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DESTROYER REPORT

GUNFIRE, BOMB AND KAMIKAZE DAMAGE

INCLUDING LOSSES IN ACTION

17 OCTOBER, 1941 TO 15 AUGUST, 1945

> The Chief of Naval Operations directs that this report be shown only to those persons to whom the report would be of value in the performance of their duties.
>
> Steps shall be taken accordingly to insure that the report will be seen by those persons responsible for design, construction and repair of naval vessels, as well as for their operation, but by no others.

Classification (cancelled) (~~changed to~~
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SEA 994
on 3/29/82
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NAVAL SEA SYSTEMS COMMAND
Department of the Navy

25 January, 1947

Preliminary Design Section
Bureau of Ships
Navy Department

WAR DAMAGE REPORT No. 51

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PLATES

At the end of each section concerning an individual ship's damage a plate is included to show the arrangement in way of the damage. These plates were prepared by this Bureau and usually were based on similar drawings forwarded by the ship or the repair activities.

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[1] Standard displacement is a term established by the Washington Naval Treaty of 1922 and is defined as normal wartime displacement less fuel and water. With the lapse of the treaty in 1936 this tonnage became merely nominal. The 2050-ton Class is generally known as the 2100-ton Class and actually displaces around 2700 tons in what might be considered a typical combat condition with a two-thirds load of ammunition, fuel and provisions.

SECTION I

FOREWORD

1-1 This report and War Damage Report No. 50 analyze cause, effect and countermeasure of damage received in action in the recent war by U.S. destroyers. Damage from torpedoes and mines is covered in Report No. 50, while this report embraces damage caused by gunfire, bomb and Kamikaze attack. The purpose of the two reports is to present, after sifting the great volume of destroyer war experience, information of lasting value to damage control and engineering personnel aboard destroyers and subsequent vessels of which they are the prototype, to salvage and repair activities, and to those responsible for the design and outfitting of similar vessels. No attempt is made to anticipate the effect of the recent CROSSROADS OPERATION on the future of destroyers. Undoubtedly, much of the information herein on ammunition behavior will be outmoded as new weapons are developed; however, the damage control problem remains essentially the same though the relative importance of various factors will change.

1-2 Eleven cases of destroyer damage have been taken up in detail in this report and are grouped as follows: three cases of damage by gunfire, five exclusively by bombs and three by Kamikaze crashes. The cases chosen are typical of damage incurred by destroyers from each of these three types of attack. The sequence of cases, within each group, is chronological. It will be noted, therefore, that the latter cases of each group involve ships of later and improved design and probably more adequately trained crews, the two factors together accounting for the greater resistance of later destroyers. The text of each case includes a narrative describing the action, the damage and the damage control measures including a resumé of salvage or interim repair procedure, a discussion of the ordnance material which inflicted the damage and also such conclusions as may be drawn regarding material design and damage control technique. For the sake of brevity, the discussions of ordnance, communications and medical problems in the damaged ships have been limited to those phases which directly concerned the ship's survival.

1-3 A general summary and discussion precede the detailed case analyses in this report so that those whose duties preclude time for perusal of the entire report may more readily obtain the salient data.

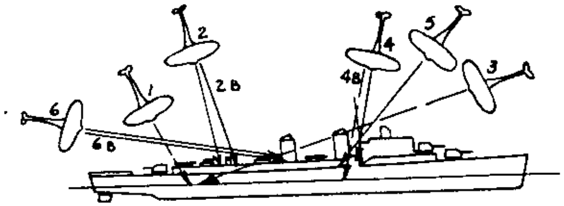
1-4 By odd coincidence what were probably the two most spectacular cases of survival after very extensive damage in destroyer hulls occurred not to DD's but to DM's converted from vessels of the short-hull DD692 Class. Illustrations of these two cases immediately follow this Section. Their damage experience has not been taken up in further detail because they were no longer, in the strict sense, destroyers.

SHIP

AARON WARD
(DM34)

2200 Tons
Standard

Damaged in
Action off
Okinawa
3 May 1945



REMARKS

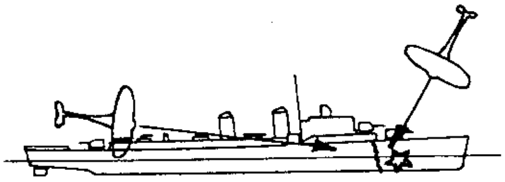
1 Near miss crash. Engine and propeller hit Mt. 3.
2 ZEKE hit Mt. 44.
2B Bomb blew out side after engineroom.
3 Near miss crash dam rigging and No.1 stac
4 VAL hit main deck, frame 81.
4B Near miss bomb blew side forward fireroo
5 VAL crashed deckho frame 90.
6 Plane hit after stack.
6B Bomb detonated in af uptakes.

Photos 2-1 and 2-2: The two photographs on the page opposite are classic illustrations of the survival power of the modern U. S. destroyer. The AARON WARD shown was one of the minelayers converted from 692 Class destroyers and should not be confused with DD483 which was sunk in 1943. She was hit as shown in the above diagram by six Kamikazes and three large bombs, estimated to have been 250 Kg GP. All spaces between bulkheads 72 and 170 flooded to the waterline except for the forward engineroom and certain starboard water tanks. Free surface extended through five major compartmen 1650 tons of water were shipped and GM was reduced to approximately 1 foot positive. Severe gasoline and ammunition fires were brought under control after about two hours with the assistance of LCS83 alongside. Firemain pressure and power forward remained available throughout due to use of the forward emergency Diesel generator. AARON WARD arrived at Kerama Retto with no freeboard aft, 18 feet draft forward and a 5-degree starboard list. After emergency repairs she proceeded under her own power to Navy Yard, Pearl Harbor, using the starboard shaft.

SHIP

LINDSEY
DM32)

2200 Tons
Standard



Damaged in
Action off
Okinawa
12 April 1945

First Hit: VAL approached from astern and crashed along starboard side as far forward as frame 69. Small bomb detonated, fragments penetrating depth charges.

Second Hit: VAL with bomb in steep dive hit port side frame 30 at first platform level. Magazine explosion blew off bow including Mt. 1.

Photos 2-3 and 2-4: The two photographs on the opposite page illustrate the effect of a powder explosion in No. 1 magazine on a 2200-ton Class destroyer. LINDSEY, a minelayer conversion from DD692 Class vessel, was hit as ndicated in the diagram. The second hit occurred about one minute after the irst. Simultaneously with the second hit a heavy dull explosion took place accompanied by heavy brown smoke. Observers also identified a sharp report believed to have been due to the detonation of the second plane's bomb. Evidence indicates that the magazine explosion consisted of a mass deflagration of 5-inch powder cartridges in A-404-M on the third platform level, frames 18 to 26. This magazine was separated from the group two magazine by the refrigerated spaces. Keel sheared at frame 30. Main deck hinged upward at about frame 60. Flooding extended to bulkhead 72. Trim by the bow increased only about 18 inches. Main propulsion plant and gyro remained intact. Local control of the after battery was regained a few minutes after the hit. LINDSEY made port stern first assisted by tow. After emergency repairs at Kerama Retto, during which bulkhead 60 was made watertight, LINDSEY was towed stern first to Guam. Return to Norfolk was made on own power with false bow installed at Guam.

SECTION II

SUMMARY AND DISCUSSION

A. General

2-1 There have been reported to the Bureau of Ships 251 instances of damage to U.S. destroyers resulting from enemy action between 17 October 1941 and the cessation of hostilities on 15 August 1945. These cases may be classified by cause and result as follows:

TABLE I

Analysis of 251 Reported Instances[1] of Destroyer Damage by Enemy Action

Cause	Gunfire, Bomb or Kamikaze	Torpedo or Mine	Miscellaneous [2]
Result	30 sunk	27 sunk	3 sunk
	162 survived	21 survived	8 survived
	84% survival	44% survival	--

[1] In many cases a single instance represents multiple hits or near misses.

[2] Miscellaneous includes strafing, suicide boats, ramming and unknown.

Note: Approximately 30 cases of damage to destroyers converted to minecraft occurred. These have not been included in the table.

2-2 In any consideration of the survival powers of the modern destroyer, the personnel factor must be recognized. The ship as built has proved its ruggedness but many vessels survived unprecedented damage largely due to the high degree of training and the heroic determination of the ship's damage control organization. For the same reasons, several that were eventually lost were enabled to remain in action appreciably longer. A study of a loss is often even more instructive than one of a survival, provided enough data are available to make a thorough analysis. In four of the eleven cases taken up in detail in this report, the ship sank. The selection of a case for inclusion in this report does not imply that it represents either one of the best or one of the poorest performances but simply that the case is illuminating and the damage control problems instructive.

