OPERATIONS EVALUATION GROUP

STUDY 289

PROCTOR, A Short History

The Rise and Fall of an Anti-Submarine Weapon

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PROCTOR, A SHORT HISTORY
THE RISE AND FALL OF AN ANTI-SUBMARINE WEAPON

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Outline

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APPENDICES

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PROCTOR, A SHORT HISTORY

THE RISE AND FALL OF AN ANTI-SUBMARINE WEAPON

ABSTRACT

PROCTOR is an acoustic, homing, airborne anti-submarine torpedo developed during the war. It turned out to be the most effective air-borne anti-submarine weapon used by the Allies in the last two years of the war. It may serve as a prototype of the weapon that we must rely upon in the future; however, experience in its use gained during the final year of the war shows that for air attacks to be effective against new submarine types it will be necessary to

(a) improve the torpedo;

(b) improve sonobuoys;

(c) improve tactics.

Operational experience indicated, furthermore, that Proctor attacks were much more effective when carried out by carrier-based planes than by land-based aircraft. The reasons for this are not yet clearly understood; and it is important that they should be understood before improved equipment and tactics are finally fixed upon.

1. INTRODUCTION

PROCTOR (FIDO, Mark 24 Mine) is an interesting example of a weapon developed, produced in quantity, and used effectively in operation, all within the war period. PROCTOR is an instructive instance of the possibilities of rapid application of modern technical developments; it could not have been achieved before the 1930's, for it is an electronic device demanding techniques which were developed only in the last decade. Finally, PROCTOR provides a satisfactory subject for a case history of the introduction, of a new weapon, for it is a specialized weapon, used in a limited, but important, field of warfare.

The idea of a homing torpedo as a countermeasure to the U-Boat undoubtedly occured many times to many people. But it was a barren one, of course, until electronic control techniques had developed to the point where the connection between detection and steering could be made reliable and the device incorporating this idea could be produced in quantity.

Military need and technical "know-how" had their first contact in November 1941, at a meeting between officers of Bureau of Ordnance Re 6 (Underwater Ordnance) and a special Subsurface Warfare Committee of the National Defense Research Committee. At this meeting, the need for an airborne homing torpedo was outlined. It was agreed that a super-sonic acoustic device offered the best hope for detection; also, that the necessary control methods were by then quite feasible. Contract negotiations were begun the first week in December; The Bureau of Ordnance contracting with the Bell Telephone Laboratories and the General Electric Company, and the NDRC with Harvard University Underwater Sound Laboratory. Work began shortly after Pearl Harbor. The final production design was agreed on in December 1942, and the first attacks on a U-Boat using PROCTOR were made in May 1943, only 17 months after the project was conceived.

This is a remarkably short time for so complex a piece of equipment to be designed, produced and put into operational use; particularly when one considers the high degree of security which was successfully maintained throughout the project. The explanation for the expedition that was achieved probably lies chiefly in the success of the cooperation of everybody concerned in the development of the weapon. Besides the Laboratories already mentioned, the staff of the David Taylor Model Basin cooperated in design and testing. The final production design was a combination of the best features of the several competing designs. It is probable that because of the friendly rivalry and the complete interchange of technical information that were encouraged in this project, the development time may have been shorter by as much as a year than what would have ordinarily been required.

2. OPERATIONAL PROCEDURE

2.1. General Description and Behavior

PROCTOR is a small torpedo designed to be dropped from a plane. It has the dimensions of the usual 1000 pound bomb; diameter 19 inches, length 83 inches. Its weight is 683 pounds. It runs at 12 knots under water, using electric propulsion, and homes on an underwater sound source of a frequency of 24 KC.

The torpedo is fitted with a wooden spoiler ring and tail stabilizer to aid its flight in air; these break off when its enters the water. After water entry the torpedo usually circles, with a turning radius of 50 to 150 feet, at a depth below 40 feet, until it comes within the sphere of influence of a sound source sufficiently intense to activate the controls. Thereafter the torpedo proceeds on an approximate pursuit course until it strikes the target (or loses it). At full battery capacity it will run from 12 to 15 minutes, travelling approximately 6000 yards, after which it will sink, since it has negative buoyancy.

A more detailed description of the construction and behavior of PROCTOR is given in Appendix A.

In designing PROCTOR, several decisions were made that contributed materially to expediting the production of the weapon. Perhaps the most important decision was that no anti-countermeasure devices were to be incorporated: the equipment was to be made as simple as possible, even though it would thus be easy to counter. This decision was amply justified by the results: the design and production were completed in as short a time as any weapon of equivalent complexity, and the enemy had not devised a countermeasure for the weapon even by the end of the war, after it had been in effective use for 24 months. The last fact can probably be considered a justification also of the high classification at which the project was held; for even at the end of the war the enemy had not yet seemed to realize just what it was that they had to counter, in spite of the fact that they had developed an acoustic torpedo of their own. It is true that the airborne version of their acoustic torpedo was a failure.

2.2. The Detection Unit

The detection unit conformed to the decision for utmost simplicity in the design of PROCTOR. It consisted of four directional hydrophones pressed against the walls -- one on top, one on the bottom, and one on each side. They pointed at right angles to the axis of the torpedo, and successive hydrophones looked out at 90 degrees to the direction of the preceding one. The most sensitive listening was thus abeam of the mine, and the least sensitive ahead and astern.

The range of detection of an acoustic mine depends on the intensity of the sound output of the target; this in turn depends on the speed and the depth of submergence of the target. For a given submarine, it may vary somewhat from run to run under similar conditions. For a 6 knot submarine running at periscope depth the average range at which the horizontal steering will take over is about 1300 yards; for a 3 knot submarine at 250 feet depth the horizontal range is about 120 yards. The vertical control microphones are set to take over at about half the range at which the horizontal control microphones take over; this is done in order to simplify the pursuit track. In general, the torpedo will steer for the stern of the submarine, since the sources of the greatest portion of the 24kc sound are the propellers.

More details of the acoustic characteristics of PROCTOR will be found in Appendix A.

2.3. PROCTOR Designed for Airborne Use Only

It was decided at an early stage of its development that PROCTOR was to be limited to airborne use. There were two reasons for this decision: first, it was considered that the weapon would improve the effectiveness of attacks on U-Boats by aircraft more than it would the effectiveness of attacks by surface craft; and this presumption was borne out in practice. Aircraft usually have only one or two opportunities to attack during a contact, whereas a surface vessel can often maintain contact after the U-Boat has submerged, and attack repeatedly.

