Staying Power:
Assessing the Damage Capacity of Ships

Christopher Carlson

Cold Wars 2012

Admiralty Trilogy Seminar

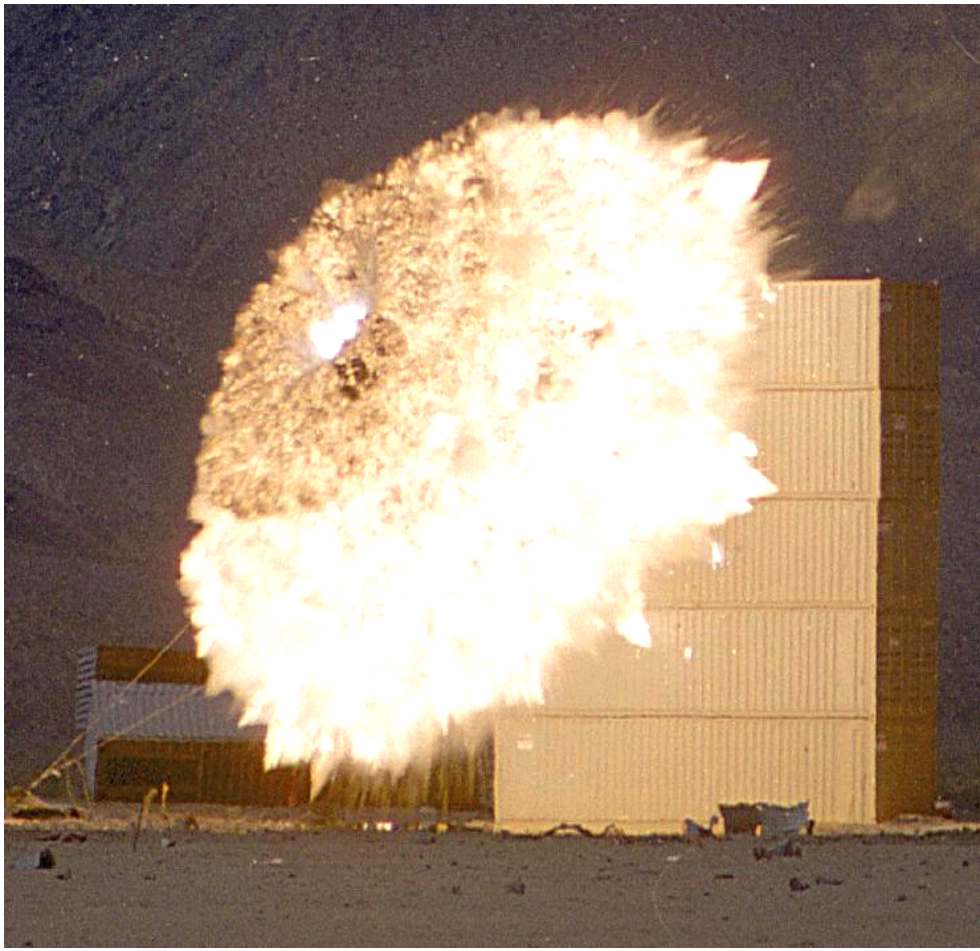
Outline

- 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

USS *Stark* (FFG-31) after AM39 Exocet attack

How to Quantify Damage?

