# Celebrating a Century of Naval Warfare

*Larry Bond & Christopher Carlson*

*Historicon 2014*

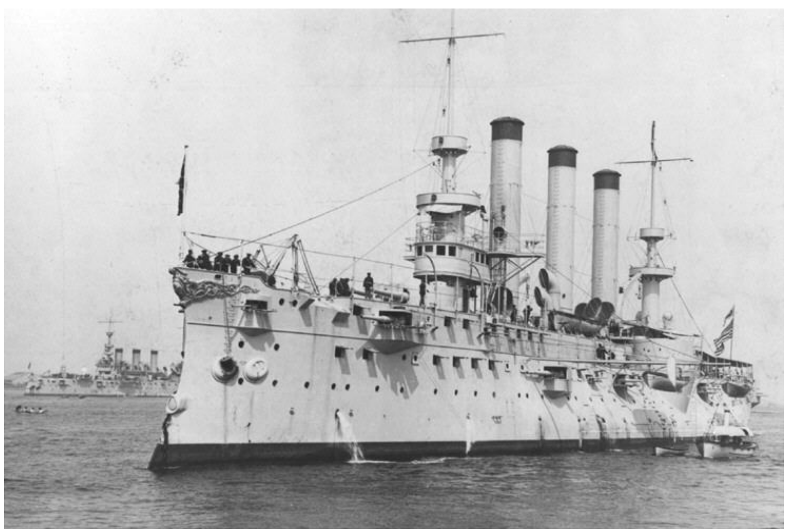
## *Admiralty Trilogy Seminar*

# Outline

- Truth in Advertising: We’re going to cover more like 134 years
- Naval technology has changed a lot in that timeframe
- Six general technological areas to be discussed
  - Materials
  - Propulsion
  - Electrical Power
  - Weaponry
  - Fire Control/Sensors
  - Navigation and Communication
- Changes in one area of technology often aids the development in another area or spurs development as a counter
- Technology drove changes in naval warfare and vice versa
- Conclusions

# 130+ Years of Innovation

- **“Bookend” examples of technological changes over the past 134 or so years**
  - **Mild steel construction – High tensile steel**
    - ***Brooklyn* had Harvey nickel steel armor**
  - **Propulsion: Triple expansion steam engines – Gas turbines**
    - **Coal to refined petroleum**
  - **Weaponry: Short range guns and torpedoes – LACMs, SAMs, and ASCMs**
  - **Fire Control: None – Aegis Integrated Combat System**
  - **Sensors: Mk1 Mod 0 eyeballs – Long range radar, sonar, data links**
  - **Navigation & Communication: Sextant/compass and flags/lights – GPS and SATCOM**



