AD NUMBER	
AD374921	
CLASSIFICATION CHANGES	
TO:	unclassified
FROM:	confidential
LIMITATION CHANGES	
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31 Jul 1978, DoDD 5200.10; ONR ltr 4 May 1979	

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Santa Barbara Analysis and Planning Corporation

SHALLOW WATER ASW COMMAND AND CONTROL IMPLICATIONS FOR SURFACE SHIP OPERATIONS (U)

Peter J. McDonough

Prepared for:
Office of Naval Research (Code 405)
Contract No. Nonr-4891(00)
July 1966

In addition to security requirements which apply to this document and must be met, each transmittal outside of the Department of Defense must have prior approval of the Office of Naval Research, Code 405.

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PREFACE

This study was conducted for the Office of Naval Research, Washington, D. C., under Contract No. Nonr-4891(00). It is one of the tasks performed as part of the ONR Naval Command Research Program under the direction of Mr. Ralph G. Tuttle. The objective of this program is to provide a scientific and technological base on which Naval planners can make improved decisions in the development, design, and implementation of Command and Control Systems.

The research was conducted by Santa Barbara Analysis and Planning Corporation under the direction of Peter J. McDonough.

ABSTRACT

This study has focused upon the implications of the shallow water environment in the Tactical Command and Control of Single Ship and Task Group ASW Operations. The tactical command of ASW Surface Forces for ASW screens, search, and patrol operations is reviewed. The shallow water areas of the world, with emphasis on the western Pacific, are outlined and the specific environmental properties which contribute directly to the degradation of ASW Forces in shallow water are stressed The Command and Control Requirements for general ASW surface ship operations are reiterated and the general extension of these requirements to shallow water ASW operations is examined. Special attention is directed to the need to improve Effective Sonar Range Prediction in both deep and shallow water ASW operations, and improvements possible are indicated by applying current propagation models, along with ray tracing techniques and programs automated for shipboard computers. Two shallow water ASW scenarios are presented which describe the operational problems and current ASW system limitations which reduce ASW effectiveness in shallow water. The Appendixes of this report provide a brief resume of the general Atlantic and Pacific Fleet organization and a short description of current ASW systems and their operation.

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INTRODUCTION

This study has addressed the assessment of Single Ship and Task Group Tactical Command and Control Requirements in Shallow Water, with the objective to specify requirements in shallow water ASW operations. Environmental characteristics such as rapid temperature fluctuations in time and area, bottom characteristics (slope, absorption, scattering), salinity, tides and other currents which contribute directly to the limited effectiveness of sonars and weapons systems in shallow water impose special requirements on command and control.

The requirements for shallow water and deep water ASW may appear similar in the general, broad aspect of the ASW problem, i.e., the functional requirements to detect, localize, classify, and kill. These requirements are fundamental aspects of ASW and pertain to most any submarine threat in any environment. However, technology has not provided individual ASW systems to operate in each of the different acoustical environments presented between deep and shallow water environments, nor have ASW systems been developed that provide similar performance in both of these different environments. ASW sonar and weapon systems have been designed and developed primarily to perform most effectively in deep water; and even then they are limited under particular environmental conditions. Accordingly, present command and control requirements have been deep-water oriented, with a minimum concern directed to shallow water operations.

The first section of this report describes tactical ASW operations and ASW command responsibilities. These descriptions which are supported by the definitions provided in current ASW Navy documents provide the basis for the command and control requirements dealt with in Section Three.

Section Two provides a limited description of the shallow water environment throughout the world.

Section Three deals directly with command and control requirements, and in particular with the problems of providing Effective Sonar Range Predictions for Fleet use, and how effective ESR predictions can improve the command and control of ASW forces.

Section Four provides two shallow water ASW operational scenarios which, in many aspects, bring together all the sections of this report in a general description of shallow water ASW procedures and indicate some of the command and control requirements peculiar to these shallow water operational conditions.

The Appendixes of this report provide supporting material for a more comprehensive description of shallow water ASW. Although this appendaged information may not bear directly upon Shallow Water Command and Control Requirements, it provides for a better understanding of the ASW forces and systems and the overall need to improve command and control of the ASW forces in shallow water.

CONCLUSIONS

In shallow water it is recognized that sonar detection range and effective weapon range, relative to deep water, are limited. Classification is more demanding (with much less time available for making decisions) since convoys and other transitting Naval forces have little or no opportunity to avoid the enemy submarine when proceeding through shallow water. Multiple sonar contacts are more possible and probable on target-like returns from the bottom and from shipwrecks in shallow water, and shipboard navigation may not be accurate enough to resolve positions of target-like sonar returns with known charted false targets (wrecks) or anomalies.

Acoustic homing torpedoes are easily bottom or surface captured in shallow water, and probable short range weapon requirements will limit the active or passive acoustic homing torpedo until a very positive control is available.

Each of these aspects of shallow water ASW requirements is important to varying degrees in current ASW command and control requirements. One of the more important requirements for the effective command of ASW forces, and for overall tactical ASW operations in shallow water (or deep water), is determining the Effective Sonar Range (ESR). ESR is fundamental in ASW surface ship screen spacing and picket and pouncer positions. Shipboard techniques for making accurate ESR predictions is one important command and control requirement that needs to be satisfied now, as well as in future planned ASW systems. Current Fleet capabilities for predicting ESR in deep water are not good, and in-Fleet methods developed for shallow water are nonexistent. In the past, only a limited effort has been directed towards supporting Fleet development of screening tactics by assisting shipboard ESR prediction with automated facilities; yet ESR is one basic factor used to establish all ASW screen positions.

1. TACTICAL COMMAND OF ASW FORCES

This section describes the designated ASW Tactical Commanders, their authority and responsibility, and the general tactical operation of ASW forces.

The highest command level in tactical ASW operations addressed in this study is the combination of the Task Force Commander ASW Forces with the Sector Commander ASW Forces to provide the required ASW forces for the designated mission. It is under this general tactical command area where the Officer in Tactical Command (OTC) directs tactical ASW operations, or where his designated commander does so; and it is where this study has been directed. There are other ASW tactical commands, particularly Barrier Commands; but in general the Tactical ASW Commands for operations depicted in Figs. 1.1 and 1.2 have received the major emphasis. In this report all specific definitions provided are obtained from Naval promulgated references.* The following basic definitions are being used when attention is directed to Surface Ship and Task Group Command and Control Requirements in shallow water ASW operations.

1.1 The Officer in Tactical Command (OTC). The OTC is the senior officer present or the officer to whom he delegates the tactical command. The OTC command relationships which are shown in Fig. 1.1 are as follows:

1. When forces or units operate at sea under the control of a commander ashore, the OTC of such forces or units reports to the commander ashore.

2. When units assigned to a commander ashore join or operate with the forces operating at sea, the commanders report to the OTC of the force.

3. When independent forces at sea join or operate in the same area, the senior OTC of the forces becomes the OTC of the combined forces.

4. When a unit is detached from an ASW Force to conduct independent operations, the commander of the detached unit continues to report to the OTC of the force unless otherwise directed.

5. The OTC is responsible for the defense of his force against the enemy threat from surface, air, and submarine units.

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*NWIP 24-(A); NWP 24(A); ATP (1A), Vol. I; and NWP 24-2(A).

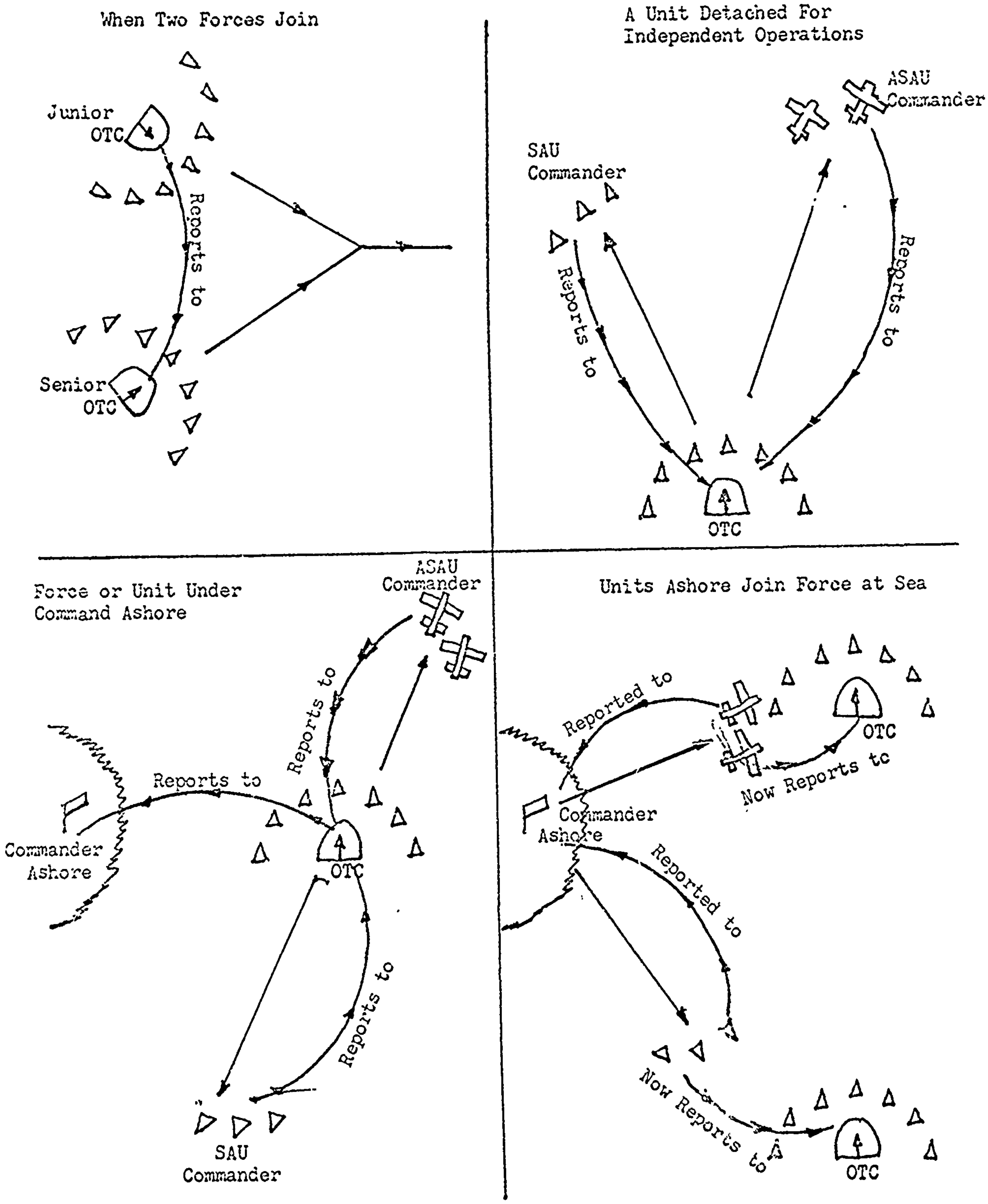
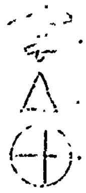


Fig. 1. 1. ASW Tactical Commands

Ref. 1.4, 1.6, and 1.7.



VS or VP Aircraft

Destroyer-type Ship

Helicopter

(A) VS or VP aircraft leave screen and operate as (ASAU).

(B) Two destroyer screen members leave screen and operate as (SAU).

(C) Helicopter operating as pouncer leaves screen to operate with Hunter/Killer Unit.

(D) Aircraft, 2 destroyers, and helicopter have now joined to form Hunter/Killer Unit (HUK).

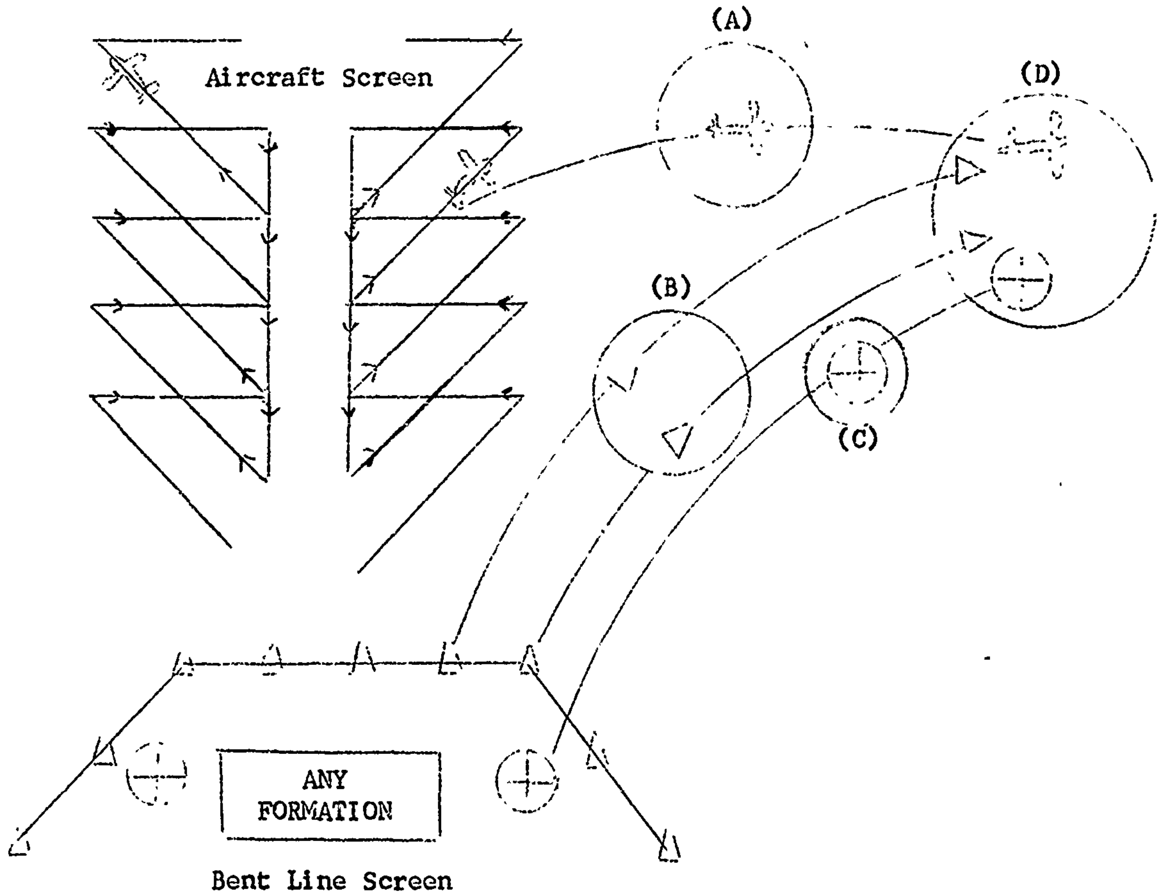


Fig. 1.2. Formation of SAU, ASAU, and Hunter/Killer Unit From Representative ASW Forces.

Refs. 1.4, 1.6, and 1.7.

He normally delegates the authority for the antisubmarine defense of the group to the screen commander. In this case, the OTC of an ASW carrier group usually retains the control of the surface screen, but the stationing and orientation of the screen ships is usually ordered by the screen commander.

1.2 The ASW Commander. Under certain circumstances, theater, fleet, or force commanders may delegate the ASW responsibility for a specific area or for a large dispersed disposition to an ASW commander. When so delegated, the ASW commander acts as the operating deputy of the OTC in all ASW matters concerning the area or disposition. These responsibilities are:

1. The control of all ASW operations in the defense of the area or force, keeping the OTC informed. The ASW commander may designate SAU's and ASAU's.

2. To recommend to the OTC the sonar employment policy for the screening units.

3. Recommending to the OTC countermeasures policy for the force against torpedoes, and the evasive measures for the protected force.

4. The coordination of supporting maritime patrol and the carrier-type ASW aircraft assigned to the force.

5. Establishing datums, the last known position of the enemy submarine.

1.3 The Screen Commander. When so directed by the OTC, the screen commander takes charge of the ASW defense of a force and normally remains in charge of the screen at all times. He recommends actions to the OTC and keeps him informed of the status of the screen.

The screen commander, as the OTC's operating deputy, must be completely aware of the screening requirements, the threat against which the force is being screened, and the capabilities of the units under his command.

The screen commander requires maximum information from all sources within the ship screens and must maintain close and effective liaison with the OTC. The screen must know the OTC's intentions in order to function effectively, and the OTC must know the tactical limitations of the screen.

1.4 Contact Area Commander. The contact area commander (CAC) may be located either in a ship, aircraft, or submarine,* depending

*This study has not included the submarine role in coordinated ASW operations. Available data on coordinated operation is limited and almost nonexistent for shallow water exercises, and the limited data available is not indicative of current successful coordinated operations.

on which of these units has the better information as to the enemy submarine's position, movements, and probable intentions. In the case of coordinated operations between aircraft and surface ships, the senior pilot of the aircraft in contact with the enemy submarine is the CAC until the search attack unit enters the contact area and formal exchange of information and command is effected. The Search and Attack Unit (SAU) commander decides when the SAU is to enter the area. When entry is made, the SAU commander normally becomes CAC unless he delegates control to another officer. This same change of command occurs when submarines and surface ships or submarines and aircraft carry out coordinated operations.

A submarine operating on the surface, or at snorkel or periscope depth, is usually an aircraft target when the target area is clear of surface ships. A submerged target is usually a target for the SAU.

Particular attention by the CAC must be given to the exact capabilities of the specific units involved in the contact area search. Units of the same type and class often have different detection, search, and weapon capabilities because of major variations in installed equipment.

These general tactical operations carried out between ASW Surface (SAU) and Air (ASAU) Units are shown in Fig. 1.2.

1.5 Search and Attack Unit (SAU). The basic designation for surface units is the Search and Attack Unit (SAU), which is normally composed of two or more ships. When these ships are supplemented by fixed-wing aircraft and helicopters capable of search, attack, and destruction of submarines, they form what originally was called Hunter/Killer (HUK) operations. A single ship capable of detecting and destroying a submarine may be designated a SAU in an emergency. The actual number of ships making up a SAU is determined by force requirements and the number of ships available.

The SAU may be organized for the specific purpose of conducting independent offensive operations. If so, it is an antisubmarine force in itself. At other times it may be a unit of a force and may be detached from that force, when required, to conduct ASW operations; however, it achieves its greatest effectiveness when used in coordination with aircraft in search/attack operations.

1.51 Aircraft Search and Attack Unit (ASAU). Antisubmarine aircraft may be either shore-based or carrier-based and include fixed-wing, helicopter, and seaplane types whose primary function is search and attack when assigned to locate and destroy submarines.

Both ship and aircraft characteristics, weapons, equipments, and pertinent ASW capabilities are provided in Appendix B.

1.6 ASW Tactical Screens, Search, and Patrol. The tactics and procedures of ASW screening and search are discussed under this section; the more important aspects of ASW procedures are included. This section can provide a very quick look at the broader, overall ASW search and screening operations.

1.61 Screening. Surface ASW forces provide ASW screens around the "protected force" to prevent the attacking submarine from acquiring an attack position suitable for launching a torpedo. This ASW screen is designed primarily to locate, report, deter attack, and destroy submarines before they can gain the attack position. The screen is composed of ASW surface ship escorts: DD's, DDE's, DE's, CVS's, along with DL's, DLG's, DDG's, DEG's, helicopters, and fixed-wing aircraft. Screening surface and air units operate in the area close around the force or convoy and provide the last opportunity for protection against enemy submarines.

Escorts of the screen are responsible for the protection of the convoy, and the operations conducted by these escorts (surface ships and aircraft) are designated escort responsibilities, whose primary objective is to ensure safe and timely arrival of convoys at their destinations. The secondary mission, to seek out the enemy and destroy him, can only be pursued if more than sufficient forces are available to carry out the primary mission. Detailed maneuvering instructions and command relationships for the escort forces are provided in reference ATP 1 (A). A representative escort problem and the ASW screen protecting a force or convoy en route are shown in Figs. 1.3 and 1.4. As will be noted in Fig. 1.4, there are three basic areas of importance in establishing a screen around the formation. These three areas, the Torpedo Danger Zone, the Danger Zone, and the Detection Circle, are explained as follows:

1.611 The Torpedo Danger Zone (TDZ) is that area around the screened body within which a torpedo with maximum operational range (R) must be fired to have a chance of a hit. The speed and range of the torpedo and the speed and disposition of ships in a formation determines the size and shape of the area; but as would be expected, it is the main intent to keep all submarines outside the Torpedo Danger Zone. This is the basic problem presented to the screen from submarine-launched torpedoes. This does not, of course, protect against enemy air-launched weapons, and it is not designed to do so. Rocket-delivered torpedoes and long-range standoff weapons are not considered in this study, primarily because the shallow water limitations imposed upon ASW surface forces are also imposed upon the attacking submarine.

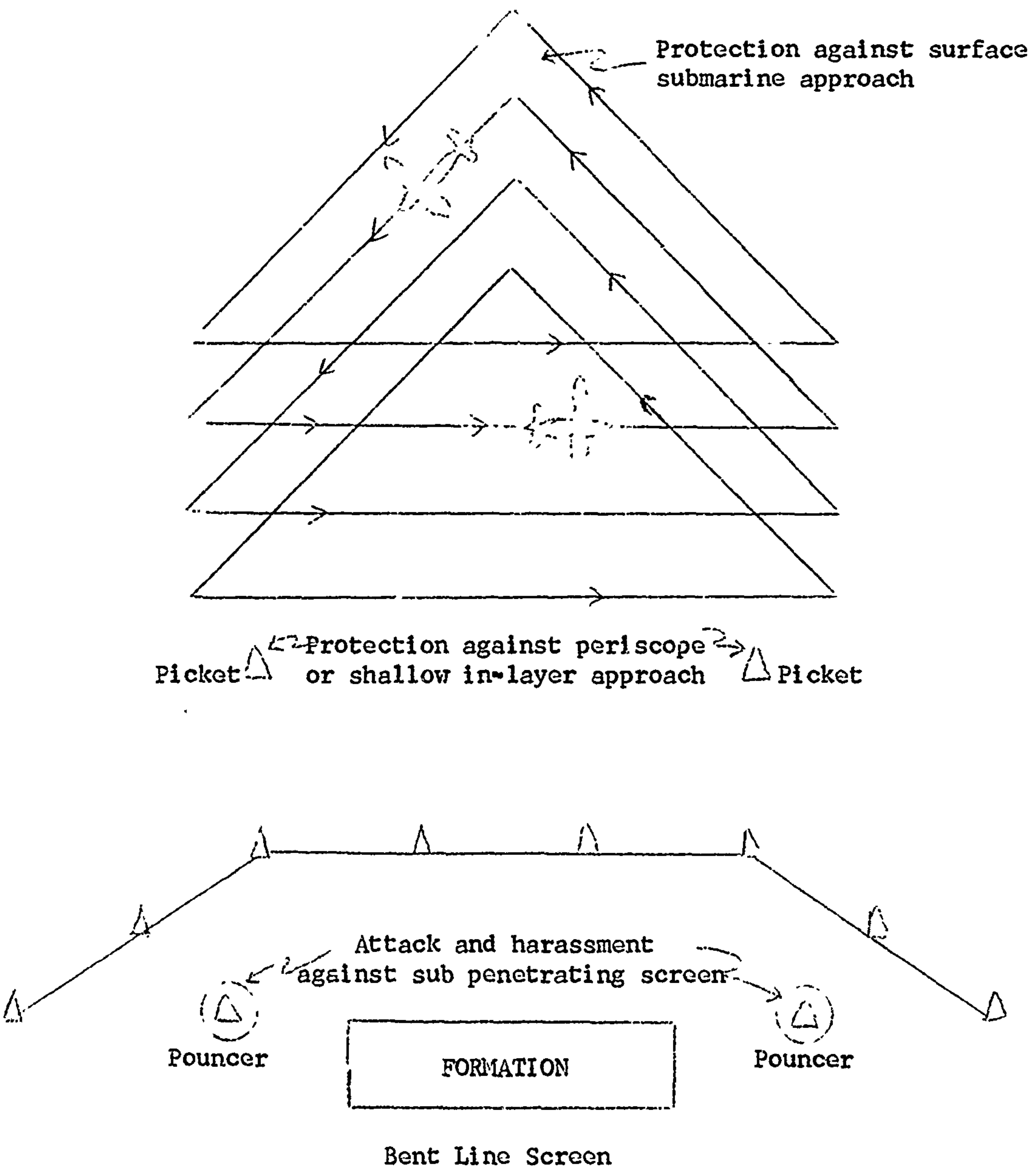
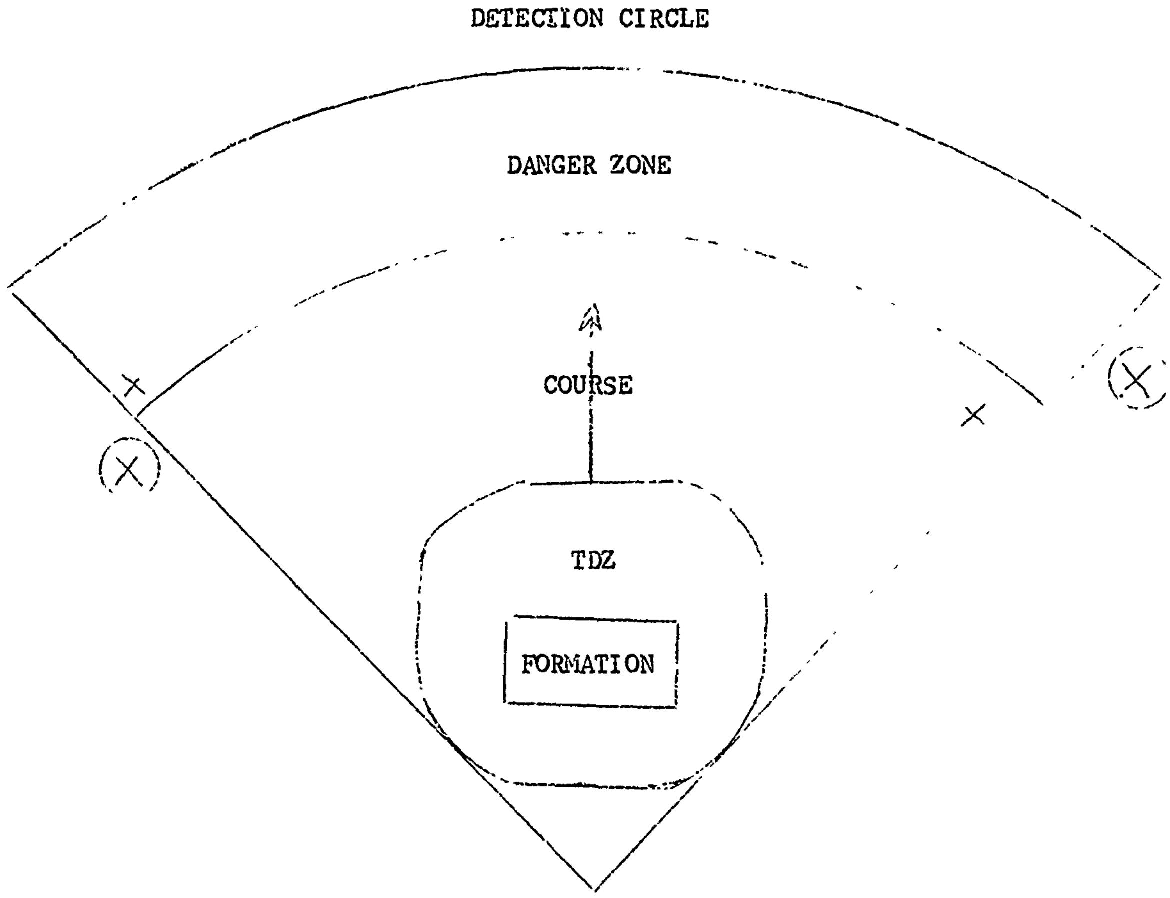


Fig. 1.3. Representative ASW Forces.

Refs. 1.4 and 1.6.



X Represents a submarine inside the Limiting Lines of Approach (LLA). This submarine poses a torpedo threat since it can possibly reach the TDZ

(X) Represents a submarine outside the Limiting Lines of Approach (LLA), and theoretically does not represent a torpedo threat.

Fig. 1.4. Critical ASW Screen and Search Areas.

Refs. 1.4 and 1.6.

1.612 The Danger Zone is the area within which a completely submerged approach to the Torpedo Danger Zone is possible. This area is formed by the arc shown in Fig. 1.4 and the limiting lines of approach.

Fig. 1.5 shows the limiting lines of approach (LLA) in more detail and indicates how they are drawn. The relative speed of the formation to the would-be attacking submarine establishes the LLA. As the speed ratio (speed of formation/speed of the submarine, V_C/V_S) gets smaller, the angle made by the LLA gets larger. When the speed of the submarine $>$ the speed of the convoy, this would theoretically permit an approach by the submarine to the TDZ from any angle behind the formation.

The larger the speed ratio, V_C/V_S, the smaller the area forward of the formation that is necessary to screen. There is a degrading effect, however, as V_C increases. The increase in formation speed requires an increase in escort speed. In general, when this occurs the Effective Sonar Range (ESR) is reduced, due to the increase in self-noise level with speed, which in turn decreases the signal/noise ratio available for a specified ESR. These problems and their particular aspects in shallow water are discussed in more detail in Section Three. When V_C is increased, the OTC must carefully consider detaching escorts for prolonged prosecution of a contact. At increased formation speeds, ships so detached for long periods probably will not be able to rejoin the formation since they will have little or no margin of speed over the main body of the force.

1.613 The Detection Circle is the circle around the force within which the submarine can detect the screened force. This detection range is much greater than the detection range from the surface ship using active sonar. The submarine receives the active acoustical ping which has traveled only one way, while the shipboard sonar must receive the signal after the two-way attenuation. Also, the convoy itself generates enough noise to be detected from fifty to a hundred miles or more by the submarine.

1.62 Advanced Screen or Pickets. When the OTC has enough escort ships available, or if he suspects enemy submarines far in advance of the force, he may want to use an advanced screen. The advanced screen, or pickets, are stationed within VHF or UHF communication range of the main body to patrol a sector or a bearing determined by the OTC. This outer screen is normally comprised of long-range sonar equipped ships that can provide detection of in-layer submarines far in advance of the screened formation. Air surveillance and helicopters with dipped sonars add to this capability and will usually be used to augment a picket destroyer.

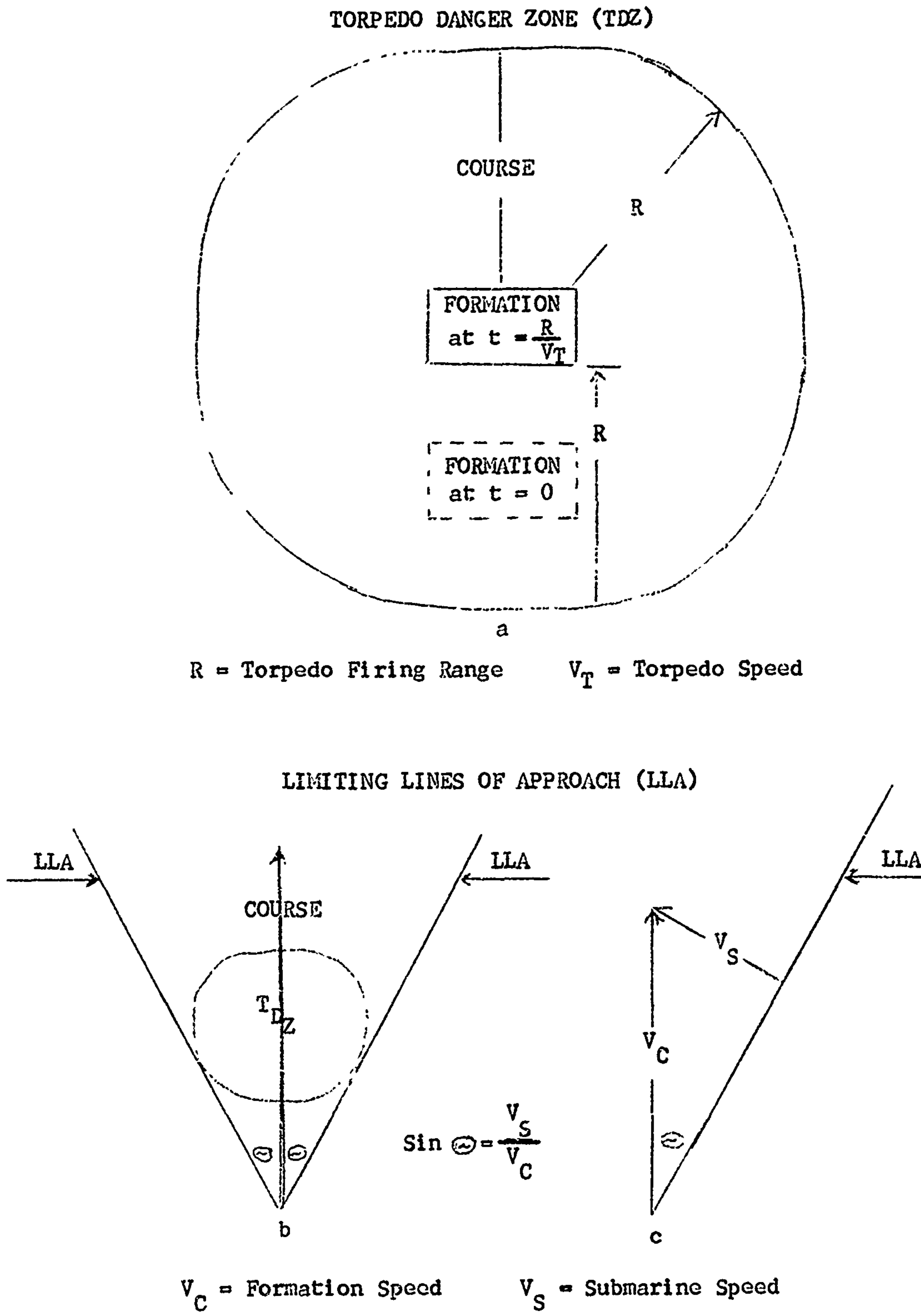


Fig. 1.5. Torpedo Danger Zone & Limiting Lines of Approach,

Refs. 1.4 and 1.6.

