Staying Power:
Assessing the Damage Capacity of Ships

Christopher Carlson
Cold Wars 2012

Admiralty Trilogy Seminar
Presented by:
Clash of Arms Games

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**
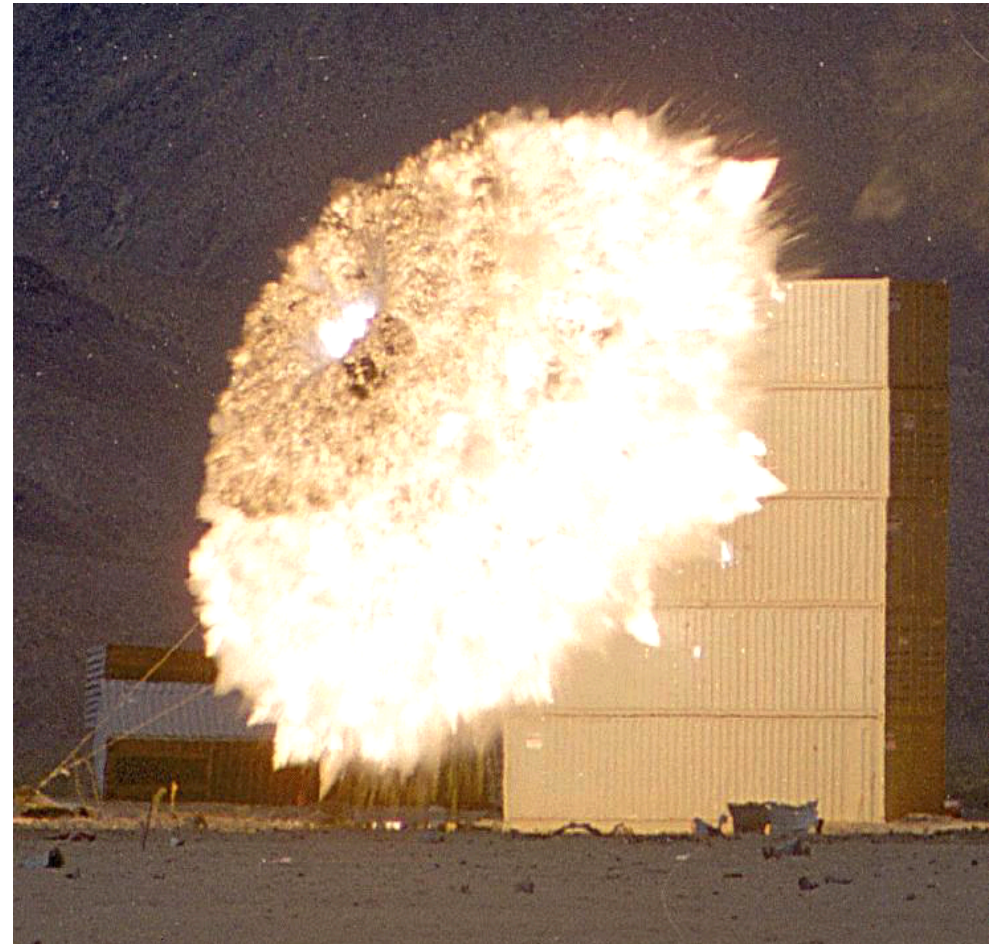
What is Damage?

◆ **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 $(1.0 \times 32.6)^{1/3}$

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**

B-B 1

BB 45,46,48 on BB 40 to 48
Guns 8-16"/45 | Armor, Side 13.5, Deck 3.65
Life 18.6 | Life (40-44) 16.7, (45-48) 18.6

