

# Engineering Aspects of War Part I

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**W**AR IS A perverse form of engineering, the latter being defined as achieving a desired result by skillful use of available resources. Commanders wish to achieve something, usually subjugation or perhaps destruction of a certain populace and/or area. They have certain (limited) resources, and are subject to the laws of physics, economics, and other laws of nature. There are opposing commanders, and the winner is not necessarily the one who appears to have the best resources.

From ancient times, what we now call engineering has been a factor in war. If the difference between engineering and science is quantity, the former is generally more important in war. We won World War II (WWII) by producing weapons faster than the opposition could destroy them, and vice versa. Ours were frequently inferior to theirs. Only occasionally does science make such a quantum leap that quantity and skill of use are not important, the atomic bomb being probably the most familiar example.

## Origin of War

War and civilization emerged together, the time being pre-historic. Civilization is necessary to wage large-scale wars (name one without leaders) and also to record them. Whether civilization can exist without war is questionable;



**MASADA:** When the Romans tried to eliminate the Jews in 70 A.D., the fortress of Masada was the last holdout. Atop a mesa with 300-1,000 ft. cliffs, Masada was thought to be impenetrable. The spine to the right of the fort reaches almost to the top and provided access, but also proved its undoing. The Romans rolled up a tower that would reach above the wall, allowing them to clear that section of defenders. Work was done mostly by Jewish captives so the defenders' last hope lay in killing their own countrymen. Faced with a hopeless situation, the Jews committed suicide.

a study of history is not encouraging. Some of the earliest cave drawings show men killing animals—and each other.

An engineer assigned to solve the problem of war would first search out the origin or cause. Much has already been written on the subject, completely contradictory. One might study the few remaining primitive peoples to try to ascertain how our ancestors got started, but there is no help here either. Cultures vary from fight-to-the-death to strictly ceremonial, where the battleground is prearranged, boasts and insults are hurled, and if someone actually gets hurt there is a time-out. For the foreseeable future war,

## MEGIDDO: THE FIRST RECORDED BATTLE ... AND THE LAST?

The first well-documented battle occurred around 1469 B.C. at Megiddo, in what is now Israel, between Egypt and an alliance of enemies. The Bible and other sources predict a great final battle near Armageddon, the English transliteration of Har Megiddo—Fortress Megiddo or Hill Megiddo.



in some form, will be a fact of life.

The word *enginery* means not engineering, as you might expect, but *instruments of war*. The Roman Empire was famous for its engineering; some roads and aqueducts not only remain, but are usable! In fact, the extent of the Empire was fairly well defined by its infrastructure; the famous Roman legions fared poorly when they attempted to push beyond their supply and communications lines, often becoming equal or even inferior to their enemies.

For part of the early days of this country the best engineering education was to be found at the United States Military Academy (West Point).

Many of the modern miracles we take for granted had their impetus in war: radar and microwaves, nuclear power, jets, computers, synthetic rubber and oil, automobiles, penicillin, etc. It almost makes war sound beneficial, perish the thought.

### Army Engineering

Warfare in B.C. was basically on land; more advanced engineering would be necessary to bring it to the water and then the air. We can imagine how it started. As tribes formed and grew, either disputes over scarce territory or resources arose, or someone simply decided that taking someone else's goods was easier than working for your own—if you could get away with it.

Effective means of subduing or eliminating the enemy were desired. A rock or a stick could do more damage than a fist. Chipping away at a rock could give it a sharper edge.

### JERICHO: ONE POORLY DESIGNED FORT

According to the Bible, the Israelites gave a mighty shout and a blast on the trumpets, and the walls of Jericho fell down. Such would have been delicate walls, indeed. Ruins have been found of a double-walled fort with the walls intact. However, the buildings just inside were constructed of single-layer masonry, notoriously fragile. These had collapsed outward over the double wall, forming a ramp of rubble that would have enabled attackers to “go straight into the city.” Allegory or history? The area is near the Jordan valley, part of a huge geological rift, and thus subject to frequent earthquakes.



### DAVID AND GOLIATH

The classic *war story* of “little guy beats big guy” (or, alternately, *good guy wins*) is familiar to most: David and Goliath. However, few can repeat the details. David picked up a sharp stone, slung it, and killed Goliath, right? Wrong!

