THE EVOLUTION OF NAVAL GUNNERY (1900 TO 1945)
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INTRODUCTION

1. The great gunnery revolution occurred between 1890 and 1945. During this period, paradigm shifts created the need for new inventions. The result was continual improvement in gunnery. A major thesis of this paper is that evolution of thought resulted in changes of technology and great increase in effective battle ranges.

The stunning improvement in gunnery over time can be seen the Table 1 below, by observing the increase in battle range with generally constant hit percentage.

Year	Shooter	Conflict	Range	% hits	Source
1898	USA	Spanish/American War	2000yds	2%	Jurens[1]
1905	Japan	Russo-Japanese War	6500yds	20%	J. N. Westwood[2]
1914	UK	WWI- Naval Battle of Jutland	16000yds	3%	N. M. Campbell[3]
	Germany			3.5%	
1930-1931	USA	-(Gunnery Exercises)	28834yds	4.4%	Jurens[4]
1939	HMS Hood	Battle of the Denmark Strait	20000yds	3.5%	Antonio Bonomi[5]
1939	SMS Bismarck		20000yds	5%	
1942	USS Washington	Third battle of Savo islands	19000yds	12%	Ben Clymer[6]
1943	USA	Quadalcanal	16000yds	16%[7]	Paul Watson

Table 1: Evolution of Hit Percentage vs firing range

2. When nations of similar technical ability compete, similar technologies and capabilities result. This is certainly true for naval gunnery. The French invented the

[1] There is some question whether any 12-inch shells struck Spanish ships during the Spanish American War in 1898. By contrast, Russian battleships during the battle of Tsushima in 1905 were struck by many 12-inch shells, vindicating the large caliber weapon as an effective military technology. The 20% hit figure given is a combination of 6-inch, 8-inch and 12-inch hits vs. total number of rounds fired in: Jurens, W. J. (1991). The Evolution of Battleship Gunnery in the US NAVY, 1920-1945. *Warship International* (3), 240-271. See also: Friedman, N. (2016). *U.S. Battleships: An Illustrated Design History.* Annapolis, MD, USA: Naval Institute Press
[2] Westwood, J. (1970). *Witnesses of Tsushima.* Tokyo, Japan: Sophia University.
[3] Campbell, N. M. (1986). *Jutland: an analysis of the fighting.* Annapolis, MD, USA: Naval Institute Press.
[4] Jurens, W. J. (1991), ibid.
[5] Bonomi, A. (2005). The Battle of the Denmark Strait, May 24th 1941. *Storia MIlitare* (147).
[6] Clymer, B. A. (1993). The Mechanical Analog Computers of Hannibal Ford and William Newell. *Annals of the History of Computing , 15* (2), 19-34.
[7] During the Guadalcanal night engagement of USS Washington & Japanese Battle-cruiser Kirishima, the U.S. battleship was using radar controlled firing control.

high velocity gun, but the British and Germans soon produced similar weapons. The British pioneered central fire control in 1910, but by 1914 the Germans possessed less sophisticated system but with similar capability. In the story of gunnery evolution, the original creator of an idea is often unclear. Military secrecy and loss of records over the years clouds the detail. As a result, the account that follows necessarily relies on most available data, which is often British. Despite such reliance, ample evidence exists of roughly parallel developments in France, Germany, USA and many other countries.

THE GUNNERY PROBLEM

3. Naval gunnery is unlike shooting a bb gun at an arcade, where hit-after-hit can be achieved by a skilled shooter. Naval gunnery is more comparable to a boy standing by a lake who throws rocks at a distant turtle. The splash of the first rock is short and the boy throws harder. Soon, the boy "finds the range"; but even then, he cannot repeatedly hit the target. The arc of the throw and variations of wind frustrate absolute accuracy. The best he can achieve is to drop rocks in a cluster, about the turtle. After "the range is found", some statistical percentage will hit. Naval gunnery is much the same.

4. For boy and naval gunnery alike, two parameters describe capability:

a. The time required to "find the range" (i.e. throws before "clustering" about target)
b. The percentage of hits (P_{hit}) achieved after "the range is found."

