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PRELIMINARY ANALYSIS OF POSSIBLE STARLITE DEVELOPMENT PROGRAM,(U)

JAN 68 D G OLSON, J E WATRING

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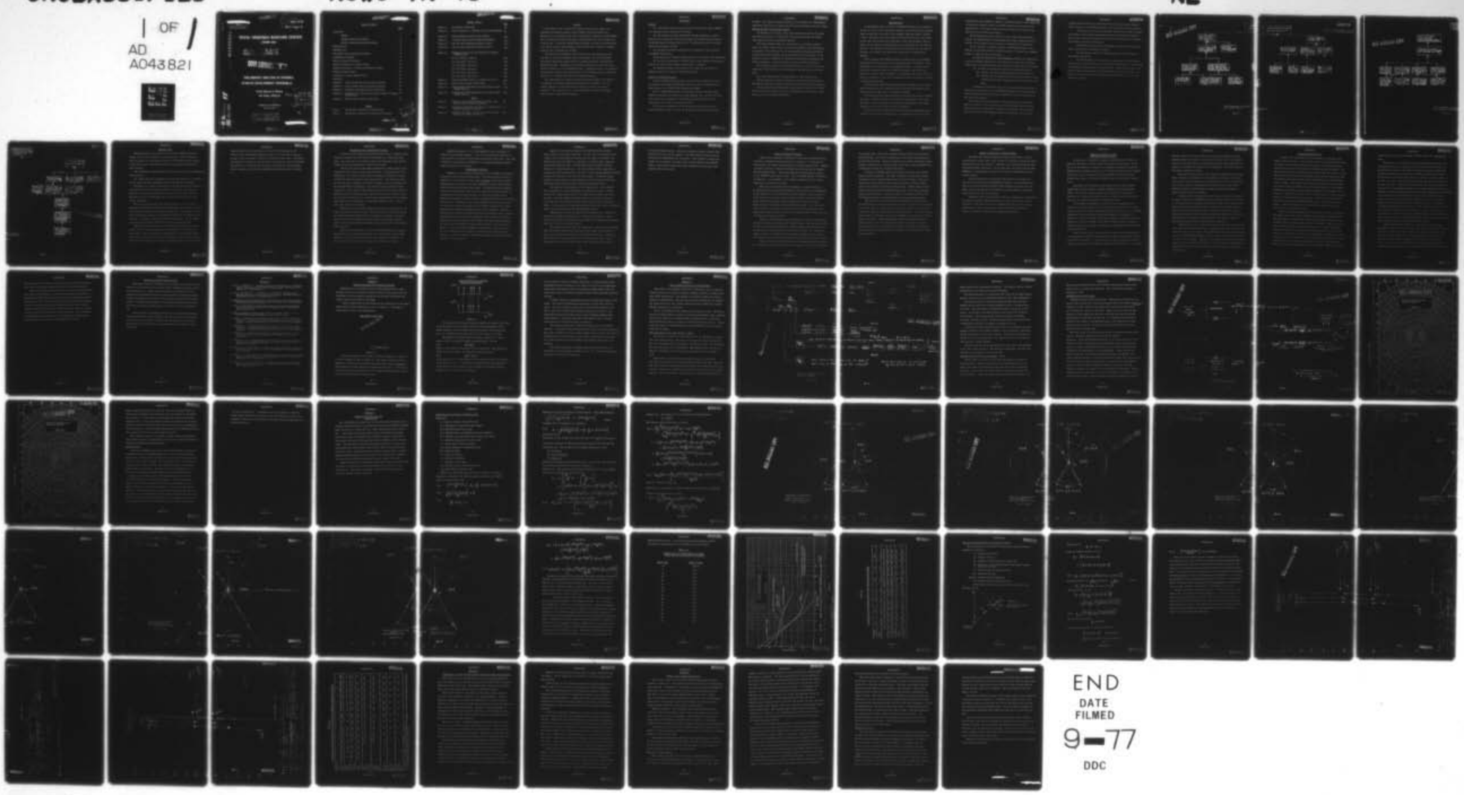

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JANUARY 1968

PRELIMINARY ANALYSIS OF POSSIBLE STARLITE DEVELOPMENT PROGRAM (U)

by D.G. Olson & J.E. Watring
San Diego, California

SUBPROJECT NO. SF1010316
TASK NO. 8132

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FIGURES (CONT.)

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FOREWORD

This Technical Note considers some technical and practical aspects of an exploratory development program to apply STARLITE (Space-Time Analysis for Recognition of Line Target Echoes) active classification techniques to PAIR (SQQ-23) and to sonobuoys delivered by helicopter, VS/VP aircraft or by gun or rocket from a surface ship. To provide NAVSHIPS 00V1C5 and 00V1B an estimate of the dimensions of an overall program, Work Breakdown Structures (WBS) and a listing of immediate tasks for the two programs are included.

The feasibility of STARLITE, either technically or operationally, has not been proven, nor has any prototype, real-time processor been built and tested. Any eventual development program should be preceded by technical and operational feasibility studies. Appendices B and C present preliminary technical and operational considerations of a STARLITE/PAIR system. Appendices D and E give background on some present sonobuoy system developments to which STARLITE might be applicable. Appendix A is a condensed description of STARLITE technique.

This note presents an informal, preliminary analysis of some of the problems of a program for developing operational applications of STARLITE. It is for planning purposes only with distribution limited to NUWC and a few outside activities. The assistance of T. F. Ball with Appendix A and of H. R. Eady as general critic is gratefully acknowledged.

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CONCLUSIONS

General:

(1) Insufficient evidence exists at this time to accept or reject STARLITE as a potential active classification technique.

(2) The technique has been verified with sea data (references 1 and 2); however, other experimental results do not agree with predicted results based on the STARLITE model and theory (reference 3). The technique should be verified before any development proceeds.

(3) No definite processor configurations or displays have been analyzed for STARLITE applications.

(4) No real-time or shipboard STARLITE processor is currently under development.

(5) The limiting equations of STARLITE permit initial studies of operational utility and tactics without complete specification of hardware.

(6) STARLITE processors can be simulated and tested with artifical and taped sea data prior to specific hardware development.

Possible STARLITE/PAIR Program:

(1) The NAVSHIPS OOV1 organization, the Active Sonar Classification Panel, and personnel from NSRDC should determine whether or not an exploratory development program for a STARLITE/PAIR subsystem be proposed.

(2) If a STARLITE/PAIR program is undertaken, schedules for determining STARLITE feasibility, developing and testing hardware, etc., should be set which will insure timely incorporation of STARLITE equipment during the initial installation of the SQQ-23 on operational ships.

(3) As shown in Appendix B, to use the aft array of a PAIR ship as an active STARLITE receiver, 24 staves, 24 beamformers and 24 preamplifiers must

be added. This requires immediate attention if raw sea data for a STARLITE/PAIR feasibility study are to be gotten during the planned PAIR data collection voyages.

Possible Sonobuoy Classification Program:

(1) Delivery of an accurate, short range classification device with speed and accurate placement in a contact area could greatly alleviate the current long range active sonar classification problem.

(2) A major analysis effort by a group similar to the Systems Analysis Group, ASW Systems Project Office, is necessary to determine the feasibility of classification with sonobuoys (with or without STARLITE processing) delivered by helicopters, VS/VP aircraft, or launched directly from an ASW ship. If the analysis is unable to detérmine the operational and technical feasibility with existing information, it should specify the factors needing investigation.

(3) An adequate program of exploratory development in this area would need several Naval Laboratories and some contractors to satisfy manpower and talent needs.

(4) A ship launched active sonobuoy system has high technical risk.

(5) The capability of passive sonobuoys or normally processed information from CASS (Command Active-Sonobuoy System) might not require STARLITE processing.

(6) Any program should consider the aid possible to tracking, fire control functions and weapon delivery, as well as classification, with the use of sonobuoys placed in a long-range contact area.

RECOMMENDATIONS

(1) Recommended general plans for a STARLITE/PAIR program and a program to explore the uses of active and passive sonobuoys for classification with surface ships are presented in the form of Work Breakdown Structures (WBS) in figures 1 and 2. The blocks show major program activities through the sea trial phase. At this time, PERT networks which would show a finer task breakdown, decision points and the complete interrelationships of all activities have not been constructed. Some immediate analysis tasks and policy decisions are necessary to establish the validity of the WBS and the desirability of undertaking the programs.

(2) We recommend that NAVSHIPS establish a working group of the NAVSHIPS Active Sonar Classification Panel and selected personnel from NAVSHIPS, NSRDC, and NUWC/SD who are interested in the STARLITE technique. This group should survey past and present work of the SACLANT ASW Centre, NSRDC and DRL and document the present status of STARLITE. The differences between the sea test results in references 1 and 2 and the experimental results of reference 3 should be resolved and explained.

(3) The several STARLITE processors described in reference (4) and others previously discussed by Dr. Wiekhorst should be reviewed for applicability to further analytical comparisons and computer simulations.

(4) the Group should study and decide upon the means of comparing different processors. Standard deviations of estimates of target aspect angle, length and width; or some type of ROC curve analysis of the detection of the cross-correlation peak might provide the basis of comparison.

(5) Once the group has decided the basis for comparing processors, system variables such as signal quantization (i. e., clipped, 3-bit or 5-bit linear

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quantization), pulse modulation, degree of "matched-filtering," cross-correlation in the time or frequency domains, estimated implementation cost and ease of implementation with existing systems should be studied and discussed as they relate to a cost-effectiveness analysis.

(6) The group should discuss whether or not an exploratory development program with STARLITE should include application to PAIR, considering the constraints of that system and its time table of development and installation.

(7) If a decision is reached to propose a STARLITE/PAIR program a more detailed Work Breakdown Structure should be prepared. Following that, NAVSHIPS OOV1B, or a group acting for OOV1B should:

(a) With the PAIR Project Office determine a deadline for demonstrating a real-time STARLITE capability with the SQQ-23 which would allow for orderly incorporation of STARLITE equipment during the Fleet installation of this system.

(b) According to this deadline, determine the possible approach:

(1) analysis followed by hardware design and construction, or

(2) immediate work on hardware design and the acquisition of taped sea data for concurrent computer simulation and hardware shore tests.

(c) Determine if sufficient manpower exists within Navy Laboratories to undertake the major portion of the STARLITE/PAIR program, or whether the development programs should be accomplished by contractors with only supervision by Navy Laboratory personnel.

(8) A program for classification of contacts detected at long range by surface ship search sonar using active or passive sonobuoys does not have as stringent schedule requirements as a program involving PAIR. Since sonobuoy systems might benefit from STARLITE processing, we recommend that the group

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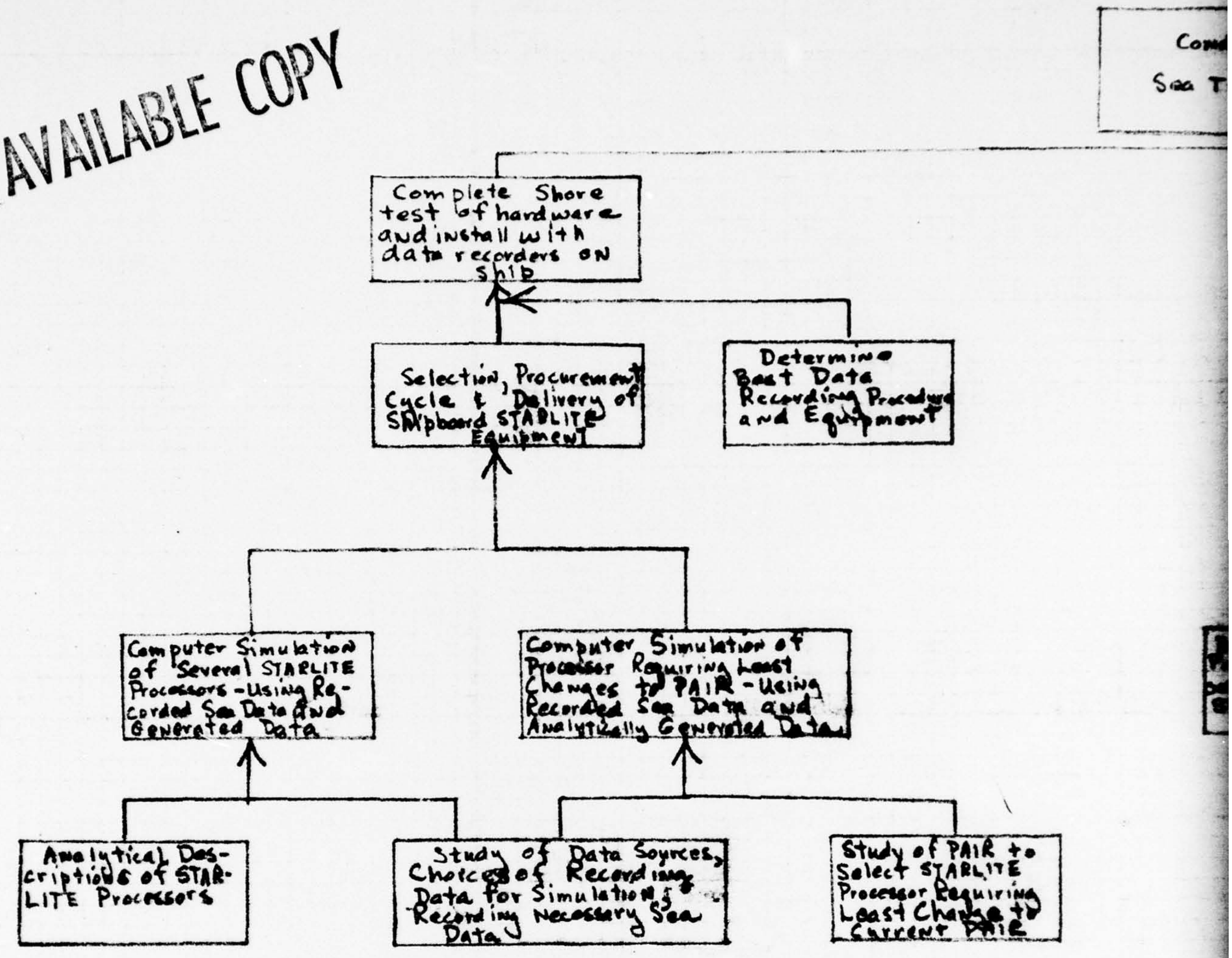
consider their application to classification and the possibility of enhancing their performance with STARLITE techniques. The group should study and discuss:

(a) circumstances under which sonobuoys launched from a ship, or dropped by supporting aircraft could significantly benefit the classification process. This involves study of the circumstances under which the search sonar experiences the greatest classification difficulty.

(b) anticipated improvements and problems of using current passive and active sonobuoys for classification purposes.

(c) circumstances under which STARLITE techniques with sonobuoys are advantageous and possible.

(d) the desirability of an analysis by a group such as the ASW Systems Project Office, Systems Analysis Group, of the cost effectiveness of ship-launched or air-dropped sonobuoy systems for classification. The preliminary work of the previous three recommendations would provide guidelines for this analysis. The results of the analysis would be used to select the most promising exploratory development programs.



Work Breakdown Structure
for STARLITE/PAIR

Figure 1

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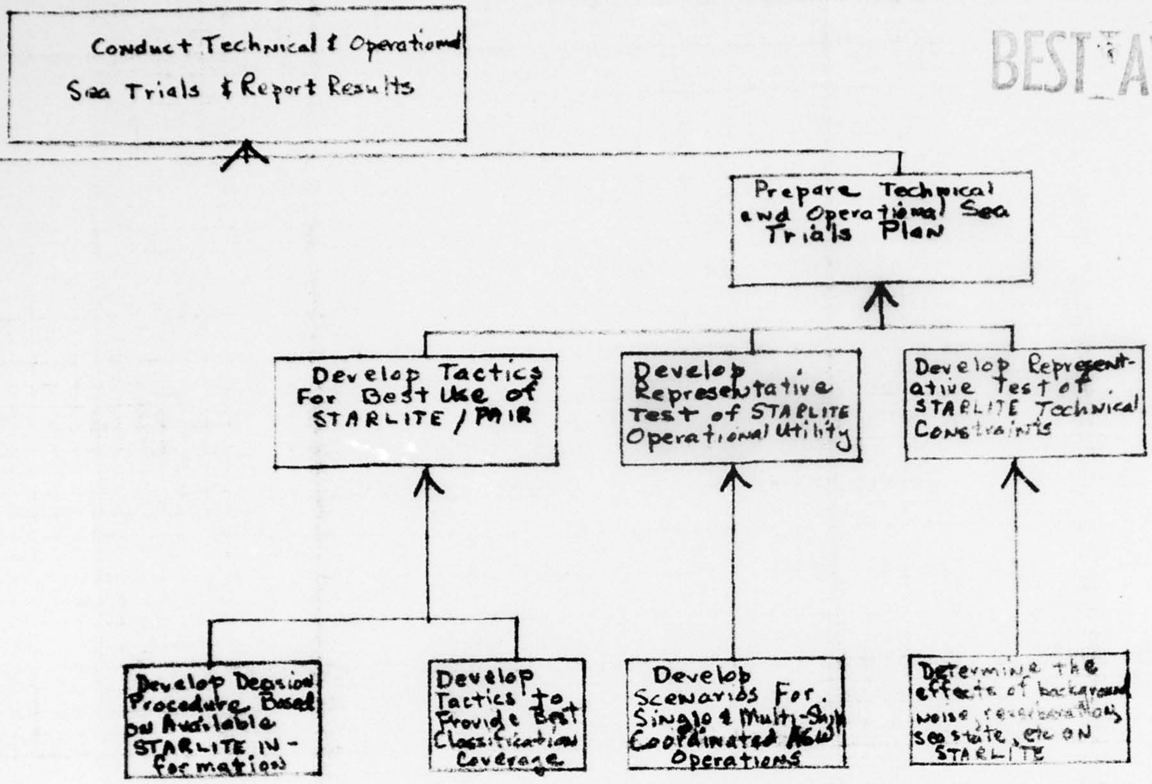
Conduct Technical & Operational Sea Trials & Report Results
Prepare Technical and Operational Sea Trials Plan
Develop Tactics For Best Use of STARLITE / PAIR
Develop Representative Test of STARLITE Operational Utility
Develop Representative Test of STARLITE Technical Constraints
Develop Decision Procedure Based on Available STARLITE Information
Develop Tactics to Provide Best Classification Coverage
Develop Scenarios For Single & Multi-Ship Coordinated ASW Operations
Determine the effects of background noise, reverberations, sea state, etc ON STARLITE

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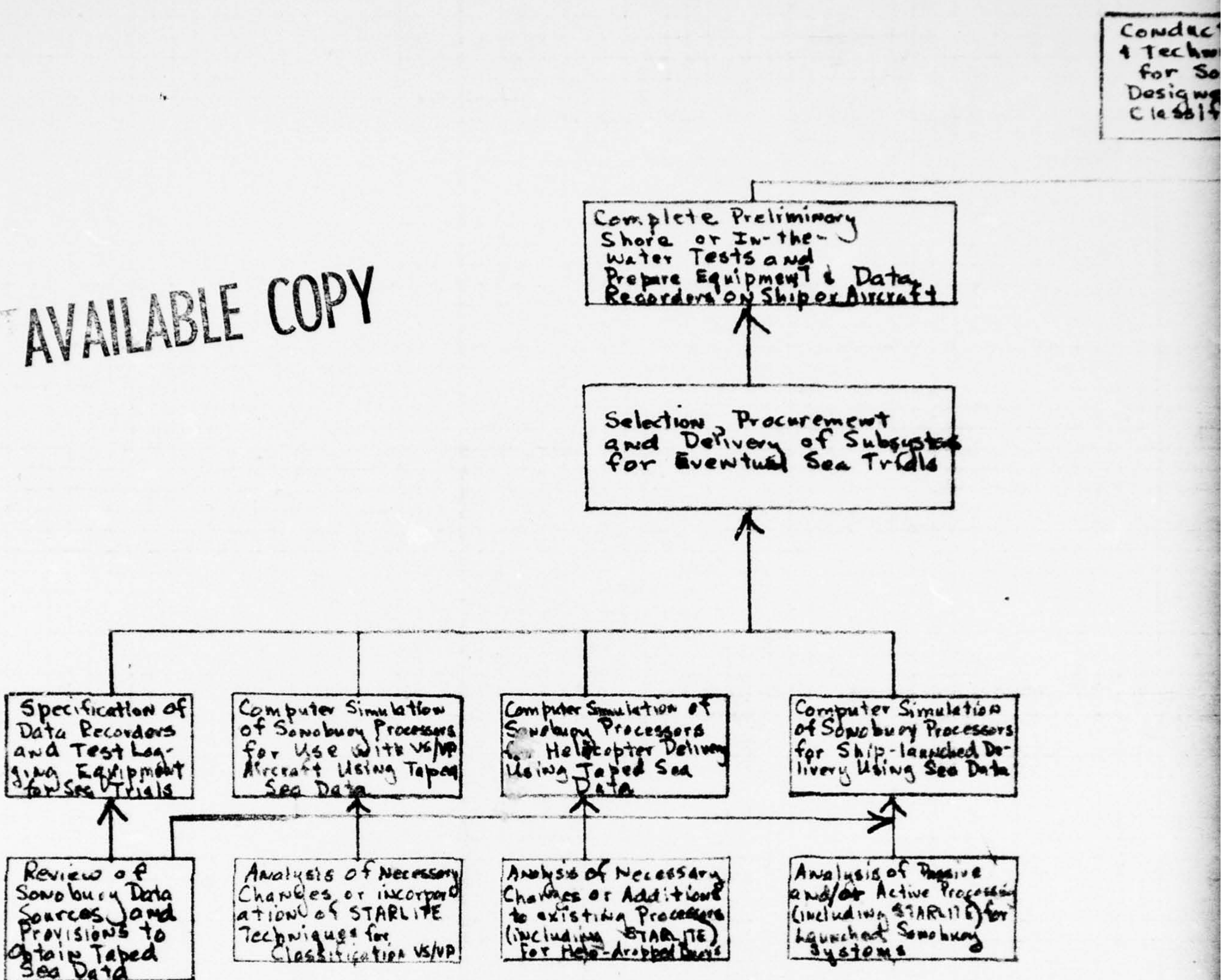

