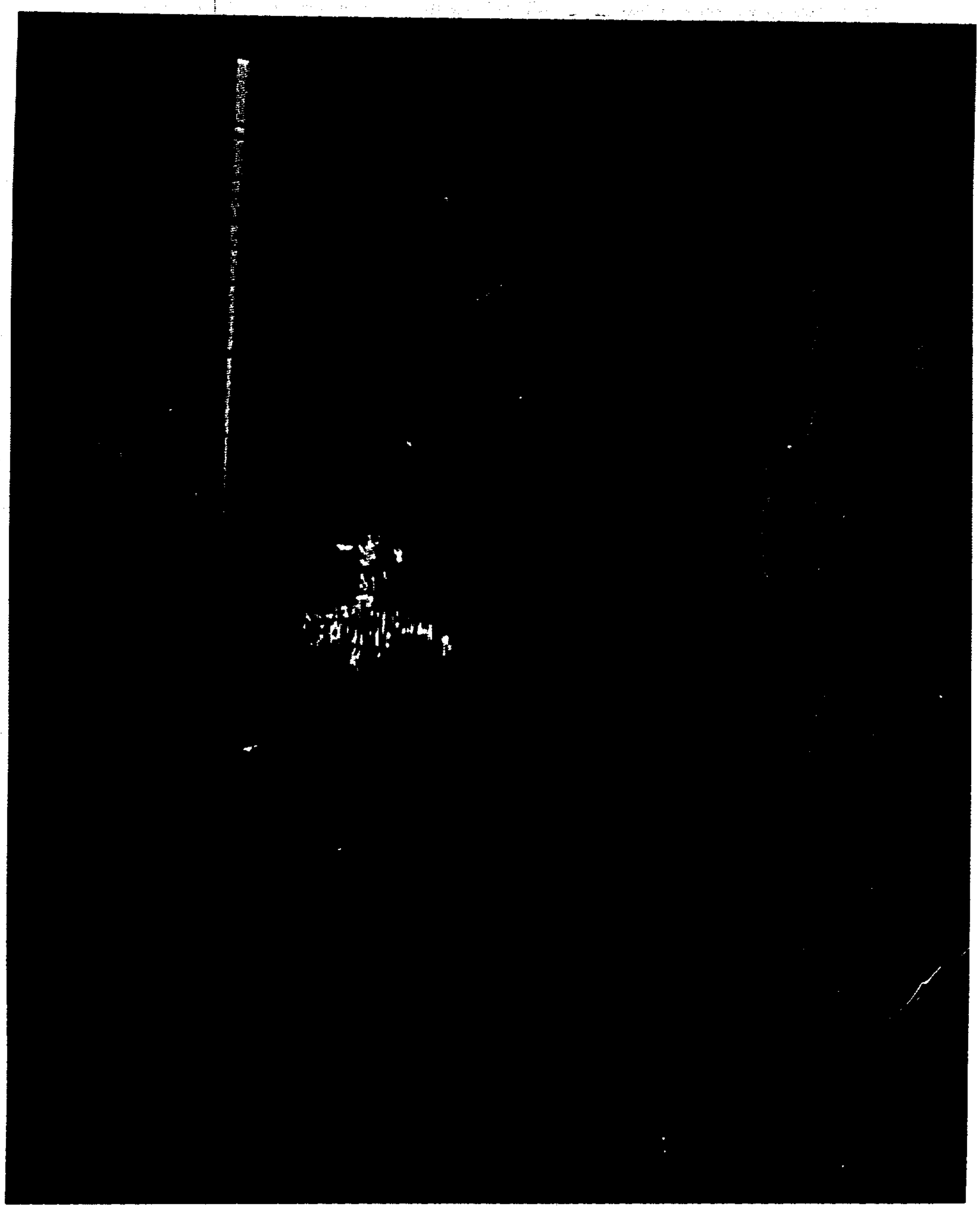

Figure D-4. PPI style display with airplane shown at close range.