**USS *Brooklyn*, ACR-3, 9215 tons, 1896**

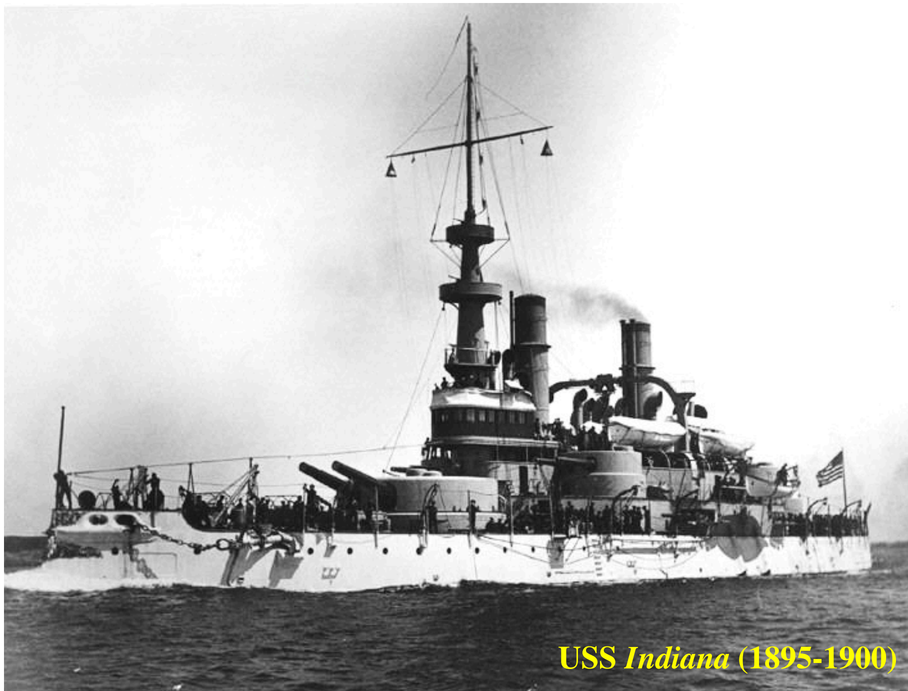

**USS *Mustin*, DDG 89, 9100 tons, 2003**

# Dramatic Change - Starting Point

- Technology has always been of primary importance to naval warfare
  - Based on the use of vehicles – ships
- The Second Industrial Revolution (1860s) focused on advancements involving steel, electricity, and chemical engineering – all crucial to naval warfare
  - Iron and steam engines were the fruits of the First Industrial Revolution
- By the 1870s, ships were largely constructed of wrought iron, had reciprocating steam engines, and muzzle loading guns
  - Some long range ships still used steam and sail
  - By early 1870s most big guns were in trainable turrets or barbettes
  - HMS *Devastation* (1871) – shape of things to come (mastless, central superstructure or breastwork, fore and aft turrets)
- 1880 represents a good starting point for the rest of the presentation

# Technological Areas

- Look at technological advancements in six general areas
  - Materials
  - Propulsion
  - Electrical Power
  - Weaponry
  - Fire Control/Sensors
  - Navigation and Communications
- Build a picture of how ship designs and capabilities changed over time
  - How technology made radical changes to naval warfare



USS *Indiana* (1895-1900)

# Materials

- Steel began replacing wrought iron as the primary building material in the mid-1870s
  - Steel was stronger, reduced hull weight, but more expensive at first
  - Initially mild steels replaced wrought iron
- By the late 1880s, medium strength nickel steels started being used – stronger and tougher
- High tensile steels became available by 1895
- High yield steels first started to be used around 1910
  - U.S. Special Treatment Steel (STS) falls into this category
- Modern high yield steels started to be used in the 1950s
  - Submarines hulls and some strength elements of surface ships
  - Expensive and hard to weld