2-3 The fundamental treatise in the U. S. Navy on the subject of damage control is the pamphlet entitled, "Damage Control Instructions, F.T.P.170(B),"[1] issued by the Chief of Naval Operations. F.T.P.170(B) defines damage control as comprising the maintenance of fire power, mobility, maneuverability and floatability, and states that it is to be accomplished by the preservation of stability and buoyancy, by control of list and trim, by the rapid repair of structure, vital systems and equipment, by counteracting the effects of fire, and by facilitating the care of personnel casualties. The size of a destroyer is such that, after major damage, firefighting and the preservation of stability and buoyancy are usually the problems of prime consideration in the ship's survival. There is little that the ship's company can do on the spot to repair major damage to either the structure or the engineering plant.

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[1] A new publication, U.S.F. 81, is scheduled to supersede F.T.P.170(B) in 1947.

2-4 In a damaged destroyer, reserve buoyancy, stability characteristics, and extent of flooding are closely inter-related and it is impracticable to consider one independently of the others. Our modern destroyers are largely four-compartment ships; i.e., four major compartments extending from one main transverse bulkhead to the next may be freely flooded from the sea before the main deck becomes awash. It is attempted in basic design to give these ships stability characteristics commensurate with this floodable length. It is therefore unlikely that a properly loaded destroyer would capsize prior to the virtual elimination of reserve buoyancy. Abnormal winds and wave forms in severe cyclonic storms have caused some destroyers to capsize without extensive flooding, but this is exceptional. The preservation of adequate buoyancy and stability is largely contingent upon the control of flooding.

2-5 Fires hazard the ship's survival not only because they may initiate explosions which demolish large sections of the ship but also because in ships of destroyer size and smaller, particularly, they seriously interfere with handling the other problems that ensue after damage is incurred. Fires normally must be brought under control before control of flooding can be undertaken. Firefighting techniques so far have been much more efficient than those employed to control flooding. For this reason more destroyer losses are attributable to progressive flooding than to fire.

2-6 Mine and torpedo hits have resulted in the loss of destroyers in a higher percentage of cases than have gunfire, bomb or Kamikaze hits, primarily because the underwater ordnance carried a larger explosive charge to a more vulnerable spot. In general, the impact and blast of a projectile or a bomb, or a Kamikaze with its bomb load caused damage centered above the waterline. In numerous cases, abnormal charges or repeated hits topside have caused structural damage as extensive as that resulting from a torpedo, but being in a less critical area with respect to flooding, the damage was not so frequently fatal. In the future, the efficiency of bombs or of guided missiles or pilotless aircraft may be increased to that of torpedoes through the use of more powerful explosive charges and improved fuzing; however, the most effective attack will remain that which introduces flooding.

2-7 As shown in TABLE I, the loss of 30 U. S. destroyers can be ascribed primarily to enemy action involving gunfire, bomb or Kamikaze attack. The further analysis in TABLE II below showing how the losses occurred is in some cases arbitrary because, from the frequently incomplete data afforded by survivors, the sequence in which reserve buoyancy or stability was lost, structure failed, or explosions occurred will never be determined.

TABLE II

Governing Elements in Loss of Destroyers Sunk By Gunfire, Bomb or Kamikaze Attack

A. Flooding - 14 Losses

a. Loss of buoyancy aggravated by radical list -

1.	PRESTON (DD379)	1500T	Gunfire	Guadalcanal	11/15/42
2.	MADDOX (DD622)	1630T	Bombs	Sicily	7/10/43
3.	HOEL (DD533)	2050T	Gunfire	Samar	10/25/44
4.	JOHNSTON (DD577)	2050T	Gunfire	Samar	10/25/44
5.	REID (DD369)	1500T	Kamikaze	Leyte	12/11/44
6.	DREXLER (DD741)	2200T	Kamikaze	Okinawa	5/28/45

b. Loss of buoyancy aggravated by radical trim -

1.	SIMS (DD409)	1570T	Bombs	Coral Sea	5/7/42
2.	DUNCAN (DD485)	1630T	Gunfire	Guadalcanal	10/12/42
3.	CALLAGHAN (DD792)	2050T	Kamikaze	Okinawa	7/29/45
4.	LUCE (DD522)	2050T	Kamikaze	Okinawa	5/4/45
5.	MORRISON (DD560)	2050T	Kamikaze	Okinawa	5/4/45
6.	W.D. PORTER (DD579)	2050T	Kamikaze	Okinawa	6/10/45

c. Loss of buoyancy on relatively even keel -

1.	DeHAVEN (DD469)	2050T	Bombs	Guadalcanal	2/1/43
2.	AARON WARD (DD483)	1630T	Bombs	Guadalcanal	4/7/43

B. Structural Failure - 6 Losses

a. Jackknifed -

1.	BROWNSON (DD518)	2050T	Bombs	Cape Gloucester	12/26/43
2.	BUSH (DD529)	2050T	Kamikaze	Okinawa	4/6/45
3.	MANNERT L. ABELE (DD733)	2200T	Kamikaze	Okinawa	4/12/45
4.	PRINGLE (DD477)	2050T	Kamikaze	Okinawa	4/16/45
5.	LITTLE (DD803)	2050T	Kamikaze	Okinawa	5/3/45

b. Sagged by the stern

1.	COLHOUN (DD801)	2050T	Kamikaze	Okinawa	4/6/45

C. Magazine Explosion - 5 Losses

a. On direct hit -

1.	LONGSHAW (DD559)	2050T	Gunfire	Okinawa	5/18/45

b. Following fire -

1.	CUSHING (DD376)	1500T	Gunfire	Guadalcanal	11/13/42
2.	MONSSEN (DD436)	1630T	Gunfire	Guadalcanal	11/13/42
3.	ABNER READ (DD526)	2050T	Kamikaze	Leyte	11/1/44
4.	MAHAN (DD364)	1500T	Kamikaze	Ormoc	12/7/44

Note (a) CASSIN (DD372) and DOWNES (DD375), which were in dock when damaged, and three 1200-ton destroyers have been omitted from the above report. Also omitted are several cases in which a torpedo hit was involved in addition to gunfire or bomb hits.

(b) The word "capsized" has been deliberately avoided in the headings of the above table in order to describe more accurately the manner of sinking. In certain cases, heavily damaged warships, notably BB's, CV's, CVE's and CA's, both foreign and U.S., have rolled over so as to expose the keel and remained bottom up for a short period before sinking. This behavior can quite properly be described as capsizing. In the DD's listed in the table this has not occurred. Where complete loss of transverse stability has occurred in these ships it has come about virtually simultaneously with the exhaustion of reserve buoyancy. Excessive trim, sometimes indicative of the loss of longitudinal stability, has also made it difficult to draw the line between groups in the table. Some of the destroyers lost have listed about 90 degrees before they submerged, also some have canted their bows or sterns almost perpendicularly as they sank, but in each case the loss has been so rapid that it is not accurate to attribute the loss of the ship entirely to the loss of either transverse or longitudinal stability.

B. Effect of Kamikaze Tactics

2-8 A short digression on Kamikaze, or suicide plane tactics, is appropriate in view of the fact that nearly half of the destroyers damaged during the war by above-water weapons were victims of this form of attack. Destroyers bore a disproportionate share of such attacks because of their employment as screening vessels and fighter director or radar picket ships. The most frequent Kamikaze approach consisted of a steep glide with some prominent feature of the superstructure as the target. Usually, one or more bombs were carried by the plane, but owing to the lower striking velocity, penetration of such bombs to the interior of the hull was generally less than normally achieved by orthodox bombing tactics.

2-9 Two publications[1] issued by the Chief of Naval Operations analyze the technique and results of Kamikaze attacks against Allied ships in some detail. These indicate that this form of attack was undeniably more accurate (i.e., more hits per plane employed) than orthodox forms had been although in part this may be attributed to the greater desperation of the enemy and the closer proximity to his major air bases. Kamikaze tactics are inefficient, however, when compared in effectiveness to coordinated dive bombing and torpedo attacks as conducted by the Japanese carrier groups early in the war and by our own carrier aircraft. The latter type of attack sank or contributed heavily to the loss of at least 31 major Japanese warships[2] and 10 of our own, whereas Kamikaze failed to immobilize a single major warship. Against unarmored vessels Kamikaze attack had greater success but still was less effective than orthodox attacks. Ninety-five of our destroyers were damaged by suicide planes or Baka bombs during the war. Only 13.7 per cent or 13 of these ships sank as a result, whereas destroyer losses following bomb or torpedo damage in air attacks were 28.9 per cent.