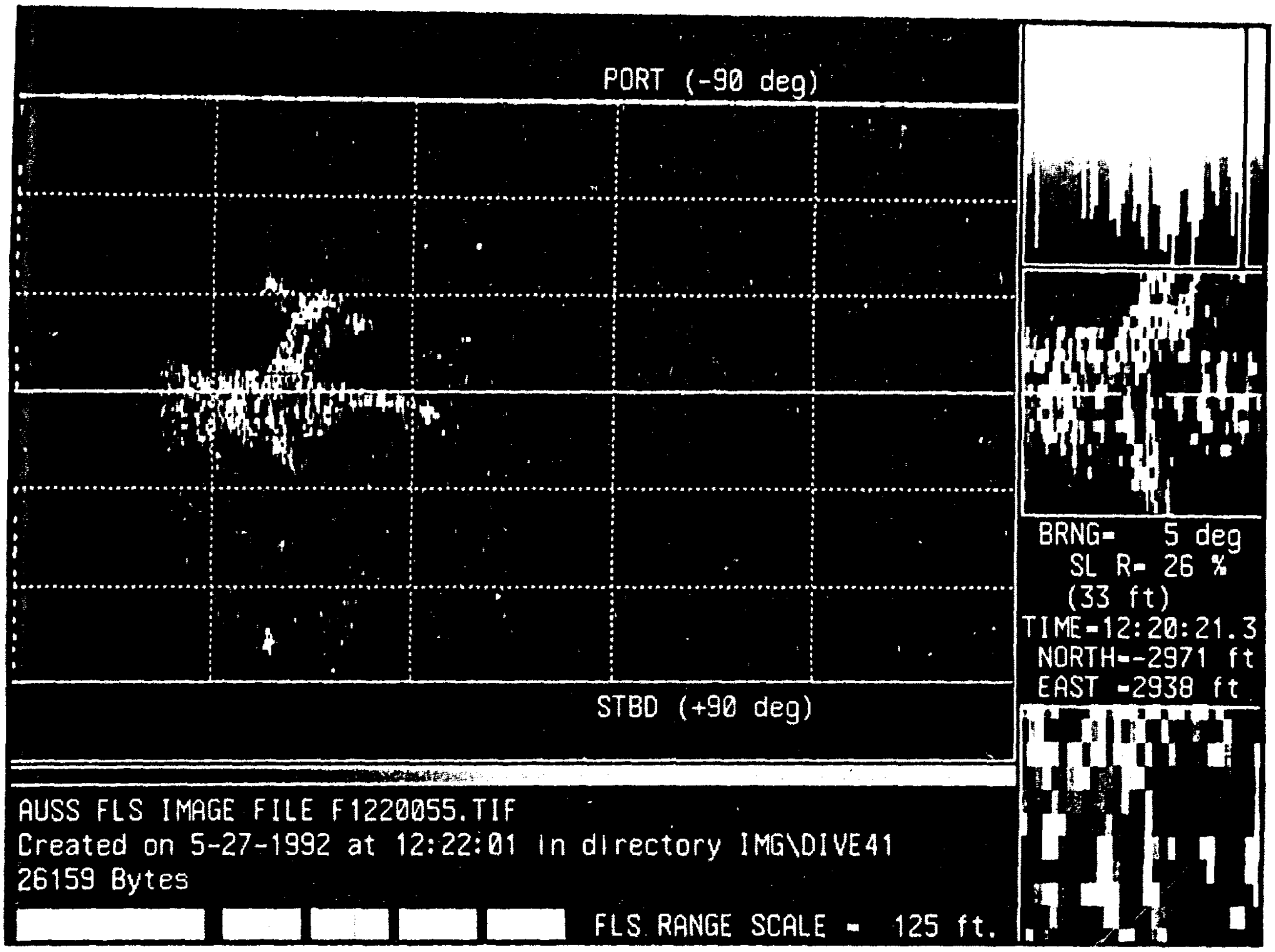

Figure D-5. B-scan format for the FLS.

As for the SLS displays, the stronger the return signal, the brighter the pixel in the image; the absence of a return shows as black. Although the images are reproduced here in black and white, the operator has the option of displaying sonar information in false color. The darker vertical stripe extending about 15% of full scale from the left edge represents the water column. Neither the FLS nor the SLS displays eliminate the water column, nor are they slant-range compensated. Slant-range compensation is, however, used in all position calculations. The darkest vertical stripe extending about 5 % of full-scale from the left edge shows the affects of blanking the receive amplifiers during the pulse transmit interval. Data for this display are written from top to bottom since the sonar is always scanned from left to right.