5. There is a loose connection between these two parameters. Generally, the gunnery system that can find the range quickly is more likely to keep the range and achieve many hits; however, other factors come into play. Repeated hitting of the target after the range has been found also relies on the "tightness" of the shell clusters (i.e. they should land in a small ellipse). Ironically, a very tight cluster actually makes finding the range a bit more difficult.[8]

6. The first vessels in the Navy to utilize radar systems to determine range were HMS Sheffield and HMS Rodney in 1938. Yet, as these systems were prototypes they were used mainly for early air target detection rather that spotting, i.e., correcting the fall of shot. Prior to the advent of radar, spotting was done visually, mainly from directors aloft, such as spotting tops on the ship's mast. Visual spotting, in good hands, is still very effective today, and is often better - at least in deflection - than radar. Accurate visual spotting took keen eyesight, good judgment, and prolonged training. The spotter had to judge the amount each shell was short (or over) by

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[8] The particulars of various navies differed a bit with respect to tightness of shell grouping. Some WWII accounts reported that the Japanese Navy shot very tight clusters, and the Italians loose clusters. The triple turrets (e.g. as used by the U.S. Navy) tended to shoot wide clusters when all three guns were fired simultaneously due to the bow wave effect of the middle shell pushing the other two away. British wire wound guns were known to be excessively limber - tending toward wide dispersion although other practices may have compensated

visually estimating the very small distance between the base of the splash and the waterline of the target. This was an almost impossible job if the waterline was below the horizon or if the pattern was off in deflection, so patterns had to be brought on in deflection before accurate range spotting could begin. At short ranges, i.e., less than 15,000 yards, so-called "direct" spotting could be used, with the spotter estimating the error in the impact point straight away. At longer ranges, the "bracket" or "halving" method was common, with the spotter depending upon the "sense" of the splashes to tell if the pattern was short or over, then coaching the pattern "on" by deliberately crossing and re-crossing the target until straddles were achieved. Secondary batteries often employed the "ladder" method, deliberately opening short, thereafter firing salvos as quickly as possible at small increments in range until the target had been crossed, then reversing so as to re-cross the target in the opposite direction. A somewhat similar technique was to aim short, fire as rapidly as possible at constant range until the target had passed through the resulting barrage, change the range by some predetermined value, and wait for the target to steam through the patterns again.

BIRTH OF THE HIGH VELOCITY GUN

7. American civil war photos show thick, stubby gun barrels of the period. Photos of contemporary European artillery look much the same. Fast burning gunpowder generated tremendous and instantaneous pressure within the gun. Such great pressures necessitated thick, stubby gun tubes.

Figure 1: Gun Crew of a Dahlgren Gun at Drill Aboard the U.S. Gunboat Mendota circa 1864[9]

8. During the 1870's, French Military Engineers changed all that. They invented slow burning powder, which gradually expanded as projectiles accelerated down long and slender gun barrels. The marriage of slow burning powder and long gun barrels

[9] Civil War Photos. (n.d.). *Civil War Photos.* Retrieved March 22, 2015, from Navy Units and Ships: https://www.civilwarphotos.net/files/images/051.jpg

resulted in greatly increased shell velocities (2500 ft/sec).

9. Invention of slow burning powder stopped the progression or larger and larger guns. The twin French inventions (slow powder and long barrels) enabled development of small, quick firing guns capable of "poking holes" through thick armor. The French (and other nations) married this technology with the breach-loading (not down the barrel) gun to achieve high rates of effective fire.

10. Major naval powers were quick to follow the French.[10] Britain developed the "wire wound gun" while Germany used shrink fit tube design. Other nations (including the U.S.) purchased gun technology from France, Britain or Germany.