The second reason for the limitation of PROCTOR to airborne use was connected with the safety of friendly surface craft. It was considered possible that a faulty torpedo might "bite its own master's hull". As a matter of fact, PROCTOR had a depth control ceiling designed to prevent its coming nearer the surface than 30 feet, in order to avert that danger; however, this control was of the simplest kind, and did not enjoy the confidence of the crews of surface vessels; hence the usual doctrine was for surface craft to avoid the neighborhood where PROCTOR was being used.

3. LETHALITY OF THE WEAPON

3.1. Overall Results

During the war, a total of about 340 Proctors was dropped by all Allied forces in 264 attacks. Of these attacks, 60 were on non-submarine targets. As a result of the

204 attacks on U-Boats, the following results were achieved:

Number of U-Boats sunk . . . . 37, or 18%

Number of U-Boats seriously damaged . . . . 18, or 9%

Number of U-Boats sunk and damaged . . . . 55, or 27%

The United States forces had better opportunities for training than the British, consequently their record is a little higher. U.S. forces carried out 142 of the 204 attacks on U-Boats, with the following results:

Number of U-Boats sunk . . . . 31, or 22%

Number of U-Boats damaged . . . . 15, or 10%

Number of U-Boats sunk and damaged . . . . 46, or 32%

It is seen that the U.S. forces succeeded in sinking a U-Boat in better than one out of every five attacks on submarines where PROCTOR was dropped. This is about one-half of the expected probability; the reasons for the smallness of the fraction will be discussed in Sections 4 and 5.

3.2. Time Trend

As would be expected, Proctor enjoyed its greatest success at the beginning of its use. The operational results of U.S. attacks by periods are exhibited in Table 1. These data were obtained at various times during the war, and the totals do not agree absolutely with those given in Section 3.1., which were collected after V-J Day, when all the returns were in.

Table 1

PROCTOR ATTACKS OF U.S. FORCES BY PERIODS

Period	1943 May-Jun	1943 Jul-Dec	1944 Jan-Jun	1944 Jul-Dec	1945 Jan-May	Total
No. of attacks on U-Boats	7	50	34	29	10	130
No. U-Boats sunk	3	18	4	2	2	29
Percent successful	43%	36%	12%	7%	20%	22%

The most plausible explanation of the rapid decrease in the number of attacks from the end of 1943 on is the following: In the early days of Proctor's history U-Boats were often caught on the surface and had to be forced to submerge before Proctor could be used. Later the U-Boats became wary and dove quickly; as a result many attacks were attempted under conditions that rendered it unlikely that the device ever could have come within sound range of the submarine.

The Allies' reply to this maneuver of the U-Boat was the radio sonobuoy, which came to be of considerable assistance in locating the submerged submarine. However, many Proctors were wasted in learning how to use the Sonobuoys.

Towards the end of the war it became apparent that the decreasing success of Proctor was in some way related to the type of plane which used it. This will be discussed in more detail below. (See Section 5).

3.3. PROCTOR Compared with Other Weapons

In evaluating the effectiveness of PROCTOR as an antisubmarine weapon, it should be borne in mind that the full tactical exploitation of the weapon was not feasible during the war. In the first place, as was mentioned, the objective of obtaining maximum speed of development and production precluded the incorporation of any anti-countermeasures. In the second place, security reasons forbade its use against surfaced submarines. Finally, there was the lack of trust in the 30-foot ceiling, which prevented combined air-surface attacks. It is probable that two more years of development work could have removed these limitations, and have enabled the addition of a few of the simpler anti-countermeasures devices; but the delay would have meant that about 12 fewer U-Boats (conservatively calculated) would have been sunk in 1943-44, and it is doubtful if this deficiency could have been made up by improved performance in 1945.

Comparison of PROCTOR'S achievements with those of other weapons indicates that the large amount of technical manpower spent in its development was amply justified. In air attacks by U.S. forces on submarines in which PROCTOR was not used, 9.5% of the U-Boats attacked were sunk; in attacks by U.S. forces in which PROCTOR was used, 22% were sunk. The homing torpedo increased our chances for success per attack by 130% over the chances for success when depth bombs only were used.

It is noteworthy in this connection that carrier-based aircraft using PROCTOR turned in a score that was 50% better than the average number for all types of aircraft given in section 3.1, and came within 10% of the theoretically expected par score.

4. COMPARISON WITH THEORETICAL EXPECTATION

4.1. Method of Calculating the Probable Performance of PROCTOR

A series of trials at Key West had led to certain definite conclusions regarding the performance that could be expected of Proctor in actual operations against an enemy submarine. These conclusions took the form of the probability of an average PROCTOR homing on and hitting a submarine, as a function of the depth of the submarine and the distance at which the PROCTOR started its run. (The data on which these probability calculations were based are tabulated in Appendix A, Table A-4). The operational results discussed in section 3 were compared with those that would have been expected from the analysis of the Key West trial data.

In order to compare the operational results with those theoretically determined probabilities it is necessary that the operating conditions be interpreted according to the conditions of the trial runs, and correspond to them in essentials. In 1943 it was common for aircraft to sight U-Boats on the surface. - If the U-Boat was still on the surface when the approach run was completed it was bombed or strafed until it dived. As soon as it dived, PROCTOR was supposed to be dropped on a point near the swirl that was estimated to be most advantageous for picking up the propellor noise of the submarine. This procedure made it possible to compute the probability of a hit as a function of the time interval between submergence and dropping of the torpedo. It is seen that this corresponds to the method of computing the probability of hits in the trial runs at Key West.

The fraction of expected hits computed theoretically from the Key West trial data is plotted as a function of the time, in seconds, that the U-Boat was submerged when PROCTOR was dropped, in curve 1 of Figure 1. From this curve it is seen that the theoretical chance of a hit is above 50% if PROCTOR is dropped sooner than 45 seconds after the U-Boat has dived; thereafter the probability of a hit falls off rapidly, unless Sonobuoys are used to relocate the submarine.

In order to measure the effectiveness of actual attacks on U-Boats, two measures can be used:

(1) the percentage of resulting kills;
(2) the percentage of attacks that gave visual evidence of a PROCTOR explosion. (See Appendix B). Both measures showed good correspondence with the theoretical curve.

4.2. Percentage of Resultant Kills.

The percentage of kills would not be expected to equal the expected percentage of hits, for a certain number of torpedoes will have fuse or control failures. The Key West trials indicated that at least 15% would be failures. Moreover, one would not expect that all PROCTOR explosions would sink the submarine. From Table 1 it is seen that in about one-third of the cases where the U-Boat was affected by the attack it was damaged and not sunk. (It should be noted that in some of these reported damage cases the damage may have been due to the depth bombs used, instead of to PROCTOR.)