SLS DISPLAY INTERPRETATION

The SLS consists of essentially two search sensors (i.e., the port SLS and the starboard SLS). The port and starboard SLS operate in tandem in the vehicle, in that they operate as if they were one sensor, but they simultaneously produce two separate sets of images. These images are handled independently by the surface sensor displays. Normally, the SLS images are directed to displays that are located side by side so that the operator views the port SLS on the left display and the starboard on the right display. This provides for a more natural presentation of the displayed information, although it is not a requirement. Figure D-6 shows the port SLS display and figure D-7 shows the starboard SLS display.

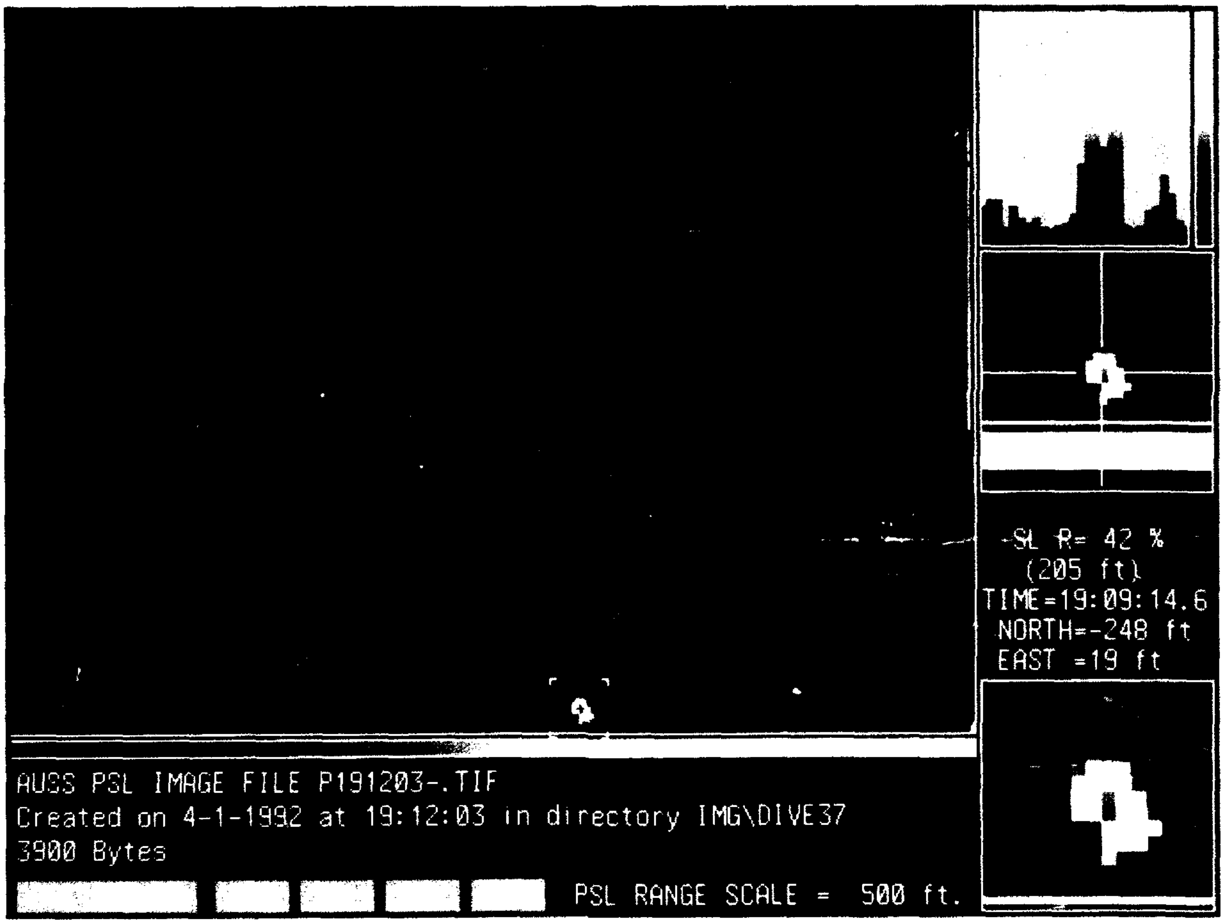

Figure D-6. Port SLS of dual targets.

