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HUMAN FACTOR PROBLEMS IN ANTI-SUBMARINE WARFARE

Technical Memorandum 206-17

NOTES ON THE PROBLEM OF TRAINING
OPERATORS FOR THE AQS-10 SONAR (U)

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21 Report on

HUMAN FACTOR PROBLEMS IN ANTI-SUBMARINE WARFARE [U].

9 Technical Memo[redacted],

6 NOTES ON THE PROBLEM OF TRAINING
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It is essential that the sonar designer be informed as to the characteristics of observers as well as to the characteristics of the transmitting medium. Sonar, then, is bounded on one side by oceanography and on the other by psychophysiology . . . .

The primary purpose of every indicator or recorder used in sonar is, in some way or other, to make the signal perceptible to the observer . . . . the quantitative evaluation of the performance of the instrument involves defining the limiting conditions under which the effect to be produced is adequately perceptible. This implies that the operation of any instrument is a joint enterprise in which the instrument is one partner and the observer the other. In stating the performance of the instrument quantitatively, therefore, certain physiological and psychological characteristics of human beings are quite as relevant as the nature and behavior of acoustic waves in the sea, or as the properties of the system by which these waves are caused to influence the instrument.

From: The Fundamentals of Sonar, by
Dr. J.W. Horton, Chief research
consultant of the U.S. Navy
Underwater Sound Laboratory

NOTES ON THE PROBLEM OF TRAINING OPERATORS FOR THE AQS-10 SONAR

Human Factors Research, Incorporated

Technical Memorandum No. 206-17

I. BACKGROUND

Great technological advances are typically accompanied by operator problems because of ignorance of how the associated equipment is most efficiently operated. Sometimes the existence of operator problems is not even recognized with the consequence that full system potential is never completely realized. In other instances operator problems might be recognized, but not their magnitude. Such problems may be solved by "in-service" trial and error extending over years, or not solved at all.

As an example of the former type of problem consider the case of a sonar target which escapes detection because the scope is set at a non-optimum brightness. There is no device which will monitor the scope/operator combination and signal the fact that a target has been missed. Thus scope brightness remains uncorrected watch after watch, year after year, with the ever present possibility of catastrophic consequences.

There is, however, an obvious and relatively simple solution to problems such as these. Given the appropriate equipment, laboratory research can result in solutions to most such problems in a matter of weeks. In the radar field a very great deal of such research has been completed: a forthcoming book on the subject, entitled "Man and Radar Displays," (Baker, 1962) reviews the conclusions of 365 unclassified research reports. In the sonar field it would be difficult to locate one tenth as many.

Fortunately, however, the results of a fair number of radar studies are directly applicable to the sonar case.

Our specific concern here is with the general problem of training operators for the AQS-10 sonar, a new sonar system which is considerably more complex than its airborne predecessors, and in some respects unique. In our opinion it poses a number of operator problems.