2-10 The widespread use of Kamikaze tactics developed only after the striking power of Japanese carrier forces had been finally destroyed in the Battle for Leyte Gulf. It was forced upon the Japanese Navy partly because the means with which to carry out effective orthodox attacks by carrier borne aircraft were no longer available and partly because U.S. Task Force

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[1] OPNAV-16-V A106 of 23 May 1945 and OPNAV-16-V A118 of 23 July 1945
[2] BB, CV, CVL, CA, CL, as indicated in NAVTECHJAP Target Report No. S-06-3 of January 1946

defenses sharply reduced the effectiveness of orthodox Japanese land-based aircraft tactics. The Kamikaze form of attack is of particular interest not so much because a repetition of such attacks is anticipated but because the damage control problems created are not unlike those which may result in the future from guided missile or pilotless aircraft attack.

C. Enemy Weapons

2-11 The primary source of information in this report on bombs and projectiles has been the pamphlets issued by the U. S. Navy Bomb Disposal School, which contain information based on recovered enemy missiles. In part this data has been amplified by reports from the U.S. Naval Technical Mission to Japan. Data on Kamikaze and Baka bombs are primarily from OPNAV publications as indicated in the paragraphs pertaining to these weapons.

2-12 To clarify the ordnance nomenclature in the subsequent text, U.S. terms have been arbitrarily assigned to designate various foreign types of bombs and projectiles. The designation used in each case has been determined by the charge-weight ratio only and other characteristics of the missile are not necessarily commensurate. The Japanese system of classifying their own bombs was quite irregular; therefore, care must be exercised in any comparison of the effectiveness of their bombs with ours of similar weight and designation. The designations used in this text for bombs and their corresponding charge-weight ratios are as follows: GP or general purpose, 50 per cent; SAP or semi-armor piercing, 30 per cent; AP or armor piercing, 15 per cent. In projectiles the designations used and charge-weight ratios are: HC or high capacity, 7 to 12 per cent; Common, about 5 per cent; and AP, 2 per cent.

2-13 The Japanese bombs most frequently encountered by U.S. warships were the 250 Kg SAP type 99 No. 25 with 130 pounds of explosive and the 63 Kg GP type 99 No. 6 with a 70-pound charge. The former usually employed both nose and tail fuzes set for detonation slightly beyond impact and the records reveal it to have been the most effective Japanese bomb against destroyer targets. Late in the war 250 Kg, 500 Kg and 800 Kg GP bombs were frequently employed by the Japanese, but specific hits on destroyers by these missiles have not been positively identified. AP bombs and AP projectiles were relatively ineffective against destroyers and were rarely employed against this type of ship.

2-14 Japanese projectiles encountered by our destroyers were of orthodox design and predominately impact fuzed. Caliber varied from 25mm to the 46cm (18.1 inches) in the main battery of YAMATO.[1]

2-15 Plane types were identified in only about 60 per cent of the Kamikaze attacks at Okinawa. Of those identified half were VALS or ZEKES, an 8000-pound dive bomber and a 6000-pound fighter, respectively. Approximate pertinent characteristics of these are given below:

	VAL	ZEKE
Wing span	47.5 ft.	36.2 ft.
Bomb load (normal)	1-250 Kg	2-60 Kg
Gas load	1700 lb.(max.)	1400 lb.(max.)

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[1] YAMATO participated in the Battle for Leyte Gulf in the gunfire action with U.S. Task Unit 77.4.3, 25 October 1944. U. S. Force included three DD's. See Section IV.

The other types employed in suicide tactics included aircraft as large as the twin engined VB, BETTY, capable of carrying a 1765-pound torpedo or bomb loads up to 1000 Kg.[1]

2-16 The Baka, a Japanese version of a guided missile, is described in detail in TAIC Summary No. 31, OPNAV 16-V T131 of June 1945. It was carried to its launching point by a parent plane, then guided to its target by a suicide pilot who could employ rocket propulsion to increase its speed or range. Total weight approximated 4500 pounds including about 1135 pounds of explosive in the warhead. Maximum range was about 60 miles from a launching altitude of 30,000 feet. Only three destroyers, MANNERT L. ABELE (DD733), STANLY (DD478) and SHEA (DM30), are definitely known to have suffered Baka hits. One of these sank, but the major portion of the damage was caused by a previous Kamikaze hit. Inefficient use of the large explosive charge in each case was indicated by a detonation that was either overly delayed or low order.

D. Structural Damage and Hull Strength

2-17 The most important strength members in the hull girder in a destroyer are the shell and the main deck and their respective longitudinals. The parts of the structure subjected to the greatest stress are normally those farthest from the neutral axis in the mid-length of the ship. Below the neutral axis the keel and bottom plating with attached longitudinals carry the major portion of the load on the ship's girder and are therefore subjected to the greatest unit stress. Above the neutral axis the sheer strakes and stringer plates with associated longitudinals carry the major portion of the load and, similarly, are subjected to the greatest unit stress. The rupture or collapse of any of these principal strength members seriously weakens the hull girder. Extensive buckling or rupture in the mid-length of both sheer strakes and stringers or of the keel and bottom plating indicates that danger of complete structural failure is critical. Survival or loss is then determined by the extent of flooding, the condition of wind and sea and the way the ship is handled. As indicated in TABLE II six destroyers, all 2050 or 2200 tons standard, were lost through structural failure following above-water attacks, usually multiple Kamikaze attacks which severely damaged the upper flange of the hull girder. Nevertheless, the reserve strength of the hull girder in the two classes is, as pointed out in War Damage Report No. 50, appreciably greater than in earlier destroyers owing to the greater beam and depth and the widespread use of STS in the hull.

2-18 Normally the repair of major structural damage is beyond the scope of damage control in destroyers. However, the case of GANSEVOORT (DD608) indicated what can be accomplished with limited resources. While on a remote assignment GANSEVOORT was heavily damaged in way of her engineering spaces by a Kamikaze with a large bomb. Structural damage was so severe amidships that it was hazardous for the ship to proceed without extensive repairs. Since no repair activities or salvage units were available to accomplish the repairs, the ship's company undertook the restoration of the upper flange of the hull girder in way of the damage. After four weeks of intensive effort handicapped by a dearth of structural material, longitudinal strength in the mid-length was sufficiently restored to permit the ship to proceed under tow more than a thousand miles to an advanced base. There will only be infrequent occasions when damage control personnel in destroyers will be called upon to repair such extensive structural damage. However, the danger of structural failure after extensive damage is an

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[1] For further information see (a) "Statistical Analysis of Japanese Suicide Effort Against Allied Shipping During Okinawa Campaign" OPNAV-16-V A118 of 23 July 1945
(b) "Japanese Aircraft," TAIC Manual No.1, OPNAV-16-VT No.301

important consideration in damage control. For this reason it is well for operating personnel to have a general understanding of the major functions of the principal strength members of the hull girder and to keep in mind the effect on the overall strength of the ship produced by various amounts of structural damage.

2-19 The plating throughout a destroyer is so light that it is readily penetrated by thin-walled shells or bombs and by fragments. Hence, the HC projectile and the GP bomb are best suited for use against this type of ship. HC projectiles are normally fuzed to detonate on impact while GP bombs are usually fuzed with a short delay to increase their chances of detonating in the vicinity of, or below, the waterline. The most effective Japanese bombs used against destroyers detonated 12 to 15 feet beyond impact. AP projectiles and bombs, since they are fuzed for a considerable delay, normally pass all the way through a lightly built ship unless a heavy unit of machinery or ordnance is encountered en route.

2-20 There was no instance in the recent war in which gunfire damage seriously weakened the main hull girder of our destroyers. The most serious damage caused by projectile hits was the disruption of watertight integrity and of vital systems or equipment. This was achieved by impact and fragmentation. Owing to the smaller explosive charge carried, the blast damage caused by a projectile hit is minor compared to that of other weapons.

2-21 Bombs of the sizes generally used against naval targets in the past war seldom produced serious blast damage to structure beyond a radius of about 20 feet. The detonation in a destroyer of a 500-pound SAP bomb usually carried away several adjacent decks and bulkheads as in KILLEN (DD593). The near misses which were effective detonated directly under a ship or within a few feet of the side. Fragments of near misses detonating in the water quickly lost velocity and were not a source of serious damage. The shock of a near miss detonating underwater close aboard, however, frequently caused a flexural vibration which buckled structure remote from the blast itself. The bombs carried by Kamikaze planes, particularly where large general purpose types were used, caused much more severe structural damage than did the impact of the plane.

