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DECLASSIFIED

STRIKING POWER OF AIR-BORNE WEAPONS

Based On Bureau of Ships Study "Vulnerability of U.S. Naval Vessels To Attack by Air-borne Weapons"

AIR INTELLIGENCE GROUP
DIVISION OF NAVAL INTELLIGENCE
OFFICE OF THE CHIEF OF
NAVAL OPERATIONS, NAVY
DEPARTMENT, WASHINGTON, D.C.

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INTRODUCTION

1. Confidential pamphlet "Selection of Bombs and Fuses to be used Against Various Targets", OpNav-16-V #A-6 issued 6 March 1944, contained provisional recommendations on bomb and fuse combinations by the Commander in Chief, United States Fleet, which were to serve as a guide until more complete information became available.

2. Upon request of the Chief of Naval Operations the Bureau of Ships made a study of the best possible quantitative estimates of the probabilities of sinking various types of naval vessels when hit by various types of airborne weapons. The results of this study were embodied in Bureau of Ships Secret letter dated 12 May 1944, on "Vulnerability of U.S. Naval Vessels to Attack by Air-borne Weapons."

3. Since the Bureau of Ships study constitutes an important contribution to the selection of bombs to be used against enemy surface vessels, it is published herewith, in full and in summary form. This study also constitutes a guide to the most effective distribution of forces against enemy ship targets.

20 June 1944

VULNERABILITY OF U.S. NAVAL VESSELS TO ATTACK BY AIR-BORNE WEAPONS

Ref: (a) OpNav-16-V #A5, March 6, 1944 - "Selection of Bombs and Fuses to be Used Against Various Targets".

Enclosure: (A) BuShips Secret ltr. S-FS/S29(424), Serial 08733, 12 May 1944 - "Vulnerability of U.S. Naval Vessels to Attack by Air-borne Weapons".

1. Tables I-VIII give the probability of sinking various categories of naval vessels with given numbers of hits with bombs and torpedoes. Immediately following each table an evaluation of near-miss effect is given. The arguments leading to the values given in these tables are set forth in enclosure (A). The tables are collected here for ready reference, and of necessity certain qualifications have been omitted. A full study of enclosure (A) is recommended to users of these tables.

2. Air-borne attacks on enemy naval vessels depend for their effectiveness upon the accurate use of an adequate number of properly selected, correctly fused weapons. Decisions concerning the choice and fusing of these weapons can be intelligently made only if there exists a wide understanding of the damage to be expected from such attacks upon various types of naval vessels.

3. Enclosure (A) is a study of this nature based upon the structure of U.S. naval vessels and the known damage to U.S. vessels from enemy attacks in the present war. It is believed that this information will be of assistance in predicting damage to Japanese vessels from our own weapons.

4. In analyzing damage to major combatant vessels it should be recognized that not enough cases exist, and are not likely to exist, to permit drawing general conclusions concerning vulnerability from statistics alone. A large number of cases would be required for each class alone to eliminate the effects of such variables as size of target, type of construction, degree of sub-division, system of protection of vitals, size of explosive charge, fore and aft location of hit, depth of hit, type of fuse, and height of release (in case of bombs). Accordingly, the discussion of enclosure (A) and the attached tables (Tables I-VIII) do not purport to be a statistical analysis. Rather, the figures for probability of sinking are based on design characteristics of each class and the damage each is intended to resist, plus war experience which serves to indicate the performance of the design when subjected to actual attack. Summarizing, the tables contain estimates which represent the judgment of the Bureau of Ships, based on design characteristics of U.S. vessels, correlated with performance in battle. The figures must be recognized as being subject to possible errors of appreciable magnitude because of the nature of the problem, the number of variable involved, and the relatively small number of cases available for study.

5. Particular attention should be paid to the distances listed under Near-Miss Effect. As pointed out in enclosure (A) the figures given are estimates and are not supported by much general data. They are, nevertheless, the best figures available and serve to emphasize that effective near misses must be close to the hull and must detonate well below the surface.

6. It is emphasized that the maximum effectiveness of bombs against surface targets can only be obtained when they are fused to penetrate. The fuse settings which should be employed to obtain optimum penetration against each class of target are fully discussed in reference (a), now undergoing revision. The revised issue will be distributed in the near future. Users of enclosure (A), therefore, should bear in mind that the vulnerability figures for bombs given in the following tables are based on the assumption that bombs are fused for optimum penetration.

TABLE I DESTROYERS, 1500 to 1630 TONS

Weapon	Assumed Charge Weight	Probability of sinking for No. of hits 1	2	3	4
Torpedo	660# TNT	0.75	0.98	0.99	0.99
250# G.P.	125# TNT	0.09	0.18	0.60	0.99
500# G.P.	250# TNT	0.09	0.65	0.99	0.99
1000# G.P.	500# TNT	0.70	0.98	0.99	0.99

NEAR MISS EFFECT

Weapon	Max. Distance from hull	No. required to sink
250# G.P.	18 feet and below surface	6 or 7
500# G.P.	18 feet " " "	4
1000# G.P.	18 feet " " "	2
All G.P.	6 feet " " "	Same as direct hits

TABLE II DESTROYERS, 1850 to 2100 TONS

Weapon	Assumed Charge Weight	Probability of sinking for No. of hits 1	2	3	4
Torpedo	660# TNT	0.31	0.90	0.98	0.99
250# G.P.	125# TNT	0.06	0.12	0.25	0.99
500# G.P.	250# TNT	0.06	0.30	0.70	0.99
1000# G.P.	500# TNT	0.30	0.80	0.98	0.99

NEAR MISS EFFECT

Weapon	Max. Distance from hull	No. required to sink
250# G.P.	18 feet and below surface	7 or 8
500# G.P.	18 feet " " "	5
1000# G.P.	18 feet " " "	3
All G.P.	6 feet " " "	Same as direct hits

TABLE III LIGHT CRUISERS, 6000 and 7050 TONS

Weapon	Assumed Charge Weight	Probability of sinking for No. of hits 1	2	3	4
Torpedo	660# TNT	0.05	0.85	0.95	0.99
1000# S.A.P.	250# TNT	0.12	0.24	0.75	0.99
1000# G.P.	500# TNT	0.12	0.70	0.95	0.99
2000# G.P.	1000# TNT	0.50	0.95	0.99	0.99

NEAR MISS EFFECT

Weapon	Max. Distance from hull	No. required to sink
1000# S.A.P.	6 feet, and well below surface or under turn of bilge giving mining effect.	4 or 5; otherwise will not sink
1000# G.P.	6 feet, well below surface	3 or 4
2000# G.P.	9 feet, well below surface	2 or 3

TABLE IV — HEAVY CRUISERS, 10,000 TONS AND LARGER, INCLUDING CAs and CLs

Weapon	Assumed Charge Weight	Probability of sinking for No. of hits: 1	2	3	4
Torpedo	660# TNT	0.03	0.40	0.85	0.98
1000# S.A.P.	250# TNT	0.12	0.23	0.40	0.75
1000# G.P.	500# TNT	0.03	0.15	0.30	0.45
2000# G.P.	1000# TNT	0.15	0.45	0.80	0.98

NEAR MISS EFFECT

Weapon	Max. Distance from hull	No.required to sink
1000# S.A.P.	6 feet and well below surface, or under turn of bilge giving mining effect.	6 or 7; otherwise will not sink
1000# G.P.	6 feet, well below surface	Same as direct hits
2000# G.P.	9 feet, well below surface	Same as direct hits

TABLE V — AIRCRAFT CARRIERS (CVs less RANGER)

Weapon	Assumed Charge Weight	Probability of sinking for No. of hits: 1	2	3	4	5	6
Torpedo	660# TNT	0.06	0.12	0.50	0.90	0.95	0.99
1000# A.P.	125# TNT	0.23	0.41	0.55	0.70	0.90	0.99
1000# G.P.	500# TNT	0.03	0.10	0.20	0.30	0.50	0.80
2000# G.P.	1000# TNT	0.10	0.30	0.80	0.90	0.96	0.99

NEAR MISS EFFECT

Weapon	Max. Distance from hull	No.required to sink
1000# A.P.	2 feet and well below surface, just below turn of the bilge	"very large number"
1000# G.P.	6 feet, well below surface	6 or 7
2000# G.P.	6 feet, well below surface	5 or 6

TABLE VI — AIRCRAFT CARRIERS, LIGHT (CVLs plus RANGER)

Weapon	Assumed Charge Weight	Probability of sinking for No. of hits: 1	2	3	4
Torpedo	660# TNT	0.11	0.48	0.93	0.99
1000# S.A.P.	250# TNT	0.18	0.33	0.45	0.80
1000# G.P.	500# TNT	0.05	0.20	0.35	0.50
2000# G.P.	1000# TNT	0.20	0.50	0.90	0.99

NEAR MISS EFFECT

Weapon	Max. Distance from hull	No.required to sink
1000# S.A.P.	6 feet and well below surface	7 or 8
1000# G.P.	6 feet " " " "	6
2000# G.P.	9 feet " " " "	5

TABLE VII AIRCRAFT CARRIERS, ESCORT (CVEs)

(a) Merchant ship design plus those converted from C-3 hulls.

Weapon	Assumed Charge Weight	Probability of sinking for No. of hits 1	2	3	4
Torpedo	660# TNT	0.12	0.90	0.99	0.99
500# G.P.	250# TNT	0.27	0.47	0.99	0.99
1000# G.P.	500# TNT	0.27	0.90	0.99	0.99

NEAR MISS EFFECT

Weapon	Max. Distance from hull	No. required to sink
500# G.P.	6 feet and well below surface	3 or 4
1000# G.P.	9 feet and well below surface	3

(b) Tanker design or converted from tankers.