Sonar information is processed in the vehicle and sent to the surface as it is acquired. As a result, the displayed images are assembled from separate packets of received information. The port and starboard images are generated simultaneously so that a part of the port display will be added followed by a part of the starboard display. The effect is that the writing of new image data appears to pingpong between the two displays.

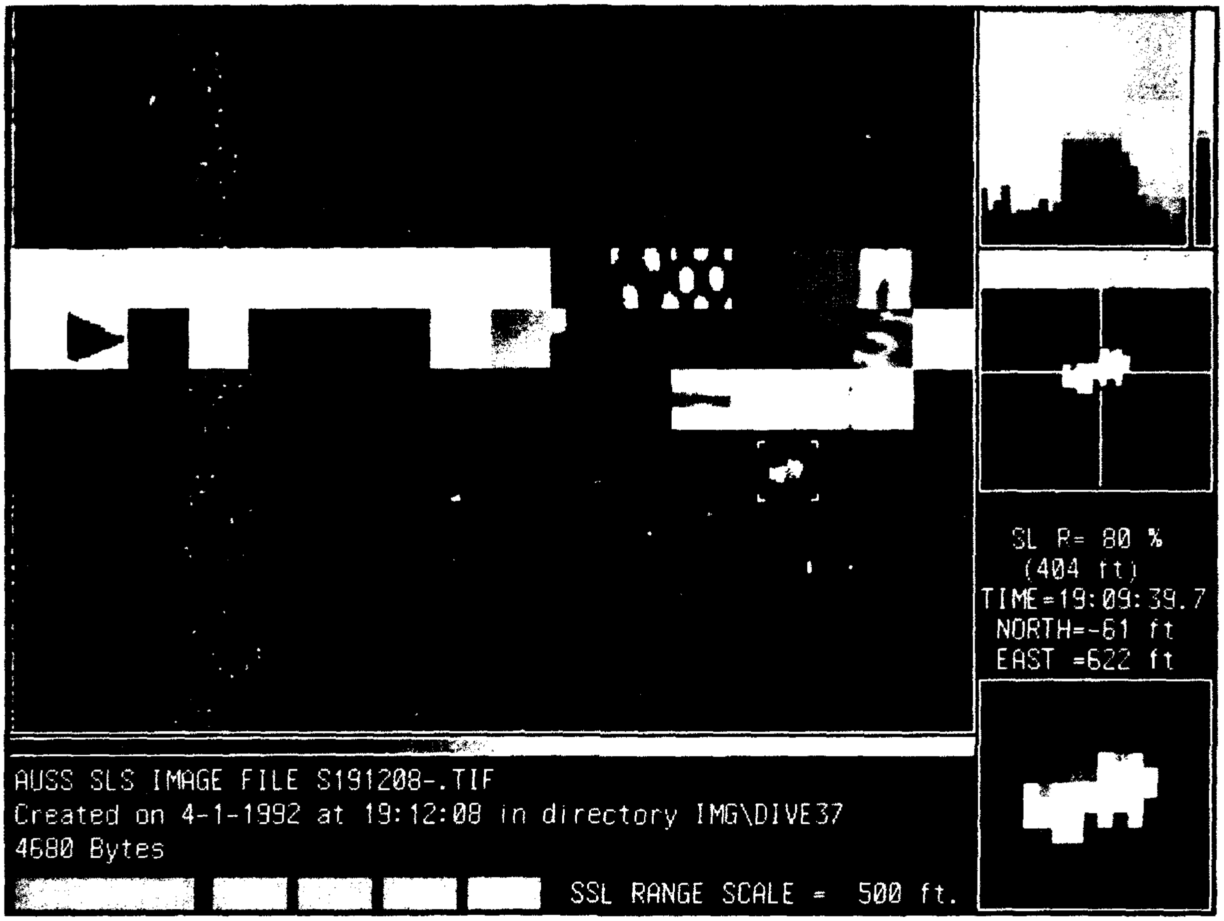

Figure D-7. Starboard display of dual targets.