QUICK FIRING GUNS VS. BIG GUNS

11. By 1890, technically advanced navies (France, US, Germany, UK, Russia, Austria & Japan) employed high velocity, breach-loading guns. Naval experts around the world understood that big guns were very heavy. The choice was to employ a few big guns, or many smaller ones. From 1890 until 1906, gunnery experts debated the relative effectiveness of a few big, powerful guns (e.g. 12-inch diameter bore) vs. many smaller quick firing guns (e.g. 6-inch to 8-inch diameter bore). Proponents of the quick firing guns argued that the smaller gun would smother the target before the larger gun made a single hit.

12. The inability to quantify the benefits of small, medium or large guns resulted in battleships of mixed battery. These ships often carried a mix of 12-inch, 8-inch and 6-inch guns to engage other battleships. In addition, they typically carried a battery of 3-inch guns for use against torpedo boats. These "mixed battery" battleships made their debut in the 1898 Spanish-American War and again in the 1904 Russo Japanese War.

TWIN GUNNERY PROBLEMS

13. The twin gunnery problems are

a. Time to find the range and

b. Hit percentage afterwards.

14. During the 1905 Battle of Tsushima, the victorious Japanese fleet required 15 minutes to "find the range".[11] We might wonder why it took so long. Returning to the "turtle analogy", a single boy throwing rocks at a turtle quickly finds the range. But

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[10] Campbell, N. M., *Jutland: an analysis of the fighting.*

[11] During the Russo-Japanese War, the Russian Baltic Fleet was nearly destroyed at the Battle of Tsushima Strait; also know as the Naval Battle of the Sea of Japan. The decisive defeat, in which only 10 of 45 Russian warships escaped to safety, convinced Russian leaders that further resistance against Japan's imperial designs for East Asia was hopeless. See: Sterling, C. H. (Ed.). (2008). *Military communications: from ancient times to the 21st century.* Santa Barbarba, CA, USA: ABC-CLIO.

when five boys all throw rocks at the same turtle, the problem becomes far more difficult. Each boy becomes confused regarding which splash was his. Often as not, he observes the fall of someone else's rock, and wrongly adjusts his next throw.

15. At the Battle of Tsushima, 20 big guns of various diameters fired at the same target. The splashes of 6 to 12-inch projectiles were confused, rendering accurate observation and correction by each gunner impossible. In 1906, British Navy took a bold step to address this problem, launching HMS Dreadnought. Unlike its predecessors, Dreadnought was armed with 10, 12-inch guns, mounted in twin turrets. There simply were no 8-inch or 6-inch guns to cause confusion. Soon after, all major powers began building "all big gun" ships of their own. The Dreadnought age was born; but another 6 years had to elapse before the invention of central fire control delivered the full benefits of the "all big gun ship".