Now, the factors just adduced that are responsible for the reduction of the expected hits and sinkings should be independent of the time between U-Boat submergence and PROCTOR drop; hence, while the number of sinkings would naturally be lower than the expected number of hits, it should be <u>proportional</u> to this latter quantity. Consequently it was gratifying to find that the operational results do turn out to be proportional to the expected-hit curve. The factor of proportionality for all plane types for this class of attack is 35%. This is disappointingly small and is hard to reconcile with expectation. It was not until the effect of plane type was investigated that the reason became apparent. (Section 5).

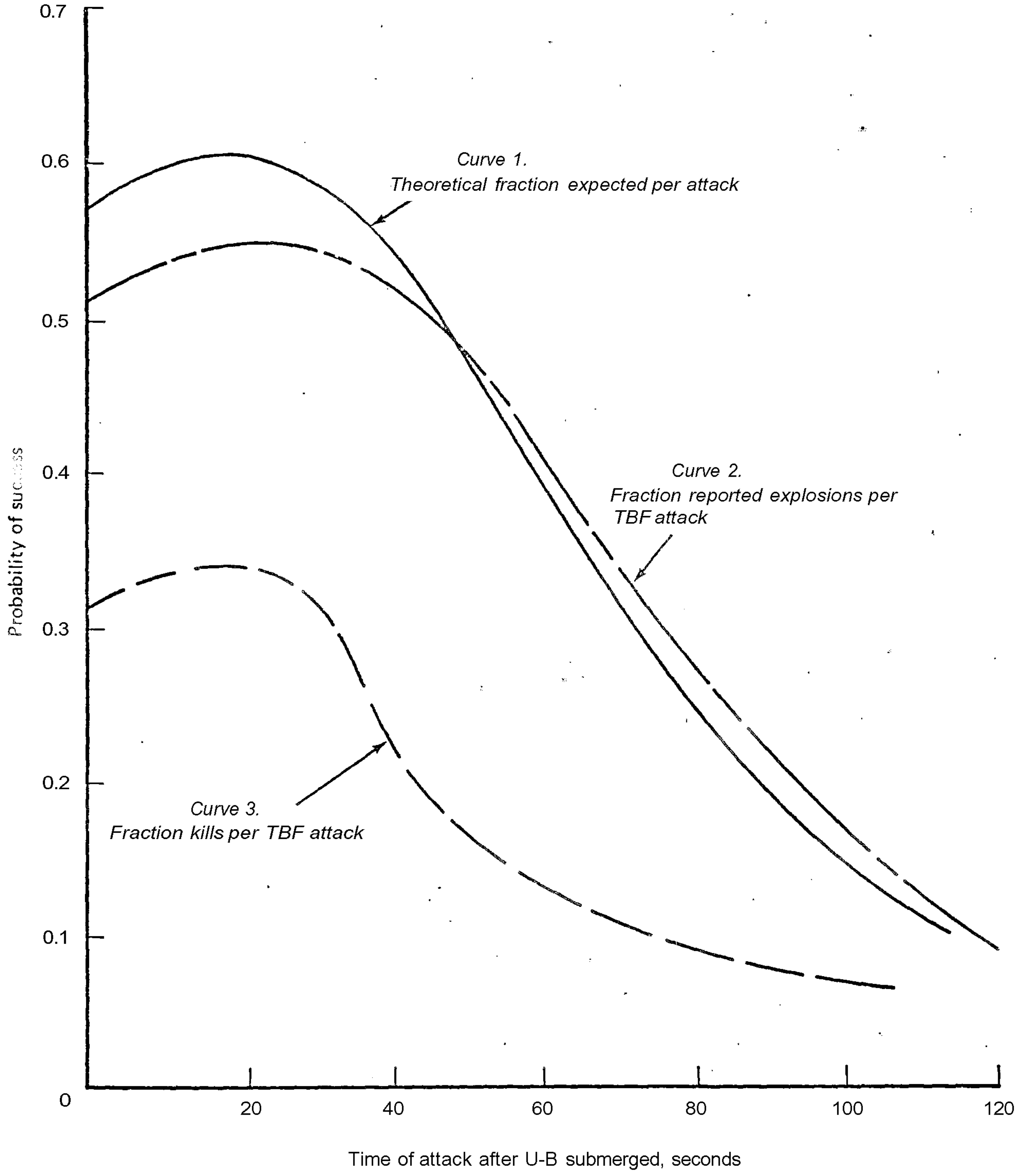

FIG. 1: RESULTS FOR ATTACKS ON U-BOATS CONTACTED VISUALLY

4.3. Percentage of Reported Detonations.

The curve for reported detonations was also found to be proportional to the expected-hit curve, the proportionality factor in this case being about 65%. This again is lower than was expected.

It was found, however, that the ratio between sinkings and reported detonations (about 55%) more nearly corresponded to the expected ratio between hits and sinkings. Evidently some factor was producing an abnormally large percentage of duds, at least in an appreciable number of attacks.

5. EFFECT OF TYPE OF PLANE

The missing factor became apparent as soon as the attacks (on U-boats visually sighted) were separated according to plane type. It appeared that the carrier planes (TBF) gave results within ten percent of the theoretical optimum, as shown by curve 1 of Figure 1. Curve 2 of Figure 1 shows the percent of reported detonations for the TBF attacks; it almost falls on top of the theoretical curve 1: the weighted ratio is 90%. Curve 3 of Figure 1 shows the percent of kills; this is almost 50% of the expected hits. If the cases of severe damage are included with the sinkings, the number of U-Boats sunk or damaged by PROCTOR carried by a TBF was about 75% of the maximum number theoretically attainable for the type of attack under discussion.

This result was gratifying in two ways. In the first place it indicated that in spite of the handicaps of security, the wide distribution of the device had not materially affected its performance in the important case of carrier planes. At the beginning some doubt had been cast on the probable usefulness of the weapon because of the possibility of maintenance troubles. The results indicated that this fear had been unjustified.

The second cause for gratification lay in the realization that PROCTOR was a "natural" for the carrier plane. Initially, these planes had been at some disadvantage in anti-submarine warfare because their size precluded the carrying of *very* heavy radar sets or of a large number of depth bombs. Consequently, this type of aircraft needed, even more than the landbased planes, a weapon which had a high probability of succeeding on the first attack. PROCTOR provided one which had a better-than-50% chance of kill or severe damage per attack.

There remained to determine why the land-based planes gave such poor results. A plot of the data on reported explosions and on kills by PB4Y's showed both these curves to be only about 30% as high as the corresponding curves for the TBF (curves 2 and 3 of Figure 1.) For PBY planes, the data show an intermediate ratio. (See Appendix B for detailed statistics.) These data ruled out the possibility that the comparatively poor performance of land-based planes might be ascribed to bad luck. They made it evident that this type of plane dropped the mine in such a way that more than half the results were duds.