David was offered the king's armor but found it cumbersome, and refused it. It wouldn't have fit; Saul was an unusually large man, while David was a boy, meaning less than 13. It might have been the only armor in the camp; the Hebrews did not have metalworking technology. (When he became king, David was quick to procure it from the Philistines, Goliath's conquered tribe.)

David picked up FIVE SMOOTH stones. A sharp stone would not fly straight. Accuracy was paramount. Hit in his unprotected forehead, Goliath fell to the ground unconscious. He was then dispatched with his own sword.

Did David expect to get a second shot? Not likely. Goliath had four brothers who were duty-bound to avenge his death. (They seem to have lost interest.)

Is the story realistic? I can attest to the accuracy of a sling, especially by a shepherd boy who had nothing better to do all day and whose life might depend on it. David claimed to have killed lions and bears. The velocity from a sling should be well above 200 mph—typhoon force.



David by Gian Lorenzo Bernini (1623)



**TREBUCHET**—The most formidable war machine before gunpowder was surely the trebuchet. In its best form it was basically an unequal seesaw lever. The short end was loaded with a huge counterweight which was winched up and into place. The long end carried a smaller weight (the missile) in a sling—smaller being up to a ton. Range was generally greater than that of the defending longbows. Thus, castle walls were no longer impenetrable. The largest was *Warwolf*, constructed by Edward I of England to attack Stirling Castle in Scotland. When the defenders saw what was being built, they tried to surrender. Edward refused their offer; he wanted to see if it worked. It did, hurling 300 lb. stones 300 yds., destroying one wall. Shown is a replica at Chateau des Baux, Southern France.



**CASTILLO**—A star fort in St. Augustine, FL. Note that any part of the outside wall may be fired upon from atop another section of the wall. Castillo de San Marcos, dating from 1695, is the oldest masonry fort in the U.S.

Lashing it to a stick extended one's reach and also velocity through (reverse) leverage. Engineering had been introduced.

Through intention, accident, or desperation, a weapon was thrown. The side whose weapons had the greater *range* might overwhelm the enemy unmolested. A new concept was introduced. The down side was, of course, that if you missed, the enemy now had *your* weapon. Many of the principles that evolved in early warfare apply today. In Vietnam, some of the mines we dropped landed on the shore. The North Vietnamese extracted the explosives and used them against us.

An important advance was the laminated bow. As a child in the *before-Wal-Mart* era, I tried to make my own bow and quickly learned that wood thick enough for the required strength was prone to crack. Thin layers held together by glue are necessary. The longbow eventually had a range of 300 yds. Excepting the crossbow, which can have more energy by virtue of winching the string back, it was thousands of years until the next major improvement. Only recently have compound bows made the laminated bow obsolete.

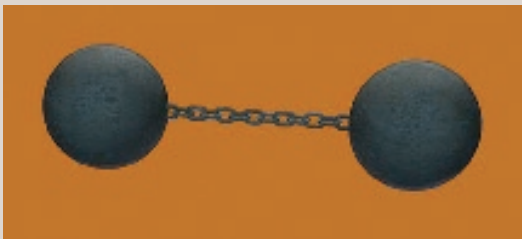
### Metalworking

Possibly the first major advance came with the Bronze Age. Metal could easily be fashioned into better shapes and sharpened with the now-unused rocks. Broken weapons could be melted and recast into new ones. Two new concepts were born: man-made materials and recycling! It was also useful for defense: bronze could be worked into sheets thin enough to be carried or even worn. Armor was born.

The Iron Age brought new strength and durability to weapons. Iron was known around 2000 B.C., but did not become widespread until approximately 1000 B.C. Ironically (no pun), it would be thousands of years before steel replaced iron—when Krupp made steel guns in Germany in 1850.

### A SWEEPING INNOVATION

The story goes that a ship captain conceived of firing two cannonballs simultaneously with a chain between them to sweep the entire deck of his opponent. It worked, sort of. One cannon failed to fire, the chain and one ball swung around in an arc, clearing his own deck!



Chain shot

### HOW NOT TO BUILD A SHIP

In 1628 the King of Sweden was determined to have the most impressive warship ever. After work had begun, he ordered a second gun-deck added. Fortunately for us, but not for the sailors, the ship was so unstable that it rolled over and sank within sight of port. The *Vasa* has recently been recovered in surprisingly good shape. A friend of mine complained to the captain of a former *Queen Elizabeth* about excessive rolling in rough seas. The captain confided a similar problem: an extra row of pent-houses had been added to the top.