Work Breakdown Structure
for Sonobuoy Classificat

FIGURE 2

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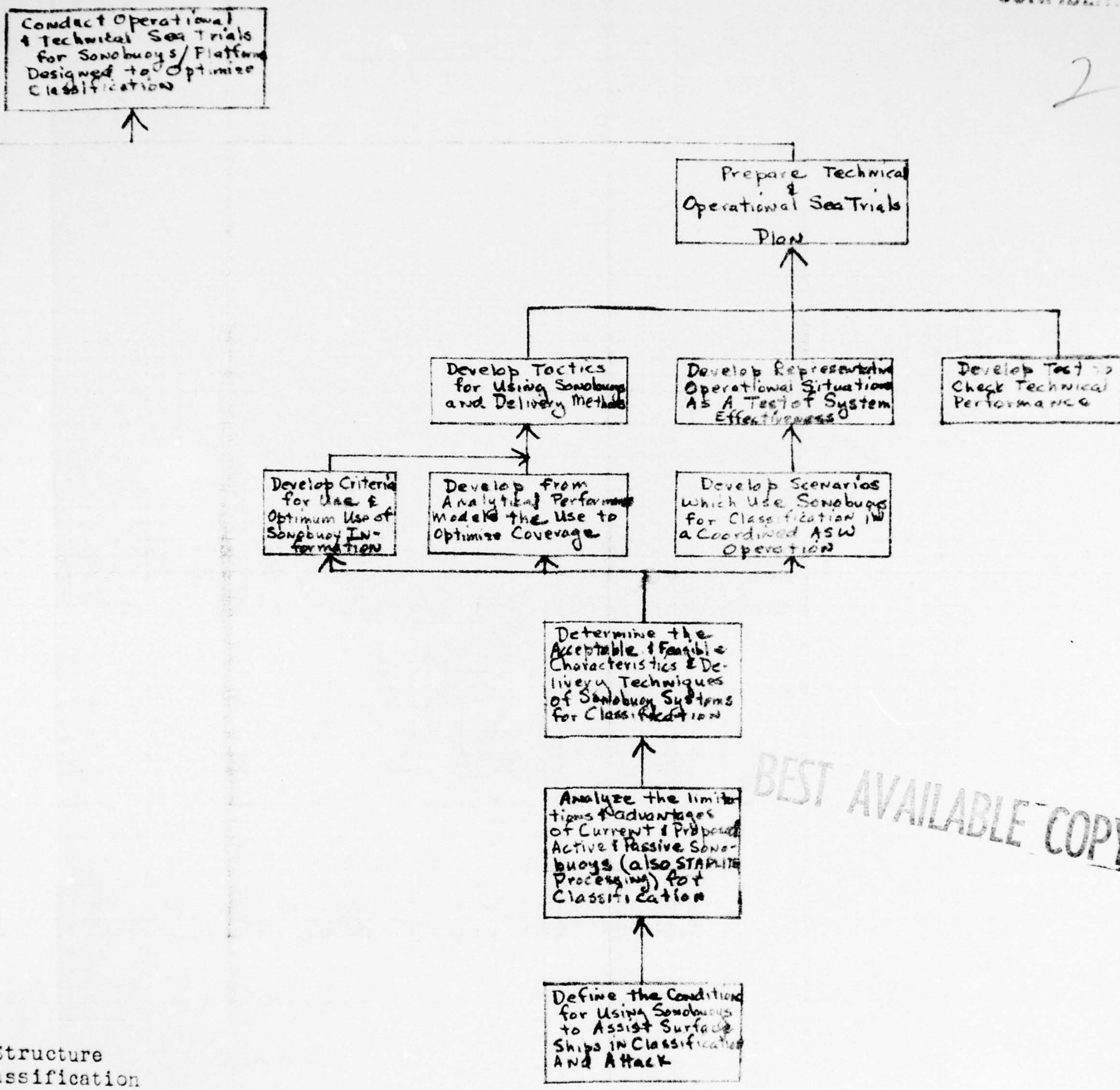

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Classification

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IMMEDIATE PLANS

NUWC/SD Code D606 could not take on a substantial STARLITE development program without a major revision of existing programs. We plan, however, to more fully assess the classification potential of STARLITE with surface ships. A brief description of this effort will show a relationship to conventional search problems.

Past developments in search (reference (5)) show that two major considerations affect detection:

(1) Certain physical requirements must be met for detection to be possible; but the meeting of these requirements does not make detection inevitable.

(2) Detection is based in last analysis on a human being and its success is influenced by the human's attention, alertness and fatigue. In short, any detection has a probability ranging from 0 to 1, but it is never inevitable. The same is true for classification and will apply to our assessment of the surface ship problem.

The range limiting equations for STARLITE depend on the sonar carrier frequency, sonar bandwidth, receiving array separation, the submarine's relative bearing from the ship and the submarine's aspect angle. The analysis will use these limiting range equations as the physical requirements for STARLITE classification. No effort is planned to estimate the exact probability of correct classification for contacts within the effective classification area.

Current ASW tactics employ the use of detection sweep widths and corresponding ASW ship's speed to determine the size sector a ship can patrol in a convoy screen. The ASW ship uses a random method of changing courses within its sector to achieve the overall detection coverage. Since the classification range of STARLITE depends upon relative ship-target geometry, no simple lateral range distribution for classification, such as the definite-range law for detection where the detection probability equals 1 or 0 according as $-R_{max} \leq r \leq R_{max}$, exists to compute an effective classification sweep width. Our analysis will endeavor to compute the size sector that an ASW ship can patrol for STARLITE classification, in the same manner it patrols for detection. This may permit better assessment of the utility of STARLITE than the calculations of Appendix C.

THE SURFACE SHIP CLASSIFICATION SITUATION

A previous report (reference (6)) described three types of submarine classification encounters by an ASW surface ship equipped with a long range search sonar: (1) short range, short duration contact, (2) long range, short duration contact and (3) long term contact at medium to long range.

The third case allows a reasonable classification confidence based on the contact track and a study of many consecutive echoes. This problem will not be treated here. The first case arises when the submarine is detected at a range of 2000-5000 yards while making a below-layer approach. The second case occurs at 10-24 kyds when a submarine comes above the layer to make an observation and then descends within a few minutes. This instance involves surface duct (SD) propagation Other versions of the second case occur with convergence zone (CZ) detections where the ensonified region varies from 2-5 miles in width at ranges up to 33 miles from the ship, or in bottom bounce (BB) detections where coverage exists only over a limited range for a particular depression angle. This can occur under marginal BB conditions.

Surface ship sonars specially designed for short range classification can improve capability in the first case. The second case can be similarly improved if a short-range classification sonar is placed near the contact. This short-range ronar must arrive quickly to achieve contact and any carrying vehicle must be reasonably invulnerable to submarine attack as its arrival will probably alert the target.

Short-range classification sonars can use higher frequencies for greater Doppler effect; use higher pulse repetition rate for more data; achieve better resolution for size and shape information, as in minehunting sonars; and use SSI-type displays to measure aspect angle, size and shape of a contact.

STARLITE (references 1, 2, 7, 8 and Appendix A) may be applicable to either short-range system approach. If so, it could confirm the presence of a line reflector and measure the aspect angle and length-to-width ratio. This paper is limited to consideration of STARLITE in an exploratory development program aimed at solving cases (1) and (2).

LIMITATIONS OF STARLITE

References 1 and 2 describe demonstrations of the STARLITE classification process with sea test data processed ashore. The limiting equations listed in references 1, 2 and 4 define an area wherein submarine classification by STARLITE processing is possible. This area is dependent on range, target bearing from the array axis, and target aspect angle. The equations neither guarantee 100% correct classification within the area, nor provide confidence levels for classification decisions within the area, nor absolutely prohibit correct classification decisions outside the area, nor completely describe the possibility of false alarms. Presently, at beam aspect, STARLITE is not effective at all; in the oral presentation of reference 7, Dr. Wiekhorst expressed some hopes of ameliorating the predicted breakdown for beam aspect submarines. Presently, however, we have ignored these possibilities and calculated the area of possible classification as determined by the length/width ratio criterion, resolution criterion, correlation criterion and the Fresnel far-field condition equations. We call this area the Effective Classification Area (ECA). The ECA for beam aspect is zero. The utility of STARLITE will depend on the size and shape of the ECA as determined by the condition of typical sensor platform/submarine encounters. Appendix C provides a preliminary analysis of the limiting effects of some realistic encounters.

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Appendix C uses detection ranges for the PAIR Wave-Period Processor search display on below-layer submarines. The first set of calculations is for a static case in which Effective Classification Area (ECA) is compared to the Effective Detection Area (EDA) for a fixed set of submarine aspect angles and corresponding detection ranges. The 60° baffle area is excluded from both detection and classification areas. For seven different aspect angles, ECA as a percentage of EDA varied from 5.4% to 90.5%. As shown by the referenced limiting equations, the ECA goes to zero for some aspect angles. If detection ranges remained the same, doubling the PAIR frequency to 10 k Hz would increase these percentages respectively from 5.4% to 21.8% and from 90.5% to 94.4%.

The second set of calculations is for a dynamic case. For a selected set of submarine and surface ship speeds, the submarine was given an initial position and a course which brought it to 4 kyds from the surface ship within one hour. The range, bearing and aspect angle of the submarine relative to the surface ship were computed at discrete times along the ship and submarine tracks. At these points, the equations governing the ECA were applied to determine where, in range, classification by STARLITE became possible.

These results are shown in figures C-4, C-5 and table C-3. Some of the tracks never offered the surface ships a classification capability. In one instance, the submarine could have been classified if the PAIR operating frequency were 5.5 k Hz but not if it were 4.5 k Hz.

The calculations do not take into account that a ship, knowing the requirements for STARLITE effectiveness, could alter course after initial contact to reach a more advantageous bearing for longer range classification. Hopefully, further analysis can provide estimates of the probability of surface ships encountering submarines at various bearings and aspect angles as a function

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of ship and submarine speeds. Tactics for optimizing relative positions after initial contact can also be considered. Then more definite conclusions about the utility of STARLITE/PAIR will be possible. While Appendix C provides some insight into the problem, this paper cannot conclude whether or not STARLITE offers a classification capability to PAIR commensurate with the cost of the equipment additions required.

STATUS OF STARLITE TECHNOLOGY

The sea trials described in references 1 and 2 show close agreement with the theory of STARLITE described more fully in reference 8. On the basis of these reports, the theory and post-experimental technique appear sound. Reference 3, however, describes a laboratory experiment which does not provide agreement with the STARLITE theory. Until these differences are explained, the status of the STARLITE theory remains unclear. Even if STARLITE operates as described in references 1, 2 and Appendix A, the equipment requirements for an accurate classification package are not clear.

References 1 and 2 state that the existence of a linear reflector can be shown by comparing the Fourier transforms of the outputs from two hydrophones. If the features of the one transformed output are shifted in frequency relative to the features of the other, this simple shift indicates a linear reflector. Such a shift can be detected by cross-correlating the Fourier transforms. This technique could provide a minimum STARLITE classifier. If we add to the shift information echo duration information from one of the hydrophones, the target aspect angle and length and width can be estimated with excellent accuracy as indicated in references 1 and 2.

Naturally, the additional processing equipment for measuring echo duration will raise the cost over a system which simply extracts a cross-correlation shift. We don't know if the added information of aspect, length and width will improve classification accuracy by enough to justify the extra cost. If a development program is begun, this problem should be analyzed, together with the problem of what STARLITE information could contribute to tracking and fire control functions.

Reference 4 discusses different methods of implementing STARLITE processors. Dr. Wiekhorst also discussed various types of processors in a meeting at NAVSHIPS on 31 October 1967. The several techniques suggested have various advantages and disadvantages with respect to performance, cost and ease of implementation as real-time processors. Analytical comparison and computer simulation of these potential implementations would constitute a basic step in moving STARLITE from a laboratory technique to a shipboard application.

To date, all STARLITE processing has been non-real-time using general purpose computing equipment. With these techniques, an experimental program can proceed without hardware construction in the initial stages. The use of digitally driven CRT displays would permit wide testing of display formats prior to the selection of sea trial hardware design. Further studies of real-time processing and display requirements might reveal that current shipboard general purpose computers such as the USQ-20 can efficiently perform most of the STARLITE processing with minimal add-ons of special purpose equipment.

The WBS's show a parallel technical and operational analysis for both STARLITE/PAIR and the Sonobuoy Classification Program. They do not show decision points where technical and operational analyses are combined to decide whether a particular system or approach deserves further attention. A full PERT network would reflect these decision points and all interrelationships between the major blocks in the WBS's. Since these projects would be exploratory development, the PERT networks and all cost/time estimates would be subject to change as knowledge accumulates. At the present, knowledge is so scanty that detailed work statements about any block above the lowest level in the WBS would reflect mostly conjecture.

METHOD OF APPROACHING A STARLITE PROGRAM

The lowest risk technical development program would involve a mission and operational analysis prior to the assignment of manpower and money for signal processing analysis and simulation. Obviously, this low risk plan requires more time before hardware realization. On the other hand, the analysis may show that STARLITE has no operational utility worth the cost of a developmental and procurement program.

The time requirements of the present PAIR program may not permit the low risk plan for developing a STARLITE/PAIR subsystem. Unless STARLITE hardware can be installed during the regular PAIR installation over the next four years, many of the ships will have reached an age where additional subsystems' costs and yard time are not justifiable.

Appendices B and C show preliminary technical and operational considerations concerning a STARLITE subsystem in PAIR ships. While more analysis would be required to fully justify or exclude a STARLITE/PAIR system, hardware design might have to be begun on the basis of presently available information to achieve an effective interlock with the regular PAIR schedule.

METHOD OF APPROACHING A SONO-
BUOY CLASSIFICATION PROGRAM

An application of STARLITE to sonobuoys launched from the ASW ship or dropped by helicopters and VS/VP aircraft could take two basic forms: (1) the use of two active/passive sonobuoys with an appropriate spacing to provide the STARLITE bistatic reception, (2) the use of two passive sonobuoys with a separate sound source such as an explosive charge, expendable acoustic sound source providing many pings, or a vehicular transducer such as a helicopter's dunking sonar.

Appendices D and E describe a ship-launched passive sonobuoy (CLASP system) and the recent tests of an airborne Command Active Sonobuoy System (CASS). Both of these sonobuoy systems offer a measure of classification capability now. However, the current systems have some classification vulnerabilities, as reference 9 indicates with respect to CLASP.

In the following paragraphs we will discuss some considerations and proposals for using sonobuoys (with or without STARLITE processing) to classify long range contacts initially detected by the ASW ship's search sonar. A possible combination of helicopters with ship-launched sonobuoys is considered. In addition, a sequential sonobuoy classification process is suggested where lack of detection by a passive sonobuoy would initiate the ship-launch or air-drop of another sonobuoy, such as CASS, for detection and classification by active means (including STARLITE).

Moving a classification package close to a contact initially detected by a long range search sonar can greatly assist the overall classification problem, as explained in reference 6. The classification package can consist of several candidate sensors and several methods of delivery to the contact area. A complete trade-off analysis of the operational and technical characteristics of these candidate systems would require a major analysis effort. Much of the analysis, particularly the operational part, could proceed without a major commitment of manpower to the design and simulation of the subsystems. This would be the low risk approach referred to earlier.

While passive sonobuoys offer cost, weight and probably reliability over active sonobuoys, their detection and classification capabilities can be nullified by such factors as promimity to the masking noise of convoy or task force, the low noise output of battery-operated submarines and slow speed nuclear submarines and some counter-measures or decoys transmitting recordings of typical submarine acoustic signatures.

A proposed active sonobuoy (CASS) which employs FM pulses and CW pulses to improve reverberation and Doppler processing is briefly described in Appendix E. The planned displays and signal processing for these active sonobuoys might solve the classification problem without a requirement for STARLITE processing. However, STARLITE processing would give an advantage of estimates of target aspect angle, length and width. These data would help reduce the effectiveness of decoys which, while easily providing Doppler and an acoustic signature, could probably never simulate the dimensions of a submarine.

VS/VP aircraft in the convoy or task force van use passive sonobuoys with LOFAR for detection and classification. Active buoys are used to localize for MAD confirmation and for attack. MAD classification does not obviate a possible need for a STARLITE/sonobuoy system. MAD is marginal for deep or evasive submarines and can be decoyed. Geological noise and debris and wrecks (in shallow water) limit MAD classification ability. In shallow water, a STARLITE/sonobuoy system could possibly improve classification if it adequately rejects bottom reverberation.

SONOBUOY DELIVERY METHODS

We recall that classification case (2) considers a long-range, short duration contact situation. Since the firm contact time of the detection system is limited, usually because several pings are used in the detection process, the time-late of arrival for the remote classification sonar is critical. The short detection range of the system will not provide wide area coverage. If the system cannot arrive during or shortly after long range sonar contact, the area of uncertainty for target location rapidly expands beyond the detection range of the sonobuoys. Even though active sonobuoys enjoy good below-layer ranges with variable depth transducers, excessive time-late results in a much greater expenditure of sonobuoys to insure successful detection and subsequent classification. Reference 6 shows some of the time-late problems associated with the placement of active sonobuoys around a datum. The WBS shows boxes considering VS/VP aircraft systems, helicopter delivered systems, and gun-launcher buoy systems. Time-late constitutes one of the principal factors governing the choice between these delivery systems.

From the time-late considerations, shipboard gun or rocket launched sonobuoy systems might offer several advantages over helicopter or VS/VP aircraft delivery systems. The MK 114 fire control system receives and displays sonar and radar information and controls the 5" gun and ASROC. Reference 11 states that the radar can detect the splash-entry point for the passive sonobuoys. Sonobuoy placement by 5" gun would be particularly attractive since the long range sonar would directly aim the gun with the MK-114. The ship-launch of the sonobuoys reduces the time-late since a helicopter or aircraft does not have to reach the datum, drop a pattern of sonobuoys, and wait for them to activate before classification and fire-control data is available. Essentially the same remarks apply to the use of helicopters or VS/VP aircraft with ship-launched buoys.

Assuming that a gun-fired or gun-fired rocket-sustained sonobuoy can be accurately placed near any contact gained by an ASW ship's search sonar, UHF and VHF radio transmission and reception between the ship and sonobuoy might constitute the greatest restriction on the effective classification ranges. If UHF and VHF transmissions were line-of-sight limited, a 100 foot antenna on the ASW ship and a 4 foot antenna on the sonobuoy would permit communication to about 13.8 miles. Reference 9, however, states "This study concluded that development of an appropriate ruggedized, gun-launched, rocket-sustained passive sonobuoy is within the state-of-the-art, that reliable sonobuoy-ship communications can be maintained in the 40-60 megacycle region up to and beyond 27 nautical miles, and that standard aircraft-type receiving, processing, and display equipment could be employed with little modification, except accommodating the particular frequency band to be used." Even if the sonobuoy payload could not include a battery large enough to provide this direct sonobuoy-to-ship communication, a helicopter or supporting VS/VP aircraft could relay the radio signal from the buoy to the ship achieving greater range because of its altitude. The helicopter or aircraft could also deliver the attack.

ASROC and extended-range ASROC will have ranges of 10 and 18 kyds, respectively. These ranges will not reach all surface duct "look zone" contacts or match the bottom bounce and convergence zone ranges achievable with the AN/SQS-26 and more modern sonars. Thus, the surface ship will have to use helicopters, VS/VP aircraft or drones such as DASH for weapon delivery. Thus, we are proposing that the surface ship detect the contact, launch the classification sonobuoys to insure a minimum time-late on the datum, classify the contact using a helicopter or aircraft for radio relay from sonobuoy to ship, and then using the helicopter or aircraft to attack the contact.

While these preceding paragraphs make a case for a ship-launched sonobuoy system, the development of classification sonobuoys for delivery by helicopters or VS/VP aircraft could probably be done more quickly and with less technical risk. While the shorter time-late and the ease of correctly placing the sonobuoys with the MK 114 recommend a ship launched system, judicious placement of helicopters or VS/VP aircraft on continuous station around the screen could reduce their time-late problem. Thus, development of classification sonobuoys for use with helicopters and VS/VP aircraft might provide a useful and more timely addition to the Fleet.

