Staying Power: Assessing the Damage Capacity of Ships

Christopher Carlson
Cold Wars 2012

Admiralty Trilogy Seminar
Outline

◆ What is damage? How does one quantify it?
◆ Comparative Values of Ships of War
◆ 1920’s – Era of Analysis
◆ Approaches to Modeling Ship Damage Effects
◆ Computer Harpoon - Probability of Sinking
◆ Back to the Future
◆ Analytical Effort & Changes to *Admiralty Trilogy* Games
◆ Conclusions

Georgian Project 206MR [Matka] Class hydrofoil
Weapon Damage Mechanisms

- **Explosives – Basis for damage mechanisms**
  - Rapid conversion of chemical potential energy into heat, smoke, noise and kinetic effects

- **Blast Effects**
  - Formation of a shock or high pressure wave

- **Fragmentation Effects**
  - Breakup and acceleration of case material

- **Incendiary Effects**
  - Chemical reaction generates a lot of heat
What is Damage?

- Damage is the result of explosive effects that causes a degradation in a ship’s functions and/or seaworthiness

- Degradation to a ship’s functions
  - Propulsion – Movement
  - Sensors – Detection
  - Weapons – Attack/Engage

- Degradation to a ship’s seaworthiness
  - Loss of flotation
  - Loss of stability

- Qualitative terms often used to describe or “measure” damage
  - Mobility kill
  - Firepower kill
  - Mission kill
  - Hard kill
Qualitative terms are all well and good, but….
- How much damage does it take to get a mobility kill?
- How much damage does it take to get a hard kill?
- How much damage does it take to cripple a target?

Assigning a number to the qualitative term *sounds* simple, in fact, it is anything but simple
- What physical characteristics of a ship determine its combat life or staying power?
  - Displacement, construction, armor?
- The same goes for weapon systems, which must be closely linked for any comparison to be meaningful

Quantifying damage is vexingly complex, and any approach is hard to defend because it is a subjective estimate
One of the earliest attempts to derive a formula to classify a ship’s military capabilities was in 1872 by Sir Nathaniel Barnaby, Director of Naval Construction. Based on armor weight, gun weight, speed, and ship’s length, offensive and defensive characteristics merged into a single value.

M. Marchal, a French naval constructor, proposed a hideously complex alternative in 1878. Based on three different speeds, metacentric height, armor weight, gun weight, number of watertight compartments, etc.

Captain Gerard Noel, RN, later Admiral of the Fleet, noted in 1885 that Marchal’s approach was so full of minute detail as to be very difficult to use. Noel’s proposal was only slightly less intricate.
Numerous other professionals and enthusiasts continued to attempt to define a ship’s military value numerically:

- Jane’s Fighting Ships, 1902
- Austrian Naval Year Book, 1907
- R.T. Banister – Yexley’s Fleet Annual and Naval Year Book, 1908
- Otto Kretschmer – Schiffbau Magazine, July 1908
- “Ardens” – Yexley’s Fleet Annual and Naval Year Book, 1910

General agreement on armor, guns, and speed as major factors:

- Little agreement on secondary factors or contributions/weighting
- No single value to define a ship’s life in combat

A mathematical deduction has no more validity than the premises upon which it is founded; and a series of approximations or guesses does not become true because it is expressed in algebraical terms.

(Commander Frank Marble, USN, U.S. Naval War College Paper, 1 May 1910)
The naval battles of WWI finally provided a reasonable historical basis from which to conduct analysis.

- The Battle of Jutland was the primary focus

Captain J. V. Chase, USN, first mentions the concept of “life of a ship” in a March 1921 paper.

- Mainly dependent on armor and watertight subdivision

The 1921 Royal Navy Wargame

- Early example of a ship’s life expressed quantitatively
- All damage tied to the number of main guns knocked out
  - A 15in gun required 3 hits of gunfire to be knocked out
    - Queen Elizabeth class BB would have a life of 24 hits

U.S. Naval War College sponsored Fire Effect Tables, 1922

- Analytical effort to characterize naval combat more accurately
- Prior to this arbitrary values by ship type were used
  - 1902 – BB has 1,000 points (based on 50 minutes of combat at 2,500 yards)
Construction of Fire Effect Tables was a multi-command endeavor (NWC, ONI, BuShips, BuOrd) that took into account:

- Ship life - number of 14in penetrating hits required to sink a ship
- Gun rate of fire
- Probability of hit
- Armor penetration
- Damage as a function of range, aspect angle, and spot type

Ship life was defined by an equation

\[ L = A \times P \times R^{1/2} \times (BT)^{1/3} \]

- \(A\) = Coefficient of Character of Construction (1.20 – 2.40)
- \(B\) = Coefficient of Above Water Tonnage (1.0, 0.5, 0.2)
- \(P\) = Probability Factor (0.25 – 0.80)
- \(R\) = Ratio of Whole Target Area to Area of Vitals (1.41 – 3.16)
- \(T\) = Tonnage, in thousands of tons (Standard Displacement)
1920s – Era of Analysis

◆ **USS Colorado, BB 45**
  - 32,600 tons standard displacement

  Ship Life = $2.40 \times 0.77 \times 3.16 \times (1.0 \times 32.6)^{1/3}$
  Ship Life = $2.40 \times 0.77 \times 3.16 \times 3.19$
  Ship Life = 18.6

◆ **The 1929 Royal Navy Wargame provides similar values**
  - *Queen Elizabeth* Class has a life of 15 penetrating 15in hits
  - Decreased life from 1921 game implies secondary damage was considered
  - NWC ship life value for *QE* = 16.6
Non-Gunnery Damage

- Torpedoes, Mines, and Bombs rated by 14in penetrating hits
  - Torpedoes Damage
    - 17.7 inch torpedoes = 1.8 x 14in penetrating hits
    - 21 inch torpedoes = 3.0 x 14in penetrating hits
    - Additional hits within a 15 minute period cause more damage
  - Mine Damage
    - First mine = 3.0 x 14in penetrating hits
    - Second and subsequent mines = 4.0 x 14in penetrating hits
  - Bomb Damage (against a battleship and armor penetrated)
    - 1,000 lb bomb = 2.0 x 14in penetrating hits
    - 500 lb bomb = 1.0 x 14in penetrating hits

Values taken from NWC Maneuver Rules 1940, June 1940
Problem solved? Not quite - while the NWC and RN games had more rigor in the process of defining ship life, how damage effects are applied is just as critical.

Two main approaches to damage effects modeling:

- Deterministic Model: A ship sinks when the cumulative damage exceeds the ship’s life
  - NWC Fire & Maneuver Rules and RN 1929 Wargame Rules
  - Combat capability and mobility decreases with damage
- Stochastic Model: A ship sinks, not from cumulative damage, but from a catastrophic event, such as a magazine explosion or excessive flooding
  - U.S. Navy Bureau of Ordnance developed this model during the war
  - Striking Power of Air-Borne Weapons Study, ONI, July 1944
  - Another way to look at it is as a loss of function model

Which is the better one to use? – BOTH

- Hybrid Model: Combines aspects of both schools
Early naval wargames were largely deterministic
- NWC Fire & Maneuver Rules
- RN 1921/1929 Wargames
- Early versions of Jane’s Naval Game (1898 – 1910)
- Fletcher Pratt’s Naval War Game (first published in 1940)

Use of the stochastic model is more rare
- Action Stations! Coastal Forces Rules
- *Admiralty Trilogy* small boat damage rules
- Battle Stations! Battle Stations!

Many naval wargames use a combination of damage points (deterministic) and critical hits (stochastic) to model damage
- Battle Stations! (Zimm)
- Thunder at Sea
- Seekrieg
- *Admiralty Trilogy* games
Faithfully executes the damage model in *Harpoon*\(^4\) miniatures game

- Not compliant with the new Harmonized Damage System

May 2011 – AGSI received a request to add a “Probability of Sinking” function to the log keeping aspect of the game

- Desire to quantify the probability of a ship sinking based on the damage taken

Research found *very* few analytical studies on the concept of “probability of sinking”

- Naval Postgraduate School theses referenced a presentation on *Warship Damage Rules for Naval Wargames* by Richard Humphrey, Naval Surface Warfare Center, Silver Spring, MD
Humphrey’s model used the Sochard Ship Damage Model (SSDM) to develop equations for the probability of a ship being disabled (mission kill) and sinking

