An Overview of Warships Damage Data from 1967 to 2013

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ABSTRACT

In the last decade, in the field of merchant ships, a long harmonization process has taken place at IMO, resulting in the enforcement of the so called probabilistic SOLAS2009 for the residual buoyancy and stability assessment of a ship in a damaged condition.

In the warships design process, the probabilistic methodology might represent a consistent approach to complement the fundamental overall ship survivability assessment. Nevertheless among the most critical issues, while discussing the possible implementation of this innovative approach, are the lack of a damage database and the significantly different threat typology.

In this perspective, significant damage cases in the field of warships are investigated and critically analyzed. The observed time period will regard the period from 1967 (sinking of the Eilat) to 2013.

Keywords: *warships, damage, survivability assessment*

1. INTRODUCTION

In the field of merchant ships, the rules for stability assessment of a damaged ship have been renewed a few years ago by the International Maritime Organization (IMO).

The new requirements are based on the probabilistic approach and represent a significant change in one of the most long-established safety issues i.e. the ship subdivision criteria.

They are the result of a prolonged process having its roots in the sixties (IMO, 1960) and passing by the adoption of the mandatory probabilistic regulation for cargo ships (IMO, 1990). An harmonization process has subsequently originated, leading to a comprehensive SOLAS Convention text for both passenger and cargo ships that has been enforced from January 1st 2009 (IMO, 2007), the reason why in the following it is going to be mentioned as SOLAS2009.

This paper is developed in the perspective that the probabilistic approach might represent an interesting hint also within the warship design context (Harmsen & Krikke, 2000; Papanikolaou & Boulougouris, 2000). In fact, in principle, it is particularly suitable to address the vulnerability characteristics of the ship in terms of survivability after damage and it can be exploited also in terms of risk assessment, for the discussion of ship survival attitude after damage due to a weapon hit (Boulougouris & Papanikolaou, 2012).

At the same time, some critical points can be raised, for example in relation with the totally different context in terms of threat and operational situations.

Moreover the lack of a rational and comprehensive damage database is another fundamental issue in order to define the statistical characteristics of hull damages.

2. PRESENT CRITERIA FOR THE DAMAGED SHIP: NAVAL AND MERCHANT FIELD

At present, major Navies in the world apply the so called "determistic" approach for the design and assessment of the appropriate ship subdivision, derived from the World War II experience and form the Sarchin and Goldberg studies (1962).

Damaged stability criteria are based on standard extents of damage, margin line and V-line concepts for buoyancy assessment and progressive flooding prevention; for the residual stability assessment, criteria are developed processing the righting arm characteristics in comparison with standard.

A remarkable overview about the current warship damaged stability criteria is given in Surko (1994), where a compared analysis is carried out among the deterministic criteria applied by Canada, France, Germany, Israel, Italy, United Kingdom, United States, Australia. In the same paper many interesting hints for improvement are suggested for example the need to treat the survivability and the damage control as a single issue in the 21st century. The same author raise the attention toward the residual strength after damage, in a comprehensive performance assessment perspective (Surko, 1988).

In the field of merchant ships, before the SOLAS2009 enforcement the "deterministic" approach was the general SOLAS damage stability paradigm. At present, the traditional set of rules has been replaced by the probabilistic approach that in principle can be described as a rational, comprehensive and able to deliver a synthetic final score parameter, representative of the damaged ship survivability global attitude. Furthermore it has the characteristic of being a versatile instrument, able to deal with innovative and peculiar ship typologies.

Notwithstanding many positive conceptual features, its implementation in actual design poses a number of problems. In general, among the less encouraging features, is the extremely long, elaborate and intricate procedure it requires (only the significant increase and availability of cheap calculation power have practically allowed the introduction of this new methodology). At the same time, a critical aspect is represented by the feeble chance to appreciate intuitively the effects of even a light modification in the ship general layout in terms of damage stability compliance. This in turn could mean that in case the investigated ship doesn't satisfy the requirements, the designer's options to improve the situation are not so clear and straightforward.