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PERSONNEL AND OVERALL PROGRAM EFFECTS

PAIR Project personnel in Washington and San Diego, plus contract personnel would have to be involved in any technical study of STARLITE application to PAIR. In-house personnel of a number of Navy activities could provide much of the analysis and preliminary development for sonobuoy systems. Contractors already involved with sonobuoy design could assist operational and technical feasibility studies. The Systems Analysis Group of the ASW Systems Project Office has been recommended for sonobuoy studies because of past work of this type (reference 10).

If set up, each of the programs could result in a major effort diverting funds and manpower from current programs. For this reason, we have recommended full discussion of the effects of implementing these programs by the NAVSHIPS Active Sonar Classification Panel and interested parties from NAVSHIPS, NSRDC and NUWC/SD.

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APPENDIX A

CAPSULE DESCRIPTION OF THE STARLITE TECHNIQUE

STARLITE looks at the target from two slightly different aspect angles. Assuming no parts of the target are hidden at either of these angles, and that the target has certain geometric properties, the technique can determine the length, width and orientation of the target.

Assume a target model of point reflectors (any similar type of line target model would do) and two hydrophones as shown in figure A-1. The target is ensonified by a source near the hydrophones.

THE STARLITE TARGET MODEL

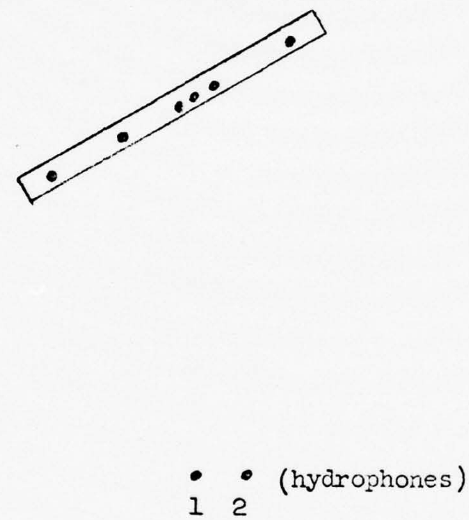

Figure A-1

The impulse response of the target as measured at hydrophone 1 would be a train of impulses as shown in figure A-2a. The impulse response measured at hydrophone 2 would be the same train of impulses (figure A-2b) but compressed, since hydrophone 2 is more abeam of the target than hydrophone 1. The limiting case of pulse compression would result for a hydrophone directly abeam in which case the response would be a single impulse.

IMPULSE RESPONSE OF A SUBMARINE ECHO AT TWO HYDROPHONES

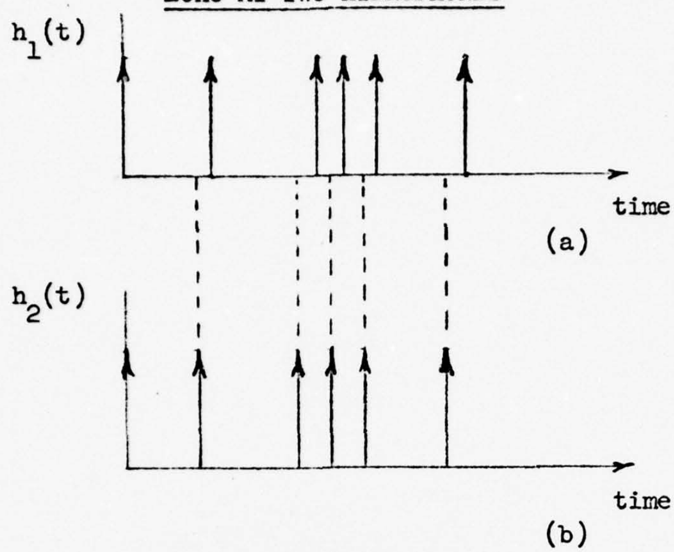

Figure A-2

If we are given the impulse responses of figure A-2, together with values of the parameters of range, bearing, separation of the hydrophones, active carrier frequency, signal bandwidth and the time duration of either $h_1(t)$ or $h_2(t)$, we can determine the length, width and aspect angle of the target.

Let $h_1(t)$ be the impulse response measured at hydrophone 1. Then, as shown in figure A-2b, $h_2(t)$ is simply a compressed $h_1(t)$. That is:

(A-1) $$h_2(t)=h_1(\tfrac{t}{a})$$

where a is some constant which depends on the aspect angle. Let $H_1(f)$ be the Fourier transform of $h_1(t)$. Then the Fourier transform gives:

(A-2) $$H_2(f)=a\ H_1(af).$$

This simply means that a compression in the time domain results in an expansion in the frequency domain. If the spectra of H_1 and H_2 were very wide, and if we observed these spectra through a small "window," the expansion could be approximated as a simple shift in frequency.

This is similar to treating a Doppler compression as a simple frequency shift. By taking the Fourier transforms of the signals received at the two hydrophones and measuring the frequency shift, we can determine target length, width and aspect angle using the measured echo duration and the other parameters previously measured.

A further refinement would directly measure the frequency response of the target. This could be implemented by transmitting a slowly swept linear FM signal. Then the envelope of the echo would be the frequency response curve. This is equivalent to measuring the frequency response of a circuit in the laboratory by measuring its output with an input of varying frequency from a signal generator. The obvious advantage of this method is that no Fourier transformations of the received echoes is necessary.

This discussion gives only a superficial description of the STARLITE technique. In practice, there are many limitations which have not been mentioned. Among these limitations are finite system bandwidth effects, Fresnel field effects, frequency shift resolution limits, and the length to width ratio of the target. All of these factors have to be considered in any detailed discussion of the technique.

The complete derivation of STARLITE theory and discussions about its limitations are best described in references 1, 2, 7, 8. The limiting equations are covered in Appendix C of this paper.

APPENDIX B

USE OF STARLITE WITH THE PLANNED PAIR SYSTEM

Since PAIR, or the AN/SQQ-23, currently in construction, uses two separated receiving arrays for the passive subsection, STARLITE application initially seems very logical and desirable. This appendix will briefly consider the technical problems of STARLITE/PAIR. Although actual processors and displays for STARLITE are unspecified at this time, certain technical features of PAIR and a possible STARLITE subsystem will be discussed.

We will not describe all the capabilities and features of PAIR. Our description and the block diagram in figure B-1 only cover the principal signal processing steps and the nature of the received signal at different points in the system. The STARLITE/PAIR processor we suggest is for illustrative purposes only. Further study might produce a STARLITE processor of greatly different form for incorporation with the SQQ-23.

Brief Description of the Active Portion - SQQ-23

The SQQ-23 will transmit at 4.5 kHz and 5.5 kHz. The forward dome contains the active receiving array. This array has 48 staves from which are formed 48 beams of 7 1/2 degrees width, overlapping at the 3db-down points. The beamformers are analog delay lines of 1-6 kHz bandpass. The received signal from the beamformers is heterodyned to 20 kHz and bandpass filtered to 470 Hz centered at 20 kHz.

After filtering, the received analog signal can go any of four paths (see figure B-1), depending upon operator direction from the console. The first path leads to the Wave Period Processor (WPP) which, for search processing, clips the signal, A/D converts, thresholds, and sends the resulting signal to a digital computer. The computer controls a display which has 16 symbols wired into its

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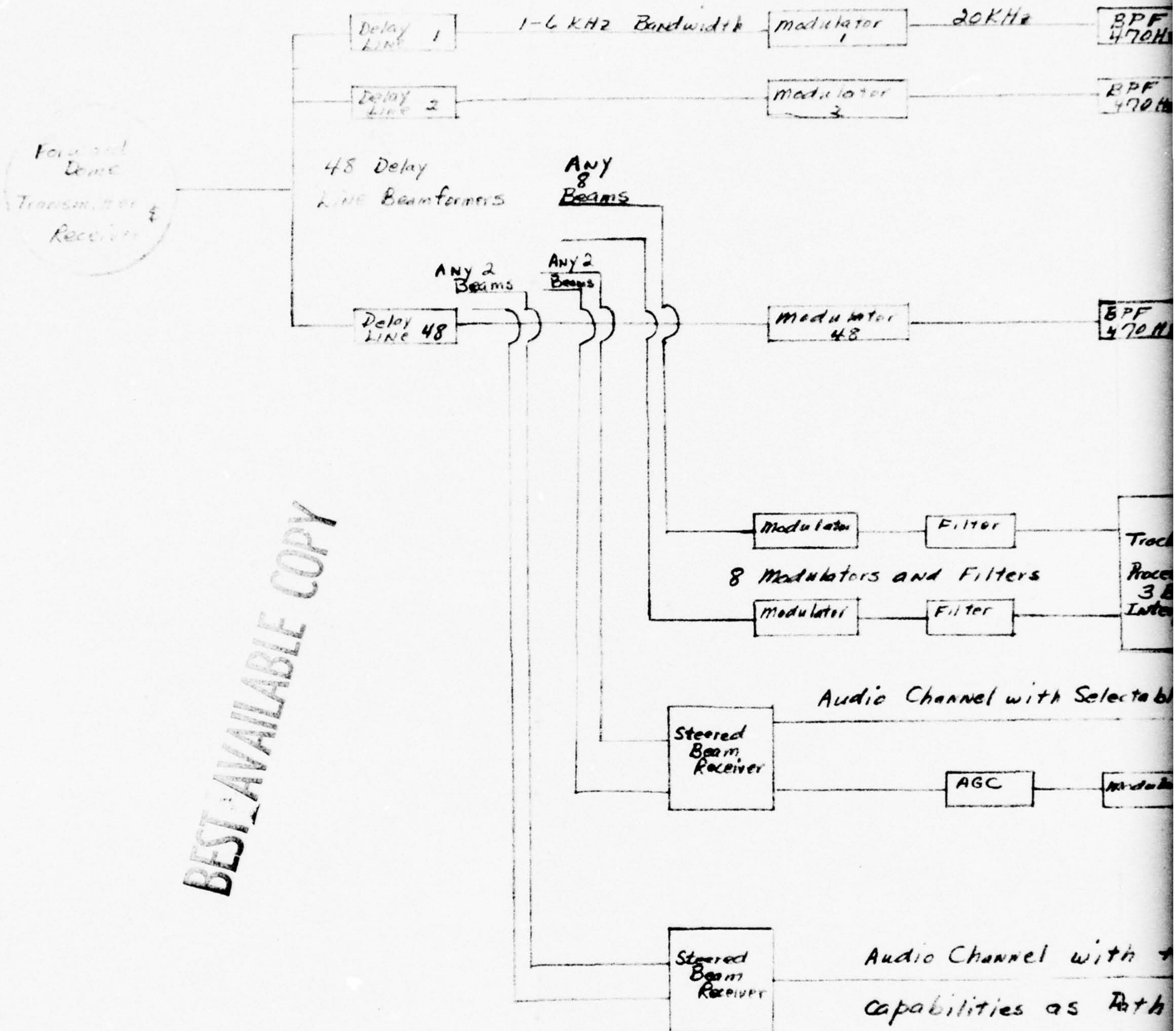


Active Processing Portion
of the AN/SQQ-23

FIGURE B-1

2

Path 1
Hz
BPF 470Hz
Analog Signal
BPF 470Hz
BPF 470Hz
Wave Period Processor
(Signal is Clipped)
DPU Computer
DPU Computer
Symbolic Displays
CRT
CRT
Twin Operator Console
Search & Tracking or Monitoring
Path 2
ers
Tracking Processor 3 Beam Interpolation
Sum & Difference Process Output
Path 3
Passive Bands
Active Bands
with Selectable Filtering: 1-1.8KHz, 1-2.5KHz, 1-6KHz / 4.5 or 5.6KHz (470Hz BW Het → 484Hz)
Branch 1
Modulator
Filter 470Hz
Quadrature Heterodyne
5 bit Linear A/D
Quadrature Replica Correlator
D/A
Paper Recorder Display
Branch 2
Path 4
nel with the same
s as Path 1, Branch 1
Steered Beam Receivers are controlled by the operator's cursor setting.

on

symbol generator (no alpha/numerics presently). The computer performs a second thresholding to limit the number of events displayed.

The second path goes to a tracking processor which uses any eight adjacent beams of the 48 to do sum and difference processing with 3 beam interpolation.

The third path goes to a Steered Beam Receiver (SBR) which uses any 2 adjacent beams of the 48 for an analog interpolation over a frequency range of 1-6 kHz. This path receives unfiltered beam outputs and has its own processing. One branch of this path provides an audio channel for passive or active signals. For the passive mode selectable filtering is provided: 1-1.8 kHz, 1-2.5 kHz, 1-6 kHz. For the active mode, the 4.5 or 5.5 kHz input is heterodyned to 484 Hz and filtered to a bandpass of 470 Hz.

In the second branch, the active signal only is then modulated to 20 kHz, bandpass filtered to 470 Hz width, centered on 20 kHz, quadrature heterodyned and A/D converted by a 5 bit linear converter. The digitized quadrature components are then replica-correlated. The correlator output is D/A converted and displayed on a paper recorder.

The fourth path goes to another SBR with the same filters and heterodyner as the first branch of path 3. This path has no correlator. Both SBR's are steerable by the operators of the two consoles.

Brief Description of the Passive Portion - SQQ-23

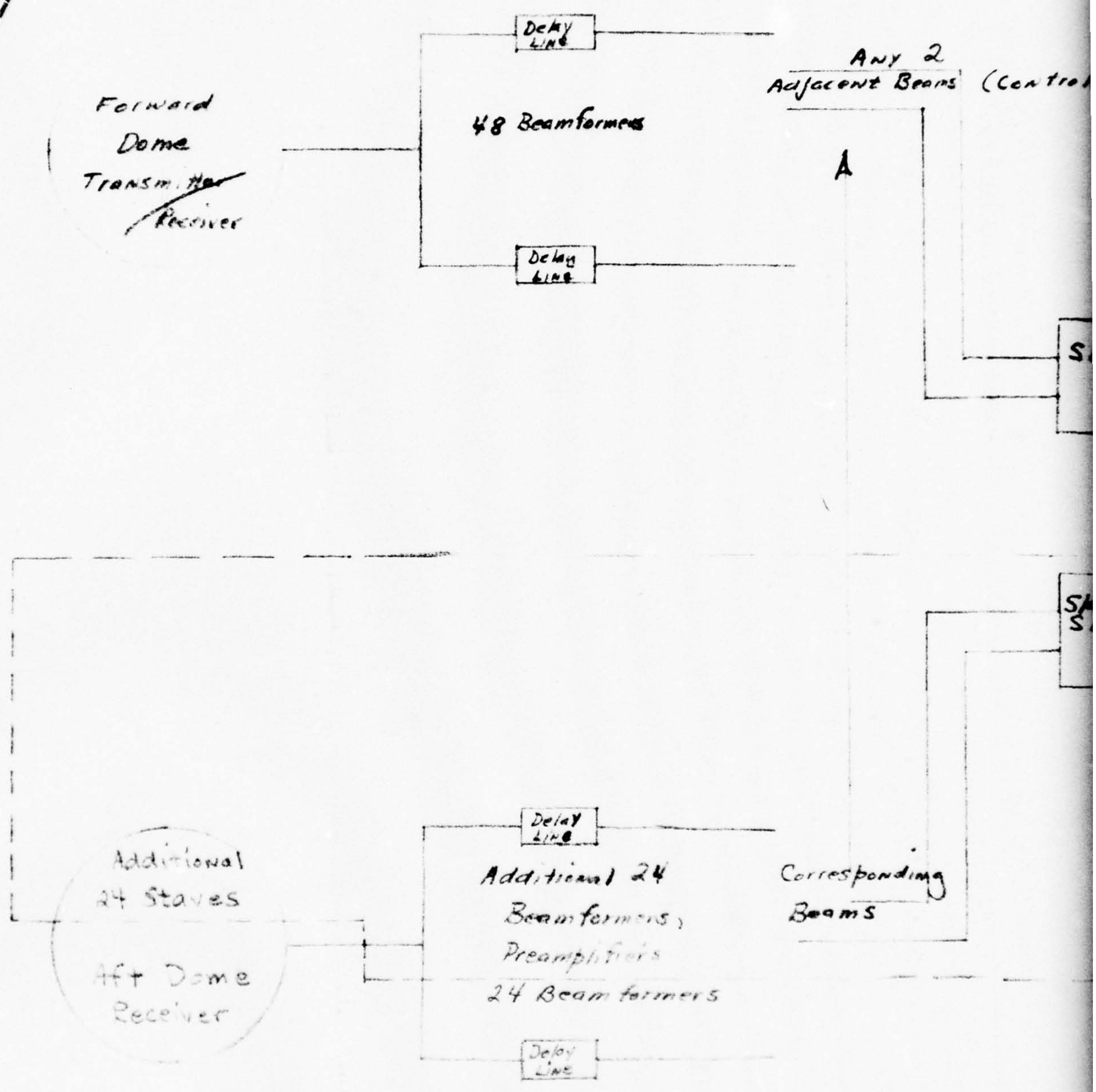
Passive bands of 1-1.8 kHz and 1-2.5 kHz are selectable with the two receiving arrays. Passive search is done at 1-2.5 kHz over 22 beams of 15 degree width formed with analog delay lines (the aft 30° is not searched). The output of the 22 beams for passive search is displayed on a paper time-bearing recorder. Passive tracking can be done at either 1-2.5 kHz or 1-1.8

kHz with one beam from each dome at the selected frequency band being clipped and then fed to a clipper cross-correlator. The output of the correlator is displayed on a CRT

STARLITE Processing with SQQ-23

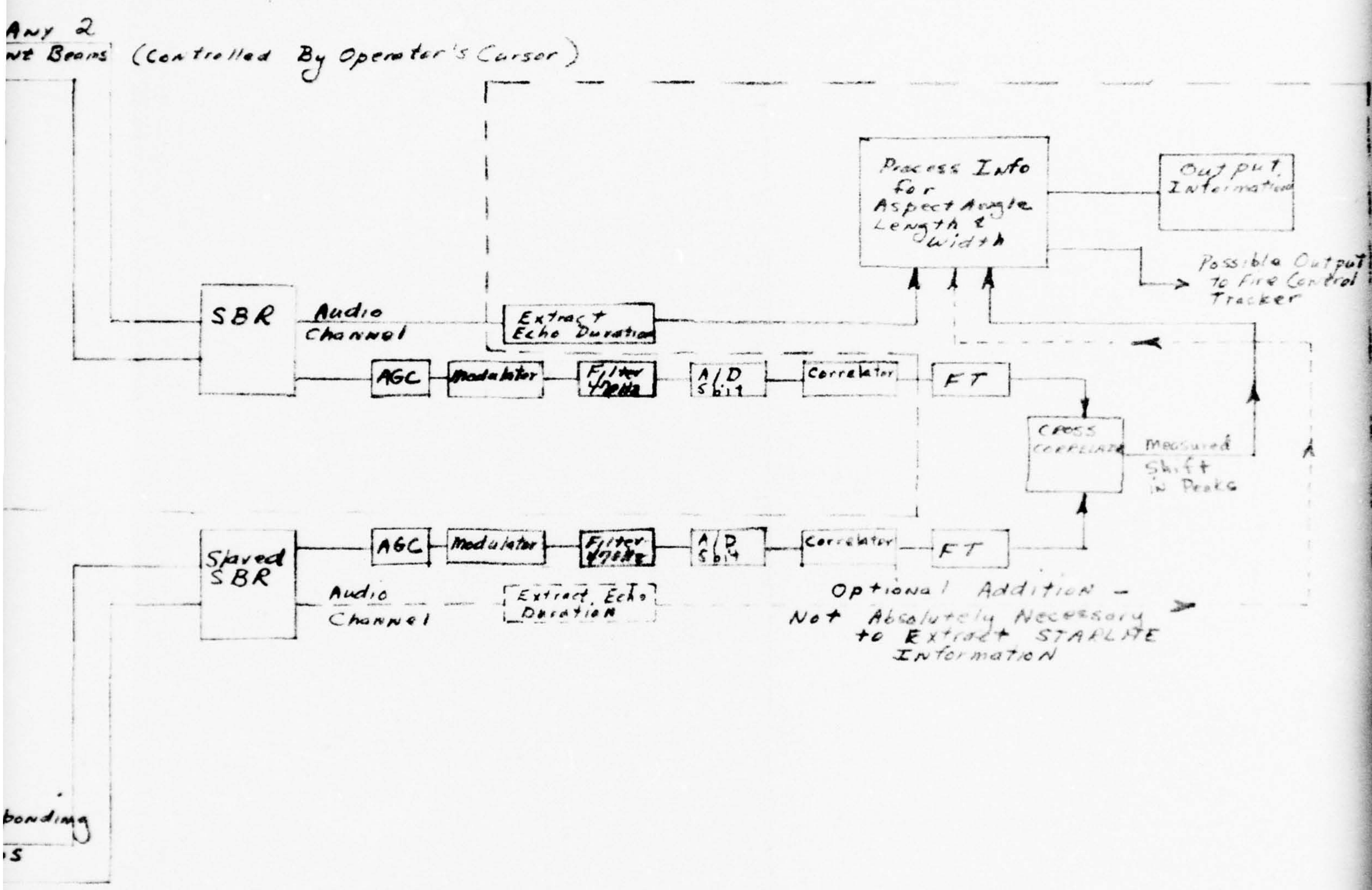
STARLITE requires both receiving arrays. Unfortunately, the aft array has only 24 staves instead of 48, since its processing channel only handles signals up to 2.5 kHz instead of 5.5 kHz. Because of the greater stave spacing, the beam pattern for this array has conspicuous side lobes. Figures B-3 and B-4 show the beam pattern of the aft array at 4.5 kHz and 5.5 kHz with side lobes respectively only 5db and 3 db lower than the main lobe. As a consequence the bearings of received active signals at the beamformed output of the unmodified aft array would be subject to error. The array also would provide substantially less S/N ratio than the forward array.

