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A PROPOSED TORPEDO COUNTERMEASURE SYSTEM

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ABSTRACT

The high-speed, straight-running, collision-course torpedo presents a very difficult countermeasure problem. A proposal is made for a countermeasure system which may neutralize this threat. The system relies primarily upon a precision acoustic detection and tracking sonar to provide accurate fire-control information at short range. Disablement or countermining of the torpedo is achieved by a salvo of simple, lightweight, ballistic rockets fired to enter the water at a range of about 400 ft. Studies and trials have been undertaken to show the feasibility of a modified Puffs acoustic technique for torpedo detection and tracking. A brief comparison with some past developments having similar objectives shows that the proposed system may overcome some of the disadvantages of previous experimental systems.

PROBLEM STATUS

This is a final report on one phase of the problem; work on other phases is continuing.

AUTHORIZATION

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TERAGRAM
A PROPOSED TORPEDO COUNTERMEASURE SYSTEM

INTRODUCTION

The U.S. Naval Research Laboratory* has for some time been engaged in research and development leading to torpedo-countermeasure systems. Work has been based primarily on diversion techniques for active and passive acoustic homing torpedoes.

A most difficult problem is that of countering the straight-running, high-speed torpedo making a collision-course approach to a target without guidance. Of necessity, the countermeasure philosophy against such a weapon must consider either avoidance or destruction (disablement) of the torpedo. In the latter case, any system devised is also limited by considerations of weight, size, complexity, and logistics.

The proposed Teragram system, which is straightforward in concept and which makes use of state-of-the-art system components and techniques, is based upon the destruction or disablement of straight-running (or other) torpedoes at short range. This report describes the Teragram philosophy and concept, analyzes some performance features of the proposed system, outlines armament requirements based on predicted performance, and makes brief comparisons with some past projects having generally similar objectives. It is emphasized that the primary purpose of the proposal is to meet the requirement for a countermeasure to the current generation of high-speed, straight-running torpedoes. It is believed that once in use, progressive improvement of the system would match future torpedo improvements, such as quieter running.

TERAGRAM PHILOSOPHY AND CONCEPT

The destruction or disablement of a running torpedo can be achieved by the detonation of a quantity of high explosive in the vicinity of the torpedo. The more accurately the position of the torpedo is known, the smaller is the charge of explosive needed, always provided that the charge can be accurately placed. If destruction is attempted at long range, fixing the position of the torpedo becomes difficult and accuracy suffers. Consequently a heavy charge must be used, and the weapon required to place the charge also becomes large. On the other hand, if destruction is attempted at short range it becomes easier to provide precise fire-control information, weapon dead time is reduced, and thus both explosive and armament requirements are minimized.

The proposed Teragram system employs:

- A precision acoustic system for torpedo detection and tracking
- A modified 40-mm or other mount and stable system
- A salvo of simple, low-angle water-entry ballistic rockets with time-fused warheads for close-range destruction of torpedoes

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The components of the system are shown in Fig. 1, and Fig. 2 illustrates the system in operation. A choice of 900 ft for initial detection was made as the minimum range compatible with the system. There is every indication that torpedo detection well beyond the 900-ft minimum is probable. A tracking accuracy with a standard deviation of 20 ft was chosen to permit employment of rocket warheads, not exceeding 50 pounds HBX or equivalent, to cause severe torpedo body damage, or countermining, or both. Rocket-performance requirements, particularly entry angles, are compatible with some existing model nose designs. The more important performance elements are considered in greater detail in the sections which follow.