- Sochard Ship Damage Model developed by Irving Sochard in 1984, Naval Surface Weapon Center, White Oak, MD – Confidential study
  - Parametric study based on Joint Munitions Effectiveness Manual
  - Memmesheimer & Brzozowsky applied the SSDM to WWII
    - Historical damage information from Korotkin’s study (1960)

Model proposed by Humphrey was cumbersome

- Two separate equations for torpedoes and bombs
  - Considered only one specific type of ordnance at a time
- Two separate equations for disabling and sinking
- Did not model modern weapons well
  - ASCMs weren’t characterized well by Humphrey’s equations
  - Modern torpedoes use influence instead of contact fuzing
NPS theses and Humphrey model describe ship life in numbers of particular weapons

- NPS and Hughes Salvo Equation papers use Thousand Pound Bomb Equivalents (TPBE)
- Humphrey model is a little more flexible, but limited to evaluating a single weapon type
- Concerns with assumptions in physics and historical damage records precluded either from being used as the sole basis for the probability of sinking function

Striking Power of Air-Borne Weapons Study, ONI, July 1944

- Purely stochastic modeling approach – catastrophic sinking
- Probability of sinking based on single weapon type
  - Study covered numerous weapon types

No single integrated approach for use in real wargaming
Lack of an existing model required original work

An iterative analytical approach using multiple documents had to be adopted

Torpedo data from Striking Power of Air-Borne Weapons Study was used to describe the shape of the curve (S-curve)

Numerous case studies were done across WWI, WWII, and modern naval ship types using data from US, UK, and Soviet sources

Major unexpected discovery – Ships in the Admiralty Trilogy system have damage point ratings that were too low
  - Particularly true for small combatants
  - Example: Sumner class DD damage points increased from 96 to 162
New AT Damage Equation

\[ y = 0.85x^{0.667} \]

\[ y = 0.177x^{0.8} \]

✈ Updated ship damage points, in Excel spreadsheet form, will be posted to the Clash of Arms website
Single curve can be used to describe both the probability of disabling (mission kill) and sinking

- Probability of Disabling = 2 x Probability of Sinking
Queen Elizabeth Class BB

- Displacement: 27,500 tons (FG&DN standard)
- Damage points: 660 (new)/536 (old)
- 1929 RN Wargame Ship Life = 15 x 15in penetrating hits
  - 15 x 30 = 450 Damage Points
- 1922 NWC Ship Life = 16.6 x 14in penetrating hits
  - 16.6 x 28 = 465 Damage Points

- Probability of Sinking (15in shells) = 80%
- Probability of Sinking (14in shells) = 83%

A few moderate critical hits raises the Probability of Sinking to 95+%
INS *Eilat* – 21 October 1967

- Attacked by two Egyptian Project 183R Komar PTGs

**Displacement:** 1,730 tons (*CaS* standard)

**Damage points:** 123 (new)/69 (old)

**P-15** [SS-N-2A *Styx*] missile damage = 48

**Probability of Sinking** (1 x SS-N-2A) = 36%

- Probability of Disabling = 72%

**Probability of Sinking** (2 x SS-N-2A) = 91%

- Humphrey model Probability of Sinking = 55%
- Third missile hit two hours later while *Eilat* was sinking

*Matches Soviet estimates for 1 to 2 P-15 missiles to sink a destroyer*
USS Buchanan (DDG 14)
- Target ship in RIMPAC 2000 Exercise

Displacement: 3,570 tons (Harpoon^4 standard)

Damage points: 169 (new)/105 (old)

Hellfire missile damage = 5 \times 3 = 15

Harpoon missile damage = 40 \times 2 = 80
- Third missile reportedly flew thru the hole made by the first two

GBU 24 damage = 58 \times 1 = 58

Total damage = 153

Probability of Sinking = 99%

*The damage model can now explain USS Buchanan example.*
Ship damage is *really* hard to model
- Many competent individuals have struggled with this problem

Wargaming is best served by a hybrid approach to damage effects (deterministic/stochastic elements)

Combining past ship life work with current publications have yielded unexpected results
- New *Admiralty Trilogy* ship damage equation
  - Finally puts to bed an issue continually raised by players concerning the short combat lives of small combatants
- Probability of disabling and sinking will be used in future operational board game versions of *FG&DN*, *CaS*, and *Harpoon V*
- Minor modifications will also be made to torpedo damage and Japanese WWII bombardment shells
Questions?