II. MAN AND SONAR DISPLAYS

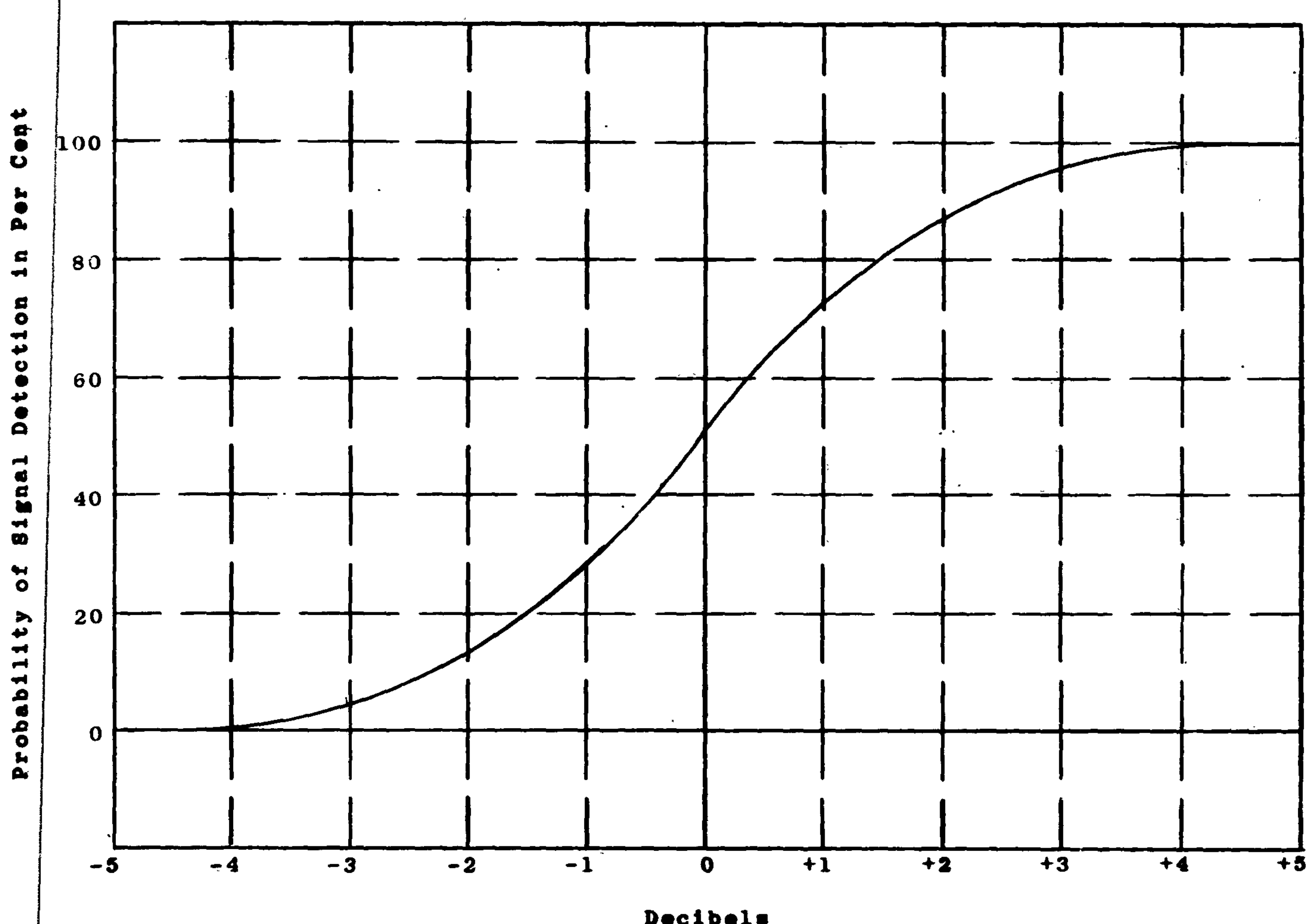
Prior to brief consideration of the existing problems our purpose here is to point out some of the more fundamental factors involved when an operator sits in front of a radar or sonar display for the purpose of detecting targets.

1. The Probability of Sonar Target Detection.

As a signal becomes less and less intense, it will be detected less and less frequently. The intensity at which it will be detected in 50 per cent of the presentations is known as the Recognition Differential. It is well known in both the radar and sonar cases that the difference between the signal intensity required in order that the target will be seen on nearly every presentation, and the intensity at which it will be missed on nearly every presentation, is about 10 decibels. The situation is shown in Figure I where it is easily apparent how probability of detection increases with an increase in signal intensity.

Note that the decibel range at the bottom of the figure is 10 decibels. Note also that the curve in the figure is steepest from about -2 to +2 decibels, or over a range of 4 decibels. Increasing signal intensity from -2 to +2 decibels results in an increase in probability of detection from 10 to 90 per cent. In other words, the greater steepness of this portion of the curve has far greater consequences than the portions outside this range. With regard to this figure the Chief Research Consultant of the U.S. Navy Underwater Sound Laboratory has stated that:

> It is evident that this region [of 4 decibels] within which the reliability of observation changes so abruptly is of the utmost significance to the design and operation of sonar systems.



Probability of Signal Detection in Per Cent
100
80
60
40
20
0
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Decibels

Figure I

2. Optimum Sonar Scope Brightness.

Let us consider, as an example, the penalty consequent to operating at a non-optimum scope brightness. For this story we must turn to the radar field, though there is reason to believe that a very similar situation obtains in the sonar field.

It is possible to vary scope brightness simply by turning a knob on the display panel and a large number of experiments have confirmed the general picture shown in Figure II which is taken from Williams et al (1948). Up the side of Figure II we have again plotted decibels, while along the bottom is plotted scope brightness consequent to various settings of the control knob. The higher any point on the curve, the better the performance, as any point tells us that a reference signal can be weakened or attenuated by so many decibels, and still be seen. The point labeled Visual Reference Intensity (VRI) is that brightness at which the sweep-line is just visible - a not uncommon operational setting. The curve is seen to go over "top-dead-center" at about 48 decibels, and target detection thereafter becomes poorer.