1.63 Pouncers. Inside the screen the OTC may assign other destroyers and helicopters. Units assigned stations inside the conventional screen, adjacent to the main body, act as pouncers. Pouncers provide additional obstacles to restrict the submarine's freedom to obtain data and to maneuver into firing position in the event that he penetrates the screen. They also provide ships for a deliberate attack on submarines contacted by advance or main screen units, or to fill vacant stations left in the screen when a screen number is deployed as a SAU. Helicopters with dunked sonars used as pouncers provide an extra element of surprise for the submarine since their presence is not easily detected, especially when dunking in a random pattern.

1.64 ASW Screen Types. Several types of screens currently in use are described below:

1.641 Bent Line Screens (See Figs. 1.3 and 1.6.) The bent line screen is a screen forward of the main body, and as its name implies, it usually forms a curve or bent line. The bent line screens and destroyer spacing included in ATP 1(A) are based on submarine speeds of 12 knots and a main body speed of 15 knots; and torpedo characteristics are straight running 45 knots, 12,500 yard range, and a salvo of six.

When there are enough screen ships available, the bent line screen would be based on the near zero percentage hit probability contour around the screened unit. This contour is the locus of firing points from which 12,500-yard torpedoes could almost reach the screened ships (TDZ). The recommended escort-to-escort distance is 90 percent of the sum of the effective sonar ranges (ESR) of adjacent ships.

1.642 Circular Screens (See Fig. 1.6) Circular screens (including the horseshoe type) provide ASW protection around a force when the submarine speeds approach or surpass the speed of the formation of the screened unit. The provision of a "solid" screen, spaced at 90 percent of the sum of the below-layer ESR, is desirable; however, the principle of equalization is recommended when there is a shortage of screen ships.

This controlling principle, equalization, is based on reconciling the two probabilities that the submarine will penetrate the surface screen undetected and that the submarine will score a hit from outside the screen. Increasing the spacing between screening units increases the chance of submarine penetration. Decreasing the distance between main body and surface screen increases the chance that the submarine can launch a torpedo and score a hit from outside the screen.

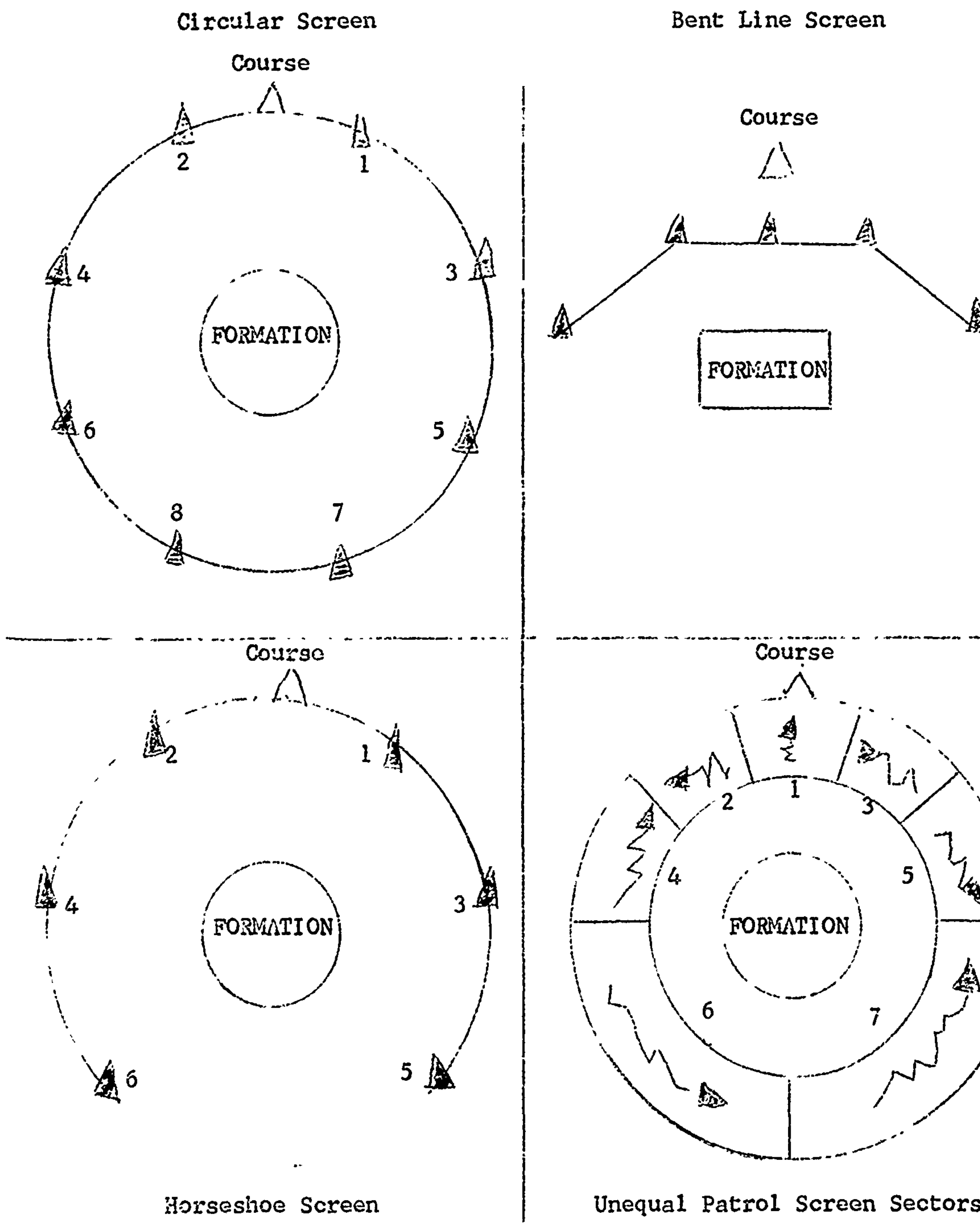


Fig. 1.6. Some Common ASW Screens.

Refs. 1.4 and 1.6.

Plan 14C of ATP (A) is used to determine the screen circle to be used, depending on the sweep width acceptable to the OTC.

1.643 Patrol Screens (See Fig. 1.6.) There are two types of patrol screens: screens with equal sectors and screens with unequal sectors. When the ratio of the formation speed to the submarine's speed increases so that attack from the van is more probable, a patrol screen with unequal sectors is indicated. Otherwise, an equal sector, circular screen is recommended.

Patrol screens allow random patrolling of sectors by the screen units at a greater distance from the screened body. This complicates the submarine's problem in definition of the formation pattern, and the determination of a safe gap through which to penetrate the screen is made more difficult.

The following sweep width criteria for patrolling escorts is given in NWP 24(A):*

Main screen unit's width = 2.25 times the below-layer ESR.

Pouncer sweep width = 2 times the below-layer ESR.

Picket and advanced screen sweep width = the sum of the above-layer ESR and the below-layer ESR.

Half-sweep width for pickets and advanced units is taken as the average of above-layer and below-layer ESR's. This average ESR recognizes that not all submarines will operate above the layer in the picket or advanced screen area.

1.7 ASW Search. For so called "area surveillance," search may mean entire ocean basins, while for a particular datum it may be confined to some area as small as a few miles square. The primary objective of search is detection. It involves the systematic investigation of a particular area with all of the ASW platforms available, with each contributing in a special way. Actual search plans and tactics designed to achieve the desired results are detailed in ATP 1 (A).

1.71 Search by Surface Ships for a submerged submarine in a small area over an extended period is more suitable than search by aircraft. The ship has a lower rate of search, and visual ranges are less than aircraft; but the sonar datum on a

*Note that the criteria is based almost completely upon ESR.

submarine below the surface will be more accurately located if and when the submarine is detected. The ship has the capability of remaining on-station for a much longer period than is possible in the case of aircraft; but both are limited by severe weather.

Single-ship search is seldom used with current sonar equipments because the initial detection range is limited. As opposed to single-ship operation, several ships operating together are more effective in searching an area. With present sonars these ships are more effective in maintaining contact; mutual support is possible; and the opportunity to conduct a rapid series of attacks invariably follows.

1.72 Search by Aircraft over large areas utilizes the advantage of a broad field of vision and a high rate of search, especially when surfaced or snorkeling submarines are involved. The aircraft provides early warning of enemy submarines, and it is almost always used in advance of the ASW force.

The sonobuoy systems with aircraft are so small that only a limited capability can be built into them, and most of the signal processing is provided by the aircraft platform. Future systems, such as the large air transportable sonobuoy, may improve the detection and search capability.

Fixed-wing aircraft equipped for radar relay are also employed in coordinated operations, which improves the effectiveness of available ships, submarines, and aircraft. Although the primary task of these aircraft is airborne early warning, as noted above, they can also be used to establish surface surveillance of a designated sea area, searching for a surfaced sub, a snorkel, or a periscope, both visually and with radar. Aircraft can also provide information required to establish surveillance plots to suitably equipped surface or airborne units.

1.73 Search by Helicopters. Helicopters are excellent for visual search and good for sonar search; and when used in conjunction with surface ships and other aircraft, they greatly increase the screening capabilities of the force. They have limited on-station time, are also weather limited; but at times they can provide tracking and trailing of enemy submarines with either passive or active dunked sonars.

1.8 ASW Patrol. Patrol operations, in contrast to search, are conducted against submarines (1) to restrict them to their bases, (2) to detect and destroy them en route to or from their bases, (3) to restrict their areas of operations, and (4) to force them to use submerged tactics. Barrier patrols (the most common patrol used) are conducted by surface ships, aircraft, submarines, or a combination of forces. They are most commonly used over limited distances; and in cold war periods they can provide a relative testing area for both combatants.

1.9 <u>Sweep Width and Effective Sonar Range</u>. Sweep width is a basic consideration in determining the type of screens to be used, as noted under the discussion of screening. Sweep width in its most simple form is merely the Effective Sonar Range (ESR), or the estimated swath of ocean covered by the sensor of a searching unit.

Normal submarine tactics are also an important factor in determining the type of screen and sweep width. The submarine will often operate in or above the layer during its approach to the force in an attempt to gain acoustic attack information; but once this information is in hand, the submarine may seek its best depth to avoid detection (approximately $30\sqrt{\text{layer depth}}$) while penetrating the screen. Consequently, the sweep width for pickets or advanced screens is based on the average of the ESR, considering both above and below layer targets, while the sweep width of pouncers and ships in the main screen is a function of the below-layer ESR.

The below-layer ESR is much shorter than the in-layer ESR. If the pouncer is to be prepared for the worst case (the last resort), he develops his inside screen defense position for this condition.

The relationship between sweep width, screen spacing, and probability of detection is expressed in NWP 24 (A)

by $\frac{W}{S} = P$

where W = Sweep Width
S = Screen Spacing
P = Probability of Detection

Most screen spacings discussed in NWP 24 (A) and ATP (A) Vol. I are established from the Effective Sonar Range, and usually 90% of the Effective Sonar Range is recommended. At the option of the OTC, screen spacings may be varied as a function of ASW platform availability, platform speed, and environmental conditions. In some situations the OTC may prefer to establish spacings at a value other than 90% of the Effective Sonar Range. The ESR is established at the range where (on the average) the returned echo from a suspected target submarine will just be detected 50% of the time, and 50% of the time it will not be detected. This varies with several things such as target aspect and position above or below layer, sonar equipments, environment, operator, and speed of platform, which will become more obvious after reading Section 3 for more details. If the OTC so desires and wants to vary the effectiveness of the screen, he can do so by increasing or decreasing the detection probability of a screen unit. By increasing screen spacing, he decreases the chances of detecting the submarine; by decreasing the spacing, he increases the probability of detecting the submarine.

An escort occupying a fixed station provides sonar coverage equal to twice his ESR on either above-layer or below-layer targets. If escorts are placed relatively close to the protected force, an enemy submarine can more easily depict the pattern of the formation, clearly revealing both position and general heading of the protected force; but at the same time it makes it more difficult to penetrate the screen. When the screen escorts are placed at greater distances and patrol sectors form a random pattern the submarine then has a more difficult problem to determine the general direction and size of the force, but could find it much easier to penetrate the protective screen.

1.10 Coordination of Surface Ship and Aircraft. Coordination within and between all ASW units is the primary requisite for success in antisubmarine warfare. To achieve the required coordination, all commanders, unit commanders, ship captains, and pilots must be thoroughly familiar with the characteristics and capabilities of their own and all other types of ASW units involved in the operation.

Surface ships and aircraft carry out coordinated operations against enemy submarines. Surface ships and fixed-wing aircraft or surface ships and helicopters are most commonly used. In this use, both exploit the primary capabilities of each type. By resorting to the surface ship's CIC for plotting and control, and taking advantage of the aircraft's speed, the possibility of a joint successful attack is increased.

Normally the fixed-wing A/C or helicopter commander initially in contact with a submarine is CAC until the SAU reaches the area. The officer assuming the duties of contact area commander informs all ships and aircraft in or approaching the contact area that he has assumed command and at all times keeps the officer in tactical command informed of the progress of operations in the area. The SAU commander decides when the SAU is to enter the contact area, but the CAC may advise the SAU commander to delay the entry of ships into the contact area if it is considered that the employment of aircraft alone would be more profitable.

The SAU commander becomes CAC after he enters the contact area and relieves the aircraft commander.

1.101 Coordinated Search by Aircraft and Surface Ships. Coordinated operations by surface ships and fixed-wing aircraft or helicopters may be divided into three phases: search by aircraft resulting in a contact and attack on the submarine by the aircraft, the approach of the SAU to the submarine contact to cooperate with the aircraft if its attack has failed, and the local search and attack by a search attack unit in cooperation with aircraft.

In coordinated operations, fixed-wing aircraft provide the means for both distant and close support, communication links with other aircraft or surface forces, and airborne early warning. The SAU provides search capability, communication links, facilities for aircraft control, and antiaircraft fire for the protection of the formation. ASW carrier aircraft complements also include ASW helicopters, which have a primary mission of reducing time late of active sonars in the contact area after detection has been made by an air search attack unit.

A systematic monitoring and positioning of helicopters is necessary if their ASW capabilities are to be used effectively. The controlling ship attempts to keep in constant radar contact with the helicopter. Ships controlling helicopters maintain at least one lookout for each helicopter being controlled with the sole responsibility for constant visual contact with the helicopter. The entire helicopter ASW operation depends on the proper maintenance of communications; and if there is communication failure the helicopter is usually returned to the carrier, especially when high sea states-severe air turbulence may make it difficult or impossible for the pilot to maintain station.

When the OTC receives an enemy submarine contact report, he decides what assistance to send to the contact area. Helicopters would normally be ordered to the area as soon as practicable. They can normally reach the contact area in less than one-third the time required by the SAU, and their active sonar is valuable in localizing the submarine. If a contact is lost, it is recommended in NWIP 24-2 (A) to send a SAU to the contact area if the reported contact can be reached within 45 minutes of the time contact is lost. The superior plotting and command facilities in a SAU usually result in more efficient coordination of the various units in the contact area.

1.102 Contact by Coordinated Forces. In coordinated operations by units of a single ship type, the contact phase is a crucial one in antisubmarine operations. Contact by a unit in a coordinated force may, if the tactical situation permits and cooperating units are at safe distances, lead to classification and immediate attack. If the immediate contact requests assistance from the ASW force members, the OTC must decide how much assistance he can provide without reducing his capability to perform the assigned mission.

When an aircraft has contacted an enemy submarine, he immediately transmits the target position to the OTC or to his controlling unit. If the aircraft holds contact until the SAU arrives in the contact area, the SAU attempts to gain contact and attack the target, directed by the SAU commander. The local search and attack phase of coordinated operations by aircraft and a search attack unit begins when the SAU enters the contact area and ends with the destruction of the submarine, or when the search is stopped at the discretion of the CAC or on orders from the OTC.

The helicopter, as with the fixed-wing aircraft, also reports the contact to the controlling unit, who in turn plots the position and informs the OTC. Again, when the SAU enters the contact area, the SAU becomes CAC.

2. SHALLOW WATER ASW ENVIRONMENT

2.1 <u>Definition</u>. The general use of the phrase "Shallow Water ASW" implies that the operations of ASW Forces in shallow water ocean areas are much different than ASW operations in "deep water". That this is true is accepted by most ASW Fleet operators;* however, there are only limited Fleet operational data collected during ASW operations in shallow water to substantiate any large differences in operational results. Not that operational differences do not exist; they do. There are very definite differences that are fairly obvious, but in the past most ASW exercises have not been conducted in shallow water to obtain the necessary detailed comparative results. Furthermore, there is available only a minimum of ASW tactical doctrine that bears directly on shallow water ASW tactical operations, which is also probably due to limited Fleet ASW exercises in shallow water. An awareness of the potential shallow water ASW problems that can, and probably will, confront the ASW forces in the future appears to be on the increase, however----especially so at the Fleet ASW School, San Diego, California, in the teaching of Surface Screen and Search Tactics and Coordinated ASW Tactics.

The differences that most Fleet ASW operators describe as special shallow water ASW operational problems can, for the most part, be attributed to the large differences in the physical environment between deep ocean areas and shallow coastal waters.

"Shallow water" and "inshore waters" are terms used interchangeably in many Naval reports; inshore operations, however, is a designated Navy term. For example: Inshore (coastal) Search, Mobile Inshore Undersea Warfare Units, Inshore ASW, etc., are used officially, and "shallow water" is used mostly in a similar descriptive sense. Shallow water is frequently defined at 100 fathoms or less. This does not, however, directly mark the demarcation from shallow water to deep water since it is not defined or marked by a single factor. In ASW operations it will always be well to consider shallow water areas to be <u>any area that forces environmental constraints upon the ASW system that differ from open area operations</u>. These constraints include all those associated with sensors and weapons as well as overall systems or subsystems. The

*Fleet ASW School, San Diego, California most important constraints are those affecting the acoustic sensors. These are bottom absorption, reverberation, and rapid temperature variations in space, time, and salinity which affect sound velocity as well as the effects on false alarm rate (the need to classify the probable many submarine-like false targets on or near the bottom). Also, localization techniques dependent upon Magnetic Anomaly Detectors (MAD) may be affected due to geological formations being much closer to the surface, and therefore closer to the target, in shallow water. The magnetic anomaly created by a large mass of iron (the submarine) in the earth's magnetic field is sometimes much less noticeable in a stronger magnetic field created by operating the submarine close to large geological formation (i.e., near the shallow water bottom). Visual sighting of submerged submarines from the air may also be reduced in shallow water. Shallow water in coastal areas near fresh water outlets has a tendency to be largely murky, turbid water which presents even more of a problem to visual sighting of submerged submarines.

For the operating submarine, shallow water may well have many other significant restrictions such as: too shallow to allow maximum speed without cavitation (cavitation is a function of vapor pressure which is directly proportional to depth), or too shallow to keep enough depth below the keel to permit recovery from depth-control malfunction. And the submarine operator, as with the surface ASW forces, may also find the ambient noise level in shallow water to be increased due to breakers on the beach and surface traffic, especially near ports. This increase in noise level certainly will reduce the effectiveness of passive sonar systems unless, of course, it comes from the target to be detected.

As may be evident by now, the exact shallow water depth is not so important---only the attendant variations in ASW operations when the water depths are near 100 fathoms, more or less, and how these variations will affect overall ASW operations. This constitutes the shore and near-shoreline throughout the world and encompasses most of the water lying over the continental shelf. It also constitutes many relatively large areas for Naval operations (see Figs. 2.1 and 2.2).

2.2 <u>Extent of Some Strategic Shallow Water Ocean Areas in Southeast Asia</u>. One of the most important bodies of water in the world to the U. S. Navy today is the South China Sea, which is unique in that it is composed of very extensive areas of shallow water (see Fig. 2.3). The Seventh Fleet operates in and out of shallow water (100 fathoms, 600 feet or less) daily, and due to present and probable future commitments, may be expected to continue these operations in

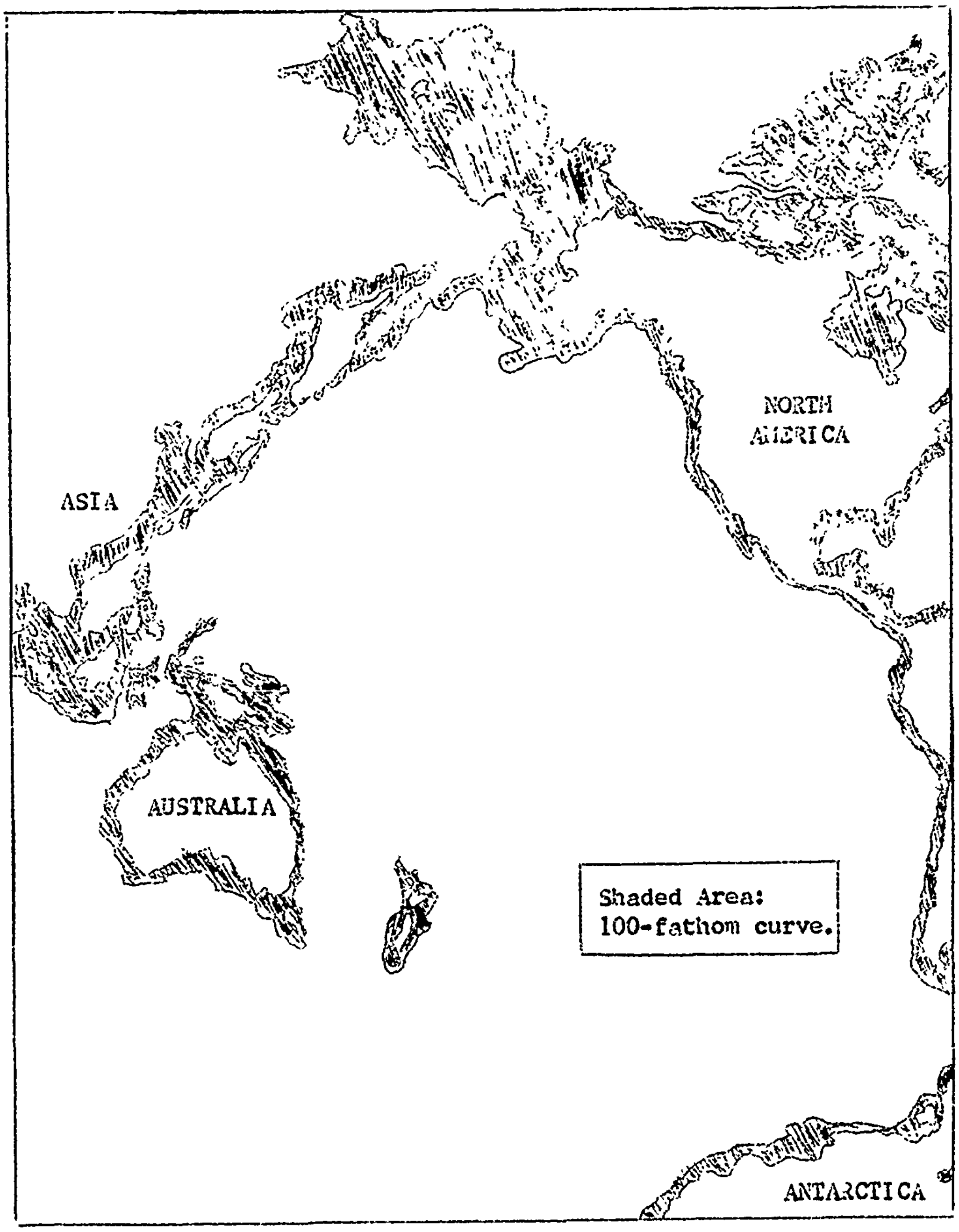


Fig. 2.1. Worldwide 100-fathom Depth Curve.

Refs. 2.1, 2.2, 2.4.

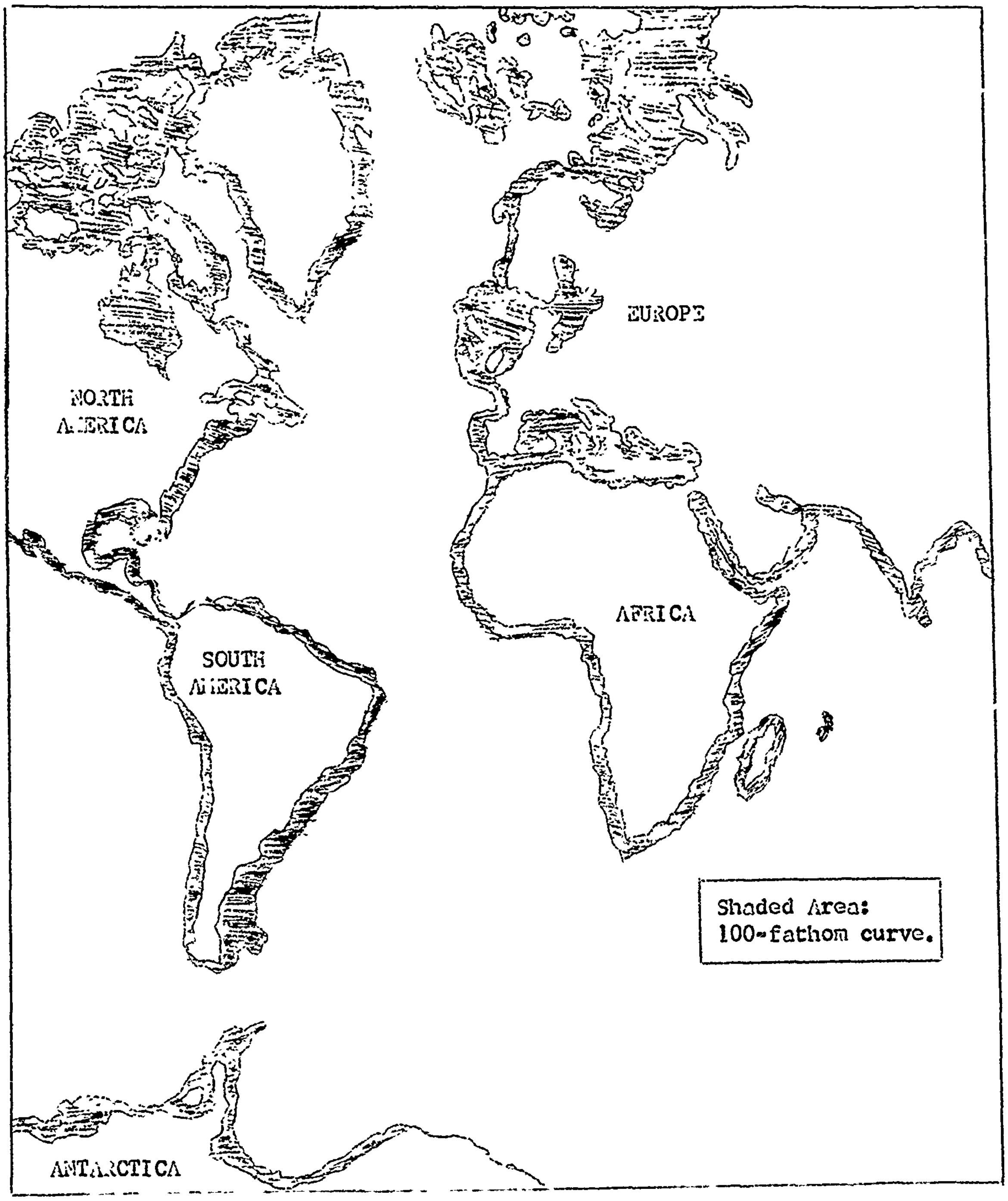


Fig. 2.2. Worldwide 100-fathom Depth Curve (concluded).

Refs. 2.1, 2.2, 2.4.

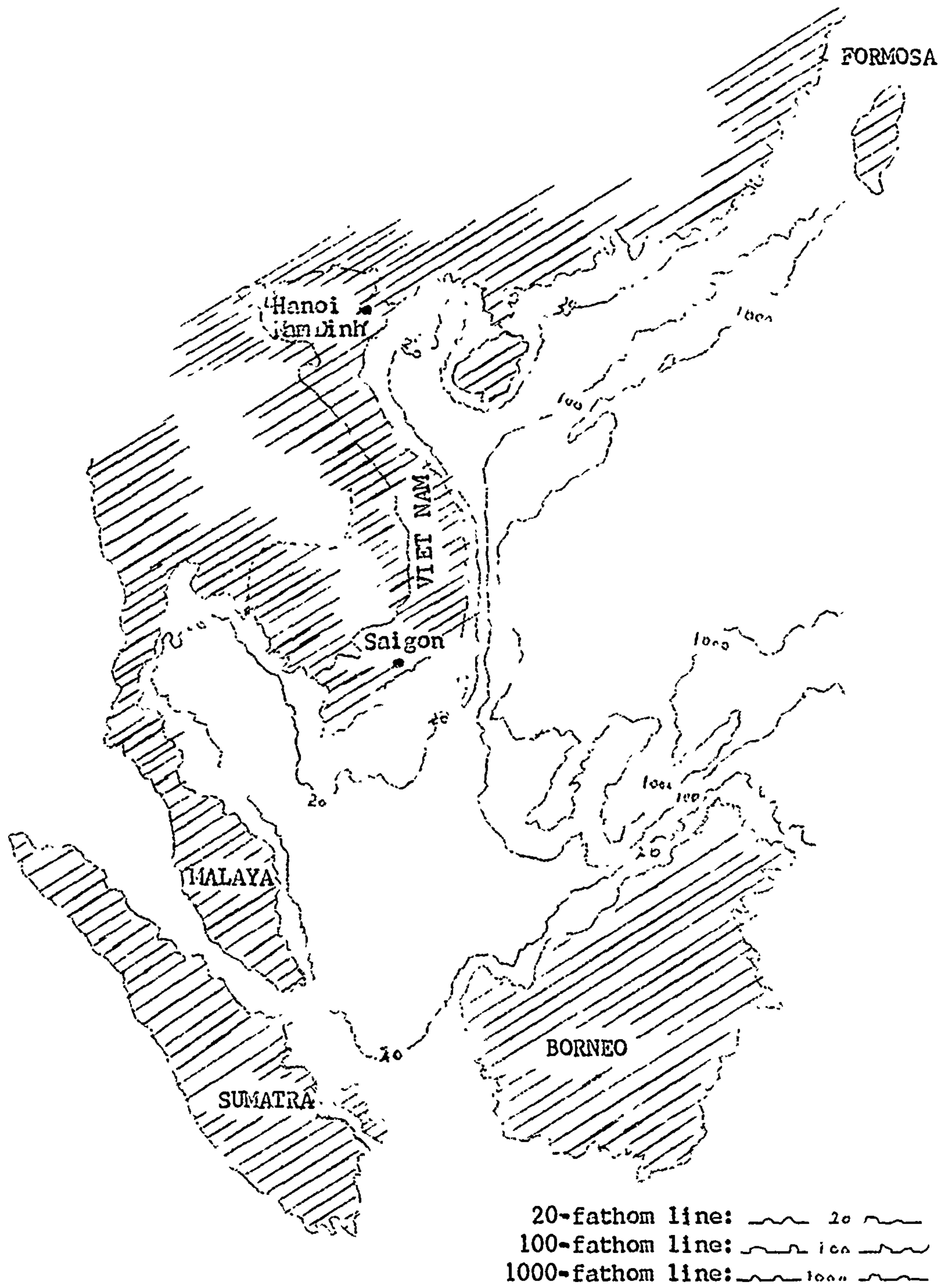


Fig. 2.3. Shallow Water Contours - Southeast Asia.

Refs. 2.1 & 2.2.

support of U. S. Forces and policy for an extended period of time. If future extenuating political or military crises require Naval operations deep in the China seas, then most all of the Naval arena in this area will be comprised of waters whose depths are less than 600 feet.

The Gulfs of Tonkin and Siam contain extensive stretches of very shallow water, some stretches less than 10 fathoms, that may extend as far as 25 nautical miles from the shore. (See Fig. 2.4 for a relative depth profile.) Over much of its shallow water area, the South China Sea is between 20 and 40 fathoms deep.

Indonesia is south of the China Sea, but readily accessible to it. Formosa does not border on the South China Sea, but access to Formosa from the west creates a shallow water problem. The Straits of Formosa (which are roughly 100 nautical miles wide and separate Formosa from the Communist-held mainland) are less than 100 fathoms deep. On the other side, the 100 fathom contour lays just to the east of this island nation.

Other areas, such as the Eastern Mediterranean, Persian Gulf, Red Sea, Baltic Sea, North Sea, Bering and Chukchi Seas, the Continental Shelf off North and South America, are all of current or future importance to the Operating Forces; but currently their defense does not bear so directly on present and maybe future operations <u>EXCEPT THAT</u>---and this should be emphasized---much of the <u>submarine training</u> today is carried out in shallow water, even our own. U. S. submarines in SUBDEV GROUP TWO out of New London, Connecticut, Soviet submarines in the Baltic, Barents, Black and White Seas, CHICOMS in the East China and Yellow Seas, and Indonesia in the Java Sea are all receiving shallow water operational experience. However, it is almost a research problem in itself just to obtain ASW Fleet exercise results, or ORE's carried out in shallow water. Either the ASW Forces in the past have had only very limited shallow water experience or the operational results have not been documented. Perhaps this lack of experience is being improved, however, with some of the recent exercises, e.g., The Plumbob Exercise of October 65 conducted in the general area off Block Island by Atlantic ASW Forces.