2-22 Fragmentation both of projectiles and of bombs is directly related to the charge-weight ratio and to the amount of metal in the missile. Extensive tests conducted at Dahlgren by the Bureau of Ordnance and described in O.P. 1458 "Fragmentation Data on Bombs and Projectiles," showed a direct relation between the charge-weight ratio and the average fragment velocity. An approximate median fragment velocity through about the first 30 feet may be expressed by the formula $v = 10{,}000\sqrt{chg/wt}$, where v is in feet per second. The constant 10,000 applies to TNT. Where a more powerful explosive is used the constant increases proportionately. Median velocity for fragments of a 500-pound GP bomb averaged about 7200 feet per second while that of fragments of a 6-inch HC shell averaged about 3200 feet per second. The size of fragments depended on the charge-weight ratio, and within the same charge-weight ratio the number of fragments varied with the size of the case. The fragment velocities discussed above apply to the burst of a missile at rest. Nearly all these fragments go out in what is called a beam spray or within an arc of 15 degrees on either side of a plane perpendicular to the axis of the missile at its mid-point. In the pattern of fragments from a missile in flight the speed of forward motion must be applied as a vector to the beam spray. The result is a cone-shaped pattern, most marked in the burst of AP shells and least noticeable in GP bombs.

2-23 The striking velocity of projectiles to date has been appreciably higher than that of any but large bombs dropped from great altitudes.

At intermediate ranges the striking velocity of 5-inch projectiles is in the order of 900 feet per second while that of 8-inch projectiles is about 1250 feet per second. A 500-pound SAP bomb delivered from an altitude of about 2000 feet by a dive bomber making about 350 knots has a striking velocity around 650 feet per second. With the advent of rockets and of jet propulsion the striking velocities of newer types of missiles undoubtedly will increase beyond that of projectiles.

2-24 The current policy of the Navy with respect to splinter protection is to eliminate intermediate weights between 30-pound STS and 10-pound STS. This was established by a CNO letter of 30 July 1945 in which it was directed that around important ship and fire control stations, except where heavier protection had been specified, 30-pound STS would be used and for other exposed personnel and for positions of secondary importance 10-pound STS would be used. Both experiments and war experience have shown that 25-pound STS is the minimum thickness which will provide reasonably effective protection from the fragments of projectiles and bombs which detonate aboard or in the air close aboard, and that penetration falls off quickly for greater thicknesses. The value of 10-pound STS is mainly in protection from weather and distant bursts (beyond a 50-foot radius).

E. Buoyancy, Stability and Control of Flooding

2-25 The tendency of a ship to right itself after an inclination in the athwartships plane is described as transverse stability. In the fore and aft plane the righting tendency is described as longitudinal stability. The two are interrelated but for purposes of analysis are considered independently, transverse stability receiving the greater consideration since longitudinal stability usually has a much larger margin of safety. The evaluation of the transverse stability requires an analysis of the ship's behavior from several aspects which are collectively described as stability characteristics and are graphically indicated in the family of statical stability curves, each of which consists of a plot of the righting arm against the angle of heel for a given condition of loading. From such a family of curves, cross curves of stability may be drawn showing the change of the righting arm with change in displacement for various angles of list and assuming no change in the ship's center of gravity. The stability characteristics of a vessel for any given condition (i.e., for a definite displacement and value of KG) are illustrated by the statical stability curve and are considered to comprise the following:

(a) The length of the maximum righting arm.

(b) The angle of list at which the maximum righting arm occurs.

(c) The range of stability or the angle beyond which the righting arm becomes negative.

(d) The dynamic stability, or the energy required to heel the ship through the range of stability, represented by the area under the curve and above the horizontal axis where the ordinates are righting moments instead of righting arms.

(e) The height of the transverse metacenter, M, above the center of gravity, G, or GM, which also is the ordinate at 57.3 degrees of the tangent to the statical stability curve drawn from the origin.

Of these measurements, GM is usually the most indicative of the overall adequacy of the ship's stability.

2-26 Usually it is not feasible for destroyer personnel to compute mathematically the reserve buoyancy or the stability characteristics of their ship after damage. The time required as well as the inexactness of data often precludes such an approach. But they should be able to estimate, without calculations, whether stability and buoyancy have been critically impaired and to recognize an improvement or deterioration in their situation beyond any damage initially incurred.

2-27 Recently issued Damage Control Books for destroyers of the DD692 (long hull) Class contain graphically illustrated data for determining the effect on stability of flooding any compartment. A limiting displacement before damage, a curve for determining allowable KG before damage and instructions for liquid loading are given. The method of obtaining the allowable deck load from the curve of allowable KG is illustrated. There is also outlined the procedure detailing the specific application to these destroyers of the principles set forth in F.T.P. 170(B) and in the Handbook of Damage Control for corrective action after underwater damage. At a later date similar data will be added to all destroyer damage control books. If the instructions for loading before damage are followed, the ship should be able to survive the flooding of any group of four main compartments aft of bulkhead 72 or the six main compartments forward of bulkhead 72. A quick determination of whether stability and buoyancy are critical must be based on whether the extent of flooding exceeds the above limit and the degree of reduction of stability which has occurred can be roughly estimated from the relation between the free surface area of detrimental flooding and the allowable limit of free surface area.

2-28 Subsequent to initial damage it is a matter of good seamanship for key personnel to discern promptly changes in reserve buoyancy and stability. A change in the former is best indicated by variation in the mean freeboard amidship. Appreciable changes in stability will be evident if information as to any variation in the extent of flooding is promptly obtained and evaluated. Whether the net effect of flooding in a specific compartment is detrimental to stability can be readily determined from the color of the flooded compartment on the Flooding Effect Diagram in the Damage Control Book. Free surface anywhere in the ship always has a detrimental effect but in certain compartments the effect of added low weight in lowering the ship's center of gravity may overbalance the free surface effect. Such spaces have accordingly been colored green in the Flooding Effect Diagram indicating that the net effect of flooding improves GM. The reduction of free surface area by the elimination of shallow flooding or by the solid flooding of low compartments invariably produces an improvement in GM. On the other hand, immersed areas of the main deck have the same adverse effect on GM as free surface areas within the ship.

2-29 F.T.P. 170(B) states that the danger of capsizing does not become serious in a damaged ship until the weather deck at the low side becomes more or less continuously awash. This criterion also may be adapted to the danger of plunging. In DD's the main deck at bow or stern can become immersed through a length of several frames without sterious loss of water plane area, but such a deep draft usually indicates that very little reserve buoyancy remains. Generalizations on the best method of determining when to abandon ship are likely to be misleading. A steadily increasing trim or list after damage,as in AARON WARD or in ABNER READ, is an unmistakable indication of approaching disaster. However, the critical nature of any specific angle of list or trim must be weighed against the prospect of halting progressive flooding and reducing free surface. In short, the question is whether control of flooding can be established before the flooded area exceeds the floodable length, which, as shown in the cases of MAYRANT and HUGH W. HADLEY, includes at least four major compartments.

2-30 The effect of flooding on the stability characteristics of a destroyer is more critical in way of the first platform aft than anywhere else in the ship. There are several contributory reasons for this, namely:

(a) The height of the first platform deck aft is such that it is at once low enough to admit flooding from the sea and high enough to thereby raise the center of gravity of the ship.

(b) The spaces in this area extend nearly the maximum beam of the ship and therefore have a large free surface effect.

(c) The main transverse bulkheads have numerous doors which make the watertight integrity highly vulnerable to blast damage.

2-31 The loss of WILLIAM D. PORTER (DD579) illustrated the danger involved in the loss of watertight integrity on the first platform deck aft. A bomb detonated under the ship in way of the after engineering spaces, flooding the after engineroom and distorting some doors and hatches along the first platform deck aft. Slow flooding progressed through four compartments abaft the engineroom and also filled the after fireroom through the damaged bulkhead gland on the starboard shaft. For three hours after initial damage the draft aft increased slowly until the after half of the main deck was immersed and the fantail was 16 feet under water. The ship then rolled on its beam ends and plunged by the stern. All hands survived. A similar sequence of flooding aft, followed by plunging, took place more rapidly in the losses of DREXLER, LUCE, MADDOX and MORRISON (See TABLE II).

2-32 In later vessels of the DD692 Class there are no doors in the third bulkhead abaft the after engineroom. Access fore and aft is obtained by going up and over via the after deckhouse. An alteration sealing the doors in bulkhead 170 both in the remaining ships of the 692 Class and in the 445 Class has now been authorized and, when accomplished, will markedly reduce the vulnerability of these ships to progressive flooding in the after end of the ship. Owing to the narrower beam and higher freeboard forward, flooding in that area is not so serious and a similar precaution is not required. With respect to the forward end of the ship, the 692 Class has an important improvement over earlier classes in that all main transverse bulkheads have been carried up to the first platform deck intact, with no access openings.