Weapon	Assumed Charge Weight	Probability of sinking for No. of hits 1	2	3	4
Torpedo	660# TNT	0.05	0.85	0.98	0.99
500# G.P.	250# TNT	0.27	0.47	0.98	0.99
1000# G.P.	500# TNT	0.27	0.85	0.98	0.99

NEAR MISS EFFECT

Weapon	Max. Distance from hull	No. required to sink
500# G.P.	6 feet and well below surface	5
1000# G.P.	6 feet and well below surface	4

TABLE VIII BATTLESHIPS

Weapon	Assumed Charge Weight	Probability of sinking for No. of hits 1	2	3	4	5	6
	Class (a)	Older Battleships					
Torpedo	660# TNT	0.01	0.05	0.40	0.90	0.99	0.99
1000# A.P.	150# TNT	0.23	0.41	0.55	0.66	0.73	0.79
1600# A.P.	240# TNT	0.23	0.41	0.55	0.66	0.73	0.79
1000# G.P.*	500# TNT	0.03	0.09	0.15	0.25	0.50	0.80
2000# G.P.*	1000# TNT	0.05	0.25	0.40	0.65	0.90	0.99
	Class (b)	New Battleships					
Torpedo	660# TNT	0.01	0.02	0.10	0.40	0.70	0.90
1000# A.P.	150# TNT	0.23	0.41	0.55	0.66	0.73	0.79
1600# A.P.	240# TNT	0.23	0.41	0.55	0.66	0.73	0.79
1000# G.P.*	500# TNT	0.01	0.05	0.10	0.18	0.40	0.70
2000# G.P.*	1000# TNT	0.02	0.10	0.20	0.40	0.65	0.90

* The probabilities for these bombs pertain to putting ships out of action, rather than sinking.

NEAR MISS EFFECT

No estimates feasible.

NAVY DEPARTMENT
BUREAU OF SHIPS
WASHINGTON D.C.

Section 424

11 May 1944

S-FS/S29(424) Serial 08733

S E C R E T

To: The Chief of Naval Operations.

Subj: Vulnerability of U.S. Naval Vessels to Attack by Air-Borne Weapons.

Ref: (a) CNO conf. ltr. Op-16-V-A-dlm, A16-3(4), Serial 0407416 of 8 February, 1944.
(b) Opnav-16-V #A6, March 6, 1944 - "Selection of Bombs and Fuses to be Used Against Various Targets".
(c) Buships secret ltr. S-F41-6(424), Serial 08027, of 12 April, 1944 to Cominch.

Encl: (H.W.)
(A) Cases of war damage to U.S. Naval Vessels.
(B) Summary of war experience to U.S. Naval Vessels.

1. Reference (a) requested this Bureau to furnish the best possible quantitative estimates of the probabilities of sinking various types of vessels when hit by various types of air-borne weapons (aircraft bombs and torpedoes). In analyzing war experience the basic data, contained in enclosures (A) and (B), include cases of damage from all types of torpedoes, that is, aircraft, surface craft and submarine. This is necessary in order to increase the number of cases of torpedo damage available for study, and because the size of warhead is largely independent of the type of carrier. The type of carrier, therefore, has been neglected, although it is true that to date aircraft torpedoes used against U.S. vessels have had in general somewhat smaller charges of explosive than those employed by surface craft and submarines. In the analysis which follows, a warhead with an explosive charge of 660 pounds of TNT has been used. This has been done because a charge of this size is considered to be most nearly equivalent in destructiveness to the warheads used to date against U.S. vessels.

2. The preliminary draft of the report on the vulnerability of cruisers and destroyers to air-borne weapons, referred to in reference (a), is based on a statistical study of cases of damage to both U.S. and British vessels. Enclosures (A) and (B) contain only data for U.S. vessels. It is considered misleading to arrive at conclusions from statistical data which combine the results of damage to vessels of both navies. Such a procedure cannot reflect the variations in design and construction methods employed by the two navies, the totally different operating conditions under which the majority of vessels have been employed to date, and finally, the differences in what may be termed operating technique in use in the two navies. The latter is evidenced primarily by different operating doctrines with respect to anti-aircraft gunnery and sea-borne aircraft. For these reasons only U.S. war experience has been considered.

3. In analyzing damage to types of major combatant vessels it should be recognized that not enough cases exist, and are not likely to exist, to permit drawing general conclusions concerning vulnerability from statistics alone. A large number of cases would be required for each class alone to eliminate the effects of such variables as size of target, type of construction, degree of sub-division, system of protection of vitals, size of explosive charge, fore and aft location of hit, depth of hit, type of fuse, and height of release (in case of bombs). Accordingly, the following discussion and tables do not purport to be a statistical analysis. Rather, the figures for probability of sinking are based on design characteristics of each class and the damage each is intended to resist, plus war experience which serves to indicate the per-

formance of the design when subjected to actual attack *. Summarizing, the tables contain estimates which represent the judgment of the Bureau, based on design characteristics of U.S. vessels, corelated with performance in battle. The figures must be recognized as being subject to possible errors of appreciable magnitude because of the nature of the problem, the number of variables involved, and the relatively small number of cases available for study.

4. Reference (a) does not specify whether the information requested is desired as a basis for studies from the offensive or defensive point of view. Since practically no information is available on the defensive characteristics of Japanese ships, the best assumption that can be made at present is to assume that Japanese ships have characteristics approximately equal to those of corresponding ships in the U.S. Navy. It becomes of interest, therefore, to include some of the older ships in the U.S. Navy, whose resistance to attack is materially less than that of the newer ships, because it is believed that a large proportion of the Japanese fleet is made up of older ships with power of survival roughly equivalent to that of the corresponding older ships of the U.S. Navy.

5. The conditions which result in magazine explosions following torpedo hits in way of the magazines or bomb detonations in or adjacent to the magazines warrant special comment. In general, magazine explosions may be caused in three ways. The first is a propellant-powder fire resulting in an explosion of the propellant-powder magazines. The powder may be ignited by hot fragments, flash from a detonation, or high temperatures outside the magazines proper. The density of loading of the magazines also appears to have an important influence on whether or not an explosion will occur. If the magazine is not vented by openings in the peripheries, such as large fragment holes, the ventilation systems or open doors and passing scuttles, the powder fire may build up sufficient pressure and temperature to cause an explosion of the remaining powder, provided there is a sufficient quantity. Prompt operation of the magazine sprinkling systems or quick flooding from the sea through damage of the side or bottom of the hull may, of course, extinguish such a fire in its early stages. It is emphasized, however, that pressures of considerable magnitude, high temperatures and high density of loading are all involved to some degree in a propellant-powder explosion. It is apparent that a magazine explosion following a powder fire thus is not necessarily an instantaneous occurrence, but ordinarily requires an appreciable interval of time (although it may be brief) to build up the pressure and temperature which will cause an explosion. An explosion of this nature seems to have occurred on ARIZONA following a bomb detonation in the forward powder magazines. There have been other cases, notably BOISE** and SAVANNAH***, where considerable powder was burned without causing an explosion. In case of BOISE, where a projectile entered below the armor belt and detonated in a 6-inch powder magazine, considerable venting through fragment holes in the magazine peripheries apparently occurred while the magazine was flooding rapidly through the projectile entry hole. In SAVANNAH considerable powder was ignited following the detonation of a large bomb in the center of the 6-inch powder magazines for turret III, but almost instantaneous flooding from the sea extinguished the burning powder. In both of these cases conditions of high pressure and temperature within the magazines proper did not develop prior to complete flooding. The second way in which a magazine explosion may occur involves a fire causing such high temperatures that a mass detonation of ammunition loaded with high explosives may occur. The roasting effect of high temperatures, applied for an appreciable period, may cause detonation of some types of projectiles or bombs. If the projectiles and bombs be thin-walled, the fragments produced from the first detonations are apt to cause the detonation of other projectiles and bombs in the bin or adjacent stowages if they be racked close together. A mass detonation may follow. Tests and war experience have shown that 5-inch A.A. projectiles are apt to behave in this manner. The fire which subjects the ammunition to high temperatures may originate in adjacent powder magazines (as on destroyers), or may come from other sources such as gasoline stowage (in case of aircraft carriers). Burning fuel oil from ruptured tanks surrounded the magazines of the SHAW****(in a floating drydock at the time) and caused a magazine explosion of great violence. All indications pointed to a mass detonation of 5-inch projectiles. More recently the 5-inch projectile stowage for the after gun on TURNER appears to have "mass-detonated" following a severe fire surrounding the stowage. The third way in which a magazine explosion may be caused involves the mass detonation of ammunition with comparatively thin-walls and loaded with high explosive, when struck by high-velocity fragments.

* For the purposes of this study it is assumed that all torpedoes and bombs detonate. In reality, there may be a small percentage of duds.
** Buships War Damage Report No. 24.
*** Buships War Damage Report No. 44.
**** Buships War Damage Report No. 7.

Five-inch A.A. projectiles and thin-walled aircraft bombs again are susceptible to this form of attack. There have been several cases which involved this type of magazine explosion. A notable example was that of NEW ORLEANS*, in which a mass detonation of thin-walled aircraft bombs occurred following a torpedo hit in way of the bomb magazine, which was not protected by either a liquid layer or armor. In the following paragraphs the possibility of magazine explosions following bomb and torpedo attack on the various classes of ships under consideration will be discussed. Needless to say, loss of the ship is considered certain in the event that a magazine explosion does occur.

6. Concerning torpedo hits it is considered that only destroyers, Classes I and II in the discussion which follows, are vulnerable to magazine explosions following torpedo hits in way of the magazines. The other classes of vessels under consideration have liquid layers outboard of the magazines with the exception of the 7050-ton cruisers, and these latter, by virtue of the magazine arrangement and type of ammunition carried, are not particularly vulnerable to a magazine explosion initiated by a torpedo hit. War experience has demonstrated that a torpedo hit in way of magazines of destroyers (destroyers carry 5"/38 A.A. projectiles) will not inevitably produce a magazine explosion. Although the number of cases available for analysis (ten, of which four apparently had a magazine explosion following torpedo hits) is not sufficient to warrant a positive statement for the probability that such an event will occur, it does appear that a torpedo hit in way of the magazines will not produce a magazine explosion more than 50% of the time. Thus, a probability figure of 0.50 has been assumed for the chance that a magazine explosion on destroyers will occur following a torpedo hit in way of the magazines. With respect to CVEs the large quantity of aircraft bombs carried in a location adjacent to the shell made the probability of a bomb magazine explosion following a torpedo hit in way of these magazines quite high for the early vessels of the CVE55-104 Class. However, these vessels either have been altered or will be altered in the reasonably near future to provide reasonable protection against this form of attack. Although the protection provided is the best that could be achieved in this class of ships, there is some possibility that a small portion of the target area presented by the bomb magazine is still vulnerable to fragment attack from a torpedo hit. There is also a very small possibility of an explosion in a 5-inch magazine, located very near the stern. Because of other possibilities of loss from flooding or fatal fire in the vicinity of the bomb and 5-inch magazines, the small possibility of magazine explosion has been neglected in this study.