Fig. 2.4 shows an accumulative cross section percentage of some of the shallow water areas of the world. These curves indicate how shallow some of the shallow water areas are, and one might rightfully ask: "Can there really be an ASW problem in waters this shallow?" (i.e., "With waters only 100 feet or so over the submarine sail when bottomed, will the submarine missions require them to operate under such

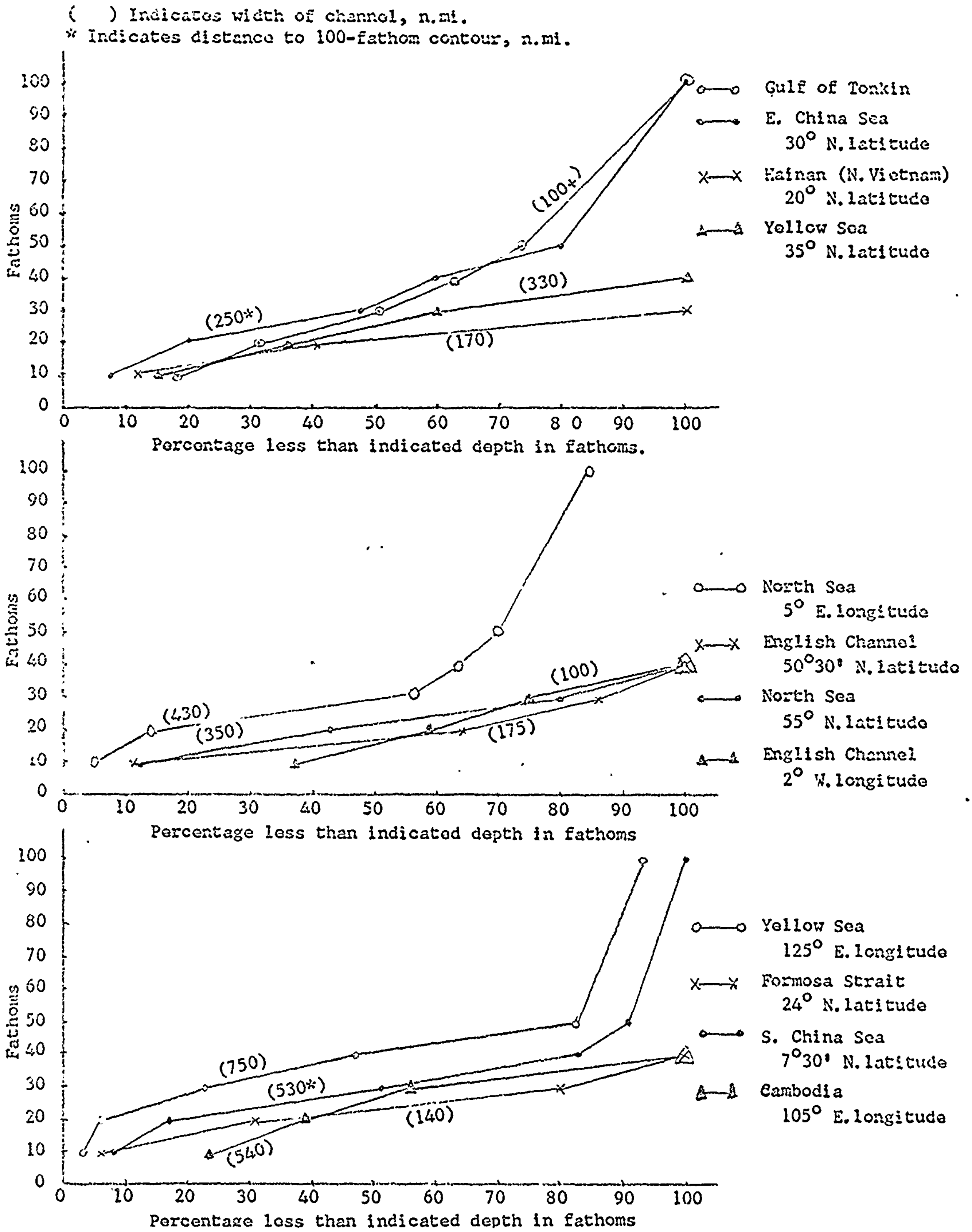


Fig. 2.4. Cumulative Water-Depth Distribution For Selected Worldwide Areas.

Ref. 2.1 & 2.4.

an environment?") This study is not in a position to answer that question; but for the time being the following historical data, which was developed by the Fleet ASW School, San Diego, California, whould be sufficient to create more than casual concern for potential ASW problems in shallow water:

IN WORLD WAR II

1. Every British battleship, fleet carrier, or cruiser sunk or damaged by submarine action was sunk or damaged <u>in shallow or inshore water</u>

2. Every German warship, cruiser size or greater, sunk or damaged by submarine action was sunk or damaged <u>in shallow or inshore water</u>

3. Every German warship torpedoed by Soviet submarines was torpedoed <u>in shallow or inshore</u> water

4. Every Italian surface warship sunk or damaged by submarine action was sunk or damaged <u>in shallow or inshore water</u>

5. Every Soviet warship sunk by submarine action was sunk <u>in shallow or inshore water</u>

6. Every British submarine sunk by enemy action was sunk <u>in shallow or inshore water</u>

Table 2.1 gives the relative shallow water areas for most of the world in sq. n. miles. The significance of these areas is not in their size, but in their geographical importance in current world conflicts.

Much of the shallow water environmental data, like most other ocean environmental data, is still very limited. Although Ref. 2.1 states, "The bottom composition of the South Sea is predominantly mud in the east (with numerous coral reefs and sea mounts), sand in the central section, and mud in the western section (Fig. 2.5), and the Straits of Formosa are primarily sand, with a small strip of mud near the island," as is shown in Fig. 2.5, <u>these conclusions are all drawn from a relatively limited sampling of the bottom</u>. For an example of how limited the accessible data is, note the legend at the top of Fig. 2.6, Ref. 2.2. Here they note data for bottom composition from fewer than 1° quadrangles, indicating the scarceness of this type of data. Even were this amount of data considered applicable for ASW, it would still be suspect for tactical ASW operations---not because of inaccuracies in Ref. 2.2, but

Area	Area < 100 Fathoms, sq.n.mi.	< 100 Fathoms, %*a	Cumulative water depths, %	
			50*b	20*c
SOUTHEAST ASIA				
Gulf of Thailand	350,000	100	92	29
Gulf of Tonkin	158,000	100	77	34
Taiwan Strait	167,000	100	78	26
Borneo	495,000	90	94	35
EAST ASIA				
Yellow & East China Seas	232,000	100	86	41
Sea of Japan & Tartar Stait	75,700	85	64	26
Sea of Okhotsk	101,000	25	39	18
NORTHEAST ASIA				
Bering Sea	309,600	40	58	26
Bering Strait	9,000	100	100	40
Chukchi & East Siberian Sea	162,000	100	100	26
NORTHWEST EUROPE				
North Sea & adjacent area	190,800	82	60	28
Baltic Sea	176,400	99.9	70	46

* a Percentage of total area considered that is < 100 fathoms.
* b Percentage of area of < 100 fathoms that is < 50 fathoms.
* c Percentage of area of < 100 fathoms that is < 20 fathoms.

Table 2.1. Distribution of Some Selected Shallow Water Areas.

Ref. 2.1
2.2
2.4

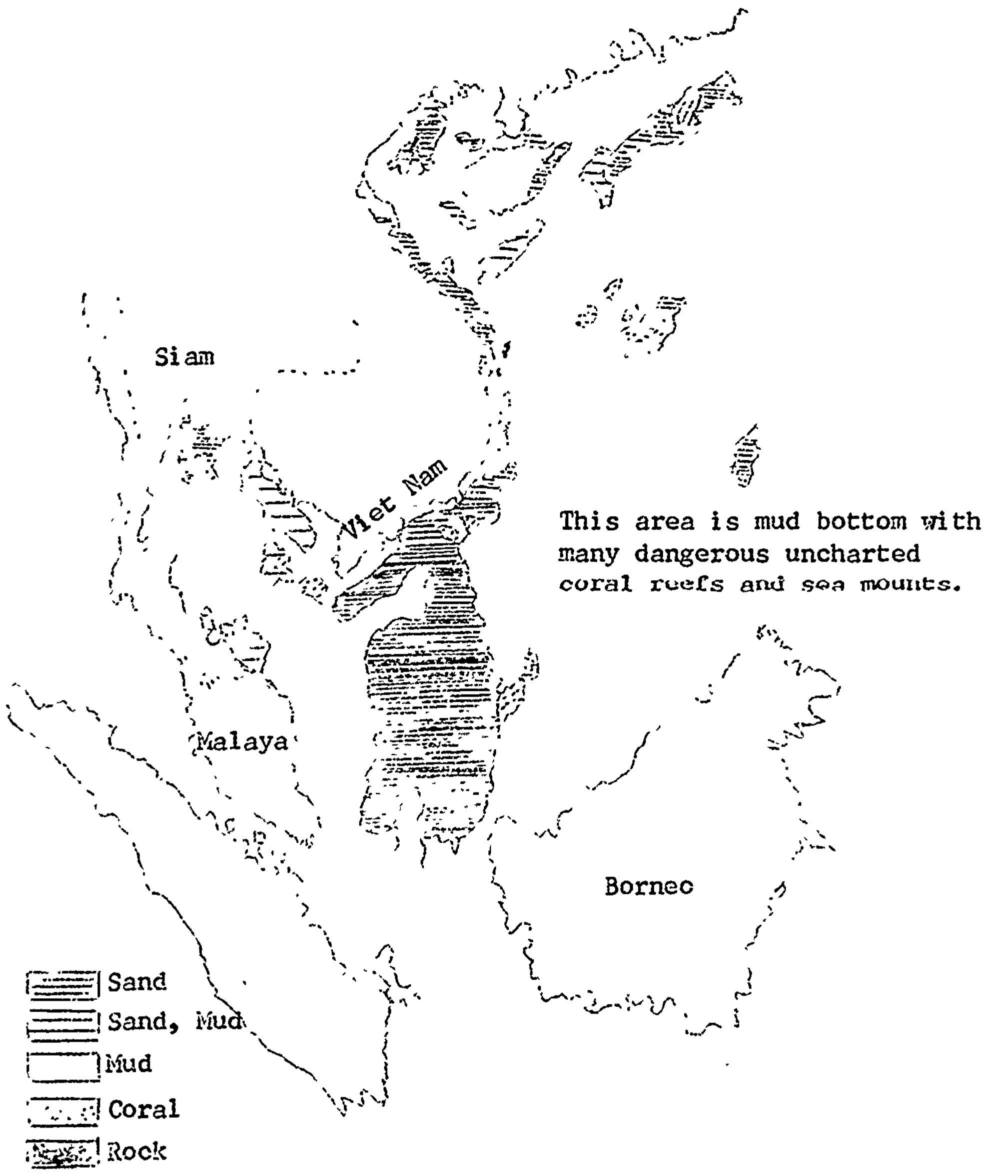


Fig. 2.5. Bottom Sediments of the South China Sea.

Refs. 2.1 & 2.2.

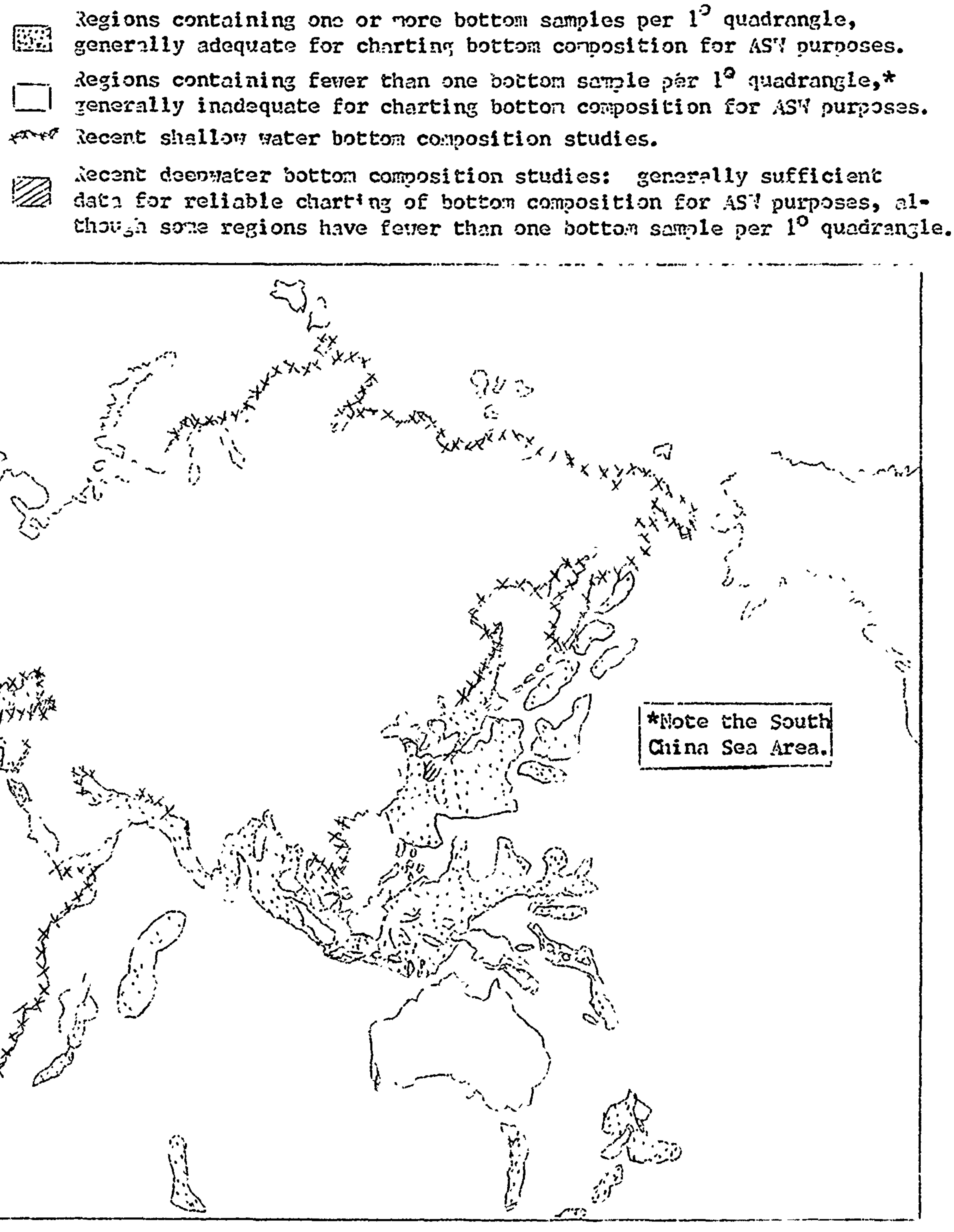


Fig. 2.6. Limited Distribution of Available Bottom Composition Data.

Ref. 2.2.

because average values of environmental data for ASW planning for which this data was developed and the environmental data requirements for tactical ASW operations are not at all compatible. The reference to the limited data on Fig. 2.6 is directed to planning. Under tactical operations, the accuracy of environmental data and the need for fine-grid surveys in the immediate operating area is much more important than for overall ASW planning where averages are satisfactory.

The future potential of a shallow water bottomed-submarine as an Advanced Sea Based Deterrence was considered in Project Sea Bed which has developed an interesting areal comparison for bottom-sitters. The Oceanography Sub-Panel Report (Ref. 2.3) presented possible bottom operational areas by 5° squares for particular ocean area environments. The particular increase in area is compared with increased operating depth capabilities (Fig. 2.7). For all the depth areas shown, a bottom operating capability of only 100 fathoms indicates the largest percentage gain in operating areas for any bottomed-submarine operating depths considered. Furthermore, it points out how much area there is at 100 fathoms or less, relative to going much deeper, on which to use bottom-sitters and indicates what greater depths are necessary to obtain comparable areas. i.e., if there is to be a bottomed submarine or ASBD enemy on the bottom, he has extensive areas in which to hide at 100 fathoms or less. And the capabilities for a bottom-hovering submarine far exceeds 100 fathoms today. Although these areas considered were for particular ocean areas of concern to Project Sea Bed in the ASBD Study, at the same time the shallow water potential for hiding the submarine by sitting on the bottom is indeed a problem for all ASW; and these areas chosen by Ref. 2.3 are just as likely as any other area to require shallow water ASW operations in the future.

2.3 Environmental Factors. Environmental properties are of importance in all of ASW; but those which take on added signicance in shallow water ASW, and which in turn affect the command and control of the ASW forces, are:

1. Gross bathymetry
2. Small and large scale bottom roughness and bottom slope
3. Sound propagation characteristics
4. Background noise
5. False targets (acoustic and magnetic)
6. Currents
7. Bottom material
8. Salinity

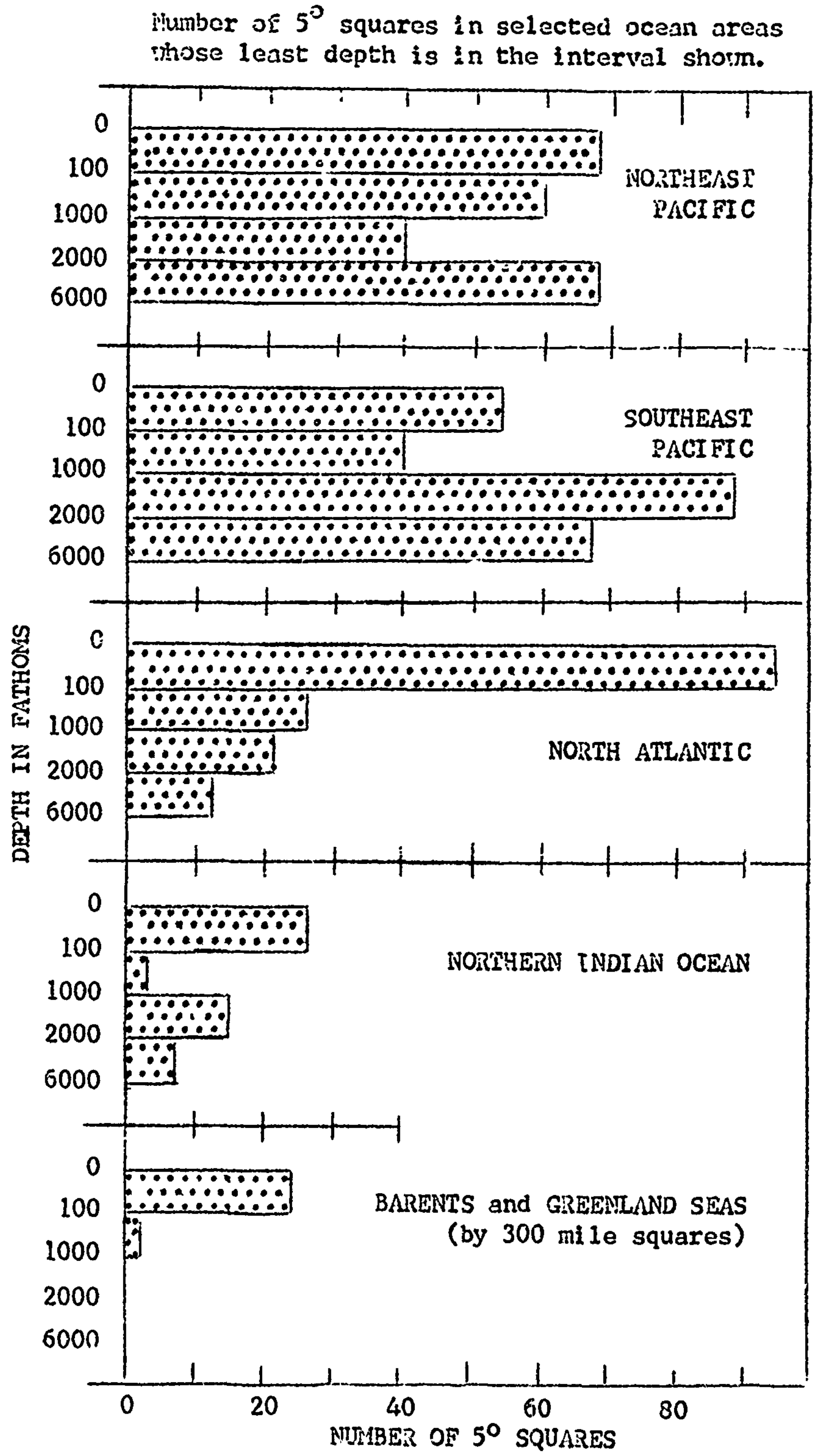


Fig. 2.7. Relative Bottom Area With Depth For Selected Ocean Areas.

Ref. 2.3.

Each of these aspects of the physical environment directly affect the application of underwater sound to sonar detection systems and are manifested in acoustical absorption, scattering, reverberation, reflection, and refraction. Theoretically, one of the essential differences between shallow and deep water sound transmission is the interference effects produced by multiple reflected transmission paths. These interference effects are largely dependent on water depth, physical characteristics of the sea surface, and bottom and sound velocity structure.

Shallow water bottom composition (and its associated degree of roughness) control, to a large extent, the reflective capabilities of the bottom, the attenuation of sound, and the degree of reverberation that contributes to the masking of target echoes. In contrast to deep-sea sediments, which are thought to be mostly mud and ooze, the sediment types in shallow water are diverse with considerable spatial variations. Areas of mud, mud sand, sand, gravel, rock, or coral are not uncommon over shelf regions.

All ASW information received via sonar systems is directly degraded because of the environment. Any improvement in detailed knowledge of the immediate environment can improve predicted sonar range and sonar operation, including high frequency torpedo systems which in turn will improve the command and control of ASW forces. Detection range, track and localization, weapon choice, launch, and fire control are all directly affected by the environment, as also is classification of targets. This is especially so for bottomed targets.

Sound propagation is highly variable in shallow water, not only from sea to sea or region to region, but also from day to day. Under all but a few circumstances, shallow water propagation does not appear to be as effective as propagation in the deep sea. In some shallow seas (South China Sea, for example) regions of the bottom are littered with water logged trees, rattan, and nipa. In others, coral heads and reefs, boulder piles, and sedimentary hummocks contribute to the small scale roughness. Other areas may be similar to the Gulf of Bothnia (adjacent Sweden), for example, with regions piled with great glacial boulders. Bottom hiding in shallow seas undoubtedly could be very effective in this and other similar regions.

In many cases the accessibility to any ASW craft (surface or submerged) could be extremely limited. Areas such as the Grecian Archipelago, Bligh Water in the Fiji, the Australian barrier reef, the Windward Island Chain of Hawaii, and the uncharted waters of the South China Sea, etc., are so complex that they constitute a vast series of mazes. Whereas an ASBD vehicle or some other submarine-type launching cruise missiles needs only a few entries to hide, an ASW vehicle if used to search and harrass must explore an impossible number of difficult and uncharted passes. (This has not received attention in this study and is only mentioned here as another of the many potential future shallow water ASW problems.)

The environmental data contained in this section is anything but new. It is data available from several sources and is presented here to develop some background for the reader. Hopefully as the reader completes this report, he will be made aware of the effect ignorance of the environment can have upon successful ASW operation, and particularly so in shallow water.

This is not an environmental assessment study in the broad sense of seeking explicit details for improving sonar operations. However, ASW vehicle screen-spacing, relative navigation and station-keeping, and accurate and effective weapon decisions are all dependent upon sonar operations in shallow water; and in shallow water these sonar operations are extremely susceptible to the variable acoustical environment.

3. TACTICAL COMMAND AND CONTROL REQUIREMENTS

In this section some of the general tactical command and control requirements usually stated for deep water ASW are reiterated, along with possible variations of these requirements when ASW forces are operating in shallow water.

The command and control requirment to improve ESR prediction in shallow water ASW is one of the basic ASW needs today, and is so expressed in this section as a fundamental requirement. Section 3 makes very evident the real need for command and control data processing on board ship to help provide an improvement in predicting ESR. It further presents specific ASWFORPAC correspondence which indicates the need for improved ESR prediction and also briefly indicates a few approaches for improving ESR prediction by developing shipboard ESR prediction models with automatic data processing. The second part of this section reviews the available sonar equations and parameters which have a direct bearing on predicting the effective sonar range.

3.1 Extending ASW Tactical Command and Control Requirements. Certainly many of the ASW command and control requirements in shallow water are similar to those in deep water, and these have been recognized. BUT: detection ranges, weapon ranges, standoff-weapons, convoy protection, screening tactics, and classification requirements are not identical. Detection ranges are less, and especially so with steep negative velocity gradients, refracting much of the acoustic sonar energy to the bottom. Advantages of weapon ranges possible with ASROC and SUBROC are difficult to achieve in shallow water since the associated detection range and weapon range are limited. Active torpedoes are easily bottom or surface captured, and spurious bounddry trips interfere with torpedo performance, depending upon refraction conditions, sea state, and depth.

Convoy and other forces under ASW protection have little opportunity to alter course for submarine evasion since in general when in shallow water, approach to the terminal point is near in both distance and time, and altering navigation and course plans could produce severe penalties. Therefore, in shallow water the target must be attacked and killed, not evaded. Furthermore, general shallow water operations are not a one-time-through-the-area procedure; forces other than those of the OTC will be coming in to land or to use the same port facilities, and the submarine threat must be nullified.

Screening tactics must account for the limited sonar detection ranges. Sortie and entry screen/search phase prior to entry or departure of the main body are peculiar to shallow water operations only. Classification in shallow water has no leeway. The target must be classified and destroyed (if a submarine) in shallow water. i.e., The contact cannot be avoided, as other forces will probably be transitting the same area; and the classification must be made soon unless unlimited ordnance is available to kill all suspects.

Classification of false targets from bottom returns and wrecks can cause more severe problems, especially so with new, potentially long-range SQS-26 sonar systems. The relative accuracy of navigation systems to provide confidence that the target detected is a known false target at that point may be found wanting.

Last but not least in a real shooting war, when an underwater explosion occurs in shallow water, the question, "Was it a mine or a torpedo?" must be answered, and quickly. In deep water this problem is not so much in evidence since mines are generally not so probable as in shallow water and inshore areas.

The one distinct command and control requirement that has not been recognized is the need for predicting ESR. It is not apparent that command and control technology is aware of the need to improve the capability of the responsible commander to perform the function of designating screen spacing and other ASW functions that are directly related to ESR prediction. It appears that maybe Tactical Command and Control Requirements/Technology have deemed it not important, ignored it, or have accidentally overlooked it from the interpretation of current tactical command and control requirements for ASW Ship Command and Control System, as designated in TDP-SS31-01, 1 April 1965, "ASW Ship Command and Control System." The following is quoted directly from the above TDP:

Page 4.4. Operational Requirements: "----To counter this threat, the Navy will continue to make use of the ASW team approach (surface ships, aircraft, and submarines) to detect, localize, classify, and kill. The specific requirement is for effective command and control of tactical ASW teams and delivery of weapons against Soviet nuclear* submarines.

*The nuclear submarine is not considered the primary enemy submarine in shallow water ASW. The word "nuclear" may be the key word here and could be a prime reason why Tactical Command and Control has not addressed the shallow water ASW problem in concert with the deep water ASW requirements.

"The need under this requirement is, in brief, to develop an ASW ship command and control system that is capable of collecting, processing, evaluating, and exchanging data rapidly and accurately for effective delivery of weapons."

Collect---process---evaluate---and exchange, yes. These are all shallow water requirements. But it is not evident from the above or elsewhere that the aforementioned TDP indicates, or even suggests, the possible need for command and control facilities to assist in the prediction of the ESR to improve the command and control of ASW forces in either deep or shallow water.

It would appear that the ESR prediction methods and improvements in use in the Fleet today have received minimal if any attention in the development of Command and Control Requirements for deep-water ASW operations, and none for shallow water or inshore operations.

The ASW surface forces are currently limited to NAVSHIPS 900,196, "Manual for Estimating Echo Range," March 1959, and a more recent acoustic ray path plotting method which applies tables and plastic overlays to trace out the limiting rays (The KEY WEST TEST & DEVELOPMENT DETACHMENT Ray Path Method). From Fleet reports, neither method is satisfactory; both give only gross predictions; neither is automated; and NEITHER WAS EVER INTENDED TO PREDICT SHALLOW WATER ESR.

The problems in shallow water ESR prediction when referred to in-layer targets may be somewhat similar to those in deep water in that both are sensitive to environmental variations affecting in-layer propagation and detection. However, shallow water environmental variations of temperature (particularly negative gradients), bottom losses, and salinity in both space and time which affect sonar conditions are much more noticeable. There are no current shipboard manuals, charts, or techniques available to the Fleet today developed for shallow water ESR prediction.

3.2 The Need for Improved ESR Prediction. One of the fundamental parameters in ASW operational doctrine for surface ship spacing in screening, search, and attack is the Effective Sonar Range (ESR) which determines ASW screen spacing, pouncer positions, picket positions, and search and attack procedures carried out by Search and Attack Units (SAU). This is readily recognized in reading Section One, "Tactical Command of ASW Forces," and is in general an accepted tenent of ASW operational procedures. It is the responsibility of the OTC or the Screen Commander to station the ASW screen, and, from a thorough understanding of the ESR in the immediate area and time, to determine the basic screen geometry.

The resulting decisions for a particular screen or search tactics are, of course, constrained by the mission, the number of screening ships available, and the expected enemy submarine, weapon, and forces; however, the OTC or screen commander has no control over these, so he utilizes the ships made available and relies upon his received ASW intelligence data. But he alone is directly responsible for the ESR predictions which he determines and which should be made on all of the information available, i.e., the different sonar systems aboard each assigned screen member and its state of readiness, and the environment in the immediate operating area.

At present there are no shipboard devices, curves, charts, tables, or even qualitative estimates purposefully designed for shallow water sonar range prediction applicable for hull-mounted sonars operating in surface screens in pouncer or picket positions.

ESR prediction is dependent almost completely upon the sonar parameters and sonar equations in one form or another. Sonar parameters are all statistical parameters, some with much larger standard deviation than others. All are instrumental in affecting the predicted sonar detection range; and likewise, most all are affected directly or indirectly by the ocean environment.

From the discussions and relatively simple mathematical approach given in Section 3.3, it would appear straightforward to predict the expected performance of present and future designed sonar systems in Fleet operations. However, unless the definition of performance prediction is assessed from a qualitative rather than in a quantitative perspective, the prediction of hull sonar system performance (except under special circumstances) still needs considerable improvement between what is experienced in Fleet operations and exercises and what is predicted with current ESR prediction schemes aboard ship. From the following evidence extracted from Fleet correspondence, only predicted detection ranges for in-layer targets with current detection range prediction techniques are considered acceptable by the Fleet, and then only for average sea states, deep water, and with good, frequent temperature measurements for estimating refraction effects and channel definition (layer depth). The standard prediction techniques applied are based on the sonar equations and parameters presented in the following sections. The propagation losses (N_W) are usually computed using AMOS data (Ref. 3.1) or prediction techniques predicted on AMOS data, and then the results are for noise-limited conditions only. NAVSHIPS 900,196 (Manual for Estimating Echo Range) is an example of what is available in the Fleet today which applies directly to predicting range for in-layer targets; however these tables and this technique leave much to be desired, and especially so for below-layer targets.

An indication of the need to improve ESR prediction can be recognized in the following extracts from ASW Fleet reports and letters. From First Fleet ASW Board Meeting No. Seven, FG3/ASW GRU 3/442, 5050, Ser. 0198, August 1964:

Agenda Item 8 states:

"A requirement exists for a better means of predicting sonar performance." Methods considered by the committee indicated that ray path plotting techniques provide more accurate sonar performance predictions (relative to NAVSHIPS 900,196). ---"Since a variety of methods for ray path plotting exist, the committee recommended assigning the Fleet ASW School in San Diego the task of examining and determining for Commander First Fleet the best method of ray path plotting to be adopted by the Fleet." *

And: From Seventh Fleet ASW Board Meeting No. 10, 10 November 1964:

Under Item 19: "Most ASW Units do not have an accurate means of determining expected sonar ranges for either hull-mounted or VDS. The Board concurred with the First Fleet Board that a need exists to determine the best method to apply ray plotting techniques to the operational conditions and that the Fleet ASW School in San Diego is the best equipped to research and evaluate existing methods for Fleet use."

Also: In ASW GROUP CHARLIE Report of Progress, 2 September 1963 - 1 November 1964, on p. 22 (C) under "Best Depth Range Determination", (meaning the best ESR prediction for a submarine below the layer at the best depth to avoid detection) COMCRUDES Flotilla Two discusses a ray tracing procedure for determining best range depth (the best depth for a submarine below a layer to avoid detection) because, as it stated there, NAVSHIPS 900,196 was considered too restrictive for determining the ESR for below layer targets.

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* The current efforts at the Fleet ASW School in San Diego are directed toward developing Tactical Range Prediction (ESR) and are discussed in Section 3.51. ESR is used interchangeably here with Tactical Range Prediction.

One of these restrictions in NAVSHIPS 900,196 is that the method predicts a maximum range of (n) yards for any particular sonar system regardless of layer depth (20 to 400 ft.), "COMCRUDES Flotilla Two is utilizing a new procedure for determining the best depth range because NAVSHIPS 900,196 is considered too restrictive. The NAVSHIPS 900,196 method predicts a maximum range of 1800 yards regardless of layer depth." The experience of ASW GROUP CHARLIE has shown that, dependent on layer depth and gradient conditions, best depth ranges greater than 1800 yards can be realized, and <u>operations at sea</u> under all sonar conditions <u>to determine</u> the best depth range is more realistic than the NAVSHIPS method. The procedure employs a table depicting the distance from transducer to bounce point in kyds. The table was developed by NavOceanographic Office for THE KEY WEST TEST and EVALUATION DETACHMENT, Ray Path Method. (A method using plastic overlays for ray tracing).

Also: From ASWFORPAC TACNOTE 4-65 (in preparation) comes:

"NAVSHIPS 900,196 is pessimistic under low sea states, is optimistic under high sea states, and is good between sea states 2 and 3." (The reference here is to in-layer targets.)

The requirement for tactical range prediction (ESR) affirmed in these quotations is in the context of relatively deep water where the environment is much more stable and where much, if not most, of the available art and knowledge of present sonar operations has been acquired. (This study is not aware of any shipboard sonars under development for shallow water.) As is well recognized, deep water is where the main submarine threat (SLBM) is believed to exist and where much of our R&D effort has gone. However, whether or not many of the deep water ASW developments are applicable in shallow water ASW will require much more experience than is evident to date.

3.21 <u>Possible Solution to ESR Prediction in Shallow Water</u>. Depending upon different conceptual requirements for prediction range and accuracies, there are available today possible solutions to improve ESR prediction in shallow water. These methods may require much more real time environmental data than is now being collected by the ASW forces in tactical exercises. They may require automation that is not deemed necessary nor developed today; they may require that sonar parameters (propagation loss, noise level, reverberation level) be measured in situ and used in real time with acceptable prediction models; and furthermore, they may require a better understanding of the overall acoustic field in shallow water. i.e., To improve or develop useful ESR prediction techniques and methods for Fleet operations in shallow water may require more fundamental knowledge about the effects environment has on sonar parameters, particularly propagation loss and reverberation, if we expect to predict long ranges under adverse conditions. But---models are available to make a feasibility assessment today and techniques are available to make the necessary measurements to determine bare minimum requirements for developing an acceptable shallow water tactical range prediction system.

The bare minimum might be to measure the reverberation level and propagation loss continually during any exercise. With these two parameters, the area to search where the most probable success would occur could possibly be developed. i.e., If the echo to reverberation level has a maximum at some range (r), then by measuring these two parameters, the most likely range to detect a submarine could be estimated. If so, this surely is an assist. Also, when knowing the sonar system is reverberation limited (by measuring reverberation level along with noise level) the decision to increase speed or search rate until self-noise and reverberation level were comparable would at least improve the effective area searched in patrol screens.