Range	Target Angle			
	90° or 0°	75° or 15°	60° or 30°	45°
1	40.78			
2	40.02			
3	32.14			
4	24.39			
5	18.71			
6	14.22			
7	11.17			
8	8.93			5.91
9	7.35 7.24			4.87 4.80
10	6.10 5.93			4.04 3.92
11	5.14 4.96			3.40 3.29
12	4.35 4.11			2.88 2.72
13	3.63 3.40			2.41 2.25
14	3.06 2.79		2.02 1.85	
15	2.58 2.26		1.71 1.50	
16	2.21 1.86		1.46 1.24	
17	1.87 1.51		1.24 1.00	
18	1.58 1.23		1.05 .82	
19	1.34 .94		.89 .62	
20	1.14 .73	.76 .48		
21	1.01—.54-	.66 .36		
22	1.06-·.48·			
23	.93 .35			
24	.82 .21			
25	.71 .12			
26	.63 .03			
27	.56 x			
28	.50			
29	.42			
30	.38			
31	.35			
32	.32			
33	.28			
34				
35				
36				

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 <u>Warship Damage Rules for Naval Wargames</u> 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
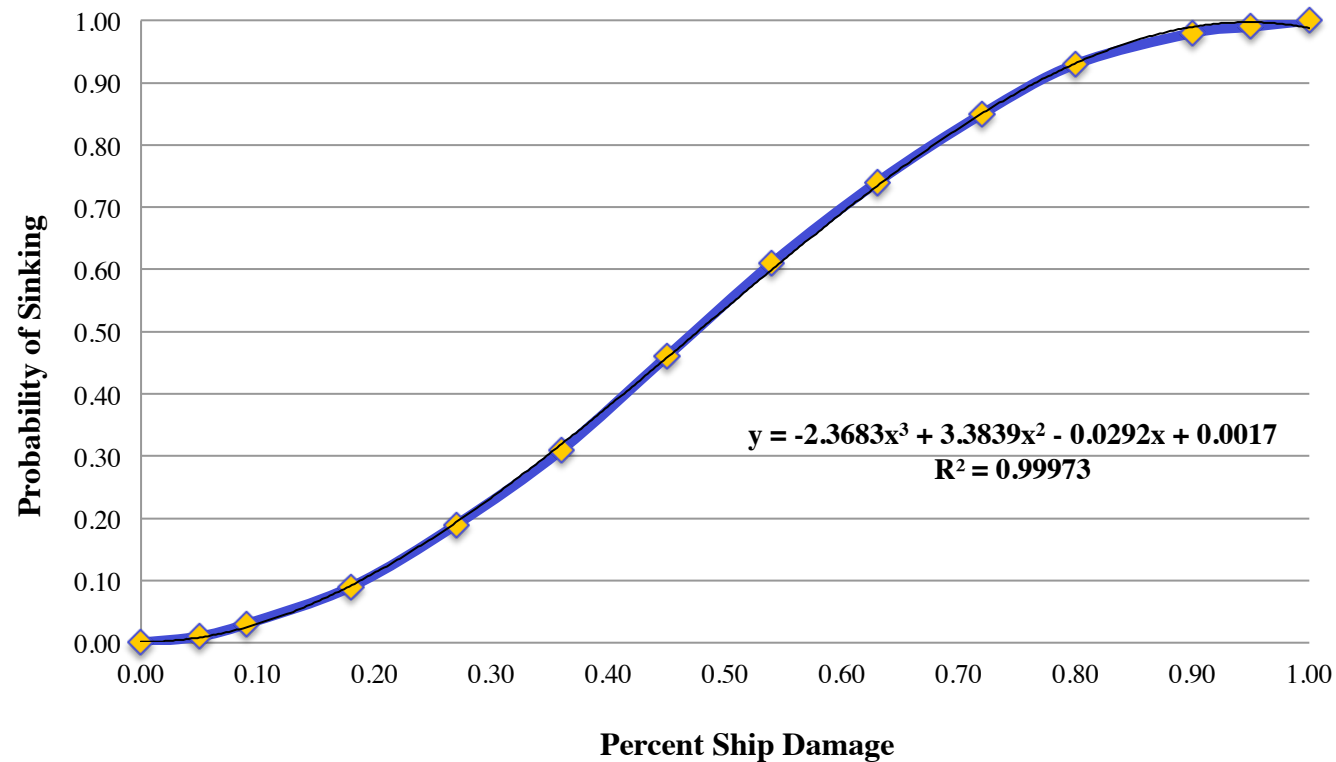
Displacement vs Damage Points