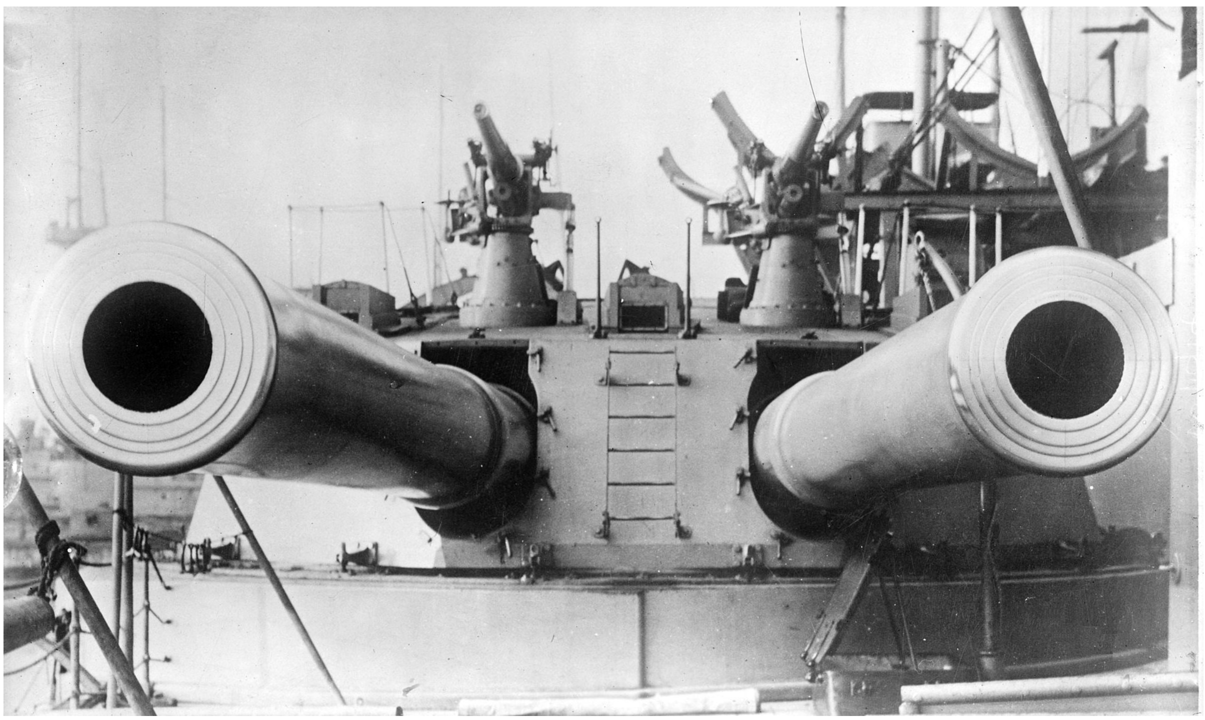

Figure 2: Turret with twin 12-inch Mk-X guns on HMS Dreadnought. [12]

INVENTION OF CENTRAL FIRE CONTROL

16. The "all big gun" ship greatly reduced the confusion that resulted from splashes of multiple calibers of gun firing concurrently.[13] In 1910, the British Navy carried out secret trials between two identical ships, one using traditional single turret

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[12] Image available at the United States Library of Congress's Prints and Photographs Division under the digital ID ggbain. 11494. Available online at: https://en.wikipedia.org/wiki/HMS_Dreadnought_(1906)#/media/File:HMSDreadnought_gunsLOCBain17494.jpg

[13] Confusion was still possible between the splashes of different 12-inch guns

firing and the other equipped with the newly invented central fire control system. The centrally controlled firing system, aimed, elevated and fired all big guns simultaneously. The 8 to 10-inch projectiles landed simultaneously in a pattern before, behind or around the target. The multiple splashes were easy to observe and all guns were corrected simultaneously. Central fire control ensured that gunnery corrections were correlated to correct observation of fall of shot thus minimizing time to "find the range".

17. Shortly after its introduction, a gunnery competition was held between two identical Orion class battleships: HMS Thunderer & HMS Conqueror. One was equipped with the new, central fire control system below the spotting top and the other used the traditional turret-by-turret command of fire[14], as shown below:

Figure 3: The four Orion Class battleships in line ahead formation, after 1915[15]

18. Gunnery Officers carefully observed the fall of shot to determine which method was more effective (in terms of finding the range quickly). Detailed analysis confirmed the obvious, that the central fire control system was far more effective than turret-by-turret fire control.[16] This happened because it offered several advantages over the traditional system. First, all the guns on the ship were fired together thus resulting in a statistical pattern of splashes fitting one of three descriptions:

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[14] Brooks, J. (2000). Percy Scott and the Director. In A. Preston, & D. McLean (Eds.). London, England, UK: Conway Maritime Press, pp. 150-170

[15] Photo from the collections of the Imperial War Museums, available at: https://www.iwm.org.uk/collections/item/object/205188072. The gunnery director is barely visible beneath the spotting top.

[16] Padfield, P. (1974). *Guns at Sea.* New York, NY, USA: St. Martins Press.

a. All short of the target
b. All over the target
c. Or a pattern about the target.

19. The entire splash pattern was easily observed and represented a single ship. There was no possibility of confusion over which splash was from which gun. Unlike single event observation, it was also very clear whether the pattern was centered on the target.