3. CRITICAL ISSUES FOR PROBABILISTIC APPROACH TRANSFERABILITY FROM MERCHANT TO WARSHIP DESIGN

A very short and not exhaustive description of the SOLAS 2009 probabilistic methodology is given in the following. The methodology is based on a calculation of the attained subdivision index A and the required subdivision index R. The ship is sufficiently subdivided when

$$A > R, \quad R = R(L_S, N_1, N_2) \quad (1)$$

In particular coefficient R, besides its dependence on the ship length (L_S), is defined as a function of the number of people for whom lifeboats are provided (N_1) and of the number of people (including officers and crew) the ship is permitted to carry in excess of N_1.

The formulation of the attained coefficient A is more complex, it is obtained after relevant calculations for three different draughts: the deepest subdivision draught (*ds*, the waterline which corresponds to the summer load line), the light service draught (*dl*, related with the lightest loading condition of the vessel) and the partial subdivision draught (*dp*, the light service draught plus 60% of the difference between the light service draught and the deepest subdivision draught). For each of the aforementioned calculation draughts *ds, dp* and *dl*, partial indices respectively *As, Ap, Al*, are to be found. The global attained coefficient *A* is calculated as the linear combination of the partial subdivision indices at each defined draught:

$$A = 0.4A_s + 0.4A_p + 0.2A_l \qquad (2)$$

Every partial index *As, Ap, Al* is the summation of the products of two parameters (*pi* and *si*) representing respectively, the probability that only the compartment or group of compartments under consideration may be flooded *pi,* (disregarding any horizontal subdivision) and the probability of survival *si* after flooding of the compartment or group of compartments under consideration, (including the effect of any horizontal subdivision). Each partial index *Aj* is therefore calculated as follows:

$$A_j = \lfloor \Sigma_i\, p_i \quad s_i \rfloor_j \qquad (3)$$

The formulation of the pi coefficients is based on the damage length and on its longitudinal position along the ship. As a matter of fact when dealing with a certain zone within two transversal bulkheads it is possible to take into account different transversal damage penetrations, correcting *pi* by the *ri* coefficient, that accounts for the probability not to damage the longitudinal bulkhead.

The *si*, parameter the survivability index, is calculated with reference to the residual buoyancy and stability characteristics of the ship after damage and accounts also for intermediate stages of flooding and external heeling moments such as wind, movement of passengers and launch of a survival craft. Moreover the survivability index coefficient can be corrected by the factor *vi* in case the horizontal watertight boundaries are fitted above the waterline under consideration and they are limiting superiorly the damage: the *vi* factor in fact, represents the probability that the spaces above the horizontal subdivision will not be flooded. The attended index *A* takes therefore the following form,

$$A_j = \lfloor \Sigma_i (p_i \quad r_i) \ (v_i \quad s_i) \rfloor_j \qquad (4)$$

In order to avoid that global index *A* is attained also in case of extremely unbalanced situations some corollary requirements have been introduced: for passenger ships, prescriptions on the *si* values are imposed regarding some specific damage scenarios defined in terms of position and extensions, depending on the number of passengers onboard. Moreover a minimum value of for partial *As, Ap, Al* indices is imposed (at least 0.5•*R* for cargo ships and 0.9•*R* for passengers ships).

To discuss the opportunity of the probabilistic approach application in the field of warship design it is worth mentioning that "survivability" in such cases is a very wide concept and also includes the concepts of vulnerability and susceptibility (Ball & Calvano, 1994).

The possible application, moreover, would imply an extensive work of re-formulation of the probabilistic parameters characterizing the damage scenario probability and of the survivability index.

In fact, one of the biggest issues for the probabilistic approach application in the warship field is the redefinition of coefficients exploited in the methodology. In this process it would be necessary to take into account the different environmental, operational scenarios and the boundary conditions the naval ship has to operate in.

Two points should be properly considered: the first one is the different performances required after damage and the second is the origin and nature of the damage.

The ship performances after damage should be tackled through the definition of a new *si* survivability factor within the probabilistic methodology.

The nature of the damage should be introduced with the definition of damage probability factors i.e. *pi, ri, vi*, respectively representing the longitudinal transverse and vertical extents of damage.

The occurrence of a damage has different features in case of a merchant ship or a naval ship: in general the first suffers damage due to collision and grounding while the second suffers damage due to offensive /aggressive threats (weapons) put in act to destroy the ship herself and characterized by more devastating effects.