Shallow water detection range prediction techniques are available; but most, if not all, models are mathematically complicated and require computing equipment, sonar parameter data, and technical skills that normally are not available nor scheduled for the immediate future on-board ship. These models have not received the same acceptance or usage in sonar system studies as the techniques that apply to deep water have, nor is any direct effort to develop or utilize them in fulfilling the present requirement for estimating ESR's in shallow water in evidence. Surface duct ESR predictions which apply equally well in deep and in some shallow water environmental areas are probably the best and only meaningful comparison where attention to ESR prediction for the Fleet in deep water is directly applicable to shallow water.

Below-layer targets, more difficult to detect in deep water, could be easier to detect in shallow water where sound energy scattered and bounced from the bottom can possibly insonify the would-be hiding areas in deep water. Targets so insonified can in turn re-radiate back to the receiver via the several potential propagation paths available.

3.3 The Necessary Sonar Equations and Parameters in Predicting ESR. The necessary detail to present or eliminate when providing background in a particular subject that is well understood by many and yet not understood at all by some has no exact solution. The eight parts of "Summary of Underwater Acoustic Data (SAD)" published by ONR, 1953 through 1956, contains in excess of 400 pages of single-spaced, highly technical data, curves, and charts which in itself represents an attempt to reduce the voluminous literature on underwater acoustics to a minimum for a comprehensive review of the overall field. To do more than point to the basic sonar parameters and how these parameters are estimated, guessed at or deduced, and applied in shallow water ASW operations as done in this section would require another level of effort and would not add measurably to the understanding of ASW Command and Control Requirements.*

The application of sonar systems in ASW operations are described by the sonar equations. The sonar equations describe the passive systems (those that listen only to the incoming noise from a self-generating noise source or target) and the active systems (those which depend upon a generated out-going signal to insonify the target and listen for the signal return, or echo). Some systems are designed to operate in either mode.**

For the convenience of being able to add or subtract variables in the sonar equations, rather than multiply or divide, those variables describing sonar equations are usually written in terms of a dimensionless logrithmic unit to the base 10.

3.31 The Passive Sonar System may be described as follows:

$$L_p = L_S - N_W \qquad (1)$$

which states the following:

Signal Level Received = Noise Level of Target - One-way

Transmission Loss.

* There are several tutorial references; among these are: Horton, "Fundamentals of Sonar" (U.S. Naval Institute); Officer, "Introduction to the Theory of Sound Transmission" (McGraw-Hill); Albers, "Underwater Acoustics Handbook" (Pennsylvania State University); the classified SAD reports mentioned above; and the "Journals of Underwater Acoustic Data" (ONR, Code 468).

** The SQS-26 operates in the passive mode at all times and also contains passive signal processing and data display. (Ref. 3.2).

If the signal received is masked by the ambient noise, some signal improvement is obtained by designing the system to listen in preferred directions. This is done by designing the transducer to discriminate against incoming noise in all directions except over a narrow beam in the particular desired direction; this is the Directivity Index (N_{DI}). Also by signal processing,* the relative amplitude, phase, and direction of the received signal may be improved. The transducer voltage is processed like any other voltage signal and is referred to as a system or processing gain (G). When these two methods of signal enhancement are included, the original equation becomes:

$$L_P - L_N = L_S - N_W + N_{DI} + G - L_N \qquad (2)$$

L is the level of the incoming passive signal. The difference between the received signal and the noise level is expressed as the signal to the noise ratio. The magnitude of ($L_P - L_N$) in db is the signal to noise ratio. Here the decibel notation ($L_P - L_N$) is used instead of the linear ratio S/N.

In general the value of ($L_P - L_N$), which will permit the detection for a particular receiving equipment display and sonar operator 50% of the time, is used as a starting point to discuss the operation of the sonar system; and any increase in the ($L_P - L_N$) over the designated value will be termed "signal excess". The passive signal received (L_P) is over a designated bandwidth of the target submarine spectrum; and when numerical computations are the point in question, L_P and L_N (both functions of frequency and measured in pressure/unit bandwidth) are assessed in the same bandwidth. That is to say, "Just where is the system listening in the submarine target spectrum, and what is the level of the unwanted noise over the same frequency range?"

3.32 The Active Sonar System necessitates a more detailed description than the passive system. This is due to the effects of introducing an active source to generate the acoustical signal which is returned to the receiver as an echo from the submarine target. It therefore becomes necessary to add to the description of the sonar system the source strength, its frequency and amplitude, the two-way propagation loss out to the target and back rather than the one-way loss used for the passive system, the target strength of the reflecting submarine,

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* The SQS-26 is a hull-mounted system that uses signal processing (Ref. 3.2).

and an increase in unwanted noise generated with the active sound source, referred to as reverberation. The negative effects of reverberation in shallow water substantially degrade the sonar system; as such, they are so significant in limiting ASW sonar operations that they are discussed separately in Sections 3.324 and 3.325.

3.321 Noise Limited Case. The active sonar system for the noise limited case is described by the following sonar equation:

$$L_e - L_N = L_{Sa} - 2N_W + N_{DI} + G + N_{TS} - L_N \qquad (3)$$

where:

$L_e - L_N$ = Echo Level - Noise Level

L_e = Echo Level (db re: 1 μbar)

L_{Sa} = Active Source Amplitude (average ping level, db re: 1 μbar, 1 yd from the source)*

N_W = One-way Propagation Loss, db (includes spreading losses, absorption loss as a function of frequency, and bottom and surface losses as a function of frequency and angle of incidence (angle between the generalized sound propagation direction assumed and the surface or bottom).

N_{DI} = Directivity Index, db (measure of the transducer effectiveness to discriminate against non-directional noise and to transmit and receive in a particular narrow beam)

G = System Signal Processing Gain, db.

N_{TS} = Target strength, db, a ratio of the sound intensity reflected from the submarine to the incident sound intensity - (measured at relative large distance from the submarine). The ratio is greater than 1 for a submarine and is usually measured between 10 and 25 db, dependent upon the target aspect angle.

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* If there is a need to interpret underwater acoustic pressures referred to 0.0002 dyne/cm^2, which is the standard reference pressure level used in air, it is only necessary to increase the db level referred to 1 μbar by the ratio of 20 log $\frac{10^{+4}}{2}$, or 74 db. This reference level was used recently in Ref. 3.3.

L_N = Noise Level around the hydrophone receiver. It includes sea state noise, biological noise, machinery noise, electrical noise, and self-noise due to platform speed. Self-noise is usually the dominating noise background above 15 kts. (in db re: 1 μbar/unit bandwidth)

L_R = Noise Level from Reverberation, which is the energy scattered back from the sea surface, sea bottom and scatters such as air bubbles, debris, and biological scatters throughout the volume (in db re: 1 μbar/unit bandwidth).

Important differences should be noted between the active and the passive systems. Active systems must contend not only with the ambient and self-noise, but also with reverberations. The echo can be returned from many different scattering objects. For active systems, the information to differentiate between different type echoes and classify targets must come from pulse information while passive systems can and do analyze the target signature spectrum. The spectrum information for classification is relatively limited in the active mode, compared to the continuous broader passive signal spectrum.

3.322 Figure of Merit. Although it is dangerous to generalize, the variables in the sonar equations can be grouped together, hopefully to improve the overall understanding of sonar operations and effectiveness in submarine detection. The effectiveness is defined as the sonar Figure of Merit (FOM). For the active systems, it is a measure of the total reduction in original transmitted signal (pulse amplitude) out to the target and back that can just be detected on its return (i.e., the Source Level minus the Minimum Detectable Level, MDL, in db = FOM.)

The Minimum Detectable Level that can be detected is defined as the signal that, on the average, can just be detected 50% of the time and will be missed 50% of the time for any one single, statistically independent ping and for some average operator. This is defined as the single ping probability and assumes the operator has no a priori target information. Its primary purpose is a "bench mark". It is dependent upon the equipment (aural and video displays), the type of operator, his experience, alertness, etc., and is itself a quantity dependent not only on equipment but also upon personnel, and obviously is a statistical variable.

However, under actual experienced conditions it hardly appears plausible for the information returned in each ping to be statistically independent of each preceding ping (which is the usual assumption when used as above) when in the vicinity of a submarine or when detection is about to occur. This is difficult to evaluate and therefore the definition used here is usually applied.

Related to detection probability is the false alarm rate, recognition differential, and threshold setting. Often only the recognition differential is in evidence when detection probabilities are provided or estimated and the other two parameters are left dangling loosely from the definition. Obviously if one overlooks the many possible false alarms, and if the integration time or look time used to observe the signal is indefinite, there may be no limit of how low the threshold may be set for the definition of detection. And by the same reasoning, if the threshold is set very high, there may be no false alarms yet very few detections (Ref. 3.4).

For the noise limited case, use will be made of the following:

$$L_e - L_N = N_{RD} = \text{Recognition Differential} \quad (4)$$

It states the required value of the echo level relative to the noise level for detection. It is a db level, so defined, that must be equalled or exceeded for detection. The Recognition Differential also is dependent upon means of detecting the signal: video display, aural recognition, doppler gates, and certainly training not unlike a radio operator's conditioning for morse code (which at times has been referred to as "awareness").* Furthermore, it should be recognized that the Recognition Differential for noise-limited detection as explained here and Recognition Differential for reverberation-limited conditions are not necessarily the same.

The Figure of Merit (FOM) as applied above establishes a positive measure of the sonar system. It does so in the following way:

$$\text{FOM} = \text{Source Level} + \text{Directivity Index} + \text{Gain} - \text{Noise Level}. \quad (5)$$

The Source Level, Directivity Index, and Gain are all controlled by the system design while the noise may be ambient noise from the sea, biological noise and wave noise,

* LCDR. Donaldson, RCN, Fleet ASW School, San Diego, California.

hydrodynamic flow noise which increases with forward speed, or noise which is plainly reverberation noise which can and does create such severe recognition problems that it is treated independently. In the first case FOM is well controlled if not completely "locked up" by sonar design. In the second case the sea noise and biological noise are independent of design. Sometimes the FOM is used to describe everything in the sonar equation but the propagation loss (N_W) (Ref. 3.5), e.g.:

$$FOM = 2N_W = L_S + N_{DI} + G + N_{TS} = L_N \qquad (5a)$$

The FOM in (5a) is the same as in (5) except that (5a) includes the target strength (N_{TS}).

3.323 <u>Signal Excess</u>. At other times, under experimental and operational conditions when it is possible to inject a simulated echo signal into the system (Ref. 3.6), the FOM is included when the following form of the sonar equation is used:

$$N^S e = FOM + N_{TS} - 2N_W \qquad (6)$$

Signal Excess = Figure of Merit + Target Strength

- Twice the Propagation Loss.

When this is compared with the sonar equation in (3), note the following:

FOM = the FOM as defined in (5)

$L_e - L_N = N^S e$

$N^S e$ = Signal Excess for noise limited conditions

$L_S a + N_{DI} + G - L_N = FOM$ and

$N_{TS} - 2N_W$ are the same as in (3).

In equation (6) when:

$N^S e = 0$, L_e (the echo level) will be detected 50% of the time, and the single ping detection probability is defined as 0.5. Then it becomes evident that when the signal excess is defined as zero:

$$L_e - L_N - N_{RD} = 0$$

And when the N^Se exceeds zero:

$$L_e - \left(N_{RD} + L_N\right) > 0 \quad \text{or}$$

$N^Se = L_e - N_{RD} - L_N$, is a measure of the excess echo signal level when the resulting echo level exceeds the threshold stated for 0.5 detection probability. It is this signal excess (N^Se) that is manipulated for estimating the detection probability with range in most ESR prediction methods after 50% detection probability range has been defined.

It is interesting to note that when the sonar equation is separated as in (6) above, it groups into the following gross characteristics. On the left-hand side with the echo level, the recognition differential appears which includes the human operator effects in detection; and on the right-hand side, all hardware terms appear in the FOM along with noise background. And the other quantities on the right-hand side, the target strength (N_{TS}) and the environment (the 2-way propagation loss $2N_{W}$) are both independent of sonar design, sonar operators, and ASW operations.

3.324 <u>Reverberation Limited Case.</u> When the sonar system is reverberation-limited, i.e., when the unwanted noise due to reverberation exceeds the other background noises described in the noise-limited case, the actual sonar equations (3) through (6) are not complete in their general description. For reverberation-limited conditions, changes in the general description are required for completeness. The returning echo must be detected in a reverberation background; the Recognition Differential may be different; and since reverberation is directive, the Directivity Index (N_{DI}) for discriminating against a noise background may in general not be the same as the Directivity Index for reverberation.

The following describes the general sonar operations when they are reverberation-limited:

$$L_e - L_R = L_S - 2N_{TS} - L_R \qquad (7)$$

where:

L_R = Reverberation Level

L_e = Echo Level in reverberation background

L_R is somewhat involved, and as such requires even more detail. It is the Reverberation Level. It is the back-scattered sound from the surface, bottom, and volume scatterers which return to the sonar receiver via several paths with enough amplitude to compete with the target echo. The Reverberation Strength is analogous to the Target Strength, and the original source amplitude is the sole source of the reverberation level and is the same source as that for the echo, namely L_{Sa}. The reverberation level, L_R, is also reduced like the echo level by the propagation loss from the source to the area doing the scattering back to the receiver.

3.325 Reverberation Level. Considering only boundry reverberation for now, and in particular, bottom reverberation:

$$L_{RB} = L_S - 2N_W + 10 \log (SA) \quad (8a)$$

$$L_{RB} = L_S - 2N_W + 10 \log (\phi r \frac{c\Delta t}{2}) \quad (8b)$$

where:

A = Area which back-scatters the sound = $\phi r \frac{c\Delta t}{2}$

and

S = scattering strength/unit area

$10 \log M_B$ = bottom scattering coefficient

ϕ = average beam width of the sonar transducer

c = velocity of sound

$\frac{\Delta t}{2}$ = effective pulse length making up the scattering area.*

The sound contributing to the reverberation level is assumed to be returned from the area A with scattering strength S_B. This is shown on Fig. 3.1, which describes the scattering area. Comparing equations (8a) and (8b), note 10 log M_B. 10 log M_B (the bottom scattering coefficient) is defined as follows (Ref. 3.7):

$$10 \log M_B = S_B + 10 \log 2\pi .$$

S_B here is the scattering strength. It is the parameter usually reported in experimental data in the literature, and is reported in (db/yd^2) db per square yard of

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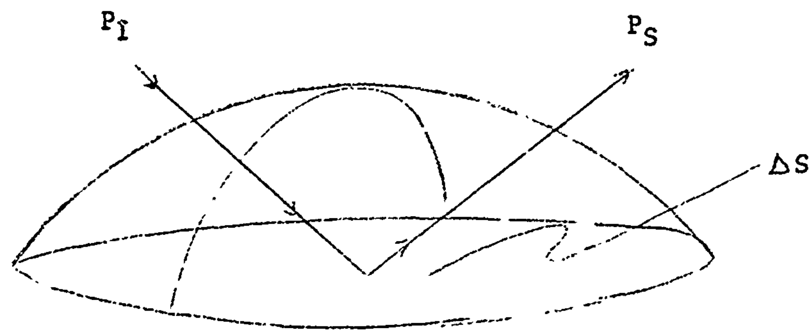
* Ref. 3.5, p.333.

scattering area. It is a function of the average incident angle the acoustic energy makes with the bottom. Most experimental results show much more sensitivity in the measured values of S with angle at relatively small angles in comparison to large angles of incidence. (Refs. 3.8 and 3.9).

The scattering coefficient and scattering strength are described as follows:



$$M_B = \text{ratio of } \frac{\text{scattered sound intensity at any angle over a hemisphere}}{\text{incident sound intensity over an area, } \Delta s}$$

$$= \frac{P_S \, 2\pi}{P_I \, \Delta S}$$

It is the ratio of the sound flux falling on a unit area to the sound flux scattered back over 2π steradians.

The difference between the echo level (L_e) returned from the target and the reverberation level (L_R) due to bottom scattering (echo returned from the bottom) is written as follows:

$$L_e - L_{RB} = L_S - 2N_W + N_{TS} - L_{RB} = \left[N_{TS}\right] + \left[10 \log M_B + 10 \log \phi + 10 \log r + 10 \log \frac{c\Delta t}{2}\right] \quad (9)$$

$\left[10 \log M_B + 10 \log \phi + 10 \log \frac{c\Delta t}{2} + 10 \log r\right]$ is the apparent reverberation target strength at range r coming from the area, $\phi r \frac{c\Delta t}{2}$, with scattering coefficient 10 log M_B.

As evident in (9), the reverberation level is competing with the target strength, N_{TS}.

To discriminate against reverberation in equation (9), the directivity index for the surface reverberation should be included. This would aid in decreasing the reverberation level and increasing the ratio of $L_e - L_{RB}$ needed for detection. It is usually written as J_S, the boundary reverberation directivity index, and is assumed equally effective for either bottom or surface reverberation. The general logrithmic expressions and their development for directivity indices for ordinary geometrical radiators (pistons in infinite baffles, lines, and point source) for both noise and reverberation (volume and boundry, surface or bottom) are given in Ref. 3.7 for very general transducer dimensions.*

Scattering coefficients vary with angle of incidence, measured between the sound beam and the bottom. One simple, interesting, and often used approach in characterizing bottom reverberation in shallow water is the following:

Experimental scattering strengths have been observed to depend upon the scattering angle θ (see Fig. 3.1) where the scattering is assumed to follow a sine law as follows:

$$S = K \sin^n \theta \quad S_B = 10 \log K + n\, 10 \log \sin \theta \quad 0 < n < 2$$

This assumption seems to be quite generally followed from which an estimate is made of the value of n (usually between 1 and 2) required to agree or support the reported

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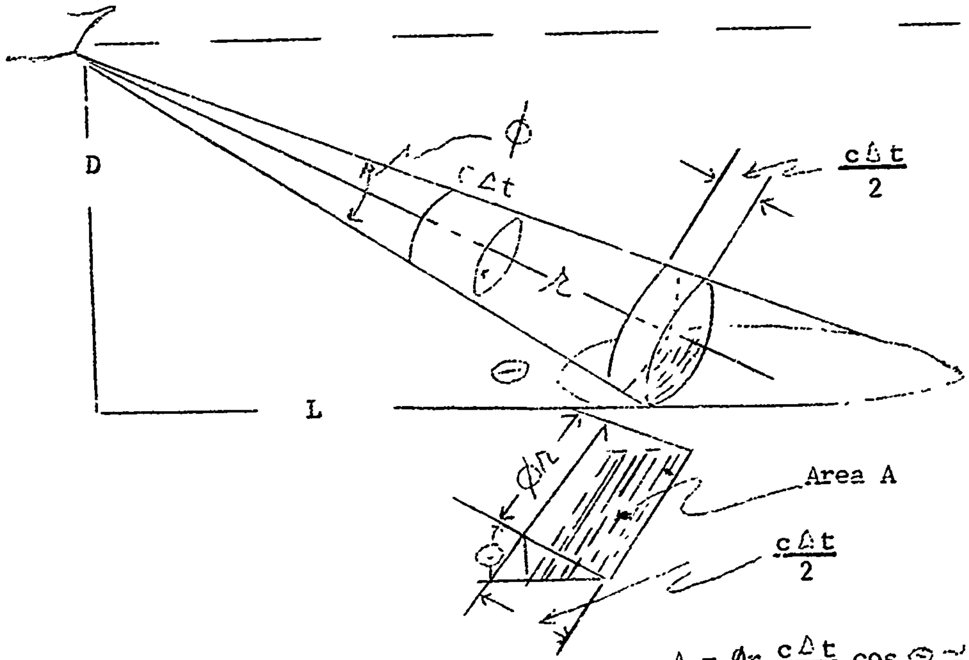
* For fixed transducer dimensions, the directivity index is proportional to frequency squared for noise limited conditions when discrimination against noise in both vertical and horizontal directions is effective; i.e., Directivity Index $\sim$ 10 log Af^2 and the echo-to-noise level should increase 6 db/octave. Discrimination against surface or bottom reverberation is nearer 3 db/octave (Ref. 3.10), indicating the vertical directivity apparently does not improve echo detection for reverberation-limited conditions in shallow water.



$$A = \phi r \frac{c\Delta t}{2} \cos\theta \simeq \phi r \frac{c\Delta t}{2}$$

For small θ:

$r \simeq L \qquad \sin\theta \simeq \tan\theta$

when

$D \leq 200$ yds; $\quad L \geq 600$ yds.

$\tan\theta \leq 1/3 \simeq \sin\theta = .316 \leq 5\%$ error

and

$\theta \leq 18^\circ$

Fig. 3.1. Reverberation Area Diagram.

experimental work,* along with the comparable value assigned for 10 log K.

When n = 2, the above is equivalent to Lambert's Law of Scattering. This is when the minimum of reverberation interference attains, and accordingly is satisfied by, very smooth bottoms. When n = 0, the sound impinging on the bottom is scattered equally well in all directions (i.e., the bottom is literally rough). Intermediate scattering is when n = 1.

3.326 Example of Shallow Water Bottom Reverberation. Reproducing equation (9)

$$L_e - L_R = N_{TS} = 10 \log M_B - 10 \log \phi - 10 \log \frac{C}{2} - 10 \log \Delta t - 10 \log r \quad (9)$$

where

$$- 10 \log M_B = S_B + 10 \log 2\pi = S_B + 8 \text{ db}$$

$$S_B = -27 \text{ db} - 10 \log \sin^2 \Theta \text{ **} \quad (10)$$

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* Ref. 3.7, p. 10 and Ref. 3.8, p. 28 and 29. Also Mackenzie (in the Journal of the Acoustical Society of America, Vol. 34, Jan. 1962, p. 65) has given:

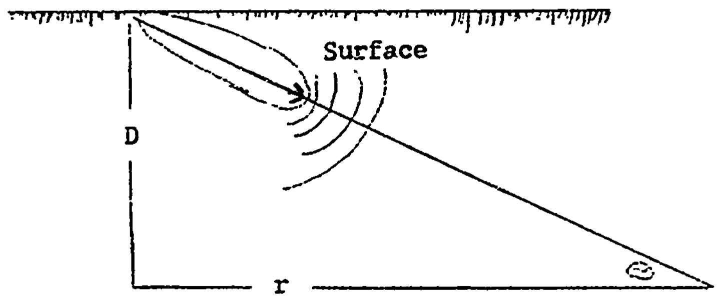
Reverberation Strength RS = $10 \log \mu_k + 10 \log A + 10 \log (\sin \phi_e \sin \Theta_e)$ where:

$10 \log \mu_k$ = -30 db, assuming n = 2
$10 \log \mu_k$ = -40 db, assuming n = 1
ϕ_e = an effective angle of incidence, and
Θ_e = an effective angle from which all the reverberation is considered to come. Both are a function of an integration which determines an average value of $\sin^n \Theta_e$ as above. This integrated value is weighted by the surface directivity factor and bottom reflection coefficient.

A = Area as given in (8a)

** These values for angles of incidence 20° and less vary between about -35 db and -15 db (Ref. 3.8, p.29), depending upon bottom material. -27 db is very optimistic and about the minimum given at 90° (Fig. 4, Ibid). For rough scattering, this value is reported as high as -5 to 0 db at 90°.

Fig. 3.2. Geometry of The Shallow Water Example.



$r \gtrsim 600$ yds.
$D \leq 200$ yds.
$\Theta \leq 18^{\circ}$
$\sin\Theta \simeq \tan\Theta = \frac{D}{r}$

$\therefore$ from (10)

$$S_B = -27 \text{ db} - 10 \log \left(\frac{D}{r}\right)^2$$

$$S_B = -27 \text{ db} - 20 \log D + 20 \log r \qquad (11)$$

Using the numbers below for an example:

D	=	200 yds	100 yds.	50 yds.
$20 \log D$	=	46 db	40 db	34 db

$\phi = 8^{\circ}$ = ave. beam width assumed for SQS-23

$10 \log \phi = -8.5$ db

$C = 1650$ yds/sec

$\frac{C}{2} = 825$ yds/sec $\qquad 10 \log 825 = 29.2$ db

$\Delta t = \frac{1}{1000}$ sec $\qquad 10 \log \Delta t = -30$ db

(12)

Substituting (10), (11), and (12) into (9):

$$L_e - L_R = N_{TS} - 25.7 \text{ db} + 10 \log \frac{r}{1000} \qquad D = 200 \text{ yds.} \qquad (13a)^*$$

$$L_e - L_R = N_{TS} - 19.7 \text{ db} + 10 \log \frac{r}{1000} \qquad D = 100 \text{ yds.} \qquad (13b)^*$$

$$L_e - L_R = N_{TS} - 13.7 \text{ db} + 10 \log \frac{r}{1000} \qquad D = 50 \text{ yds.} \qquad (13c)^*$$

* t = 1 msec.

As D gets smaller (the water becomes more shallow) the original angle, $\sin \Theta = \frac{D}{r}$, is getting smaller and the reverberation level dependent on $\sin^2 \Theta$, is getting smaller.

Note the Directivity Index has not been included in equations (13a), (13b), or (13c). This normally would reduce the reverberation background.

In this example assume the receiver Directivity Index of about 25 db for noise (equivalent to the SQS-23, Ref. 3.11)* is equivalent to the Reverberation Index, and a 30 millisecond pulse** instead of the one millisecond pulse is assumed; then for the case of D = 200 yds in (13a) we now have the following:

$$L_e - L_R = N_{TS} - .7 - 10 \log 30 + 10 \log \frac{r}{1000} = N_{TS}$$

$$- 15.5 + 10 \log r(ky)$$

With an average target strength of about 15.5 db, the echo to reverberation level ($L_e - L_R$) is positive and increasing, with r increasing beyond 1 kyd. The recognition differential, however, will require at least that $L_e - L_R$ be in excess of 21 db (Ref. 3.11)** for detection 50% of the time, which is almost hopeless; i.e., if the description here is correct, then the only hope of improving it would be to increase the range r until $10 \log \frac{r}{1000}_{yds} = 21$ or $r \cong 125{,}000$ yds.

For a depth of 50 yds. (D = 50 yds) in (13c), the minimum example and a directivity index of 25 db and target strength of 15 db:

$$L_e - L_R = + 11.2 \text{ db}$$

This is certainly an improvement, but it will not exceed the recognition differential of 21 db assumed necessary for detection. However, again if this is a good description of the detection problem in shallow water, then out at about 10,000 yds the detection probability would be about 0.5.

What has been described here as an example is the Reverberation Problem in a very simple form. It is obvious how dependent these numerical manipulations are upon the value of n in $10 \log M_B + S_B + 8$ db where $S_B = -27 \text{ db} - 10 \log \sin^n \Theta$, and where the value of n = 2 and a scattering coefficient of -27 db for S were chosen. This is nothing more or less than saying the results are very dependent upon the type of

* Ref. 3.11, p. 16-17.
**See Appendix B - Table B.2.

scattering (what the bottom is like) and the bottom slope and range which are S_B and Θ respectively. Furthermore, complications not included in this descriptive example are: the active source being near the surface, a finite beam width with side lobes, the reverberation generated by scattering from the sea surface back to the receiver, the fact that the transducer may not be tiltable or that the submarine may not be on the bottom, and last but not least, refraction of the sound with varying velocity gradients which increases the angle of incidence.* Each of the above complications is another aspect of the problem that requires detailed attention in any model which predicts detection under these various conditions; however, the simple description given here is in general still useful for our purposes, which are to discuss possible tactical range prediction models for future shipboard use applied to predicting ESR.

3.4 Shallow Water Propagation Models. Existing shallow water sound propagation models can be divided into two broad categories, theoretical and empirical. The empirical models are based primarily on data gathered in sound transmission experiments, and if necessary, experimental reverberation data. In general, an attempt is made to fit a reasonable and simple descriptive expression to the data. The COLOSSUS II propagation loss equations (Refs. 3.15 and 3.16) and the work by K. V. Mackenzie (Ref. 3.17) are the standard examples of this approach. The theoretical models, on the other hand, are based on inferred mathematical and physical arguments in which acoustic behavior is derived from the assumed characteristics of the medium. Normal mode theory is representative of this type of approach One of the earliest applications of normal mode theory was used by C. L. Pekeirs (Ref. 3.18). The most recent is probably the work reported by Pedersen, Bucker, Morris, and Gordon of NEL (Refs.3.19 and 3.20).

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* To add further confusion to reverberation levels expected at low frequencies, work by both NEL (700-1200 cps), Ref. 3.12, and USL (20-3000 cps), Ref. 3.13, indicates that the echo level to reverberation level for some cases in shallow water is nearly constant with range and provides experimental data to support this claim. However, the apparent coupling between surface and bottom at frequencies around 1000 cycles, as reported in both references, may play a larger part in this phenomenon. The same may not be true for higher frequencies. Certainly some studies have indicated 1000 cycles is a very good, if not the best, operating frequency for both minimum propagation losses and echo level to reverberation level ratios in shallow water (Ref. 3.14).

In general, the empirical approach has been the more successful, or at least acclaimed to be the more useful, of the two. It is well recognized that the shallow water does not lend itself readily to theoretical analysis; and as such, most theoretical models ignore some features of the environment that complicate the picture. This simplifies the mathematics and limits realistic results. However, simplicity is desired since complex analysis techniques have received limited use unless computerized.

Techniques for predicting sonar detection ranges have certain features in common. Nearly all start with the concept of detection probability where the usual procedure is to specify a desired single-ping detection probability and an acceptable false-alarm rate, and then proceed to determine ranges for which the predicted detection probability and false-alarm rate are equal to the desired value.

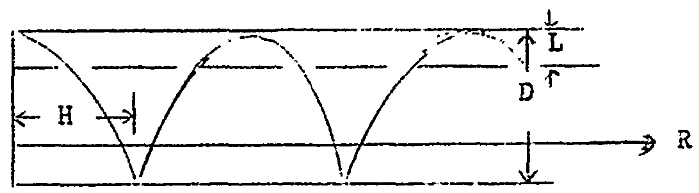
Most prediction techniques differ markedly in the way N_W is estimated and in the methods used to compute reverberation levels, L_R. Predicted sonar detection ranges (ESR) in shallow water appear to be most sensitive to the variation in methods for estimating these two sonar parameters, N_W and L_R. Reverberation is one of the limiting factors in shallow water echo ranging and appears to offer the most resistance to solution. Although paramount, reverberation is not the only limit in shallow water, as proven in available operational results; other limiting effects, such as ambient noise, at times prevail, especially so at great ranges, and of course at <u>all</u> ranges in the passive mode for detection in both shallow and deep water.

"Propagation loss is problematical." The cause of these detailed fluctuations is not well understood, and the most direct approach assumes propagation variability to be a constantly fluctuating random process. This is particularly true in shallow water where the nearness of the bottom and the effects of vertical and horizontal variations in temperature, salinity, density, and current greatly complicate the picture and ping-to-ping variations of several db are continually reported. At present, the best that any theory can hope to do is to predict correctly a broad average value for N_W. This is implicit in the formula for detection probability, which assumes that N_W (along with other sonar parameters) is a random variable normally distributed whose mean is equal to its predicted value.

3.41 <u>COLOSSUS II Propagation Loss Model.</u> One simple approach to shallow water transmission loss, and one of the most often used and quoted, is the application of the COLOSSUS II shallow water propagation loss equations.

The COLOSSUS II shallow water propagation loss equations are based on a model which employs the "skip distance" concept (see Fig. 3.3). The skip distance (H) is the range covered by a limiting ray between successive reflections.

Fig. 3.3. COLOSSUS II Model and Geometry



R	Range in kiloyards	(0-100)
f	Frequency in kilocycles per second	(0.1 - 2.8)
D	Water depth in feet	(100 - 600)
	Bottom type	(sand or mud)
L	Layer depth in feet	(0 - 600)
S	Sea state	(0 - 5)
h	Wave height in feet	
H	Skip distance in kiloyards	
a_T	Attenuation factor, db/bounce	
a	Absorption coefficient, db/kyd	
k_L	Near Field Anomaly, Lower Limit, db	
K_U	Near Field Anomaly, Upper Limit, db	

In terms of these symbols, the following equations hold for mean value

$$N_W = 20 \log_{10}R + aR + 60 \text{ (db)} - k_L^* \qquad R < H \qquad (14a)$$

$$= 15 \log_{10}R + aR + a_T\left(\frac{R}{H} - 1\right) + 5 \log_{10}H + 60 \text{ (db)} - k_L^*$$

$$8H \geqslant R > H \qquad (14b)$$

$$= 10 \log_{10}R + aR + a_T\left(\frac{R}{H} - 1\right) + 10 \log_{10}H + 64.5 \text{ (db)}$$

$$- k_L^* \qquad R > 8H \qquad (14c)$$

where

$$H = \sqrt{\frac{L + D}{8}} \text{ kyd}$$

$$a = 0.01 f^2 \text{ approximately.}$$

In the empirical model (equation 14a), sound diverges spherically $\left(\frac{1}{r^2}\right)$ between the source and the first reflection. It then undergoes a transitional phase for the next seven skip zones, while gradually changing from spherical to cylindrical spreading $(\frac{1}{r})$ (equation 14b). Thereafter, the sound spreads cylindrically (equation 14c). Surface and bottom effects enter in the form of the additive term, $a_T\left(\frac{R}{H} - 1\right)$ noted in equations 14b and 14c, where R denotes range and H is the skip distance. R/H is the minimum number of contacts (bottom or surface) for a ray traveling from the source to range R. a_T is an attenuation coefficient, measured in db per bounce. Its value depends on wind velocity, frequency, and bottom composition. The skip distance H depends on water depth and layer depth. It is the only parameter which reflects the velocity structure of the water, and even then it has only one value for COLOSSUS II data.

In project AMOS, the values determined for H were $H = 0.5\sqrt{L}$ in kyds for upward refraction in isothermal water and $H = 0.4\sqrt{D}$ in kyds for downward refraction in negative gradient water; but values for H "that fitted the data better in the COLOSSUS II model" were: $H = \sqrt{\frac{L + D}{8}}$ in kyds.

Propagation over a sloping bottom was neiter considered in AMOS data nor in the COLOSSUS II model, and at present there is no sure way of dealing with it.