INVENTION OF FIRE CONTROL COMPUTERS

20. By World War I, battle ranges were such that shell flight time was approximately 30 seconds. During 30 seconds, a battleship cruising at 21 kts moved forward 300 yards. A perfectly aimed shell fired at the ship would thus fall harmlessly behind by the time it arrived. Simple math thus dictated that gunnery systems be developed that would enable shooting at the target's future location.

21. Just prior to WWI, major powers developed mechanical Fire Control Computers, which integrated with Central Fire Control Systems to properly adjust the aiming point. The following elements were integrated into an effective system:

a. Central Fire Control (that controlled all the big guns for both elevation & train)
b. Quality optical range finders to determine initial enemy range
c. High up observers in the ship to watch/report the fall of shells to the gunnery officer
d. Observers to watch changes of course and speed of enemy targets
e. A mechanical fire control computer which accepted inputs 2, 3 & 4 and predicted where the guns should be pointed to land shells into the future position of the enemy, given the flight time of the shells.

22. By WWI, Britain, Germany, the U.S. (and likely all other major powers) employed central fire control systems augmented by fire control computers. As a result, WWI naval battles were fought at ranges of 10,000 to 20,000 yards. At those ranges, 3% to 4% hits were achieved with 11-inch to 15-inch guns despite bad North Sea visibility.

23. While such percentages might appear low, the effect of such gunnery was devastating. During the Battle of Jutland, several British Battle Cruisers were blown apart when German shells pierced British magazines. German ships also suffered with Battlecruiser Lutzow sunk after 24 large caliber hits. Other German had barely a gun turret functional by the end of the battle (e.g. Von der Tann).