7. Concerning bomb hits in way of propellant-powder magazines, two cases of war damage have shown that a magazine explosion is not inevitable following such a hit (see paragraph 5). If the side or bottom is ruptured and permits quick flooding of the magazines from the sea, causing quick extinguishing of any powder fire which may be ignited, there is a good chance that a magazine explosion will not occur. Destroyers and cruisers are of such size that rupture of side and bottom plating is almost inevitable following a bomb detonation in the magazines. However, they do carry 5"/38 A.A. projectiles which are susceptible to fragment attack as discussed in paragraph 5. While the number of cases does not permit an authoritative figure for the probability of a magazine explosion, it is believed that this probability is not more than 0.50 and this figure accordingly has been used in the tables which follow. For large vessels, such as battleships and aircraft carriers (CVs), rupturing of the side, with quick flooding from the sea, is much less probable than for the smaller ships. For this reason, and because these two types carry a comparatively large quantity of explosives, a magazine explosion (of either propellant powder or of high explosives) following a hit with bombs of the size which probably would be used against these vessels seems certain (see paragraph 10) and the probability of such an event has been assumed as 1.00, although this figure may prove to be pessimistic**. For smaller carriers (CVLs and CVEs) the type and quantity of explosives carried (thin-walled aircraft bombs) indicates that the probability of a magazine explosion following a bomb hit in the magazines should be the same as for battleships and large carriers, that is 1.00, primarily because of the susceptibility to fragment attack of the explosives carried.

* Buships War Damage Report No. 38.

** The Italian battleship ROMA was lost by a direct hit in a magazine, as were the HOOD and certain British battle cruisers in the last war. No battleship or aircraft carrier is known to have survived a direct bomb or projectile hit in a magazine.

8. In general, near misses with bombs have not been a very serious hazard to U.S. warships, particularly in the Pacific, during the course of the war up to the present time. The reasons for this are not known beyond the fact that many near miss bombs have detonated on impact with the water, rather than below the surface. This suggests that the Japanese lack selective fuses, especially for G.P. bombs. It would appear reasonable, however, to assume that the enemy will develop means of obtaining proper fusing for maximum underwater effect. Accordingly, in the discussion of near miss effect which follows each table, it has been assumed that the G.P. bombs, as well as the A.P. and S.A.P. types, will produce maximum underwater effect.

9. One of the most important considerations in any vulnerability analysis is the spacing of hits, whether they be with bombs or torpedoes. For example, NORTHAMPTON * was struck by two torpedoes, spaced such that structural damage did not overlap but flooding did overlap. The total extent of flooding thus was considerably less than would have been the case had the two torpedoes been separated by a greater distance. For this reason, NORTHAMPTON had a very good chance of survival although eventually she sank. Again, HORNET ** was struck initially by two torpedoes very close together. Flooding in this case was scarcely more extensive than would have resulted from one torpedo hit, and the hull was of such size and strength that there was no danger of the vessel breaking in two as a result of the overlapping of the structural damage. Had not other attacks, both with torpedoes and bombs, occurred, HORNET undoubtedly would have survived ***. This study, as noted in paragraph 3, does not purport to be a statistical analysis but rather contains estimates of vulnerability. Nonetheless, this important consideration of spacing of hits has been taken into account in the tables which follow and is reflected by the fact that a probability of sinking of 1.00 has not been assigned in any case. Furthermore, a lucky hit is always possible, and this consideration is reflected by the fact that a probability of sinking of 0.00 has not been assigned, even with a small bomb.

10. Reference (b) promulgates recommendations for the selection of bombs and fuses to be used against naval targets among others. Reference (c) presented this Bureau's comments on reference (b). In the following tables the types of bombs shown are those which it is believed would be used against the particular class of target under discussion and are consistent with the comments contained in reference (c). This has been done because information is incomplete concerning enemy doctrine for the employment of bombs against naval targets.

11. There are such wide variations in the degree of vulnerability of the various types of war vessels, and even in different classes of the same type (particularly destroyers, cruisers, aircraft carriers and battleships) that the major types of combatant vessels, for the purpose of this study, have been subdivided into eight classes.

12. For each class there is presented a short discussion of the factors considered in arriving at the figures. Immediately following each table a short discussion of near miss effect is given.

13. <u>Class I - Destroyers, 1500 to 1630 Tons</u> - Vessels of this class probably will survive with two main compartments flooded but probably will be lost if three main compartments are flooded. A torpedo with 660 pounds of explosive, if it hits in the middle length, probably will flood at least three compartments and, furthermore, probably will destroy enough of the ship's girder to cause breaking in two. Loss, under these circumstances, is almost inevitable. About 65% of the vessel's length is vulnerable to this form of attack. The probability of a magazine explosion, with loss of the vessel resulting, has been placed at 0.50 as explained in paragraph 6. Approximately 25% of the vessel's length, in addition to the 65% of length discussed above, is vulnerable to this form of attack, so there appears to be a 12.5% (.25 x .50) chance of this. Total vulnerability would then appear to be 0.125 + 0.65 = 0.775 (say 75%).

* Buships War Damage Report No. 41.

** Buships War Damage Report No. 30

*** On the other hand, HELENA was broken in two by two hits very close together. In this case if they had been more widely separated, the ship might have survived.

Turning to war experience we find that 12 of 16 destroyers of this class, or 75%, have sunk following one torpedo hit - a rather close agreement. It is obvious that two or more torpedo hits can be considered as almost certain to cause loss.

With respect to bomb hits, reference (c) endorsed the use of 250, 500 and 1000-pound G.P. bombs against destroyers. These three bombs are listed in the table below. Probability of sinking from one hit for the two smaller bombs is based solely on the chance of hitting a magazine. Multiple hits with small bombs, reasonably spaced, involve loss by flooding and fire (with derangement of damage control facilities) rather than by breaking up. It is considered that three hits with 250-pound bombs, if fused to penetrate, would probably open at least three main compartments to the sea. The figure for three hits is thus quite high (0.60) but less than that for one torpedo hit. Two hits with 500-pound bombs, if fused to penetrate, will probably produce flooding almost equivalent to that from one torpedo hit. One thousand pound G.P. bombs are considered almost, but not quite, as lethal as torpedoes. We find that the table so deduced agrees reasonably well with the small number of cases which constitute the war experience with bombs for this class. For example, the vessel (SIMS) which was lost following three 550-pound bomb hits (believed to be S.A.P. and hence equivalent in bursting charge to about a 250-pound G.P.) received one hit in the forward engine room, one hit in the after engine room, and the third was adjacent to or involved in some manner the after magazines. Although the table lists the probability of sinking from three 250-pound G.P. hits as 0.60, and the SIMS was lost from three hits, it seems reasonable after analyzing the damage to conclude that she would have survived had the third hit been located in a less vulnerable spot.

Weapon	Assumed Charge Weight	Probability of sinking for No. of hits 1	2	3	4
Torpedo	660# TNT	0.75	0.98	0.99	0.99
250# G.P.	125# "	0.09	0.18	0.60	0.99
500# G.P.	250# "	0.09	0.65	0.99	0.99
1000# G.P.	500# "	0.70	0.98	0.99	0.99

It is difficult to arrive at general conclusions regarding vulnerability to near misses. War experience is very inconclusive on this subject, primarily because of the difficulty of obtaining reliable data as to the charge weight, the distance from the hull at which the bomb detonates and the depth beneath the surface at which detonation occurs. Underwater explosion tests, however, have thrown some light on this problem. Assuming that a near miss occurs about 18 feet from the hull, it is believed that six or seven near misses with 250-pound G.P. bombs probably would cause loss through flooding. For 500-pound G.P. bombs probably four would be sufficient, and for 1000-pound G.P. bombs probably two would be sufficient to cause loss. If the near misses were as close as 6 feet from the shell it is considered that they would be nearly as effective as direct hits; and the table above probably represents, as well as can be estimated, the vulnerability under this condition.

The case of MAYRANT is of interest in this connection. A comparatively large bomb detonated very close to the turn of the bilge and not more than 5 feet from the shell. Fortunately, the weather was calm and MAYRANT survived even though the machinery spaces were flooded and freeboard was not more than 12 inches. The Commanding Officer estimated the bomb to have been of the 500 or 1000-pound type. Analysis of the damage indicates that it probably was the 500 Kg. (1100 pounds) classed as SC(thin-walled) with about 550 pounds of explosive which the Germans are known to employ against surface targets. The effects of damage were serious and the vessel was very nearly lost. This case is consistent with the table above for direct hits in which the 1000-pound G.P. bomb is given a probability of 0.70 of causing loss.

14. Class II - Destroyers, 1850 and 2100 Tons - Vessels of this class probably will survive with three main compartments flooded. This makes sinking as a result of flooding following one torpedo hit unlikely inasmuch as a single hit probably will not flood more than three main compartments. Structural strength is superior to that of the smaller destroyers and beam and depth of hull are larger. The chances of breaking in two, therefore, are somewhat less than for the smaller destroyers. The difficulty of assigning a reliable probability figure to the chance of breaking in two will be recognized, but so far it has happened once in the three cases (the STRONG broke in two but LaVALLETTE and PORTER survived) of a torpedo hit in the 55% of the vessel's length amidships, where complete structural failure results in loss of the ship. Con-

sidering all these factors, and in the absence of other data, it appears that a probability figure higher than 0.35 should not be assigned for breaking in two, if hit in this region. It may develop that this figure will be even smaller. The probability of a magazine explosion following a single torpedo hit is given by the ratio of the length of magazine to length of vessel (0.23) multiplied by the 0.50 chance that such an event will occur, as discussed in paragraph 6. Total vulnerability to one torpedo hit, thus, would appear to be 0.55 x 0.35 + 0.23 x 0.50 = 0.31. From this we would expect this class to be much more resistant to torpedo damage than the smaller destroyers, and this conclusion is borne out by war experience to date in which only one of six (17%) large destroyers has been lost as the result of a single torpedo hit. The figure of 17% is lower than the predicted figure of 31%, but three of the vessels which survived were damaged by a hit at one end or the other, the least vulnerable location. Two torpedo hits will be almost certain to cause loss except in the rare circumstances of one hit at the stem with the second at the stern, or with both hits separated longitudinally by not more than 25 feet and both occurring in either the forward or after quarter length (there is some evidence that SELFRIDGE received two closely-spaced hits in the forward quarter length). Thus, a figure of 0.90 for the probability of sinking when two torpedo hits are received seems a reasonable estimate.