At top-dead-center we have a condition known as optimum scope brightness. The realy significant aspect of this curve is the very large range of decibels covered. It will be seen that the difference between operating at Visual Reference Intensity and at optimum intensity is, in this case, 18 decibels, and on page 3 we pointed out the critical nature of a range of just 4 decibels!

3. Time on Sonar Watch.

A closely related problem concerns operator effectiveness as the watch progresses. The factor of operator vigilance is of concern here, as it is very well known that vigilance deteriorates as a watch progresses.

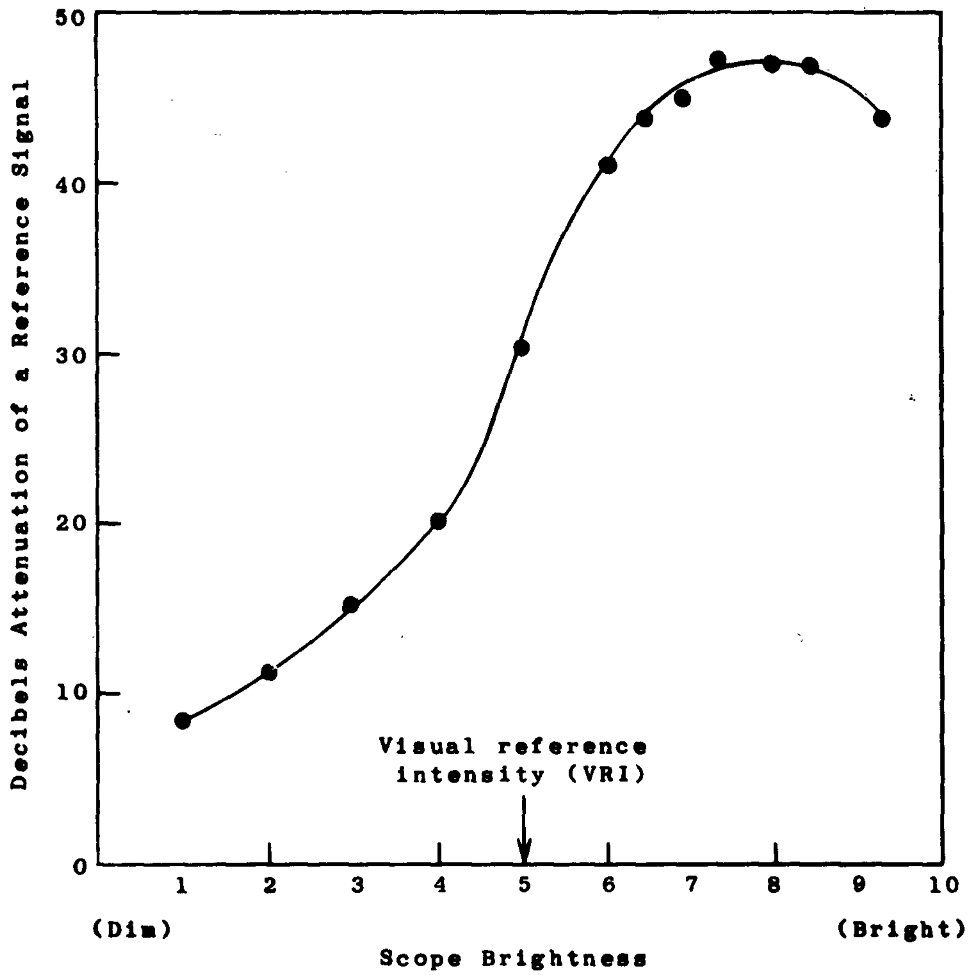

50
40
30
20
10
0
Decibels Attenuation of a Reference Signal
Visual reference intensity (VRI)
1
2
3
4
5
6
7
8
9
10
(Dim)
(Bright)
Scope Brightness