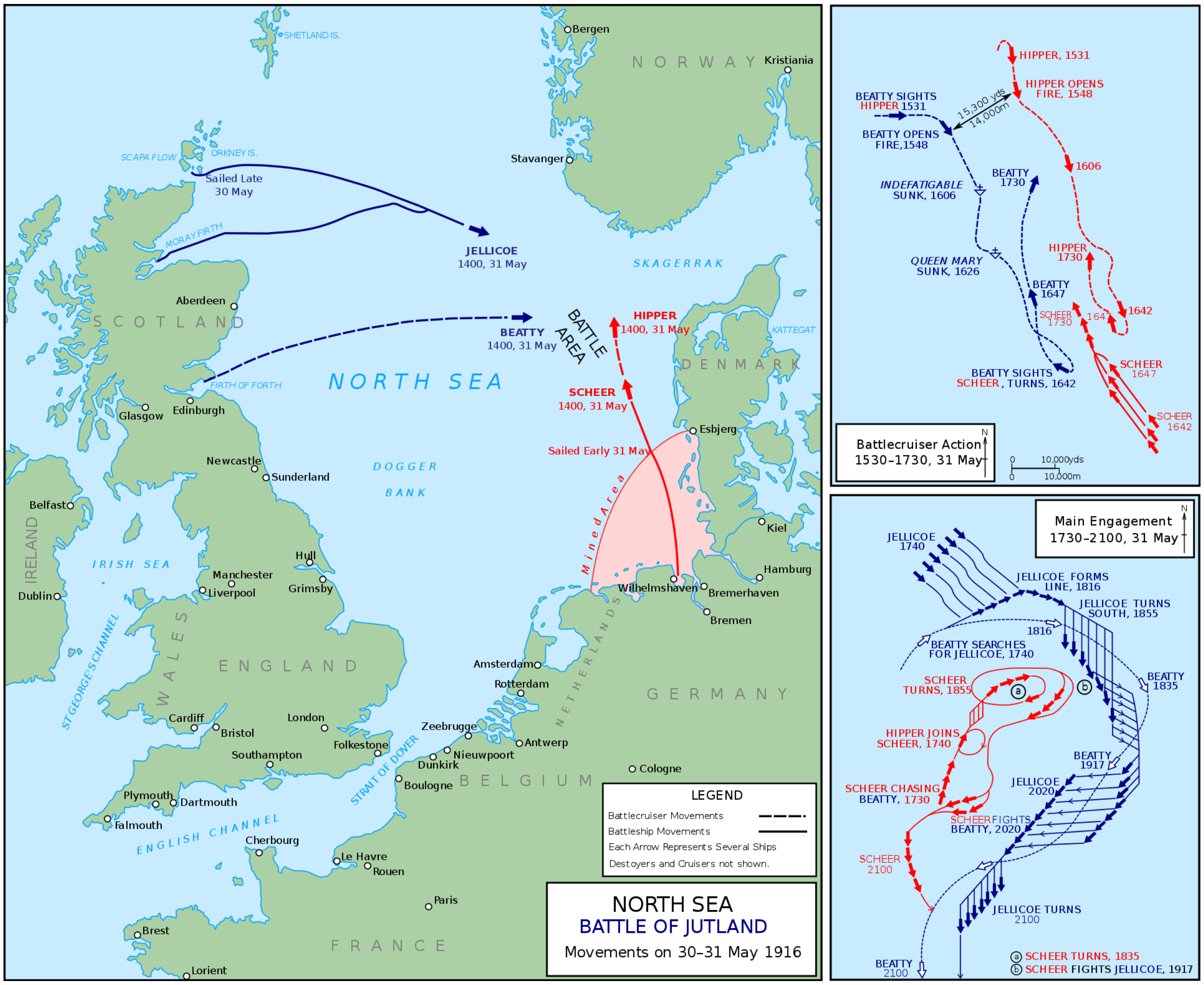

Figure 4: Maps showing the maneuvers of the British (blue) and German (red) fleets on 31 May – 1 June 1916[17]

BETWEEN THE WARS

24. During the period between WWI and WWII, navies continued to develop more effective technologies. Analysis of U.S. Naval practice during 1930s suggests that the hit percentage expected during battle should greatly exceed the 3% to 4% achieved in the North Sea during WWI.[18] During the 1930-31 practice, three battleships fired 56 shots each at 12800 yards range.[19] The target was Battleship representative in terms of length and height. "West Virginia would have gotten five hits, Maryland six, and Colorado only one." Assuming such performance typical, 7% hit percentage was achieved during the opening salvos of a match battle. Records from both the British

[17] A Work of the Department of History at the United States Military Academy; Additional details taken from
Sondhaus, L. (2004). *Navies in Modern World History.* London, England, UK: Reaktion Books, pp191-192**.**
[18] Jurens, W. J. (1991). The Evolution of Battleship Gunnery in the US NAVY, 1920-1945. *Warship International* (3), 240-271.
[19] 7 salvos of 8 rounds.

5th Battle Squadron at Jutland and American interwar practice suggests about 4 salvos are required to "get the range" and "bracket" on enemy target. From this, we conclude that 3 or 4 salvos were simply thrown away and the long-term interwar war hit percentage for American Battleships should be about 14%.

RATES OF FIRE

25. The rate of firing for Battleship main armament increased from 1900 reaching its maximum about 1930. For the Russo-Japanese war period (1904-05), Janes Book of Fighting Ships reports normal rate of fire for Russian battleships as one every 3 minutes. It appears the Japanese long term firing rate was similar in 1905. Jurens provides information for a later period. "In 1919, battleship main batteries averaged about 1.9 shots per gun per minutes. By 1930 the rate had risen to about 2.5 (but never got much higher than this).[20]

FIRE CONTROL RADAR

26. During WWII, both the German Bismarck and U.S. battleships were equipped with Fire Control Radar. For the U.S., its effectiveness was such that even during daytime, it was used in preference to optical fire control. During the night actions at Guadalcanal, an American Battleship using Radar achieved 9 hits on a Japanese target after 56 rounds fired, scoring a 16% hit percentage. Once again, the long-term hit percentage would have been much higher if firing had been prolonged or if "ranging shots" are discounted.[21]

CONCLUSION

27. From 1890 through 1945 a continuous stream of technological improvements increased battleship big gun effectiveness in terms of three major parameters: firing rates, battle ranges; and hit percentages