DETECTION AND TRACKING

Preliminary Study

The key to successful application of the Teragram philosophy and concept lies in the short-range detection and tracking capabilities of the acoustic portion of the system. At the suggestion of NRL, a preliminary study was made at the U.S. Naval Ordnance Laboratory, White Oak, Maryland, during the summer of 1961 to determine the feasibility of tracking torpedoes in both bearing and range using Puffs techniques. For this study, tracking errors of less than 50 ft were considered acceptable for ranges in the interval 900 to 300 ft. Tracking accuracy had to be maintained over a sector ±45 degrees from the beam.*

A system consisting of two linearly spaced hydrophone pairs, where the spacing between pairs was 200 ft and the separation of hydrophones in each pair was 40 ft, was analyzed. This analysis indicated that torpedoes could be tracked with the required accuracy in the listening band 4 to 8 kc, if the signal-to-noise power ratio was greater than 1/4 for torpedo speeds up to 60 knots.

Trials

Arrangements were made with Destroyer Development Group II to conduct tests using the Sperry-Padloc installation on the USS GLENNON. Three hydrophones on a line spaced 58.25 ft apart were available in this installation. Although this spacing is not ideal for tracking torpedoes, the data which have been obtained are useful for establishing the feasibility of torpedo tracking.

To date two tests have been conducted. The first test was performed in October 1961 with the USS SABLEFISH as the firing submarine. A total of five Mk 14 steam torpedoes were run at depths of 50 ft, and at two different speeds, four at 45 knots and one at 30 knots. The sea state was 1 and the GLENNON, steaming at 5 knots, was the target. All torpedoes were tracked from the time of launch, which occurred at 7200 yards for the 30-knot torpedo and at 3600 yards for the 45-knot shots.

The second test was conducted in June 1962, with Mk 37 electric torpedoes launched from the Destroyer USS BERRY. The GLENNON was again the target. Three of four torpedoes fired failed to operate properly, but in the one good run the torpedo ran at 25 knots at a 50-ft depth. Both ships were steaming at 17-1/2 knots, and the range on firing was 1200 yards. Although the noise of BERRY masked the torpedo for a time, it was detected at a range of 1600 ft.

*Bearing errors increase only slowly to about 1 degree directly ahead. However, range accuracy decreases as the cosine squared of the angle from the beam. Many hydrophone configurations can be devised to alleviate this difficulty.