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*or k_U

3.411 <u>COLOSSUS II Results</u>. The COLOSSUS II study represents a large quantity of experimental data covering a broad cross section of shallow water environment conditions, and on the average, the predicted value should be relatively good. Unfortunately for the present operational sonars, all data presented are at frequencies between 100 and 2,820 cps. and the graphs which give attenuation as a function of frequency, sea state, and bottom composition do not extend beyond 3,000 cps. However, they probably could be extrapolated for 3.5 kc (the SQS-26) and maybe to 5 kc (the SQS-23).

The results of an error analysis, in which propagation loss values were computed by means of the COLOSSUS II equations, were compared with the original data and are given in Ref. 3.13. When the results obtained over all ranges from 3 to 90 kyd were grouped together, the standard deviations (σ) incurred by using the equations varied from about 2 to an excess of 15 db, depending on frequency. An increase in frequency and/or range was associated with an increase in standard deviation (σ). For example, when the results obtained at 3 kyd were considered separately, the sigma value was only 2 db at 112 cps and 4 db at 2,820 cps. At 9 kyd the sigma value at 2,820 cps has changed but little, but at 30 kyd the sigma value is 11 db. The randomness of the data for one frequency can be observed from Figure 3.4, which is reproduced from Reference 3.16. Other frequencies, 112 cps and 446 cys, were also plotted.

From Figure 3.4 it is quite obvious that shallow water propagation loss models for accurately predicting sonar detection range, if this represents the best available, are difficuit to use effectively. This figure displayed is for 1,112 cps, which is the highest frequency displayed in the above report. Undoubtedly a similar distribution for higher frequencies would be equally random, if not more so.

Figures 3.5, 3.6, and 3.7 are also reproduced from the same report. They represent the error between the computed propagation loss, using either equation 14a, 14b, or 14c and the measured data. These plots display in a different way the same randomness in the predicted vs the experimental propagation loss. From these, it is evident that propagation loss in shallow water is far from being understood completely today, or at least from being <u>predictable</u> in any other than a gross statistical way.

3.412 <u>Propagation Loss Effects on Range Prediction</u>. One curve computed from the COLOSSUS II results (Ref. 3.16) is given here to indicate the variation in predicted sonar detection range with variations in just one of the sonar parameters, N_W . This also will indicate how the variation in propagation loss data affects the ESR prediction in shallow water.

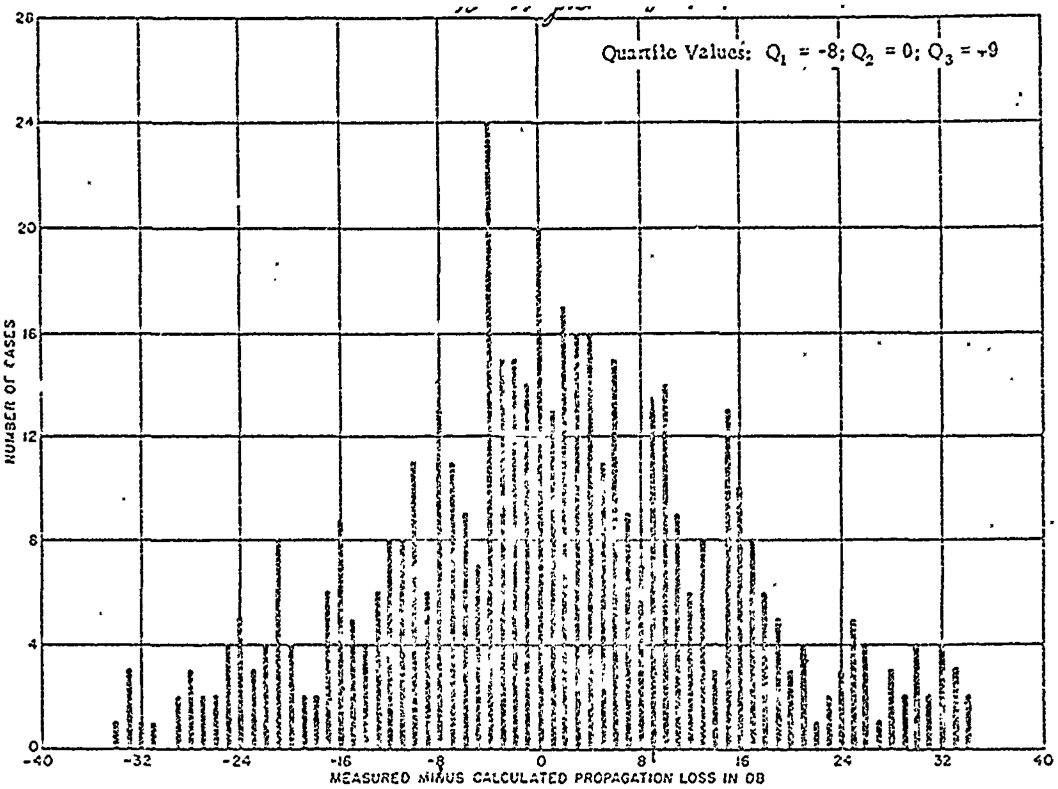

Fig. 3.4 – 1120 cps

Distributions of Propagation Loss Anomaly

Distributions of the propagation anomaly, N_A, were computed for frequencies 112, 446, and 1120 cps for the ranges 3, 9, 30, 60, & 90 kiloyards combined. The interquartile ranges are larger than might be desired. One reason for this could be the variability in the source level of the explosives and another is the inevitable bias of data due to lack of homogeneity. Thus, there are fewer measured values at the longer ranges, because the field is sometimes too weak to be measured. Thus, unweighted averages show a trend toward apparently unpredictable strong fields at the longer ranges. These fields are probably due in part to other modes of propagation, principally seismic. The analysis and prediction data presented herein are valid for values of estimated propagation loss less than about 135 db. Scatter diagrams were prepared to show the variability of the measured loss with the predicted propagation loss. These appear as Figs.3.5, 3.6, and 3.7. Ref. 3.16.

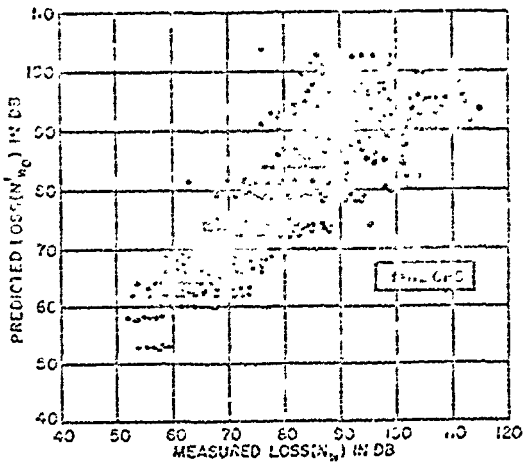

Fig. 3.5 - 112 cps

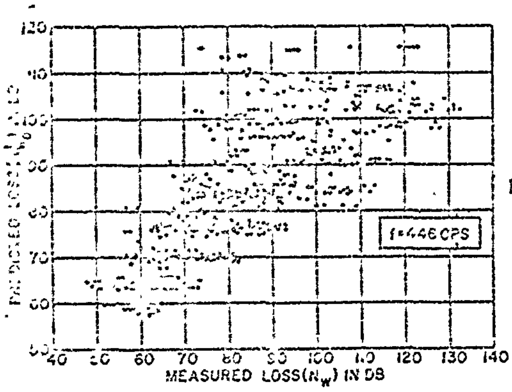

Fig. 3.6 - 446 cps

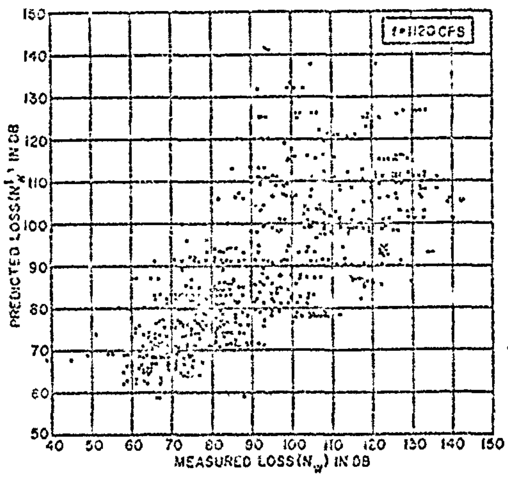

Fig. 3.7 1120 cps

Scatter Diagram - Predicted vs Measured Loss.

Ref. 3.16.

Assume the following:

a water depth of 200 feet and no recognizable layer (this is about as shallow as the submarine would operate)

sea state 3

a frequency of 1 kc (much lower than present sonars, but data for these higher frequencies was not presented)

$$H = \sqrt{\frac{0 + 200}{3}} = 5 \text{ kyd}$$

$$a = .01 f^2 \text{ db/kyd}, \quad f \text{ in kc} \quad \text{or}$$

$$a = .01 \text{ db/kyd}$$

$$a_T = 3.7 \text{ db/bounce for mud bottom and sea state } 3$$

Next, assume a 10 db error between the method being used and the propagation loss that really exists, and we will use equation 14b to predict the propagation loss.

$$N_W = 15 \log_{10} R + aR + a_T \left(\frac{R}{H} - 1\right) + 5 \log_{10} H + 60 \text{ db} - k_L \qquad (14b)$$

If equation (14b) is in error 10 db for these conditions, the propagation loss computed, N_W, is either 10 db too large or 10 db too small.

Assume under the existing operating conditions the sonar operator can detect a signal of 0 db level 50% of the time, the sonar is self-noise limited due to speed, the average ping level is 140 db, and a target strength of 20 db is available from a target closing the range. With 140 db + 20 db the operator can therefore accept an overall propagation loss of 160 db, or 80 db in one way (i.e., the signal loses 80 db of ping level out to the target and has 60 db for return; but the signal enhancement from the target reflection provides 20 db more of signal amplitude, or 80 db for the return).

Next, it should be understood that whatever error is made in prediction comes out affecting the estimated sonar detection range.

An example of how this 10 db affects the predicted range is shown on Fig. 3.8. Fig. 3.8 is a computed curve for the propagation loss (N_w) in db vs range in kiloyards. It has been computed using equation (14b) given on Fig. 3.3 and from the values given above.

From Fig. 3.8 the operator, or analyst, would estimate a detection range of about 12,000 yards for the 80 db propagation loss he can accept; but if the actual propagation loss is 10 db or more, then his detection range is reduced accordingly. By coming down the curve 10 db, an estimate of about 5 kyd for detection range might be appropriate.

The same reasoning applies if the propagation loss is 10 db less than estimated. In this case the 10 db error would show up as an increase in the detection range. If so, 20 kyd is a more appropriate estimate.

What this very simple approach hopefully has indicated is the very large variation in detection range possible due to the limited specific knowledge of the propagation loss at any given time or place and the dependence of predicted sonar detection range upon average values. The other parameters in the sonar equations are also average values, but with variations usually less than indicated here.

3.42 Some LORAD Results in Shallow Water. The LORAD program at NEL has also developed an empirical relation for shallow water propagation from experimental data gathered in shallow water areas off California and Hawaii and in the Bering and Chukchi Seas. Using frequencies of 700 and 1200 cps and at ranges of 2 kyd to 50 kyd, Ref. 3.12 reports the echo level in shallow water (50 yds, and less) can be represented by the following:

$$\text{Echo Level, } L_e = \text{Constant} + B \log R$$

where the Constants depend upon source level, layer depth, bottom conditions, sea state, target aspect, and others. Following the approach from work done by Mackenzie* where the transmission anomalies in shallow water were generalized with a dimensionless parameter R/D, the same generalization is applied with good results for similar bottom types.

*Mackenzie, K.V., "Long Range Shallow-Water Transmission", Journal of Underwater Acoustics, Vol. 7, p.239-259, CONFIDENTIAL, Oct. 1957; and Mackenzie, K.V., "Long Range Echo-to-Reverberation Ratios in Shallow Water and the Application to Echo-Ranging", Journal of Underwater Acoustics, Vol. 8, p. 359-378, CONFIDENTIAL, July 1958.

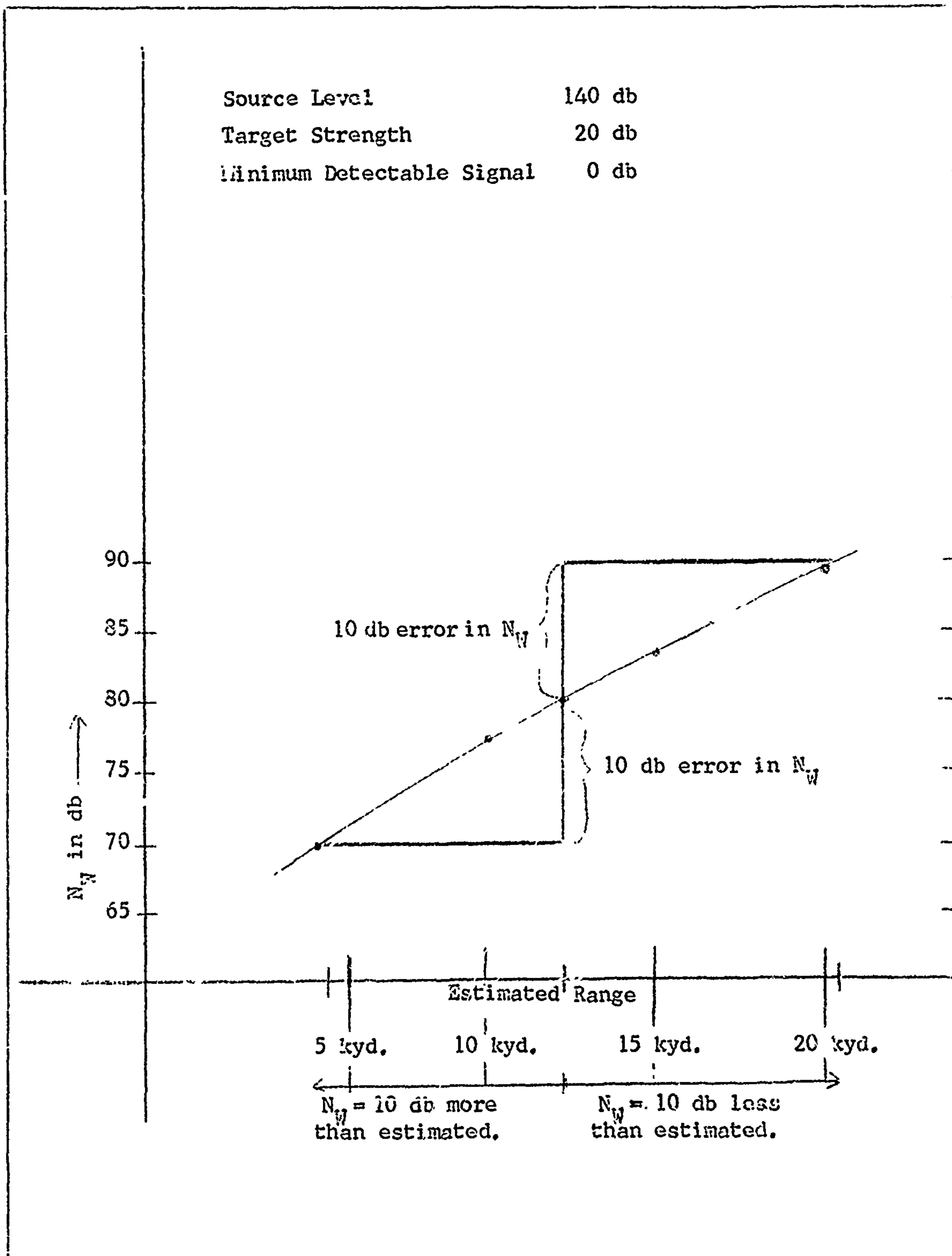

Fig. 3.8. Estimated Range Error With Error in N_W.

Fig. 11, given in Ref. 3.12, is a plot of experimental data from four California coastal areas and one Hawaii area showing this relatively good agreement between echo level (L_e) in db vs 50 x $\frac{\text{Range}}{\text{Depth}}$ for two normalized depths, 25 yards and 50 yards, with an estimate of 2.6 db as the standard error. Also it is interesting to note the following taken from the same reference:

"In each area the level of peak reverberation decreased with range at approximately the same rate as the echo level. At beam aspect the differences in levels (echo to peak reverberation ratio) were nearly constant with range. The ratios were 11 to 15 db for 100-millisec pings, varying from area to area." The reverberation levels in these examples followed the approximated empirical curve even better than the echo level. i.e., L_R = Constant_R + B log R was a very good fit to the reverberation levels presented, which also estimated reverberation from areas as near as 2000 yards in range. Most of the results in this LORAD report are compared with Mackenzie's earlier work which is based on a ray tracing approach and which provided good agreement in these examples.

Although this might indicate an acceptance of the ray tracing approach, there are indications that ray tracing leaves much to be desired, especially so in explaining some of the more complex problems of interest to specialists working in underwater acoustic propagation, as the following extract will affirm:

"These ray path pictures are useful for many purposes; but for those cases which require estimates of the acoustic field in a shadow zone, the ray method is not applicable or useful. This requirement has not commonly occurred in sonar design studies because shadow zones are always regions of relatively high loss. One might imagine that need for wave acoustic problems would be encountered only rarely in the deep ocean, but surface-bounded ducts (e.g., surface channels) frequently are of dimensions comparable to long-range sonar wavelengths. Even though a duct may have a depth of many wavelengths, the boundry conditions are usually those of a 'leakly' duct, so we require an analysis for many wavelengths below the channel. Other types of shallow channels and shallow water propagation pose similar problems. For all of these, the normal mode theory seems to be the approach having the greatest promise, and perhaps it is the only approach which can be used to sweep away the debris left by improper use of the ray theory." (Ref. 3.2, Frank Hale, p. 65)

There still is a very important use for the type of results presented above since it could be possible for propagation losses to be extracted from the experimental results. Although the frequencies presented in Ref. 3.12 are too low for direct application to current shipboard systems in the Fleet or under development, this would only necessitate accounting for the effects of higher frequencies in the experimental loss curves.

3.5 Computerized Ray Tracing Programs for Possible Shipboard Application to Improve Command and Control. Computerized acoustic ray tracing techniques are well developed today and have been in evidence since World War II in one form or another. Several groups have developed their own ray tracing program for particular interests, and the few presented here are only an example of a limited review of the literature. Before electronic computers, mechanical analogs were devised to describe the behavior of acoustic rays under water. Two such analog devices are described in the chapter on ray tracing in "Physics of Sound in the Sea."*

A special circular slide rule was used which simplified the calculation for obtaining changes in the depth with range along a ray. The instruments, developed by the Woods Hole Oceanographic Institution early during World War II, gave horizontal range covered by a ray in its passage through a layer with a constant gradient. The layer thickness (h), temperatures at the beginning and end, and direction of the ray at the projector (Θ_0) are given to start with. With the slide rule, the direction of the ray when it enters and leaves the layers, Θ_1 and Θ_2 respectively, is calculated. From the average of the two directions, the horizontal range traversed in the layer is obtained.

$$R = h \cdot \cot\left(\frac{\Theta_1 + \Theta_2}{2}\right)$$

Continuous application of this formula from layer to layer provides the necessary information to obtain a complete raypath.

Another instrument described in the above reference was a sonic ray plotter which was developed by NDRC. This device mechanically integrates a second order differential equation in range and angle and exhibits the solution as a curve giving the raypath. With our present day computers, new approaches to those awkward tasks of ray plotting are in use. Several programs for electronic analog and digital computers have been developed which are used to generate raypath traces.

*"Physics of Sound in the Sea," Summary Technical Report of Div. 6, NDCR, Vol. 8, Washington, D.C., 1946.

One analog computer available commercially is the "Sperry Sound Wave Ray Tracer".* The Woods Hole Oceanographic Institution made an evaluation of such a device in 1958 and found it very useful for plotting sound rays. Like the mechanical sonic ray plotter, any function can be programmed.

The Electronic Associates Inc. have an analog computer program for their line of general purpose analog computers.** It is completely electronic. Their choice of parameters permits the study of rays out to ranges as far as 700,000 yds., and depths to 14,000 ft.

These various programs mentioned were used only for the generation of raypaths. Spreading loss is obtained by qualitative analysis of the ray diagrams obtained. None of these perform actual intensity loss calculations. The Research Laboratories of the United Aircraft Corporation provided an example of intensity calculations, using analog computers.*** The program was based on using time and Θ_0 as the independent variables instead of the usual horizontal range r and Θ_0.

There are several digital programs available. One of the very early programs developed was by the U. S. Naval Ordnance Test Station at Pasadena, California, for use with an IBM 709 computer.‡ This program generates both raypaths and intensity loss due to spreading. A similar program was developed by the Ordnance Research Laboratory of the Pennsylvania State University to be used in the IBM 7074 computer. In both programs, the intensity loss obtained is only approximate.‡‡

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*A. L. Bradshaw and J. B. Hersey, "Evaluation of the Sperry Sound Wave Ray Tracer," WHOI Ref. No. 58-13, March 1958.

**"Underwater Acoustic Ray Analysis," Technical paper presented at the 61st Meeting of the Acoustical Society of America, May 11, 1961. Abstract published in the Journal of the Society, Vol. 33, No. 6, June 1961.

***Anderson, R. Gocht, and D. Sirota, "On Spreading Loss of Sound in an Inhomogeneous Medium," Report B440132-1, United Aircraft Corporation Research Laboratories.

‡"Sonar in Refractive Water," Program 02431, U.S. Naval Ordnance Test Station Report P129/MR576, Pasadena, California, 9 Oct 1959.

‡‡"Underwater Sound Rays and Transmission Loss Using Analog Computer," ORL TM Memo 26.2000-72, 14 Aug 1963. Ordnance Research Laboratory, Pennsylvania State University, University Park, Penn.

NOTS, China Lake, has a program on IBM 7090 computer that makes available transmission loss and reverberation level. It also takes into account the transducer pattern.*

The Pacific Naval Laboratory describes ray tracing programs for an LGP-30 computer** and for a PB-250 computer.*** Both have provisions for multiple velocity profiles as well as bottom and surface reflections.

This is a very limited list of ray trace programs available today, none of which has been used or studied directly. Recently an extensive list of Navy-Only computer programs has been provided by NOTS, China Lake, for the Systems Analysis Staff, Naval Ordnance Laboratory, Silver Spring, Maryland. This list also includes several ray trace programs applicable to transmission loss and sonar detection.

3.51 <u>Limitations of Current Surface Ship Ray Trace Methods</u>. In the past, ray plots were not developed for on board ship use, and only recently has any direct use been made of these techniques. The KEY WEST TEST and EVALUATION DETACHMENT has developed a technique for drawing ray plots by hand using predrawn curves and transparent overlays. The curves and overlays were developed for ESR prediction for deep water only. The method provides the solution to the sonar equation for noise-limited conditions (3.321) and the plotted rays provide information on shadow zones and surface contacts. It was not intended for shallow water use. However, it does provide a way of obtaining the ray plot without transmission loss for shallow water.

The only recent in-Fleet development at all applicable to ESR prediction is the Tactical Range Prediction System (TACRAPS) which is a shipboard sonar range prediction system under development at the Fleet ASW School at San Diego. The large mechanical slide-rule-like system uses a circular nomogram that gives detection probability as a function of range and figure-of-merit, which was not available in NAVSHIPS 900,196, and a circular slide rule that can be used to compute the parameters that describe a ray plot. The slide rule is patterned after the instrument developed by Woods Hole Oceanographic Institute during World War II.

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*"Investigation of the AQS-10 Sonar and Torpedo MK 46 Acoustic Performance in Shallow Water as Related to the HSS-2 Helicopter as an Attack Vehicle," by Weapons Planning Group, U.S. Naval Ordnance Test Station, China Lake, Calif., February 1962.

** H.W. Dosso, J.E. Lokken, C.D. Maunsell, and J.P. Greenhouse, "Ray Tracing with an LGP-30," Pacific Naval Laboratory Report 60-3, March 1960.

*** H.W. Dosso, T.T. Robertson, and S.R. Clark, "Ray Tracing with a PB-250," Technical Memo 63-11, Pacific Naval Laboratory, November 1963.

The nomogram is developed on the application of noise-limited solution to the sonar equation (3.321), using the AMOS equations and figure-of-merit inputs determined by shipboard measurements. Like other methods as NAVSHIPS 900,196, it uses the AMOS equations which are descriptive of deep-water transmission loss; and therefore it is appropriate only for deep water or for shallow water areas that appear like deep water acoustically. If the noise background is reverberation rather than own-ship noise, the present nomogram cannot yield a solution unless the figure-of-merit is measured. The present figure-of-merit is estimated for noise-limited conditions.

3.6 Results of One Propagation Loss Study in Shallow Water Done at NEL. Propagation studies pursued at NEL have utilized both ray trace and normal mode methods for explaining the experimental results from various cruises made in the Pacific areas supporting the LORAD program.

One of the most recent publications is included in Ref. 3.20 and indicates relatively good correlation between computed and experimental propagation losses in shallow water to ranges within 20,000 yards. Beyond 20,000 yards, correlation between the model and the experimentally measured propagation losses is found wanting. This is understood since a small db error in propagation loss measured or estimated is very influential at long ranges under question, e.g., at 50,000 yards rather than at the nearer ranges around 20,000 yards. The sensitivity of the loss in this model to errors in describing the bottom conditions was pointed out in a previous work done by one of the authors.*

3.7 Import of Model Results to Surface Ship Command and Control Requirements. These results are indicative of the continued effort to better understand acoustic propagation in shallow water. The understanding of acoustic propagation anomolies is continually being extended, even if only by small increments, since this understanding is so important to the operating force; and slowly the methods for predicting detection range and submarine detection seem to be improving. However, the desire to develop accurate ASW detection and prediction techniques at extended ranges and models that can account for all anomolies over all ranges for all conditions should also be tempered with using and developing those limited techniques now available that could improve predicted detection ranges in shallow water that are needed today.

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*H. P. Bucker, "Normal Mode Propagation in Shallow Water," Ref. Journ. Acoust. Soc, Am., Vol. 36, Feb. 1964, p. 251.

This point is believed worthy of consideration in the context of the current study. ESR prediction methods for shallow water that have been developed for use in the Fleet are nonexistent. Any improvement would help the ASW operators; however, they must have access to this improvement or it is meaningless. Since NEL is the only laboratory with a current shallow water program (Ref. 3.10), any significant improvement over the short time may revolve around the current work being done there; and maybe their most current work (Ibid.) is indicative of what to expect in the near future. It is a possible approach to improving ESR prediction in shallow water if the environmental conditions are accurately known. If the model is satisfactory for ranges out to 20,000 yards and if several environments were used to predict or develop a whole set of curves with these methods, then by measuring a few (maybe only two) points on the loss vs range curve, it is conceivably possible to place these two experimental points on those curves developed from environmental conditions in the immediate operating area. These are not ideas that guarantee a solution; they may require a great deal of bottom sediment data; but some of the tools are available, particularly the models, and the need exists.

If the responsibility for automatic data processing in the area of Command and Control is also responsible for data processing in ASW, surely Command and Control technology and planners must accept the requirement to develop methods to improve ESR prediction in the Fleet.

There is no claim in this study that a consensus of opinion exists today by professional personnel specialized in understanding the many vagaries of propagation loss anomolies as to the most opportune approach to take for improving the prediction of Effective Sonar Range for the Fleet, and especially in shallow water. Furthermore, it must be understood that there is no imperative requirement to predict ranges for surface ship sonar beyond the capability of their weapons in shallow water (which certainly now is much less than 50,000 yards); but if a potential detection range prediction scheme is effective to ranges near 20,000 yards, along with a similar detection capability, then Command and Control technology should be aware and remain abreast of this potential ESR prediction in shallow water, because even a 10,000 yard prediction method in shallow water would be welcome today.*

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*LCDR Beaumont, RAN, Fleet ASW School, San Diego, California.

4. ASW SHALLOW WATER SCENARIO AND IMPORT TO COMMAND AND CONTROL REQUIREMENTS (U)

4.1 Amphibious Force Protection. The two scenarios presented here are taken from Ref. 4.1, which was based on actual Fleet operational readiness exercises and realistic free-play exercises. They are examples of ASW action during amphibious operations which relate directly to shallow water operations and present some of the tactical problems in this type of ASW operation that need better solutions to improve operational control than are currently available. Improvement required in the information bearing directly upon detection, navigation, classification, attack, and weapon launch, as well as making the information available to all team members, is made evident throughout the scenario by a parallel commentary, "The Import of the Scenario to Surface Ship Command and Control Requirements."

The first example presented, Amphibious Force Protection, is directed to the point in time at which an amphibious force has entered a shallow water area and is approaching its objective area. The general direction taken by the force is known to the adversary, who is endeavoring to place submarines in a position to intercept. The amphibious force described in Ref. 4.1 consisted of a fast transit group made up of a landing ship squadron (LST's) and minesweeping forces consisting of one MCS and six MSO's. The amphibious objective area (AOA) is off the 15-mile beach east of Ha Tinh, North Vietnam.

The approach to the AOA involves a long, shallow water transit through much of the Gulf of Tonkin. The rendezvous point for the slow and fast transit groups will be very nearly over the 100-fathom contour leading to the shallow water stretches of the Gulf itself, which will be a relatively long distance from the AOA. The chief threat to the formation in its transit through the Gulf was thought to be represented by the small, fast, surface craft and possibly by inshore submarines, although portions of the Gulf are too shallow for submerged submarine operations.

At the beginning of the narrative, the time is 1800. The rendezvous of both the slow and the fast transit group near the entrance to the Gulf has been accomplished and the combined amphibious force is steaming northward. It still has a 230-mile transit to the beachhead area, and with its SOA of 10 knots (dictated by the low speed of the LST's), it will require about 23 hours steaming time. The CVS has joined the main body; it will detach with its escorts when the 30-fathom line is reached.

The combination of forces (including five destroyers from the fast transit group, eight from the slow transit group, and four from the CVS group) permits a massive circular patrol area screen, with the added provision for an advance screen (three DD's) and pouncers inside the main screen. One of the pouncer stations was occupied by the solitary APD which has no assigned amphibious mission, but was being used as a destroyer since it still carries SQS-10 Sonar and depth charges---useful shallow water systems.

It must be pointed out, lest one unknowingly ignores the fact, this enormous support group---20 DD's and 1 CVS---has been stationed, wrongly or rightly, for maximum or minimum protection of the transitting force by an estimate of the Effective Sonar Range (ESR). Although factors affecting screen selection are: the predominant threat (submarine or air, which in this case is submarine), mission of the main body, intelligence pertaining to enemy submarine type and weapon (which are parameters in defining the TDZ), etc., once the screen type is selected, the positions within the protection screen and the pouncer positions have all been made dependent upon the ESR, right or wrong. And ESR prediction techniques for shallow water are non-existent as such in the Navy today!

The force travels 230 miles in its movement up the Gulf. The first 110 miles are through a region where water depth is between 50 and 100 fathoms. The next 75 miles cover depths between 30 and 50 fathoms, and the next 25 miles beyond that have water depths between 20 and 30 fathoms. The sea echelon area of the AOA will be in about 10 fathoms, 7 miles offshore. Inside the 20 or 30 fathom curve, submerged submarine operations are virtually impossible, and mines and PT boats are considered the principal threat to the AOA. If submarines are employed, they will have to meet the surface force farther down the Gulf where there is sufficient water to permit them to operate submerged, or nonconventional type submarines will have to be used.

The minesweepers are in the vanguard of the amphibious formation, but inside the destroyer screen. They are equipped with UQS-1 continuous-transmission, 100 kc, minehunting sonars. They can offer little detection range; but their high frequency, high resolution sonars possibly can aid classification. However, when operated inside the DD screen during transit, their submarine classification capabilities will not be too useful, for once the submarine is inside the DD screen (where the MSO's are), in all likelihood he will launch his weapons (torpedoes); and this will surely classify him. Nevertheless, it is thought that the MSO's may have some value in an ASW role, and they will therefore be operating their mine-hunting sonars to provide a backup to the DD screen.

When the 30-fathom line is passed, the MSO's will move ahead of the DD screen and begin their sweeping and hunting operations under the guns of the destroyers.

The front presented by the main body of the amphibious force is about 2½ miles across. The main screen forms a circle about the force (see Section 1.64), the diameter of the screen circle being about 12 miles. There are 12 destroyers in the screen; spacing between the ships averages about 3 miles, and random sector patrolling may occasionally create gaps somewhat greater or less than this.

The CVS accompanying the force is maintaining S-2 aircraft on patrol ahead of the formation, carrying out radar and visual searches. The carrier's ASW helicopters are operating inside the destroyer screen, dipping randomly.

As the surface force enters the Gulf at 1800, 23 hours before commencing the land-operation, the enemy submarine force is deploying to meet it. The enemy has initially been aware of an impending amphibious operation through shore-based intelligence.

In amphibious operations much shallow water usually will be involved, timing is important, and ASW operations will not have the possible benefits of convoy course-changes to avoid possible submarine contact. This is one problem which shallow water ASW forces will most normally encounter--- the direction of the main body can not be altered, and classification must be fast since alternate courses, which may be possible in deep water where destination may still be days away, will not be available to the OTC. This is brought out again in the scenario.

A submarine task group, made up of three diesel-electric submarines, is moving southward to deploy across the Gulf between Hainan and the coast of Vietnam. The group is moving southward at a SOA of 10 knots, which will require the diesel-electric boats to run on the surface most of the time. All three submarines are to proceed independently and to operate essentially in a solitary mode.

Scenario I	Import of Scenario to Surface Ship Command and Control Requirements
<u>1800</u>: The surface force is entering Tonkin Gulf. Submarines are still proceeding southward to meet it.	
<u>1825</u>: An A-4 aircraft, returning from a strike mission, reports sighting a surfaced submarine. The A-4 descends to low altitude (it was below cloud cover initially or it would not have seen the sub) and prepares to open fire. The submarine, however, submerges. The A-4's fuel supply is very low and it can not immediately locate or contact the amphibious force. It does make contact with its own CVA, and the latter transmits the positional information to the CVS accompanying the amphibious task force. In order not to compromise EMCON, communication is via a middleman aircraft (A-1).	
<u>1840</u>: The CVS is assessing the information. The A-4 can only classify the sub as probable, for a positive classification rests with higher authority. However, while recognizing that visibility is not very good and the A-4 may have merely seen some transient phenomenon, from fairly high altitude, that dissovlved upon closer inspection, the CVS is inclined to suspect that the sighting may well have been a valid one. The aircraft, running out of fuel, would have had to be rather strongly stimulated for it to make a detour under the circumstances. The "probable" submarine is approximately 200 miles northwest of the main body, but it is close enough to the projected track to constitute a threat in, say, 12 to 14 hours. It is about 50 miles offshore.	Note the discussion in Section 1.6 pertaining to screens and to the limiting lines of approach to help define the threat. Estimating submarine speed, position, and probable weapon along with course of the main body provides the OTC with a probable threat and its relative value.