Moreover a new definition of the required index R is necessary, since in the SOLAS 2009 it has a statistical origin too; the harmonized SOLAS has been applied to several ships which complied with the old deterministic rules and their attained indexes A have been calculated. The index R has been defined by means of a regression of such set of values with the aim to keep an equivalent level of safety. A similar approach should be followed with a proper set of naval ships to define its naval formulation.

From what above, the critical points for probabilistic approach transferability to navy ships are summarized below:

- Definition of suitable probabilistic terms to evaluate damage extensions statistics and damage effects
- Definition of survivability index
- Definition of a new R factor, i.e. the level of sufficient subdivision

Unfortunately a database of damage cases for ships in the military context with all the necessary data for a statistical analysis is not available.

In the following paragraph an overview about the damage scenario of warships in the latest decades is carried out; the aim is to investigate what kind of framework and information would be useful in the perspective of a possible probabilistic approach for damage stability assessment for warship design. A special attention is given also to the threat typology as a fundamental parameter to class the damage size and typology.

4. A TAXONOMY FOR A WARSHIP DAMAGE DATA OVERVIEW

Year 1967 marks a breakthrough in naval warfare, specifically the sinking of INS Eilat by means of guided ship-launched anti-ship missiles (ASMs) a few months after the Six-Day War.

Guided weapons had already been used during the Second World War: the German Luftwaffe used several kinds of remotely-controlled glide bombs, such as the Henschel Hs293 and the so-called “Fritz-X”; two hits from the latter in fact sunk the RN Roma in 1944. All of these weapons were however dropped by a bomber and usually controlled via radio signals by an operator within visual range, following the smoke trail left by the bomb to help steering.

When INS Eilat was sunk in October 21st, 1967, the three hits were by P-15 Termit (NATO name: SS-N-2 Styx) missiles, fired from two Komar-class missile boats, carrying their own radar sensors, and attacking well outside visual range (17 nm as reported).

From 1967 to 2013, 45 hits by guided anti-ship missiles, both surface- and aircraft-launched, have been suffered by naval ships. Of these hits, 16 concerned 9 different naval ships with a displacement larger than 1000 t (corvette-sized or bigger) and are therefore interesting for our study; hits on smaller ships are less interesting because smaller platforms can hardly survive missile impacts. In those cases, specific details are also hard to come by (the ship, typically a missile boat, is usually listed as "sunk", without other information).

Of these 16 hits, 6 were by P-15 Termit (3 of those during the Eilat attack and 3 during Operation Trident), 4 by some versions of the Exocet, 3 by Harpoon missiles, 2 by Sea Sparrow missiles (a "blue-on-blue" incident) and 1 by a YJ-82. 4 out of 9 of the hit ships were sunk. In 7 cases out of 9, the ships were clearly mission-killed, i.e. lost the capability to carry out their operational tasking.

In 6 out of 9 ships, and in 3 out of 4 ships being sunk, fire is mentioned as a significant damage mechanism; specifically, HMS Sheffield and IRS Sahand were lost due to incontrollable fires, even though the first one eventually sunk due to flooding and the second due to secondary ammunition explosions. INS Eilat on the other hand suffered a complete loss of integrity of the hull girder (i.e. "broke in two") after the third hit whereas the fate of PNS Khaibar was probably caused by extensive flooding.

Note that this statistic doesn't include non-naval ships (several oil carriers were hit by ASMs during the so-called Tanker War, for example) and doesn't include merchant ships in military use such as the Atlantic Conveyor, which despite being a container ship was in military use during the 1982 Falklands War, and the Venus Challenger, which was reportedly carrying ammunition (this is contested) when sunk during the 1971 Operation Trident.

In the same historical period, 15 ships larger than 1000 t sustained hits from weapons other than guided missiles: 3 were torpedoed, 8 were hit by bombs, 3 struck a mine and 1 was struck by a suicide boat. One of the ships hit by bombs (IIS Sahand) was also hit by missiles, and therefore our list below is composed of 23 entries rather than 24.

The three ships that were hit by torpedoes all sunk, in a quite short time frame and with large loss of life.

The three ships that were hit by mines received severe damage and were mission-killed in two cases, whereas USS Tripoli, undoubtedly also due to her large displacement, remained mission-capable. Casualties were low.

USS Cole, struck by a suicide boat, was certainly unable to continue her mission, and was ultimately drydocked and brought back to the US for repairs.