SLS information is written on the image displays from the bottom up; newer data appear higher on the display leaving older data toward the bottom. The resultant display could be viewed as a map that is unrolled as the vehicle proceeds toward the top of the screen. When the last line of data has been written at the top of the screen, the information wraps over the top and new data for the next image start at the bottom of the display, overwriting the data from the last image.

The port SLS data start at zero range (i.e., information closest to the vehicle) at the right side of the image display region and increases in range toward the left side. Conversely, the starboard SLS has zero range at the left side of its image display region with increasing range toward the right side. If the image display regions for the two displays were abutted, with the right edge of the port display aligned with the left edge of the starboard display, then the line formed where they join is the track of the vehicle, with increasing range of bottom coverage to the left and right emanating from that line.

The images of figures D-6 and D-7 were simultaneously acquired in AUSS dive 37 during an SLS run in which two targets were detected within 25 seconds of each other, one on the port side and one on the starboard side. Several interesting insights into the operation of the AUSS system can be gleaned from these two images.

In both figures D-6 and D-7, the respective targets have been marked and the cursors are still positioned over those targets. In the target-mark region for each figure, the times shown are the times at which the original sonar ping was fired that contains the target information, not when it was marked on the display. The port target was acquired at time 19:09:14.6. When the target appeared on the port display, the sensor operator moved the cursor over the target and pressed the plus key to mark its position. Meanwhile, the vehicle was continuing along its track, transmitting more sonar data, unaware that a target had been detected. Before the operator was able to send the pause command to the vehicle to begin a target closure, a second target appeared on the starboard display.

After the second target appeared, the operator transmitted a pause command to the vehicle. This pause command, however, was not immediately detected by the vehicle, and the uplink transmission of more data was corrupted by the downlink transmission; the acoustic link is half-duplex and cannot operate both directions simultaneously. The strange series of patterned blocks in the starboard display are a result of the surface display computers attempting to uncompress a corrupted packet of received data. The blocks only appear in the starboard display because it was a transmitted packet of starboard SLS data that was corrupted by the downlink pause command.

The vehicle soon detected the pause command, stopped sending data, and began to halt its forward motion to await the next command from the surface. Since no new data were transmitted, approximately the top half of both the port and starboard displays contain old data from a prior image that was not overwritten. A blue line is written on the edge of all sensor displays after an image is saved. This line is overwritten by new image data as it is written to the screen. Presence of the line, therefore, indicates the point on the display at which new data ends and old data begins. Because the images in this document are reproduced in black and white, the line is impossible to see in the starboard display. It is faintly evident about halfway up the left side of the port image and indicates the point at which the new data stopped being received.

While the vehicle came to a stop, the sensor operator moved the cursor to the last good return on the starboard display, just below the beginning of the corrupted area, and pressed the "R" key to mark the resume position. This is the point at which the vehicle will resume the SLS search when given a resume command. The operator then marked the target position. A command was then issued to the vehicle to start the optical evaluation of the two marked targets.

Note the names of the files in the respective message region for each figure. The port image was stored in file P191203-.TIF in the directory IMG\DIVE37, and the starboard image was stored in file S191208-.TIF of the same directory. The dash in the file names indicate that the images were manually saved. This was necessary because the images were prematurely terminated by the pause command, and the automatic saving routines would not have saved them until an end-of-picture message was received. This message would not have been sent.

The A-scan region of both SLS images shows the target strength of the two targets and demonstrates the utility of this region for sonar image analysis. An even more dramatic use of the A-scan region is shown in figure D-8. In this figure, the sonar target is a 58-inch-diameter free flooded sphere that is exhibiting a strong ringing response. The use of such a target for passive navigation marking has been investigated for use by AUSS.