Scenario I

The only available vehicle that is capable of closing this distant datum and carrying out further investigation is the VP aircraft. There are S-2's aboard the CVS, but a 200 mile transit is a long way for these aircraft; it would require more than an hour just to get there. The S-2 is not configured to use SSQ-15 active sonobuoys for localization, and in the shallow water of the Gulf it would have little chance of detecting the submarine if the latter submerged. Considering the gathering darkness, the S-2 would probably not be able to gain visual contact even if the sub stayed on the surface. However, there is still a VP on station ahead of the force, carrying out radar and visual search. It can reach datum from its present position in roughly ½ hour. There is no air opposition expected, which is fortunate since the VP will possibly be acquired by shore-based radar and it would be a sitting duck for an enemy interceptor. But under the circumstances it appears both feasible and desirable to direct the aircraft to the datum.

1910:
The VP is over datum, flying at 500 feet to get under the clouds. Radar off. Nothing in sight. The VP will fly southeast, keeping about 50 miles offshore. Visibility is poor, but the aircraft might still be able to pick up the contrast of a surfaced submarine's wake. It will plant Jezebel buoys about 10 to 20 miles south of the last known datum, in an arc between the datum and the present position of the surface force.

1935:
VP has a readout on one of the buoys--possible submarine. The aircraft requires about 5 minutes to confirm the possible validity of the readout, from the time it first begins to appear on the paper recording strip. The aircraft will not go into a CODAR plant procedure; it knows that detection range will be short,

Import of Scenario to Surface Ship Command and Control Requirements.

In shallow water areas, due to the probable nearness to land, land-based aircraft offer more possibilities for assistance (longer station time) than would be expected in deep ocean operation; however, the JULIE system using dropped charges has severe reverberation and detection range limits in shallow water. Therefore the aircraft usefulness in providing a positive contact is certainly limited. But on the other hand, the JEZEBELL (passive listening) aircraft system may be better matched for shallow water ASW than JULIE since the slower diesel-electric, shorter ranged submarines are more probable and these are all snorkel boats which present high-amplitude, low-frequency noise signals for passive devices when on snorkel.

In shallow water (coastal), concentrated ship traffic may negate much of the usefulness of the passive system unless accurate tracking and position information along with position information of surface traffic is available. Also shallow water passive detection ranges will be limited compared to deep water detection ranges. This shorter range reduces the time for classification, localization, and kill, thus demanding a faster overall response to a contact.

Typical sonobuoy plants are discussed in Appendix B.4. In shallow water, due to limited detection range, the probable usefulness of CODAR plants is even less than in deep water, where their usefulness operationally has been found wanting in ASWFORPAC reports.

Scenario I

and if the sub is no more than a few thousand yards from the buoy, its position is proba'ly already fixed within the limits of CODAR accuracy.

1940:
The aircraft is descending to 300 feet. It gets an on-top indication from the readout buoy and begins a spiral out from the buoy to try for a MAD contact or visual confirmation. It could drop active sonobuoys to try for acoustic contact, but it will not do so until its spiral has proved unsuccessful. Even while snorkeling, a submarine might detect the echo ranging of the SSQ-15 sonobuoy and might then take evasive action. For the same reason--keeping the possible submarine unaware of the aircraft's proximity--radar is still off.

1945:
Aircraft is down to 150 feet, flying a spiral outward from the radiating sonobuoy. Signal is fading but not cutting off abruptly.

1948:
There is visual sighting of a small craft, leaving a considerable wake. Possibly a patrol boat. (Aircraft are under orders to destroy any small craft that might be in a position to detect the amphibious force on its way in.) Aircraft activates its searchlight. The small craft appears to be a PT-type boat or small motorship.

1949:
The boat has opened fire with small arms and a machine gun. The aircraft is coming down the axis of the boat's course; it will drop depth charges, pre-set for explosion at 25 feet.

1952:
Depth charges are going off as the ASW aircraft turns to come in again. It will launch its HVAR's (5-inch rockets with inert heads).

Import of Scenario to Surface Ship Command and Control Requirements

Magnetic noise due to closeness of underground geological formations that can increase the magnetic background is more prevalent in shallow water, again reducing the potential usefulness of MAD in these operations. This in turn reduces the effectiveness of one of the better classification techniques available and indicates an even greater need for new classification methods.

Scenario I

Import of Scenario to Surface Ship Command and Control Requirements

1954:
Target is on fire as the VP releases its rockets and pulls up.

1958:
Fire disappeared. VP is operating its searchlight again. It is difficult to pick up small objects in the rather rough sea, but the vessel seems to have disappeared.

The Jezebel buoy readout, then, was apparently that of the small patrol boat. With the boat destroyed (at the cost of a considerable portion of the aircraft's ASW ordnance) the VP can now return to its primary mission of seeking out the possible submarine. The aircraft assumes that the submarine will either proceed southward or will remain in the general area to await arrival of the surface force. Datum is 1½ hours old now, and the ability of the aircraft to relocate the submarine can be regarded as mostly a matter of chance. Its Jezebel sonobuoys have only a very limited ability to generate shallow water detections, and the plane cannot saturate large areas with them; it can only monitor 16 buoys at a time, and this will permit it to cover only small areas in view of the expected detection ranges. Visibility is too poor to expect sightings, unless the aircraft happens to pass very close to a submarine on the surface. The plane will go active on radar and patrol the area for a time; at least it can try to keep the sub from using the surface. This will effectively prevent the sub from moving very far while the aircraft remains on station and may possibly create a battery problem for it.

Traffic problems mentioned earlier, sorting out which noise-source is a probable target, will be much more severe in shallow water. The effectiveness of all passive systems operating in shallow water could be improved with accurate knowledge of traffic in the area. This includes range, direction, friendly or possible enemy, and also acoustical spectrum information. This data must be stored and retrieved when needed.

2200:
The VP has had no apparent success. The surface force is now aware of the plane's activities, having established communication via a middleman aircraft link.

This is one very different and very important aspect of possible shallow water ASW problems which was mentioned before. Coordination and timing are

Scenario I

(Launch and retrieval of the middleman aircraft, from the CVs, involved momentary breach of EMCON security.) The OTC will not attempt to turn the force; there is not a great deal of maneuvering room and overall coordination of the amphibious movement requires fairly close adherence to the original course unless an extreme emergency arises.

The submarine that was originally detected by the A-4, and which went down to evade, subsequently attempted to return to the surface. However, it became aware of aircraft activity and decided that a surfaced transit was inadvisable. After a time, it raised its ECM mast to determine whether it could safely snorkel; it picked up radar signals from the aircraft and concluded that snorkeling also was inappropriate. Thus, at 2200, both the aircraft and the submarine are frustrated--the former because it isn't getting any contacts and the latter because it thinks it can't surface or snorkel, and it is falling far behind its predicted SOA and mission requirement.

By this time the three submarines of the task group are spaced some 40 to 50 miles apart, all proceeding in a generally southerly direction. There will be no further communication among them, and their efforts to intercept and attack the amphibious force will be essentially independent operations. They recognize that sinking or disablement of one or two more transport ships will materially delay, and may prevent, the landing.

<u>2400</u>:
The end of the day shows the surface force some 60 miles into Tonkin Gulf. There have been no submarine incidents, or other unusual developments, up to this point. The remainder of the night and the following day will represent the period of maximum danger from submarines. Thereafter, during the final hours of darkness before the landing, the major threat will be from small boats of the type that was destroyed earlier by the VP. But the force itself is probably still too far out to sea to expect a threat from PT boats.

Import of Scenario to Surface Ship Command and Control Requirements

very important aspects in amphibious operations which usually include some shallow water. Is it or isn't it a submarine must be answered quickly since time to act is limited, and out maneuvering the submarine by altering the course is not possible. In the deep water (off shore) case if the mission of the OTC is the safe and timely arrival of a defended force and the threat can be eliminated by evasion, then this would be the normal procedure. The secondary mission, to seek out and destroy the enemy, will be pursued if available forces are sufficient. In general this is not applicable in shallow water, and especially so with an amphibious force making a landing which is very dependent upon timing. The submarine threat must be eliminated.

Scenario I

0600:
Daylight again. During the night there were several "false alarms" that on one occasion resulted in detachment of a SAU. Several attacks were made on that target, which subsequently evaporated and was tentatively classified as a school of fish.

0800:
The force has now been in the Gulf 14 hours. It is steaming through an area where water depth is a little less than 50 fathoms--still more than ample for submarine operations. Dawn brought a low, solid cloud cover with ceiling between 100 and 200 feet; sea state 3 conditions prevail, with some whitecaps. Sonar conditions are still not bad, considering the water depth; the SQS-23 equipped vessels are getting ranges of 4,000 to 5,000 yards, on occasion, on marine life and other nonsubmarine targets, with relatively little reverberation. This is achieved, however, by shifting to the maximum frequency deviation of ~250 cycles and thereby effectively reducing the sonar's power output and its range capability. Inside about 4,000 yards the SQS-29 sonars seem to be presenting a better picture on the scope, with less clutter, than the SQS-23.

At this time, one of the three submarines operating in the Gulf is in fact very close to the surface force, but the submarine doesn't know it yet. Another, which was delayed considerably the night before, is still far to the north, still moving slowly southward. It did not get an opportunity to recharge and is now attempting to snorkel in spite of recurrent air activities originating from both the CVS and the two CVA's. The third submarine is some 50 miles to the east of the amphibious force.

Import of Scenario to Surface Ship Command and Control Requirements

Weapon inventory in shallow water is another OTC requirement that can well be different for shallow water ASW operations. In the deep water (off shore) case usually the terminal point is still some distance and time away and conservation of the limited supply of ASW weapons will be uppermost in the OTC plans. However, when in shallow water and nearing the end of the mission, unloading his arsenal on any suspect target rather than spending classification time could be one solution. If so, a current listing of available armament aboard each ship in the ASW force, its location, time to suspected target, etc., will be a positive requirement that will need more rapid and continued updating in shallow water ASW operations than in general for deep ASW operations. The SAU assigned to investigate a shallow water contact may depend upon the available and applicable weapons aboard the chosen destroyer.

Reverberation discussed in Section 3.324 is one of the limiting factors in shallow water ASW sonar operations. Present data displays and signal processing have not measurably improved detection in reverberation backgrounds. During some operational exercises, some individual operators have improved the clutter problem on displays by reducing the source level which, as noted in Section 3.324, contributes directly to the reverberation level. Reverberation may be the most severe equipment problem necessary to overcome to improve shallow water ASW operations. This improvement will undoubtedly depend somewhat upon improved signal processing, along with scope presentation, displays, and other assists to the human operator, including a better understanding of the basic reverberation problem itself.

Scenario I	Import of Scenario to Surface Ship Command and Control Requirements
0830: The enemy submarine nearest to the force still has no contact, though it is within about 10 miles of some of the screen elements. The mud bottom of the Gulf acts as a blotter, absorbing much of the noise generated by the massive ship formation, and still more is lost through the multiple-bounce effect between bottom and surface. The submarine's sensor range is essentially about equivalent to the horizon as seen through its periscope (that is, about 6 or 7 miles for visual detection, the same for radar, and probably very much the same for its passive sonar). The submarine is operating submerged in water of 40 fathoms' depth. It is a W-class boat and draws about 42 feet of water at periscope depth, with the periscope exposed 3 feet. It is proceeding on the batteries, at 3 knots, with periscope and ECM mast exposed continuously. ECM so far has been unproductive, due largely to the strict EMCON policy adopted by the surface force, but also because during unavoidable periods of electronic emission, the submarine simply hasn't been searching the right frequencies at the right time.	Mud bottoms are not always the case in shallow water, but when the bottom absorbs much of the energy, the reverberation problem is reduced--when the bottom is hard or sandy the assumption of large absorption and minimal transmission does not hold, and extracting the signal from the reverberation background again becomes a severe problem. The shallow water environment, which has been pointed out in this study, of course controls many if not most of these effects we have been considering. Without a complete knowledge of the immediate environment, how it is affecting the particular sonar systems and operation, only gross estimates of what to expect will be available. The need for real time environmental data collected and used during the immediate operation becomes more evident with each problem considered in shallow water ASW.
0845: Submarine has sonar contact--5 kc echo ranging, bearing 195T. Can't discern ship noise.	The 5 kc active source is, of course, the SQS-23. The submarine is most usually alerted to the searcher before the searcher detects with sonar, since the active signal at the submarine is of a much higher intensity, having been reduced by the one way transmission loss only.
0846: Visual search along the bearing has disclosed a faint highlight on the horizon, apparently a ship's superstructure.	
0848: Visual image has not improved noticeably. Echo ranging still held. No bearing rate determined yet.	

Scenario I

Import of Scenario to Surface Ship Command and Control Requirements

0849:
ECM holds a radar signal, of a type carried by U.S. carrier-based ASW aircraft, bearing 205T.

0851:
ECM advises signal strength is increasing. Submarine will hold its present course and will keep its masts elevated; it has little to fear from the aircraft in terms of periscope detection in a sea state 3.

0853:
Sonar advises echo ranging signal is drifting right. The sub will turn to the right to maintain the bearing.

0854:
ECM says signal from the aircraft is still getting stronger. The plane is visible now, a little dot just above the horizon.

0855:
The plane has disappeared into low cloud cover, but signal strength from its radar continues to build up. The submarine does not think that it will be detected, but as a precautionary measure it dips the periscope and ECM masts below the surface. It will carry out regular periscope observations every minute or so, but will not expose the scope for more than a few seconds at a time.

0905:
ECM search; signal diminishing.

0907:
ECM signal lost. Sonar contact bearing is still drifting right, sub has again turned right to try to maintain the bearing. It estimates the contact is on course 350, speed 10 knots. Sonar now has a noise level bearing 190T.

At this point the submarine still does not know whether it has made contact with screening elements of the amphibious force or whether it has encountered an ASW ship, or ships, that are detached from the main body. The surface force itself is still unaware of the submarine's presence.

0913:
The 5-kc echo ranging contact is going to pass about 4 miles off the submarine's bow. The sub cannot close it. However, the sub has now identified 8 and 10-kc echo ranging amid the increasing noise level coming from the south. It correctly deduces that its first contact was with an advance screen unit, or picket, and that the main body is still to the south.

The sub knows there is a good thermal layer at 90 feet, for it takes a BT reading every time it dives or changes depth. Its concealment from approaching surface ship sonars would be considerably enhanced if it went below this layer, but it will remain at periscope depth where its information-gathering activities can be most satisfactorily carried out.

0916:
Visual observation of ships to the south. Periscope reveals masts of three vessels, the nearest being at about 4 miles. The submarine is still attempting to "sort out" the noise level coming from the south but has not been able to ascertain whether there are heavy ships involved. The sonarman is using various filters to make different elements of the overall acoustic signal stand out.

The relatively small W-class submarine is not especially constrained in this shallow water region, as far as speed and maneuverability are concerned. It has some 200 feetof water under its keel when it is at periscope depth. With a layer at 90 feet, the sub probably wouldn't have any special desire to go much deeper than about 150 feet--to get its superstructure, etc., well below the layer.

Scenario I

Import of Scenario to Surface Ship Command and Control Requirements

There are no pinnacles or abrupt depth changes to be concerned about in this area. But the sub continues to move slowly and cautiously, to optimize its ability to obtain intelligence on the course, speed, and disposition of the target. It recognizes that the surface escorts' sonar ranges will be rather short, and it desires to stay at a reasonable distance while it sorts out the target disposition. If it closes too hastily it may find that it has closed the wrong force and it may miss its chance at the amphibious ships themselves; it still is not sure whether this is in fact the amphibious force.

The information-gathering problem for the submarine is acute. It is on its own now; it has had no contact with the outside world for a considerable period of time. The passive sonar cannot present a clear picture of the target, for it is now receiving signals from a multiplicity of sources spread over several miles of ocean area. The visual sensor is barely elevated above a turbulent ocean surface, and the few seconds of exposure time is seldom productive of a clear and undisturbed examination of the horizon, for the waves are high enough to block the view at times. The sub recognizes the short-range utility of ECM, but its ECM receiver doesn't scan frequencies very rapidly, and mostly all it has been picking up are surface search radar signals from DD-type vessels. This still doesn't positively identify the amphibious force. The sub has stopped using ECM now; it is getting fairly close to the surface force and will risk exposure of the attack periscope only.

The surface force also has a critical information problem, the best evidence of which is the fact that it is still completely unaware of the submarine's presence. The low cloud cover prevents effective

Scenario I

Import of Scenario to Surface Ship Command and Control Requirements

visual search by aircraft, and both surface and aircraft radars have little capability in sea state 3 against periscopes. Sonar ranges, as noted earlier, are rather short, and the submarine is still well out of range.

0920:
The submarine can see five destroyer-type vessels now across its bow. Three of the five have moved north of the sub's present position. The approach may have been a bit too cautious; the surface force may be slipping past. But the periscope can discern several more vessels to the southwest, apparently the main body. Range to the nearest ship of the lead row is estimated at about 4½ miles. The sub will go down to penetrate the screen now; it would like to come up near or under the main body.

0925:
The sub has been moving slowly southwest for the last 5 minutes, at a depth of 150 feet. It heard the screws of a DD passing very close overhead; the DD's echo-ranging pattern did not change, and the sub thinks it was not detected.

0930:
Sub is still deep; it can still hear warship noises. Considerable heavy ship noise now.

0935:
Sub is coming back up. Though the enemy submarine crew is schooled in sonar-only fire control with single-ping active ranging and no periscope exposure, the submarine will in this case attempt to generate a visual fire control solution. This procedure is generally necessary to obviate the confusion existing when making an attack on a large ship formation.

Scenario I

0937:
DD-14, a pouncer inside the main screen, has sonar contact--range 1,600 yards, bearing 000T (main body is on course 350 and this is the base course of the DD). This is by no means the first sonar contact for the DD; false contacts are fairly common and are usually resolved in a few minutes. The destroyer's SQS-30 sonar (10-kc version of the SQS-29) is providing a rather strong echo, however. (The sub inadvertently provided a beam aspect, as it had failed to note the presence of the pouncer.) DD-14 reports the contact over the SAU CI circuit and is directed by the OTC to prosecute the contact. DD-3, the nearest ship in the main screen, is directed to assist; DD-3 is actually closer to the contact than DD-14 but presently does not hold contact.

If the contact is in fact a submarine, the situation is an urgent one. The "submarine" is within about 4,000 yards of the main body and within range for torpedo firing. It probably would want to get closer, and perhaps the DD's have a little time to verify the contact.

0938:
As the sub's periscope clears the surface, it observes DD-14 off its port bow, now about 1,300 yards distant; DD-3 is off the port stern quarter, perhaps ½ mile distant. This is disconcerting; the sub has not been able to ascertain the presence of the pouncer in the midst of all the other ship noise, and it had expected to see only heavies ahead of it. As the sub starts to dip its periscope, it observes DD-3 beginning a rapid turn to port.

The sub is now concerned that it may have been detected. It has no specific basis for this concern, as the DD-3's turn may have been only a random one and the DD's were both pinging on short scale all along; there has been no change in scale. But the engagement at this point begins to

Import of Scenario to Surface Ship Command and Control Requirements

In shallow water, since sonar ranges are limited, the possible long range detection providing early warning will not be the usual situation and the 1600 yd. first contact range indicated here may be more realistic than some planners prefer to consider. Early warning, long range, standoff weapons do not conform with the facts of shallow water experience where maybe the World War II conventional depth charge, hedgehogs, and "bang weapons" do. The short range detection, the short range weapon, and the element of surprise are factors in shallow water ASW that must be emphasized in ASW command and control systems. The routine contact report indicated here, DD-14 to OTC, is hardly routine when detection occurs at 1600 yards inside the screen and the OTC must decide to prosecute and who will aid the SAU in the prosecution of the contact, who has enough ordnance to "unload", or will it be necessary to classify and save the ordnance in case other possible subs are also operating in the same area.

assume the aspect of a battle of wits. The starting motors of the steam torpedoes intended for attack on the main body have been warmed up, and the firing order only awaits the final set of inputs from visual observation. The sub, now figuring that it has been detected, concludes that it will not have an opportunity to develop a refined solution. CO decides to fire a spread into the main body while remaining fully submerged; he will then attempt evasion by proceeding toward the formation and trying to escape astern of it. (If the force were more lightly protected, he would possibly attack the escorts and then proceed with his attack on the main body.)

<u>0939</u>:
DD-3 now has contact, range 1,000 yards.

<u>0940</u>:
DD-14 observes torpedo wakes off the starboard bow. The DD is turning toward the torpedoes as an evasion measure. From knowledge of the approximate location of the target and observation of torpedo wakes, the DD cannot be sure whether it is itself the intended target or whether the attack is directed toward the main body. The OTC is advised, but the ships of the main body will have only about 1½ minutes in which to react, and this is not enough time for the slow moving amphibious vessels to take effective action. They may direct gunfire at the torpedoes (this is not far-fetched; it was sometimes done in World War II).

<u>0941</u>:
The submarine is going to 10 knots and descending to 150 feet as it closes the main body. However, DD-14 is holding contact and has interposed itself between the submarine and the amphibious vessels. It is developing an urgent attack to forestall the submarine's approach.

Scenario I

The destroyer's weapon selection problem is complicated not only by the urgency of the attack situation, but also by the shallow water factor. It has Mk 44 torpedoes at its disposal, but the use of the torpedo is questionable in 40-fathom water. The situation appears to call for quick attack with Hedgehogs and depth charges, but the target is now moving fairly rapidly and the effectiveness of these devices is doubtful. The decision is made on the basis of making the submarine fully aware that it is under attack and forcing it down. The DD will cross over datum, launching Hedgehogs at 280 yards--about the time that sonar contact is being lost due to short range--and will roll depth charges as it proceeds on over datum. It will then circle and attempt to regain contact.

0945:
The sub is being rocked by the concussion of depth charges exploding overhead. Additional explosions occur off the bow (as DD-3 joins the engagement, cutting ahead of DD-14). Sub is turning to divert to the south.

0947:
DD-4, coming up from its screen position to the south, is joining the engagement.

0950:
The sub has gone to 220 feet--only 20 feet from the bottom--and is creeping southward at 2 knots. It has been under depth-charge attack continuously for the past 5 minutes. The charges are going off some distance overhead, but their cumulative effect is beginning to create a fine spray of water coming into the interior of the sub in places around packing glands.

Import of Scenario to Surface Ship Command and Control Requirements

Active acoustic homing torpedoes have not enjoyed success in shallow water runs. Attack on bottom or surface are not uncommon. Acoustic torpedoes, too, must operate in a reverberation background. Wire guided torpedoes, Mk 37 and the newer Ex-10, may offer some solutions; however the surface ship launched Mk 37 has had problems in wire separation. The concept of launching acoustic homing torpedoes at submarines inside the screen and among the transitting group is difficult to reconcile with the many adverse problems encountered in bottom and surface capture. Wire guided torpedoes for shallow water with limited wire ranges, less than 6000 yards, may offer some solution; and if so, the contact and display from each launching vehicle (DD) must be contemplated and accounted for in command and control planning for shallow water ASW.

Scenario I	Import of Scenario to Surface Ship Command and Control Requirements
The submarine is not aware that its torpedo salvo resulted in two hits on an LSD in the outer column of the amphibious force; it can hear only the repeated detonations of depth charges. It recognizes that its surface antagonists also can hear only depth-charge explosions and that their sonar is ineffective. Presumably they have had no contact for several minutes. When the barrage ceases, the sub hopes to move quietly off, staying close to the bottom, and perhaps the DD's will not be able to relocate it. The sub still has an important mission to complete--that of transmitting position information on the present whereabouts of the amphibious force.	
<u>0952</u>: The SAU commander (DD-14) has directed the three DD's to terminate the depth-charge barrage. They are about out of ordnance anyway (current destroyers don't carry many depth charges). The DD's will now endeavor to regain contact and will continue to prosecute the contact until directed to rejoin. The submarine is probably not now a threat to the main body, and even with the low SOA of 10 knots the sub could not overtake it again without a surfaced run. But the surface forces recognize the desirability of preventing the submarine from transmitting positional information to shore.	The ordnance problem might not be so severe when coming into an area with prepositioned ordnance for reprovisioning--But unless this is the case, weapon status in shallow water can be a problem. What weapons are available for attack, where are they, and how long to get them on target? The OTC requires that this information be kept current if wasted ordnance is to be the modus operandi instead of target classification. However, ASPECT for ASW classification in shallow water may be well matched with the limited detection ranges and could possibly be an aid to the classification requirement, particularly so for shallow water.

4'. ASW SHALLOW WATER SCENARIO AND IMPORT TO COMMAND AND CONTROL REQUIREMENTS (II)

4'.1 Coastal Convoy. This scenario, also from Ref. 4.1, is termed "a coastal convoy" since the discussion will concern the coastal and shallow water area only.

There are 26 merchantmen, escorted by a half dozen DD and DE types. As they near the Philippines, they have steamed some 8,000 miles since departing Hawaii; they have been at sea for about a month; their 10-knot SOA permits an advance of only 240 miles per day. The merchant ships are steaming in eight columns of three or four ships each, with 2,000-yard spacing between rows and columns. The front of the convoy encompasses an ocean area some 7 miles across. Six escorts are operating in a patrol area screen ahead of and flanking the main body.

It is thought of essentially as a coastal convoy even though deep water is encountered fairly close to the Luzon coastline. The convoy is well within range of friendly shore-based air patrols and can enjoy VP protection.

After penetrating the Luzon Strait, the convoy is still 3 days away from Manila Bay. Somewhat different from Scenario I, "Amphibious Force Protection", this coastal convoy continues to carry out periodic course changes and to move in a somewhat circuitous route, making it more difficult for a would-be enemy submarine to get into attack position. 24 hours before arrival at Manila, the OTC will inform appropriate authorities of his estimated time of arrival at Point X---this point being the seaward end of the swept channel leading into the Bay. The swept channel will be narrow and the convoy will enter in column, with escorts approximately disposed in an entry formation. However, the force will maintain its present broad-front configuration until it approaches to within perhaps 15 to 20 miles from Point X and will begin breaking formation at Point O, the exact location of which will be designated by the OCA. The enemy submarine is attempting to operate in an area that is heavily defended by U.S. forces.

Assuming that Manila is a primary staging area and supply center, the enemy would recognize that U.S. logistics ships and warships would have to enter and leave the port. The submarine still has as a major problem the task of finding and closing targets. If it can put itself in a position where targets are forced to transit, this problem of finding targets will be greatly reduced.

In the 1965 time frame, the enemy submarine would probably be a diesel-electric boat. It would therefore probably retire from the area for most of the night to snorkel (or run on the surface) to recharge its batteries. At pre-arranged times during the night it could receive Fleet intelligence broadcasts that would cause the night snorkel program to be modified.

At sunset, about 1½ days before the scheduled arrival of the convoy at Point X, the enemy submarine that has been maintaining surveillance off Manila Bay is preparing to leave station and proceed westward.

On this night, the Fleet broadcast has alerted the submarine force to a convoy of some 25 to 30 merchantmen with an escort of six destroyer types that has transited the Luzon Strait and is heading south toward Manila.

Heavy weather is in prospect and both the submarine force and the approaching convoy are aware of the worsening weather situation.

The night is uneventful for the convoy, still steaming southward along the Luzon coast. At daybreak the next morning, the force is just 1 day away from its destination. The OTC has conveyed his ETA (0730 the following morning) to the authorities at Manila. The OTC has designated his own ship (DD-2) as air control ship. He will exercise tactical control of the shore based VP aircraft through the air control officer. The convoy continues to proceed southward through a gray sea that is still only moderately choppy.

During the day, the picket ship that has been on station some 10 miles ahead of the main body falls back and joins the screen. DD-2 has in turn dropped back inside the screen to undertake a "pouncer" role. The OTC has determined this disposition, designed to provide defense in depth as sonar conditions deteriorate.

The submarine by this time is endeavoring to prepare for the approach of the convoy, which it assumes will occur some time during the night or early the next morning.

The weather is severe; it is raining very heavily, and winds have created a state 5 condition for which sea keeping is marginal for destroyers.

Scenario II

0105:
The submarine's periscope observation indicates that visibility is, for all practical purposes, zero. It won't be able to see anything until daylight, unless the target is virtually on top of it. Sea state appears to have moderated; there is heavy rain. The submarine will surface to conduct ECM searches; this is easier and more efficient than staying at periscope depth, as long as there is no air activity.

0200:
The center of the main body is now 40 miles from Point 0 (the point at which the force will break formation), on course 130. The convoy will now proceed in a straight line, no more course changes, until it reaches Point 0 at approximately 0600. Point 0 is 15 miles west northwest of Point X, the seaward end of the swept channel. Water depths on this last phase of the transit are variable, but the force will cross the 100-fathom line for good shortly before reaching Point 0.

0300:
Sea conditions are considerably calmer now, though heavy rain continues and visibility is poor. The present conditions could probably be characterized as a sea state 4, with some waves up to 5 feet high and many whitecaps. Rain is not slackening. Due both to weather conditions and to the shallow water now being transited, surface ship sonars are having considerable difficulty. SQS-23-equipped vessels are taking measures, as described earlier, to reduce reverberation. But nothing can be done to stop the quenching effect that is still manifested even in the slackening sea, and sonar screens are a mass of light flecks, periodically "washed out" by quenching. With visibility near zero, surface search radars are operated now primarily for position-keeping; they

Import of Scenario to Surface Ship Command and Control Requirements

As it is probably obvious to the reader from the preceding scenario, one very important aspect of aircraft in ASW is to harass and keep the submarine off the surface when the submarine is a diesel-electric type since this severely limits its operations. Furthermore, most submariners contacted during this study imply they like to use the periscope rather than sonar for a fire control solution, and will usually try to get to the surface for a look. Aircraft further can function as an excellent communication and data relay center since it can get up off the surface to receive and radiate EM energy to all ASW team members.

Scenario II

Import of Scenario to Surface Ship Command and Control Requirements

have no capability whatever, in this weather, to detect periscopes or snorkels (in the unlikely event that some submarine would be attempting to snorkel).

The submarine, too, is observing some moderation in sea conditions. This has both good and bad aspects from the submarine's viewpoint. If conditions had gotten any worse than they were a few hours ago, the sub probably could not have made an attack even if it had been able to locate the surface force. However, it is now counting on adverse weather to facilitate its attack plans. It has about concluded that it has little chance of intercepting the surface force on this black, rainy night, in the open sea. It can't see more than a few feet, literally; sonar conditions are very bad; and ECM performance is inhibited by atmospheric conditions. The sub has decided to enter the "hornets' nest" just off the seaward end of the swept channel and await the arrival of the convoy. It is now retiring on the surface to this area where it will stand by, at periscope depth, in 35 to 45 fathoms of water. Assuming present weather conditions continue past daylight, the sub thinks it can get off an attack from this point. (In very good weather, with extensive air activity in the area, the sub would be dubious about taking station so close in to shore and in water depths such that it would be constrained in both depth and speed.)

<u>0400</u>:
The main body has some 20 miles to go before reaching Point 0; that is, the guide ship in the center of the first row in the main body is 20 miles away. Some screen ships are 3 or 4 miles closer. Sea conditions have continued to improve, which will facilitate the execution of the complicated maneuvers that will begin at Point 0.

Scenario II

Low frequency sonars, both SQS-23 and SQS-29, are likely to provide many non-submarine contacts in shallow water, and it may be assumed that the escorts are in fact picking up such false contacts. When they do, the first reaction will be to check the wreck charts. Unfortunately, it is difficult to pinpoint contacts accurately enough to identify a given contact positively as a wreck. Also, in poor visibility the ship's own uncertainty as to its position may make it difficult to determine precisely where it is relative to the known position of the wreck.

If submarine contacts are generated now the convoy will continue to steam directly for the breakup point. To attempt evasion, with this slow and awkward merchant ship formation, would only increase exposure time and perhaps give an enemy submarine a better opportunity for reattack.

0410:
The submarine still has no contacts at all. Sea conditions continue to improve, and the tremendous strain involved in maintaining depth control at periscope depth is moderating. The sub has periscope and ECM mast up all the time now (it is aware that there is still no air activity) but hasn't generated any contacts.

0415:
The convoy continues to experience steadily improving sea conditions. However, search sonars are still not providing anything approaching their deep water capabilities. Reverberation is severe for all sonars in the relatively shallow water through which the force is moving. It is difficult to generalize about detection ranges in this shallow water environment, but a reasonable guess is that detections at ranges greater than 1,000 yards are most unlikely.

Import of Scenario to Surface Ship Command and Control Requirements

The SQS-26 will probably be plagued with even more non-submarine target problems than the SQS-23 and 29 series. With better signal processing against reverberation, more targets can possibly occur, which may be the most serious problem to future SQS-26 operations in shallow water. If so, present position of known wrecks, which for the South China Seas are now stated in a catalog, will need to be known and correlated accurate[ly]. How much error can be allowed between the suspected false target and suspected enemy submarine? This is important but was not resolved during this requirements study. False targets from the bottom are peculiar to shallow water ASW operations and there is a definite requirement to provide the capability to d[if]ferentiate between known false target and suspected target positions. These positions must also be known rapidly, since as mentioned in the previous scena[rio] the transitting force cannot in general be rerouted away from danger while the contact is investigated.

This is a sad but accurate commentary on shallow water sonar systems, judging from a review of operational results. Our cur[r]ent capability in shallow water, due to reverberation, propagation loss, and displays, is only good compared to World War II. And even worse, the capability to assess how poor the detection capability (range) is in shallow water is non-exist[ent]. Predicting sonar detection range (ESR) in shallow water is not an in-Fleet capability today. Even in deep water the ESR prediction has been found wanting and some fleet operators suggest that it be measured.

Scenario II

Import of Scenario to Surface Ship Command and Control Requirements

0530:
The submarine has a contact at last. Sonar reports ship noise, a noise level in the quadrant bearing 270 to 360. Can't pin it down any better. There appears to be more than one noise source. The noise is in the form of a rumble, like that of a freight train, that probably represents ship noise; but sonar can't ascertain whether it is from a group of "heavies" or not.