28. Prior to 1906, high rates of fire for the intermediate caliber gun enabled them to compete with big naval guns. [22] From 1906 to 1914, the emergence of Central Fire Control and Fire Control Computers ushered in the period of the Big Gun, a period when destructive power and accuracy of the big gun totally dominated naval warfare. Around 1900 rates of fire were quite low. During the Russo Japanese war of 1904-05, Janes reports the "normal rate of fire" for Russian battleships as 0.3 rounds per minute. This is consistent with reports that Orel's magazines were exhausted of 12 inch shells following about 3 hours of firing. Also at Tsushima, the Japanese emptied their 12 inch magazines (80 rounds per gun) between 2pm and 7pm (a period of 300 minutes) indicating a long term firing rate of about 0.3 rounds/minute. Note that

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[20] Ibid

[21] "Ranging shots" refers to the sequence of shots fired to establish the correct range of the target.

[22] An "intermediate caliber" gun refers to a 4 to 8-inches bore diameter; there are, however, several articles arguing it to be between 6 to 8-inch. Big naval guns for that period had a caliber of 11 inch to 12 inch. In modern Navies, any gun with bore diameter more than 8 inches is labeled "major caliber".

Russian ships generally carried almost 60 rounds per gun for the main batteries, whereas the British-built Japanese battleships carried 80 rounds per gun.

29. Battle ranges increased as hit percentage grew throughout the period. In 1898, a mere 2% was achieved by the Americans in the Spanish American War, at ranges of approximately 2000 yards. By 1905, the Japanese achieved 20% hit percentage at battle ranges of 6500 yards in the Russo-Japanese War. By WW I, 3% to 4% was achievable under the worst sea conditions at 14000 yards range. During the interwar years, 15% hit percentage at 15000 yards was a realistic battle expectation using optical fire control. While such hit percentage may seem low, the enormous destructive power of each hit deemed it sufficient: SMS Lützow was sunk by 24 hits at the battle of Jutland. Japanese Battle-cruiser Kirishima was effectively destroyed by 9 hits at the battle of Guadalcanal. HMS Hood was blown up after only a few hits at the battle of Denmark Straits. Such observations explain why the Battleship reined supreme for 50 years.

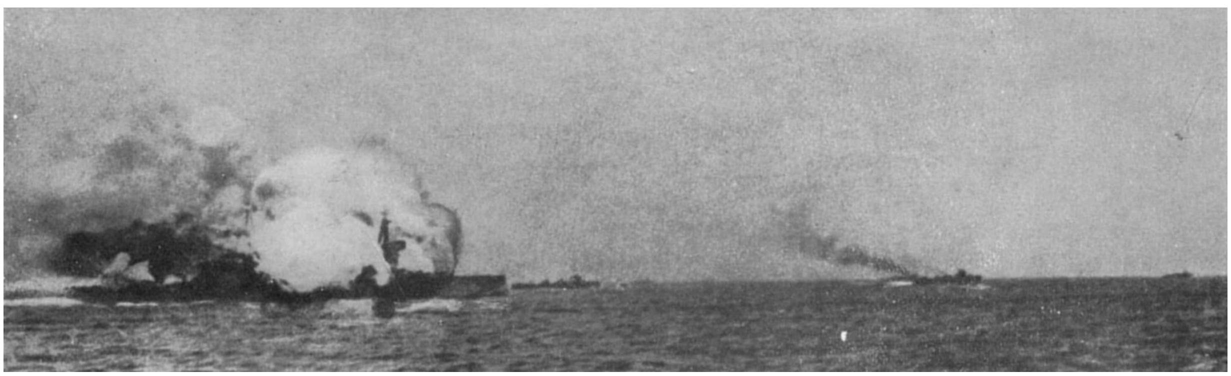

Figure 5: SMS Invincible exploding at the battle of Jutland, photo possibly from SMS Lützow.[23]