With respect to bomb hits, the same basic considerations used in the case of the smaller destroyers will apply. The area of the magazines is relatively less, being only 12% of the total horizontal target area. Thus, the probability of single hits with the two smaller bomb types causing loss by magazine explosion becomes 0.50 x 0.12 = 0.06. Two hits with the 250-pound bomb have approximately twice the probability of causing a magazine explosion that one hit will have. It is improbable that a reasonable number of hits from either the 250 or 500-pound G.P. bombs can cause structural damage sufficient to result in breaking in two unless they are very closely grouped. Multiple hits, however, will cause extensive flooding if the bombs penetrate below the main deck prior to detonation. For these reasons it is considered that three hits by the 250-pound G.P. bomb or two hits by the 500-pound G.P. bomb will be almost but not quite as lethal as a single torpedo hit. Numbers of hits beyond three for the 250-pound bomb would appear almost certain to cause loss from either flooding or fire or a combination of the two. It is considered that three hits with the 500-pound bomb will be more destructive than a single torpedo hit, but not as destructive as two torpedo hits. More than three hits by 500-pound G.P. bombs probably will cause loss either by flooding, fire or a combination of both. 1000-pound G.P. bombs should be almost, but not quite, as lethal as torpedoes.

Unfortunately, there are very few cases of war damage with which to compare the above probabilities for bombs. One vessel survived two direct hits, and another was sunk by three direct hits and one close near-miss. The size of bombs in both of these cases is unknown although there is some reason for believing that they were 550-pound S.A.P. bombs with about 133 pounds of explosive. These two cases are not inconsistent with the probability figures given in the table below. It is pointed out, however, that the effects of multiple hits from comparatively small bombs are speculative and will remain so until many more cases of war damage are available for analysis.

Weapon	Assumed Charge Weight	Probability of sinking for No. of hits 1	2	3	4
Torpedo	660# TNT	0.31	0.90	0.98	0.99
250# G.P.	125# "	0.06	0.12	0.25	0.99
500# G.P.	250# "	0.06	0.30	0.70	0.99
1000# G.P.	500# "	0.30	0.80	0.98	0.99

The difficulty in arriving at general conclusions with respect to near-misses is explained under the table for Class I destroyers. The same difficulties exist with this class of vessel. Assuming that a near miss occurs about 18 feet from the hull, as assumed for the smaller destroyers, it is believed that seven or eight near misses with 250-pound G.P. bombs, five with 500-pound G.P. bombs and three with 1000-pound G.P. bombs probably would be sufficient to cause loss through flooding. As in the cases of smaller destroyers if the near misses were within 6 feet of the shell, it is considered that they would be nearly as effective as direct hits, and the table above probably represents, as well as can be estimated, the vulnerability under this assumption.

15. Class III - Light Cruisers, 6000 and 7050 Tons - By virtue of size and subdivision there is only a small possibility that one torpedo hit will cause loss by either flooding or structural damage. Nonetheless, it is conceivable, under circumstances of bad weather, that one hit can cause loss. This possibility, although remote, is reflected in the figure of 0.05 assigned the probability of sinking from one torpedo. A magazine explosion following a single torpedo hit is improbable as discussed in paragraph 6. As in the case of large destroyers, two torpedo hits in the middle body will be almost certain to cause loss by flooding. However, in the case of two hits under the circumstances of one at each end or both in either the forward or after quarter length, there is a small probability that the vessel will survive. The probability of sinking in this event is somewhat less than in the case of large destroyers because the cruisers under consideration are larger and thus are inherently more resistant to damage. The probability of sinking from two hits for these reasons has been assigned a value of 0.85. War experience with this class is scanty but consistent with the figures given.

In connection with bomb hits it will be noted from the following table that the bombs which it is assumed will be used against this type of target are much larger than those which were assumed in the case of destroyers. The types listed are consistent with the comments in reference (c).

The probability of sinking with one or two hits with the 1,000-pound S.A.P. bomb, because of the comparatively small blast effect from the 250-pound charge, lies almost exclusively in the chance of hitting a magazine. The target area presented is 23% of the total horizontal area, and the probability that a magazine explosion will occur if the magazine area is hit, is about 0.50 as discussed in paragraph 7. Probability of sinking thus becomes 0.12 for one hit and about 0.24 for two hits. Multiple hits beyond two involve the probability of loss by flooding, fire or a combination of both. Three hits would cause flooding of at least three and possibly more main compartments, and the probability of sinking thus becomes about 0.75. Four hits, if well dispersed, may cause more flooding than two torpedoes and loss can be considered almost inevitable; the probability figure thus becomes 0.99.

The thickness of the armored deck in the CL51-54 Class is 1-1/4 inches. The equivalent thickness of the armored deck (35# STS on 25# MS) of the CL4-13 class is somewhat less. Information available to this Bureau indicates that the large G.P. bombs probably will penetrate decks of these thicknesses if fused for delay action. The following discussion is based, therefore, on the assumption that penetration will occur. If it should develop that G.P. bombs may not penetrate decks of these thicknesses, the probability figures given in the table below will be somewhat high.

With respect to the 1000-pound G.P. bomb, the probability of sinking with one hit primarily involves the chance of causing a magazine explosion rather than flooding. The probability figure is thus the same as that for the 1000-pound S.A.P. bomb. Two hits, however, because of the weight of explosive involved, involves a probability of sinking almost as high as that resulting from two torpedo hits. Multiple hits beyond two are considered to be almost certain to cause loss.

The 2000-pound G.P. bomb, by virtue of its large bursting charge, is considerably more lethal than a torpedo with the 660-pound charge assumed for this study if it be fused for penetration prior to detonation. The probability figures assigned to this bomb, therefore, are somewhat larger than those for torpedoes.

There is almost no war experience with which to compare the vulnerability figures for bombs given below. Only two vessels of this class have suffered direct hits, and both cases involved much smaller bombs than those listed. The figures, therefore, are speculative, and further war experience may indicate the necessity for revision.

Weapon	Assumed Charge Weight	Probability of sinking for No. of hits 1	2	3	4
Torpedo	660# TNT	0.05	0.85	0.95	0.99
1000# S.A.P.	250# "	0.12	0.24	0.75	0.99
1000# G.P.	500# "	0.12	0.70	0.95	0.99
2000# G.P.	1000# "	0.50	0.95	0.99	0.99

Near misses with the 1000-pound S.A.P. bomb probably would not involve sinking, because of the comparatively small charge, unless they were either so close to the hull that the effect of a contact explosion would be produced, or else were close under the turn of the bilge and produced a mining effect. In either of these circumstances probably four or five near misses would be required to cause sinking.

The situation with respect to the G.P. bombs, if they be so fused as to give detonation well below the surface, is considerably different. Six feet from the hull in case of the 1000-pound G.P. bomb and 9 feet from the hull for the 2000-pound G.P. bomb are considered to be maximum distances for extensive hull ruptures. If the bombs be within these distances and detonate well below the surface, several near misses are capable of sinking. Under these circumstances, three or four close near misses with the 1000-pound G.P. bomb and two or three close near misses with the 2000-pound G.P. bomb probably would be sufficient to cause loss.

16. <u>Class IV - Heavy Cruisers, 10,000 Tons and larger, including CAs and CLs</u> - These vessels are of such size and design that a single torpedo hit should never result in sinking. Ten have been hit by a single torpedo and all of them survived the one hit. Their chances of surviving two torpedo hits are favorable if the hits be well separated. The loss of a considerable portion of the bow and a lesser portion of the stern is not necessarily fatal. To date four have been hit by two torpedoes and two of these have survived the two hits. A probability of 0.50 of sinking following two hits, based on war experience alone, appears to be too high, particularly considering the increased size, greater strength, better stability characteristics, and improved damage control facilities of the newer vessels, which will soon comprise a majority of this class in service. Probability of sinking following two hits thus has been placed at 0.40, to reflect the increased resistance of the newer vessels of this class. Of the older CAs and CLs three hits can be considered as almost certain to cause loss, except in such rare circumstances as two hits at the bow and the third at the stern. The newer vessels, however, because of better stability characteristics and larger size have a somewhat greater probability of surviving three hits. Probability of sinking following three hits thus has been placed at 0.85 to reflect both the improved resistance of the newer ships and the possibility of favorable locations of the hits.

In connection with vulnerability to bomb hits it is necessary to keep in mind that all U.S. cruisers in this category now in service or expected to be in service during the next two years, have armored decks not greater than 2-1/2 inches in thickness, and most of them have decks of 2-inches. The S.A.P. bombs will penetrate decks of such thicknesses if dropped from above 5000 feet in horizontal bombing or above 1600 feet in dive bombing. The table below assumes that penetration with the S.A.P. bombs will occur. It is probable that the G.P. bombs will not penetrate the armored deck.

If the G.P. bombs be fused to give detonation below the main deck, however, they can be expected to do extensive damage of a serious nature. Sinking damage with one or two hits with these bombs is not probable except as a result of fire following widespread destruction of firefighting facilities. Three and four hits with the 1000-pound G.P. bomb would appear to offer a fairly good chance of causing loss simply because of the large scale of destruction. Chances of sinking with three or four hits with the 2000-pound G.P. bomb are correspondingly better inasmuch as this number of hits probably would gut the vessel more or less completely above the waterline.

For one and two hits with the S.A.P. bomb the probabilities of loss depend almost entirely on the chance of a magazine explosion. The magazine area is about 24% of the total horizontal target area, and with a 0.50 probability that a magazine will explode if hit (see paragraph 7), vulnerability becomes 0.12 and about 0.24 for one and two hits respectively. For three or more hits loss involves the additional probability that flooding will be so extensive as to jeopardize the vessel. Thus, three hits are roughly comparable to about two torpedo hits and four hits probably will be almost as lethal as three torpedo hits. It is pointed out, however, that multiple hits with the S.A.P. bomb must have reasonable spacing or the vulnerability figures given below will be too high. For example, two S.A.P. bomb hits within a comparatively small distance of each other would not cause flooding in any sense comparable to that which would be caused by the same two bombs separated by some 100 feet.