Finally, the 8 ships that were struck by bombs: 3 were hit by multiple bombs and sunk (HMS Ardent during defusing operations); 3 were struck by unexploding bombs only and survived (HMS Argonaut suffered a partial missile magazine explosion and fire and had to be towed away); 1 was struck by a single bomb and lost propulsion but survived (IIS Sabalan) and 1 was struck by multiple bombs and missiles and sunk (IIS Sahand).

In 4 out of 5 cases of ships struck by bombs which exploded successfully, and in 1 case out of 3 of unexploded bomb hits only, fire is mentioned as a significant factor. Only HMS Coventry was lost mainly due to loss of stability.

The following review goes into some detail, as available from unclassified or de-classified sources, about the damage sustained by the ships as listed in table 1.

It appears evident that the definition of damage as described in the SOLAS2009 (i.e. in terms of longitudinal, transverse and vertical extension) is not commonly available, and that the damage is usually described in terms of source (i.e. kind of weapon) and effects (i.e. residual buoyancy, total loss, fire, fatalities).

INS Eilat (1967)

INS Eilat (ex HMS Zealous) was a WWII Z-class destroyer with a displacement of about 1700 t. She received three hits (sources report anything from 2 to 4 hits), all by P-15 Termit missiles (carrying 454 kg warheads), which sunk her.

Reports are unclear on the location of the hits but it's clear that after the two first hits the ship was dead in the water (boiler rooms out of order) and with severe structural damage; some sources report one hit very close to the waterline (and therefore flooding) and fire is reported as well.

The ship was still floating when two hours later the third hit finished her by splitting the already damaged hull into two parts. Further underwater damage from a near-miss by a 4th missile was reported (the ship was attacked by two Osa missile boats carrying two missiles each).

PNS Khaibar (1971)

PNS Khaibar (ex HMS Cadiz) was a WWII Battle class destroyer with a displacement of about 2300 t standard (3300 full load). She received two hits by P-15 Termit missiles which sunk her (Harry, 2002).

The first hit was on the starboard side, low on the water; propulsion and electrical power were lost (possibly due to shock?) Boiler room 1 was lost and the ship was engulfed in thick black smoke, with spreading fires reported. The second subsequent hit was on the same side and destroyed boiler room 2 as well as some boats, causing a heavy list. The ship sunk shortly thereafter.

Name	Year	Country	Weapons	Final status
INS Eilat	1967	Israel	3 x P-15 Termit	Sunk
PNS Khaibar	1971	Pakistan	2 x P-15 Termit	Sunk
PNS Shah Jahan	1971	Pakistan	1 x P-15 Termit	Unknown, did not sink
INS Khukri	1971	India	1 x 550-mm torpedo	Sunk
ARA General Belgrano	1982	Argentina	2 x Mk 8 torpedo	Sunk
HMS Sheffield	1982	UK	1 x Exocet (did not explode)	Sunk
HMS Ardent	1982	UK	Multiple aircraft bombs	Sunk
HMS Antelope	1982	UK	2 aircraft bombs	Sunk during defusing operations
HMS Coventry	1982	UK	Multiple aircraft bombs	Sunk
HMS Broadsword	1982	UK	1 unexploded bomb	Mission capable
HMS Argonaut	1982	UK	2 unexploded bombs	Towed away
HMS Antrim	1982	UK	1 unexploded bomb	Unknown

HMS Glamorgan	1982	UK	1 x Exocet	Mission capable after damage recovery
USS Stark	1987	USA	2 x Exocet (1 did not explode)	Severe damage, mantained propulsion
USS Samuel B. Roberts	1988	USA	1 x M-08 contact mine	Severe damage, reduced propulsion
IIS Sahand	1988	Iran	3 x Harpoon, 2 x CBU, 2 x LGB	Sunk
IIS Sabalan	1988	Iran	1 x LGB	Severe damage, towed away
USS Tripoli	1991	USA	1 x LUGM-145 contact mine	Mission capable after damage recovery
USS Princeton	1991	USA	1 x MN-103 influence mine	Severe damage, towed away
TCG Muavenet	1992	Turkey	2 x Sea Sparrow	Crippled by loss of staff
USS Cole	1999	USA	1 x suicide boat	Severe damage, drydocked
INS Hanit	2006	Israel	1 x YJ-82 missile	Moved away from the area
ROKS Cheonan	2010	South Korea	1 x unknown torpedo	Sunk

Table 1: List of the analyzed ships with some summarized details

PNS Shah Jahan (1971)

PNS Shah Jahan (ex HMS Charity) was a C-class destroyer with a displacement of about 2500 t. She received one hit by a P-15 Termit missile.