# Materials

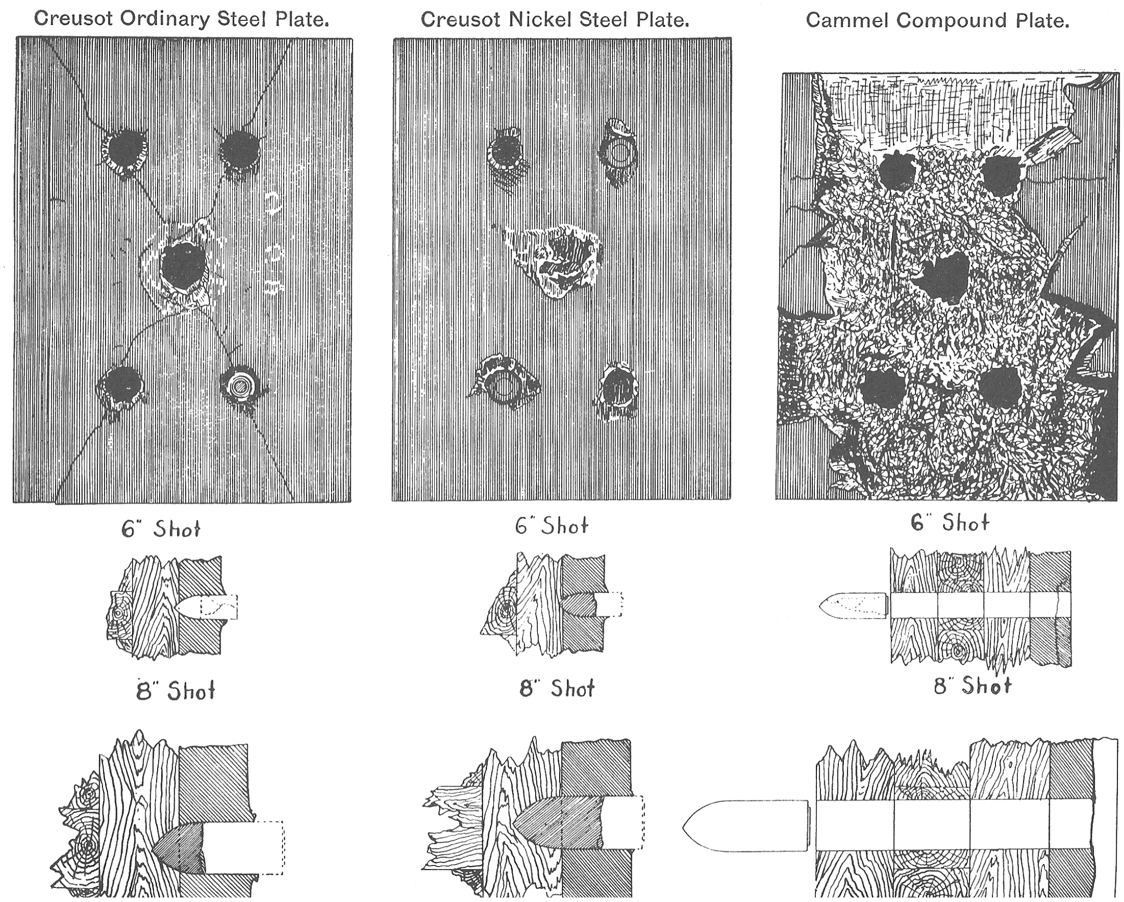
- Aluminum was introduced during the 1930s primarily as a means of saving topside weight
  - Not as strong as steel, but weighs about 50-55% less
  - Difficult to weld, won't bond with steel easily, requires transition plates
- Titanium used very sparingly in modern ships
  - About as strong as steel, but weighs 45% less
  - Very expensive, hard to weld
  - Used in Soviet submarines: Alfa, Papa, and Sierra I/II classes
- Composites have seen growing use since introduction in 1960s
  - Very lightweight, non-magnetic, largely immune to seawater corrosion
  - Tough, but little protection from a direct hit
- Construction material and practices are accounted for in the damage point modifiers

# Armor

| Armor Type | Available | AT AQF |
|---|---|---|
| Wrought Iron | Mid-1850s | 0.40 |
| Mild Steel | 1875 | 0.50 |
| Compound Armor | 1878 | 0.55 |
| Nickel Steel | 1889 | 0.65 |
| Harvey Nickel Steel | 1891 | 0.75 |
| Krupp Cemented Old | 1894 | 0.85 |
| Krupp Cemented New | 1928 | 1.10 |
| U.S. WWII Class A* | 1933 | 1.00 |
| RN Cemented Armor | 1933 | 1.20 |

- * = Reference
- Weight for all iron/steel type armor for 1in thickness is 40.8 lbs/sq ft