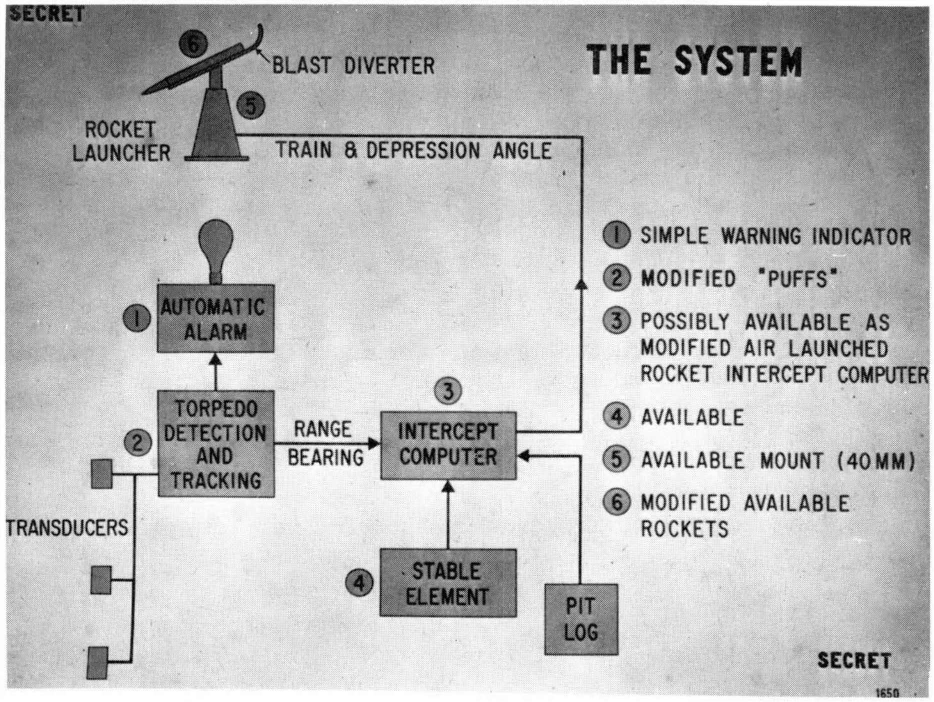

Fig. 1 - Components of the proposed Teragram system

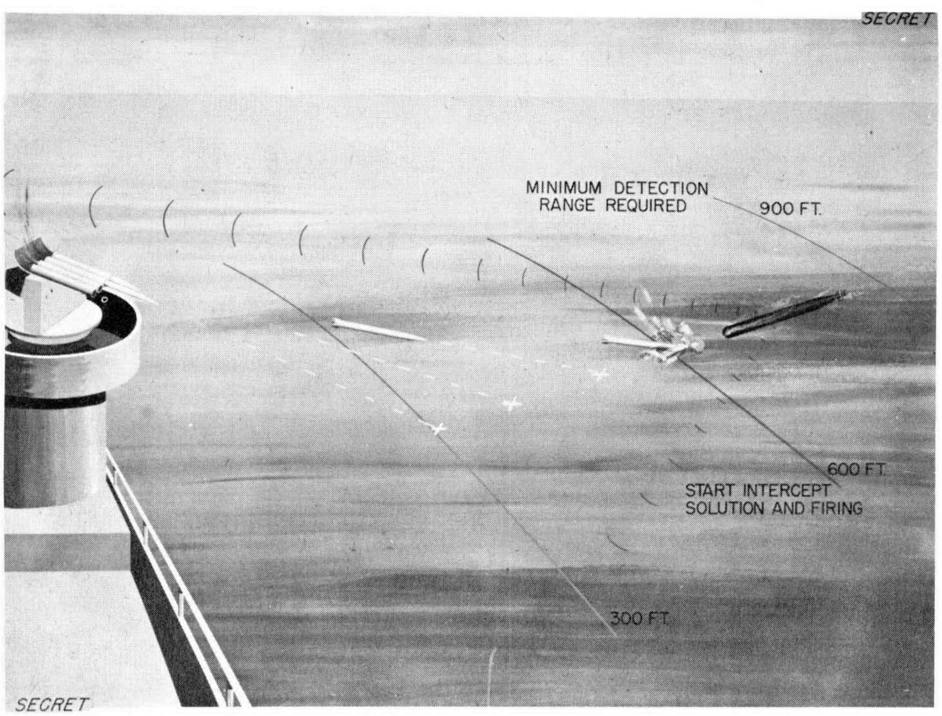

Fig. 2 - Artist's conception of the Teragram system in action

Automatic Tracker

In order to handle high bearing rates, and to obtain ranges which are very short compared with the ranges for which the present Puffs equipment was designed, a modified automatic tracker was assembled at the Naval Ordnance Laboratory. It is a digital rate-compensating tracker and was built from Computer Control Company S-pacs digital modules. The results of the analysis of the recorded data obtained in the above tests using the Deltic Correlators and the modified tracker are presented below.

Tracker Outputs

Three quantities are printed out by the tracker every 0.78 second. These quantities are designated τ_1, τ_2, and ΔT. Quantities τ_1 and τ_2 are the delay times with respect to the center hydrophone necessary to produce the correlation maximum. Quantity ΔT is the absolute value of the difference between τ_1 and τ_2. No postintegration was used on the correlator outputs for the Mk 14 torpedo runs.

Considering the forward pair of hydrophones, the formula for range is

$$R = \frac{\ell^2 \cos^2 \theta}{v \Delta T} 10^6$$

where

θ_1 = the bearing angle measured from the perpendicular bisector of the line connecting the two hydrophones

$$\sin \theta_1 = \frac{v \tau_1}{\ell} 10^6$$

R = range

ℓ = hydrophone separation

v = velocity of sound

ΔT and τ are in microseconds.

For the hydrophone configuration used,

$$R = \frac{678500}{\Delta T} \cos^2 \theta_1,$$

and

$$\sin \theta_1 = \frac{\tau_1}{11650},$$

where R is in feet. The number 11650 is the time, in microseconds, for sound to travel 58.25 ft, which was the hydrophone separation distance.