Not much is known about this attack, except that the ship did not sunk but was eventually scrapped due to the extensive damage.

INS Khukri (1971)

INS Khukri was a Type 14 (Blackwood-class) frigate with a displacement of about 1450 t (full load). She received one hit by a 550-mm torpedo which sunk her.

According to open literature accounts, the torpedo hit "exploded under the oil tanks". This apparent fact, taken together with the small displacement of the ship, explains the reportedly quick sinking of the ship and proportionally large loss of life.

ARA General Belgrano (1982)

ARA General Belgrano was a WWII Brooklyn-class light cruiser with a displacement of about 12200 t at full load. She was hit by two Mk 8 torpedoes which sunk her, earning her the dubious distinction of being the first and only ship to be killed by a nuclear submarine in history.

The torpedoes hitting the Belgrano had a 363 kg warhead. The first hit came very close to the bow, outside both the armored belt and the anti-torpedo bulge, and blew it up; the damage was however ultimately very small as the ship water integrity was preserved.

The second hit was sustained aft, again outside the armored area, and proved catastrophic: the aft machinery room and two mess rooms were immolated causing about 275 casualties, and subsequently the explosion vented through the main deck.

The ship very quickly filled with smoke. Electrical power was lost due to the explosion and the list that the ship soon developed could not be countered by pumping. Twenty minutes later the order to abandon ship was given and she eventually slipped beneath the waves.

HMS Sheffield (1982)

HMS Sheffield was a Type 42 destroyer with a displacement of about 4800 t. She received one hit by an Exocet which sunk her.

This is probably the missile attack that has been discussed most in the brief history of naval missile combat. According to the official RN account (UK-MOD 1982a) Sheffield sustained the hit on her second deck, 2.4 meters above the waterline. Immediate damage included the control room, fire main, forward auxiliary and machinery room being lost. Fire spread and could not be fought due to heavy smoke and no fire main, so eventually the ship was abandoned. Sheffield then sunk during towing due to flooding through the side hole, but fire (and smoke) was definitely the primary damage mechanism in this attack.

It is significant that the missile with its 165 kg warhead did not detonate, according to official statements, though this is contested by some.

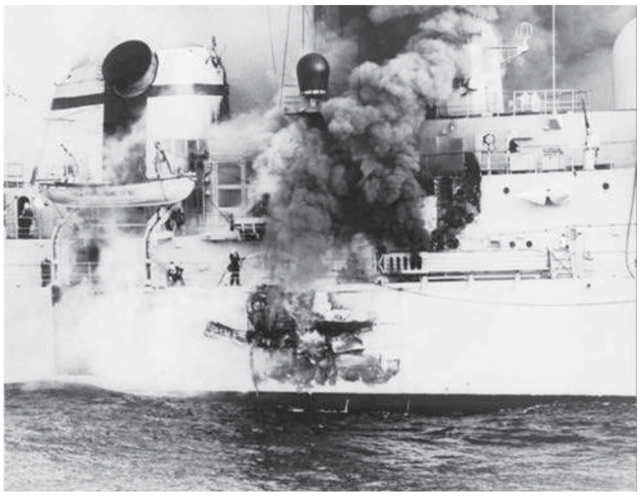

Figure 1: HMS Sheffield on fire after the Exocet hit
(photo credit: UK MoD - believed to be in the public domain)

HMS Ardent (1982)

HMS Ardent was a Type 21 frigate with a displacement of about 3200 t. She received several bomb hits which sunk her (UK-MOD 1983).

Ardent was hit by several waves of air attacks.

The first three hits were sustained in the hangar (two weapons) and aft auxiliary machinery room (one weapon, which failed to explode but caused significant damage nonetheless by destroying a switchboard which left, among other things, the main gun inoperative). The hangar hits destroyed the helicopter and a missile launcher, as well as started a large fire and caused significant crew casualties.