War experience with hits by bombs of large bursting charge on U.S. cruisers is meager. The case of SAVANNAH, struck by a large A.P. bomb with a 660-pound bursting charge, is the only case so far available for study. Structural damage and the extent of flooding were both somewhat greater than would be expected from a hit with a torpedo of equivalent charge. There have been, in addition, a few cases of one and two hits with bombs of small bursting charge on vessels of this class and they have caused only superficial damage. The Battle of Midway offers some interesting, although incomplete, data with regard to the efficacy of 500-pound and 1000-pound G.P. bombs against Japanese heavy cruisers, believed to have armored decks of about 2 inches in thickness. Reports indicate that MIKUMA was sunk after receiving a minimum of five hits from 500-pound and 1000-pound G.P. bombs, that MOGAMI survived at least two hits from 500-pound or 1000-pound G.P. bombs, that either KUMANO or SUZUYA survived a minimum of two 1000-pound G.P. hits and that TAKAO survived at least two 1000-pound and one 500-pound G.P. hits.

Thus, war experience with large bombs against U.S. cruisers of this class is admittedly sketchy. The probability figures, therefore, are speculative and will remain so until more cases of bomb damage to U.S. cruisers become available for analysis.

Weapon	Assumed Charge Weight	Probability of sinking for No. of hits 1	2	3	4
Torpedo	660# TNT	0.03	0.40	0.85	0.98
1000# S.A.P.	250# "	0.12	0.23	0.40	0.75
1000# G.P.	500# "	0.03	0.15	0.30	0.45
2000# G.P.	1000# "	0.15	0.45	0.80	0.98

Near misses with the 1000-pound S.A.P. bombs probably would not involve sinking, as was the case with the smaller cruisers, unless they were either so close to the hull that the effect of a contact explosion would be produced, or else were close under the turn of the bilge and produced a mining effect. In either of these circumstances probably six or seven near misses, within 6 feet of the hull, would be required to cause loss.

As in the case of the smaller cruisers, the maximum distance for extensive hull rupture is believed to be about 6 feet for the 1000-pound G.P. bomb and about 9 feet for the 2000-pound G.P. bomb. If the G.P. bombs be fuzed for underwater detonation, the probabilities of sinking probably would be about the same as those given in the table above for direct hits, primarily because serious underwater damage and flooding would be involved. This estimate is admittedly speculative in the absence of any war experience with near misses from such large bombs. Therefore, it will require re-examination if and when cases of close near miss damage with large bombs become available for analysis.

17. Class V - Aircraft Carriers (CVs less RANGER) - Because of the size and protective features of vessels of this class, the total number of hits with both torpedoes and bombs has been placed at six rather than four as in the case of previous classes discussed. This class is comprised of vessels of the CV9 (ESSEX) class plus ENTERPRISE and SARATOGA. Ships of the CV9 class are somewhat better protected than ENTERPRISE and not quite so well protected in some respects as SARATOGA. This discussion and the probability figures given are based primarily on the characteristics of the CV9 class. The torpedo protection system is such that uncontrollable flooding following a torpedo hit (with a warhead charge of 660 pounds of TNT) probably would be limited to one main compartment inboard of the torpedo defense system, except in the event of a hit in way of a main transverse bulkhead - in which event possibly two main compartments would be flooded. For purposes of analysis it is considered that 1-1/2 main compartments would be flooded by a single hit. The floodable length characteristics are such that about six main machinery compartments in the middle length or about four main compartments in the quarter lengths at the ends could be flooded without causing sinking. The magazines are well protected against underwater attack and a magazine explosion from a torpedo hit is unlikely. The hazard of large quantities of aviation gasoline, however, is present and must be considered. The torpedo protection system probably would prevent a large-scale rupture of the gasoline stowage system. The presence of modern firefighting equipment and of features designed to prevent the spread of gasoline vapors furthermore should reduce the danger of subsequent vapor explosions, such as caused difficulty on both LEXINGTON * and WASP **. It thus appears that the occurrence of a fatal fire follow-

* Buships War Damage Report No. 16.
** Buships War Damage Report No. 39.

ing a torpedo hit in way of the gasoline stowage is by no means certain. In the absence of specific data this probability has been assumed arbitrarily as 0.50. The gasoline stowage comprises about 12% of the vessel's length so that total probability of the occurrence of a fatal fire as the result of a single torpedo hit becomes 0.50 x 0.12 = 0.06.* For one or two hits flooding should not jeopardize the vessel and the probability of loss thus becomes the figure for the probability of the occurrence of a fatal fire. Three hits on one side, in addition to the probability of causing a fatal fire, would cause considerable flooding, although not necessarily fatal unless all the hits be located either at one end or the other. Probability of loss following three hits thus has been assigned a figure of 0.50. Four hits on one side would cause extensive flooding and probably fire, and loss seems almost certain if the hits be favorably spaced for maximum flooding. There is a possibility of sinking by taking an extreme trim and capsizing. The probability of sinking has been placed at 0.90, however, to reflect the chance of closely-spaced hits or hits at the extremities as discussed in paragraph 9.

War experience with torpedoes against CVs indicates that the probability figures so derived are reasonably accurate. Four vessels received one torpedo hit and four survived; three received two hits, only one of which (LEXINGTON (CV2)) sank - and there is some evidence that the LEXINGTON received three hits. It is somewhat difficult to place the cause of LEXINGTON's sinking solely on the fact that she was torpedoed. One CV would have survived three hits had the ship not been sunk by later attack (HORNET**); and one CV (YORKTOWN***) sank following four hits.

The main deck of the CV9 class is 2-1/2 inches of STS, and the fourth deck is 1-1/2 inches of STS. These decks can be penetrated by the 1000-pound A.P. bomb. Because of its small bursting charge, the chances of sinking with the 1000-pound A.P. bomb will depend almost entirely upon the probability of initiating a magazine explosion or of causing a fatal fire for number of hits up to and including three. Because of the size of the charge, which makes instantaneous flooding following a penetrative hit in the magazines somewhat unlikely, it has been assumed that a hit in the magazine will cause an explosion (see paragraph 7). Likewise, it is considered that a hit in the gasoline stowage very probably will cause a serious gasoline fire and one of considerable danger to the magazines because of the proximity of the magazines to the gasoline stowage. The magazines comprise 19.2% and the gasoline stowages 3.9% of the total hroizontal target area. Probabilities of sinking thus are 0.23, 0.41 and 0.55 for one, two and three hits respectively. More than three hits will involve extensive structural damage with the probability of considerable flooding, especially if hits occur forward or aft of the protected portion. Probabilities of sinking thus increase somewhat more rapidly for four, five and six hits than for one, two and three hits.

The 1000-pound G.P. bomb probably will not penetrate the 2-1/2-inch main deck. Because of its 500-pound bursting charge, however, it can be expected to cause extensive structural damage in the hangar and to the flight deck if fused for slight delay. If sufficient hits be made with this bomb, the vessel can be put out of action even though probabilities of sinking are not as high as with the A.P. bomb. Multiple hits with the 2000-pound G.P. bomb, because of the 1000-pound bursting charge, probably will cripple the ship completely, cause extensive structural damage, and start raging conflagrations, the combined effects of which probably would render the ship completely useless in a very short time. These considerations underlie the high probability values assigned for numbers of hits greater than two. It will be noted from the table that this bomb is considered to be more lethal than a torpedo and the 1000-pound A.P. bomb (considering numbers of hits greater than three).

U.S. carriers have not been hit with large A.P. or G.P. bombs to date. The figures of probability of sinking from bomb hits, particularly the G.P. bombs, are admittedly speculative and will be subject to re-examination if and when war experience furnishes factual data.

Weapon	Assumed Charge Weight	Probability of sinking for No. of hits 1	2	3	4	5	6
Torpedo	660# TNT	0.06	0.12	0.50	0.90	0.95	0.99
1000# A.P.	125# "	0.23	0.41	0.55	0.70	0.90	0.99
1000# G.P.	500# "	0.03	0.10	0.20	0.30	0.50	0.80
2000# G.P.	1000# "	0.10	0.30	0.60	0.90	0.96	0.99

* For two hits the probability is 0.12.
** Buships War Damage Report No. 30.
***Buships War Damage Report No. 25.

The torpedo defense system offers excellent protection against near misses at the side. Although the 1000-pound A.P. bomb will cause underwater damage, a very large number of near misses very close to the hull would be required to cause sinking.

The 100-pound G.P. bomb, with hydrostatic tail fuse, probably would not penetrate the torpedo defense system even if it were to detonate so close to the hull that the effect of a contact explosion were produced. If the bombs were so located that detonation was just below the turn of the bilge and close enough to rupture the bottom, within about 6 feet, one bomb so located probably would cause uncontrollable flooding of not more than one main compartment. Under this rather remote circumstance and also considering the effect of opening a large number of the torpedo defense voids to the sea, probably six or seven close near misses with this bomb would be required to cause sinking.

A near miss with the 2000-pound G.P. bomb not more than 6 feet from the shell might rupture the holding bulkhead of the torpedo defense system because of the large explosive charge. A near miss so close that the effect of a contact explosion was produced unquestionably would rupture the holding bulkhead. The 1000-pound charge thus makes this bomb a potent underwater weapon even against ships with torpedo defense systems. The effect of distance from the hull, however, is so marked that any estimate of the number required to cause sinking is necessarily speculative to a large degree. With this reservation it is possible that sinking could be caused by five or six close near misses with the 2000-pound G.P. bomb.

18. Class VI - Aircraft Carriers, Light (CVLs plus RANGER) - Vessels of this class have hull characteristics somewhat similar to the larger cruisers of Class IV. Possibly the most significant difference lies in the fact that the CVLs have a blister in the middle half length. Although the blister, by virtue of the additional layer of liquid, offers somewhat increased resistance to contact underwater explosions, the difference in damage caused by a 660-pound warhead to hulls with and without blisters is not significant. Resistance to non-contact explosions from near misses, however, probably will be significantly better. Notwithstanding the presence of the blister, the CVLs are somewhat more vulnerable to torpedoes and bombs than cruisers of Class IV because of the presence of large quantities of aviation gasoline and of explosives susceptible to mass detonation from fragments, as discussed in paragraphs 6 and 7.

Concerning torpedo hits the probabilities given for the cruisers of Class IV have been increased by 0.08 to include the added hazard presented by the gasoline stowages. They comprise about 11% of the length, and the probability that a fatal fire will occur following a large rupture of the gasoline stowage has been placed at 0.75 inasmuch as the gasoline stowage is not so well protected as on vessels of the CV9 class (where the corresponding figure was 0.50). The probability figures thus become 0.11, 0.18, 0.93 and 0.99 for one, two, three and four hits respectively. War experience consists of two cases: one CVL was hit by one torpedo and survived easily, and the other case (WASP) is difficult to evaluate. WASP was struck initially by two torpedoes which hit in way of the gasoline stowage, starting bad fires which caused her to be abandoned. Nonetheless, three additional torpedoes, fired several hours later, finally were required to insure sinking. These experiences are consistent with the figures quoted.