The second branch of the third path of active sonar processing; namely, the SBR with correlator, provides some of the possible STARLITE processing. If we specify STARLITE processing as the cross-correlation of the Fourier transforms of the forward and aft correlator outputs gated around the echo, plus a means of measuring echo duration, we can state some preliminary requirements for modifications to the planned SQQ-23. Figure B-2 shows the present processing and the necessary hardware additions for STARLITE. The minimum addition consists of 24 staves, 24 beam-former delay lines and 24 preamps in the aft array to complete 48 aft beams at 4.5 and 5.5 kHz. This addition would be to make the system suitable for recording signals for shoreside STARLITE experiments and prepare it for later addition of processing. Complete implementation would add to the aft array a slaved SBR with a correlator, two Fourier transform boxes, a cross-correlator echo duration processor, an overall



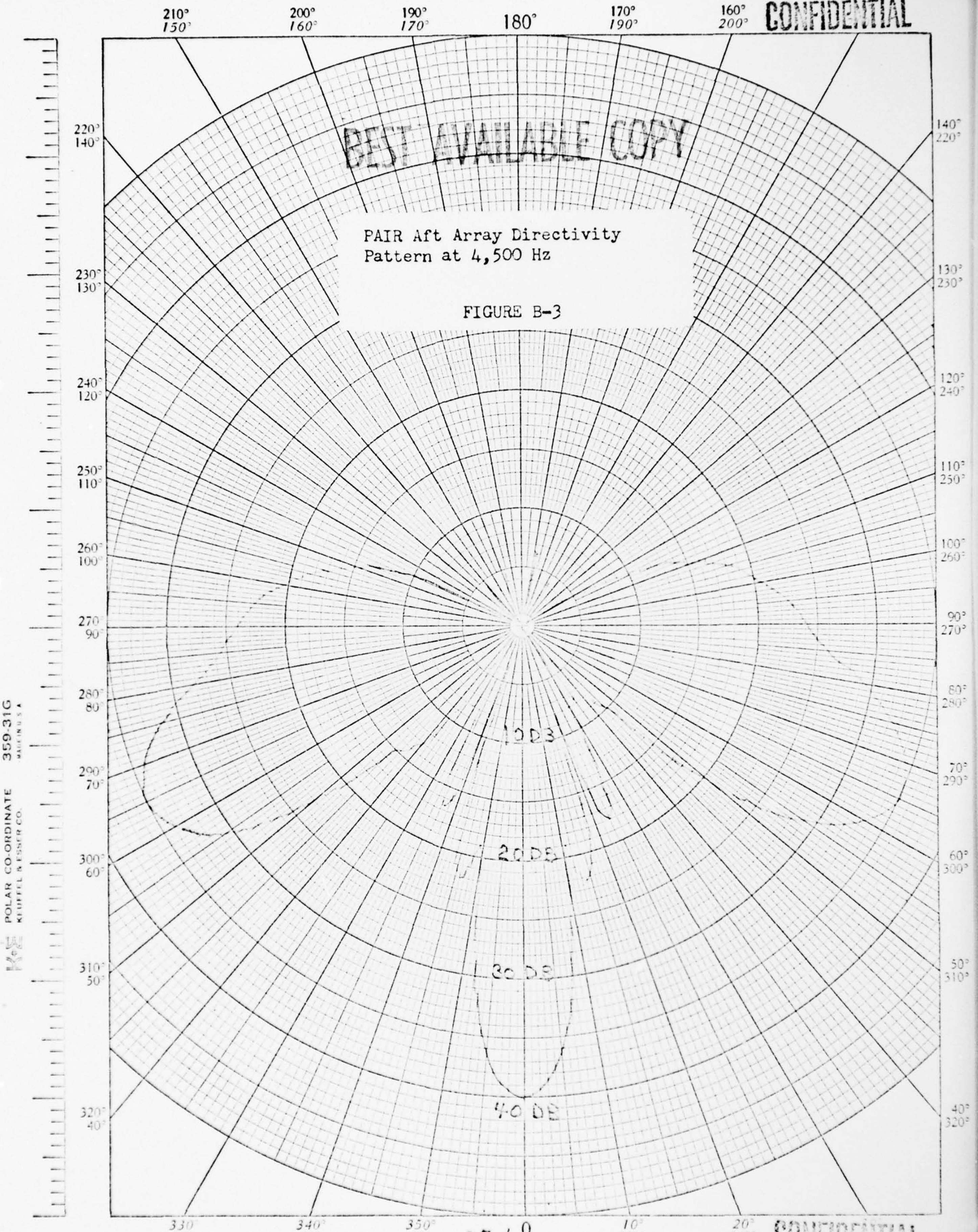
A Possible STARLITE/PAIR
Hardware Configuration

FIGURE B-2



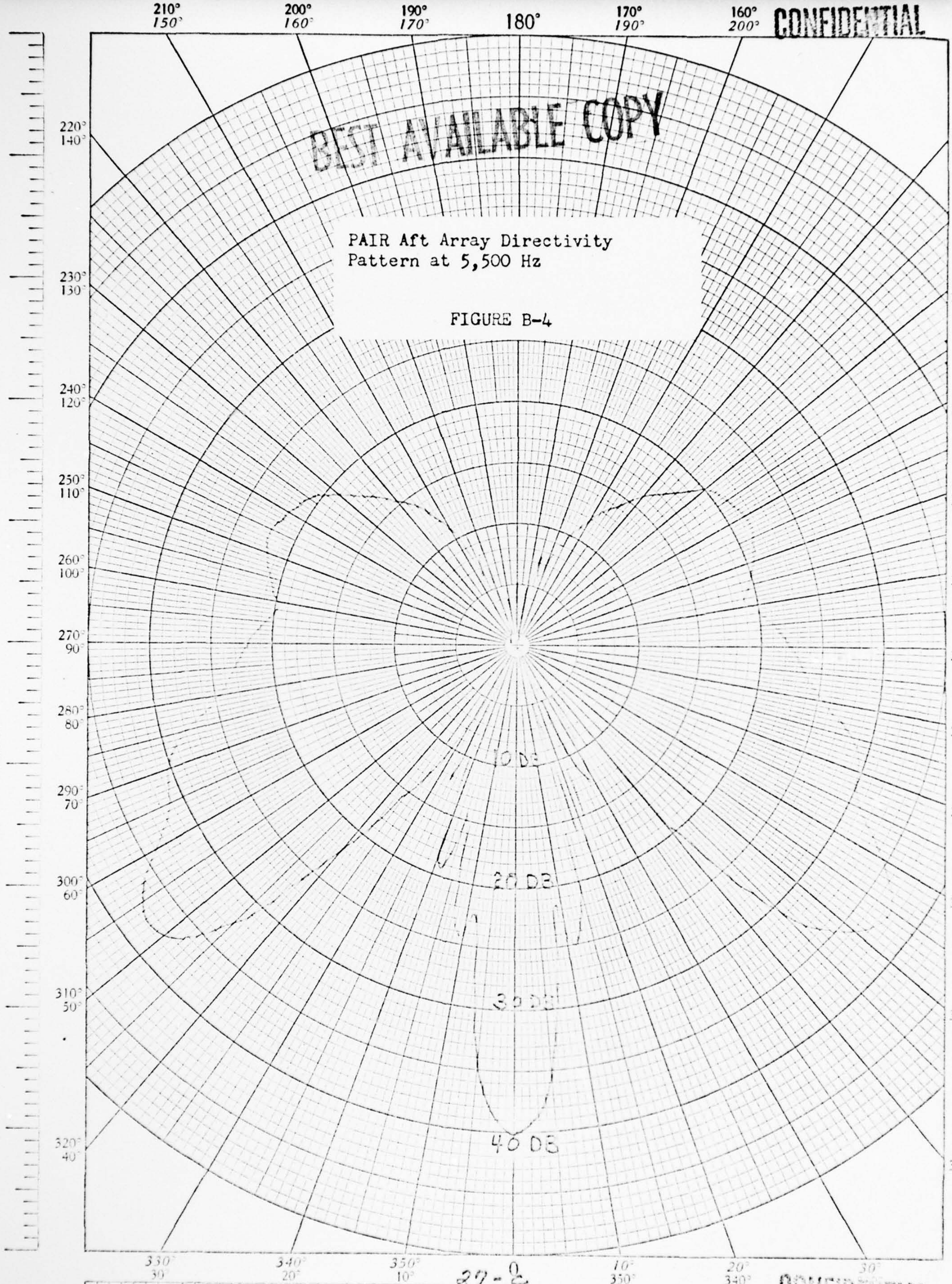
ALL COMPONENTS WITHIN THE BROKEN LINES MUST BE ADDED TO CURRENT AN/SQQ-23 FOR STARLITE

R



PAIR Aft Array Directivity Pattern at 4,500 Hz

FIGURE B-3



PAIR Aft Array Directivity Pattern at 5,500 Hz

FIGURE B-4

output information processor and a display. The cross-correlation shift and echo duration measurement would provide the basis for determining: (1) whether or not target is a linear reflector, (2) target aspect angle, and (3) target length and width. If the echo duration from both array channels were measured, estimates of (2) and (3) could be improved by using an average or weighted mean of the two measures. The active PAIR signal most useful for STARLITE application has a bandwidth of 440 Hz and a pulse length of 161 Msec.

This suggested processor is not unique. Further thought and development could possibly produce a processor design which would not require the additional correlator and Fourier transform provisions.

Technical Issues

Assuming that STARLITE works as the current theory predicts, the maximum classification range for STARLITE/PAIR, with a 5 kHz active signal, 60 foot array spacing, 300 foot submarine length, and a minimum submarine aspect angle of 21°, is about 5600 yards abeam of the classifying ship. If the transmit frequency were increased to 10 kHz, the corresponding maximum classification range doubles to 11,200 yards. The costs of providing STARLITE/SQQ-23 at 5 kHz and at 10 kHz should be compared before making final design decisions.

Transmission and reception at 10 kHz might be possible by the use of several transducer rings of quarter-wave elements. While the attenuation losses at 10 kHz would be greater and the source level probably less, the greater effectiveness of the receiving array at 10 kHz would regain some of this loss. With the 10 kHz signal we don't need to match potential ranges of the 5 kHz signal since STARLITE will not be effective beyond limits well short of these. Even the maximum STARLITE range needn't be matched, since this range is well beyond expected below layer detection ranges at 5 kHz and therefore will not be needed often. In addition, because the operator is alerted to target location before the classification step, S/N requirement is less, being of greater concern to the echo duration measurements, than to a requirement such as initial detection.

APPENDIX C

OPERATIONAL CONSIDERATIONS FOR STARLITE/PAIR

For a STARLITE/PAIR equipped ship, we have calculated the Effective Classification Area (ECA) relative to the Effective Detection Area (EDA) for differing aspect submarines in a below layer case. These calculations are for a static case. Since operationally aspect angles and relative bearings will change continuously except on a restricted set of relative courses, a second set of computations were made with the submarine placed at different initial starting points. These points were selected such that the submarine at a chosen speed and straight-line course reached a point within 4 kyds of the surface ship at the end of an hour. At specified points along the submarine track, a computer program determined whether or not the target could be classified, considering its range, bearing from the surface ship and aspect angle at that point.

Neither of these sets of computations really shows whether or not STARLITE/PAIR offers a classification capability worth the cost, which hasn't been estimated yet. More analysis is planned. Meanwhile the following results may assist decision-making at this time.

Classification Area Relative to Detection Area

Definitions:

R = Range of submarine from surface ship

R_D = PAIR detection range (below layer target)

R_S = STARLITE classification range

R_F = STARLITE minimum range (Fresnel far-field condition)

ϕ = Submarine axis angle (90° = bow or stern on, 0° = beam)

Θ = Submarine bearing from the surface ship

B = Spacing between receiving arrays

f_c = Carrier frequency of transmitted signal

Δf = Signal bandwidth

L = Length of submarine

D = Diameter of submarine

C = Speed of sound in water

A_S = STARLITE Effective Classification Area

A_D = PAIR Effective Detection Area

Baffle area = 60° sector astern in which a submarine can neither be detected nor classified. The following equations determine the STARLITE effective classification range:

(C-1) $$\left|\frac{f_c B \cot\phi \sin\theta}{\Delta f}\right| < R_s < \left|\frac{L}{C} f_c B \sin\theta \cos\phi\right|$$

(C-2) $$\sqrt{\left|\frac{f_c L^2 B \cot\phi \sin\theta}{2C}\right|} < R_s$$

(C-3) $$\left|\frac{L}{D} \sin\phi\right| > 4$$

Equation (C-2) states the Fresnel far-field condition. Using PAIR parameters,

$$\sqrt{\left|\frac{f_c L^2 B \cot\phi \sin\theta}{2C}\right|} > \left|\frac{f_c B \cot\phi \sin\theta}{\Delta f}\right| \quad \text{when } \phi$$

is greater than 21° (equation C-3). Therefore,

(C-4) $$R_F = \sqrt{\left|\frac{f_c L^2 B \cot\phi \sin\theta}{2C}\right|} < R_S < \left|\frac{L}{C} f_c B \sin\theta \cos\phi\right|$$

and equation (C-3).

The equation for R_S defines two circles with center at $\pm R_S max/2$ (where R_S max is the value of R_S for $\theta = 90°$) and at relative bearings of 090° and 270° from the surface ship. For any fixed value of ϕ three conditions can hold:

(a) $R_S \max < R_D$

(b) $R_S \max/2 < R_D < R_S \max$

(c) $R_D < R_S \max/2$

These three conditions are illustrated in figure C-1 (a-f) for 5 kHz and 10 kHz. The mathematical derivation of A_S for each condition is:

Condition (a): From figure C-1(a) the effective detection area is $A_D = 5/6\pi R_D^2$. The effective classification area is found as:

$$A_S = 2\left[\int_0^{\frac{5\pi}{6}} \frac{R_S^2}{2}\, d\theta - \int_0^{\frac{5\pi}{6}} \frac{R_F^2}{2}\, d\theta\right]$$

$$= 2\left[\left(\frac{1}{2}\right)\left(\frac{L}{C} f_c B \cos\phi\right)^2 \int_0^{\frac{5\pi}{6}} \sin^2\theta\, d\theta - \left(\frac{1}{2}\right)\left(\left|\frac{f_c L^2 B \cot\phi}{2C}\right|\right)\int_0^{\frac{5\pi}{6}} \sin\theta\, d\theta\right]$$

$$= \left(\frac{L}{C} f_c B \cos\phi\right)^2 \left(\frac{10\pi + 3\sqrt{3}}{24}\right) - \left(\left|\frac{f_c L^2 B \cot\phi}{2C}\right|\right)\left(\frac{2+\sqrt{3}}{2}\right)$$

$$= R_S^2 \max\left(\frac{10\pi + 3\sqrt{3}}{24}\right) - R_F^2 \max\left(\frac{2+\sqrt{3}}{2}\right)$$

(C-5) $$A_S/A_D\ (\%) = 100\left[\frac{R_S^2 \max\left(\frac{10\pi+3\sqrt{3}}{24}\right) - R_F^2 \max\left(\frac{2+\sqrt{3}}{2}\right)}{\frac{5\pi}{6} R_D^2}\right]$$

Condition (b): From figure C-1 (b-c), the effective detection area is

$A_D = 5/6\pi R_D^{\,2}$.

The effective classification area is found as:

$$A_S = 2\left\{2\int_0^{\theta'} \frac{\left(\frac{L}{C} f_c B \cos\phi \sin\theta\right)^2}{2} d\theta + \pi R_D^2\left(\frac{\pi - 2\theta'}{2\pi}\right) - \int_{5\pi/6}^{\pi} \frac{\left(\frac{L}{C} f_c B\cos\phi \sin\theta\right)^2}{2} d\theta - \int_0^{\frac{5\pi}{6}} \frac{\sqrt{\left|\frac{f_c L^2 B \cot\phi \sin\theta}{2C}\right|}^{\,2}}{2} d\theta\right\}$$

$$= 2\left(\frac{L}{C} f_c B\cos\phi\right)^2\left(\frac{2\theta' - \sin 2\theta'}{4}\right) - \left(\frac{L}{C} f_c B\cos\phi\right)^2\left(\frac{2\pi - 3\sqrt{2}}{24}\right) + R_D^2(\pi - 2\theta') - \left|\frac{f_c L^2 B\cot\phi}{2C}\right|\left(\frac{2+\sqrt{3}}{2}\right)$$

$$= \left(\frac{L}{C} f_c B\cos\phi\right)^2\left(\frac{24\theta' - 12\sin 2\theta' - 2\pi + 3\sqrt{2}}{24}\right) + R_D^2(\pi - 2\theta') - \left|\frac{f_c L^2 B\cot\phi}{2C}\right|\left(\frac{2+\sqrt{3}}{2}\right)$$

$$= R_{S\,max}^2\left(\frac{24\theta' - 12\sin 2\theta' - 2\pi + 3\sqrt{2}}{24}\right) + R_D^2(\pi - 2\theta') - R_{F\,max}^2\left(\frac{2+\sqrt{3}}{2}\right)$$

(C-6) $$A_S/A_D(\%) = 100\left[\frac{R_{S\,max}^2\left(\frac{24\theta' - 12\sin 2\theta' - 2\pi + 3\sqrt{2}}{24}\right) + R_D^2(\pi - 2\theta') - R_{F\,max}^2\left(\frac{2+\sqrt{3}}{2}\right)}{\frac{5\pi}{6} R_D^2}\right]$$

where θ' = bearing where $R_D = R_S$.

Condition (c): From figure C-1 (d-f) the effective detection area is $A_D = 5/6\pi R_D^{\,2}$.