0535:
Sonar now holds the "chirp" of a 5-kc sonar, echo ranging at a true bearing of about 295. ECM has been carefully searching over known U.S. frequencies but hasn't picked up anything. Still nothing in sight, but that is not surprising as visibility is still near zero.

Meanwhile the convoy has been advised that it will have some air support during the last hours of its transit, after all. Planes have been in a standby condition most of the night, awaiting improvements in weather conditions. The OTC is now advised that the two skimmer-scrapper teams will not operate as such; rather the S-2's will be placed under the OTC's control for prosecution of close-in sonar contacts (since sonar contacts are expected to be frequent in the inshore environment). The aircraft cannot use JULIE for localization and classification of contacts, and they are not configured to carry the SSQ-15 active sonobuoy, which has some shallow water capability. Their primary sensor against submerged submarines will be MAD, though MAD also is degraded in shallow water. These two aircraft will rendezvous with the convoy at 0600. A detachment of three more S-2 aircraft is currently commencing MAD sweeps through the channel, as the minesweepers have now completed their work in the channel. After completing their sweeps, these aircraft will take

Without any useful sonar detection capability in shallow water the aircraft ca always assist as a visual ASW platform and relay station. The frequent sonar contacts as suggested here in the Scenar are experienced operationally, but to pro pose MAD as any more than a partial solu tion is not justified. MAD too is susceptible to wrecks and inshore magnetic environment (possible magnetic noise due to nearness of large geological formations). Also aircraft navigation as a relative position measure is no better, if as good as, shipboard for differentiating between position of a known wreck and the position of a possible contact. Note! Using MAD techniques with mine countermeasures is not too applicable. Mine countermeasures using magnetic tracking devices generate magnetic field which distort MAD readings. During operations considered here with the mine countermeasure forces in conjunction wit the ASW forces, a real need for coordinating mine sweeps and aircraft MAD operation will be a requirement.

Scenario II

station in the vicinity of Point 0 and will also be at the disposal of the OTC for prosecution of contacts. Three shore-based ASW helicopters (SH-3A) have begun dipping operations at Point X and are sweeping toward Point 0. They will report to the air control officer and may be utilized at the discretion of the OTC during the entry.

Import of Scenario to Surface Ship Command and Control Requirements

Mine countermeasure forces can provide some ASW capability in shallow water and as such should interface with shallow water ASW forces. This brings a distinct facet of shallow water ASW unrelated to deep water ASW operations of which command and control requirements and technology must be aware.

The mine countermeasure ships use high frequency sonar for mine hunting that have ranges on small mines to as far as 500 yards and on submarines, with much larger target strengths, this range may be increased. (The SQQ-14 uses 80/kc for detection and 380 kc for classification. Much higher frequencies are used for other mine hunting systems but they are range-limited and not considered.) These mine countermeasure ships can surely help perform localization and classification in shallow waters. Furthermore the relative navigation accuracy requirements for mine countermeasures operations, in gener is much higher than for the ASW forces. This accuracy will be available for ASW ships, which may be necessary in shallow water for false target classification. Many of the false target problem areas in shallow water can conceivably receive a very large assist from these mine counter measure forces. Here then is another interface problem of large proportions and importance to command and control technology: the transfer of information from the mine countermeasure ships to the ASW ship pertaining to target detection, classification, localization, and possible weapon choice. The mine countermeasure force will in general be part of most any naval operation in shallow water near enemy shores and can provide a real ASW service

Scenario II

Import of Scenario to Surface Ship Command and Control Requirements

0540:

As the convoy begins to react to the impending arrival of air support, the submarine is attempting to develop further information on the contact gained 10 minutes earlier. Both ship noise and echo ranging are very noticeable now, flooding the sonar over a bearing bandwidth of more than 90 degrees. But the sub still can't see anything. As the sea continues to grow quieter, depth control is easier, and the sub has ascended to a point where the top of the sail is nearly awash, in order to increase the periscope height and obtain a better view. There is a dim gray light over the land areas to the east but this is not much help to the sub, looking west. If the weather were clear, a rising sun would highlight masts and superstructures at considerable distances, but the heavy overcast that still prevails will mean poor visibility even after sunrise. The sub decides it cannot improve its position by maneuvering; it will await the approach of the surface force. If there is an engagement, the sub will have to close to short range--probably not much more than 1,000 yards--to fire salvos of torpedoes.

Again in the Scenario the short range us for weapon launch is emphasized. At thi range even a slow 30 knot torpedo will permit only two minutes of evasion or countermeasure time for the ship under attack; i.e., total reaction time can only be one minute. Accordingly, response time becomes an even more important parameter under the shallow water limitations assumed here.

0550:

The convoy is still steaming in an unchanged formation, still on course 130. Point 0 is about 1 mile from the leading row of the main body, and a redisposition into the entry formation is about to begin. All escorts are experiencing very poor sonar performance, and sonarmen are taking measures to reduce the gain and darken scope. (Sonarmen are sometimes criticized for darkening the scope too much and thereby giving up potentially useful information, but in these conditions the desirability of a darkened scope is enhanced.)

At this point the scenario again indicat the experience of the operating forces with reverberation problems during exercises, which at times reduce the usefulness of sonars in shallow water to almost zero. The reference here to a darkened scope implies the operators are attempti to eliminate some of the numerous spots appearing on the display, indicating acou tical returns from all over the area rat than just from the target. This is the general reverberation problem. The numerous spots on the scope are an indication that the echo level/reverberation level is small indeed. This parameter, echo level/reverberation level, is not necessarily constant with range and ther could be a best range for search depending upon the bottom slope, type, grazing angle, and operating frequency.

Scenario II	Import of Scenario to Surface Ship Command and Control Requirements

0600:
The sub is still searching visually for a target. Now it finally discerns something, perphas a little darker than the darkness of the sky. Once located, the target is identified with more assurance as in fact a ship. Stadimeter range determination is not feasible, but in view of the fact that the sub can see the hull, as distinguished from merely masts or superstructure, and further in view of the apparent lateral dimensions of the hull, it is likely that the target is not more than 2 or 3 miles distant. Steering the listening array to the precise bearing of the target, the sub's sonarman can pick out 10-kc echo ranging from among the confusion of ship noise now flooding the sonar. The sub will continue to wait; the massive surface ship formation will require considerable time to break formation and even when the first "heavy" passes Point X, it will probably still be almost 2 hours before the last one enters the channel. The sub figures it has plenty of time, and it expects to take advantage of early daylight to facilitate its fire control solutions.

0612:
The sub can see several ships now, as lighting conditions improve. However, contemplation of these potential targets is abruptly interrupted by the sudden onset of 10-kc echo ranging on the submarine's beam, on the port side, loud and clear. The sub had neither seen nor heard the helicopter that is immediately recognized as the source of the echo ranging. It is visible enough as the CO swings the periscope toward the bearing, just before ordering "down scope." The sub cannot go deep here, for there is a maximum of about 40 fathoms of water; but it will go to 150 feet (keel depth) and hover. It was only making 2 knots, just enough to maintain steering and depth control, but will increase speed in order to hasten the depth change by making use of its diving planes.

Helos, as surprise sonar platforms when other background noise is high as from a convoy or ASW force, provide an excellent pouncer platform. Once they have a target they may need to communicate or direct a weapon-carrying vehicle to the target to provide the kill. Although some currently carry weapons, their best use is to hold the contact and direct another ASW platform carrying several weapons (torpedoes), or direct another Helo in to drop its weapon.

Scenario II

Import of Scenario to Surface Ship Command and Control Requirements

The helicopter that was the source of the submarine's discomfort has indeed gained a detection. Range is 600 yards, probably accurate to within plus or minus five percent. The north-stabilized dipped sonar gives a true bearing from the helo as 350. The helo cannot simply turn toward the datum and close the contact. Before it can move, it must get the dipped sonar clear of the water (winch speed is 5 feet per second and if the helo is using all 150 feet of available cable, some 30 seconds would be required to retract it completely. However, the helo can move out of the hover position as soon as the sonar is clear, and before it is fully retracted). The helo can hover only into the wind, and when it shifts from hover to forward flight, it must head into the wind. It must build up an indicated airspeed of 60 knots before it can turn; otherwise it may fall into the water. So the helo will actually have to head away from datum for a few seconds, then turn in such a way as to come up on datum from downwind. It will still require 30 seconds or more to reassume a hover position and again lower the sonar into the water. Thus a signal helo is unlikely to attempt to pursue and attack a submarine contact; rather, its tactics will be designed to tract the contact while bringing other units into the picture. (Of course, if contact is visual, so that classification is clear and the target is located precisely, the helo may proceed immediately to datum and release a weapon. But with a sonar contact, further evaluation and the participation of other units are most likely.)

<u>0613</u>:
The helo has advised the air control officer aboard DD-2 of its sonar contact. This is not cause for immediate excitement or frenzied activity in the destroyer's CIC; there have been a number of sonar contacts in the last couple of hours and all have been disposed of, with varying degrees of certainty, as nonsubmarine. Sonar contacts are to be

At this point in the scenario the target classification problem is again made very evident. In the future the classification problem, rather than reverberation, may be the most critical problem in shallow water ASW when sonars like the SQS-26 with increased capability for signal processing become available. Contrary to the many varying comments

Scenario II

expected in shallow water, and the odds are that this one is another false alarm. However, the air control officer reacts in an appropriate manner. He directs an S-2 to proceed to the assistance of the helo. The nearest escort is about 4,500 yards from datum and is presently turning away to take its place in the entry screen barrier. This is DE-6, an SQS-23-equipped destroyer escort with DASH, Weapon A, and acoustic homing torpedoes. The OTC decides, however, that his own ship, DD-2, is better configured for the kind of urgent attack that will be dictated if the contact proves to be a valid one. Therefore DD-2, in a pouncer role, will move in on the contact if further assessment indicates a reasonable possibility that it is in fact a submarine, and DE-6 will assist. (This will require the OTC to delegate his overall responsibility for maneuvering of the force to another ship, for vigorous prosecution of a submarine contact with his own ship will require his full attention. But, DD-2 is considerably better placed, at present, to prosecute the contact if this is necessary than is any other ship with SQS-29 sonar and short-range weapons.)

<u>0614</u>:
The helo hasn't moved yet. It has continued to ping on the target and has picked up doppler effects indicating target movement. The target moved west, into the wind, but now appears to be stationary, or nearly stationary. Perhaps the doppler indication was imagined; possibly the target is indeed a stationary object--a wreck or pinnacle. (The noisy, vibrating helo is far from an ideal platform in terms of providing a quiet, stable environment for deliberate assessment of sonar output. Because of the weather conditions--operating the helo at all in this weather is a difficult business--the aircraft is carrying a three-man crew instead of the usual four. The assistant sonarman was left on the deck to reduce weight, and there is only one sonarman aboard.) Bearing of the contact

Import of Scenario to Surface Ship Command and Control Requirements

on the large power source of the SQS-26 and its negative contributions to the reverberation problem, this may be partly solved with improved data processing, but the SQS-26 may have a much more severe problem in classifying the many multiple targets detected in shallow water operations. Classification, always a problem in deep water, will become much more severe in shallow water with longer range detection systems.

As is evident here, a very important decision is now made mandatory since classification <u>is not positive</u>--i.e., the OTC has delegated his overall ASW responsibility to another commander and has taken on the role of a subordinate SAU Commander. Without a positive classification he is prepared for the worst, an enemy submarine, and decides his own ship is best equipped at the time to nullify this threat. All this because he is not sure--Is it a submarine?--In shallow water his convoy cannot evade, he must take every precaution, and in this case, assign his own ship to the datum.

Scenario

has moved over to about 340, range 680 yards. The S-2 is flying over datum to attempt a MAD confirmation.

0615:
S-2 has obtained MAD contact. This still doesn't prove anything conclusively; any sizeable metallic object or bottom anomaly could cause the needle to jump. The S-2 will circle and come over datum again.

The sub, meanwhile, is hovering at 150 feet, with 90 feet of water under its keel. It doesn't want to go down and sit on the bottom, as it might damage its chin-mounted electronics. It can hear the helo still echo ranging, but is otherwise unable to keep track of what is happening on the surface. It is willing to hover here for a prolonged period, as it still expects to have plenty of time for attack on the convoy.

0616:
S-2 has another MAD contact. Aboard DD-2, wreck charts have been reexamined; there does not appear to be anything charted that would explain the contact. But the contact is still classified as "possible" submarine, not "probable". Aircraft have been briefed to carry out attacks on possible contacts only in accordance with particular tasks as directed by the OTC.

The breakup of the convoy is under way. The screen has already begun a re-disposition. If the contact is a submarine, it is positioned where it will constitute a continuing threat to the entry operation. The incoming convoy will pass very close to the datum. The OTC decides that an attack is warranted, and so advises his air control officer, who, in turn, advises the helo, which still holds contact and is directing the S-2.

Import of Scenario to Surface Ship Command and Control Requirements

The comparison of an estimated submarine target position in shallow water with a wreck chart is a very gross comparison. To be sure, the position should be resolved at least to submarine length (300 ft or less). And even then it is doubtful that a high degree of confidence in classifying a false target "yes or no" will be attained. This again is a peculiar shallow water navigation, position plotting, and classification problem that must receive high priority, or excessive ordnance should be available. In shallow water the suspected submarine cannot be avoided.

Scenario II

<u>0618</u>:
S-2 is coming in on the MAD mark for a depth-charge attack. The aircraft has a mixed load of Mk 44 torpedoes and Mk 54 depth charges, but the use of the torpedoes is thought inadvisable because of water depth. The aircraft drops three depth charges across datum; depth charges are pre-set to explode at 50 feet. (Usually these charges are ineffective unless the sub is shallow enough to be visible, or unless it has at least a periscope exposed. However, visibility is still too poor to see anything unless the sub was actually awash, and it seems unlikely that it could be very deep in view of the 40-fathom water depth.)

<u>0619</u>:
Sub is rocked by depth charges going off overhead. Quick evaluation indicates no apparent damage. The attack was clearly very close, however. The submarine is now confronted with the question of whether to clear the area and defer its own attack plans for perhaps an hour or so, or whether to remain where it is and hope that it can still lead the attackers to believe that it is some sort of non-sub contact. It has no way of knowing what degree of certainty is attached to the classification made by the air and surface forces opposing it. By making an effort to clear the area, it may provide additional classification information to the attackers, thereby helping to resolve a doubtful classification and increasing the likelihood of further attacks. But if it merely remains quiescent, it may undergo repeated attacks; clearly the attackers have pinpointed its present location.

The sub doubts that it will be left alone. The chances that it will be able to return to periscope depth to carry out its own attack plans would appear to be greater

Import of Scenario to Surface Ship Command and Control Requirements

The torpedoes are not only easily bottom or surface captured and reverberation limited but they also have little target discrimination. Enabling an acoustic torpedo against a submarine target in shallow water amidst a convoy is a dangerous weapon commitment. Without positive control over the torpedo, a convoy ship could easily become its target. The submarine cannot be very deep in shallow water, and although torpedoes have ceiling settings, they can run very near or on the surface when the ceiling switch malfunctions.

Wire-guided control of the torpedo in shallow water from a sonar display, and a possible false target planted near the suspect target for bearing guidance, could offer a solution. This is the LORELI concept, and should be considered for shallow water weapon control and direction.

if it can change its positi... It decides to make an attempt to close the approaching convoy and get under it. There will be a tremendous amount of noise in the water, confusion of ships maneuvering to break formation, etc. This may be the safest place for the sub, and probably will also be the most feasible course to take to develop its own attack. It will move due west for about 2 miles to see whether it can lose the helicopter. Sub will remain at 150 feet and go to 6 knots (higher speeds may be hazardous as the sub isn't absolutely familiar with the bottom topography).

<u>0621</u>:
The helo is settling down over the last known datum, hovering into the wind and lowering its sonar transducer again. As echo ranging begins it picks up the target once more, bearing 280 true, range 750 yards, distinct down doppler. The target is moving. This adds further credence to the judgment that it may indeed be a submarine. The OTC is so advised, and decides to take further action. DD-2 is now about 4,000 yards from datum. The destroyer will proceed to datum in company with DE-6, where it will assume direction to further action against the contact.

<u>0625</u>:
DD-2, being guided to the contact area by the helo, has sonar contact, range 1,300 yards. This is a fairly long range, in view of water conditions, but knowing where to look is very helpful. The DD is getting an up doppler and estimates the speed of the contact as 5 knots, course 270.

<u>0627</u>:
Range 600 yards. The DD has directed the helicopter to secure its sonar and proceed astern of the ship and upwind, to carry out dipping operations between the ship and the main body, which is beginning to break up and form a column about 3 miles astern.

Scenario II

This is clearly an urgent attack situation. While there is still no positive evidence that the contact is a submarine, the various indications suggest that it may be. If it manages to get among the ships of the convoy it can do a great deal of damage; ships are highly vulnerable during the interval between breaking formation and entering the swept channel. The DD will make every effort to keep the sub down or destroy it.

0628:
DD-2 is carrying out Hedgehog and depth-charge attacks over datum. Like the helo before it, the destroyer is dubious about the utility of homing torpedoes in this shallow water environment. Anyway its overriding requirement at this point is to keep the sub down and prevent it from maintaining its present course toward the convoy. The depth charges, even if they don't actually destroy it, will at least "disturb its equanimity" and perhaps break up its aggressive plans.

0630:
The sub is experiencing another series of shocks from exploding depth charges. Also, the Hedgehogs are going off as they impact on the bottom. The sub is apparently undamaged, but the cumulative effects of depth-charge attacks are probably more significant than a single chance hit. However, there is always the possibility that one of the massive charges will detonate in direct proximity, and if it does, that will end the action.

Import of Scenario to Surface Ship Command and Control Requirements

The possible loss of a ship at this time requires the OTC to make another decision that is unique to shallow water ASW operation. Was it a mine or a torpedo? If a torpedo, there is "a wolf among the flock" and every suspect must be attacked. If a mine, must the mine countermeasures forces provide still more sweeping and hunting? The interface between the mine warfare countermeasures and the shallow water ASW forces becomes more obvious when these decisions must be made. What mines are possible?--moored floating, bottom buried? Are the mine countermeasures forces cognizant of a possible enemy submarine? Has a suspect been noted? When? What are the position accuracies of the present known torpedoed or mined ship in respect to mine countermeasures possible mine positions, or enemy submarine? These are not trivial question in the context of a real engagement and could present the OTC with the most frustrating and important decision of his entire mission.

Appendix A

THE ASW FORCES AND THEIR COMMANDS

A.1 ASW Organizational Commands (Ref. A.1). The tactical command and control of ASW forces considered in the main section of this report began at the command level of the Officer in Tactical Command (OTC) and extended down through the ASW Commander (if so designated), the Screen Commander, the Search and Attack Unit (SAU) Commander, the Contact Area Commander (CAC), to the ASW Platform Commander.

Although the main study was not addressed to ASW commands above the OTC, the overall ASW forces and their command above the OTC are outlined in this Appendix for a limited understanding of overall command responsibility. For a more complete discussion on ASW command responsibility, see Ref. B.1, which covers the Operating Forces of the Navy.

The Organizational Commands comprised for Antisubmarine Operations are:

The Chief of Naval Operations
The Fleet Commander in Chief
The Fleet Commander
The Sub-Area Commander
Sector Commander (if required by the Sub-Area Commander)
Supporting Commanders

These command relations are shown on Fig. A.1, "ASW Organizational Commands."

A.2 ASW Unified Command Responsibility. CINCLANT and CINCPAC are responsible for the overall coordination of antisubmarine operations throughout the Atlantic and Pacific Oceans, the western and eastern portions respectively of the Indian Ocean, and their contiguous waters. These commanders in chief, in coordination with adjacent commanders in chief, are directed to develop overall plans to provide for the best utilization of available resources for the conduct of these operations against enemy submarine threats in any specified area. Commanders of adjacent unified commands submit their plans pertaining to ASW in their areas to CINCLANT and CINCPAC for integration into the overall plan.

A.21 ASW Command Relations in the Atlantic Fleet. Commander Antisubmarine Warfare Force, U. S. Atlantic Fleet, is the commander under CINCLANTFLT responsible for defensive and other designated operations.

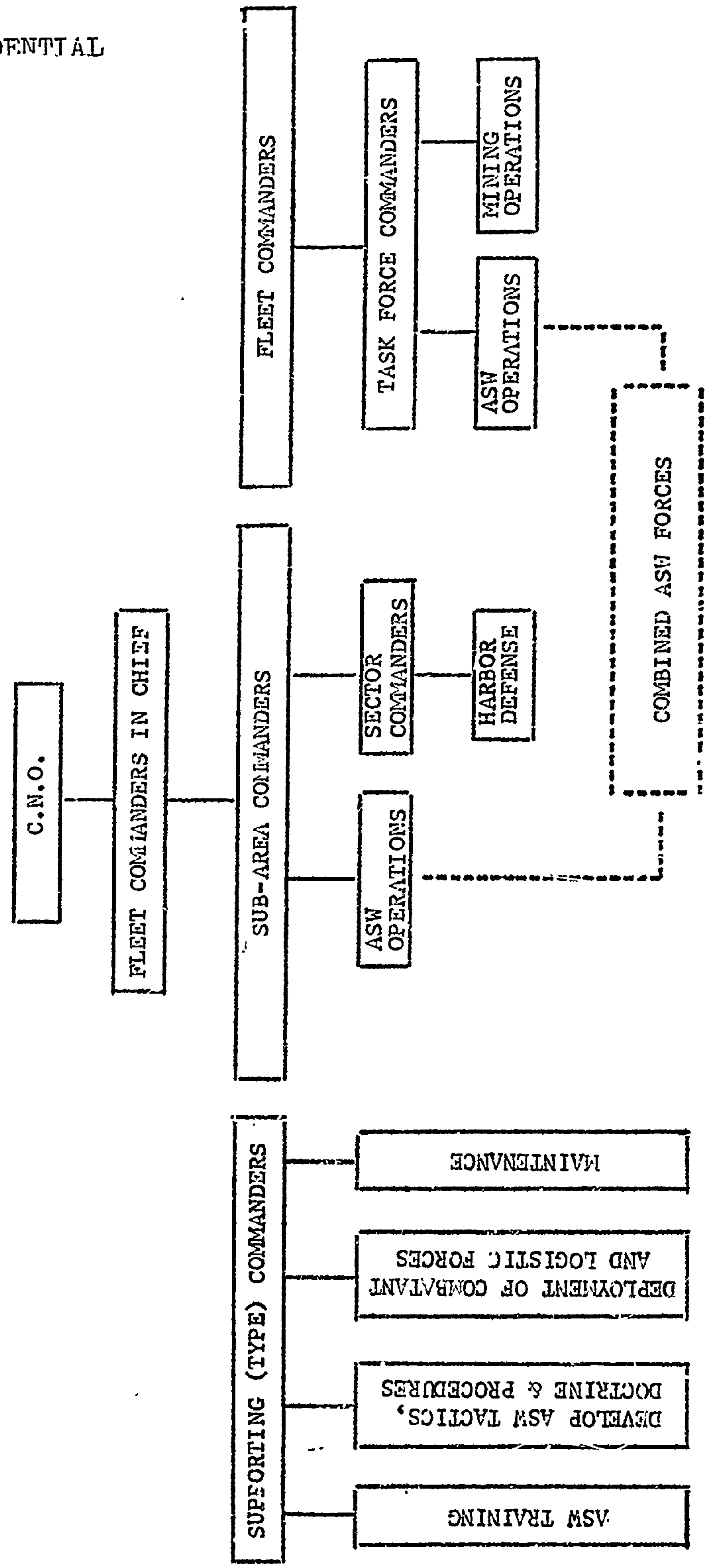

Fig. A.1. ASW Organizational Commands

Ref. 1.4.

Commander ASWFORLANT directs the submarine investigation efforts of sub-area commanders other than USCOMEASTLANT and coordinates with USCOMEASTLANT in accordance with the current CINCLANTFLT INSTRUCTION 03360.5.

COMSUBLANT conducts submarine, antisubmarine operations and other operations as directed by COMASWFORLANT.

Commander Barrier Forces, U. S. Atlantic Fleet (COMBARFORLANT), is responsible to COMASWFORLANT for the conduct of barrier operations in the Atlantic Command area.

Commander Hunter-Killer Force (COMHUKFOR) (CTF 83) is also responsible to COMASWFORLANT for the conduct of barrier operations in the Atlantic Command area.

COMHUKFOR (CTF 83) is also responsible to COMASWFORLANT for tasks as specified, relating to the employment, training, and readiness of assigned antisubmarine carrier groups and for the development of A/S carrier group tactics, doctrines, and procedures.

COMASWFORLANT is assigned additional duties as COMOCEANSUBAREA (CTF 85) and Commander Close-In Defense Force (CTF 81).

A.22 ASW Command Relations in the Pacific Fleet. CINCPACFLT exercises centralized direction of ASW operations in PACOM through COMASWFORPAC, COMFIRSTFLT, and COMSEVENTHFLT.

COMPACFLT directs the ASW operations of PACFLT forces through COMASWFORPAC and the numbered Task Fleet commanders. COMASWFORPAC serves as the principal advisor to CINCPACFLT in all matters pertaining to ASW and control and protection of shipping. The PACFLT OCA's are elements of the ASWFORPAC task organization and hold task force designators in the 30 series. Task force designators in the 30 series are used exclusively for ASW and control and protection of shipping for operational purposes in PACFLT.

A.3 Contacts with Unidentified Submarines. COMASWFORPAC has the overall responsibility for investigating incidents involving hostile or unidentified submarine contacts. He exercises this responsibility through the Operational Control Authorities (OCA), who have cognizance for all incidents in their assigned area.

Under Fleet Commanders in Chief are Sea Frontier Commanders and certain other Naval Commanders who serve as Operational Control Authorities (OCA). These latter commanders are charged with the control of the movements of U. S. and designated Allied merchant ships at sea within their respective ocean areas as follows. In both Fleets this overall command responsibility is assigned to Commander ASW Forces.

A.31 <u>Atlantic Command</u>.

CINCLANTFLT OCA (Ex-Officio)
- a) COMASWFORLANT OCA (Ex-Officio)
  - 1) COMOCEANSUBAREA OCA
  - 2) COMEASTSEAFRON OCA
  - 3) COMCARIBSEAFRON OCA
  - 4) COMSOLANT OCA
  - 5) USCOMEASTLANT OCA

A.32 <u>Pacific Command</u>.

CINCPACFLT OCA (Ex-Officio)
- a) COMASWFORPAC OCA (Ex-Officio)
  - 1) COMNAVDEFEASTPAC OCA
  - 2) COMALSEAFRON OCA
  - 3) COMHAWSEAFRON OCA
  - 4) COMNAVFORJAPAN OCA
  - 5) COMNAVMARIANAS OCA
  - 6) COMNAVPHIL OCA

Appendix B
ASW SYSTEMS AND SUBSYSTEMS

B.1 General Ship Characteristics for ASW. The largest ships doing ASW duty are the CVS Carriers which serve as mobile bases to support fixed-wing ASW aircraft. These carriers normally operate at about 15 knots and can operate at sustained speeds in excess of 30 knots. The aircraft complement is given under "ASW Aircraft," Section B.4.

The workhorse of surface ASW operations is the destroyer and destroyer-type ships. Destroyers are designed to perform several Naval tasks, and all are designed to perform ASW functions. Although these ASW ships are not necessarily configured for ASW operations, their required equipments and weapons for submarine detection and kill are many and costly.

B.11 ASW Ships Relative Size and Speed. The largest ASW ships are the Frigate type, DL and DLG, with cruise speed at 20 knots and maximum sustained speed of approximately 35 knots. Cruisers, which may operate independently, also operate with ASW forces; but usually they do not operate as members of a surface screen, and as such are not included here.

The next class size, the Destroyer DD's, DDE's, DDR's, and DDG's, have cruise speeds around 12 knots; but like the larger Frigate Class, some classes can operate at maximum sustained speeds near 35 knots.

The smaller patrol-type ships, the DE's, DEG's, and DER's, operate at various cruise speeds 10 through 20 knots; and future DE's in the current building program will operate at maximum sustained speeds in excess of 27 knots.

B.12 ASW Surface Ship Classes.*

B.121 The Destroyer Types most common are the destroyer DD's (Gearing, Sumner, LaVallette, and Sherman classes), Mitscher class frigate (DL), escort destroyer (DDE), radar picket destroyer (DDR), and escort vessel (DE).

These destroyers are World War II ships for the most part. All of the DD-931 class are post-war construction. The FRAM I conversion provides the old DD's with SQS-23 sonar and ASROC (AS Rocket Launched Torpedo). The FRAM II conversion provides them with SQS-29 sonar and DASH (Drone AS Helicopter). The more recent ships, the DDG's, mostly have the SQS-23 sonar and ASROC.

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*See Tables B.1 and B.1' for more complete details.

Vessel Class	Length/Beam (ft) (ft)	Draft/Displacement (ft) (tons)	Complement Off./Enlist	Max. Sust. kts/n.mi.	Cruise kts/n.mi.
Patrol Craft Type					
DE-1006 Dealey	325/36	17/1,980	11/159	25 /1670	12/ 6000
DE-1037 Bronstein	372/41	23/2,650	16/180	24 / --	15/ 4000
DE-1040 Garcia (Bldg)	415/44	24/3,400	13/226	27.5/ --	20/ 4000
DE-1052 (Bldg)	418/44	25/3,600	13/195	27 / --	20/ 4500
DEG-1 Brooke (Bldg)	415/44	24/3,400	14/226	27.5/ --	20/ 4000
DER-386 Savage	306/37	11/1,990	13/185	20 /3900	10.5/13300
Destroyer Type					
Fram II DD-692 Allen M. Sumner	376/41	20/3,250	18/290	32 / 865	12/ 3990
Fram II DD's (710, 711, 764, and 825 classes)	391/41	19/3,540	18/270	31 /1430	12/ 5800
Fram I DD's (DD's, DDR's, and DDE's)	390/	/2,425	23/350	35 /	11/ 5155
DD-931 Forrest Sherman	419/44	19/4,050	18/305	31 /1300	20/ 4500
DDG-2 Chas. F. Adams	437/47	22/4,500	18/316	30 /1800	12/ 5500
Frigate Type					
DL-1 Norfolk	540/54	26/7,300	35/488	31.5/1600	20/ 6000
DL-2 Mitscher	493/50	21/5,000	24/345	34.2/ 800	20/ 5000
DLG-(N)-25 Bainbridge	565/58	26/8,580	27/423	29 / --	20/ --
DLG-16 Leahy	533/53	25/7,630	24/352	31 /2100	20/ 5500
DLG-26 Belknap (Bldg)	547/54	29/8,150	25/415	31 / --	20/ 7100
Carriers					
CVS, Modernized Essex Class Yorktown	890/196	31/40,600	128/2000	30 /4600	13.4/14,000

Table B.1. ASW Surface Platform Characteristics.

Refs. B.1
B.2
B.7

Vessel Class	Sonar		Radar		ASW Fire Control Systems	Weapons			No. in Active Fleet, Yr.			
	Hull	VDS	Surf. Search	Air Search		ASW	AAW	SSW	64	66	68	70
Patrol Craft Type												
DE-1006 Dealey	SQS-23	None	SPS-5	SPS-6	Mk 105	DC, Wp. A, DASH, Mk 44, 46, 37 torps.	3"/50	3"/50	13	13	13	13
DE-1037 Bronstein	SQS-26	None	SPS-10	SPS-40	Mk 114	ASROC, DASH, Mk 44, 46, 37 torps.	3"/50	3"/50	2	2	2	2
DE-1040 Garcia (Bldg)	SQS-26	None	SPS-10	SPS-40	Mk 114	ASROC, DASH, Mk 44, 46, 37, 43 torps	5"/38	5"/38	0	8	12	12
DE-1052 (Bldg)	SQS-26	SQA-13	SPS-10	SPS-40	Mk 114	ASROC, DASH, Mk 44, 46, 37, 48 torps	5"/38	5"/38	0	0	9	33
DEG-1 Brooke (Bldg)	SQS-26	None	SPS-10	SPS-40	Mk 114	ASROC, DASH, Mk 44, 46, 37 torps.	Tartar	5"/38	0	6	11	17
DER-386 Savage	SQS-29	None	SPS-10	SPS-28	Mk 105	HH, DC, Mk 44, 46, 37 torps.	3"/50	3"/50	20	14	11	11
Destroyer Type												
Fram II DD-692 Allen M. Sumner	SQS-29	SQA-10	SPS-10	SPS-29	Mk 105	HH, DASH, Mk 44, 46, 37 torps.	5"/38	5"/38	33	33	27	0
Fram II DD's (710,711, 764, and 825 classes)	SQS-23	SQA-10	SPS-10	SPS-29	Mk 105	HH, DASH, Mk 44, 46, 37 torps.	5"/38	5"/38	10	10	4	0
Fram I DD's (DD's, DDR's, and DDE's)	SQS-23	None	SPS-10	SPS-29	Mk 11, Mk 114*	ASROC, DASH, Mk 44, 46 torps.	5"/38	5"/38	60	79	79	70
DD-931 Forrest Sherman	SQS-23	None	SPS-10	SPS-40	Mk 114	HH, DC, ASROC, DASH Mk 44, 46, 37 torps.	3"/50	5"/54	18	18	18	18
DDG-2 Chas. F. Adams	SQS-23	None	SPS-10	SPS-29	Mk 111, Mk 114*	ASROC, Mk 44 torps.	Tartar	5"/54	22	23	23	23
Frigate/Destroyer Type												
DL-1 Norfolk	SQS-23	None	SPS-10	SPS-37	Mk 102, Mk 111	ASROC, DASH, Wp.A, Mk 44, 37 torps.	3"/70	3"/70	1	1	1	1
DL-2 Mitscher	SQS-23	None	SPS-10	SPS-37	Mk 102	Wp. A, DASH, Mk 44, 46, 37 torps.	3"/70	5"/54	2	0	0	0
DLG-(N)-25 Bainbridge	SQS-23	None	SPS-10	SPS-40	Mk 111	ASROC, Mk 44, 46 torp	Terrier	3"/50	1	1	1	1
DLG-16 Leahy	SQS-23	None	SPS-10	SPS-29	Mk 114	ASROC, DASH, Mk 44, 46 torps.	Terrier	3"/50	9	9	9	9
DLG-26 Belknap (Bldg)	SQS-26	None	SPS-10	SPS-29	Mk 114	ASROC, DASH, Mk 44, 46, 37 torps.	Terrier	5"/54	0	9	9	9
Carriers												
CVS, Modernized Essex Class Yorktown	SQS-23	None	SPS-10	SPS-43	Aircraft control	Aircraft	3"/50	5"/38	9	9	9	9

*Some ships have one, some the other.