Model of the restored *Vasa*

### CANNON ON BOARD

Legend has it that a ship captain was tired of being shelled by a fort he was supposed to capture, brought his own cannon on board, and lashed it to the rail. The recoil tore the rail apart. So he unlashd it to let it roll backwards on its wheels, which it did, destroying the rail on the other side. The problem was solved by attaching the end of a piled-up chain to the cannon. As it rolled backwards, it dragged more and more chain, slowing and then stopping. Modern guns have a recoil mechanism that allows the barrel to move backwards somewhat, but a large gun (16-inch on the *USS Missouri*) still shakes the entire ship.



The *USS Missouri*'s 16-inch guns in action during WWII

## Forts

The first man-made forts were probably a few piled-up rocks to hide behind. Similar but recent ones can still be seen in the Southwest U.S. Eventually forts became architectural masterpieces. The British castles with moats and drawbridges come to mind, as do European fortresses dominating entire hilltops.

With the advent of fortresses came the antithesis: siege warfare, equally highly developed. Those inside had to be able to store a sufficient supply of weaponry, food, and water or else have an uninterrupted supply of water and source of food (usually impractical). Those on the outside had to maintain similar supplies, by a long or difficult route if the location of the fort was well chosen. If neither side were able to find a flaw in the other's plans, it was a war of wills—who could outlast whom.

In the gunpowder era (below) the attackers had to be able to transport their guns within range. A major advance was the *star fort* (see photograph). Previously if the attackers could reach the foot of the walls they would be below the sweep of big guns atop the walls or of small guns firing through slits. With a star-shaped fort, any portion of the wall could be fired on from another section.

## Horses

Beasts of burden were no doubt used early on to transport war supplies, but they were too slow to be of use in battle. Horses were fast, but the original wild horses were too small and weak to pull anything, much less be ridden. Breeding, the original genetic engineering, produced bigger and better animals. Eventually they could pull a chariot. The speed of battle had taken a quantum leap. Chariot soldiers could now surround foot troops before they could run. The chariots themselves served as mini-forts, and the loss of his ride left the charioteer no worse off than his opponent.

Later horses were strong enough to carry a rider, and cavalry warfare began. A surprisingly important development here was stirrups. A rider no longer needed to hang on, but could have both hands free, at least momentarily, to fight. The movies showing American Indians firing a rifle one-handed while riding bareback are realistic only in that the Indians seldom seemed to hit anything.



Fort McHenry, home of the Star Spangled Banner. Note the 15 stars and 15 stripes on the flag. In 1812 the U.S. was drawn into a war between the British and the French as both were raiding our ships for supplies and men. The British took advantage of a lull in the original war to try to retake the Colonies. They took a poorly prepared Washington, and then the fleet headed to Baltimore. The harbor entrance was protected by a relatively small fort manned by a meager contingent of men, women, and children, plus stragglers from Washington. The British attacked, expecting a quick surrender. They could then easily take Baltimore, breaking the back of the U.S. The fort fought back defiantly, repeatedly re-erecting a flagpole broken by shells. Late into the night the fort stopped firing and then the fleet, neither sure of victory. When dawn broke the British were amazed to see the remnants of the flag still flying, meaning “no surrender.” Discouraged, they sailed away. It was later said that the flagpole had been held in place by dead bodies. Baltimore Harbor, MD

## Naval Warfare Engineering

Likewise, ships had long been used to move armies and supplies, but sailing ships were less than ideal as weapons because of relatively poor maneuverability and dependency on the wind. The first true fighting ships were rowed, the most famous being the trireme, perfected by the Romans, with three decks of oarsmen, usually slaves. The bow was reinforced. A good captain and crew could gain advantage in position and ram another ship broadside.

Navies were of major use to the troops only if they were close to the water. However, much of the population was indeed near the coast to take advantage of the water. The Mediterranean was the center of civilization for some time. Further development had to await the following.

## Gunpowder

Probably the biggest advance between metalworking and the nuclear age was the invention of gunpowder. Generally attributed around 1000 A.D. to the Chinese, who may have used it first for fireworks, chemical energy storage density was orders of magnitude higher than mechanical.

Nevertheless, the *gunpowder revolution* was slow in taking hold; it was 1300 before it was common in Europe and 1450 before a castle was breached. The original gun *barrels* were made by banding strips together; hence the term. These were inefficient due to irregularities and leaks and often blew up, killing the user rather than the enemy. Solid, bored barrels were better, but still unreliable, because steel was still unknown.