Figure II

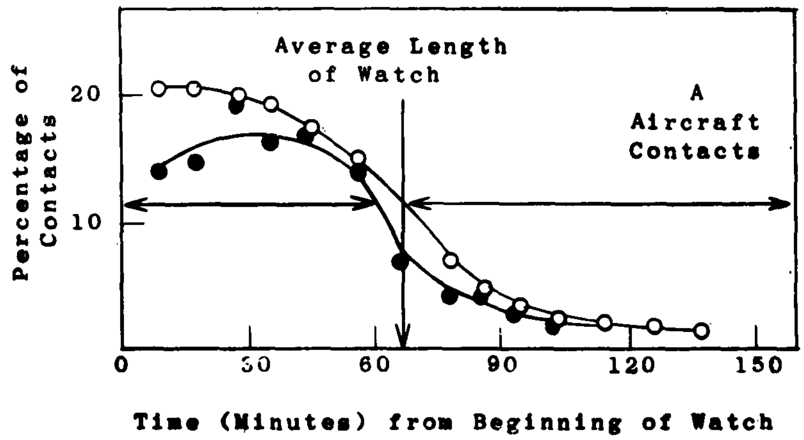
During War II it was found from an analysis of British operational data that airborne radar contacts were made with decreasing frequency as the length of time on radar watch increased. Figure III shows the general story: contacts of aircraft and surface submarines were most frequent during the operator's first half-hour on watch (Anonymous, 1944). The British report goes on to state that, "If all watches had been half an hour's duration, there would have been a gain of nearly 50 per cent" in detections of surfaced submarines.

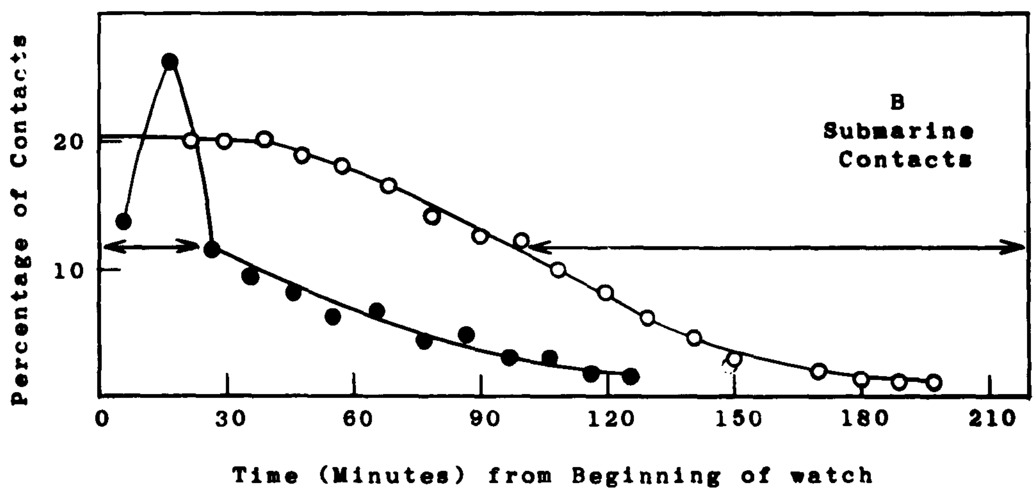
A great deal of laboratory research in recent years has demonstrated two things: (1) degradation of performance as the watch progresses is a form of behavior characteristic of all human beings, and is not simply a product of the radar situation, and (2) degradation does not necessarily occur after half an hour on watch; depending upon the situation it may be earlier, or later.

While Figure III concerns operator vigilance in the radar case, a similar situation is known to prevail in the sonar case. Two very recent experiments, one in Britain (Elliott, 1960) and the other undertaken this year at the Fleet ASW School in San Diego (Baker and Harabedian, 1962), have resulted in idential conclusions. The sonar operator's vigilance deteriorates by from 2 to 4 decibels <u>within the first three minutes on watch!</u>

4. Brief Statements Concerning Some Other Factors.

A host of other operator factors merit attention. The brief statements following are primarily drawn from the radar literature, and although they are doubtless potent in the sonar situation the necessary experimental work needed to quantify the losses, to determine whether they are the same, greater, or less, has not yet been done.





Cumulative percentages of lengths of watches and percentages of submarine contacts as a function of time on radar watch for two operational conditions.

Figure III

(1) Nature of the pattern of visual search. The conventional search pattern results in a loss of about 4 decibels, for targets at extreme ranges, in comparison with a method of search which is a rather minor modification of the conventional method.