A subsequent wave of attackers hit the ship in the aft area with an unknown number of weapons, estimates range from two to four bombs. There are reports of more weapon hitting the ship at the same time but failing to explode, which was fairly common due to the low altitude the attacks were performed at. These attacks caused many casualties and the ship lost steering as well. Fires aft grew out of control and a list was developed from flooding due to underwater explosions of near misses. The ship was abandoned and sunk about 12 hours later.

According to Argentine sources both Mk 83 (450 kg) and Mk 82 (230 kg) bombs were used, in the normal and retarded type.

HMS Antelope (1982)

HMS Antelope was a Type 21 frigate with a displacement of about 3200 t. She was sunk when the defusing attempts on two bombs that she had received failed (UK-MOD, 1982b).

Antelope sustained two bomb hits, the first in the starboard side, the second close to the main mast, from an aircraft that crashed through it. No one of the bombs exploded.

Defusing attempts on the aft bomb failed and the ship was torn open from waterline to funnel. Major fires were started in both engine rooms. Electrical power was lost and the starboard fire main was fractured as well, making fire fighting all but impossible.

The ship was abandoned and shortly thereafter missile magazines began exploding. The ship was still afloat, her keel broken and her substructure all but melted, the following day, but eventually sunk after breaking in half.

HMS Coventry (1982)

HMS Coventry was a Type 42 destroyer with a displacement of about 4800 t. She received four hits by bombs, two of which exploded, and eventually sunk.

Coventry was hit a first time on her flight deck by a 450-kg bomb which destroyed her helicopter but did not explode. Then, she was hit by three 225-kg bombs on her port side, just above the waterline: two of the bombs exploded, one putting the computer room and most of the senior staff out of commission; the second in the forward engine room. The latter hit destroyed the bulkhead separating the two engine rooms, causing an incontrollable flooding (the ship could survive two compartments being flooded but not the two engine rooms as they were too large).

The ship capsized in about twenty minutes and sunk shortly thereafter.

HMS Broadsword (1982)

HMS Broadsword was a Type 22 frigate with a displacement of about 4400 t. She received one hit by a bomb which did not explode.

During the same action in which Coventry was sunk, Broadsword was hit by a bomb of unknown weight, which bounced on her flight deck, destroying her helicopter (similarly to Coventry) and then exploded harmlessly in the water.

The ship remained mission capable (but for the loss of her helicopter of course) and in fact was instrumental in rescuing most of the crew of Coventry.

HMS Argonaut (1982)

HMS Argonaut was a Leander-class frigate with a displacement of about 3250 t at full load. She received two hits by bombs which did not explode.

HMS Argonaut was hit by two bombs which did not explode; however, one of them entered a missile magazine, detonating two missiles and causing some casualties and a fire.

The ship moved away from the area under tow, which suggests some internal damage for which however documentation is lacking.

HMS Antrim (1982)

HMS Antrim was a County-class destroyer with a displacement of about 6850 t at full load. She received one hit by a bomb which did not explode.

HMS Antrim was hit by one 450-kg bomb which did not explode.

Information is lacking about what damage, if any, was caused by the impact.

HMS Glamorgan (1982)

HMS Glamorgan was a County class destroyer with a displacement of about 5400 t (6200 full load). She received one hit by an Exocet which she survived despite some extensive fire damage.

The hit was sustained on the port side of the hangar deck, close to the Sea Cat launcher, and deflected upwards (the ship was violently maneuvering to present the stern to the missile). The hangar deck was holed by the explosion, fire spread in the galley below; the missile body kept going and penetrated the hangar, destroying the ship helicopter. Eventually the crew managed to contain the spread of fire but there was extensive damage in the hangar area (Inskip, 2012). The ship was definitely able to float, though there was some list caused by the extensive quantity of water used in firefighting, and moved away at high speed soon after the attack; her fighting capabilities are unclear, but her main sensors were probably still active. The following day however saw the ship in sheltered waters for repairs. After the end of the war the ship traveled back to the UK under her own power.

USS Stark (1987)

USS Stark was a Perry class frigate with a displacement of about 4200 t (full load). She received two hits by Exocet missiles which she survived despite significant, fire, flooding and crew losses.

The ship received two hits in the same location, on the port side close to the waterline (more or less below the bridge); the first missile did not detonate but started a fire, the second exploded in crew quarters causing large losses among the crew.

Official statements (USN, 1987) indicate that the first hit was more damaging as a large quantity of propellant was injected further inside the ship, whereas the second hit is estimated to have occurred about 1 m inside the ship and vented some of its energy outside her.