It is not certain that the reasons for this amazing difference are all understood even today, for the fact that this difference existed was not discovered until near the end of the war, when sufficient operational data were made available for thorough analysis. (This may be the one place where the high security regulations had a seriously detrimental effect). Three reasons have been advanced:

(1) The difference in aero-dynamic characteristics of the planes may be responsible.

(2) The larger planes did not place their PROCTORS (nor their depth bombs either) as accurately as did the smaller planes.

(3) The facilities for maintenance of the device could be kept at a higher level on a carrier than at some out-of-the-way land base.

Of these three reasons, the second one is probably the most important. It is discussed in detail in Appendix B.

Whatever may be the reason for the great difference in the performance of the several types of planes in effectiveness with the use of PROCTOR or some simular weapon, it is essential that this difference in performance be investigated and understood before land-based planes are again used for anti-submarine attacks.

6. LATER ATTACKS USING SONOBUOYS

As the escort carriers "closed the gap" in plane coverage of the Atlantic, the U-Boats everywhere became more timid, so that it became more and more difficult to close in on a surfaced submarine. The number of attacks that could be made on a just-submerged submarine decreased greatly, so that most of the incidents were out at the small tail of the curve 1 of Fig. 1. It was obvious that a device was required which would help to relocate the submarine with sufficient accuracy so that the plane could drop PROCTOR within the latter's detection range. The only available device that would fulfill this requirement was the radio sonobuoy.

The results using Sono-buoys were not very satisfactory: it is estimated that about 5% of all sonobuoy attacks resulted in kills. However, even this small percentage was better than the results achieved against timid U-Boats by the use of any other airborne weapon. It must be borne in mind that a large part of the time during which the sonobuoy-PROCTOR combination was used, was spent in learning how to carry out the attack. Thus the actual results do not indicate the full possibilities of the combination.

Nevertheless, the results were poor enough so that, in case a surface anti-submarine vessel was nearby, it was good judgment to turn the attack over to this vessel. This had not been true earlier in the PROCTOR period.

It is well to point out that in many cases combination sonobuoy-PROCTOR attacks took place under circumstances such that no results at all could have been obtained by the use of any other weapon. PROCTOR results, low as they were, were better than no results at all.

Finally, it is possible that improved tactics using improved sonobuoys and improved models of PROCTOR may increase the chance of success with this combination to a reasonable quantity. The extreme importance of such development is immediately obvious; for otherwise the anti-submarine aircraft, particularly the land-based types, will have lost most of their offensive value against the new type of submarine.

The analysis of the data on the use of PROCTOR with sonobuoys is given in Appendix C.

7. PROCTOR AGAINST SCHNORCHELLING U-BOATS.

The use of PROCTOR against the schnorchelling U-Boat brought up the question of the noise output of a submarine running submerged on Diesels as compared with its. noise output on electric drive. As far as audible noise (below 15 kc) is concerned, a Diesel-driven boat has a greater output per knot of speed than when it is running on its electric motors. This is not true of the supersonic sound output in the region of 24 kc, however; the noise of the electric motors has a higher level in this band than the noise from the Diesels. Nevertheless, a schnorchelling U-Boat is still a good acoustic target - perhaps as good as a submarine at periscope depth running on electric motors. Consequently, the probability of sinking a schnorchelling submarine with PROCTOR should be about as given in Table 2.

Table 2.

PROBABILITY OF SINKING SCHNORCHELLING U-BOAT WITH PROCTOR (TBF'S)

Submarine Speed (kts)	Using 1 PROCTOR	Using 2 PROCTORS
2-3	0.32	0.54
4	0.44	0.69
5	0.48	0.73

For PB4Y planes these probabilities should be reduced by one-half.

Very little precise information is available regarding attacks on schnorchelling submarines, most of such attacks having been made by the British and the results being in the form of dispatches; hence it is not easy to determine the validity of these probability estimates. Table 3 summarizes the available data.

Table 3.

ACTUAL ATTACKS ON SCHNORCHELLING U-BOATS

Total attacks made on swirls or schnorchels	10
Submarines assessed probably sunk	3
Per cent	30%

Considering that most of these attacks were made by PB4Y's and Liberators, the agreement between actual and predicted results for the PB4Y plane is as good as can be expected.

It should perhaps be mentioned at this point that the tables given above have nothing to say concerning the difficulty of finding a schnorchelling U-Boat by means of aircraft. Until this problem is solved, the high chance of successful attack is merely a tantalizing possibility.

Submitted by,

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APPENDIX A

SUMMARY OF THE CHARACTERISTICS OF PROCTOR

1. GENERAL CHARACTERISTICS

As stated in Section 2. 1 of the Study, PROCTOR was designed to correspond closely in dimensions to the standard 1000 pound bomb that was in use in early 1942. The chief reason for choosing this size was to make the new weapon readily adaptable to existing bomb-bays with a minimum of effort.

As finally developed, the weapon had the following general characteristics, given in Table A-1.

TABLE A-1

General Characteristics of PROCTOR

Weight in Air	683 pounds
Weight in Water	20 "
Weight of Explosive (Torpex)	95 "
Overall length	83 inches
Diameter (cylindrical section)	19 " (Fins, rudders, elevators extend a few in.)
Speed	12-12-1/2 knots
Life (depends on battery state)*	8-15 minutes (See below).
Ceiling cut-off	30 feet
Cruising depth (shallow)	45 feet
Cruising depth (deep)	125 feet

*To be in good condition, the battery must be fully charged and at a temperature of 50 to 90 degrees F. An internal heating circuit is provided to keep the temperature above 50 degrees F. A typical mine having a battery that has been recharged many times and is in a slightly discharged condition, may operate for only 8-12 minutes. Low battery temperatures have a pronounced effect on running time: at zero degrees F, for example, one can expect a running time of only 3 minutes.

Other miscellaneous characteristics are the following:

Variation of one foot depth gives 0. 75 degrees elevator.
Variation of one degree from horizontal gives 1. 5 degrees elevator.
In water, when running a straight, level course, maximum yaw is 1-1/2 degrees, average.yaw, less than one degree.
Maximum pitch, twenty degrees, average, nine degrees.
Maximum roll forty degrees, average, seventeen degrees.
With 30 foot ceiling will attack target at 15 feet.
Has made attacks against acoustic targets as deep as 370 feet.
Mark 142 fuze arms at 25-30 feet.

Hydrostatic control: 0. 75 degrees of elevator throw results from every foot of displacement from the cruising depth. When above cruising depth the elevator is down; below cruising depth the elevator is up.