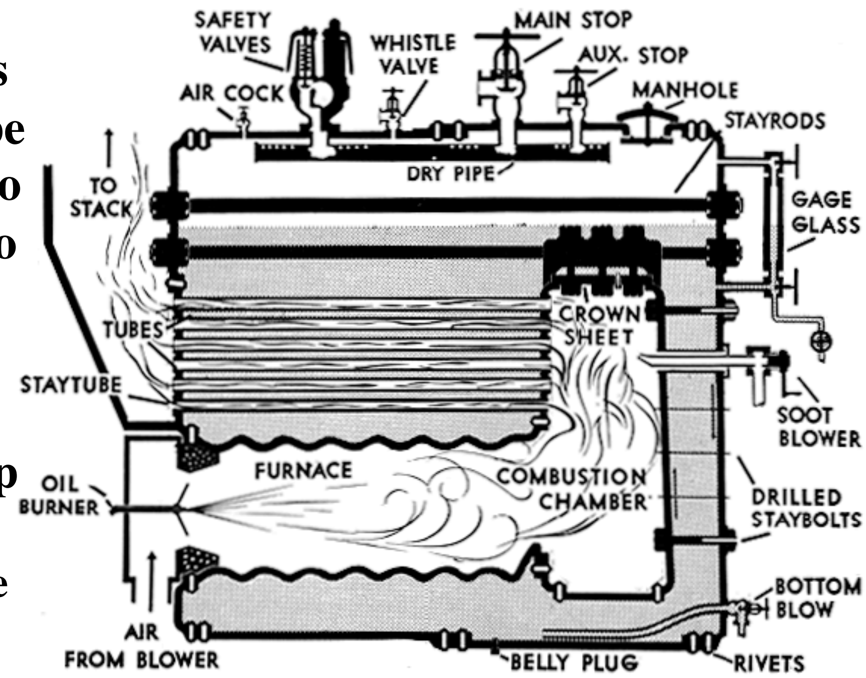
# Armor




- Assumed use of nuclear weapons made armor obsolete
- AT games use an abstracted, area weighted average for armor ratings
  - Design choice to help speed play, no hit location die roll
  - Armor penetration is assumed to be a binary function, yes or no

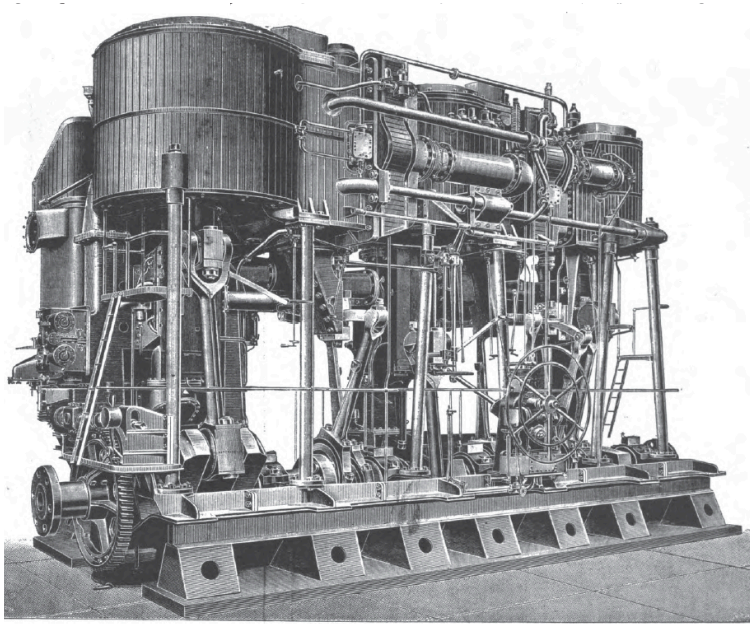
# Propulsion

- **Steam boilers – Fire-tube designs**
  - By the 1870s, cylindrical "Scotch Boilers" had replaced box boilers raising steam pressure from 30 psi to 60 psi
  - Mild steel used in boiler manufacture raised pressure to 90 psi and then 130 psi by mid-1880s
- **Steam boilers – Water-tube designs**
  - Smaller and lighter than fire-tube designs
  - By the mid-1880s, reliable water-tube type boilers, such as the Bellville type, began to be widely used – raising steam pressure to 250 or even 300 psi
  - By the mid-1920s reliable 600 psi plants were available
  - By the early 1950s, very high pressure (up to 900 to 1,200 psi) plants were adopted
    - 1,200 psi plants proved to be troublesome



# Propulsion

- **Single and compound (dual) expansion reciprocating engines**
  - **Limited by low stream pressure**
- **In the early 1880s, triple expansion reciprocating engines became the norm – steel boilers could provide the pressure**
- **Steam turbines introduced in mid-1890s**
  - ***Turbinia* demonstration in 1894 – 34.5 knots**
  - **Royal Navy adopted them in early 1900s**
  - **Smaller, lighter, more economical, but initially were direct drive (inefficient)**
  - **Reduction gears (1920s) would make steam turbines efficient and universally accepted**
- **Turbo-electric drive**
  - **Heavier than turbo-reduction**
  - **DC Motors were large, shock sensitive**
  - **Really didn't take off until rare earth magnets made permanent magnet motors feasible – late 1990s**