Energic damage control carried out for several hours with the help of nearby ships managed to contain the spreading of fires and saved the ship, which at a point had an extensive list, reported as 15° (USN, 1987). The ship eventually made it to Bahrain where she sustained temporary repairs before returning home.

While propulsion was maintained, it took a while before the ship was able to move safely; also, the Standard launcher was reportedly down and the ship could not retaliate nor defend herself (except with the CIWS) from further attacks.

USS Samuel B. Roberts (1988)

USS Samuel B. Roberts was a Perry class frigate with a displacement of about 4200 t (full load). She sustained one hit by a contact mine which caused extreme damage but did not sink her.

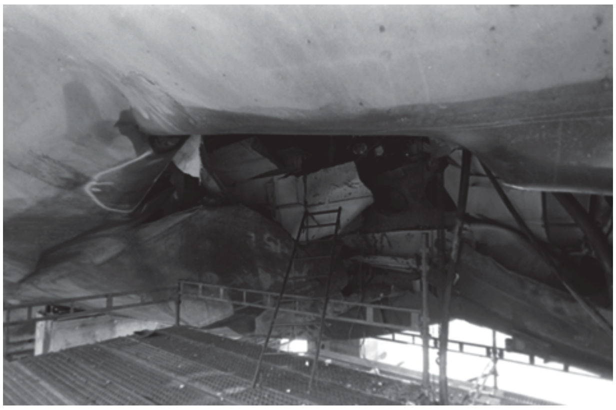

Figure 2: The damaged hull of USS Samuel B. Roberts
(photo credit: PH2 Rudy D. Pahoyo - USN - public domain)

Samuel B. Roberts struck an M-08 contact mine with a nominal charge of about 115 kg (Watts, 1991). Literature suggests however that some of the mines encountered in the Persian Gulf had a higher than normal charge in exchange for flimsier chains, which could explain the fact that the mine was encountered in a commercial shipping lane.

The hit broke the keel of the ship and blew a 5 m hole in the hull, flooding the engine room and knocking the two gas turbines from their mounts; a large fire was also initiated. Heroic damage control managed to contain the damage and save the ship, which then moved away under the power of her auxiliary thruster and reportedly maintained (or quickly regained) radar coverage and weapon readiness; however her extreme structural damage as well as her much reduced mobility still qualifies this hit as a mission-kill.

IIS Sahand (1988)

IIS Sahand was a British-made Alvand-class 1500 t full load frigate that was sunk after sustaining 3 Harpoon hits plus further hits by 2 cluster bombs and at least 2 laser guided bombs.

It is reported that either of the first two Harpoon shots (with a 220 kg warhead) hit the superstructure in the command area, effectively disabling the fighting capabilities of the ship; further hits had the ship ablaze from bow to stern, dead in the water and listing; eventually the ship blew up when the flames reached her ammunition magazines.

IIS Sabalan (1988)

IIS Sabalan was a British-made Alvand-class 1500 t full load frigate that was hit by 1 225-kg laser-guided bomb.

Sabalan sustained a hit by a Mark 82 bomb, reportedly close to her exhaust stack, which caused the ship to lose propulsion and set her on fire. It was eventually towed back to port and repaired. Not much more is known about this event.

USS Tripoli (1991)

USS Tripoli was a Ivo Jima-class amphibious assault ship with a displacement of 19300 t that was hit by a contact mine (USN 1992, Atkinson 1994).

Tripoli was hit on her starboard bow by an LUGM-145 mine carrying about 145 kg of explosives, the effect of the hit being magnified by the close bottom. The explosion ripped a 5 by 7 m hole in the hull and caused damage throughout the bow, including an artillery magazine being flooded with JP5 kerosene and water and a mixture of paint and thinner being vaporized and filling part of the hull with its toxic vapors.

Damage control managed to contain the effects of the damage; the ship resumed operations after 20 hours, remaining in the combat area for several days until relieved, though she was unable to deploy her mine-hunting helicopter due to the relevant fuel tanks having been damaged by the hit.

USS Princeton (1991)

USS Princeton is a Ticonderoga-class cruiser with a displacement of 9800 t at full load. She was hit by two influence mines (USN 1992, Atkinson 1994).