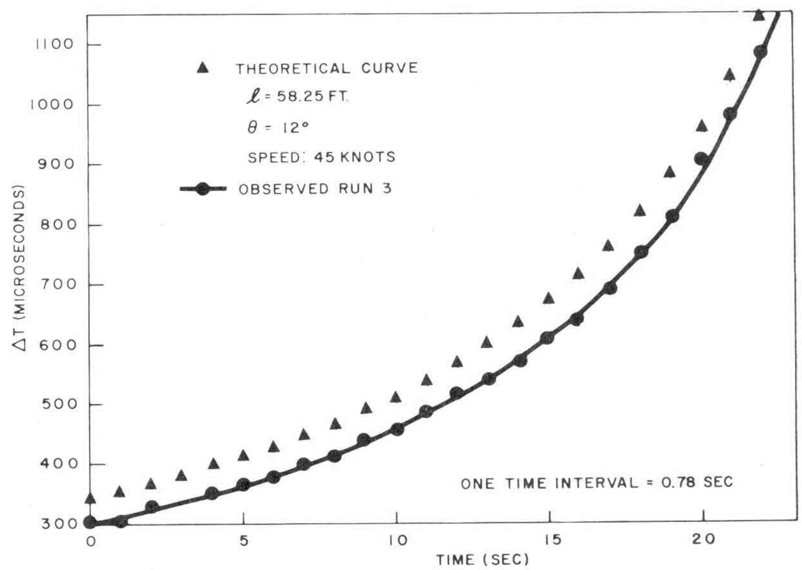

Fig. 3 - Comparison between computed and observed values of ΔT vs time for run 3

A single hydrophone was selected from each array in the three domes. The noise levels at domes 1 and 2, for a ship's speed of 6 knots, were 10 db and 6 db respectively below sea state 2, but at dome 3 the noise level was 11 db above sea state 2. The after hydrophone position is situated just forward of the fire room and experiences considerable noise interference compared with the other two positions.

Figure 3 shows a comparison between the computed and observed value of ΔT vs time for run 3 of the Oct. 1961 tests. The computed curve was obtained by assuming that the torpedo speed was 45 knots. This corresponds to 58.8 ft of travel per time interval of 0.78 sec. The two curves are in good agreement, except for a biasing error of 50 microseconds. The biasing error is probably caused by displacement of tape-recorder heads in playback, phase shift in the instrumentation, or misalignment of the three hydrophones that were used.

A plot of range in feet vs time for the same run is shown in Fig. 4. The observed values of ΔT have each been increased by 50 microseconds before converting to range. In this part of the run, θ changes from 12 degrees to 13 degrees. Since the points fall on a straight line, the correction used is reasonable. The mean difference between the observed and theoretical values of range, assuming that the torpedo speed is 45 knots, is 10.3 ft.

Figure 5 is a plot of observed values of ΔT vs time for run 4 of the Oct. 1961 tests. The data are provided to show variations in ΔT at the longer ranges which are believed to be caused by multipath interference. The range interval in Fig. 5 is from 4400 to 2100 ft, whereas the range interval in Fig. 4 was from 1600 to 400 ft. At 2300 ft the variations in ΔT indicate that very little multipath interference is present.