Effective classification area is found:

$$A_S = 2\left\{\int_0^{\theta'} \frac{\left(\frac{L}{C} f_c B\cos\phi \sin\theta\right)^2}{2} d\theta + \pi R_D^2\left(\frac{\frac{5\pi}{6} - \theta'}{2\pi}\right) - \int_0^{\frac{5\pi}{6}} \frac{\sqrt{\left|\frac{f_c L^2 B\cot\phi\sin\theta}{2C}\right|}^{\,2}}{2} d\theta\right.$$

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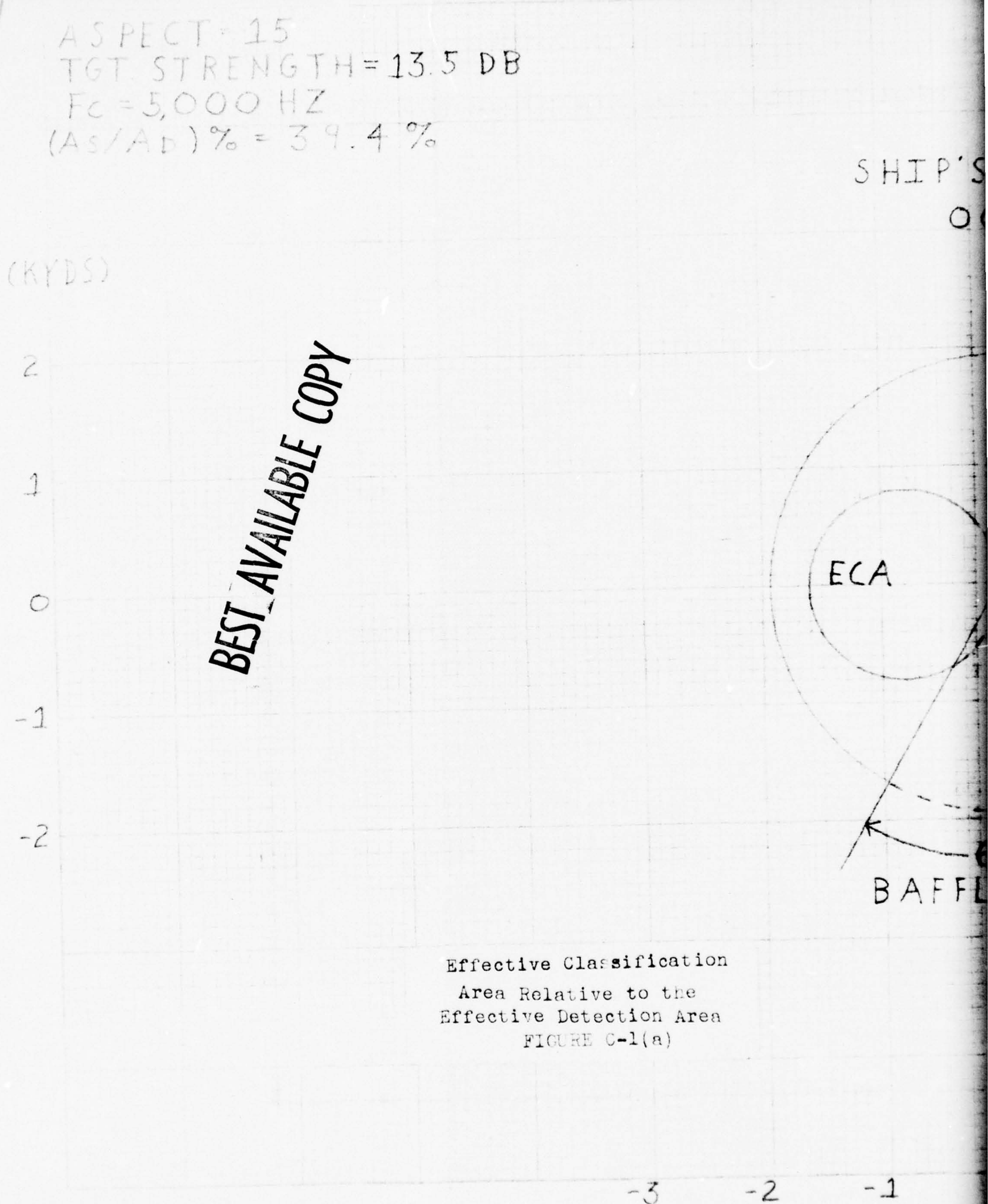
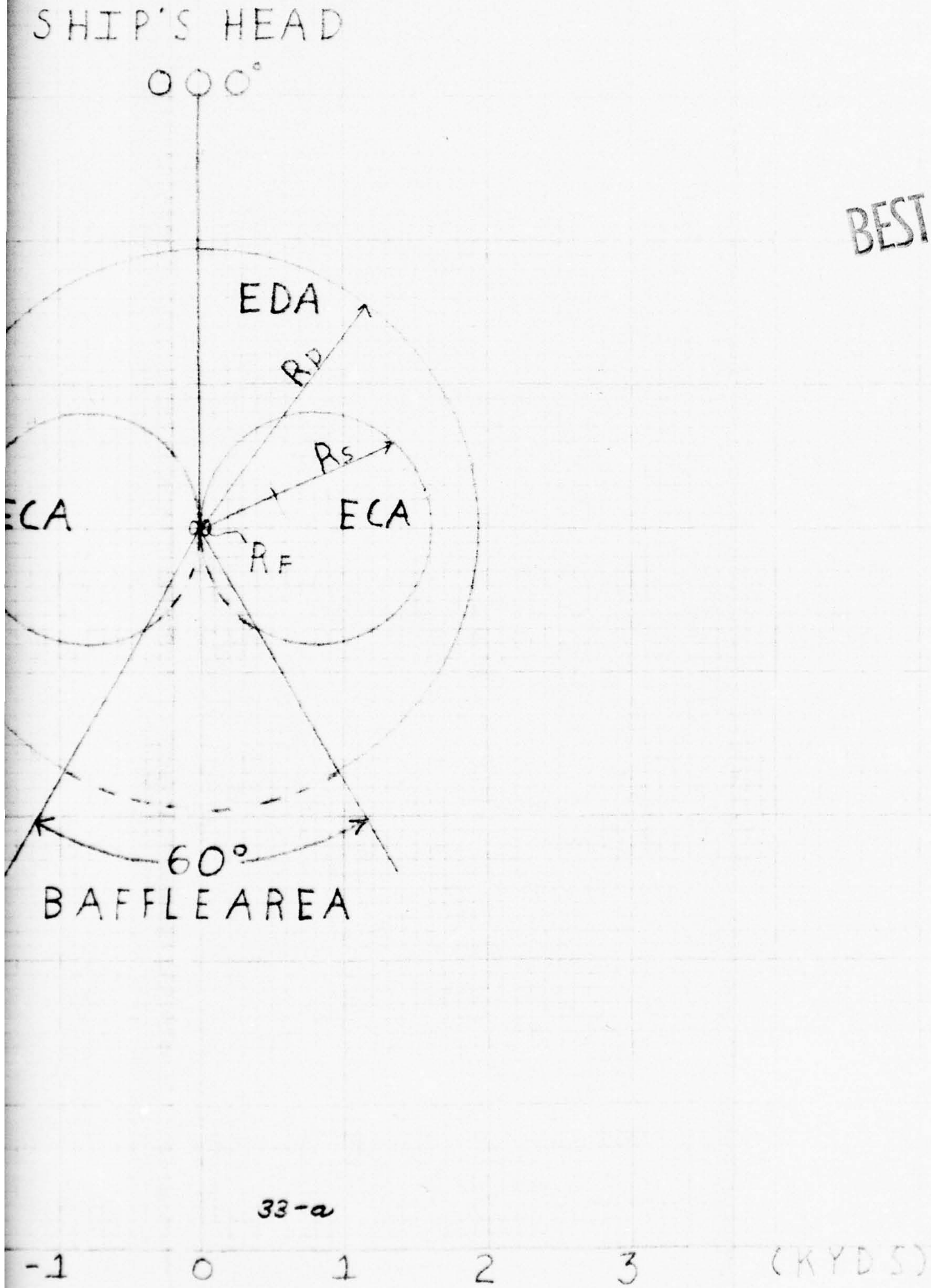
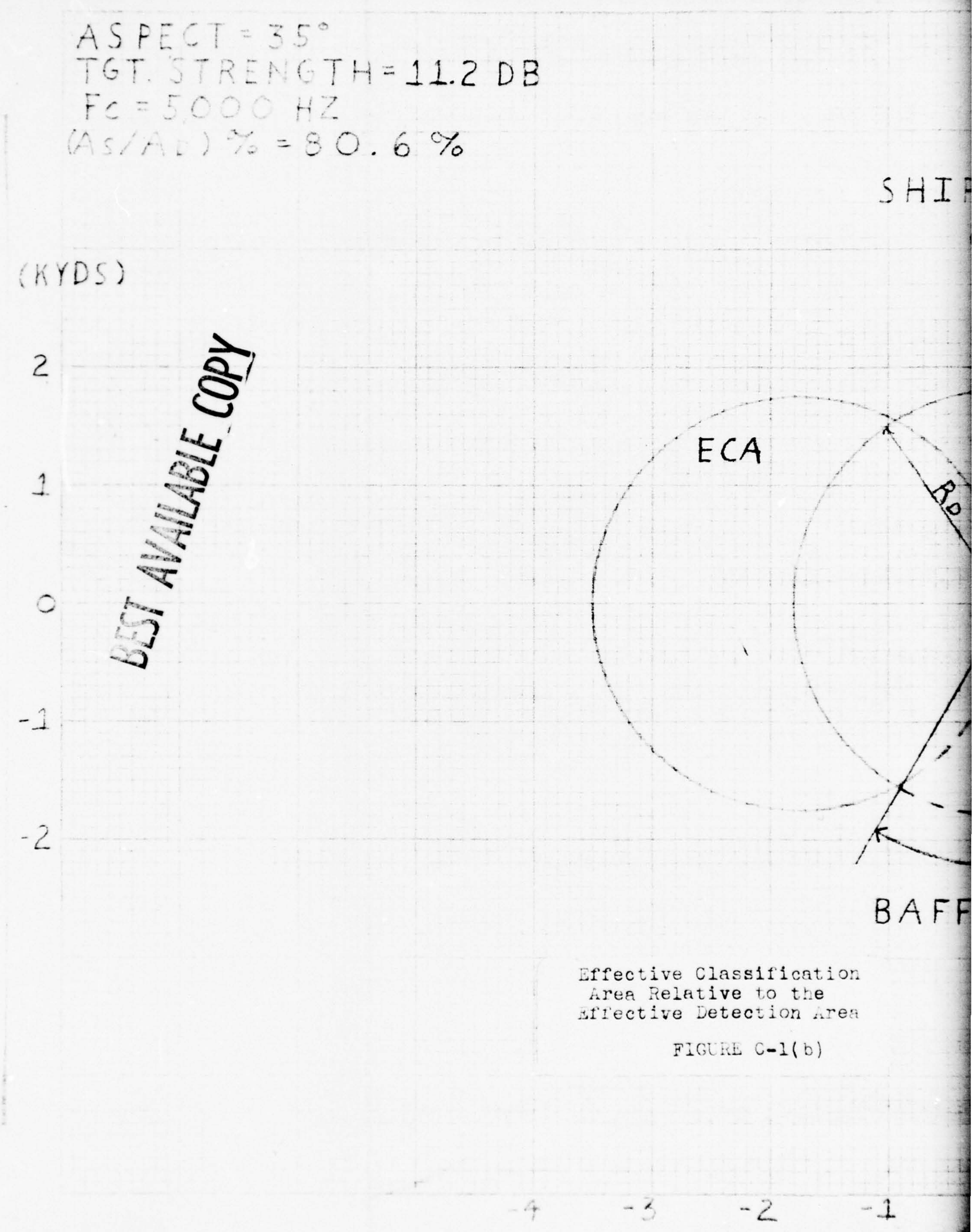


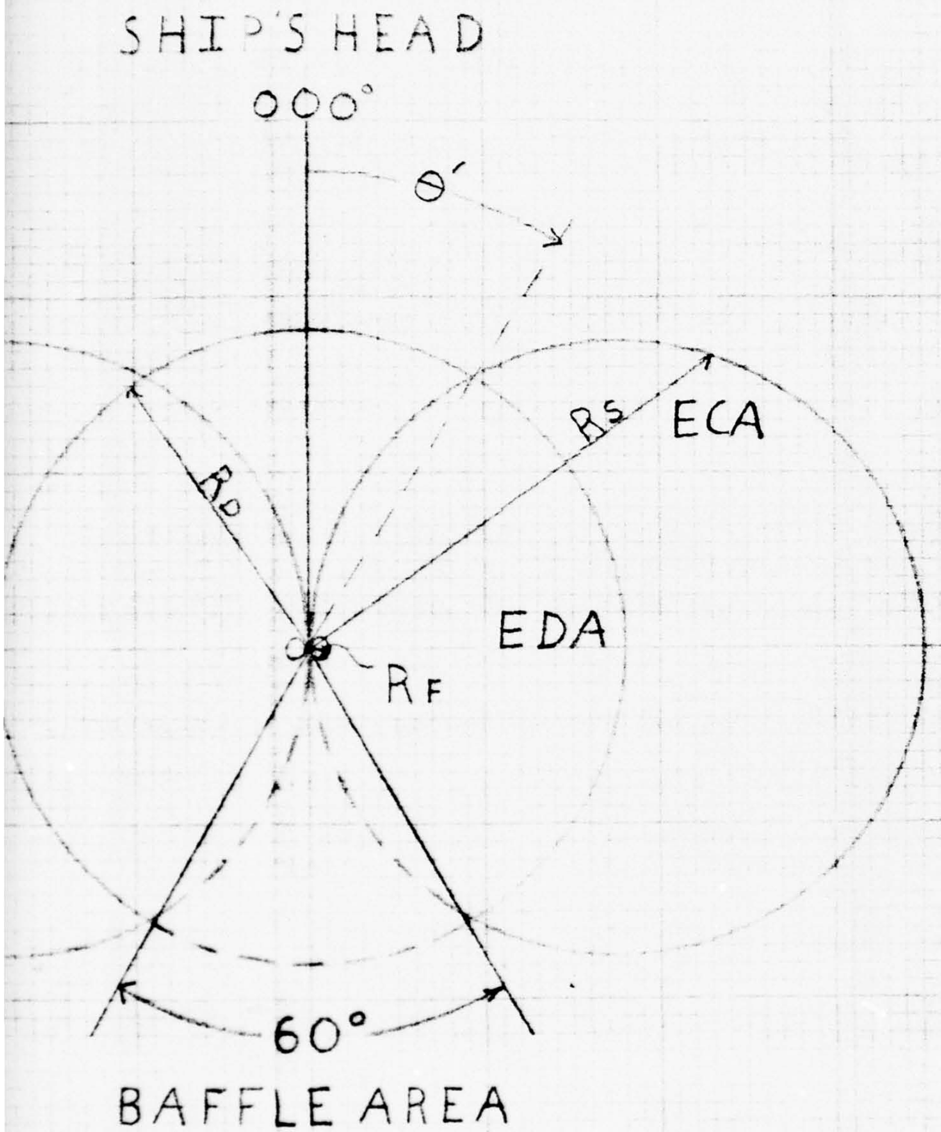
Effective Classification
Area Relative to the
Effective Detection Area
FIGURE C-1(a)


SHIP'S HEAD
000°
EDA
R_D
R_S
ECA
ECA
R_F
60°
BAFFLEAREA
-1
0
1
2
3
(KYDS)



Effective Classification
Area Relative to the
Effective Detection Area

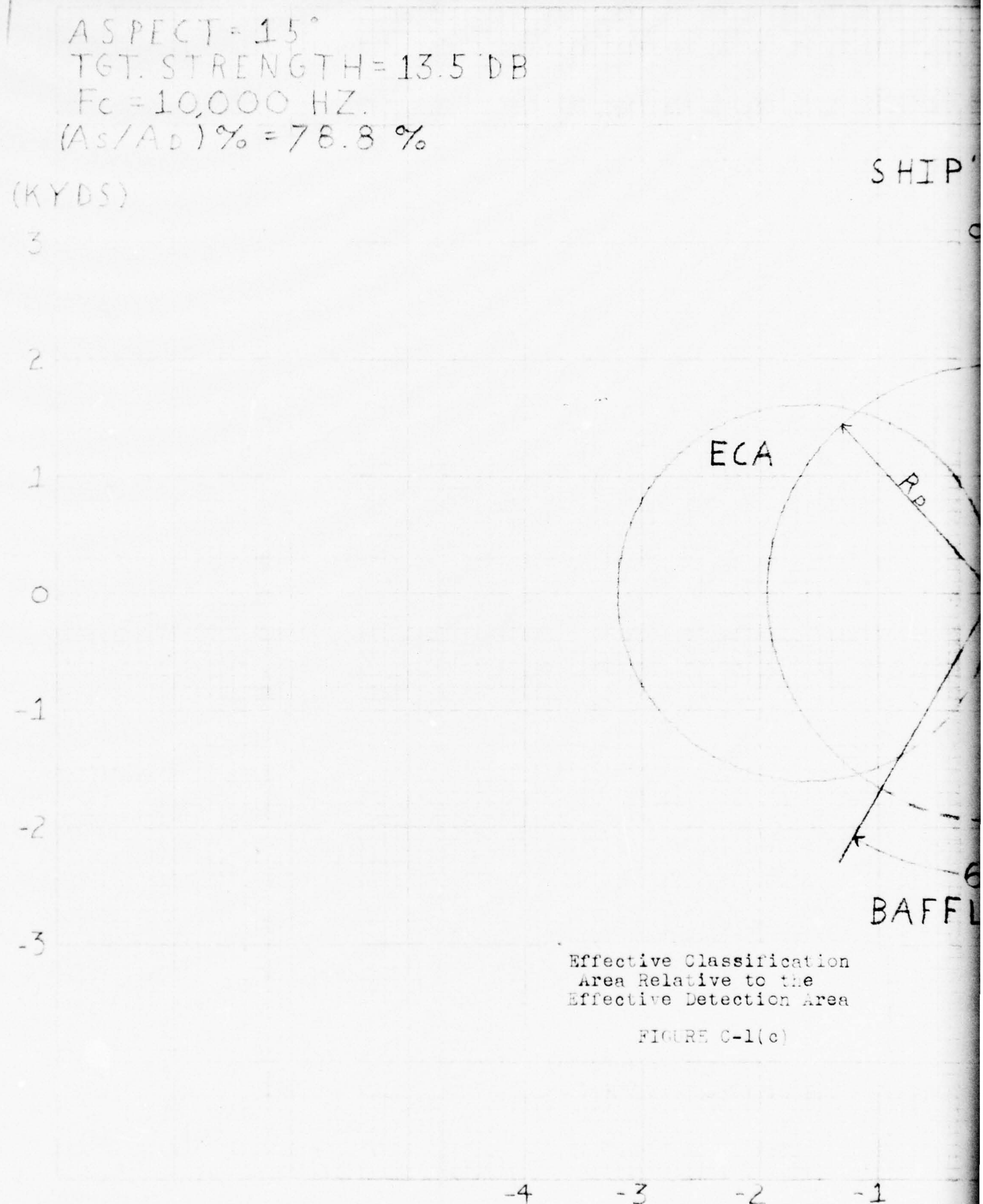
FIGURE C-1(b)



ation
he
Area

b)

-1 0 1 2 3 4 (KYDS)



Effective Classification
Area Relative to the
Effective Detection Area

FIGURE C-1(c)

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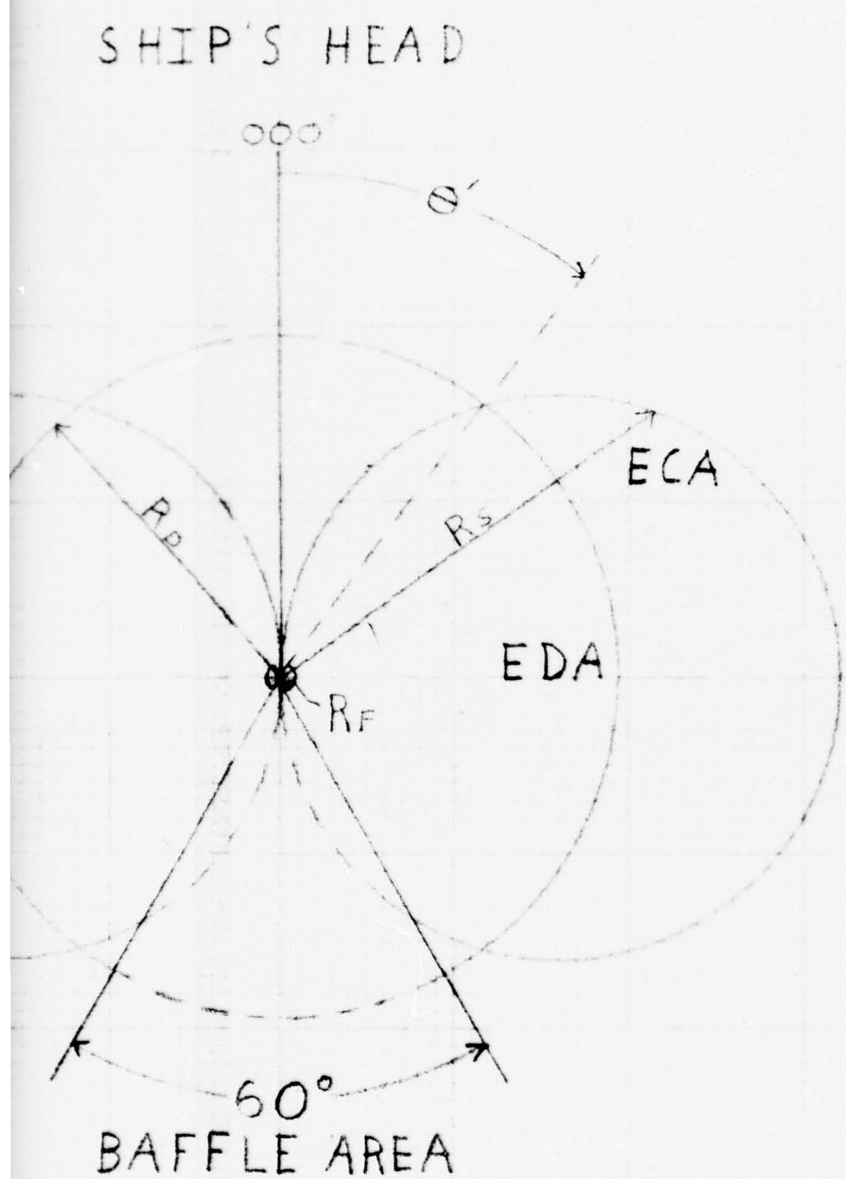