As discussed in paragraph 7 the probability of a magazine explosion following a bomb hit in the magazines of a CVL has been placed at 1.00. Magazines comprise 14% of the total horizontal target area. In addition, gasoline fires, with danger of a magazine explosion, would appear inevitable following a bomb detonation in the gasoline stowages which comprise 4.5% of the total horizontal target area.

The 1000-pound S.A.P. bomb will penetrate the armored deck. Probability of sinking following one hit is thus about 0.13, about 0.33 for two hits and about 0.45 for three hits. Four hits may involve flooding so extensive as to cause sinking in addition to the hazards of a magazine explosion and fire. This consideration underlies the probability figure of 0.80 assigned for four hits.

The 1000-pound G.P. bomb, although it probably will not penetrate the 2-inch STS armored deck, is a lethal weapon against carriers of this size, both because of its comparatively large bursting charge and also because it will penetrate deeply if fused for delay action (the armored deck is the third deck, deep in the vessel). The presence of gasoline and other inflammable material makes the 1000-pound G.P. bomb relatively more destructive against CVLs than against the larger cruisers of Class IV. These considerations underlie the probability figures assigned. The same reasoning underlies the figures assigned for the 2000-pound G.P. bomb which would appear to be about as lethal as the torpedo and somewhat more lethal than the S.A.P. bomb. It will be recalled that this was also the case for the larger cruisers of Class IV.

There has been no war experience with bombs against carriers of this class. The figures are thus based on design characteristics and on knowledge of the effects of smaller bombs on other types of vessels.

Weapon	Assumed Charge Weight	Probability of sinking for No. of hits 1	2	3	4
Torpedo	660# TNT	0.11	0.48	0.93	0.99
1000# S.A.P.	250# "	0.18	0.33	0.45	0.80
1000# G.P.	500# "	0.05	0.20	0.35	0.60
2000# G.P.	1000# "	0.20	0.50	0.90	0.99

Because of the presence of the blister these vessels are somewhat more resistant to near miss damage than the larger cruisers of Class IV. Possibly seven or eight near misses within 6 feet of the hull with the 1000-pound S.A.P. bomb would be required to cause sinking.

The probabilities of sinking from near misses with the G.P. bombs, if fused for underwater detonation, probably would be somewhat less than those given in the table above for direct hits. Possibly six near misses with the 1000-pound G.P. bomb and five with the 2000-pound G.P. bomb would be required to cause sinking. It is emphasized, however, that near misses must be close to the hull (within about 6 feet for the 1000-pound G.P. bomb and within 9 feet for the 2000-pound G.P. bomb) to be effective. As in the case of the larger cruisers of Class IV the estimate given in this paragraph will require re-examination if and when cases of close near miss damage with large bombs become available for analysis.

19. Class VII - Aircraft Carriers, Escort (CVEs) - In general, these vessels fall into two classes:

(a) Those built as escort carriers (CVE55-104) following merchant ship design and construction practice, plus those which have been converted from C-3 hulls (CVE1, 9-25, 30, 31).

(b) Those which have been converted from tankers (CVE26-29), or designed as CVEs, using tanker design as a basis (CVE105-119).

The vulnerability of all CVEs has been a matter of concern since the first ships were placed in commission, primarily because merchant standards of stability and subdivision are much lower than those which are acceptable in combatant ships exposed to the hazards of war. This natural concern led to an investigation which culminated in the issuance of ballasting instructions, and recommendations that certain prescribed drafts not be exceeded. All CVEs of all classes have been furnished with these ballasting instructions and with figures for the drafts which should not be exceeded if maximum resistance to underwater damage is desired. It is necessary to emphasize this point because the degree of resistance varies so widely with loading. For example, the CVEs of the 55-104 class will have an excellent chance of surviving one torpedo hit if the draft be less than 20 feet, but the probability of sinking increases materially if draft exceeds about 20'-7", which is the maximum permitted under existing instructions. Again, the CVEs of the 105-119 class will have an excellent chance of survival when struck by one torpedo if the wing tanks be ballasted to the waterline, as required by existing instructions, but will take a very large list with small probability of survival if the wing tanks be empty. In the analysis which follows it is assumed that specified ballasting procedures are being followed and that prescribed drafts will not be exceeded.

In general, the CVEs of Class (b) above are somewhat more resistant to damage than CVEs of Class (a). Although the difference is not significantly large, it nevertheless exists. Accordingly, a table of vulnerability for each class is given below.

When operating as carriers (rather than as aircraft transports), and following the prescribed ballasting procedure and loaded so that the prescribed drafts are not exceeded, the floodable length characteristics of the CVEs of Class (a) are such that these vessels will survive with three main compartments flooded. Inasmuch as a torpedo will not cause flooding of more than three main compartments, a single torpedo hit is not expected to cause loss by flooding. The gasoline stowage, however, is unprotected and a torpedo hit in way of or adjacent to the stowage probably will cause a fire which might be fatal. The gasoline stowage occupies about 12% of the vessel's length. The possibility of an explosion of the bomb or 5-inch magazines as a result of a torpedo hit can be neglected as explained in paragraph 6. Probability of loss thus becomes about 0.12. Two torpedo hits, except when located almost at the extremities, probably will be certain to cause loss, either by flooding or by breaking in two if the hits be so close together that structural damage overlaps.

One CVE of Class (a) has been lost from a single torpedo hit which caused an explosion of the bomb magazines. As noted in paragraph 6, vessels of this class have been provided, or are being provided, with protection for the bomb magazines. This will materially reduce the probability of a recurrence of such a casualty.

The CVEs of Class (b) are similar to tankers, which as a class are somewhat more resistant to underwater attack than other merchant vessels of corresponding size. These CVEs, therefore, may be expected to survive the flooding of three main compartments inboard of the wing tanks if the latter contain liquid at least to the level of the external waterline.

Fuel oil in the wing tanks presents a serious fire hazard in the event of a torpedo hit in way of such tanks. Experience with commercial tankers has shown that the explosion of a torpedo is almost certain to rupture the main deck. If the torpedo hits in way of the wing tanks, which contain fuel oil at the time, the explosion will scatter oil in large quantities in the hangar and over the topsides. A serious fire will almost certainly result. A study of torpedo attacks on 36 loaded tankers disclosed the fact that on about 70% of them a serious fire developed immediately. In recognition of the hazard presented by carrying fuel oil in the wing tanks (which comprise 57% of the length) instructions have been issued which require that the wing tanks be ballasted with salt water to the external waterline except when the assigned mission makes acceptable the increased risk. In this study it has been assumed that the wing tanks are ballasted with salt water as prescribed by existing instructions.

The ballasting procedure recommended for this class has also taken into account the danger of loss by plunging by the stern in the event that the main machinery spaces (aft of the after quarter point in the CVE26-29 Class) are flooded by a torpedo hit; and if these ships be ballasted as prescribed, the hazard of plunging by the stern will be eliminated. This possibility, therefore, has been neglected. The gasoline stowage in CVEs of this Class is protected by a liquid layer which, while not complete protection, reduces the probability of a gasoline fire. The gasoline stowage comprises about 7% of the length of the vessel, but the probability of loss from a hit in gasoline tanks has been taken at 0.05. The probability of loss from a single hit, therefore, is about 0.05. These CVEs are somewhat larger and better subdivided than those of Class (a). Probability of loss following two hits thus has been placed at 0.85, rather than at 0.90 as in the case of CVEs of Class (a), to reflect their somewhat better over-all resistance to damage.

No CVEs of Class (b) in the U.S. Navy have been struck by torpedoes. Nonetheless, experience with commercial tankers has been such that, if the limitations on maximum draft and if the prescribed ballasting procedures be adhered to, the figures deduced above appear to be reasonable estimates.

As discussed in paragraph 7 the occurrence of a magazine explosion following a bomb detonation in the magazines is considered to be almost inevitable. Furthermore, a bomb detonation in way of the gasoline stowage seems almost certain to cause a fire which may well be fatal. The 500-pound G.P. bomb, with a bursting charge of about 250 pounds, probably will not cause flooding extensive enough to jeopardize CVEs of either Class (a) or Class (b) from a single hit. Probability of loss following one hit thus becomes the chance of hitting the magazines or gasoline stowage. Horizontal areas are about 21% and 6%, respectively, of total target area. Probability of loss thus becomes 0.27 for one hit with the 500-pound G.P. bomb, if fused for delay action, for both classes. Two hits on CVEs of both classes probably will not jeopardize the vessel by flooding to any greater extent than will a single torpedo hit; thus, the probability of hitting the magazines and gasoline stowage becomes the determining factor. This probability for two hits is 0.47. Multiple hits beyond two are almost certain to cause loss of CVEs of both classes.

The 1000-pound G.P. bomb, with a bursting charge of 500 pounds, is probably as lethal as the torpedo. Even though the bursting charge is somewhat less, the improved chance of causing a magazine explosion at least offsets the reduction in explosive power.

There has been no damage from bombs to CVEs as yet. The figures thus are speculative to a considerable extent.

Weapon	Assumed Charge Weight	Probability of sinking for No. of hits 1	2	3	4
		CVEs of Class (a)			
Torpedo	660# TNT	0.12	0.90	0.99	0.99
500# G.P.	250# "	0.27	0.47	0.99	0.99
1000# G.P.	500# "	0.27	0.90	0.99	0.99
		CVEs of Class (b)			
Torpedo	660# TNT	0.05	0.85	0.98	0.99
500# G.P.	250# "	0.27	0.47	0.98	0.99
1000# G.P.	500# "	0.27	0.85	0.98	0.99

CVEs of Class (a), because of light construction and the lack of a liquid layer adjacent to the shell throughout most of the ship's length, are considered to be quite vulnerable to near misses. If the 500-pound G.P. bomb, fused for delay action, detonates about 6 feet from the hull, probably three or four such near misses would cause loss. If the 1000-pound G.P. bomb, fused for delay action, detonates within about 9 feet of the hull, probably three such near misses would cause loss.