2-33 Control of flooding after damage may be divided into two important phases:

(1) Halting leaks.
(2) Pumping out.

The ship's pumping facilities are important in halting leaks as well as in pumping out. Compartments which fill slowly sometimes can be regained by rigging portable emergency pumps to handle the leakage while plugging efforts are going on. If the level of flood water cannot be lowered by the pumps, at least they may produce enough flow to aid in locating the holes. Experience shows, however, that too often the first phase is neglected and the second in consequence fails. In AARON WARD (DD483) the salvage pumps of the assisting tug futilely circulated water between an engineroom and the sea. In WILLIAM D. PORTER no leaks were plugged and the ship slowly flooded and plunged despite the use of numerous pumps. Controlling flooding, like firefighting, requires much preparation and training. ALBERT W. GRANT, in the light of her hazardous experience, recommended carrying prefabricated patches of box and folding plate types in assorted sizes. The availability of such gear greatly expedites the job of plugging leaks and also makes the patches more seaworthy. War experience indicated that halting leaks was one of the weakest phases of damage control.

2-34 The importance of promptly plugging above-water holes in the shell should not be overlooked. Frequently such holes have become submerged some time after initial damage due to an increase of list, trim, or bodily sinkage. Lists temporarily introduced in damaged destroyers by the use of rudder, or by the "squatting" aft as speed was increased, have resulted in taking on water due to failure to plug above-water holes. In ALBERT W. GRANT, holes above the waterline at the time of damage were later immersed by bodily sinkage and change of trim, despite a list to the opposite side. JOHNSTON shipped water through a hole in the main deck due to heeling on high speed turns.

2-35 The experience of ALBERT W. GRANT also illustrated the principle that in controlling flooding it is advisable to start in the compartments on the periphery of damage and work toward the center. Before attempting to handle leaks in spaces where damage is severe, thereby making the success of the venture doubtful, repair personnel generally do better to remove loose water and patch fragment holes in way of damaged compartments remote from the hit, so that the watertight integrity of these compartments is promptly regained.

2-36 The free surface effect of loose water is independent of its depth, hence shallow flooding is as detrimental to GM as deep flooding, and important improvements result with a minimum amount of pumping if the shallow water is removed first. An interesting point in connection with the problem of removing loose water from a listed ship is that the removal of shallow flooding has an entirely beneficial effect in reducing the list; whereas, in the case of flooding pocketed against the overhead, the removal of flood water can at first aggravate the list since the first water removed may reduce the weight of flood water on the high side of the ship and may also increase the free surface area. In critical cases of damaged stability where GM has become negative, this small difference in the effect of pumping out shallow flooding versus pumping out deep flooding might prove to be the determining factor in the retention or loss of a positive righting arm. The removal of flooding pocketed against the overhead should, therefore, be undertaken with caution in damaged ships with an appreciable list if stability is critical.

2-37 Engineering personnel in some destroyers have deliberately flooded machinery spaces to a depth of about 2 feet to provide a haven from live steam in case of damage. The unwarranted hazard to which this practice subjects the ship with regard to its stability and reserve buoyancy has been the subject of correspondence between this Bureau and the Forces Afloat. The obvious risk involved from a stability standpoint was brought to the attention of commanding officers of destroyers and destroyer escorts by ComDesPac Serial 01498 of 1945 (included in ComCruPac-ComDesPac Monthly Orders of 1 May 1945).

2-38 Destroyer pumping facilities cannot handle more than relatively slow leakage, as from a bulkhead that has been punctured by a few fragments rather than one ruptured by blast. Fixed drainage facilities are described in each ship's Damage Control Book. The authorized destroyer allowance of portable pumping equipment consists of five 2-1/2-inch portable electric submersible pumps, one 60 GPM gasoline handy-billy and two portable P-500 gasoline pumps. Two 4-inch eductors are provided with each P-500 pump, giving each pump a capacity up to 1000 GPM under low discharge head conditions. Repeated cases of failure of portable pumping equipment have been reported. Improper maintenance or operation usually has been the cause. Damage control personnel require thorough knowledge of the proper maintenance as well as the limitations and operating principles of such equipment. Recommended sources of pertinent information on this subject are the manufacturer's instruction books, the booklet "Uses and Applications of Portable Emergency Pumping Equipment" (NavShips 250-689) and BuShips War Damage Report No. 50, paragraphs 2-28 to 2-34.

F. Fire Protection

2-39 About 50 per cent of the destroyers damaged by above-water weapons had to combat resultant fires. Of the eleven cases detailed in this report, seven involved serious fires and three had minor fires. The minor fires might have grown to serious proportions, had they not been promptly extinguished. The high percentage of survivals among destroyers damaged by above-water attack is in great measure due to the effectiveness of a three-fold fire protection program:

(1) Reduction of fire hazards
(2) Increased allowance, dispersion and effectiveness of firefighting equipment
(3) Training of officers and men at the Navy Firefighter Schools

2-40 During the first year of our participation in the war the Navy suffered severe losses due in large measure to inadequate fire protection in combatant ships. The zeal with which fire hazards were eliminated from ships after this became evident was commendable, but in some cases excessive, as in one case where the fuel for the handy-billy was jettisoned as a fire hazard. In subsequent construction, in addition to numerous improvements in firefighting facilities, most of the avoidable fire hazards in ships were eliminated during the building period. Many unavoidable hazards remain, however. Besides fuel and ammunition, items such as books, papers, clothing and bedding constitute a fire hazard of considerable magnitude in action and the reduction of that hazard is a continuous day-to-day task.

2-41 The wartime improvement in firefighting facilities in destroyers has been very extensive. In the 2100-ton destroyer, the firemain is now served by four fire-and-bilge pumps, plus two fire-and-flushing pumps. Including portable pumps, these ships each have been provided enough pumping capacity to operate about thirty 1-1/2-inch all-purpose fog nozzles simultaneously. The 2200-ton destroyer has been even better equipped. In addition to the above equipment, two emergency electric fire pumps are located outside the engine spaces and operable from the emergency Diesel generators. These pumps serve stand-pipes to the main deck, as well as connections to the firemain. The pumping capacity of destroyers of this Class is such that it is possible to employ about fifty 1-1/2-inch fog nozzles simultaneously under optimum conditions. In all classes of destroyers the variety of firefighting techniques for which equipment is now provided is notable. High and low velocity water fog, which are most useful against fires of large magnitude, CO_2 for use on electrical or minor class B fires and chemical and mechanical foam for oil or gasoline fires, each may be selected as occasion demands. The times required to control three large conflagrations in well equipped ships furnish an interesting standard for comparison. ZELLARS (DD777)[1], HUGH W. HADLEY, and STORMES, each overcame a severe gasoline and ammunition fire in 15, 25 and 20 minutes, respectively.

2-42 Probably the greatest damage control problem introduced by the suicide plane was the sudden intense and widespread gasoline fire which usually enveloped the area of the hit. One such fire, uncontrolled, led to the handling room explosion and loss of ABNER READ, despite only minor initial structural damage. In HUGHES (DD410), efficient firefighting personnel brought a fire of similar proportions under control. The promptness with which an adequate number of hose streams was brought to bear has proved the most important factor in controlling such fires. The handling of a serious gasoline fire following a Kamikaze crash on WALKE (DD723)[2] was another excellent example of efficient firefighting. A plane approaching from the port quarter crashed WALKE's navigating bridge just abaft the 5-inch battery director. Fire boundaries were quickly established by sprinkling the 40mm ready service rooms under Nos. 1 and 2 mounts and the No.2 5-inch upper handling room. The pyrotechnic locker and ready service ammunition topside were then drenched with high velocity fog. The fire itself was brought under control in 15 minutes using four 1-1/2-inch and two 2-1/2-inch hoses with applicators and one 1-1/2-inch hose with mechanical foam.

2-43 A ruptured firemain has been a frequent casualty, one which RALPH TALBOT, ALBERT W. GRANT, ABNER READ, KILLEN and HUGH W. HADLEY all experienced. In KILLEN and ALBERT W. GRANT the break was located and isolated restoring adequate pressure for firefighting. ABNER READ's personnel were unable to do so and their ship succumbed to an uncontrolled fire. HUGH W. HADLEY successfully employed the independent risers from her emergency pumps and extinguishe the fire without the use of the firemain proper. RALPH TALBOT, failing to identify her difficulty, fought her fire with CO_2 and bucket brigades while the fire pumps poured more than 200 tons of water into the ship from breaks in the main. The resultant list submerged holes which otherwise would have remained above water, and the ship remained in a precarious condition for 10 hours.