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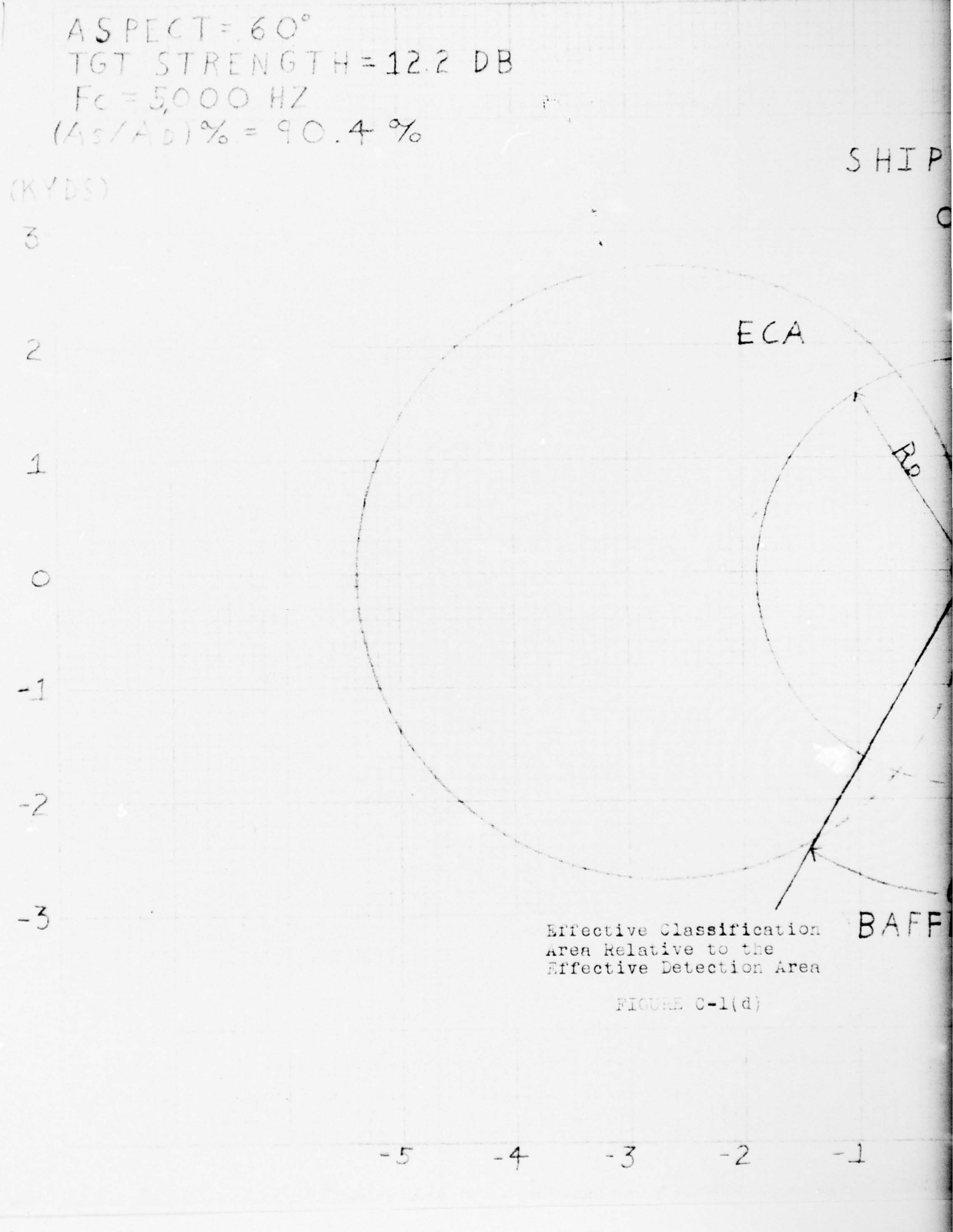
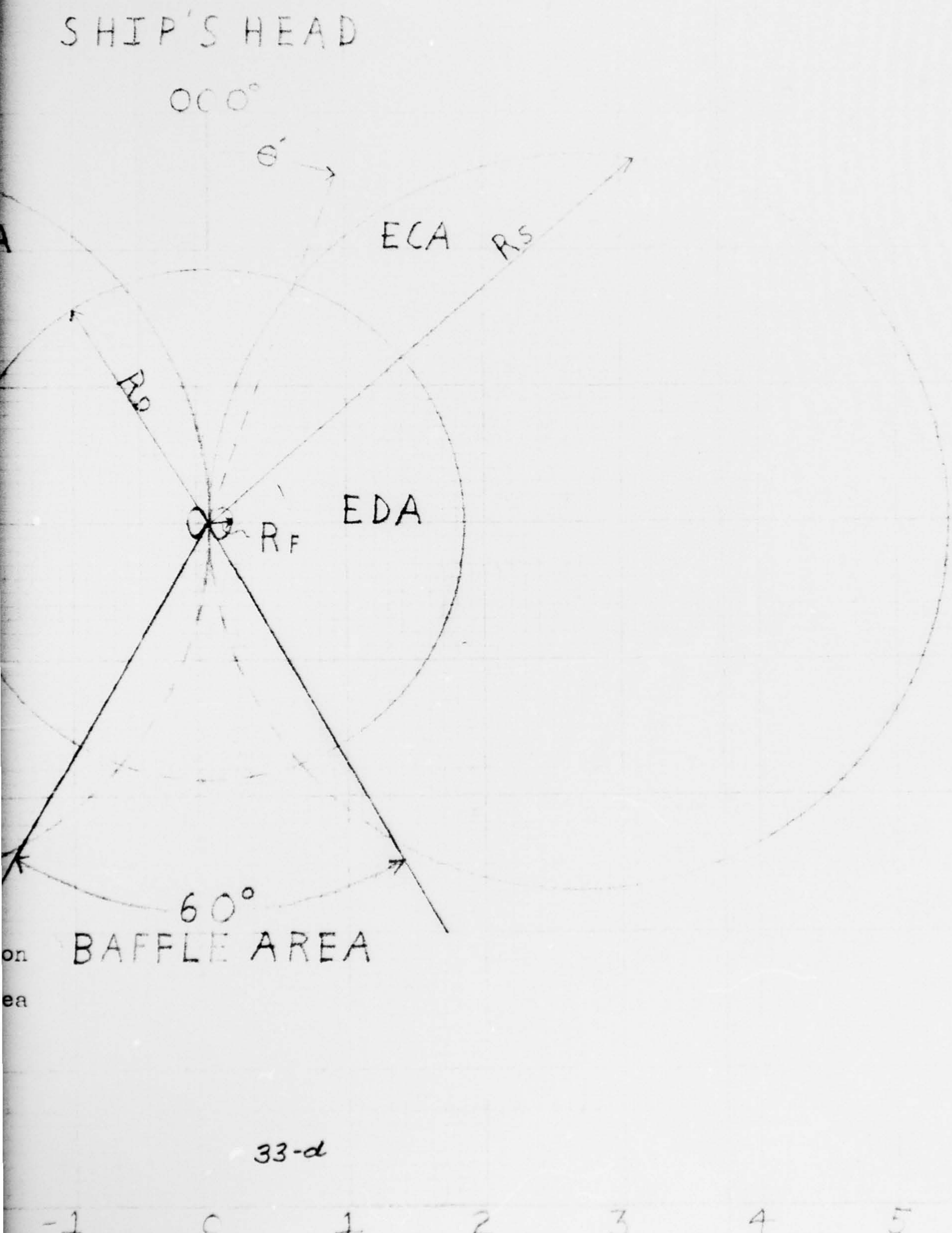
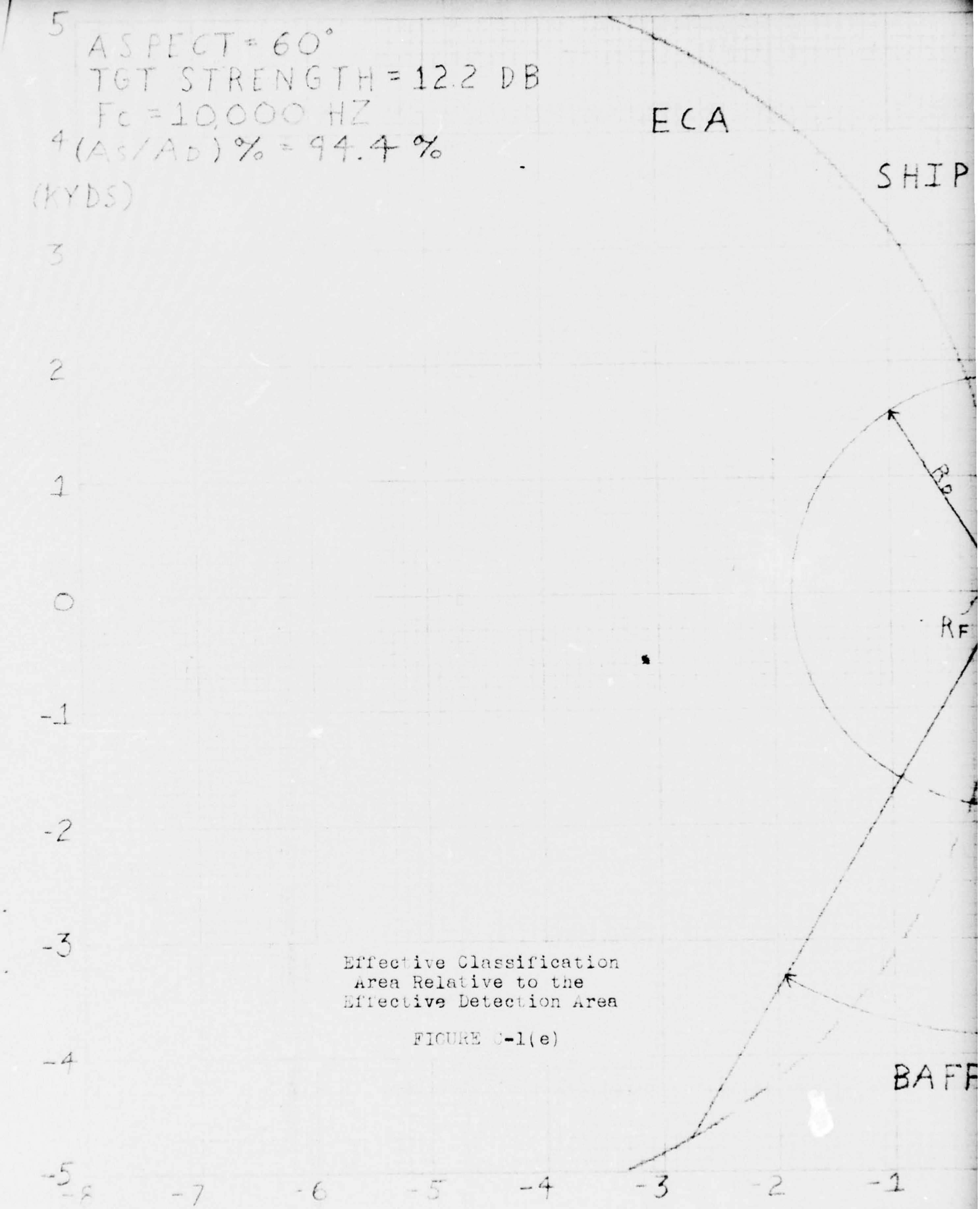
-1 0 1 2 3 4 (KYDS)



Effective Classification Area Relative to the Effective Detection Area

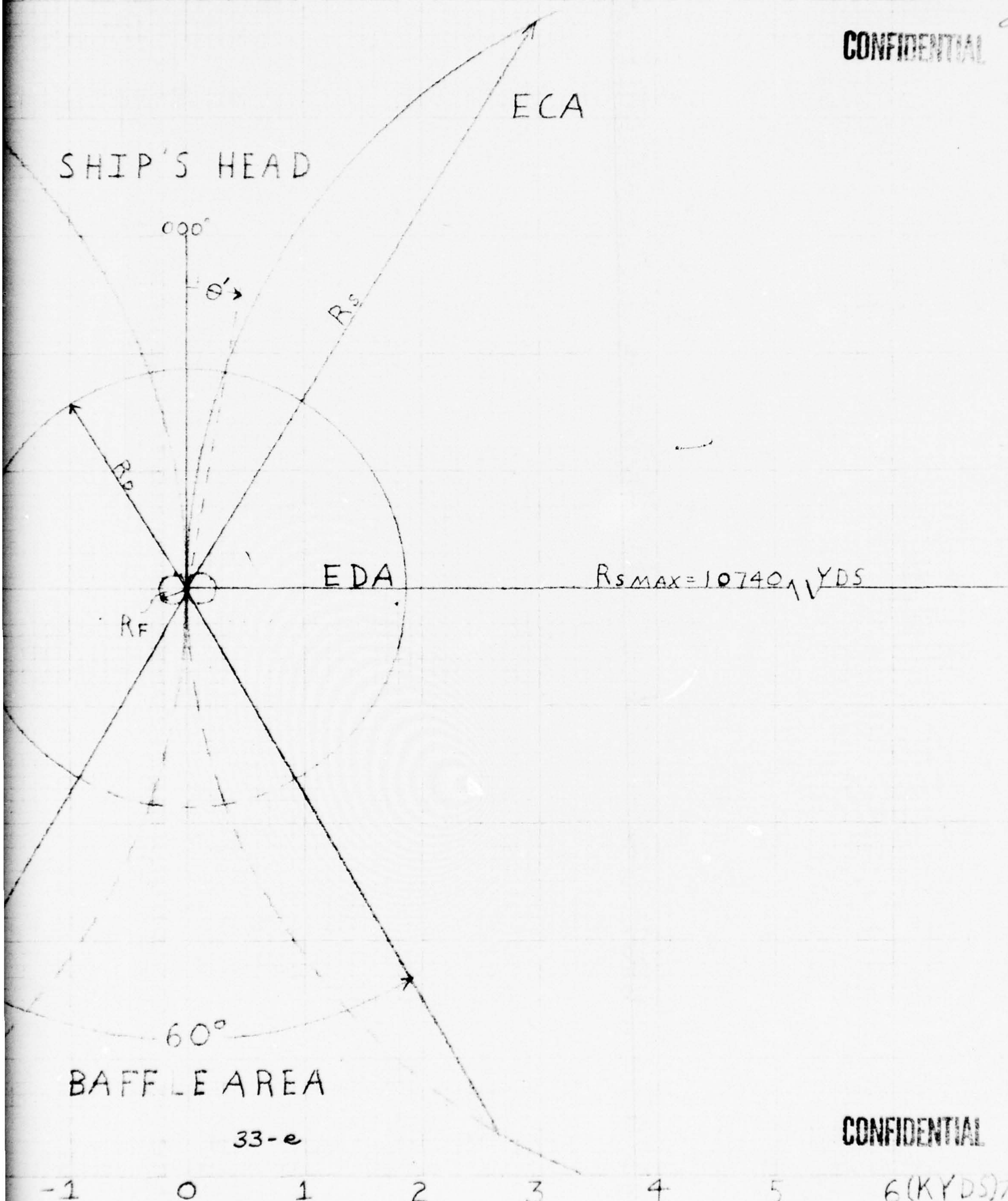
FIGURE C-1(d)


SHIP'S HEAD
000°
θ'
ECA
R_S
R_D
EDA
R_F
60°
BAFFLE AREA
-1 0 1 2 3 4 5 (KYDS)

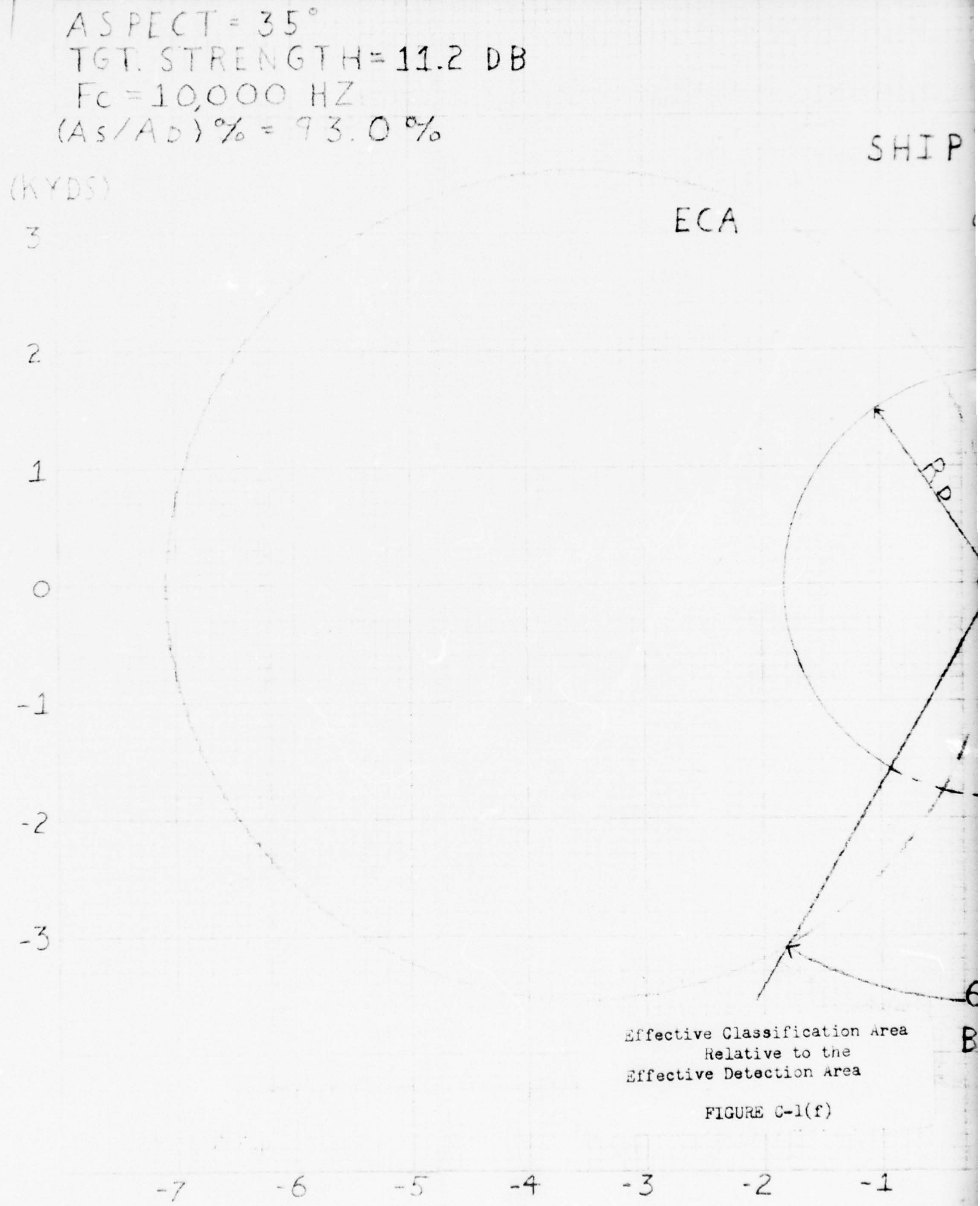


Effective Classification Area Relative to the Effective Detection Area

FIGURE C-1(e)

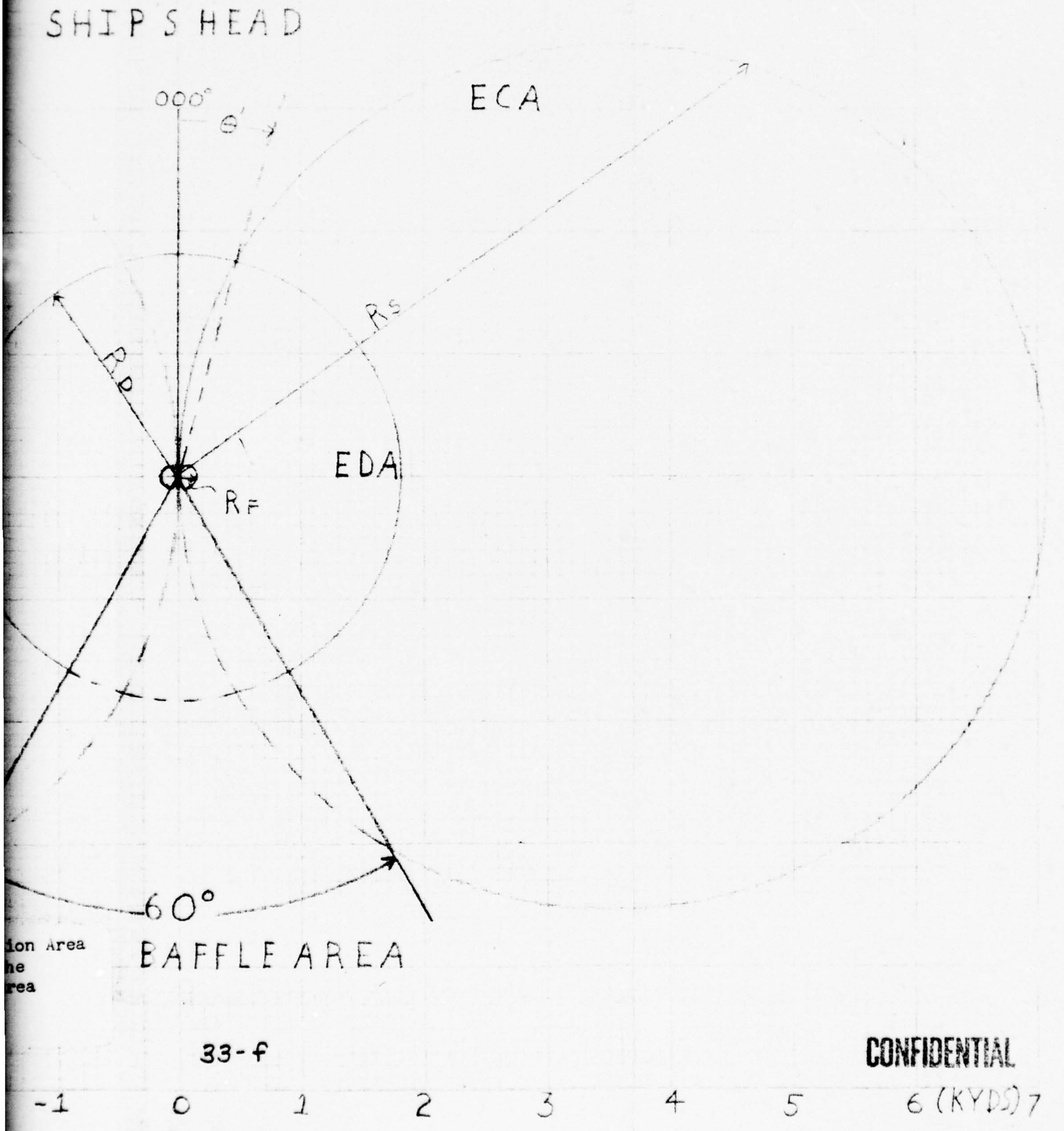

ECA
SHIP'S HEAD
000°
θ'
R_S
R_D
EDA
$R_{S\,MAX}$ = 10740 YDS
R_F
60°
BAFFLE AREA
-1
0
1
2
3
4
5
6 (KYDS)

33-e



Effective Classification Area
Relative to the
Effective Detection Area

FIGURE C-1(f)



ion Area
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rea

$$A_S = \left(\frac{L}{C} f_c B \cos\phi\right)^2 \left(\frac{2\theta' - \sin 2\theta'}{4}\right) + R_D^2 \left(\frac{5\pi - 6\theta'}{6}\right)$$

$$- \left(\left|\frac{f_c L^2 B \cot\phi}{2C}\right|\right)\left(\frac{2+\sqrt{3}}{2}\right)$$

$$= R_{S\,max}^2 \left(\frac{2\theta' - \sin 2\theta'}{4}\right) + R_D^2 \left(\frac{5\pi - 6\theta'}{6}\right) - R_{F\,max}^2 \left(\frac{2+\sqrt{3}}{2}\right)$$

(C-7) $$A_S/A_D(\%) = 100\left[\frac{R_{S\,max}^2 \left(\frac{2\theta' - \sin 2\theta'}{4}\right) + R_D^2 \left(\frac{5\pi - 6\theta'}{6}\right) - R_{F\,max}^2 \left(\frac{2+\sqrt{3}}{2}\right)}{\frac{5\pi}{6} R_D^2}\right]$$

The detection ranges in this section were calculated using data from previous PAIR work which produced that curve of figure C-2 showing the effect of input S/N ratio on the 50% probability detection range. The curve in figure C-2 is based on four consecutive pings on a 15db target strength submarine under the layer conditions shown. Table C-1 shows the target strength/submarine aspect angle function used in calculating the curve.