Originally round shot was used, the only shape that wouldn't tumble wildly. But irregularities caused the path to curve, causing an error proportional to the double integral of range. In an attempt at perfection, drops of molten lead were dropped from tall shot towers, the material coalescing into spheres during the crude *zero-g* freefall.

The powder was ignited by touching a torch to a hole in the side of the barrel stuffed with additional powder, a cumbersome process. Flintlocks created a spark with a piece of flint striking against iron—much better, but still giving a serious delay between the time the trigger was pulled and the actual firing. The gun came of age with the self-contained cartridge: a small *percussion* primer ignites when struck, which ignites the main charge, which blasts the projectile(s) loose from the cartridge and out the barrel. Smokeless powder was a significant advance. Previously, firing left a cloud of smoke which gave away ones position.

Usable guns downgraded the value of nearly everything else. Standoff range was greatly increased. Armor that would stop a spear could not stop a bullet. A cavalryman's height in battle was no longer an advantage over a foot soldier; it just made him a better target. If he were moving too fast, you just shot the horse. On the other hand, a *sharpshooter* could amass an endless list of victims, until he himself were caught unaware.

When guns became large enough to place a secondary charge inside the projectile, they became capable of killing many with one shot, opening a breach in a fort and causing fires. Battlefield combat moved up another notch. Ships became offensive weapons—moving forts! Guns on wheels were used to besiege fortresses. In fact, the first steam-powered carriages were used to transport guns.

### The Civil War

The Civil War marked a turning point. Thereafter, military advancements would come basically in terms of the World Wars: I, II, and III, the latter known as the Cold War. The rest of this series will be grouped mostly according to these conflicts. Many advances would be made during a war and many made between the wars would not be recognized until proven in the next war, including a few coming from wars in which the U.S. had no interest.

The Civil War occurred during the coming of age of science. It might seem odd, but science was preceded by technology! Engineering had made great strides, but mostly through trial-and-error. Analytical analysis was typically applied to things that had already been built (and usually broken), and lab research was not viewed as connected to technology.

In the decades before the war, invention shifted from amateurs to professionals, from lone mavericks to working groups. The terms *scientist*, *mechanical engineer*, and *military science* were first used. The American Association for the Advancement of Science gained recognition, the petroleum industry was born, electric motors and telegraph were invented, and photography advanced enough to document the war (although a rolling laboratory was required). Panama was surveyed for a canal, the first operation under ether was performed, and pollution of nature by man

### DAHLGREN—GENIUS AND FOOL

John Adolphus Dahlgren is known as “The Father of naval ordnance.” He was appreciated mostly because his guns seldom exploded, a rare and important advantage in the Civil War. His guns were the best of the smooth-bore, but also the last.



However, his mechanical expertise exceeded his leadership capabilities. His expedition to recapture Ft. Sumter was a textbook case in mismanagement. He refused to cooperate with another unit planning an attack and went ahead on his own. He split his forces, hindered further by ambiguous orders and poor communication. Reconnaissance was inadequate. One force attacked the strongest part of the fort as a too-obvious ruse. The mission was a disaster. This tarnished his reputation, but only temporarily. The Navy's principal gun laboratory today is named for him. My own Naval Ordnance Laboratory was absorbed by it.

was documented. The Bessemer process (England, 1855, although independently discovered by a Kentuckian eight years earlier!) made steel affordable.

In 1824 Rensselaer Polytechnic Institute opened as the first technical college. My own Massachusetts Institute of Technology, founded by William Barton Rogers—a fellow Virginian, was scheduled to open three days before the outbreak of the war (it didn't)! The National Academy of Sciences was born during the war.

This war placed a virtual moratorium on science; neither side thought the duration would be sufficient for any



Fort Monroe, the largest stone fort in the U.S. After the Civil War Jefferson Davis, president of the Confederacy, was held here. Ironically, Robert E. Lee was one of the engineers who had designed the Fort. Hampton, VA



**BOW-TIE:** a train rail heated and bent into a shape that made it unfixable. Essex Steam Train, CT

research to reach the battlefield. Of the already-few pure scientists, many quit their profession, left a contested area, joined the troops, and were killed or just never returned to science. Among the latter was George Meade, in charge of the Union army at Gettysburg. In the already more rural South, science was virtually eliminated.