CVEs of Class (b), by virtue of the fuel oil tanks inboard of the shell, are considerably more resistant to the effects of near miss detonations below the surface. With this in mind, possibly five near misses with the 500-pound G.P. bomb or four with the 1000-pound G.P. bomb, if they detonate at the distances from the hull given in the preceding paragraph, would be sufficient to cause loss.

20. Class VIII - Battleships - A majority of the older battleships now in service have undergone modernization which has included the installation of additional deck armor and blisters. Nevertheless, their resistance to damage is not as good as that of the newer battleships which are larger, have better subdivision and better stability characteristics. Accordingly, battleships have been divided into two classes:

(a) Older battleships,

(b) Newer battleships.

Three of the older battleships, viz., CALIFORNIA, TENNESSEE, WEST VIRGINIA, have been fitted with a double blister system which puts them in a class by themselves insofar as resistance to underwater attack is concerned. It is believed that the older Japanese battleships more nearly correspond to the remainder of our older battleships. Therefore, the CALIFORNIA, TENNESSEE and WEST VIRGINIA have been excluded from consideration in this study.

Notwithstanding the fact that the torpedo defense systems of the remainder of the older battleships have been improved, a warhead with 660 pounds of TNT probably will result in a rupture of the holding bulkhead. Uncontrollable flooding of one main compartment inboard of the holding bulkhead following one torpedo hit is probable. Three hits, spaced along one side so that flooding is the maximum, would have a very good chance of causing loss, particularly if the hits occurred almost simultaneously so that initial list is large, making a difficult damage control problem. Four hits on one side would be almost certain to cause loss. With these considerations in mind the following probability figures have been assigned: 0.01, 0.05, 0.40, 0.90, 0.99, and 0.99 for one, two, three, four, five and six hits respectively. It can be seen that resistance to torpedo attack has been estimated as only slightly better than that of the CVs (Class V).

The modern battleships have, of course, the most efficient torpedo defense systems of any U.S. ships now in service. This, coupled with their large size and excellent stability characteristics, makes them considerably more resistant to torpedoes than the older battleships. In general, a 660-pound TNT warhead is not expected to rupture the holding bulkhead. It is true that the first two vessels of this class had one layer of the torpedo defense system omitted forward, abreast No. I turret, in order to obtain the hull characteristics necessary for high speed. However, in this area the spaces inboard of the holding bulkhead have been subdivided into comparatively small watertight compartments so that flooding inboard of the holding bulkhead will be sharply limited. The chief danger from torpedo attack, thus, on the modern battleships involves an extensive fore and aft rupture of the inner voids of the torpedo defense system. Taking the BB61 Class as an example, the design characteristics are such that about 360 feet of inner voids must be flooded to produce a list which would put the main deck at the waterline on the damaged side. War experience with torpedo hits has indicated that about four torpedoes, spaced at 80 feet intervals along one side, would be required to cause this condition. Even should this occur the damage control facilities installed in these vessels provide means for quickly removing the list, unless other damage disrupts damage control facilities. Under the circumstances of well-spaced hits, it is estimated that at least five hits, all on one side and striking almost simultaneously would be required to place the modern battleships in definite jeopardy. Probabilities of loss thus have been estimated as 0.01, 0.02, 0.10, 0.40, 0.70 and 0.90 for one, two, three, four, five and six hits respectively.

War experience with torpedo hits on U.S. (and British) battleships has been rather curious. With the exception of the Pearl Harbor cases, the only battleships sunk by torpedoes in this war have received at least four hits, whereas the only ships which have returned to port have suffered but one hit. The battleships damaged or sunk at Pearl Harbor were, of course, older vessels, and in most cases not in a state of complete closure at the time of the attack. Analysis of the Pearl Harbor cases indicates that two undoubtedly would have been sunk from torpedo attack, even though they had been in the open sea and in a condition of complete closure. One of these vessels received seven hits and the other is believed to have received five hits. In both cases all hits were on one side, occurred almost simultaneously and were so spaced that extensive fore and aft flooding of the torpedo defense voids occurred, plus some initial uncontrollable flooding inboard of the torpedo defense systems.

All war experience has indicated that rapid sinking of battleships, including even the old battleships, can only be obtained by several hits, occurring almost simultaneously, on one side and spaced so that extensive fore and aft flooding results. On the other hand, in many cases large ships with torpedo defense systems have been attacked by torpedoes after the ship had already been fatally damaged. In some instances this has reduced the time required for the vessel to sink; while in other cases, particularly when the vessel was damaged on the other side, this has increased the time required for sinking. Unless each case be analyzed in some detail, an exaggerated opinion of the number of torpedoes required to cause loss is apt to result. For example, WEST VIRGINIA was struck by seven torpedoes, but three of these undoubtedly were superfluous inasmuch as the flooding caused by the other four was more than sufficient to have caused her to sink.

The majority of older battleships, since their recent modernization, have armored decks of about 4 inches in thickness. Only the A.P. bombs, dropped from above 4500 feet in dive bombing or 6000 feet in horizontal bombing, will penetrate decks of this thickness. Chance of sinking with a reasonable number of hits thus must be based primarily on the chance of hitting a magazine inasmuch as the bursting charges are too small to cause extensive flooding. Total magazine area, including that for the 5-inch A.A. guns and for the aircraft bombs, is about 23% of the total horizontal area. Probabilities thus become 0.23, 0.41, 0.55, 0.65, 0.73 and 0.80 for one, two, three, four, five and six hits respectively. Insofar as direct hits are concerned, there is little distinction between the 1600-pound and the 1000-pound A.P. bombs provided both are dropped from heights sufficient to penetrate the armored deck.

The older battleships have light main and upper decks. The large G.P. bombs, therefore, can be expected to cause fires and large-scale destruction of upperworks. Although inflammable materials have largely been eliminated since the start of the war, the hazard of ready service ammunition for A.A. guns not only exists but has been somewhat increased because of the increase in numbers of A.A. weapons. Therefore, troublesome ammunition fires may be expected. Even though fires and extensive structural destruction above the armored deck result from the employment of G.P. bombs, sinking is not to be expected except when a comparatively large number of such hits are received; rather, such bombs would be expected to wreck the vessel above the armored deck to the extent that the vessel is gutted and put out of action. These considerations have governed the estimates given in the table.

The newer battleships have decks equivalent in thickness to about 6 inches in armor For penetration the A.P. bombs have to be dropped from altitudes in excess of 10,500 feet. If hits are obtained from this altitude, the chances of sinking are about the same as those for the older battleships inasmuch as target area of magazines is about the same.

The main deck, however, is 1-1/2 inches STS, and much of the topside structure is also of STS in sufficient thickness to limit blast effect and fragment damage. Information avai able to this Bureau at the present time indicates that the G.P. bombs probably will not penetrat a 1-1/2-inch STS deck prior to detonation, although deflagration (detonation either high order c low order in advance of fuse action) may result in rupture of the deck, particularly with the 2000-pound G.P. bomb. The hazard of ready service ammunition fires is present but is somewhat less than for the older battleships because of the more extensive use of STS as fragment protection. The estimates given for the G.P. bombs therefore are somewhat less than for the older battleships.

War experience with bomb hits on U.S. battleships consists almost entirely of the experiences at Pearl Harbor. It will be noted from enclosure (B) that at least six and possibly as many as fourteen A.P. bombs scored hits on the battleships present in the harbor. Of these, probably only one was lethal (ARIZONA) and it is believed to have penetrated to the forward magazines. NEVADA was hit by five bombs forward of amidships (none of which penetrated the armored deck), which caused extensive structural damage and started bad fires which were a major factor in causing her to sink. Although no U.S. battleships are now as vulnerable to fire as wa NEVADA at that time, an idea of the effects of bomb detonations above and forward of the main armored box will be obtained from a study of this case (Buships War Damage Report No. 17).

It will be noted from the tables that against the older battleships it is estimated the A.P. bombs will have a greater probability of causing loss than the G.P. bombs for numbers o hits up to and including four. For numbers of hits beyond four the 2000-pound G.P. bombs are co sidered to somewhat surpass the A.P. bombs in effectiveness if the G.P. bombs be fused for moder ate penetration prior to detonation.

Weapon	Assumed Charge Weight		Probability of sinking for No. of hits 1	2	3	4	5	6
		Class (a)						
Torpedo	660# TNT		0.01	0.05	0.40	0.90	0.99	0.99
1000# A.P.	150# "		0.23	0.41	0.55	0.66	0.73	0.79
1600# A.P.	240# "		0.23	0.41	0.55	0.66	0.73	0.79
1000# G.P.*	500# "		0.03	0.09	0.15	0.25	0.50	0.80
2000# G.P.*	1000# "		0.05	0.25	0.40	0.65	0.90	0.99
		Class (b)						
Torpedo	660# TNT		0.01	0.02	0.10	0.40	0.70	0.90
1000# A.P.	150# "		0.23	0.41	0.55	0.66	0.73	0.79
1500# A.P.	240# "		0.23	0.41	0.55	0.66	0.73	0.79
1000# G.P.*	500# "		0.01	0.05	0.10	0.18	0.40	0.70
2000# G.P.*	1000# "		0.02	0.10	0.20	0.40	0.65	0.90

Near miss effect with the A.P. bombs will be comparatively minor because of the small weight of explosive. Near misses with the G.P. bombs, if fused for detonation well under the surface, will be considerably more effective than with the A.P. bombs, but for serious damag detonation must be very close to the shell. In any event the presence of a fully-developed torpedo defense system makes the probability of sinking from near misses very small. With these circumstances in mind, it does not appear feasible to predict the number of near misses required to cause sinking.

* The probabilities for these bombs pertain to putting ships out of action, rather than sinking.