The aspect angles in this table are different from, but related to the submarine axis angle ϕ used in the STARLITE equations. ϕ is a quadrant angle, $0^\circ \leq \phi \leq 90^\circ$, of 0° at bow or stern and 90° at beam. The target strengths of table C-1 were used with the data of figure C-2 to calculate detection ranges. PAIR parameters of B=60 feet, f_c=5kHz, Δf=440 Hz and submarine parameters of L=306 feet, W=27 feet were used to compute the values of Effective Classification Area as a percentage of Effective Detection Area which are shown in table C-2, along with values of R_D, $R_S$max and $R_F$max. Values are shown for f_c of 5 kHz and 10 kHz. The submarine axis angle of 20° slightly violates equation (C-3) and is given only for illustrative purposes. Except for the 85° axis angle case, the Effective Classification Area generally covers a large percentage of the

Effective Detection Area. At this preliminary stage of analysis, however, this does not automatically mean that STARLITE is tactically sound.

Table C-1

FUNCTION VALUES OF TARGET STRENGTH VS ASPECT ANGLE USED FOR PAIR PERFORMANCE PREDICTIONS

ASPECT ANGLE	TARGET STRENGTH
0°	10.0 db
5	10.5
15	13.5
18	14.4
20	14.5
22	14.2
35	11.2
40	10.8
45	10.5
50	10.8
60	12.2
70	15.4
75	12.8
80	19.6
85	21.2
90	21.8

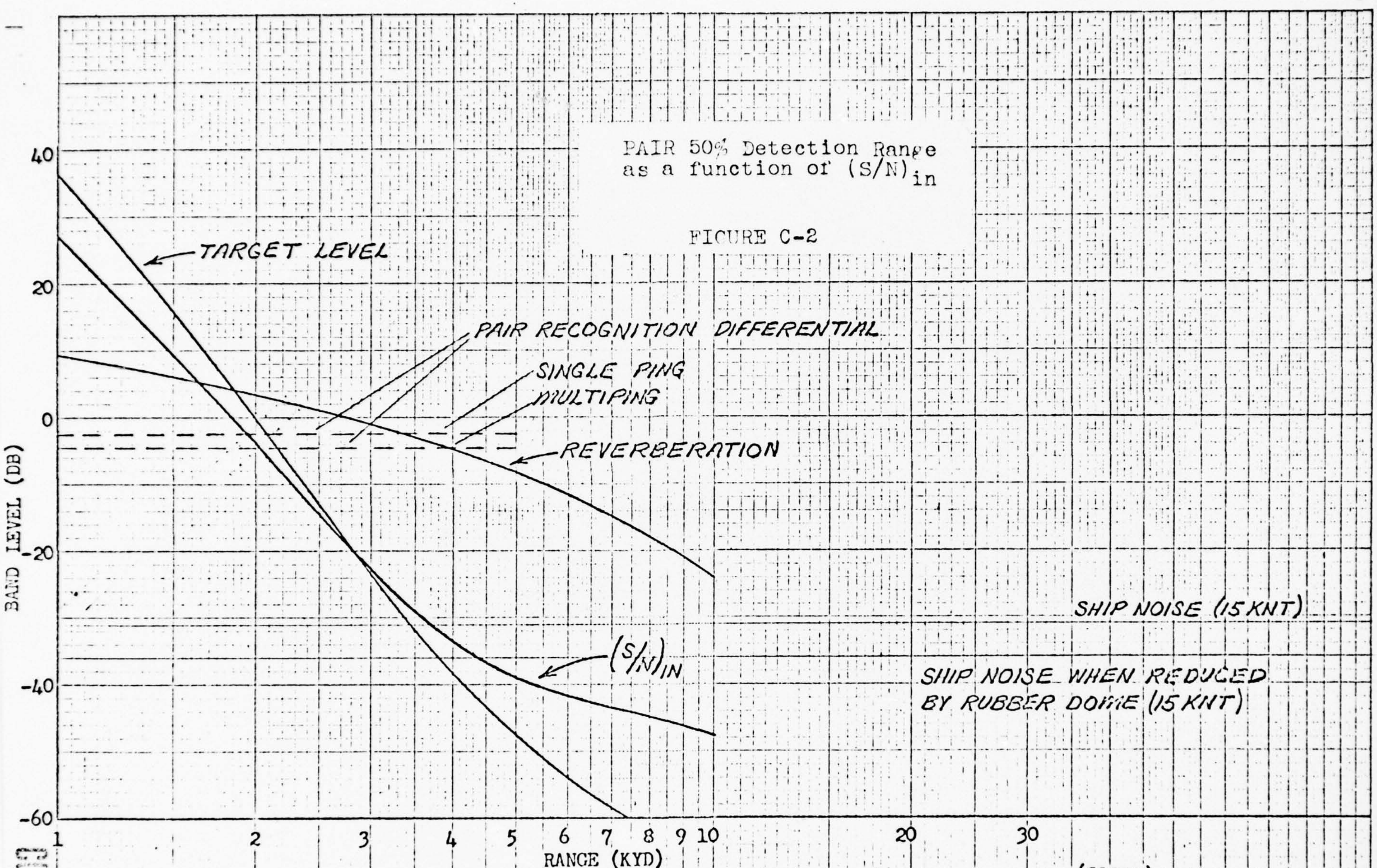

FIGURE : PAIR DEEP WATER POSITIVE GRADIENT PERFORMANCE PREDICTION (BELOW LAYER) (212BP) (712BP)

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TABLE C-2

CLASSIFICATION AND DETECTION COVERAGE FOR VARIOUS SUB AXIS ANGLES

Sub-Axis Angle	85°		45°		55°		30°		75°		70°		20°	
Target Strength	10.5 DB		10.5		11.2		12.2		13.5		14.5		15.4	
f_c	5000	10000	5000	10000	5000	10000	5000	10000	5000	10000	5000	10000	5000	10000
R_D (yds)	1765	1765	1765	1765	1810	1810	1870	1870	1950	1950	2000	2000	2060	2060
R_S max (yds)	540	1080	4384	8769	3557	7113	5370	10740	1605	3210	2120	4241	5826	11653
R_F max (yds)	37	52	126	178	105	149	165	234	65	92	75	107	208	294
A_S/A_D (%)	5.4	21.8	89.2	94.1	80.6	93.0	90.5	94.4	39.4	78.8	61.6	87.5	90.2	94.0

Classification Opportunities Along Intercept Courses

The calculations of this section are based on the tactical situation diagrammed in figure C-3.

$\underline{V}$ = Surface Ship Velocity

$\underline{U}$ = Submarine Velocity

$\underline{W}$ = Submarine Velocity relative to surface ship

α = Submarine's initial relative track angle (angle from $\underline{V}$ to $\underline{U}$ measured clockwise.

Θ = Submarines Bearing from Surface Ship

ϕ = Submarine Axis Angle

(X_o, Y_o) = Submarine Initial Coordinates

R = Submarine Range from the Surface Ship

*Other symbols in this section are the same as defined in the preceding section.

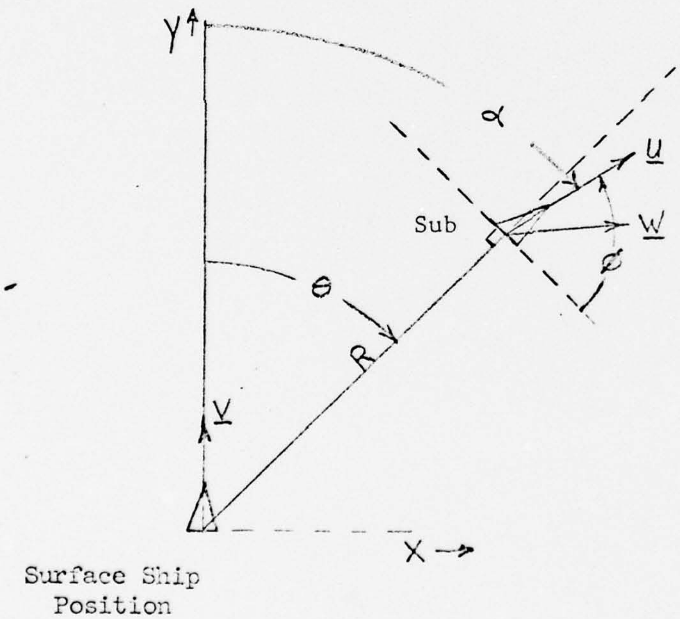


Figure C-3

Surface Ship-Submarine Relative Track

From figure C-3:

$$\phi = \theta + \pi/2 - \alpha$$

Using the STARLITE conditions we have:

$$R_S = \left| \frac{L}{C} f_c B \sin\theta \cos\phi \right|$$

$$= \left| \frac{L}{C} f_c B \sin\theta \cos\left(\theta + \frac{\pi}{2} - \alpha\right) \right|$$

(C-8) $$R_S = \left| \frac{L}{C} f_c B \sin\theta \left[-\sin\theta \cos\alpha + \cos\theta \sin\alpha \right] \right|$$

Now substituting $\sin\theta = \frac{X}{\sqrt{X^2+Y^2}}$ and $\cos\theta = \frac{Y}{\sqrt{X^2+Y^2}}$ we have

$$R_S = \left| \frac{L}{C} f_c B \frac{X}{X^2+Y^2} \left(Y\cos\alpha - X\sin\alpha \right) \right|$$

Similiarly for R_F we have

$$R_F = \sqrt{\left| f_c \frac{L^2 B \sin\theta}{2C} \left[\cot\left(\theta + \frac{\pi}{2} - \alpha\right) \right] \right|}$$

$$= \sqrt{\left| f_c \frac{L^2 B \sin\theta}{2C} \left[\frac{-\sin\theta\cos\alpha + \cos\theta\sin\alpha}{\cos\theta\cos\alpha + \sin\theta\sin\alpha} \right] \right|}$$

(C-9) $$R_F = \sqrt{\left| f_c \frac{L^2 B}{2C} \left(\frac{X}{\sqrt{X^2+Y^2}} \right) \left(\frac{-X\cos\alpha + Y\sin\alpha}{Y\cos\alpha + X\sin\alpha} \right) \right|}$$

For the STARLITE condition:

$$\frac{L}{D} \sin\phi > 4$$

and submarine dimensions of L=306 ft. and D=27 ft.

$$\left| \sin\left(\theta + \frac{\pi}{2} - \alpha\right) \right| > 0.3529411$$

$$\left| \sin\theta \sin\alpha + \cos\theta \sin\alpha \right| > 0.3529411$$

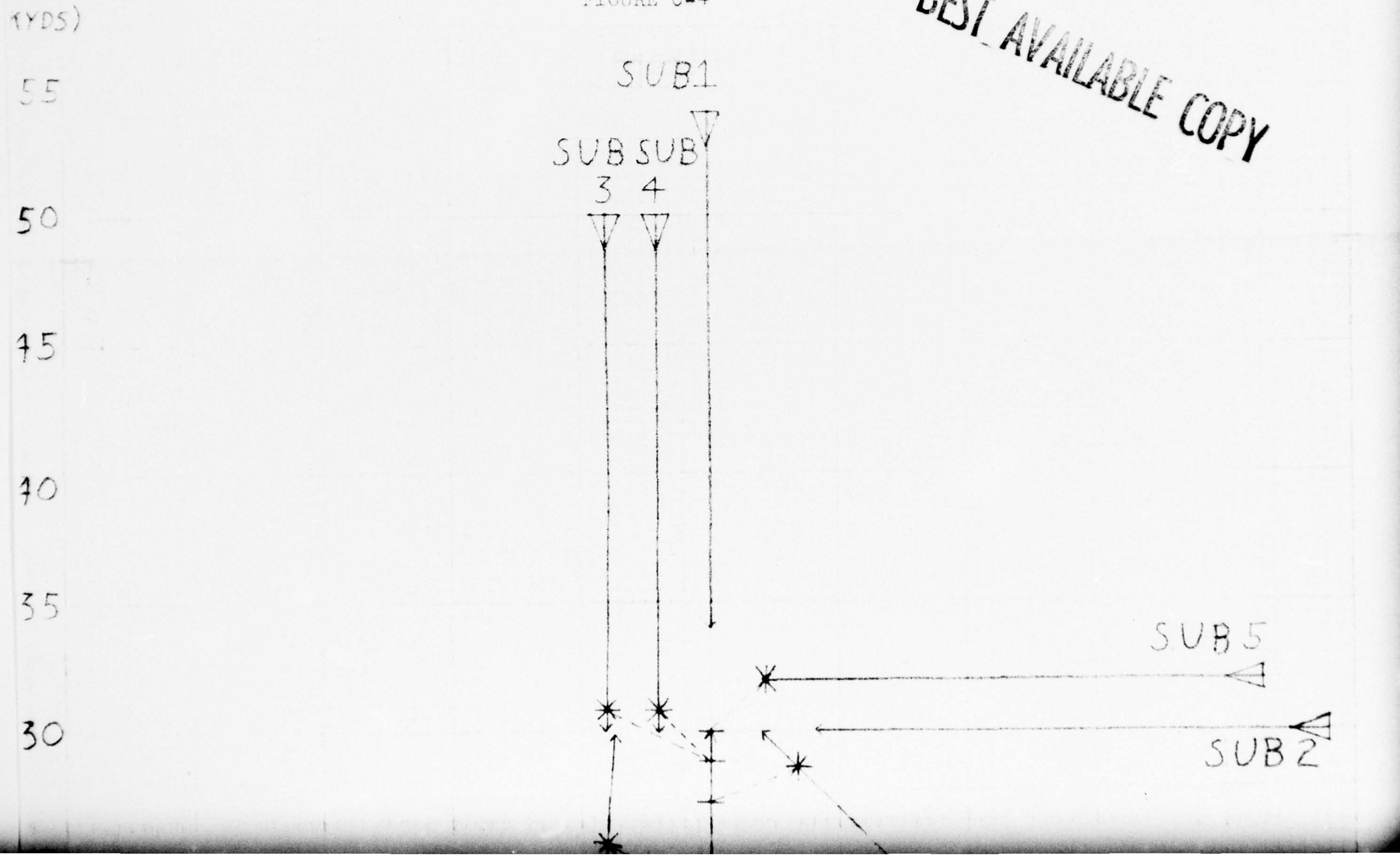
(C-10) $$\left| \frac{X \sin\alpha + Y \cos\alpha}{\sqrt{X^2+Y^2}} \right| > 0.3529411$$

Using as input parameters submarine velocity, and its range and bearing from the surface ship, plus surface ship velocity, a computer program generated a path defined by the submarine's velocity relative to the surface ship. The program then computed the submarine range R at incremental distances along this path. At the point after each increment this value is compared with the STARLITE constraining equations using the PAIR system carrier frequencies of 4.5 and 5.5 kHz, bandwidth of 440 Hz, and hydrophone separation of 60 feet. If the submarine range R at the point satisfied equation (C-10) and $R_F \leq R \leq R_S$, the submarine was within the ECA. Otherwise, the submarine was considered outside the ECA.

The results of these calculations are shown in figures C-4 and C-5. These figures show: (1) where the submarine entered the ECA, (2) the surface ship's true path, (3) the submarine's true path. One important result not shown in figures C-4 and C-5 is the period of time on each submarine track during which classification was possible. This result and the number of pings (for 5 and 10 kyd range scale settings) that could provide classification information are shown in table C-3 for each submarine track.

Classification Opportunities
Against Different Target
Tracks- (4,500 Hz)

FIGURE C-4



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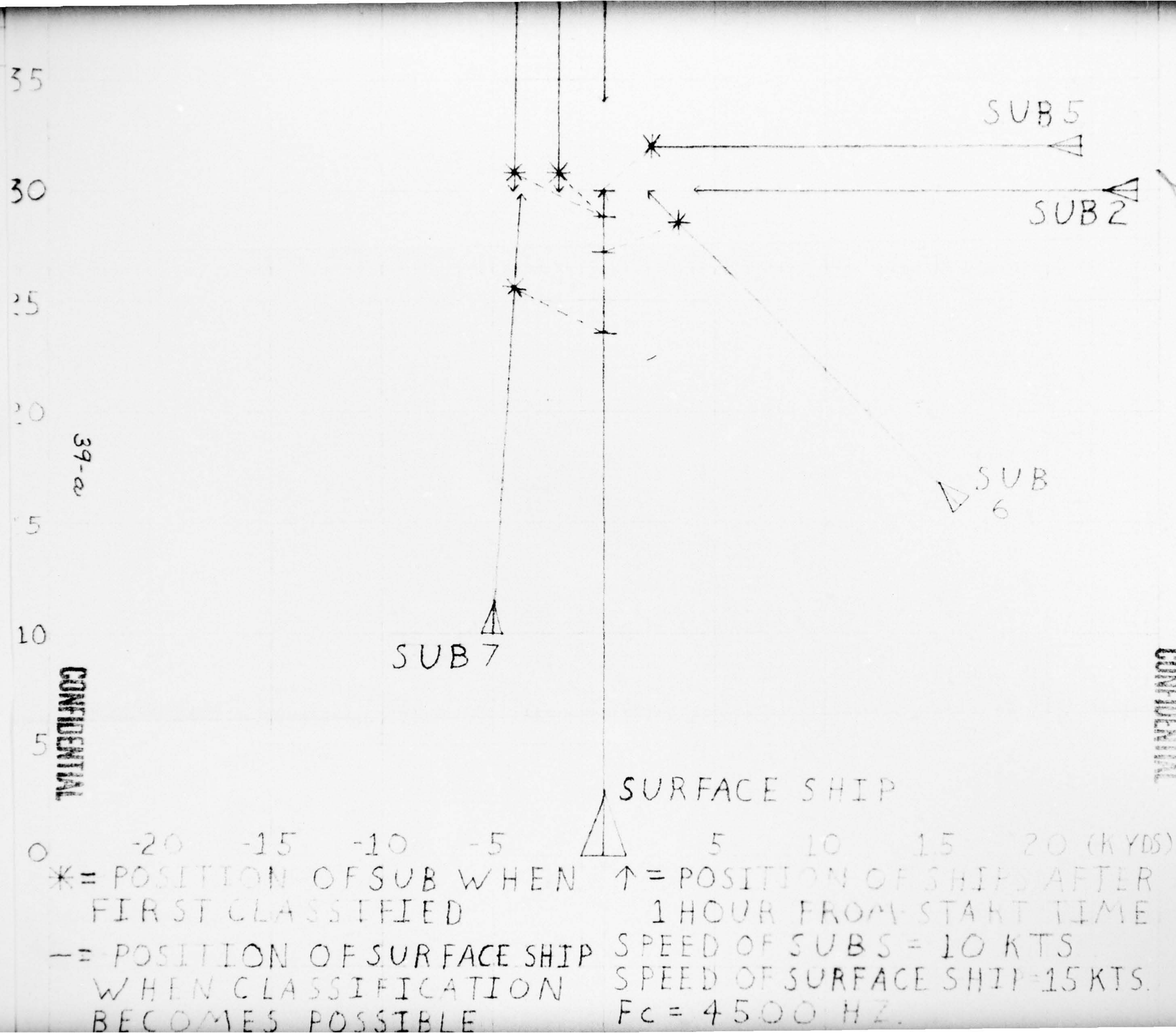

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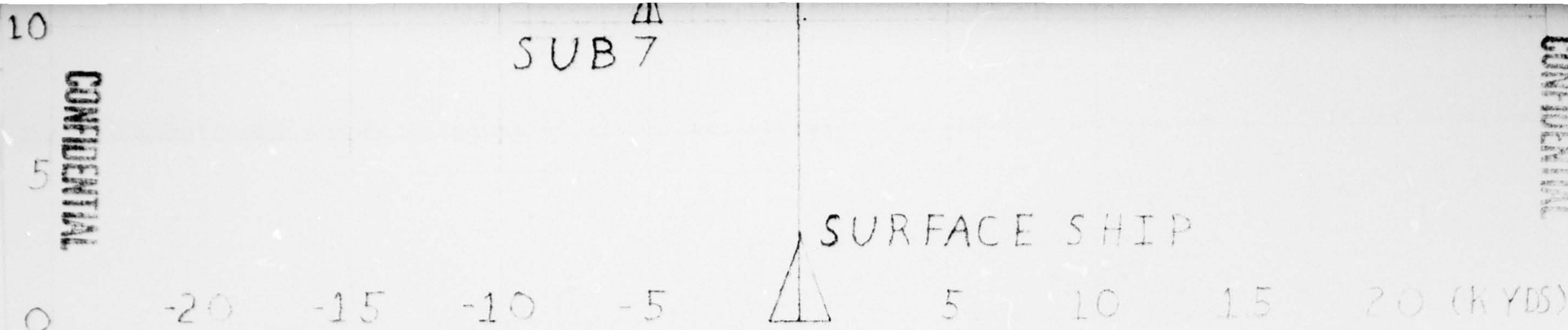

* = POSITION OF SUB WHEN FIRST CLASSIFIED

— = POSITION OF SURFACE SHIP WHEN CLASSIFICATION BECOMES POSSIBLE

↑ = POSITION OF SHIPS AFTER 1 HOUR FROM START TIME

SPEED OF SUBS = 10 KTS

SPEED OF SURFACE SHIP = 15 KTS.