2-44 To reduce the vulnerability of the firemain and to improve the accessibility of suitable plugs after damage, the loop firemain was developed for large combatant vessels. Its installation in later classes of destroyers was given detailed consideration, but was not adopted because it would have added weight disproportionate to the advantage gained. Its installation also required too many man-hours compared to that required for other urgent alterations. However, two changes were made in the original installations which constituted an appreciable improvement. In both the 692 and 445 Classes, a superstructure riser from the firemain was authorized and in the 692 Class cutouts forward were rearranged and added to permit pressure to be kept on the Group II sprinkling system by the forward electric emergency fire pump despite breaks in the firemain forward and aft. The severe conflagrations overcome by WALKE, HUGH W. HADLEY, STORMES and ZELLARS proved the adequacy of the fire protection systems in the 692 Class. The installation of the two electric emergency fire pumps with independent risers to

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[1] DD692 Class, Kamikaze crash and bomb hit, Okinawa, 12 April 1945.
[2] DD692 Class, Kamikaze crash, Lingayen Gulf, 6 January 1945.

the main deck virtually guaranteed an adequate supply of water anywhere in the ship despite any damage to the main proper. This largely eliminated the need for a loop. However, it is probable that in subsequent destroyer designs the size of the ship will warrant installation of a loop system.

2-45 The use of asbestos suits and rescue breathing apparatus has permitted access to below-deck fires which were difficult to locate or approach due to intense heat, smoke or fumes. Drills in the employment of rescue breathing apparatus have proved valuable because use of the unit has frequently been necessary not only for firefighting but also for entrance to steam or smoke-filled spaces to rescue injured personnel, secure valves, find sources of flooding or to undertake shoring or plugging of bulkheads.

2-46 In general, the firefighting performance of destroyer crews in the latter part of the war, utilizing their improved training and newly developed equipment, was very encouraging. Their record proved that speed in getting water to the fire is all-important and is the mark of effective drilling. One hose stream brought to the scene of the fire within a minute often proved more valuable than several a few minutes later. Drills in immediately running hose and rigging portable pumps for use in the damaged area and in promptly checking the intactness of the firemain repeatedly proved their value.

G. Ammunition Behavior

2-47 Definitions for some standard terms used in the Naval Service to describe ammunition behavior are given in Ordnance Pamphlet No.4. In general usage, however, the inexactness of the terminology in discussions on this subject has led to considerable confusion. It is appropriate, therefore, to explain beforehand in some detail the intended meaning of the nomenclature of ammunition behavior as used in this report.

2-48 The action of an explosive is the result of a chemical transformation, largely or entirely internal, which liberates a large amount of gas and heat in a very short time. The total quantity of energy liberated in the decomposition of a conventional explosive is much less than that given off by an equal weight of any of the standard fuels. However, the rate at which the energy is released, due to the velocity with which the reaction travels through the explosive, is very much greater.

2-49 The impulse required to initiate an explosive reaction in an explosive charge is local in nature. The application of a certain amount of energy through heat or impact at one point or surface of the charge starts the chemical transformation. A resultant transition wave passes through the balance of the charge initiating the reaction as it passes. In high explosives under the influence of a sufficiently powerful initial impulse this wave attains a supersonic velocity which is a characteristic constant for each explosive material of specified density and composition. This is called a detonation wave and its effect is called a detonation. The wave front constitutes a surface of sharp discontinuity in temperature and pressure and upon reaching the boundary between the explosive and the surrounding medium it introduces a shock wave in the latter. In low explosives and also under certain conditions in high explosives, the reaction takes place in way of a transition wave of subsonic velocity such that, at the wave front, rise in pressure and temperature, although steep, is not discontinuous and the disruptive effect is noticeably less for the same weight of explosive. The latter process is an explosive or accelerated combustion in which the period required to consume the charge varies with pressure and temperature. This process is described as a deflagration and is typical of the action of propellants. In addition to the processes of detonation and deflagration, any explosive under certain conditions may decompose at a relatively slow rate which is comparable to combustion or burning in ordinary fuels.

2-50 Detonation is an action peculiar to high explosives. Complete and virtually instantaneous transformation of a high explosive charge into energy and decomposition products is called a high order detonation. A perceptibly incomplete transformation of such a charge is described as a low order detonation. With some inconsistency the same term is sometimes used to describe a deflagration or reaction which fails to proceed at a supersonic velocity throughout the charge. Propellants, which are low explosives, develop maximum power in an accelerated combustion or deflagration. The slowest rate of transformation (combustion or burning) which has occurred frequently in TNT and smokeless powder, merely creates an intense fire.

2-51 The sensitivities of high explosives to impact, shock or deformation vary widely and bear no evident relation to velocities of explosion nor violence of detonation. Low explosives, theoretically, by definition, do not detonate because in them the maximum rate of propagation of the chemical transformation remains at subsonic levels despite extreme pressure and temperature conditions. Velocities of explosion under designed operating conditions vary from figures in the order of 18,000 feet per second for detonations in a high explosive to about 3 feet per second for deflagration in smokeless powder, the latter being a typical propellant or low explosive. The lower rate in propellants is accelerated and controlled by the granular construction of propellant charges and by the use of ignition charges with a higher velocity of explosion. Frequently, however, the designed conditions do not obtain and the performance of a charge, particularly where its action is initiated accidentally, may differ markedly from that intended. Where explosions of shipboard ammunition have occurred, therefore, careful studies of all available evidence are required before any conclusions can be drawn as to their origin or the means for preventing recurrences of the casualties. The question of whether a magazine explosion has consisted of a mass detonation of bursting charges or of an explosive combustion of propellant charges may seem to be a quibbling refinement. It is of considerable importance, however, in the protection of ships, to understand the mechanics of such blasts. It should be noted that in a high explosive charge the reaction may rapidly pass from the deflagration stage to the detonation stage or vice versa. Also, explosions of propellant powder can develop tremendous power if occurring under conditions of dense loading and sufficiently rigid confinement.

2-52 To distinguish between high order and low order detonations in high explosive charges, the most readily available criteria are the smoke, the size and velocity of fragments, and the disruptive blast effect. Light smoke colored by pulverized particles of the unconsumed portion of the charge, poor fragmentation and low fragment velocity, and subnormal blast damage are typical of low order detonations. In some instances where the action has been initiated by roasting, projectiles have simply split open permitting the filler to burn out. This can be described as a low order detonation degenerating into burning. High order detonations are characterized by severe shock effect, uniform and relatively small fragments with high velocity, by black smoke in the case of Explosive D and by gray smoke from TNT and torpex.

2-53 Where a number of bursting charges are stowed together in a magazine or handling room, the detonation of one or more by fragment attack, fire, premature fuze action or otherwise may initiate, probably through fragment attack, a virtually instantaneous detonation of others. Despite the comparatively low velocity of the explosive reaction in smokeless powder, explosions of propellant powder magazines have occurred apparently due to fragment attack or fire, which ignited one or more charges leading to accelerated ignition of additional charges and thereby building up momentarily abnormally high temperatures and pressures in the magazine. Both the mass detonation and the mass deflagration described above are of comparable violence and can properly be called magazine explosions. These should be differentiated from fires in ammunition accompanied by the low order detonation of individual charges, since a number of damage reports have mistakenly described the latter as magazine explosions.

2-54 There have been a few cases both ashore and afloat in which well separated magazines have apparently been exploded simultaneously by a single initiating impulse. JUNEAU (CL52) may have suffered a disaster of this nature. Such occurrences have given rise to an impression that explosives are subject to "sympathetic" detonations merely from the shock wave of a moderately distant explosion. Extensive investigations and tests have failed to substantiate such a contention, however, and it is now generally accepted that fragment attack or flame is the means by which the detonation of the farther magazine is initiated.

2-55 Cases discussed in this report involving fires or explosions in stowed ammunition include RALPH TALBOT, JOHNSTON, BROWNSON, KILLEN, ABNER READ, STORMES and HUGH W. HADLEY. Pertinent information on ammunition behavior in damaged ships also will be found in the Bureau of Ships War Damage Reports furnished to DD's as follows:

Ammunition Involved	Report in Which Discussed
Torpedo warheads and airflasks	No. 13 - CASSIN (DD372) and DOWNES (DD375), Bomb Damage, 7 December 1941
Bombs and projectiles	No. 31 - ERIE (PG50), Torpedo Damage and Loss, 12 December 1942
Propellant powder and torpedo airflasks	No. 33 - STERRETT (DD407), Gunfire Damage, 13 November 1942
Propellant powder and projectiles	No. 50 - DESTROYER REPORT, Torpedo and Mine Damage and Loss in Action

2-56 The text of the paragraphs on the mechanics of magazine explosions in War Damage Report No. 44 on SAVANNAH is repeated below, because it is equally applicable to destroyers and is a necessary preliminary to a more detailed discussion of specific cases.