CC(with encls)to:
Cominch
Buord

C.D. Wheelock
By direction of Chief of Bureau

ENCLOSURE (A)

Cases of War Damage (Used in Compiling Enclosure (B))

Class I - Destroyers, 1500 to 1630 Tons

Name	No. of Torp.Hits	No. of Bomb Hits	No. of Near Misses	Sunk
MAYRANT(402)	-	-	1-large G.P.	No
RHIND(404)	-	-	2-	No
MUGFORD(389)	-	1-550 S.A.P.	-	No
JARVIS(393)	1	-	-	Yes
BLUE(387)	1	-	-	Yes
BENHAM(397)	1	-	-	Yes
ROWAN(405)	1	-	-	Yes
HENLEY(391)	1	-	-	Yes
SIMS(409)	-	3-550 S.A.P.	-	Yes
O'BRIEN(415)	1	-	-	Yes
HAMMANN(412)	1	-	-	Yes
WALKE(416)	1	-	-	Yes
BUCK(420)	1	-	-	Yes
KENDRICK(612)	1	-	-	No
LAFFEY(459)	1	-	-	Yes
BARTON(599)	2	-	-	Yes
SHUBRICK(639)	-	1-500 G.P.	-	No
AARON WARD(483)	-	1	4	Yes
MADDOX(622)	-	2	2	Yes
KEARNY(432)	1	-	-	No
HAMBLETON(455)	1	-	-	No
BRISTOL(453)	1	-	-	Yes
BEATTY(640)	1	-	-	Yes
GWIN(433)	1	-	-	No
"	second	-	-	Yes
MEREDITH(434)	2	1	1	Yes

Class II - Destroyers, 1850 and 2100 Tons

Name	No. of Torp.Hits	No. of Bomb Hits	No. of Near Misses	Sunk
PORTER(356)	1	-	-	No
SELFRIDGE(357)	1	-	-	No
WADSWORTH(516)	-	-	1	No
CONVERSE(509)	-	-	1	No
SAUFLY(465)	-	-	3	No
CONY(508)	-	2	-	No
DeHAVEN(469)	-	3	1	Yes
LaVALLETTE(448)	1	-	-	No
FOOTE(511)	1	-	-	No
STRONG(463)	1	-	-	Yes
CHEVALIER(451)	1	-	-	No
"	second	-	-	Yes

Class III - Light Cruisers, 6000 and 7050 Tons

Name	No. of Torp.Hits	No. of Bomb Hits	No. of Near Misses	Sunk
MARBLEHEAD(CL12)	-	2-220 G.P.	1-220 G.P.	No
SAN JUAN(CL54)	-	1-550 S.A.P.	-	No
RALEIGH(CL7)	1	1-1575 A.P.(1)	-	No
ATLANTA(CL51)	1	-	-	No
JUNEAU(CL52)	1	-	-	No
"	second	-	-	Yes

(1) Omitted in enclosure (B).

Class IV - Cruisers (10,000 Tons and Larger, CLs and CAs)

Name	No. of Torp.Hits	No. of Bomb Hits	No. of Near Misses	Sunk
HONOLULU(CL48)	-	-	1-1575 A.P.	No
PHILADELPHIA(CL41)	-	-	1-3080 A.P.	No
SAVANNAH(CL42)	-	1-3080 A.P.	-	No
MONTPELIER(CL57)	-	2-130 G.P.	-	No
BIRMINGHAM(CL62)	1(2)	2(2)	-	No
HELENA(CL50)	1	-	-	No
HONOLULU(CL48)	1	-	-	No
ST.LOUIS(CL49)	1	-	-	No
DENVER(CL58)	1	-	-	No
HELENA(CL50)	3	-	-	Yes
CHESTER(CA27)	-	1-130 G.P.	-	No
HOUSTON(CA30)	-	1	-	No
CHICAGO(CA29)	1	-	-	No
CHESTER(CA27)	1	-	-	No
PORTLAND(CA33)	1	-	-	No
NEW ORLEANS(CA32)	1	-	-	No
PENSACOLA(CA24)	1	-	-	No
MINNEAPOLIS(CA36)	2	-	-	No
QUINCY(CA39)	2	-	-	Yes
NORTHAMPTON(CA26)	2	-	-	Yes
CHICAGO(CA29)	2	-	-	No
"	4	-	-	Yes

Class V - Aircraft Carriers, CV (less WASP)

Name	No. of Torp.Hits	No. of Bomb Hits	No. of Near Misses	Sunk
ENTERPRISE(CV6)	-	-	1-130 G.P.(3)	No
YORKTOWN(CV5)	-	1-550 S.A.P.	1-550 S.A.P.(3)	No
ENTERPRISE(CV6)	-	3	1	No
ENTERPRISE(CV6)	-	2	-	No
SARATOGA(CV3)	1	-	-	No
SARATOGA(CV3)	1	-	-	No
LEXINGTON(CV2)	2(4)	2(4)	-	Yes
YORKTOWN(CV5)	2	2-550 S.A.P 1-130 G.P.	-	No
"	2	-	-	Yes
HORNET(5)(CV8)	2	3-550 S.A.P.	-	No
"	1	2-130 G.P.(4)	5-550 S.A.P.(4)	No
"	9-?	plus gunfire		Yes
LEXINGTON(CV16)	1	-	-	No
INTREPID(CV11)	1	-	-	No

Class VI - Aircraft Carriers, CVL (plus WASP)

Name	No. of Torp.Hits	No. of Bomb Hits	No. of Near Misses	Sunk
INDEPENDENCE(CVL22)	1	-	-	No
WASP(CV7)	5	-	-	Yes

(2) Considered separately in enclosure (B).
(3) Omitted in enclosure (B).
(4) Considered separately in enclosure (B).
(5) Suffered 3 separate attacks; the last, by own forces considered to have sunk her, but not included in enclosure (B).

Class VII - Aircraft Carriers, Escort(CVE)

Name	No. of Torp.Hits	No. of Bomb Hits	No. of Near Misses	Sunk
LISCOME BAY(CVE56)	1	-	-	Yes

Class VIII - Battleships

Name	No. of Torp.Hits	No. of Bomb Hits	No. of Near Misses	Sunk
SOUTH DAKOTA(57)	-	1-550 S.A.P.	-	No
PENNSYLVANIA(38)	-	1-550 S.A.P.	1[6]	No
TENNESSEE(43)	-	2-1575 A.P.	-	No
MARYLAND(46)	-	2-1575 A.P.	-	No
NORTH CAROLINA(55)	1	-	-	No
ARIZONA(39)	1[7]	8-1575 A.P.[7] and 550 S.A.P.	-	Yes
NEVADA(36)	1[8]	4-550 S.A.P.[8] 1-130 G.P.	-	Yes
OKLAHOMA(37)	5	-	-	Yes
WEST VIRGINIA(48)	7[9]	2-1575 A.P.[9]	-	Yes

(6) Omitted in enclosure (B).
(7) Treated separately in enclosure (B). Would have survived the one torpedo hit.
(8) Combined effects caused sinking.
(9) Treated separately in enclosure (B). Would have survived the two bomb hits.

ENCLOSURE (B)

SUMMARY OF WAR EXPERIENCE

Class I - Destroyers, 1500 to 1630 Tons

1. Torpedoes

(a) 16 were struck by 1 torpedo - 12 sank as result.

(b) 3 were struck by 2 torpedoes - 3 sank as result.

(includes 1 which survived 1 hit, (a) above)

2. Bombs

(a) Hits	No. Ships	Sunk	Survived
1 large G.P.	1	0	1
1-550# S.A.P.	1	0	1
3-550# S.A.P.	1	1	C
(b) Hits plus near misses			
1 hit + 4 NMS	1	1	0
2 hits + 2 NMS	1	1	0
(c) Near Misses			
1-500# G.P.	1	0	1
2	1	0	1

Class II - Destroyers, 1850 and 2100 Tons

1. Torpedoes

(a) 6 were struck by 1 torpedo - 1 sank as result, (1 of the 5 survivors subsequently sunk by gunfire for tactical reasons).

(b) 1 was struck by 2 torpedoes - 1 sank as result, (includes 1 struck previously by 1 torpedo, (a) above).

2. Bombs

(a) Hits	No. Ships	Sunk	Survived
2	1	0	1
(b) Hits plus near misses			
3 hits + 1 NM	1	1	0
(c) Near Misses			
1	2	0	2
3	1	0	1

Class III - Light Cruisers

6000 and 7050 Tons

1. Torpedoes

(a) 3 were hit by 1 torpedo - 3 survived.

(b) 1 was hit by 2 torpedoes - 1 sank, (includes one survivor of (a) above).

Class III - Light Cruisers (Cont'd)

2. Bombs

	No.Ships	Sunk	Survived
(a) Hits			
1-550# S.A.P.	1	0	1
(b) Hits plus near misses			
2-220# G.P. + 1 NM(220# G.P.)	1	0	1

Class IV - Cruisers (10,000 Tons and larger, includes CL's and CA's

1. Torpedoes

(a) 10 were hit by 1 torpedo - 10 survived.

(b) 4 were hit by 2 torpedoes - 2 survived, (of the 2 sunk, in one case gunfire seems to have been major factor).

(c) 1 was hit by 3 torpedoes - 1 sank.

(d) 1 was hit by 6 torpedoes - 1 sank.

2. Bombs

	No.Ships	Sunk	Survived
(a) Hits			
1-3080# A.P.	1	0	1
2-130# G.P.	1	0	1
1	1	0	1
1-130# G.P.	1	0	1
2	1	0	1
(b) Near Misses			
1-(A.P. large)	2	0	2

Class V - Carriers, CV (less WASP)

1. Torpedoes

(a) 4 were hit by 1 torpedo - 4 survived.
(b) 3 were hit by 2 torpedoes - 2 survived.
(c) 1 was hit by 3 torpedoes - 1 survived.
(d) 2 were hit by 4 or more torpedoes - 2 sank.

2. Bombs

	No.Ships	Sunk	Survived
(a) Hits			
1-550# S.A.P.	1	0	1
2-(mod)*	3	0	3
3-(mod)*	2	0	2
3-550# S.A.P.	1	0	1
3-550# S.A.P. and 130# G.P.	1	0	1
(b) Near Misses			
5-550# S.A.P.	1	0	1

* Accurate estimate of size not made, but were of moderate size or smaller.

Class VI - Carriers, CVL (+ WASP)

1. Torpedoes

(a) 1 was hit by 1 torpedo - 1 survived.

(b) 1 was hit by 5 torpedoes - 1 sank.

Class VII - Carriers, CVE

1. Torpedoes

(a) 1 was hit by 1 torpedo - 1 sank.

Class VIII - Battleships

1. Torpedoes

(a) 2 were hit by 1 torpedo - 2 survived.

(b) 1 was hit by 5 torpedoes - 1 sank.

(c) 1 was hit by 7 torpedoes - 1 sank.

2. Bombs

(a) Hits	No.Ships	Sunk	Survived
1-550# S.A.P.	2	0	2
2-1575# A.P.	3	0	3
5 {4-550# S.A.P. 1-130# G.P.}	1	1	(plus 1 torpedo)
8 {1575# A.P. 550# S.A.P.}	1	1	0