New

$y = 0.85x^{0.667}$

Old

$y = 0.177x^{0.8}$

Ship Damage Points

Standard Displacement (tons)
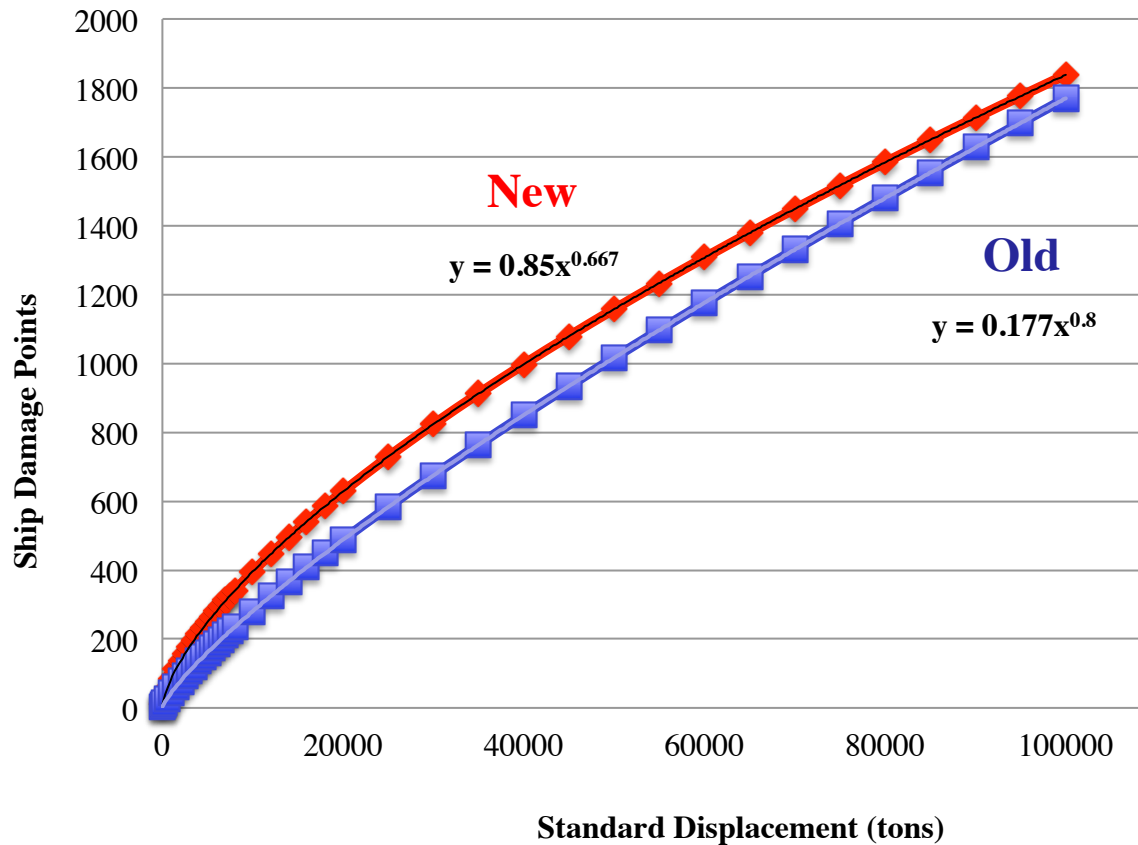
◆ **Updated ship damage points, in Excel spreadsheet form, will be posted to the Clash of Arms website**

Probability of Sinking Curve

Probability of Sinking vs Ship Damage

$$y = -2.3683x^3 + 3.3839x^2 - 0.0292x + 0.0017$$
$$R^2 = 0.99973$$

◆ **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?