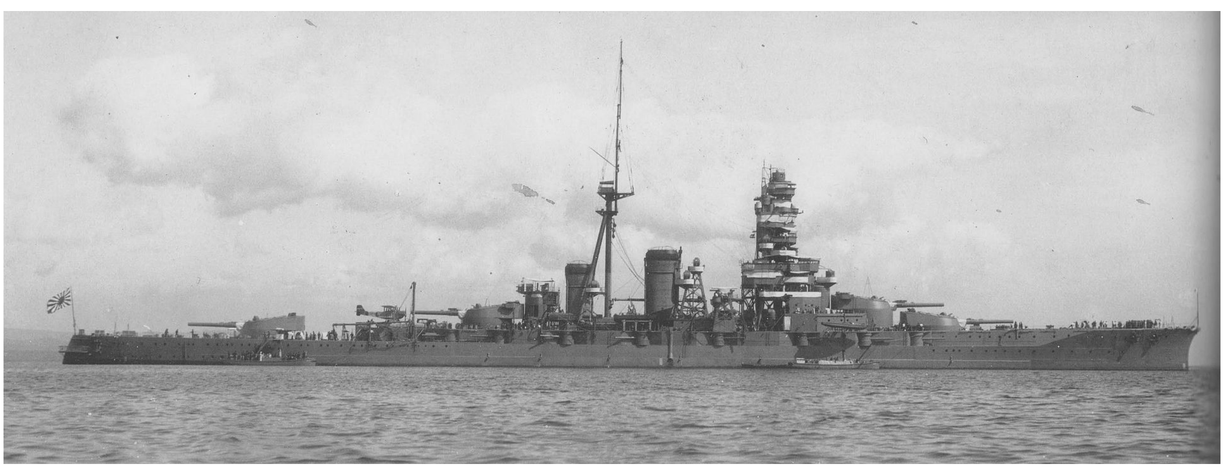

Figure 6: Japanese Battle-cruiser Kirishima in 1932, following her first reconstruction.[24]

[23] Fighting at Jutland: the personal experiences of forty-five officers and men of the British fleet. London Hutchinson and Co, Ltd. 1921, photo available online at: https://en.wikipedia.org/wiki/SMS_Lützow#/media/File:InvincibleBlowingUpJutland1916.jpg

Figure 7: Aerial view of *Hood* in 1924.[25]

[24] Shizuo Fukui - Kure Maritime Museum, (edited by Kazushige Todaka), *Japanese Naval Warship Photo Album: Battleships and Battle Cruisers*, p. 120

[25] The two forward gun turrets are visible with their prominent rangefinders projecting from the rear of the turret. Behind the turret is the conning tower surmounted by the main fire-control director with its own rangefinder. The secondary director is mounted on top of the spotting top on the tripod foremast, photo of the U.S Naval Historical Center photography, under the Photo #: NH 60450

Bibliography

Bonomi, A. (2005). The Battle of the Denmark Strait, May 24th 1941. *Storia MIlitare* (147).

Brooks, J. (2000). Percy Scott and the Director. In A. Preston, & D. McLean (Eds.). London, England, UK: Conway Maritime Press.

Campbell, N. M. (1986). *Jutland: an analysis of the fighting.* Annapolis, MD, USA: Naval Institute Press.

Civil War Photos. (n.d.). *Civil War Photos.* Retrieved March 22, 2015, from Navy Units and Ships: https://www.civilwarphotos.net/files/images/051.jpg

Clymer, B. A. (1993). The Mechanical Analog Computers of Hannibal Ford and William Newell. *Annals of the History of Computing , 15* (2), 19-34.

Friedman, N. (2016). *U.S. Battleships: An Illustrated Design History.* Annapolis, MD, USA: Naval Institute Press.

Jurens, W. J. (1991). The Evolution of Battleship Gunnery in the US NAVY, 1920-1945. *Warship International* (3), 240-271.

Padfield, P. (1974). *Guns at Sea.* New York, NY, USA: St. Martins Press.

Sondhaus, L. (2004). *Navies in Modern World History.* London, England, UK: Reaktion Books.

Sterling, C. H. (Ed.). (2008). *Military communications: from ancient times to the 21st century.* Santa Barbarba, CA, USA: ABC-CLIO.

Westwood, J. (1970). *Witnesses of Tsushima.* Tokyo, Japan: Sophia University.