# Propulsion

- **Internal combustion engines**
  - Dr. Rudolf Diesel introduced diesel engines in 1893
    - Very compact, highly fuel efficient, used initially for small craft and submarines, today massive marine diesels are the most popular and economical prime movers
  - Otto cycle (gasoline) engines – not so much
- **Sterling cycle - external combustion**
  - Larger and heavier than diesel, but quieter
  - Submarine AIP system - 1995
- **Gas turbines**
  - First used in 1947 on a MGB
  - UK Type 81 used gas turbines (1961)
    - Combination steam and gas turbine
  - Usually combined with another prime mover due to fuel consumption
- **Nuclear power**
  - Just another type of steam plant
  - First used in 1955, USS *Nautilus*

Wärtsilä 18V32 Marine Diesel

# Electrical Power

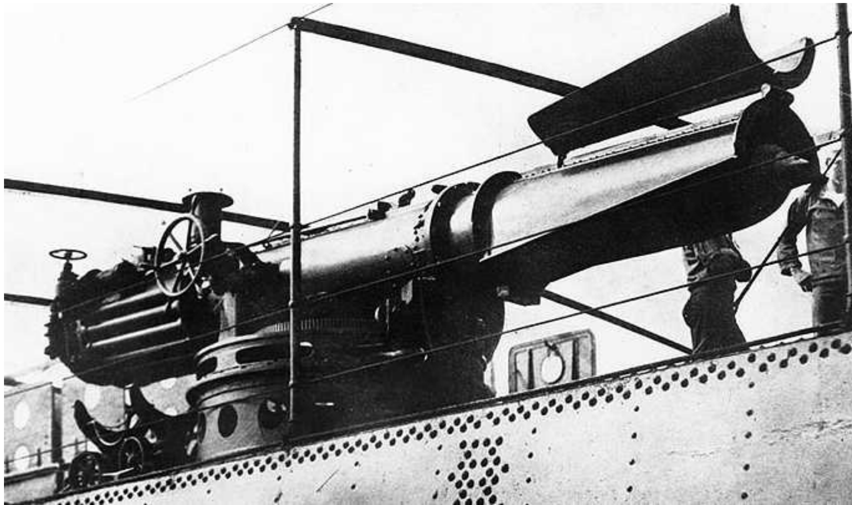
- From the mid-1870s through 1880s, electrical power was experimented with to varying degrees on ships – mostly for searchlights and internal lighting
  - HMS *Victoria* (1881) was the first Royal Navy ship to have electric lighting
  - Oil lighting perceived as a fire threat and not very efficient
- During the 1890s through early 1900s, auxiliary systems (pumps, fans) were converted to electric power vice steam driven
- Allowed the use of ship internal communications, and eventually wireless
- By the mid-1990s, talk about all electrical ships had become common – particularly with the cruise industry
  - Naval applications followed in following decade
- Electrical power generation is the *unsung hero* of the modern age, without it there would be no radio, radar, sonar, fire control, satellite navigation – high-tech modern warships exist because of electricity

# Weaponry

- In the 1880s, breech loading guns were the norm
  - Maximum ballistic ranges were far in excess of effective firing range
    - Large guns could fire out to 10-15 kyds, accurate firing range was 2-3 kyds
    - Cast and forged steel projectiles had replaced cast iron Palliser shells
- By the end of WWI, ballistic range had doubled, effective range had increased five fold
  - Gun bore size hadn't change significantly, but caliber (barrel) length had increased from 25-30 to 40-50, along with considerably higher muzzle velocity
  - Armor piercing caps adopted in the early 1900s – improve penetration
- At the end of WWII, ballistic range had tripled, out to 45-50 kyds, effective firing range improved only slightly (15-20 kyds)
  - Longest hits were about 25 kyds
- With the change in emphasis from ASuW to AAW, bore size shrank considerably – high ROF was more of a priority
  - "Big guns" are now 127mm to 130mm, but U.S. 155mm AGS in development