Similarly, new inventions were scorned by the bureaucracy as not fitting the existing infrastructure and taking money away from operations! But as the war dragged on, improvements could no longer be ignored—particularly by the more desperate South.

## Guns

The principal weapon was the gun, either small enough to be carried by a soldier, not too large to be pulled by animals, or huge in the case of the *impregnable* fort (which usually made the history books by being easily captured). In 1861, 20-year old Christopher Spencer offered the U.S. Army a gun that embodied all of the recent advances. It fired a cylindrical, rifled bullet from a self-contained percussion-fired cartridge that by a simple motion was ejected from the breech and replaced by a new one from a hole in the stock—remarkably similar to a modern lever-action. It was not accepted.

Rifling (grooving) the barrel spun the bullet, gyroscopically stabilizing it. This allowed the use of pointed-cylindrical slugs. Imperfections now caused a corkscrew path, straight on the average and much better than the arc of a round ball. The breech-loaded cartridge greatly increased

the rate-of-fire and kept the powder dry. An integral primer detonated by percussion (impact) rather than fire perfected the process.

At the beginning of the Civil War, guns were in short supply, and a variety were used. Some were smooth-bore, some were muzzle-loading, and some used a percussion cap separate from the powder cartridge. Some weren't much better than Revolutionary war weapons.

The machine gun is impressive and makes for great movies. However, it is hard to control and uses ammunition at a prodigious rate. It was best used as a psychological weapon except in special situations, e.g., when the enemy cooperates by advancing as a crowd, when the exact location of the target is unknown, or when you alone must defend against an onslaught.

Machine guns had been tried as early as the 17th century, but invariably the barrels overheated. The Civil War Gatling gun was the first really successful one, and the most famous. As a set of barrels rotated, a spent cartridge was ejected from one, and a fresh cartridge was inserted in another while a third fired. The saving grace was that while one barrel was being heated all others were cooling.

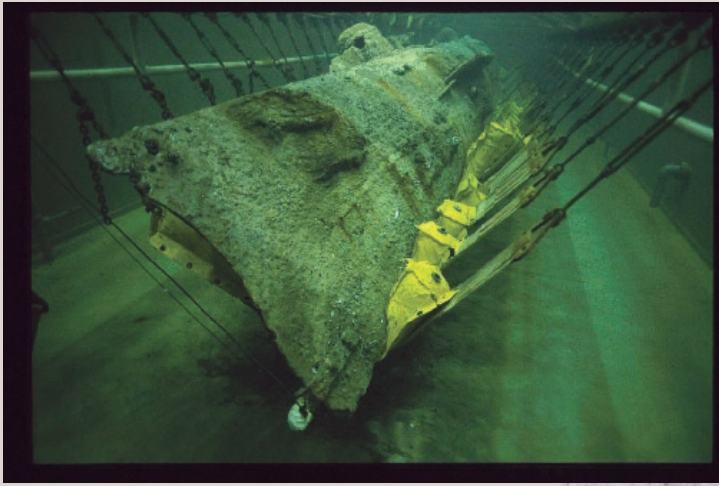
Explosive shells had likewise been tried, but the round shot of the smooth bores required multiple impact sensors, as orientation would be random. These often detonated in the barrel. An alternative was a timed fuse, but calculation of trajectory was in its infancy. (Almost a century later the first commercial electronic computers would be purchased by the Navy's Dahlgren Laboratory for just such calculations.) Cylindrical shells eliminated the problem. Paradoxically, so did ironclads: the sharp impact and resultant shattering would ignite any powder present.

Railroads changed the scope of war. They greatly aided logistics and allowed an army to appear far from where it had been the day before. Trains could move heavier guns than were previously possible. These advantages were limited by the tracks, but most cities and ports were served. The railroad system was more extensive then and the road system less so compared to the present.