Princeton was hit by the blast of an Italian-made MN-103 Manta, a bottom-mounted influence mine, which exploded under the port rudder; immediately thereafter a second mine of the same type (probably in a sympathetic detonation) exploded forward of the starboard bow. The whipping induced by the detonations caused the ship to suffer severe structural damage.

The fantail nearly separated from the rest of the ship. Cracks developed in the hull and in the superstructure which was nearly divided in two parts by a crack going completely through its sides. The port rudder was jammed and the starboard propeller shaft was damaged. A fire main was damaged, flooding part of the ship and shorting one of the main switchboards.

The AEGIS system was brought back online in a short while and the forward weapons were still operational, but the ship could not be safely moved due to the severe structural damage and eventually had to be towed away, so as in the case of Samuel B.

Roberts this must be considered a mission-kill as well.

TCG Muavenet (1992)

TCG Muavenet (ex USS Gwin) was a mine layer destroyer that was hit by two Sea Sparrow missiles fired inadvertently by USS Saratoga.

The missiles were meant for AA use and therefore had smaller 40-kg warheads; however the first hit destroyed the bridge and the CIC, whereas the second struck the aft magazine but did not detonate.

Damage control operations saved the ship which was still capable of floating and moving, but she had been effectively crippled due to the loss of most of her bridge crew and command rooms.

USS Cole (1999)

USS Cole is an Arleigh Burke-class destroyer with a displacement of 9000 t at full load. She was hit by a suicide small boat on her port side. It is estimated that 200-300 kg of explosives, possibly formed in a shaped charge, were used. The attack was probably the most successful attempt at asymmetric warfare in the post Cold War era and has influenced naval thinking and design in recent times.

The hit opened an 18 by 12 m gash in the ship at the waterline, driving two lower decks upward toward the main deck and opening the room containing the starboard main engine to the sea. Fuel lines were ruptured and power throughout the vessel went out as well. Damage control took three days until the situation was stabilized enough for the ship to be towed and then dry-docked.

INS Hanit (2006)

INS Hanit is a Sa'ar 5 class corvette with a displacement of 1300 t (full load) which received a single hit by what has been reported as a YJ-82 missile.

The hit was sustained in the stern area of the ship; the explosion split the helo deck, caused crew casualties and reportedly extensive damage to propulsion. Despite this the ship made it back to a safe port under her own power; her fighting capabilities after the impact remain however unknown.

ROKS Cheonan (2010)

ROKS Cheonan was a Pohang-class corvette with a displacement of 1200 t which, according to the official investigation, received a single torpedo hit which sunk her.

The matter is contested, but what is clear is that a medium-sized explosive charge, estimated as 250 kg of TNT equivalent, detonated just below the hull in the stern area, somewhat off to port; the resulting bubble jet broke the ship in half, separating the stern, and the ship capsized and sunk in a very short time frame.

5. CONCLUSIONS

At the base of this paper there is the opinion that the SOLAS2009 probabilistic approach might represent and interesting methodology to be implemented in the warship survivability assessment. After the indication of the main critical points for the approach transferability to the warship design process, attention is given to the need of a consistent and comprehensive investigation, about the different damage scenario characteristics..

As an initial approach to the problem an overview is carried out evidencing the importance to discuss about the ship characteristics, the kind of threat, the primary effects (hull damage and flooding), the secondary effects (for example fire or systems failures) and the final evolution of the situation.

It appears evident that the damage size description in terms of length, penetration and height is not a straightforward activity and that some further studies are necessary in the perspective of a probabilistic approach, SOLAS2009 like, the field of naval ship assessment. Actually some analytical probability density function derived from literature (Przemieniecki, 2000) able to describe the ship damage statistics, might represent a more suitable way to move forward, as already proposed by some authors.

The efficiency that the watertight subdivision can express is of course in close relation with the weapon overall power intensity that in some occasions is really devastating. To this regard, it might be more interesting to focus on a possible optimization of the ship subdivision considering the effect of an asymmetric threat, characterized by a lower power, but usually oriented to possibly offend a sensitive part of the ship. However there is growing attention to the assessment of a warship performance not only to survive a hostile damage, but also in relation with typical merchant fleet accidents like collision and grounding (Smith & Heywood, 2009) and in this sense the possible application of the probabilistic approach for the warship design might find its exploitation.

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