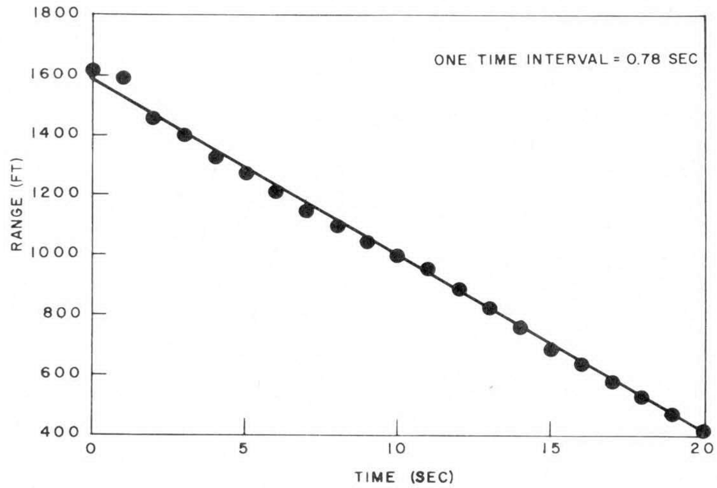

Fig. 4 - Plot of range (in feet) vs time for run 3

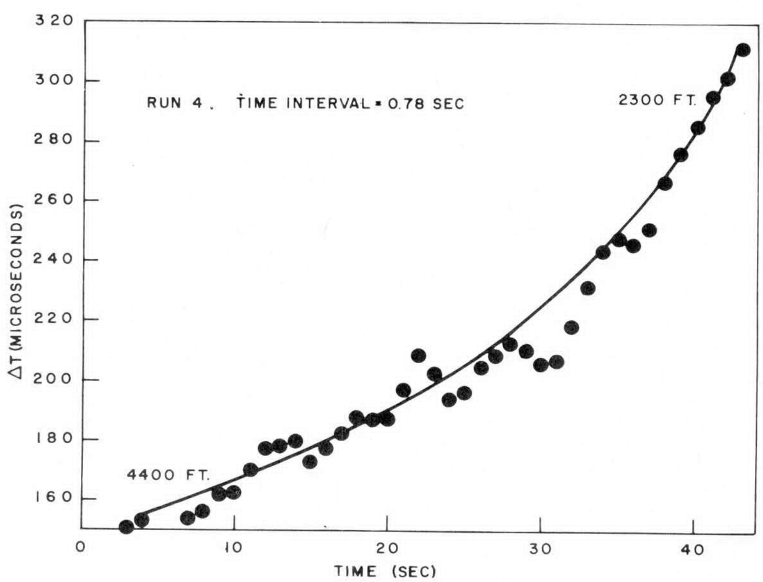

Fig. 5 - Plot of observed values of ΔT vs time, showing effects believed to be caused by multipath interference

Results from the trial in June 1962 are presented in Fig. 6, which shows observed delay vs time for the Mk 37 torpedo. Tracking was possible in the range interval 1100 to 200 ft. The torpedo traveled some distance before its bearing could be resolved from the bearing of the radiated noise of the launching destroyer. At the GLENNON's speed of 17.5 knots, the noise levels at domes 1, 2, and 3 were 12, 24, and 23 db respectively above sea state 2.

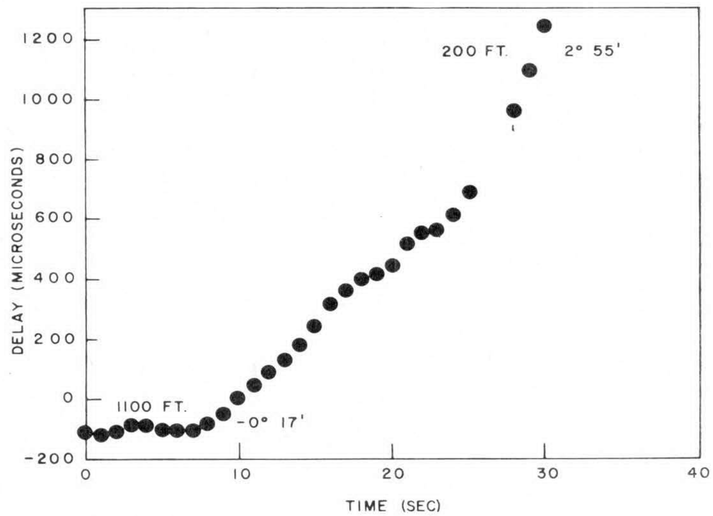

Fig. 6 - Plot of observed delay vs time for run with Mk 37 torpedo

WEAPON COMPONENTS

The Rocket Launcher

For installations where weight is of secondary importance, such as on merchant vessels, a standard 40-mm quad mount with amplidyne drive could be used. After removing the guns, an estimated 8000-lb rocket load could be added. This would be far more than necessary for the rocket weapons. For a merchant vessel two mounts, one on each side, would probably be required, for a total weight of 44,000 lb.