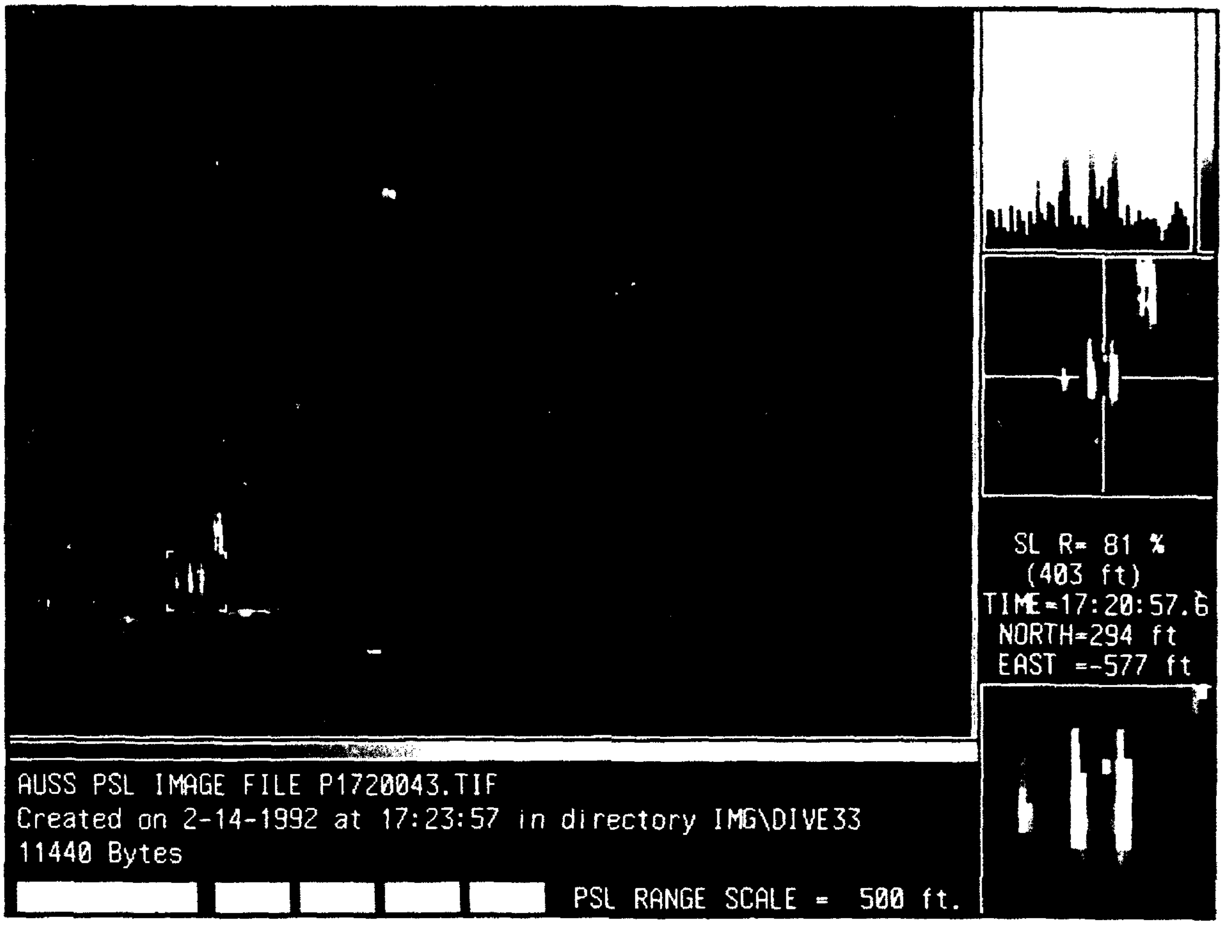

Figure D-8. The sonar target exhibiting a strong ringing response.

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13 ABSTRACT *(Maximum 200 words)*

This report explains search tactics and many of the innovative ideas and technologies that are used to perform the AUSS deep search and inspection. These include the acoustic link, which makes untethered communications possible; the Doppler sonar, which enables it to track its position and navigate without interfering with the acoustic link; high-quality sonars and optical sensors; supervisory control and sophisticated computers and software.

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