(2) Scope size can be a factor. For targets near extreme range a 14 inch scope is 2 decibels inferior to a 7 inch scope, whereas the reverse is true for targets at close range.

(3) Compartment illumination. The loss consequent to the use of 1 foot-candle of illumination, instead of 0.1 foot-candle, is 7 decibels. In the HSS-2 the ambient illumination is much too high, with the consequence that a viewing hood must be employed.

(4) Pulse length. Increasing a radar pulse length from 1 to 3 microseconds can increase target detectability by 6 decibels.

(5) Target shape. In a situation such that a triangular shaped target in the real world can be recognized as a triangle when displayed on the radar scope in 56 per cent of presentations, a cross-shaped target is correctly discriminated on only 22 per cent of the presentations. Because of the classification problem, experimental data of this nature are much more important for the sonar than for the radar case, yet none exist.

(6) Sweep repetition rate. In the radar case the loss consequent in changing from 1/2 to 8 scans per second, is 8 decibels.

(7) Focus. The loss consequent to changing from an optimum focus setting to a "best focus" set by operators, using scopes well below optimum brightness, was found to be 17 decibels. At optimum brightness there was no loss.

(8) Pre-exposure of the eyes to daylight sky brightness.

If an operator is exposed for 5 minutes to a brightness of 25 millilamberts (daylight sky brightness), a target must be 20 or more decibels above the threshold (recognition differential) if it is to be detected immediately.

(9) Target detection and indirect viewing. If an operator looks 4 inches away from where a threshold target is displayed, its strength must be increased by about 15 decibels before it is detected. (This problem is connected, of course, with the problem of scope size.)

(10) Knowledge of target location. If a sonar target is known to be present but must be searched for, it must be 3 decibels stronger than in the case where its precise location is known.

These 10 factors are but a sample of the large number known to exist. The degree to which they affect performance in the case of the AQS-10 sonar is not known, and cannot be known without research.

Finally, it is one thing to know the potency of a factor in degrading operator efficiency and quite another to know what can be done about the situation. In the radar case, because of the research done, a number of answers are known. Research appears indicated in the case of sonar displays.

III. THE PROBLEMS

The following statements are based upon a number of interviews and training flights with personnel of HS10, Ream Field, during the month of April, 1962, and consequently should be considered with specific reference to this squadron only.

Some Operating Factors With Respect to the AQS-10.

1. To date the AQS-10 sonar has earned the reputation of being very variable in performance - "sometimes good, sometimes terrible," and the concensus of opinion appears to be that unsatisfactory equipment performance is a consequence of the "unusually bad" water conditions in the area around San Diego. In Florida waters, however, experience with the AQS-10 has been reportedly quite satisfactory. After consultation with a leading oceanographer who is familiar with both waters, we have reached the conclusion that it is the Florida waters which are unusual. The San Diego waters, while possibly being somewhat more variable than average from day to day, are much more typical of those in which submarine warfare might be expected to occur than waters such as those found off the Florida coast. From this we infer that while Florida waters may be very suitable for determining whether or not a sonar system meets its engineering specifications, they are not as suitable as San Diego waters for operator training.

At the same time there is some evidence to suggest that poor performance is not completely caused by "poor water." On at least one occasion a predecessor of the AQS-10, the AQS-4, was tracking an underwater object quite effectively, while a nearby AQS-10 was unable to even detect the same object.

It is anticipated that a forthcoming evaluation of the AQS-10, by the Naval Electronics Laboratory, will shed considerable light on the problem of whether the water, the sonar, or both, are to be held responsible for periodically unsatisfactory performance. At our suggestion NEL personnel have agreed to try and simultaneously compare the AQS-10 with the AQS-4.

2. From the operator's point of view the ambient illumination surrounding his display is far above tolerable limits (see p.6). To surmount this problem a viewing hood is employed. Viewing hoods have several disadvantages, two of the more important being that, (1) instruction of students in target detection and classification is seriously hampered, and (2) repeated exposures to the high ambient illumination when the operator's head is removed from the hood result in repeated losses of the required level of visual adaptation (see p.6). It is hoped that the current effort we are making to control illumination by curtaining and the use of a variable window filter, will help to alleviate this problem.

3. It is probably trite to state that the audio returns of a sonar system are extremely important. In the absence of information concerning the tolerable degradation in fidelity of the audio returns it is a risky policy to transmit the audio returns to the operator through circuits and earphones known to be inferior to others which are available. In the AQS-10 this information is transmitted through the a/c intercommunication system to phones which are not the best. It should be determined whether or not audio information <u>is</u> being lost through the use of the current system, and, if it is, we consider it mandatory that the system be improved.