Fc = 4500 HZ

SEE TABLE FOR CLASSIFICATION DURATION

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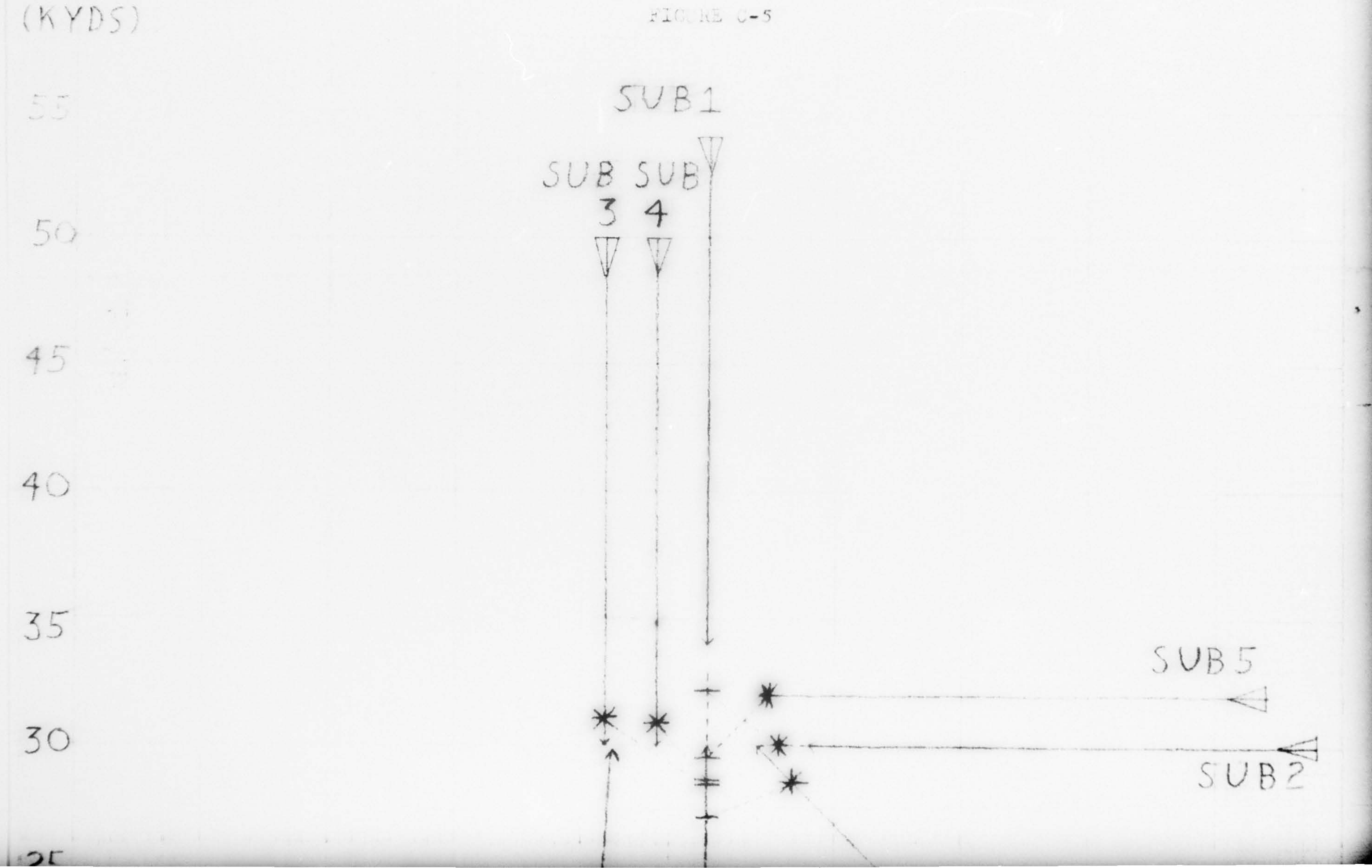
Classification Opportunities Against Different Target Tracks- (5,500 Hz)

FIGURE C-5



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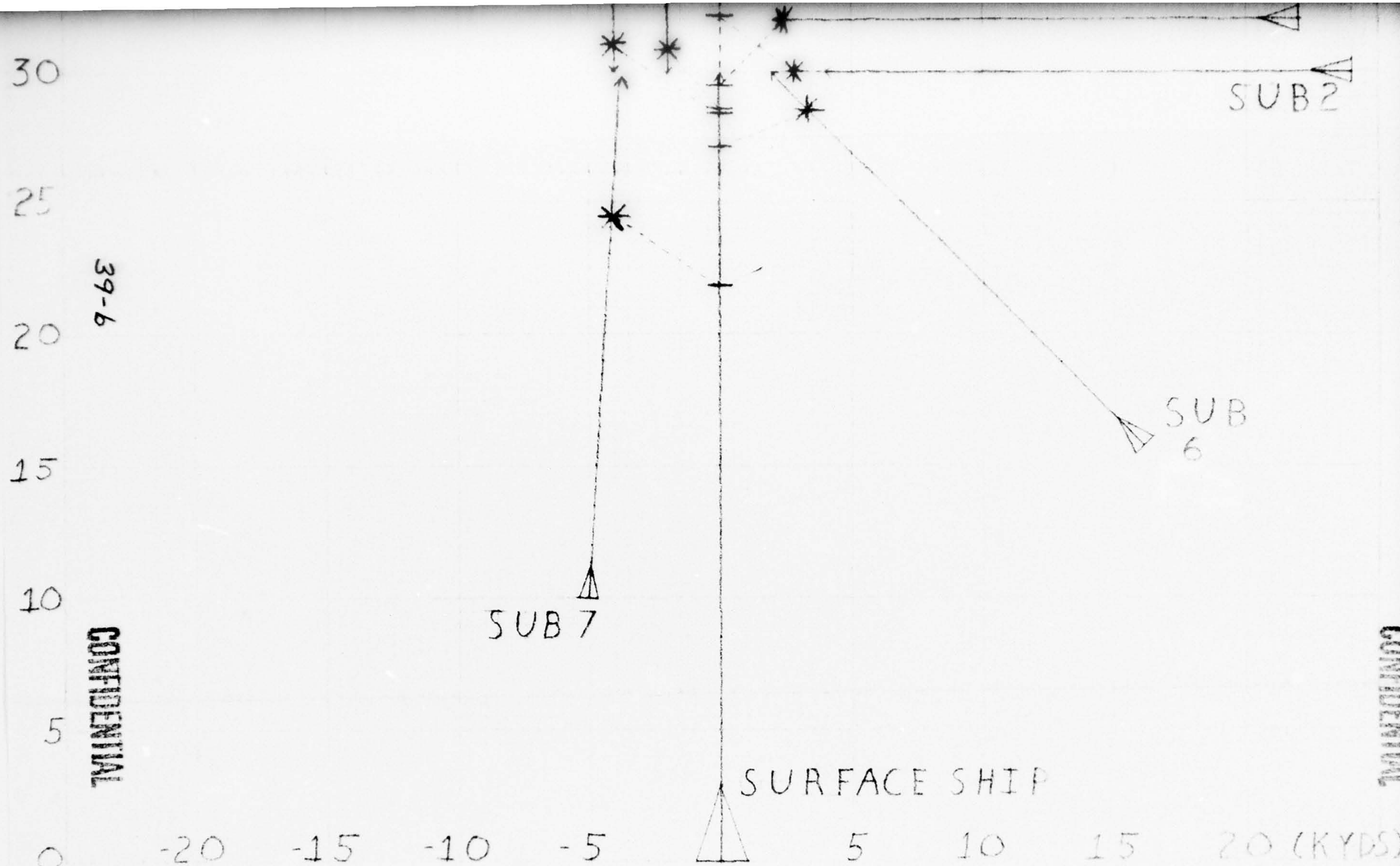

✱ = POSITION OF SUB WHEN FIRST CLASSIFIED

— = POSITION OF SURFACE SHIP WHEN CLASSIFICATION BECOMES POSSIBLE

↑ = POSITION OF SHIPS AFTER 1 HOUR FROM START TIME

SPEED OF SUBS = 10 KTS

SPEED OF SURFACE SHIP = 15 KTS

Fc = 5500 HZ

SEE TABLE FOR CLASSIFICATION DURATION

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TABLE C-3

PARAMETERS AND PARTIAL RESULTS FOR THE SURFACE SHIP-SS TRACKS OF FIGURES C-4 AND C-5

Submarine Number	1		2		3		4		5		6		7	
f_c (Hz)	4500	5500	4500	5500	4500	5500	4500	5500	4500	5500	4500	5500	4500	5500
Initial Range (Kyds)	54	54	38.4	38.4	50.2	50.2	50	50	38.8	38.8	22.6	22.6	11.2	11.2
Initial Bearing	0°	0°	39°	39°	355°	355°	358°	358°	34°	34°	46°	46°	333°	333°
Track Angle	180°	180°	270°	270°	180°	180°	180°	180°	270°	270°	315°	315°	4°	4°
Range/Class. Begins (Kyds)	-	-	-	3.346*	4.463	4.771	2.814	3.003	2.785	3.394	3.656	3.656	4.442	4.835
Range/Class. Ceases (Kyds)	-	-	-	3.410*	4.272	4.272	2.132	2.132	.726	.713	1.537	1.519	4.238	4.238
Class. Duration (Sec)	-	-	-	39	34	78	88	106	222	286	495	508	126	343
No. of Pings (5 Kyd Setting)	-	-	-	6	5	12	14	17	36	47	81	83	20	56
No. of Pings (10 Kyd Setting)	-	-	-	3	3	6	7	8	18	23	40	41	10	28

W = 440 Hz B = 20 yds V = 15 KTS. U = 10 KTS.

* Classification becomes possible on this submarine only after its point of closest approach to the surface ship when the range between them is increasing.

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APPENDIX D

DESCRIPTION OF A SHIP-LAUNCHED PASSIVE SONOBUOY FOR TARGET CLASSIFICATION.

CLASP (Classification, Ship-Projected) is a passive sonobuoy fired from the 5"-38 calibre gun of an ASW ship and used for the classification of contacts 4000-10,000 yards from the ship. The system has been fired at sea and successfully used to receive the radiated noise of a submerged submarine.

After initial detection of a contact by active sonar, radar, visual, or ECM, the passive sonobuoy is delivered in a 5" window projectile. An omnidirectional hydrophone on a 60 foot cable detects noise in the 20 to 5000 Hz frequency band. The noise is amplified and transmitted to the ship for reception on an aircraft sonobuoy radio receiver. The noise is monitored by means of headphones for submarine-like sound characteristics. While reference 11 does not indicate any tests with LOFAR-type processing, that would probably increase detection and classification capability.

Reference 11 states; "Standard shipboard fire-control equipment is used to aim the 5" gun, and fire control radar locates the splash point to verify accurate placement of the sonobuoy at the contact location. After splashdown, the sonobuoy is expelled from the projectile. The antenna and hydrophone are deployed and the sonobuoy becomes operational about 1 minute after water entry."

The effective range between sonobuoy and submarine for detection and classification depends on sea-state, submarine noise output, and background noise. Reference 11 based performance estimates on the background noise contributed by the ASW destroyer, in addition to the ambient sea noise. Reference 9, however, considered the more general case of use in the vicinity of large convoys. This reference states that the sonobuoy system would be effective for convoy speeds of 10 knots or less, but marginal for a 15 knot convoy.

Reference 9 provides insight into many areas of concern and deserves careful reading. For the purposes of this appendix two of its conclusions appear very important:

(1) the yearly cost of a projected omnidirectional sonobuoy system is not clearly lower than the cost of a small helicopter for contact confirmation.

(2) a projected omnidirectional sonobuoy system should not be used as a classification aid by ASW ships in multi-ship situations, such as convoy or task group screening operations. However, the report recommends a detailed investigation of directional sonobuoy systems, including both a design feasibility study and a study of operational effectiveness in a number of tactical situations.

In the cases presented in reference 9, the ranges for passive detection and classification never equalled the detection ranges reported in reference 12 for CASS. However, CASS was never operated in the vicinity of a large convoy, nor was an analysis of this situation indicated in the reference. On the basis of some of the findings in reference 9, a new study should consider the use of two passive sonobuoys and an independent active source. Reference 9 discusses the use of an additional gun-fired sonobuoy and a gun-fired explosive charge for explosive echo-ranging against quiet submarines, or submarine contacts close to a convoy. Instead of an EER charge, the sound source might be an expendable transducer providing wideband transmission at a source level comparable to CASS.

A first passive sonobuoy might be fired to classify by detection of the radiated submarine noise. If no submarine noise was detected, a second passive sonobuoy and a sound projector would be fired to provide active detection, localization and classification perhaps with STARLITE techniques. Other candidates for the sound projector might include a helicopter dunking sonar or the ASW ship's long range search sonar. These ideas warrant careful analysis.

APPENDIX E

COMMAND ACTIVE SONOBUOY SYSTEM (CASS)

The technical evaluation of the Command Active-Sonobuoy System (CASS) is reported in reference 12. This appendix will describe briefly the characteristics of the sonobuoy. As background, an operational analysis performed by NAVAIRDEVCEN showed that a single active sonobuoy would need a minimum detection range of 6000 yards to cope with a deeply submerged submarine traveling at 30 knots. Thus, the development sought to provide fixed-wing aircraft with an echo-ranging system capable of acquiring and localizing for attack, the quiet, high-speed, deeply submerged submarines expected in the 1970-1975 period.

Reference 12 states: "For a 50 percent echo-to-ping ratio the CASS was shown to be capable of reliable in-layer and below-layer detection of an underwater target out to a range of 6500 yards. (When the target had up Doppler, a maximum range of 7800 yards was achieved; with down Doppler, a maximum range of 6500 yards was achieved, under typical summertime conditions of bathythermograph).

The CASS was shown to be capable of detecting underwater targets at radial speeds of 30 knots and tracking underwater targets with up or down Doppler at radial speeds of 6, 12, 18 and 27 knots.

When adverse bathythermograph conditions were encountered (a layer depth of 100 to 150 feet) and a target was below layer, detection capability was enhanced by using a 1500 foot transducer depth. When the target was in the layer, the shallow transducer depth (60 feet) proved effective."

Transmission Characteristics

CASS is designed to transmit CW, LFM (linear swept FM) DIFM (Doppler-invariant FM), and PRN (pseudorandom-noise) signals. The sonobuoy can transmit on 4 different frequencies centered at 6.5, 7.5, 8.5 and 9.5 kHz. The avionics

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subsystem consists of a signal generator, a signal analyzer and a display system. The sonobuoy is expendable. The signal generator feeds a function generator in the aircraft which transmits an amplitude-modulated UHF signal to the sonobuoy. A receiver in the sonobuoy demodulates the transmission and sends the pulse to the sonar transmitter for transmission into the water. In CW operation, four pulses of 1.0, 0.5, 0.1 and 0.01 seconds are selectable with bandwidths of 100,200 or 400 Hz. Pulse durations of 1.0 second are selectable for the LFM and DIFM transmission modes. In the LFM, DIFM and PRN modes, the signal generator sends a replica centered at 800 Hz to the analyzer for cross-correlation with the received sonar signals. After sonic transmission, the sonobuoy switches to the listening mode. The sonobuoy bandpass receiver amplifies the sonic information, and transmits it via a frequency-modulated VHF carrier to the aircraft receiver. The signal generator translates the demodulated VHF signal to a center frequency of 800 Hz.

In the CW, LFM and DIFM modes of operation, the 800 Hz center frequency received signal is clipped, sampled at a rate of 4096 samples per second, and fed to a magnetic-core time compressor and memory unit (MACTIC) where it is time-compressed by a factor of 9728 to 1 and stored. For the LFM mode the memory is read at different speeds to compensate for the Doppler dispersion (change in slope of the FM sweep) correlation loss. The received signal is read out of the MACTIC memory serially and beat against the stored replica. The serial code shifted out of the replica memory is the reverse order of the code used to generate the sonic pulse. Beating this with the received signal produces a single-frequency signal which includes the Doppler shift. To permit the use of a single output filter, the output of the beat frequency correlator is heterodyned by a step oscillator, such that the difference between the frequency of the step oscillator and the Dcpplered echo remains constant.

With LFM or DIFM, either a detection or classification mode can be selected. The detection mode gives a B-scan presentation on either a full 8000 yard scale or 400, 800 or 1600 yard range-gated scales. The B-scan shows Doppler along the vertical axis and range along the horizontal. The writeout is a sloping line moving from left to right with the point of maximum intensity centered about the target's Doppler. When alternate upswept and downswept LFM pulses are used, the intersection of the two slopes provides a range resolution capability of 40 yards. The classification mode provides either 400, 800 or 1600 yard range-gates on a split-screen presentation. The top half of the screen shows a presentation similar to the detection mode, but a dark horizontal band is evident. This band corresponds to a particular 4 kt Doppler increment selected by a switch setting. The amplitude modulated signal within this Doppler band is presented in an A-scan on the bottom half of the screen. With the range-gated operation target highlights are visible in the A-scan traces.

STARLITE Application

The limiting range equations for STARLITE and the equations using measured frequency shift and echo duration for estimates of the target aspect angle, length and width require knowledge of receiving hydrophones spacing and of the target bearing relative to the axis of the two hydrophones. Sonobuoy location by aircraft already is required for weapon delivery and in dropping buoys for a trapping field about a datum. The methods of location involve radio- direction finding on the sonobuoy transmitter and the use of an "on-top" indicator. This is not accurate enough to determine sonobuoy spacing (hundreds of feet) for STARLITE. Timing the difference between acoustic transmission from one sonobuoy to reception at the other seems to offer the simplest and easiest alternative. Since the sonobuoy separation for STARLITE purposes will not exceed several hundred feet and the S/N of received pulses will be very high, the most accurate timing would be based on pulse leading edge estimates from the raw signal rather than from the peak envelope output of the correlator. This should provide accuracies within a few feet.

The effect on STARLITE processing of CASS signal clipping before correlation is not known because no quantitative information is available on this. The CASS system capability for operating from active buoys simultaneously provides the multi-channel condition STARLITE needs. We have not made any analysis of the supplements required for adding STARLITE to CASS such as we have done for PAIR.

The classification capability of CASS may be adequate without STARLITE. If this proves true, then the classification problem for the long range contact situation is solved. This active system will provide better localization information than the current passive methods. The source level of CASS, 102 db above 1 microbar, together with the 80 db receiver gain may permit use at closer ranges to the convoy than passive buoys.

Reference 12 provides many more technical details and also sea test results of the technical evaluation.