Refs. B.1, B.2, B.7

Table B.1'. ASW Surface Platform Characteristics (concluded).

B.122 The Frigates are the largest of the destroyer types. They are capable of maintaining acceptable speeds with a carrier in high sea states. The smaller DL-2 and DL-4 frigates are being converted to guided missile destroyers (DDG's). The other frigates will acquire Terrier or Tartar missile systems and become DLG's. Plans are for 10 new DLGN's by 1975.

The prime mission of the destroyer and frigate groups is to operate offensively with strike forces and hunter/killer groups in support of amphibious assault operations and to screen support forces and convoys against submarine, air, and surface threats. The DL and DLG classes have the additional capability of working independently from these forces. The secondary missions of the destroyer are essentially the same as those of the patrol craft.

B.123 The Patrol Craft group noted in Table B.1 will be the main construction effort for future ASW surface shipping. This is the improved DE-class ship. The early DE's were much smaller than destroyers, about 2,000 tons, while the newer construction is much larger and can mount SQS-26 sonar, ASROC, and DASH. Present plans are for 123 new DE's and 14 new DEG's by 1975. These craft have ASW as a prime mission. The DE's and DEG's generally provide screens for support forces and convoys. The DER's also provide early warning of airborne threats. Patrol craft secondary missions include search and rescue, limited air control, electronic intelligence and hydrographic and oceanographic survey data.

B.13 Search by Surface Ships for a submerged submarine over an extended period is usually more suitable in small areas than search by aircraft. The surface ship has a lower rate of search and visual ranges are less than for fixed-wing aircraft, but the datum will be more accurately located when the submerged submarine is detected. The ship has the capability of remaining on-station for a much longer period than is possible in the case of aircraft, but visual search is difficult from the surface because the submarine normally will detect the ship in time to dive before being detected. Single surface ship search is seldom used because the initial detection range is limited.

Many types of ships are assigned the role of ASW duty. These ships possess four features which readily fit them for this role. They have an all-weather capability which allows them to remain in the "contact" area in the most severe weather. They have the ability to remain with a contact for days, or weeks, at a time. They may work either offensively with a HUK group or defensively with a convoy. And finally, they are the only ASW surface units carrying all the weapons and systems necessary to conduct a complete attack on a submarine.

The greatest advantage the destroyer has in ASW is that it can operate on the interface between the submarine and the aircraft. The destroyer can be the basic unit coupling these two in operations. It can use the most advantageous ASW techniques and sophisticated detection systems used by both the submarine and the aircraft. The destroyer as a passive sonar listening platform is probably not as good as the submarine since it is much noisier and operates on the surface; however, the destroyer communicates much better and can relay its information to other members of the ASW force, which currently is not an attribute of the submarine.

The primary means of submarine detection from ASW surface ships is sonar. Although ASW ships are also equipped with surface-search radar and air-search radar for their own early warning against aircraft or for surface surveillance of ships, seldom are submarine targets detected by surface ship radar.

B.2 ASW Surface Ship Hull-Mounted Sonar.* All ASW ships have sonars installed as their only means of detecting underwater objects, particularly enemy submarines. The oldest non-FRAM DD's still have the SQS-4. The newest ships and those in building have the SQS-26. All others either have the SQS-29 series or the SQS-23.

Three types of surface ship sonar, hull-mounted active sonar, variable depth active sonar (VDS), and passive sonar, are available to the Fleet today. Only hull-mounted and VDS will be discussed here. Passive sonar is incorporated in some hull-mounted active systems; and with future plans for developments, the number may grow. Some current ships carry both hull-mounted and VDS equipment, and an increase in number here is also planned for the future.

B.21 Hull-Mounted Active Sonar. The principal types of operational hull-mounted sonar used by major ASW surface ships today are the AN/SQS-29 series, the AN/SQS-23, and the AN/SQS-26.

B.211 The SQS-4 Sonar is representative of the basic design of existing shipborne equipment. The different models (1, 2, 3, and 4) operate at discrete frequencies of 8, 10, 12, and 14 kc respectively, and at a source level of 116 db/re: 1 μbar/1 yd. with omnidirectional transmission. Its range is limited to approximately 4000 yards against above-layer targets and to approximately 1000 yards against below-layer targets. It is the oldest sonar in the Fleet today and will soon be completely phased out.

B.212 The SQS-29-32 Sonar series is similar to the SQS-4 model but incorporates Rotational Directional Transmission (RDT), which concentrates the radiated power into a narrow beam and thereby

*See Table B.2 for more complete details.

Sonar	Freq. (kc)	Trans-ducer Dimen-sions:	Trans-mission Mode	Source Level (db*1	Pulse Length (ms)	Perform-ance Fig.*2 (db)	50% Detection Range (yd*2) Surface Path: In Layer	Below Layer	Presentation: Range Scales (kyd)	Visual	Audio	Cost
SQS-4 Mod 1	8.0	54/54	OMNI*3	116	6,30 80	146	5,500	1,100	1, 2½, 5,10,15	PPI,TCD,SCD	Headphones, loud speakers	?
Mod 2	10.0	"	"	"	"	"	"	"	"	"	"	
SQS-4 Mod 3	12.0	"	"	"	"	"	4,500	"	"	"	"	
Mod 4	14.0	"	"	"	"	"	"	"	"	"	"	?
SQS-23	5.0	54/96	OMNI	130	2,30 120	172			1,2½,5 10,20,40	"	"	$325,000 (Ref.B.7) $700,000 (Ref.B.6)
			RDT*4	140			13,500	2,500				
SQS-26	3.2	66/192	OMNI	130	30,100 300,1000					PPI	"	$1.4 million
			RDT	142	30,100, 300		20,000	4,000	2½,10 15,25,50			
			BB*5	144	CW(500) Coded (500)		10,000 40,000			Passive BQR-2 recorder		
			CZ*6	132	CW(1000, 4000) Coded (500)		60,000					
SQS-29	8.0	54/54	RDT	130	2,7,30 120	162	7,500	1,500	1,2½,5 10,15,30	PPI,TCD,SCD	"	$145,000
SQS-30	10.0	"	"	"	"	"	"	"	"	"	"	"
SQS-31	12.0	"	"	"	"	"	6,500	"	"	"	"	"
SQS-32	14.0	"	"	"	"	"	6,000	"	"	"	"	"

*1 db re: 1 bar at 1 yard
*2 Sea State - 2.
Ship Speed - 15 kt.
Random Aspect Target (15 db)
Layer Depth - 100 ft.

*3 Omnidirectional
*4 Rotational Directional Transmission
*5 Bottom Bounce
*6 Convergence Zone

Ref. B.1
B.2
B.3
B.6
B.7

Table B.2. Hull-Mounted Active Sonars

achieves a source level of about 130 db/re: 1 μbar/1 yd., which varies some with frequency. The improvements over the SQS-4 extend the range for in-layer targets to about 7500 yards and to 1800 yards for below-layer targets.

The SQS-29 series includes the SQS-29, 30, 31, and 32. The principal differences in these sonars, as with the SQS-4 Models 1, 2, 3, and 4, are in transducer frequencies. The SQS-29 is 8 kc/sec., the SQS-30 is 10 kc/sec., the SQS-31 is 12 kc/sec., and the SQS-32 is 14 kc/sec. These sonars are being replaced by the SQS-23 and the SQS-26 in new construction and in conversion of larger World War II vessels. Although the AN/SQS-29 series sonar is being phased out of the Fleet, it will be about fiscal year 1971 before the sonar is completely replaced. The AN/SQS-29 series sonar is still installed in all of the World War II destroyer and destroyer escort types except FRAM I and selected FRAM II conversions.

B.213 <u>The AN/SQS-23 Sonar</u> is the follow-on to the AN/SQS-29 series and includes all the improvements of the SQS-29 series. It is the principal sonar in most all DL's and the DD 931/945 class and in FRAM I and selected FRAM II and destroyer escort types. It is the most prevalent sonar in the Fleet at present and is also installed, or scheduled for installation, in large ships (CVS and CLG) as a defensive sonar to enable these combatant ships to detect and avoid submarine attack. The SQS-23 was originally designed to make use of bottom-bounce as well as surface-duct acoustic propagaton. However, OPTEVFOR evaluation and Fleet experience has shown it is not powerful enough for bottom-bounce; so surface-duct RDT is the only mode available (as with the SQS-29). The predicted longer ranges of the SQS-23 make it the first sonar capable of utilizing the ASROC stand-off range. Its range is about 18,000 yards for in-layer targets and 2,000 yards for below-layer targets.

B.214 <u>The SQS-26 Sonar</u> has the design requirement to provide an advanced surface ship sonar system for use on select units of new construction AG(DE), DE, DEG, DL, DLG, and DLG(N) class ships. It has been designed with the intention of providing surface ships with the capability for detection of submarines by means of bottom-bounce mode of transmission. If successful, such a sonar would provide for detection of below-layer targets at ranges from 10-15 kyds. out to 20-30 kyds. in deep water.

The SQS-26 comprises three equipments operating simultaneously in one compatible system. It is designed to operate in three active modes and a passive mode. In the active modes, three transmission paths are employed. These are the <u>surface-duct path</u> (the region bounded by the sea surface and the depth at which the main thermocline starts), the <u>convergence-zone path</u> (that acoustic path made available in sufficiently deep water by the ocean's sound-velocity structure), and the <u>bottom-bounce path</u> (that path obtained when the sonar beam is tilted downward so that the sound wave is reflected from the ocean bottom and directed back up toward the surface).

The SQS-26, which is still in the developmental stage, is the first surface ship sonar designed to use bottom-bounce and convergence-zone modes of acoustic propagation in addition to surface-duct. Its improvements over previous sonars include signal coding and digital correlation techniques for increased signal-processing gain, higher source level, multiple performed beams, multiple simultaneous search modes, and three frequencies to reduce ping-to-ping interference. The SQS-26 is a heavy system, and while the dome for its large cylindrical transducer may improve the seakeeping characteristics of the employing ship under some circumstances, it is too large to be mounted on smaller ships. At present there are six different models of the SQS-26 with standardization expected to occur with more testing. Present plans are for the SQS-26(CX) to be the operational model.

B.3 <u>ASW Surface Ship Variable Depth Sonar (VDS)</u>.* Variable depth sonar, a sonar transducer lowered into or below the thermal layer, is a significant aid to conventional hull-mounted equipments. When thermal layers are present the VDS is streamed to the optimum depth, which can increase the detection range against a submarine attempting to hide below the layer. Performance on the VDS/Hull combination varies with the thermal structure and the sound channel depth. In some instances, ranges obtained by VDS have exceeded expected performance by a wide margin due to refraction in an advantageous way. However, VDS offers little improvement under strong negative gradients and may not be useful at all in shallow water. Limitations and restrictions during ORE's and Fleet Exercises, where concern for the danger to exercise submarines is real, have limited complete Fleet exercise evaluations.

The one VDS accepted by the Fleet and most of the several under development are designed around current hull-borne sonar systems. The SQA-10 is designed around the SQS-29 series sonar. The SQA-11 was being developed around the SQS-23 sonar, but has been cancelled and requirements for both the SQA-11 and the SQA-19 will probably be cancelled. The SQA-8 was designed around the SQS-4 sonar.

The SQA-13 is a small ship VDS sonar designed for patrol-type craft. It has been approved for use with the AN/SQS-17 sonar; however, it is undergoing another evaluation for use with the AN/SQS-35 sonar, a follow-on of the AN/SQS-17. If the evaluaton is successful and the equipment is approved for service use, plans are to install the AN/SQA-13 and AN/SQS-35 sonar in the DE-1052 class destroyer escort. The SQA-17 is being developed around a full size SQS-23

*See Table B.3 for more complete details.

VDS GROUP	SONAR SYSTEM	FREQ. (kc)	TRANSDUCER DIMENSIONS HEIGHT (in.)	TRANSDUCER DIMENSIONS DIAMETER (in.)	WATER (lbs.)	TRANS-MISSION MODE	SOURCE LEVEL (db re: 1 μ bar at 1 yard)	FIGURE OF MERIT (15 KN) (db)	50% DETECTION RANGE (yards) SURFACE PATH IN LAYER (Hull-Mounted)	50% DETECTION RANGE (yards) SURFACE PATH BELOW LAYER (VDS)
AN/SQA-10	AN/SQS-29 REDUCED SIZE	8.0	30	30	5,162	RDT	128	149	7,500	4,500
	AN/SQS-30 REDUCED SIZE	10.0	30	30		RDT	128	149	7,000	4,000
	AN/SQS-31	12.0	30	34		RDT	132	153	6,500	4,000
	AN/SQS-4 Mod 3	12.0	30	34		OMNI	109	130	4,500	3,000
	AN/SQS-32	14.0	30	34		RDT	132	153	6,000	4,000
	AN/SQS-4 Mod 4	14.0	30	34		OMNI	109	130	4,500	3,000
AN/SQA-11	AN/SQS-23 REDUCED SIZE	5.0	54	60	17,000	RDT	137	158	13,500	7,200
AN/SQA-13	AN/SQS-17 REDUCED SIZE	13.0	19	19	2,000	OMNI	111	142	4,500	6,300
	AN/SQS-35	13.0	19	19		RDT	132	166		6,300
AN/SQA-17	AN/SQS-23 ENLARGED	5.0	90	96	28,000	RDT	147	189	18,000*a	8,000
	BOTTOM BOUNCE SONAR (BASED ON AN/SQS-26)	3.5-4.0	90	96		Long Directional Pulses and RDT	149	199	70,000*b	8,000

*a Bottom Bounce
*b Convergence Zone

Table B.3. Surface Ship Variable Depth Sonar — Ref. B.1, B.2

sonar and will also be capable of handling a reduced size transducer of the SQS-26 type. For more details of VDS operation and capabilities, see Ref. B.1.

B.4 ASW Aircraft.*

B.41 Carrier ASW Aircraft. The CVS with its fixed-wing aircraft and helicopters is particularly adapted for conducting ASW operations in ocean areas where a continuous on-station aircraft with ASW capabilities is necessary. The CVS embarks two VS squadrons of 10 ASW aircraft each, one HS squadron of 16 HSS aircraft, and a detachment of four AEW and four VA (jet) fixed-wing aircraft. Of the nine active CVS's, five are in the Atlantic and four are in the Pacific. The CVS with 16 helicopters and 22 S-2 ASW fixed-wing aircraft will probably keep 25% of their vehicles airborne around the clock.

The carrier ASW aircraft are all-weather single package types equipped with radar, ECM, and sonobuoy systems. Their primary purpose is to conduct ASW warfare while operating from aircraft carriers. Their main contribution in the past has been to deny the submarine the freedom to operate on the surface. Their capabilities include detection, identification, tracking, localization, and destruction of enemy submarines. Capabilities include all-weather barrier patrols, convoy escort, hunter-killer operations, and area search functions. They are also equipped to carry a wide variety of ASW weapons. The S2D/E Tracker is an example of our present and future fixed-wing aircraft.

The advantage of aircraft in ASW is its great mobility and the ability to extend visual and radar horizons by changes in altitude. The submarine is of little or no menace to the aircraft because of the latter's speed and mobility. At relatively long ranges ECM, radar, and visual searches are the primary methods for detecting submarines which have some part exposed above the surface. Search by aircraft over large areas utilizes the advantage of a broad field of vision and a high rate of search, especially when surfaced or snorkeling submarines are involved; and as such, aircraft are effective units to provide early warning of enemy submarines. The extended radius of action which the aircraft brings to coordinated ship-aircraft ASW operations vastly increases the enemy submarine problem.

B.42 Search With Sonobuoy. The fixed-wing aircraft utilizes sonobuoy acoustic systems for detecting submerged submarines. The sonobuoy is a passive acoustic detection equipment which (under favorable conditions) can detect the underwater sounds of a fully submerged submarine and transmit this information and target movement via radio transmitters to radio receivers in ASW aircraft.

*See Table B.4.

Aircraft Model	Patrol Aircraft SP-2H (P2V-7S)	P-3A (P3V-1)	SP-5B (P5M-2)	Helicopters SH-34G	SH-34J	SH-3A	Carrier Aircraft S-2D/E
Engines	Wright (2)R-3350-32WA (2)J-34-WE-36	(4)T-56	(2)R-3350-32WA				H-1820-82A(2)
Horsepower (T.O. ESHP)	3700	4500	3700				
Dimensions Wing Span	101' 4"	99' 8"	118' 2"				
Length	91' 8"	116'10"	101' 1"				
Height	29' 4"	33' 8.5"	20'11"				
Fuel (lb)	20,280	59,800	20,300				4,368
Gross Wt(lb)	80,000	127,400	76,600	11,371	11,732	17,760	26,552
Payload (lb)	2910	4740	2490				
Crew Officer	3	4	3	3 - 4	2 - 4	2 - 4	4
Enlisted	7	8	8				
Mission Radius (Nm-kts)	1050/174	1530/290	860/138	227/84	225/84	492/115	410/130
Endurance hrs/basic Mission	15.1 Includes 3 hrs. on Station	13.5 Includes 3 hrs. on Station	15.5 Includes 3 hrs. on Station	2.7	2.7	4.0	7.7
Patrol Speed Normal(kts)	162	194	140				
Max. Speed (kts-alt)	350 - 11,200'	395 - 14,400'	240 - 15,000'	123 - S.L.	122 - S.L.	140 - S.L.	218 - 4000'
Remarks	All Weather	All Weather	All Weather	Operat'l in Serv.	Operat'l in Serv.	Operat'l in Serv.	
Hoist Capability (lb)	600	600	600				
Combat Ceiling (ft)							18,200
ASW Sensor Capability	Jezebel Julie, MAD Sniffer	Jezebel Julie, Mad Sniffer	Jezebel Julie, MAD Sniffer	AN/ASQ-4	AN/AQS-5	AN/AQS-10	Jezebel Julie, MA. Sniffer
Ordnance							Mk 101, LULU, Torpedoes; Depth Bombs Rockets
Max. Cv Landing Wt. (lb)							24,617

Table B.4. ASW Aircraft

Ref, B.1
B.2

Sonobuoys are placed in patterns and must be laid accurately and marked so that positions of the individual buoys can be observed. The patterns may be small area patterns or larger sonobuoy barriers. Small area patterns are used primarily for tracking submerged submarines and for investigating contacts obtained initially by means other than sonobuoys.

The JULIE system (used primarily for localization of the contact) is comprised of sonobuoys for passive acoustic listening and aircraft-dropped explosive charges as the active source; the JEZEBEL system (a passive system) uses passive sonobuoys for listening and analyzes the submarine-generated noise with LOFAR equipment, and the CASS system (an active sonobuoy system) is also used for localization; and all are examples of the sonobuoy systems in use in the Fleet today.

Once the contact has been developed, which for aircraft is more often than not with JEZEBEL buoys, it must be classified as a submarine. Classification with fixed-wing aircraft is done with MAD (Magnetic Detection). MAD is probably the best aircraft classification means today, but it is not available to surface craft because of their large magnetic fields and relative low speeds.

B.43 Localization By MAD. The magnetic airborne detector used for localization and classification operates on the theory that the presence of a very large metal object such as a submarine will perturb the earth's magnetic field and vary the measured intensity. This change will be detected by MAD. MAD is used against a submerged submarine and is accurate enough to permit an effective attack. Initial detection by MAD is possible only at short ranges, and usually the detection range assumed is roughly 3 times the length of the submarine.

B.44 Sonobuoy Barriers. There are three broad types of sonobuoy barriers: the intercepting barrier, the flank barrier, and the containing barrier.

B.441 The Intercepting Barrier is a line ahead of and across the estimated track of a submarine, or is a bent line centered on the submarine's track. Line orientation is based on tactical assumptions. Protectively, the intercepting barrier is used in defense of formations, to augment flanking barriers, and to detect submarines trailing the formation or which have attacked and are dropping astern.

B.442 Flank Barriers protect against submarines attempting to reach an attacking position off the formation flanks.

B.443 The Containing Barrier is so placed to enclose an area of a limited size to detect enemy submarines entering or leaving the area.

B.45 Sonobuoy Systems.

B.451 The JEZEBEL System. While JULIE and CASS are primarily ASW localization systems and MAD is a classification system, the JEZEBEL system installed in ASW aircraft is completely passive and can be used in a variety of tactical situations to detect and localize submarines. The system is composed of recorders and appropriate JEZEBEL sonobuoys and receivers. Recommended search altitudes for all patterns is at a minimum altitude of 5000 feet, the altitude from which LOFAR sonobuoys are dropped.

In all patterns, detection capability of the system is reduced in high sea states.

JEZEBEL analyzes low-frequency sounds received on sonobuoys by LOFAR (Low Frequency Analysis and Recording) and CODAR (Correlation Display Analyzing Recorder). LOFAR displays the discrete frequencies contained in target signatures to provide long range detection and classification. CODAR provides bearing information on the target which can be converted to a fix.

The LOFAR part of the JEZEBEL system detects line components of a target spectrum in the frequency range of 10 to 200 cps., the CODAR part detects broad-band energy in either of two bands: 110 - 300 cps. and 310 - 500 cps. Localization by CODAR whenever a target is detectable by LOFAR does not always occur. Sometimes a target may have less broad-band energy in the CODAR bands, relative to the few strong line components in the LOFAR bands, which does not permit localization.

Many variations in detection ranges are reported in the Fleet for JEZEBEL, which is very susceptible to variations in ambient noise level, sea state, and environment in general. For even marginal prediction precision, very precise specifications of target source level, ambient noise conditions, bottom conditions and the availability of convergence zone transmission, and signal-to-noise detection capability of the equipment are required for JEZEBEL performance.

B.452 JULIE (Explosive Echo Ranging) is an active localization system utilizing omnidirectional low-frequency passive sonobuoys, small explosive charges, and electronic equipment in the aircraft for processing signals received from the sonobuoy. Passive sonobuoys are dropped from an aircraft and then an explosive charge, detonated in the water at deep or shallow depth, is the active source. The sound from the charge is reflected from the submarine target to the sonobuoys and relayed to the aircraft via the radio link in the buoy. Equipment in the aircraft processes the signal and enables the operator to obtain range and bearing on the submarine. The system gives the A/C an "active sonar" capability in deep water.

B.453 CASS (Command Active Sonobuoy System) is an active sonobuoy system under development. It will replace the SSQ-15 and SSQ-47 active sonobuoy system which has had limited success achieving desired detection ranges. CASS is an air-droppable active system whose primary development is to provide fixed-wing aircraft a capability for detecting, classifying, tracking, and localizing deep-diving, high-speed, and quiet-running submarines. It is designed for a reliable active detection range of 6,000 yards for an 18 db target strength with a two-way propagation loss of 152 db.*

B.46 Patrol Aircraft. The current ASW fixed-wing patrol aircraft have endurance capabilities of 13 to 15 hours. Being larger than VS aircraft permits more equipment, more crew members for some rotation of duty, and more weapons stored. Also, with more space and superior navigation, it has particular advantages in long-range search and barrier patrol. SOSUS contacts can be prosecuted with patrol aircraft that fly out on a two station SOSUS fix and search in the general area indicated. With their long time-on-station and speed to the datum, they are an ideal SOSUS team member. Patrol aircraft can also be an advantage in forward areas where no airfields are available but where it can operate from sheltered sea anchorages. All patrol aircraft use the JEZEBEL and JULIE systems, with MAD for localization.

B.47 ASW Helicopters. The extreme maneuverability, capacity to hover with precision, and ability to launch or land in a small area gives helicopters distinct advantages in ASW operations. The hoverability of the helicopter is a great asset in conducting close investigation of a suspected location or series of locations.

B.471 Sonar Search by Helicopter** consists of a series of stationary dips and forward jumps. Time of flight (jump time) during exercise operations determined by reference to the jump time and distance table, which currently is based on a dip time of six minutes (NWIP 24-2(A)). To maintain position at high formation speeds, jump distances greater than the effective sonar range may be required unless the best of environmental conditions prevail. When equipped with dipping sonar, the helicopter becomes an integral part of the ASW team and is also excellent for visual search. When used in conjunction with surface ships and other aircraft, they greatly increase the screening capabilities of the force.

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* TDP W21-20X

** See Tables B.4 and B.5

Nomenclature	Vehicle	Type	Cable Length (ft)	Frequency (kc)	Ave. Range (yd)	Remarks
AN/AQS-4	SH-34G	Dipped	90	20,21,22	In layer: 1,900 Below layer: 1,300	Cable length is 60 ft. below surface. Active or passive.
AN/AQS-5	SH-34J	Dipped	200	20,21,22	In layer: 1,900 Below layer: 1,300	Modified AQS-4. Active or passive.
AN/AQS-10	SH-3A	Dipped	200	9.25,10 10.75	In layer: 7,900 Below layer: 4,000	Ave. ranges are estimates. Active or passive.

AN/AQS-10

Frequency (kc) 10
Source Level (db re: 0.0002 μ bar at 1 yd.) 186
Directivity Index (db) 18
Weight (lb) 750
Allowable Propagation Loss (Sea State 3) (db). 83.5
Max. Transducer Dept (ft.) 150

Layer Depth (ft)	Sonar Depth (ft)	Target Depth (ft)	0.5 Probability Detection Range (kyd)
0 100 400	50	50	2.1 5.6 7.6
0 100 400	50	500	3.6 3.3 5.7
0 100 400	150	50	2.5 4.8 7.3
0 100 400	150	500	4.1 3.6 6.2

Table B.5. ASW Helicopter Dunked Sonar

Note: These charts have been extracted from Ref. B.2.

Helicopters may also be used to augment surface screens. When not used on other forms of screening, helicopters may be usefully employed as pickets in advance of the surface screen. They may conduct dipping entirely at random in sectors within the submarine limiting lines of approach and near the torpedo danger zone. Effectiveness as pickets is the unpredictable nature of their movements.

Helicopters do have disadvantages however. The primary ones are low maximum speed, very limited on-station time, and except for the SH-3A, their small weight carrying ability. Speeds vary between types and at different altitudes, but the maximum averages little more than 100 mph. Hovering requires 25 to 50 percent more power than does forward flight. They can be expected to dip for about six minutes and use one minute for raising the dipped sonar.

Briefly, the ASW types (SH-34G, SH-34J, SH-3A) have the following features:

SH-34F: This single engine model is designed to operate from carriers or land bases. The antisubmarine search version carries a four-man crew.

SH-34J: This is a modification of the SH-34G. The SH-34J also employs dipping sonar and carries special weapons.

SH-3A: The primary mission of this twin-engine, turbine powered helicopter is to detect, identify, track, and destroy enemy submarines. The SH-3A is capable of all-weather operations from carriers, cruisers, and from other naval and merchant ships which have adequate landing provisions. It is considerably larger than the SH-34G and SH-34J.

The helicopter configured with dipping sonar (VDS) is able to detect and track the submarine. With dip time the order of minutes and with the ability to retrieve and fly to a new dip position for a better advantage, the helicopter also becomes an excellent localizing platform. Each dip gives the helicopter a fix on the target. As the range to the target decreases, the helicopter spends a larger part of available time dipping, listening, and retrieving the sonar. A single helicopter can carry out an attack from the last dip information if the target range is close. He does so by flying over the aim point determined from his latest dip information.

With the single helicopter, contact with target is lost between dips. When two helicopters are used, and when one always maintains contact with the dipped sonar, it is possible to vector the other in for attack. In this manner, the attacking helicopter can be provided target information from the dipping helicopter.

A SHORT GLOSSARY OF ASW TERMS AND ABBREVIATIONS

A/C................AIRCRAFT

A/D................ATTACK DIRECTOR

A/P................ATTACK PLOTTER

A/S................ANTI-SUBMARINE

ASCAC..............ANTI-SUBMARINE CONTACT ANALYSIS CENTER

ASR................ASSURED SONAR RANGE (obsolete term)

ASROC..............ANTI-SUBMARINE ROCKET

ASW................ANTI-SUBMARINE WARFARE

BD.................BEST DEPTH TO AVOID DETECTION

BDR................BEST DEPTH RANGE

BELL HOP...........AIRBORNE RADAR RELAY TO SURFACE SHI.

B/H................BLOOD HOUND

BLOODHOUND.........HOMING TORPEDO

B/T................BATHYTHERMOGRAPH

CAC................CONTACT AREA COMMANDER

C/B................CENTER BEARING

CIC................COMBAT INFORMATION CENTER

COLD...............CONTACT NOT HELD

DASH...............DRONE ANTI-SUBMARINE HELICOPTER

DATUM..............THE LAST KNOWN POSITION OF THE SUBMARINE

DB.................DECIBEL

D/C................DEPTH CHARGE

DRA................DEAD RECKONING ANALYZER

DRT................DEAD RECKONING TRACER

ECM................ELECTRONIC COUNTERMEASURES

EMCON ....EMISSION CONTROL- THE DEGREE OF RESTRICTION PLACED ON THE USE OF ELECTROMAGNETIC RADIATING EQUIPMENT

EP.................ESTIMATED POSITION

ERP................EMERGENCY RANGE RECORDER PLOT

ESR................EFFECTIVE SONAR RANGE

FANFARE............CONTROLLED TOWED ACOUSTIC NOISEMAKER USED TO DECOY HOMING TORPEDOES

FCS................FIRE CONTROL SYSTEM

FEATHER............SUBMARINE PERISCOPE WAKE

FRAM...............FLEET REHABILITATION AND MODERNIZATION PROGRAM

GOBLIN.............A SUBMERGED OBJECT WHICH HAS BEEN EVALUATED A SUBMARINE

H/H................HEDGEHOG

HOT................CONTACT HELD

HS.................ANTI-SUBMARINE HELICOPTER

HUK................HUNTER KILLER

HUMP...............UNIDENTIFIED ELECTROMAGNETIC RADIATION

MAD................MAGNETIC AIRBORNE DETECTION

MADVEC.............VECTOR MAD A/C TO CONFIRM A SONAR CONTACT

MEERS..............MAXIMUM EFFECTIVE ECHO RANGING SPEED

MSA................MULTI-SHIP ATTACK

OCA................OPERATIONAL CONTROL AUTHORITY

OCE................OFFICER CONDUCTING EXERCISE

ORE................OPERATIONAL READINESS EXERCISE

ORI................OPERATIONAL READINESS INSPECTION

OTC..................OFFICER IN TACTICAL COMMAND

OSE..................OFFICER SCHEDULING EXERCISE

OU...................OCEANOGRAPHIC UNIT

PDC..................PRACTICE DEPTH CHARGE

PDR..................PERISCOPE DEPTH RANGE

PIM..................POSITION AND INTENDED MOVEMENT

RDT..................ROTATIONAL DIRECTIONAL TRANSMISSION

R/R..................RANGE RATE

R/T..................RADIO TELEPHONE

RTDC.................ROCKET THROWN DEPTH CHARGE

RTT..................ROCKET THROWN TORPEDO

SAS..................SEARCH ATTACK SUBDIVISION

SAU..................SEARCH ATTACK UNIT

SHADOW ZONE..........A REGION INTO WHICH VERY LITTLE SOUND PENETRATES BECAUSE OF REFRACTION

SINKER...............A VISUAL OR RADAR CONTACT WHICH DISAPPEARS AND IS PRESUMED TO HAVE SUBMERGED

S/M..................SUBMARINE

SNIFFER..............EXHAUST TRAIL DETECTION DEVICE

SOURCE LEVEL.........A MEASURE OF THE SOUND OUTPUT OF A SONAR SYSTEM

SS...................SUBMARINE

SUS..................SOUND UNDERWATER SIGNAL

TDZ..................TORPEDO DANGER ZONE

TRE..................TRAINING READINESS EVALUATION

TRR..................TACTICAL RANGE RECORDER

UQC.................UNDERWATER TELEPHONE (GERTRUDE)

VDS.................VARIABLE DEPTH SONAR

VDT.................VARIABLE DEPTH TRANSDUCER

VECTAC..............VECTOR A/C TO ATTACK ANOTHER UNIT'S SONAR CONTACT

VP..................PATROL AIRCRAFT (P2V, P5M)

VS..................A/S AIRCRAFT (CARRIER BASED S2F)

WOLF................ENEMY SUBMARINE

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CONFIDENTIAL
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Santa Barbara Analysis and Planning Corporation	2a. REPORT SECURITY CLASSIFICATION Confidential 2b. GROUP 4

3. REPORT TITLE

Shallow Water ASW Command and Control Implications for Surface Ship Operations (U)

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final July 1966

5. AUTHOR(S) (Last name, first name, initial)

McDonough, Peter J.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
July 1966	135	38

8a. CONTRACT OR GRANT NO. Nonr-4891(00) b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) SBAnP 66-1 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. AVAILABILITY/LIMITATION NOTICES
U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through: Office of Naval Research (Code 405).

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Office of Naval Research (Code 405) Washington, D. C.

13. ABSTRACT

This study has focused upon the implications of the shallow water environment in the Tactical Command and Control of Single Ship and Task Group ASW Operations. The tactical command of ASW Surface Forces for ASW screens, search, and patrol operations is reviewed. The shallow water areas of the world, with emphasis on the western Pacific, are outlined and the specific environmental properties which contribute directly to the degradation of ASW Forces in shallow water are stressed. The Command and Control Requirements for general ASW surface ship operations are reiterated and the general extension of these requirements to shallow water ASW operations is examined. Special attention is directed to the need to improve Effective Sonar Range Prediction in both deep and shallow water ASW operations, and improvements possible are indicated by applying current propagation models, along with ray tracing techniques and programs automated for shipboard computers. Two shallow water ASW scenarios are presented which describe the operational problems and current ASW system limitations which reduce ASW effectiveness in shallow water. The Appendixes of this report provide a brief resume of the general Atlantic and Pacific Fleet ASW organization and a short description of current ASW systems and their operation.

DD FORM 1 JAN 64 1473

CONFIDENTIAL
Security Classification

[illegible] Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
ASW						
Command and Control						
Shallow Water						
Surface Ship ASW Systems						
ASW Surface Ship Tactics						
Scenario						

INSTRUCTIONS

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