Oscillations are damped somewhat by a pendulum potentiometer, which always acts so as to restore the mine to an even keel. A tilt of one degree from the horizontal causes 1. 5 degrees of elevator. If the mine is 30 feet above the cruising depth and diving at an angle of 20 degrees, the depth potentiometer would try to cause a down elevator of 22 degrees, but the pendulum potentiometer would try to give up elevator of 30 degrees; these two effects would counter each other and as a result the mine would actually have 8 degrees up elevator.

Hydrostatic steering shows a 10-foot double amplitude variation from course, with an average pitch angle of less than 10 degrees. The actuation of the gate relay, giving sonic control for vertical steering, (see Section 4. 3 below) shunts out the depth potentiometer. The mine can dive vertically under sonic control and will show double amplitudes of 50 feet or more.

(A discussion of the aerodynamic stability of a projectile released from an A/C will be found in "Completion Report on No-94 (Fido)", OSRD, Section No. 6. 1-sr 287-2078, 1 Jan. 1946, H U S L. Ch. IX, p. 90.)

2. CONSTRUCTION OF PROCTOR

PROCTOR consists of three sections, held together by bolts and nuts; the seal is an ordinary rubber gasket. The three sections are:

(1) The warhead: nearly hemispherical in shape, containing an impact fuze in the nose, the detonator, the booster, and the explosive.

(2) The Main Body: this is the cylindrical section. It contains the acoustic and electric equipment: the hydrophones, electronic switch, A. C. Amplifier, detector, D. C. amplifier; the circuits leading to the after-body; the dry-cell power pack for the electronic system; the main power supply (a 48-volt acid battery); the systems for heating and charging the battery; the hydrogen venting system; and the pre-start switch.

(3) The After-Body: generally tapering, but with protruding fins. It contains the pressure start switch, the ceiling switch, the hydrostatic depth control, the pendulum control, the steering motors, steering yoke and rods; the rudders, elevators, fins, main motor relay, main motor, spline coupling, propellor shaft, bearing-packing gland, and propellor.

3. THE DESCENT OF THE MINE

3. 1 Before Water Entry.

In the bomb bay the mine is held by a sling or by two harness bands. Two wires are fastened to the bomb bay; one passes through the fuze, providing a safety lock, and the other is fastened to the arming fork. The arming fork serves a two-fold purpose: (1) it holds open the hydrogen vent, permitting a flow of hydrogen from the acid battery cells to the outside; (2) it holds back the spring that is to close the pre-start arming switch.

As the mine falls away after release, the fuze safety wire and the arming fork are pulled out. Following the removal of the arming fork, the hydrogen vent snaps shut and in the same operation closes the pre-start arming switch. This latter switch applies double voltage to the filaments of the electron tubes as well as potentials to the grids and plates, and arms the main motor relay circuit. A wooden block on the stabilizer (which is shattered by the impact on the water) locks the propellor so that the motor is not caused to rotate during the air drop. The fall takes 3-1/2 to 4-1/2 seconds.

3. 2 After Water Entry.

On striking the water, the stabilizer and spoiler ring fall off. The behavior of the mine after it enters the water has been described to some extent in section 2. 1 of the Study. At a depth of 15-20 feet the fuze is hydrostatically armed. At about this same depth the hydrostatic starting switch closes, completing the main motor relay circuit, thus putting power on both the main motor and steering motors; this also removes the double voltage from the filaments.

At a depth of 30 feet the ceiling switch is operated. During the interval in passing from the 15 ft to the 30 foot depth the following events occur: The closing of the hydrostatic starting switch at 15 feet starts the electron tubes warming up — this should take from 0 to 3 seconds. The grids on the vertical control tubes, however, are biassed to cut off until the ceiling switch is operated at 30 feet. This grid bias insures up elevator during this period. The rudder will go hard port and remain there until the tubes are warmed up. The momentum of the falling mine will carry it through the 30-foot ceiling level in spite of the up elevator.

During this period several possibilities of control exist. The actual control assumed during this period is not important, because of its short duration (1 to 3 seconds); the possibilities are enumerated only in order to present a clear picture of the mine's operation.

(1) Tubes not warmed up when start switch is operated. In this case there will be hard port rudder and hard up-elevator until the tubes are warmed up; or the hydrostatic control will predominate.

(2) Tubes warmed up when start switch is operated: The rudders will have sonic control, and, since the noise of the splash will dominate during the first few seconds, the rudder response will be unpredictable. There will be up-elevator until the 30-foot level is reached. Then either hydrostatic or sonic control is possible.

(3) If the transient condition prevailing during the first ten seconds has died away and there is no signal, there are two possibilities: (a) the mine will attempt to go off in a straight line in an arbitrary direction, but due to minute disturbances will swing either to port or starboard. Turning in a circle increases the self-noise on the inboard side by about 3 db; this is usually, but not always, sufficient to cause the mine to circle in this direction. The radius of the circle is 30 feet. (b) The hydrostatic depth control will cause the mine to have down elevator, gradually leveling off at cruising depth, either at 45 feet or at 125 feet, depending on which of two settings is used.

4. ACOUSTIC CHARACTERISTICS

4. 1 General

<u>Frequency:</u> Maximum response of the hydrophones is to sound of 24. 5 ± 1 kc.

<u>Pass-band width:</u> 1. 2 kc.

<u>Directivity:</u> the hydrophones will respond to a point source on their acoustic axes that is 11 decibels below the background noise as measured with a non-directional hydrophone.

<u>Hydrophone Response:</u> In decibels relative to the response at right angles to the course of the mine.

Angle from Mine Axis (plus or minus)	Relative db
0 degrees	-19 db.
30	-10
60	- 3
80-100	0
120	- 3
150	-10
180	-19

4. 2 Acoustic Control — Horizontal

There are three sources of sound that must be considered as affecting the torpedo: (1) the ambient noise, (2) the self-noise of the torpedo, (3) the signal.
Note: All sound levels are referred to a pressure of 1 *dyne/cm*^{2}.

<u>At the 45-foot depth.</u>

Ambient noise: The acoustic device in the mine is set so that ambient noise does not affect its control if its sound level, in the band at 24 kc, is less than -51 db. This is from 2 to 8 decibels higher than the average level of the self-noise of the mine.

Self-noise: average level *is* -56 ±3db. Twenty to thirty seconds are required, after the mine strikes the water, for its self-noise to drop to this value. It is 8 to 10 db higher than this 3 seconds after water entry.

Signal level: the AVC is set so that a signal of level -56 ± 3 db will assume control.

<u>At the 125-foot depth.</u>

Ambient noise of level less than -57 db will not affect the mine.

Self-noise at the hydrophones is -58. 5 ±3 db.

Signal-level: the AVC is set so that a signal of level -61 ±3 db will assume control.