# Weaponry

- **Torpedoes have undergone substantial improvement**
  - Early torpedoes used compressed air/flywheels, very short range
    - 400 to 800 yards at 25 to 27 knots – effective attack range <300 yards
    - No gyroscope for course stability, not very accurate
- **By the early 1900s heated steam torpedoes had increase range by a factor of ten and speed by about 50%**
  - Gyroscopes were introduced about 1895, course keeping improved
  - Effective attack range still fairly short – approximately 1.5 kyds
- **At the close of WWI, torpedo range had increased dramatically out to 10-15 kyds**
  - Rudimentary fire control extended effective engagement ranges to 2-3 kyds
  - Wet guncotton filler largely replaced as the explosive filler by TNT/Picric Acid



# Weaponry

- During WWII, speeds of about 45 knots common, slow speed range on the order of 15-20 kyds
  - Type 93 broke both speed and range values by a considerable amount
  - Improved fire control boosted effective engagement ranges only slightly, about 4-6 kyds
    - Pre-war idea of long range sniping didn't really work out
  - High explosives replace TNT-based fillers in mid-1940s (e.g. Torpex)
  - Mid-1940s, acoustic homing torpedoes introduced by Germany and U.S.
- Modern torpedoes can achieve speeds of 50-60 knots, with effective ranges out to about 15-20 kyds
- Wire-guidance, influence fuzing, more energetic explosives, and smart seekers make torpedoes far more deadly


Mark 48 Torpedo

# Weaponry

- **Mines**
  - Originally a defensive weapons, contact fuze (inertial/electrochemical)
  - Influence fuzing started showing up at the end of WWI (magnetic)
  - Multiple influence fuzing common by WWII, including pressure fuzes that cannot be swept
  - Propelled warhead mines – encapsulate torpedoes/rockets
- **Cruise Missiles**
  - Soviet invention late 1950s – both land attack and anti-ship
    - P-15 [SS-N-2 Styx] grabbed the world’s attention with the sinking of INS *Eilat* in October 1967
  - Rapid advancements in speed, range, stealth, and guidance make cruise missiles the primary anti-ship weapon in today’s fleets

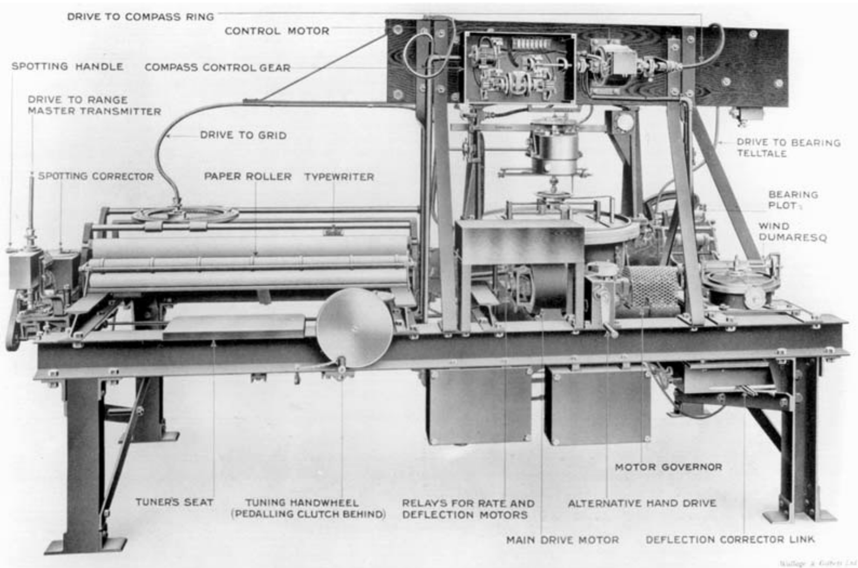
# Weaponry

- Surface-to-Air Missiles (SAMs)
  - High speed jet aircraft and missiles clearly show AA guns cannot defend ships from air attack, Kamikaze threat hinted at this
- SAMs started development towards the end of WWII
  - German experimented with Wasserfall, Rheintochter, and others
  - U.S. Project Bumblebee (December 1944)
- By 1955 – 60, first naval SAM systems deployed
  - U.S. 3T family (Talos, Terrier, Tartar)
  - Soviet Union Volna [SA-N-1A Goa]
- Range, speed, and guidance improvements largely due to advancements in electronics
- SAM systems now the mainstay of fleet air defense