For installations where weight considerations are paramount, it should not be difficult to design a lightweight, stabilized, power-operated mounting, since no recoil forces are involved. It is possible that such a light mounting has already been developed for other purposes, such as radar antennas, but this possibility has not been explored. Certainly the development of such a mounting is well within the state of the art.

The Rockets

Information available from previous torpedo-countermeasure work (1, 2, 3) indicates that a charge of approximately 50 lb HBX exploded in water at a distance of 20 ft should countermine or disable a wide variety of straight-running torpedoes. It is believed that disablement, rather than countermining, should be the objective, since it is more difficult for the torpedo designer to counter. That is, all components must be modified rather than the pistol alone.

The requirements placed upon the rockets in the proposed Teragram concept are that they should be fired to ranges between 600 and 300 ft from the launching point, and that they should not richochet, but should enter cleanly and sink rapidly to firing depth. It does not appear difficult to design a rocket to carry the charge the required distance. However, the problems of water entry at shallow angles may present greater difficulties. A simple fuse is feasible.

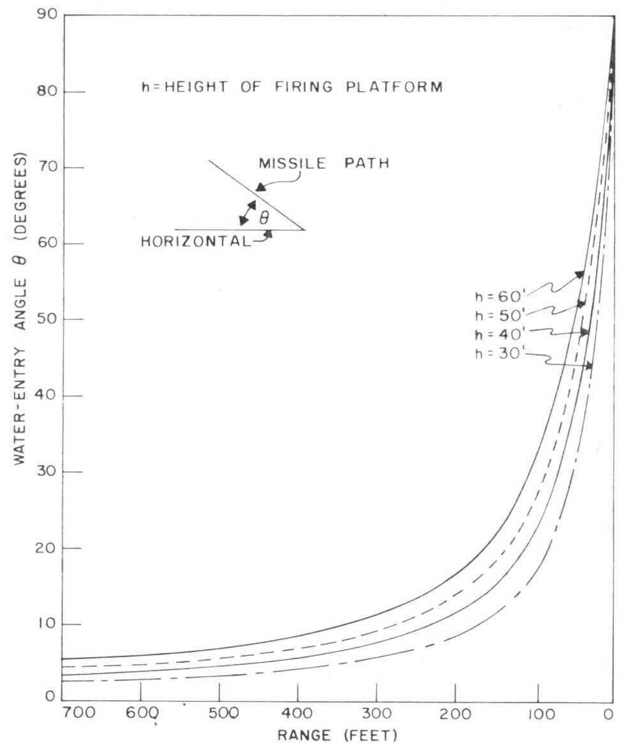

Fig. 7 - Water-entry angle vs range and height of firing platform

A report (4) of model tests for a depth bomb indicates that stable water entry can be obtained to a lower limit of about 5 degrees entry angle. This was for a prototype velocity of 860 ft/sec. The prototype model had a sinking rate of 46 ft/sec. Even better results were obtained with some model Subroc vehicles (5). Figure 7 shows water-entry angle plotted against height of firing platform (trajectory considered as a straight line). It can be seen that to get an entry angle of 5 degrees or more at a range of 600 ft, a firing-platform height of at least 50 ft is required. This would be readily available on most merchant vessel hulls. In practice the trajectory could be tailored to some extent, although this could mean an increase in time of flight.

A brief analysis of these requirements by rocket-design personnel of the Bureau of Naval Weapons has developed the following characteristics for a Teragram rocket weapon.