<u>Steering Response:</u> The mine will respond to about 0. 4 db differential in the horizontal control. This differential gives a rudder angle of 1. 5 degrees and a radius of 300 feet. This is the limiting control and is unstable. Positive control is given by a one db differential, resulting in a 5 degree rudder throw and a 100 foot radius of curvature. In Table A-2 are given the rudder angle and radius of curvature as functions of the differential in sound level.

TABLE A-2

Difference in db	Rudder Angle	Radius of Circle
1	5 degrees	100 feet
2	10	48 "
4.5	22 "	30 "

Table A-3 gives the differential required to overcome circling.

TABLE A-3

Differential Required to Overcome Circling.

Radius of Curvature	Differential in Sound Level
30 feet	3 - 6db
50 feet	3db
75 feet	2db

The circuits are balanced to ± 1 db. An unbalance of 3 db does not cause more than a 10-foot displacement at the target.

4. 3 Acoustic Control -- Vertical

Acoustic control of vertical steering does not occur until the signal has attained the relatively high level of -47 ± 3 db; it then operates a gate relay which permits acoustic control. This level is 9 db higher than the one that controls horizontal steering at the 45-foot depth, and 14 db higher than the one at the 125-foot depth. The reason for the high level is to prevent violent changes in depth at extreme ranges, where the signal will have a relatively low level.

Up to the time the vertical gate relay is actuated, the vertical control of the mine is hydrostatic, even though it is already under acoustic control in the horizontal plane.

4. 4 Behavior of the Mine under Acoustic Control

Since the hydrophones have maximum sensitivity in a direction at right angles to the direction of the mine, the target at extreme range will first be heard when the mine is on a course at right angles to the line joining it with the target. The first impact of the signal causes a rudder throw towards the target; as soon as the mine has turned only a few degrees, the signal is lost. At this point, there are three possible courses that the mine may take: It may

(1) turn away, in which case the signal will again be heard;
(2) continue in a more-or-less straight course; in this case it will eventually again hear the signal;
(3) continue to turn until it has traversed an arc of 180 degrees, whereupon it will again hear the signal, this time on the opposite hydrophone to the original one. It will now turn in the opposite direction. This is the most likely procedure.

At extreme ranges the rudder throw is small; therefore, in the process of turning through 180 degrees the mine will advance from 200 to 400 feet nearer the target, thus placing the mine in a more intense field. As the signal intensity increases the mine will tend rapidly to straighten out and follow a straight course, ultimately with an average yaw of only one degree.

Actually the response to the target signal at extreme range is usually more positive than is indicated by the above, as the mine will probably not be moving in a straight course, but will rather be circling (in a circle of radius 50-100 feet), when it first hears the target. The effect of this circling is to provide a bias of one to three decibels (due to higher self-noise on the inside hydrophone); and this bias the target signal must overcome. Once this has been done and the mine has been pulled out of the circle, a differential of one to three decibels will be acting on the mine. The reason for the high level for vertical gate action is now apparent, since the 50 to 150 foot vertical oscillations at extreme range would greatly impair the performance of the mine.

5. RANGE OF ACTION

Table A-4 gives the ranges at which PROCTOR was activated by a U.S. submarine, at various depths and speeds. The data were obtained at the tests carried out at Key West.

TABLE A-4

Range of Action of Proctor at Various Speeds and Depths

Depth	Speed kts	Horizontal Range, Yards			Vertical Range, Yards		
		Average	Minimum	Maximum	Average	Minimum	Maximum
Periscope	3	120	21	790	55	20	300
	4	420	55	1800	160	30	900
	5	930	180	2600	400	75	1400
	6	1350	400	3100	620	150	1750
	7	1600	550	3400	800	215	2000
	8	1750	620	3600	870	250	2150
150 feet	3	120	22	790	55	20	320
	4	150	25	850	65	20	360
	5	245	35	1200	100	22	560
	6	500	70	1900	200	35	970
	7	860	170	2500	360	70	1350
	8	1200	320	2900	540	120	1600
250 feet	3	120	20	790	55	20	315
	4	130	25	800	60	20	320
	5	160	30	930	65	20	400
	6	230	35	1200	95	22	540
	7	390	55	1700	145	30	820
	8	650	95	2200	260	45	1150

APPENDIX B

ANALYSIS OF OPERATIONAL RESULTS

As indicated in Section 4.1 of this Study, the general method used to determine the effect of various factors in the attacks on submarines is to compare the actual results in reported incidents with the results that could be expected from knowledge gained by experimental tests and information from prisoners of war.

The attacks on U-Boats were classified according to whether the submarine was sighted visually or by use of sonobuoys. In Appendix B only the visual sightings are considered; the sonobuoy cases will be discussed in Appendix C.

1. METHOD OF ANALYSIS

In calculating the probability that in a given incident a hit could be expected, the following assumptions were made.

1.1 Assumptions Concerning the Performance of PROCTOR:

The performance of the mine was assumed to be determined by the results of the trials the data of which are shown in Table A-4 of Appendix A. For each attack reported, the position, relative to the submarine, of the mine, at the instant it hit the water, was calculated. (The mine was dropped near the swirl.) The relative positions of PROCTOR and the U-Boat gave the distance between the two, along the surface and in depth; and by interpolating in Table A-4, the chance of a hit could be calculated.

1.2 Assumptions Concerning the Submarine.

The position of the submarine was determined by assuming that
(a) it had submerged at the rate of two feet per second;
(b) it had advanced at the rate of six knots after submergence;
(c) it was equally likely to have gone hard to port, hard to starboard, or straight ahead.

1. 3 Assumptions Regarding the Effectiveness of PROCTOR.

In order to compare the expected results with those actually achieved, it was necessary to make a more-or-less arbitrary estimate of PROCTOR effectiveness, since in many cases the mine was dropped along with depth charges. It was assumed that PROCTOR was the effective agent in any incident in which it was used, provided there was sufficient evidence of its detonation. The bases of this assumption are the following:

Of 84 incidents in which PROCTOR was used, 47 were assessed as resulting in sinking or serious damage.

(a) Of these 47, 32 were ascribed to PROCTOR; in 29, or 90%, there was evidence of detonation of the mine.

(b) Of the 15 accredited to other weapons, only 2, or 13%, showed evidence of PROCTOR detonation.

(c) Of the 37 that were assessed not damaged, only 5, or 13%, showed evidence of PROCTOR detonation.

The incidents in which the evidence was not sufficient to make an assessment showed about the same percentage (35%) of PROCTOR detonations as the incidents in which the evidence sufficed to warrant an assessment (43%).

Evidence of detonation was obtained as the result of analysis of reports of water domes, shock waves, PROCTOR dye slick, debris and oil slicks.

The reliability of this assumption is further confirmed by the remarkable consistency between assessments and reported detonations when the incidents are classified according to the type of plane making the attack, as will be seen below.