"75. In general, magazine explosions may be caused in three ways:

"(a) A propellant-powder fire which results in an explosion of the propellant-powder magazines. Ignition of powder may be caused by hot fragments, flash from a detonation, or high temperatures outside the magazine proper. High density of loading of the magazine, high temperature in the magazine and some pressure within the magazine are all important factors. Inasmuch as an appreciable interval of time is required to build up temperature and pressure sufficient to cause the powder to explode, a magazine explosion is not likely to occur if the sprinkling system is operated promptly, or if the magazine floods rapidly from the sea through damage to the underwater shell thus extinguishing the fire, or if large fragment holes in the peripheries or other openings (doors, ventilation ducts and passing scuttles) are present in the bounding bulkheads or decks.

"(b) The roasting effect of high temperatures applied for an appreciable interval to projectiles or bombs loaded with high explosive. In general, a detonation of one or two projectiles or bombs may occur first. If the projectiles or bombs be thin-walled, fragments produced by the initial detonation striking adjacent projectiles or bombs may result in a mass detonation of the other projectiles or bombs in the bin or adjacent stowages if they be racked close together. It is emphasized that an appreciable period of high temperature ordinarily is required to cause the initial detonation, but that the mass detonation will occur almost simultaneously with the initial detonation.

"(c) High velocity fragments striking thin-walled projectiles or bombs loaded with high explosive, resulting in a mass detonation of the magazine contents. This is, in effect, but a variation of (b) with the difference that the fragments are from sources external to the magazines. A bomb or projectile detonation in the magazine or a torpedo detonation in way of the magazine, if it be unprotected by a liquid layer or armor, may result in high velocity fragments striking the magazine contents."

2-57 A destroyer's powder magazines and handling rooms are subject to explosions of the first category outlined above. At Okinawa, LONGSHAW (DD559) was lost due to an explosion of 5-inch powder in her forward magazines initiated apparently by a powder fire following a direct hit from an enemy shore battery. In destroyers the 5-inch AA projectile is the type most susceptible to mass detonations of category (c). The loss of HALLIGAN (DD584) and TWIGGS (DD591) is believed to have been attributable to explosions of this type following mine and torpedo hits, respectively. Explosions of category (b) occurred in the upper 5-inch handling room in CALLAGHAN (DD792) and apparently in the lower 5-inch handling room in ABNER READ (DD526), but were less severe due to the smaller weight of explosives involved.

2-58 Other types of ammunition for naval guns carried in destroyers have not appeared susceptible to mass detonation. Extensive war experience for 20mm and 40mm ammunition and limited war experience with 3-inch ammunition has shown that, despite prolonged and intense roasting and repeated fragment attack, this ammunition will merely detonate low order singly, or split open and burn, a form of low order detonation or deflagration which has also occurred in larger projectiles subjected to prolonged roasting.

2-59 The cases of KILLEN (DD593) and STORMES (DD780) and those of the cruisers SAVANNAH[1] and BOISE[2] are interesting in that each involved a direct bomb or projectile hit in way of a magazine or handling room causing brief powder fires or ammunition fires which did not result in a magazine explosion despite the intense blast and fragment attack to which both powder and projectiles were subjected. The remains of split and burned-out projectiles and powder cartridges

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[1] War Damage Report No. 44, Bomb Damage, off Salerno, 11 September 1943

[2] War Damage Report No. 24, Gunfire Damage, off Guadalcanal, 11-12 October 1942

in each case indicated that inrushing water had quickly extinguished the fire and probably saved the ship from a magazine explosion. In each case the venting of the powder fire possibly was a factor in the failure of an explosion to occur, but the effectiveness of venting is open to question.

2-60 The TNT loaded depth charges and torpedo warheads of destroyers have appeared surprisingly stable when subjected to the various hazards encountered by combatant vessels, although some detonations have resulted. Sensitivity tests conducted by the Bureau of Ordnance at Dahlgren showed that both can be detonated by fragments of sufficient weight and velocity. The results of these tests have been substantiated by war experience which has also indicated that depth charges are susceptible to detonation by prolonged roasting. No positive case of detonation of TNT loaded torpedo warheads by prolonged roasting has yet been brought out from war experience. BROWNSON (DD513) suffered a bomb hit which detonated high order either on or below the warheads in her after mount and apparently resulted in the detonation of one or more warheads causing severe structural damage which led to the loss of the ship. KALK (DD611)[1] and STORMES (DD780) both received direct hits on torpedo mounts, but the warheads did not detonate although in each case several airflasks blew up. HYMAN (DD732)[2] suffered a direct bomb hit and plane crash in way of her forward torpedo mount and reported a warhead detonation in the midst of a severe gasoline fire 90 seconds later. The amount of damage, however, indicated that the second blast was very much less than would result from the detonation of the 800-pound charge in a warhead. It is more likely that the second blast was caused by an airflask or a segment of the warhead broken off by the first explosion. In many cases TNT loaded torpedoes have been subjected to prolonged roasting which caused molten exudate to drip out and burn, yet neither airflasks nor warheads exploded. In DOWNES (DD375) at Pearl Harbor an explosion occurred in way of several burning warheads which may have been the result of a warhead detonation but damage was not indicative of a high order detonation. In ISHERWOOD (DD520)[3] the detonation of a bomb carried by a suicide plane burst open the cases of two depth charges and initiated a prolonged fire which resulted 26 minutes later in a blast which caused more damage than the plane crash or bomb detonation. The blast was apparently caused by the detonation of an intact depth charge. MULLANY (DD528)[4] suffered an identical casualty 23 minutes after a gasoline fire engulfed her depth charge throwers. ROWAN (DD405)[5] suffered a magazine explosion, apparently in her after depth charge magazine, immediately following a torpedo hit. However, in the great majority of cases depth charges and torpedo warheads have withstood prolonged roasting and severe fragment attack.

H. Machinery Damage and Casualty Control

2-61 The main power plant of a modern destroyer occupies over a third of the length and about half the volume of the hull of the ship. It is probable, therefore, that when major damage is sustained by this type of ship some machinery will be deranged. Of the cases detailed in this report only three, RALPH TALBOT, KILLEN and STORMES, escaped

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[1] 1630-Ton Class, bombs, off Biak, 12 June 1944
[2] 2200-Ton Class, Kamikaze, off Okinawa, 6 April 1945
[3] 2100-Ton Class, Kamikaze, off Okinawa, 22 April 1945
[4] 2100-Ton Class, Kamikaze, off Okinawa, 6 April 1945
[5] 1570-Ton Class, Torpedo, off Normandy, 11 September 1943

damage in the main machinery spaces, yet even these suffered temporary derangement of some major machinery units. Split plant operation clearly offers the best assurance of retaining mobility and is therefore the basis of casualty control.

2-62 One of the outstanding examples of successful casualty control through split plant operation was JOHNSTON (DD557). Her after turbines, gears and boilers were completely disabled early in the action by heavy caliber gunfire, nevertheless the ship continued to effectively engage the enemy at speeds around 20 knots for two hours afterward although additional hits finally sank her. In HYMAN (DD732) a Kamikaze crash, bomb blast and severe gasoline fire in way of the forward engineroom caused her starboard shaft to wipe its bearings and lock, and also forced personnel to abandon the forward plant. Employing only the independent after plant, HYMAN continued a vigorous antiaircraft action for over an hour, maneuvering radically at 18 knots and assisting in shooting down three more attacking planes.

2-63 In addition to the separation of the main propulsion plant into two independent units, it is equally important that the power system be broken up into several self-contained segments. The destroyer, in common with other combat types, carries such a complex mass of electric wiring that it is rare for even a minor hit to be sustained without some damage to wiring by blast and fragments. Even if the generators remain undamaged some dislocation of the power distribution system is almost certain to occur. After damage, severed circuits or circuit breakers opened by short circuits cause sections of the ship to be without power until the shorted or broken circuit can be identified and isolated or repaired. It is therefore advantageous to open all non-vital circuits prior to an action to reduce the likelihood of losing power when it is most needed.