- **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**

Comparative Values of Ships of War

- 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

Comparative Values of Ships of War

- 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)*

1920s – Era of Analysis

- **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)**

1920s – Era of Analysis

- **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

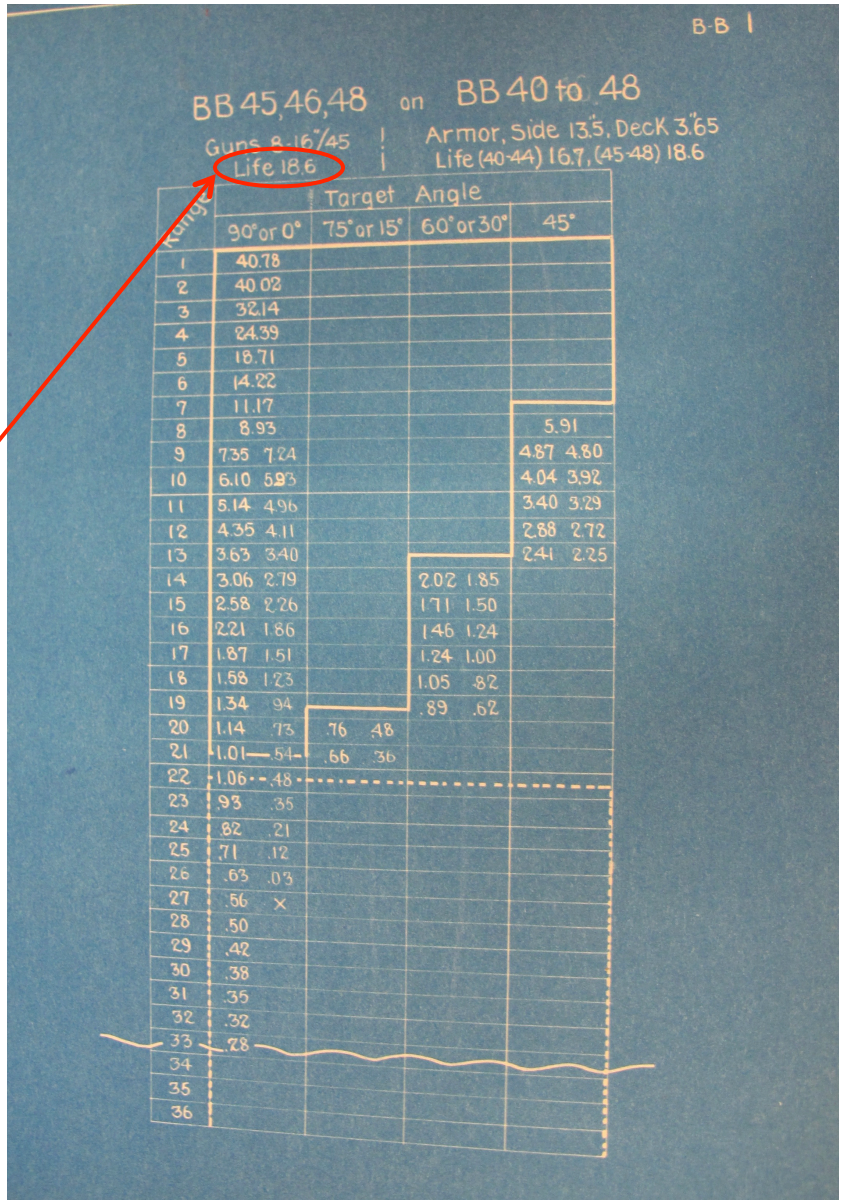
- **USS *Colorado*, BB 45**
  - **32,600 tons standard displacement**

Ship Life = 2.40 x 0.77 x 3.16 x (1.0 x 32.6)$^{1/3}$

Ship Life = 2.40 x 0.77 x 3.16 x 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

Modeling Ship Damage Effects

- **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**

Damage Models in Naval Wargames

- **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**

Computer Harpoon

- **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**
  - **U.S. Navy Wargaming Manual (1969) – linear based approach**