<u>Maintenance of the AQS-10 Sonar Equipment</u>.

In 1951 one third of the electronic equipment used by the U.S. Navy was not in operating condition. In the decade which has since elapsed electronic equipment has increased considerably in sheer volume and complexity, and though we don't know the present proportion of non-operating equipment we would be very surprised if it was smaller.

The AQS-10 is extraordinarily complex when compared with its predecessors; the current analogy is that of a color TV set compared with a five-tube radio. Such being the case it can be anticipated that there will be a continuous need for shop maintenance of this equipment.

To our pleased surprise this need is at present being met at Ream Field in a most satisfactory manner. The typical trouble-shooting and repair of black boxes is being completed in hours, rather than in days or weeks. We must emphasize, however, that the excellence of this current service is primarily due to the initiative, skill, and leadership of the Warrant Officer in charge, and cannot be expected to be typical of all maintenance facilities where the AQS-10 will be repaired. The primary problems of this shop are the lack of a stockpile of parts and long delivery periods.

In summary, while the current system of electronic maintenance of the AQS-10 at Ream Field is satisfactory, it should not be taken for granted that this state of affairs will continue to prevail should there be a turnover of key personnel. Because of the complexity of the AQS-10 a substantial maintenance problem should be anticipated and planned for. Such a plan should involve an investigation to determine the level of electronic skill needed to maintain the equipment, and assurance that personnel having the skills required will be available in the numbers needed.

Operator Training

1. The Melpar trainer at Ream Field, is, so far as the sonar operator is concerned, a procedure trainer. As a procedure trainer

it is probably adequate. It will definitely not be adquate for giving training in the difficult tasks of detecting and classifying targets. We know of no training device which will, and, indeed, it is probably impossible to build one which will be a complete substitute for training with the actual equipment in an operational environment.

2. Even if such a device was available there are as yet no personnel who are sufficiently experienced with the AQS-10 to serve as instructors in the full meaning of the term. Both the audio and visual displays are unique, there is little if any doppler, and the expanded display, typically designed for use in classifying targets, is on a scale without known precedent. It can be anticipated that "expert" instructors in the use of the AQS-10 will not be available for some time.

3. At the present time helicopter pilots and sonar operators are being trained simultaneously, i.e., most flights are undertaken to instruct a student pilot as well as a sonarman. The nature of pilot training is such that repeated exercises in hovering, navigating, and general piloting are required. The sonar operator might get his transducer in the water for four or five minutes and then have to recover it so that another training maneuver can be made by the student pilot. The net result is that by the time that a sonar operator is "trained" - a matter of about four months - he may have had his transducer in the water a total of four or five hours at the most.

In our view a sonar operator, to be considered trained in the matter of target detection and classification, must have had from 80 to 100 hours of actual operating time. The current system, admittedly the only one possible at this time, cannot be expected to produce the type of trained operator upon which the outcome of any future hostilities can very strongly depend.

To emphasize this point further we must point out, to those unfamiliar with the AQS-10, or indeed with sonar displays in general, that detection and correct classification of a sonar target is a <u>most</u> <u>difficult</u> <u>perceptual</u> <u>task</u>. It is considerably more difficult than, say, the task of the radar operator. In this general connection it is pertinent to quote from a research report published by the Naval Electronics Laboratory (Lichtenstein, 1955).

> Equipment and associated circuitry characteristics often contribute to the heterogeneity of video noise on PPI's. Also, in the case of sonar, water and bottom conditions yield characteristic general patterns some of which may not change too rapidly as the ship moves. Usually, targets are the main objects of operator concentration in sonar search, whereas the general nature and consistent specifics of the noise pattern do not receive much attention save as something apart from which objects must be distinguished. In such a case, the noise characteristics are assumed to be random and unable to yield any direct or even comparative information about actual signals of possible interest. Unusual characteristics of noise - such as shape, area of concentration, outstanding spikes, consistent patterns, display - have been shown to interfere with maximum target detectability. The indications are, therefore, that operators should continuously and actively study their scope display patterns, even when no targets are likely to appear. This should be done to become familiar with the appearance of video noise on particular equipment, to note what is consistent in noise, so as to effectively eliminate some of it from the category of random noise. Effective noise elimination can be achieved when the operator is able to recognize such effects so that his problem of deciding which aspects of his display characteristics are or are not noise becomes less difficult. If operators can be trained to study their scopes, to keep the heterogeneous noise charactertics of the scopes always in mind, to observe gradually changing effects as ships move, and to be continuously aware of "equipment injected" patterns, however slight, improvement in target-detecting ability should result. (Incidentally, the continuous study of a scope should serve to keep up an operator's attention during times when a target is not around. This feature might alleviate a serious situation encountered in sonar operations: the fact that likelihood of detections after operators have been on watch more than 5 minutes is decreased because of reduction in operators' alertness.)