2-64 Emergency Diesel generators have repeatedly proved themselves invaluable in damage control. Ships of the 1630-ton Class had to have their Diesel generators removed for weight compensation and were seriously handicapped thereby. Subsequent classes have retained their emergency sets and the 2200-ton Class each carry two, one forward and one aft below decks outside the main engineering spaces. The latter arrangement has largely overcome the formerly frequent casualty of losing all electric power. Two Diesel generators, each with an automatic starting feature, a separate emergency board and an independent riser for casualty power distribution, have very much simplified the problem of establishing control of fires and control of flooding after damage because emergency power becomes immediately available and its distribution may be kept completely independent of all other installed systems.

2-65 The casualty power supply system, although originally devised for only large combatant ships, is now installed in numerous other types. It was intended originally that the system be employed to provide only the services urgently required by a damaged ship to permit her to get from the scene of combat to some forward repair activity where temporary restoration of the ship's service installation could be undertaken as necessary. In destroyers the system has adequate capacity to supply power to the vital maneuvering auxiliaries and the I.C. board, to essential damage control equipment and to the 40mm battery. Risers from each generator and from each main control board in the engineering spaces to the main deck, with bulkhead terminals and lengths of portable cable, are available to provide power to units immobilized by the cutting or grounding of installed circuits. In DD692 Class there are also available 17 outlets for portable equipment such as pumps or welding machines. The degree of usefulness of this system has exceeded anticipations and several ships have made voyages of several thousand miles to a home yard using the casualty power system. The allowance in the DD692 Class of casualty power cable has been raised from an initial 1300 feet to over 1900 feet in various lengths up to 100 feet as a result of war experience.

2-66 High pressure steam piping has demonstrated surprising resistance to blast and fragments although several cases could be cited where virtually intact plants have been made inaccessible by steam leaks. In ALBERT W. GRANT main steam lines withstood the full impact of a 6-inch AP projectile in two instances. Her tough 7-inch carbon-molybdenum steel lines, almost half an inch thick, were dented so that only half the original flow area remained, yet they did not rupture and remained serviceable. Similar piping in other ships has frequently been severely distorted without rupture.

2-67 Several destroyers, including EVANS (DD552), GANSEVOORT (DD608) and BROWNSON, after suffering severe damage in way of a fireroom, have reported boiler explosions. However, there is no substantiated case of an explosion of an express type boiler in our naval experience. The old type fire-tube Scotch boiler was subject to such a phenomenon because the tubes were integral with the water jacket and a very large volume of water was carried at a high temperature so that if the pressure parts suddenly failed at any point a large amount of water flashed into steam with explosive effect. In the express type, however, the amount of water carried is only a small fraction of that in the Scotch boiler and the strength of the drums is much greater than that of the tubes so that excess pressure usually ruptures the tubing only and bleeds off gradually. Even if a steam or water drum were demolished by a direct hit, the small amount of highly heated water flashing into steam would not add greatly to the damage caused by the hit. The drums also are entirely capable of withstanding the stresses introduced by sudden submergence in cold water. Some of the blasts mistaken for boiler explosions have been due to the detonation of the missiles which penetrated the boiler. In cases in which the blast has occurred some time later it is possible that an oil vapor explosion took place. A more remote possibility has been described in a recent issue of "Shipbuilding and Shipping Record,"[1] based on express boiler casualties in British and German warships. This reported that in two cases low water in an express boiler caused the iron in boiler tubes to burn in steam at a temperature around 1300 degrees F. in a self-sustaining reaction which released hydrogen. Under these conditions if the air supply were cut off it is possible for hydrogen to collect in an explosive concentration in the fire box and uptakes.

2-68 Loss of power to ventilation sets supplying the machinery spaces has forced their evacuation in some instances due to the rapid increase in temperature in these spaces. In ALBERT W. GRANT, interruption of power stopped ventilation. Consequently, the after engineroom was abandoned and attempts to restore the after fireroom to operation were hampered by heat and smoke. Late destroyers have two sources of power (normal and alternate) to ventilation in way of machinery spaces. A recent alteration provides for casualty-power terminals on machinery-space ventilation set power panels.

I. Conclusions

2-69 During the course of the war the capacity of our destroyers to survive battle damage and maintain offensive power increased markedly. While the 2050 and 2200-ton Classes were obviously heavier and stronger ships than their predecessors, one of the largest factors in this improvement was the development of aggressive damage control organizations provided with adequate equipment and well-drilled in its use.

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[1] Issue of 9 May 1946, pp 150

2-70 The damage control organization consisting of three repair parties has proved itself well adapted to the later destroyers. It consists of two parties, one forward and one aft containing primarily deck, artificer and electrical rates and an amidships party composed primarily of engineering rates. A satisfactory complement for each party includes about 10 men who have no other General Quarters assignments. When properly indoctrinated, each member of a repair party should be thoroughly conversant with the duties of each of the others in his party in addition to his own duties and should possess a thorough knowledge of access and firemain arrangements throughout the ship. No standardized repair locker has been adopted, but each of the three parties has its own locker so equipped that no reliance need be placed on either of the other parties for the gear or the procedure to undertake damage control assignments in its respective section of the ship. After serious damage the repair organization normally can use greater manpower to advantage. To provide for this contingency, some ships have made a practice of assigning to an auxiliary repair organization personnel who may be spared from their regular battle stations after damage to assist the regular repair parties, thus permitting the rest of the ship's company to continue to fight the ship with a minimum of disorganization.

2-71 Since destroyers have no JZ circuits, communications between each of the repair parties and the bridge, before damage, have usually been maintained over the 1JV circuit. Portable leads and sound-powered phones are available if necessary to reestablish this communication after damage. However, it should be anticipated that at the most critical periods the only communication available to coordinate repair activity may be messengers. In ships of destroyer size this has not proved a very serious handicap. More complicated systems have frequently been proposed and some German warships had an installation resembling the engineroom telegraph for this purpose, but the weakness of any such system is the vulnerability of the wiring which may fail when most needed. Portable radios, so-called "walkie-talkies," are not suitable for this purpose due to interference. It is good practice in drills, therefore, to place little reliance on installed interior communications circuits for inter-party coordination in destroyers.

2-72 The following conclusions may be drawn from the study of war damage made in this report.

(1) A modern destroyer, efficiently manned, may be expected to survive extensive damage from gunfire, bombs or guided missiles.

(2) Dispersion of vital personnel, equipment, and facilities, a high standard of watertight integrity, compliance with prescribed loading instructions, and split plant operation are some of the essential preparatory measures for effective damage control.

(3) Upon entering action, the damage control organization should anticipate loss, in substantial part, of (a) main propulsion power, (b) steering control, (c) normal electric services and (d) firemain pressure.

(4) Meticulous attention to material and training within the damage control organization is of major importance to the ship's survival.

(5) Virtually without exception the buoyancy and stability characteristics of our destroyers have proved satisfactory up to the point that hull girder collapsed due to extreme structural damage or until the extent of flooding exceeded the floodable length which comprised at least four main compartments.

(6) The function of halting progressive flooding is the damage control technique least adequately mastered to date.

(7) The deciding factor in establishing control of severe fires is the promptness with which hose streams are brought to bear.

(8) To date, explosive ordnance of all types carried in destroyers has indicated surprising stability. If ammunition in a damaged area is not instantaneously ignited or detonated, there is an excellent chance to prevent fire from causing its subsequent ignition or detonation by promptly wetting it down and by jettisoning it as soon as practicable.

2-73 At the present writing the most battleworthy destroyers afloat are probably the ships of our long hull DD692 Class. Before the end of the recent war the TERUTSUKI Class Japanese destroyers and NARVIK Class German destroyers exceeded it slightly in size as did some earlier French and Russian classes. Before the recent war the latter navies developed 40-knot vessels of about 100,000 shp and about 450 feet long exemplified by L'TRIOMPHANT which has since run some interesting trials on the Rockland course. Current destroyer design, both here and abroad, has indicated a trend to ships of comparable size and shaft horsepower. The necessity for more powerful antiaircraft and anti-submarine armament as well as for the greater speed required to operate with carriers and against modern submarines has forced increases in the displacement of new designs of destroyer-type vessels. The replacement of previous ordnance installations with weapons giving greater fire power, the additional weight of propulsion machinery required for the greater horsepower and the additional hull weights required to retain an efficient speed length ratio and adequate cruising radius--all involve appreciable additional displacement. Until radically new types of power plants and armament are developed and tested, the trend to larger destroyers may be expected to continue.

2-74 Undoubtedly important developments in the design of warships will result from the employment of nuclear fission as a source of power for propulsion and for armament. The CROSSROADS Operation indicated the introduction of certain additional problems in damage control but the accuracy of the conclusions drawn from this report on damage from conventional weapons has been in no way compromised thereby but rather confirmed.