Standard Missile-1

# Fire Control

- Prior to 1900 there was none, other than the gunner's eye
  - Effective engagement range was around 2,000 yards
- The introduction of optical rangefinders and crude mechanical calculators pushed ranges out to about 6,000 yards
  - First B&S FA1 coincidence rangefinders (1893-94), FA2 (1895-96)
  - Dumaresq relative motion calculator (1904), Vickers Range Clock (1906)
- By WWI engagement ranges were extended out to about 18,000 yards
  - Optical rangefinders could now provided accurate range to 20 – 25 kyds
  - More advanced mechanical computers, Dreyer Table and Argo Clock, could theoretically support the longer range
- At the end of WWII, engagements out to 30+ kyds were feasible
  - Radar fire direction big improvement
  - In practice, hits at ≈25 kyds were rare



Mark V Table—rear view.

# Fire Control

- Anti-aircraft fire control
  - Much slower development timeline: before the mid-1930s virtually nonexistent
    - Searchlights, sound detectors only available sensors, optical rangefinders for tracking
    - Barrage fire only available tactic
  - By the late 1930s, two primary schools of AA fire control emerged
    - “Flyplane” and “Tachymetric” – neither were fantastic, the former was worse
  - Combat Information Center concept validated in the Pacific Theater
    - Kamikaze and early guided weapons still proved to be particularly difficult
- Advent of jet aircraft, nukes, and ASCMs made things worse
  - Shorter reaction times required faster decision making – automated tracking data
    - Use of new electronic computers to speed up processing
    - Data links to pass information on to other ships (i.e. NTDS early 1960s)
- Digital microprocessors increased the number of contacts tracked and engaged and increased the amount of data that could be shared
- AAW had replaced ASuW as the dominant warfare area for ships

# Fire Control

- **In 1997, the “new” theory of Network Centric Warfare emerged, a distributed integrated network with sensors and shooters**
  - **Key part was the accurate transfer of data**
    - **CEC and JTIDS (Link 16) came out of this effort**
  - **NCW advocates viewed information as a weapon itself**
    - **Many skeptics responded that NCW was neither new or entirely logical**
- **Significant emphasis on data links and the use of unmanned vehicles as sensor nodes and then later shooters**
  - **Implicit assumption is the network will be available**

Knifefish UUV

Protector USV

MQ-9 UAV

# Sensors

- From 1880 until late 1930s the only surface and air search sensor was the Mk1 Mod 0 Eyeball
  - On a good day 20-30 kyds against a large ship, half that against an aircraft
- Naval radar started being fielded in 1938-39, detection range increased quickly with new models, and it worked at night
  - Display technology improvements – Planned Position Indicator (PPI)
- Radar evolved significantly over the next 60 years
  - U.S. CXAM 2D AS (1938): 50 nm to AN/SPS-48G 3D AS (2011): 250 nm
  - Passive and Active Electronically Steered Arrays height of development
- Sonar started out as little more than "stethoscopes in the water"
  - PGS Omni Hydrophone (1915), first ASDIC Type 112 (1919) – short range (<1 kyd)
  - Digital beam-formed active sonars and towed arrays offer potential ranges of tens of nm
- Infra-red sensors debuted in mid-1940s, range in 10's of yards, 4th gen starring focal planar arrays can image targets 10's of miles away
- For every active sensor, there was a passive detector
- Active sensor's performance could be degraded by "stealth" technology

# Navigation

- Navigation fix based on sextant, clock, and skill
  - Multiple celestial fixes required per day as no way to accurately dead reckon
  - By 1906-08 navigation gyroscopes started being used
- Loran radio navigation system first deployed in 1942
  - Hyperbolic ranging between master and slave stations
  - Loran C came into service in 1974, accuracy was 2% of range out to 1,400 nm
- Omega radio navigation system introduced in 1971, shorter-range system than Loran, out to 300 nm, 4nm accuracy
- Transit was the first satellite navigation system, in service by 1964. Operated on the Doppler principle, accuracy about 100m
- Global Positioning System (GPS) – fully operational in 1995
  - 24 satellite constellation provided 3D position accuracy
  - Fix was accurate between 13–20 meters, DGPS can be accurate within cms
  - GLONASS, Beidou, Galileo foreign equivalents