2. COMPARISON BY TYPE OF PLANE.

2.1 Comparison by Ratios of Reported Detonations to Expected Hits.

The discussion of the effect of type of plane on PROCTOR performance in Section 5 of the Study is based on an analysis of 85 incidents in which Proctor was dropped, using visual sighting only. The incidents were sorted according to plane type. The number of hits to be expected was calculated and compared with the number of reported detonations. The results are summarized in Table B-1.

Table B-1

Ratio of Reported Detonations to Expected Hits by Type of Plane

Type of Plane	(1) Number of Incidents	(2) Expected Hits	(3) Reported Detonations	(4) (3)/(2)
PB4Y (a)	39	23.0	7	.30
PBY-5a	9	7.5	6	.80
Other Land-Based	8	5.2	0	0
TBF	38	31.7	28	.88
Totals.	85	67.4	41	.61

(a) Includes British Liberators and Army B-24's.

In calculating the number of hits to be expected, differences due to target opportunity and Proctor placement errors were taken into account. Columns (1) and (2) show that the ratio of expected hits to number of incidents is smallest for land-based planes, being 77% for PB4Y and 65% for others, and highest for TBF, 84%.

The striking feature of the analysis is, of course, the low ratio of reported detonations to expected hits of the PB4Y class of planes compared to the PBY-5A's and the TBF's.

2.2 Comparison by Assessed Damage per Incident

Numerical Presentation of Assessed Damage.

The comparison of the ratios of detonations to expected hits does not tell the whole story. It is necessary also to compare the actual results of the incidents, as given by assessments, with the number of reported detonations.

The problem of presenting the assessed damage numerically was handled by allotting weights to the assessments, the weights being determined by comparison of assessments with actual results discovered subsequently. The probabilities that the various assessments correspond to sinkings are as follows:

Assessment	Weight
A (Known sunk)	1.00
B (Probably sunk)	.80
C (Probably seriously damaged)	.50
D (Probably damaged)	.30
E (Probably slightly damaged)	.05
All others	0

Results by this Method.

Table B-2 summarizes the analysis by this method. Column (3) shows that the average probability of a kill in the case of the PB4Y is only about one-third that of the TBF. Referring to Table B-1 it is seen that this is about the same as the comparative effectiveness measured by the ratio of reported detonations to expected hits. This indicates that any differences in performance due to target opportunities and placement errors are small, since these were taken into account in arriving at the expected hits in Table B-1. It eliminates the possibility that the poor showing of the PB4Y's was due to these factors. The percentage of detonating Proctors that resulted in sinkings should be the same for all types of planes. This is seen to be the case by the ratios of weighted assessments to reported detonations, shown in column 5 of Table B-2. The average of these ratios is 50%, and the three items are seen not to vary much from this figure. This fraction is rather low. The remaining 50% presumably resulted in damage of some form, for it is a fact that assessments in general tend to be pessimistic. On the other hand, reports of detonations tend to be on the optimistic side. It was mentioned in Section 1 of Appendix B that incidents that were assessed as showing insufficient evidence of damage have a distribution in "damage" and "no damage" which is similar to all the other cases where an assessment was made. Consequently, it is probable that the 10 cases of reported detonations involved in these "F" assessments resulted in about five kills. Assuming this, the ratio of kills to detonations would come out to be 60% instead of 50%; and it is believed that 60% is the more reasonable value.

Table B-2

COMPARISON BY ASSESSED DAMAGE PER INCIDENT

Type of Plane	(1) Number of Incidents	(2) Total Weighted Assessment	(3) Average Assessment	(4) Total Reported Detonation	(5) Ratio of Weighted Assessments To Reported Detonations
PB4Y	30	3.65	.12	7	.52
PBY-5A	9	2.65	.29	6	.44
Other land-based planes	8	0	0	0	---
TBF	38	14.35	.38	28	.51
Totals.	85	20.64	.24	41	.50

2.3 Discussion of Results.

The difference between the PB4Y and TBF performances is an important and significant difference. In attempting to determine the factor or factors responsible for it, the following factors suggest themselves:

(a) Time interval between submergence of the submarine and dropping the mine;
(b) speed and altitude of the attacking plane;
(c) calendar period;
(d) comparative size and maneuverability of the aircraft.
(e) comparative placement errors.
(f) the manner in which the plane launches the mine.

With regard to (a) to (d) inclusive, the statistical analysis showed that none of these could be held accountable for the difference in performance.

Placement errors:

It was stated above that the effect of errors in placing the mine was small; this statement was based on an analysis the results of which are tabulated in Table B-3. They showed that this factor also did not explain the difference in performance of the planes.

The measurements in Table B-3 are made from the swirl. Range errors are measured (in feet) from the swirl along the submarine course, positive if ahead, and negative if behind it. Deflection errors are measured at right angles to the submarine's course, positive to starboard and negative to port. The aiming point is based on doctrine which assumes a submerged speed of advance of seven feet per second.

(It is interesting to compare these data with those of depth bomb attacks on surfaced submarines. From a study of the latter, ORS/CC 270, it appears that the error of MPI about the aiming point, and the dispersion, are in general, greater in the case of Proctor attack. The results in the depth bomb attacks are those achieved with seamen's eye aiming. When taking into consideration the higher average altitude of Proctor attacks, the comparison is believed to be favorable to the acoustic mine.)

The Real Reason for the Difference in Performance of Plane Types.

The conclusion is inevitable that there was something wrong with the manner of launching the mine from the land-based planes. It is true that the reports of Proctor failures as given in the ASW-6 action reports cannot be considered as even approximately complete, since it is not possible, as a rule, to know whether the mine failed or not. However, reported instances of porpoising, releasing the mine with depth bombs, or releasing it too soon after depth bomb explosions, arming failures, etc., were tabulated, and showed that the percentage of failures was about 2-1/2 times as great for the PB4Y's as for the TBF's.