Recent Analytical Work

- **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**

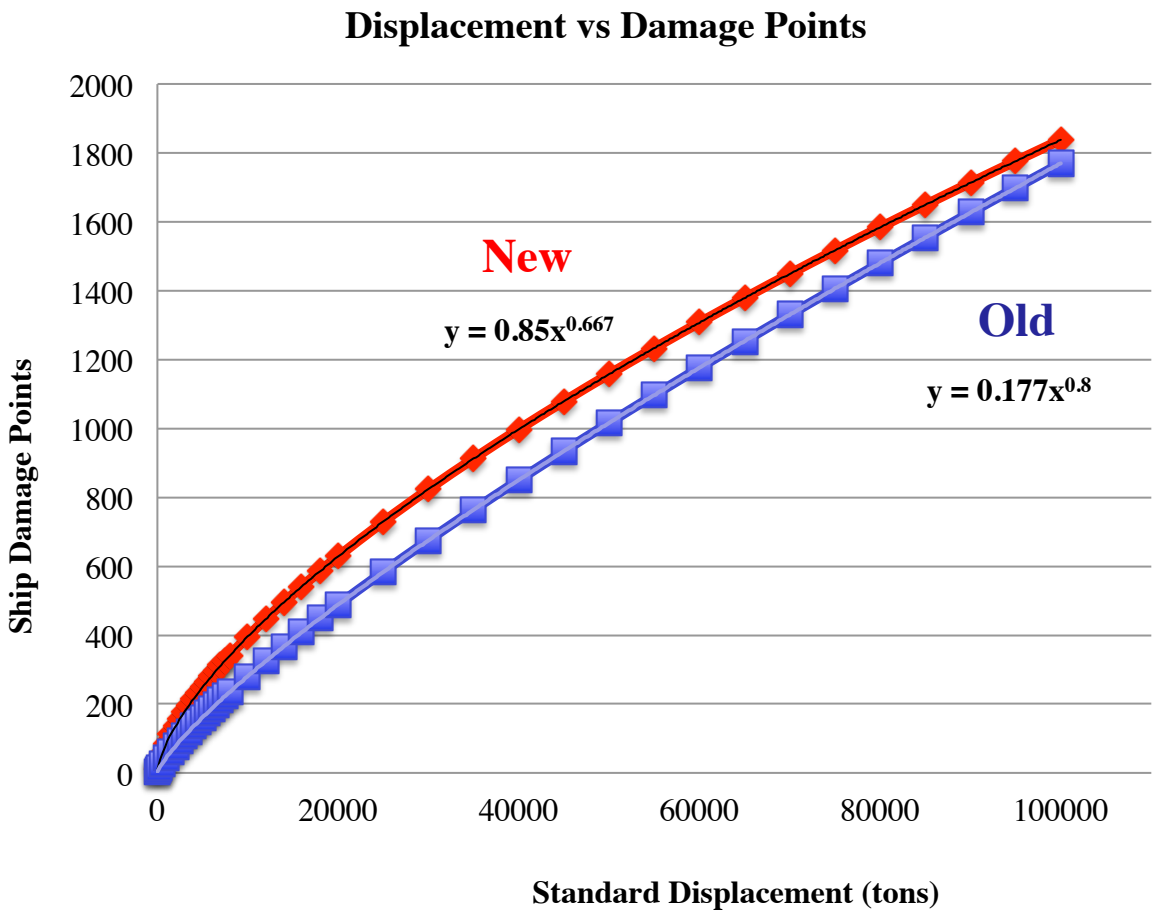
Back to the Future

- **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**

Back to the Salt Mines

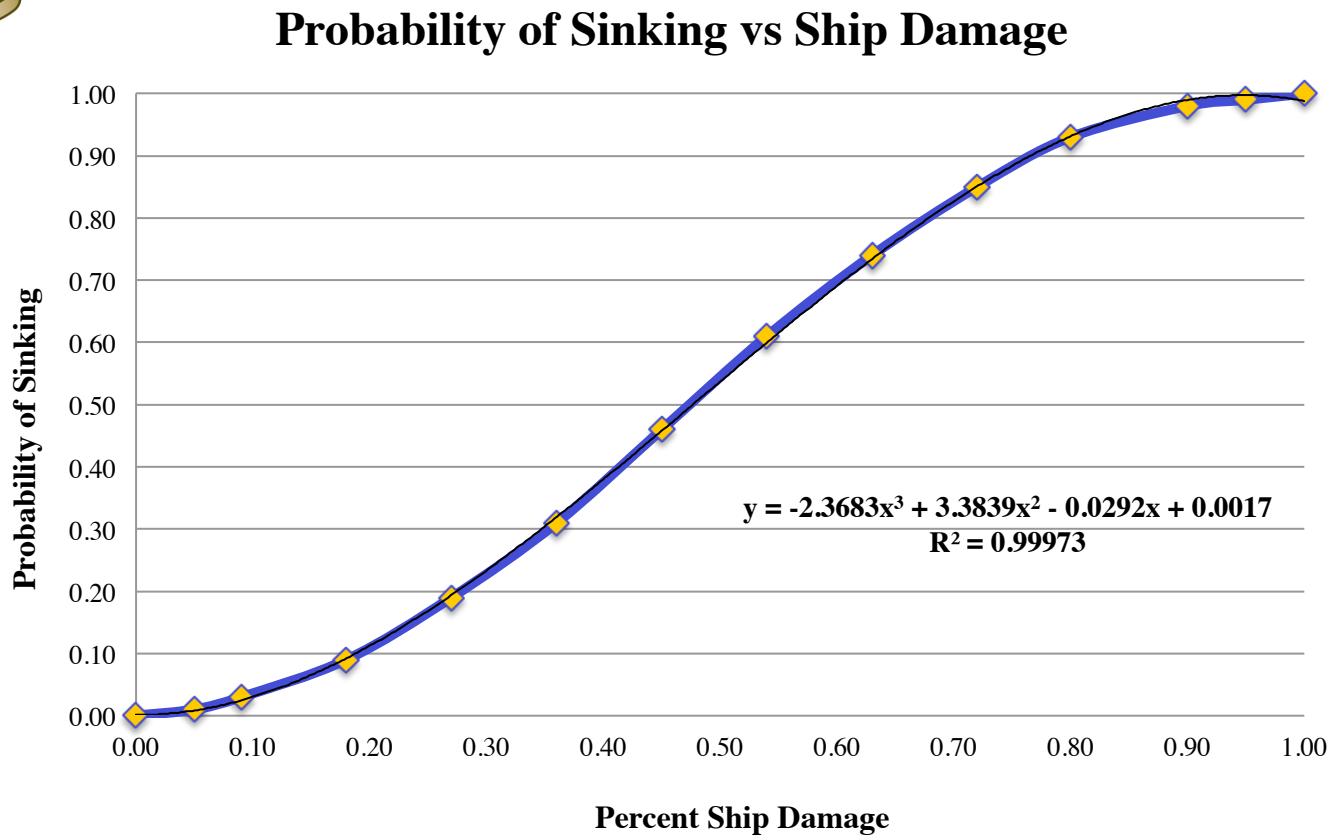
- **Lack of an existing model required original work**
- **An iterative analytical approach using multiple documents had to be adopted**
- **Torpedo data from Striking Power of Air-Borne Weapons Study was used to describe the shape of the curve (S-curve)**
- **Numerous case studies were done across WWI, WWII, and modern naval ship types using data from US, UK, and Soviet sources**
- **<u>Major unexpected discovery</u> – 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



- Updated ship damage points, in Excel spreadsheet form, will be posted to the Clash of Arms website

Probability of Sinking Curve



- 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+%

Z Class DD

- **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* SinkEx

- 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 x 3 = 15
- Harpoon missile damage = 40 x 2 = 80
  - Third missile reportedly flew thru the hole made by the first two
- GBU 24 damage = 58 x 1 = 58
- Total damage = 153
- Probability of Sinking = 99%

The damage model can now explain USS Buchanan example.

Conclusion

- **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**
    - **<u>Finally</u> 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?