# Communications

- In the beginning there were flags
  - Visible out to 6-8 kyds on a good day
- Signal lights followed along with searchlights in the 1880s
  - Long haul communications were by cable-based telegraph and courier ships
- 1898 Marconi makes first wireless transmission from a ship
  - 1899 Royal Navy conducts first exercise with wireless
- By 1905, wireless communication adopted by most navies
- During WWII radio frequencies in LF, MF, and HF bands were used by varying platforms
- Lower frequencies, that can penetrate into water, used for submarine communications
  - VLF (1960s) and ELF (late 1970s) have low data rates
- Satellite-based communication systems provide reliable long-haul communications and now Internet connectivity

# Technological Change Rarely in Isolation

- Naval technology development in one area is spurred by break-throughs in other areas and vice versa…
  - Measure and counter-measure
  - "Dialectical negation in military affairs" (Ogarkov)
- Initially, guns vs armor was THE debate
  - Thicker armor, new materials led to guns with higher muzzle velocity and new shell technology
    - Palliser shells → Cast steel shells → Forged steel shells → AP caps
- The technological maturation of the aircraft radically changed the debate
  - Development of VT fuze, CIC, Radar, Fire Control, SAMs
  - In turn led aircraft to rely on electronic countermeasures and stealth
- Submarines also dramatically altered the discussion
  - Sonar → SOSUS, towed arrays, CZ capable hull sonar, homing torpedoes
  - Submarines counter with more quieting, anechoic coatings

# Technology Drives Changes in Naval Warfare

- **From the 1880s through the 1920s, anti-surface warfare was the main concern of naval officers and planners**
  - Aircraft and submarines held promise, but technically immature
  - Naval warfare was largely a two dimensional problem
- **WWII clearly demonstrated that the aircraft carrier and airpower had supplanted the battleship as the primary platform**
  - Naval warfare was now a three dimensional problem
  - Naval technology shifted to focus on combating the air threat
- **Nuclear power freed submarines from having to run an engine to recharge the battery, to a lesser extent AIP has done the same**
  - Significantly reduced the threat of detection, shifted the primary ASW sensor from radar to sonar
  - Soviet submarine threat raised ASW technology development to a similar level as AAW – focus on better passive systems, and quieter and quieter boats

# What Were The Key Drivers?

- The development of electronics has had the greatest impact on the advancement of naval technology
  - Even more so than nuclear weapons (personal opinion)
  - Affects everything from sensors, fire control, weapons, counter-measures, communication, navigation, and even propulsion
  - Courtesy of the development of electrical power generation
- The improvement in aircraft capabilities caused navies to shift their focus from anti-surface warfare to anti-air warfare
  - Reduced warning time due to jet propulsion aggravated the situation
  - When combined with radar and electronics, unmanned Kamikazes emerged as a significant threat to ships, possible nuclear warheads made things worse
- The advent of nuclear power allows submarines to be independent of the air, providing long submerged endurance and high speed
  - Freed from the surface, radar's effectiveness is greatly reduced
  - Stealth, endurance, and speed greatly complicated ASW efforts

# Conclusions

- **Since the 1880s, naval technology has undergone huge changes**
- **Technological advancements in one area forced a response in another, and the cycle repeats itself**
  - **Development of counter-measures, leads to counter-counter-measures, etc**
- **Radical changes in technology changed the primary focus of naval warfare from anti-surface to anti-air and anti-submarine**
  - **Land attack or strike warfare has also risen, but typically has had a lower impact on ship design – exception ballistic missile submarines**
- **Electronics has had the single greatest impact due to its wide range of applications**
- **Future developments could bring new changes as well…**
  - **Hypersonics**
  - **Non-acoustic, remote sensing ASW sensors**
  - **Anti-ship ballistic missiles**

# Questions?