<u>Table B-3</u>

PROCTOR PLACEMENT ERRORS (IN FEET)

	Time after Submergence (Seconds)	Number of Incidents	Average Aiming Point	Mean Point of Impact	Errors of MPI about Aiming Point: Range	Errors of MPI about Aiming Point: Deflection
			A	I	R	D
TBF						
PBY-5A	1-30	28	106	79	-27	29
	31-60	14	307	275	-32	40
	61-90	13	530	496	-34	57
	91-120	3	840	833	- 7	67
		58			-29	39
PB4Y	1-30	19	86	141	55	140
PBM	31-60	14	347	176	-17.1	10
PV	61-90	16	559	293	-266	-20
	91-120	3	728	300	-428	12
	121-135	1	847	250	-597	250
		53			-141	47
All Planes Combined -- AVERAGE			317	234	-83	43

Excerpt from Reference (b), OEG Study 289

A Distance from swirl based on 7 feet-per-second rule
I Distance from swirl
R Measured along submarine's estimated course
D Measured perpendicular to submarine's estimated course

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Standard Deviation	
Range	Deflection
R	D
319	123
220	79
312	120
573	149
326	110
182	260
183	128
377	62
297	237
263	177
294	132

At about the time this analysis was made, ASDevLant had initiated some tests to determine the aerodynamic stability of Proctors launched from planes. Tests with PB4Y planes indicated that there were many interferences in the bomb bay and in the release from the bomb bay, which would lead to poor flight characteristics and consequent damage to the mine upon striking the water. Near the end of 1944 further tests were conducted, as a result of which a new and stronger stabilizer, nose spoiler ring, and an improved release mechanism were designed. Tests of models of these new devices indicated that they would do much to improve the operational experience of the PB4Y; however, there was little operational opportunity thereafter to test these devices.

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APPENDIX C

ANALYSIS OF ATTACKS BASED ON SONO-BUOY INDICATIONS

1. OPERATIONAL RESULTS.

No incidents in which Proctors were dropped on the basis of Sonobuoy indications have been assessed as kills, but, as stated in Section 6 of the Study, it is estimated that about 5% of all Sonobuoy attacks had that result.

A total of 97 attacks with the Proctor-Sonobuoy combination were analysed. Of these, 27 were assessed "H" and "I" -- "insufficient evidence of the presence of a submarine" and "target attacked not a submarine". The remaining 70 incidents were assessed "D" (probably damaged, sufficiently seriously to force the submarine back to its base). "F" (insufficient evidence of damage), and "G" (no damage).- The results of the analysis are summarized in Table C-l; a discussion of the results will follow in the next section.

Table C-l

PROCTOR-SONOBUOY ATTACKS, BY ASSESSMENT

Assessment	No. of Runs	Reported Explosive Hits	Expected Kills	Estimated Actual Kills
D	1	1	.4	.3
F	16	2	1.8	1.2
G	53	1	2.3	0
	70	4	4.5	1.5

2. DISCUSSION OF THE RESULTS

2.1. Assessment.

In order to evaluate the performance of the Proctor-Sonobuoy Combination, it was necessary to assign some value to the "F" assessments. In some of these cases there is. little convincing evidence of the actual results of the attack; visual evidence in the form of debris or oil cannot be expected if the submarine was hit in certain parts at great depth. Some cases had Sonobuoy information of possible damage.

For the purpose of this analysis it was decided that 60% of the F assessments were kills. The reasons for this assumption are the following: An analysis of attacks on submarines submerged less than 120 seconds indicates that the "F" assessments are very similar in composition to all the attacks assessed on the basis of sufficient evidence, from the standpoint of the ratio of damaging attacks to the number of reported detonations (see Section 1. 3 of Appendix B). On the basis of weighted assessments (see Section 2.2 of Appendix B and also Table B-2), about 60% of the reported detonations resulted in kills.

2.2. Reported Explosive Hits. .

It will have been noticed that the term "Reported Detonations" used in section 1.3 of Appendix B has been replaced by "Reported Explosive Hits" in Table C-1. The reason for this is that in the Sono-buoy cases the reported detonations had to be culled. Only these explosions were accepted which were definitely loud and lasted at least thirty seconds, and which were heard less than five minutes after the Proctor was dropped. The first requirement was based on the frequent necessity of depending on Sonobuoy information for information as to a detonation; reports of explosions are characteristically optimistic, and listening to a Sonobuoy is not easy, especially in the stress of battle. The second requirement was made to eliminate the explosions resulting from water-pressure actuation; the five-minute limit was adopted as a result of an analysis of the reported detonations in all attacks that were assessed as having resulted in damage.

These considerations led to the conclusion that of forty-one explosions reported as being heard over Sono-buoys and possibly caused by Proctor, only twelve, or 29%, were actually due to Proctors exploding against the target.

2.3. Expected Kills

The number of expected kills was derived as a result of the following considerations:

Cavitation:

On the basis of the results of the Key West trials, one can assume that there is nearly a 100% chance that the Proctor will be activated by a cavitating submarine and will home into it. Previous experience indicates that about 36% of the expected hits kill the submarine, the reduction being due to damage to the Proctor in dropping, or to fuze failures, or both; or to failures to kill even when the mine detonates against the submarine. One would assume, then, that about 36% of the Proctors dropped near a Sonobuoy giving indication of a cavitating submarine might be expected to sink it. The actual results came to only about one-third of this value.

2.4. Estimated Actual Kills.

The reasons for this low value are found chiefly in the unreliability of the reports claiming cavitation sounds being heard. It is estimated that only 14% of the attack runs were actually based on cavitation sounds. The considerations leading to this estimate are that the enemy tactics of diving to 250-300 feet and slowing down to two or three knots precludes the possibility of hearing cavitation, and that even when it does occur, it is very difficult to recognize by sonobuoy listening, due to the mass of confusing background noise. Table C-2 will illustrate this paragraph.

Table C-2

CAVITATION SPEEDS AND PROCTOR RANGES '

Keel Depth	Speed at which Cavitation Starts	Average Proctor Range
60 feet	4 knots	420 yards
150	5	245
250	6	230

As a result of these considerations, it is estimated that of the runs where cavitation was definitely believed to be heard, kills resulted in 15% of the cases; whereas in the case of runs where cavitation was not considered likely to have actually heard, no success could be expected.

A second reason for the low value of estimated actual kills is found in the fact that when a single Sonobuoy in a calm sea gives an indication of the presence of a submarine (whether cavitating or not), the average probable submarine area indicated by the sono-buoy is about one hundred times the average area over which Proctor can listen. The size of this sono-buoy area can be narrowed down to some extent by sonobuoy tracking; but the absolute probability of the Proctor being able to listen even in this case is small.

3. RESULTS BY TYPE OF AIRCRAFT.

The attack runs are divided between carrier based planes and land-based ones; the latter are mostly FAW-7 Dunkeswell. The results are shown in Table C-3.

Table C-3

PROCTOR RUNS BY TYPE OF AIRCRAFT

Type of Plane	No. of Runs	Reported Explosive Hits	Expected Kills	Estimated Kills	Ratio of Estimated to Expected Kills
Carrier-based	50	1	2.7	.3	.11
Land-based	20	3	1.7	1.2	.70
	70	4	4.4	1.5	.34

It would appear from this that land-based planes were more successful in the Proctor-Sonobuoy combination than carrier-based ones, thus reversing the case when Sono-buoys were not used. However, the number of explosive hits is too small to permit any valid statistical evaluation.