In view of the above few paragraphs it is our opinion that the training of sonar operators is incompatible with the training of helicopter pilots, and a major change is required in the technique of training sonar operators for the AQS-10.

4. RECOMMENDATIONS

As a preamble we remind the reader that the primary purpose of each million dollar copy of the HSS 2/AQS-10 system is to arrange conditions such that a sonar operator can, if a target is within range, initiate procedures for target detection and classification with a high probability of success. If there is serious intent that this goal be realized, then we very strongly doubt that the present state of knowledge concerning the equipment, and the present methods of training, are adequate. The following recommendations, if implemented, would bring the ultimate goal very much closer.

1. A laboratory research program should be initiated to determine the optimum operating conditions - brightness, gain setting, etc. - of the AQS-10. In our opinion, with an AQS-10, appropriate target and noise generating equipment, and representative sonar operators, the important questions posed in the introduction could be answered in a relatively brief period of time.

2. Systematic target data should be collected as recommended in Human Factors Research, Inc. Technical Memo 206-15, with a view of producing a film which will:

(1) enable clues to target classification to be acertained,

(2) demonstrate optimum operating procedures for target classification and tracking, and

(3) serve as an immediate training aid for target detection and classification.

3. It is mandatory that AQS-10 operators be <u>really</u> trained. The concept of the flying classroom is a proposal in the right direction but, in our view, would still be inadequate.

We recommend that the training squadron at Ream Field be supplemented by a training ship. Mounted on the fantail stern of such a ship, or on a platform slung outboard, there would be a cabin containing a complete AQS-10, and ample room for an instructor and student. The ship would also contain a number of cubicles, (at least six) in each of which would be audio and visual AQS-10 displays slaved to the main operating set. An intercommunication system would connect all stations and helicopter noise would be fed into all stations. This ship would routinely carry seven or more students to active shipping areas such as the approach to San Diego harbor, heave to, put out a sea anchor, and drift. In this manner one student would operate the sonar, under the instructor's guidance, while the others observed the results at their individual stations.

Problems of interest would be discussed over the ICS with the audio noise turned off, and then operations would proceed. Surface vessels could be tracked for miles, in many aspects, and visually determined range and identification of type would be correlated with the information displayed on sonar. Students would rotate hourly through the "command" position. Just ten hours a week of "wet ball" time would give each operator 100 hours of training in 2 1/2 months. During the remaining 1 1/2 months each operator would graduate to in-flight training, in the manner done at present.

3. If it is shown that there is a causal relation between water conditions and performance of the AQS-10, water conditions should be "measured" daily in the training area, much in the same way that weather is surveyed from hour to hour. We have been given to understand that the instrumentation for such measurements would be relatively simple. It would include, of couse, instrumentation for ensuring that the equipment was operating at peak performance.

The purpose of such measurements would be to apply a weighting factor to operators' performance on what might be termed a "sonar target range." Such a range would consist of several (six or more) triplane reflectors anchored near the general training area. For each triplane there would be a datum point where the pilot would hover and give the operator an arbitrarily limited period of time - say 5 minutes - to try and detect the triplane. The helicopter would then fly to another datum point (and another triplane at known range and bearing) and repeat the process. The order of selection of the range targets would be randomly different on each flight and unknown to the student.

After each flight over the range the student would be given a detection score. If he detected 4 out of 7, then the weighting factor for water conditions would be applied so that a score of 4 out of 7 might represent 5 out of 7 on "bad water" days, or 3 out of 7 on "good water" days. It would be expected that an instructor, or a well trained operator would consistently achieve a high score on the range.

We recognize that there would be numerous technical difficulties in implementing such a proposal, but suggest that it merits serious consideration.

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