Payload	60 lb HBX
Warhead	100 lb total weight
Propellant	13 lb
Burning time	6/10 sec
Burnout range	227 ft
Max. velocity	810 ft/sec
Total length	60 in.
Total weight	117 lb
Max. acceleration	44 g

Intercept Computer

The intercept solution could be obtained with a number of current computers. Favored at present is a modified air-launched rocket-intercept computer.

REVIEW OF PAST EXPERIENCE

Because there have been many past attempts to devise a destructive countermeasure to the straight-running, collision-course torpedo, some attention is now directed to past efforts in order to demonstrate the probable advantages of the Teragram concept. The background and history of the various approaches to such a countermeasure have been described in a paper presented to the USAG Sonar and Torpedo Countermeasure Workshop by Mr. Lewis L. Stone of the U.S. Navy Mine Defense Laboratory (6). His paper is used as the source for comparative information on past approaches, and no attempt is made here to describe each in any detail.

Project Phoenix

This countermeasure consists of a string of charges towed along each side of a ship and directed outward by paravanes. Although not officially canceled, the program is inactive. The chief drawback is the limited coverage provided, coupled with the fact that the explosive charges were at or closer than 220 ft from the hull. Since countermining of the torpedo is quite probable, the shock-loading factor must be kept in mind. The further away the torpedo can be countermined the lower the hull shock factor. Hull shock factor is expressed as $\sqrt{w}/r$, where w is the weight of TNT explosive in pounds and r is the range from the explosion to the hull in feet. This factor is an indication of the severity of a shock reaching a ship's hull. It is not a measure of expected damage, since some ships can experience more severe shocks than others and still perform their allotted tasks. For instance, some minesweepers are expected to be able to continue operating after experiencing a shock factor of 0.2. However, as little as 0.07 may disable an unmodified liberty ship. For a warhead of about 900 lb TNT equivalent, the shock factor at 220 ft is approximately 0.14. For Teragram the closest approach should not be less than 300 ft, for a shock factor of 0.1, and the mean range of the rocket salvo would probably be at 400 ft or further. At 400 ft the shock factor is down to 0.075.

Coverage of Teragram is possible over 360 degrees (see note on page 3). However, this will entail careful consideration of weapon siting unless a number of weapon mounts are to be employed.

Project Ruler

In Project Ruler, a British approach, a torpedo was detected by passive sonar. Then the approaching torpedo was ranged on by an active sonar to obtain fire-control information which was used to aim and fire a four-barrelled mortar. The weapon range was 600 ft, and each shell had a charge of 200 lb high explosive. An acoustic proximity fuse was to have been employed. The total weight of the system was close to 26 tons, and there were difficulties with the fuse. The project was shelved largely because of these factors.

The Ruler approach was also studied by Vitro. The approach considered was to use the Hedgehog projector and a torpedo echo-ranging modification for the 14-kc SQS-4 sonar. It is not known if this sonar modification was in fact even developed. The advantages of the Teragram concept over the Ruler approach should lie in Teragrams greater simplicity.

Project Camrose

In this project, another British approach, a torpedo was detected by passive-scanning sonar, and if the steadiness of the bearing indicated a possible hit, a salvo of torpedo-like rockets running underwater were fired to intercept the torpedo. A passive acoustic fuse was used. Rough range for determining when to fire was obtained by assuming a certain torpedo acoustic spectral density; then by listening on two separate frequencies and considering the relative attenuation, a range estimation could be made. Once again a large head for each rocket (200 lb high explosive) was required. Once again total weight of the system became prohibitive and the project was dropped.

Teragram appears to offer a considerable advantage in accuracy over the original Camrose concept, but it is quite interesting to speculate on the use of a single Camrose weapon with the Puffs acoustic technique.

Another idea which is being studied at MDL envisages the use of a wire-guided torpedo, which would be kept on the bearing of an approaching torpedo which has been detected by a passive sonar. A proximity fuse would actuate the weapon. The method requires continuous tracking and control of the weapon, so that it can be kept on the bearing of the approaching enemy torpedo. It is believed that the Teragram concept should offer greater simplicity and reliability than this scheme.

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