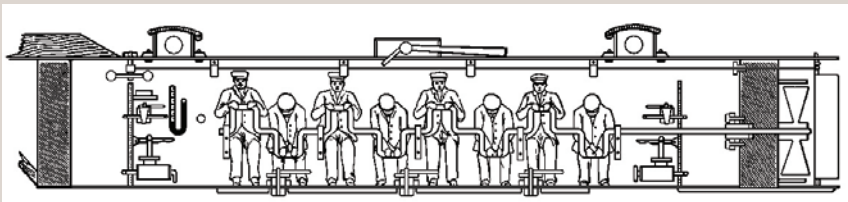
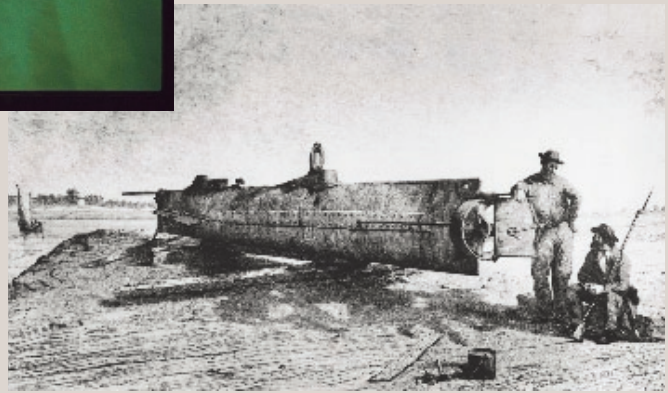
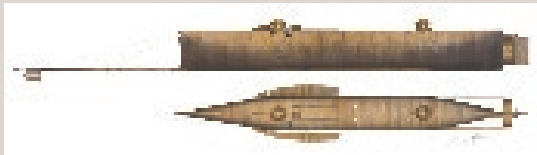
Preservation, capture, destruction, and rebuilding of railroads had a high priority, and the latter two were developed to a fine art. Wooden structures and rolling stock were torched. Very valuable iron stock and rails were stolen whenever possible, especially by the blockaded South. Otherwise, the rails were heated in fires made with the convenient cross-ties and bent around trees to make *bow-ties*. Boilers could be self-exploded by wiring the safety valve shut. Tunnels could be collapsed by explosives.

(Re)construction kept pace. The Rebels destroyed most of the bridges between Harper's Ferry and Martinsburg (VA/WV) only to find the line reopened in three days. Gen. Haupt of the Union corps of engineers completed a 100 ft. high, 400 foot-long bridge in nine days.

The Baltimore & Ohio Railroad, running mostly along the Potomac River—the virtual border, was the most hotly contested line, but it served the Union for most of the war. The parallel Chesapeake & Ohio Canal was both harder to damage and zealously defended, and it was subject to relatively little damage.



C.S.S. Hunley, the first true submersible to sink a ship, in its conservation tank. It rammed and sank a ship in Charleston Harbor with a charge on the end of a spar. It later sent a signal of success, the *blue light*, but never returned. It has been recovered and is being painstakingly deconstructed to find the cause of its sinking, which after several years remains elusive. A funeral service to inter the remains of the crewmen drew over 10,000 people, more than for some of our presidents. It rests a few miles from the scene of the successful attack, at the Warren Lasch Conservation Center, South Charleston, SC. Photo: Friends of the Hunley.



Likewise, the telegraph lines that ran along the railroads enabled instantaneous coordination and order changes at long distances. Balloons, inflated by hydrogen gas from chemical reaction, provided aerial reconnaissance half a century before airplanes. Telegraph wires relayed reports to the troops below. Retargeting information eventually proved highly valuable, but initially the gunners refused to be told by *amateurs* that their shots were missing! Flagging was also used for communication, with a less sophisticated system than I learned as a boy scout. However, because the enemy could also see, encryption had to be used, although being likewise crude.

*Torpedos* were used, but they were not self-propelled as we are accustomed to seeing. They were simply charges—either attached to a long spar on a ramming ship and set adrift in a river in hopes of running into a (preferably enemy) ship, or moored in hope that ships would run into them. The latter we would call *mines*. Some were sophisticated enough to discriminate between upstream and downstream traffic! Some were remotely controlled by sentries on shore

or ship by wire, but electricity was not commonly understood, with the result that they were tested with short wires and deployed with long wires and often failed to fire. Hand grenades were used and became more effective when the timed fuses were replaced with percussion. Rockets were tried, but they had a nasty habit of circling or ricocheting and returning whence they came.

Possibly the most formidable weapon available today, the missile-carrying submarine, had its beginning in the Civil War. The South built a fleet of *Davids*, ramming ships that could be mostly submerged, leaving only a conning tower exposed. These were quite successful, being hard to hit and almost invisible at night.

Horace Lawson Hunley took the final step with a true submarine vessel, named for him. Subs had been tried before, but his was the first successfully used. With a torpedo on a spar, it sank the *USS Housatonic*. The Hunley itself sank on the return trip, possibly also damaged by the explosion. Recently recovered, it is being restored.

*End Part I (to be continued).*