# Engineering Aspects of War
## Part II

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In spite of half a century of progress in science and engineering, including the height of the Industrial Revolution, the first part of World War I was pretty much fought with technology available at the end of the Civil War. The few exceptions, radio, aircraft, trucks, and torpedos, were underused for some time. The images WWI (known as the "Great War" until WWII came along) brings to mind are: trenches, barbed wire, shell shock, gas attacks, submarines, battleships, aerial "dogfights"; the foregoing roughly in decreasing order of importance. Fighting occurred around a considerable portion of the globe, but one thinks primarily of the Western Front (Western Europe). There the war proper began, was most intensely fought, and ended.

An early British Mark I "male" tank, named C-15, near Thiepval, 25 September 1916. It was probably in reserve during the Battle of the Somme. The tank is fitted with the wire "grenade shield" and steering tail, both features discarded in subsequent models. Photo: Imperial War Museum

### Trench Warfare

Both sides envisioned a rapid advance ending in quick victory. They were wrong. Weapons and tactics of the time favored defense. Battle lines stabilized to the point where the enemy was often less than a football field away, advances were measured in yards, and in the spring you might be in the same trench as the previous fall. Brightly-colored uniforms were quickly replaced by dirt-colored, the forerunner of camouflage. Again it would be years before the war bureaux diverted significant monies from lots-more-of-the-same to new weapons.

With nothing better to do, the soldiers dug in deeper and deeper. A system of trenches replaced trails, reaching clear to the rear for resupply. Underground rooms were deep enough to withstand bombardment. Tunnels were dug under enemy lines and mined; your own trench might suddenly explode. The combination of trenches and denuding of the landscape made for a sea of mud, making motorized vehicles and even early tanks ineffective. Heavy rains removed the distinction between trenches and latrines—in many months more soldiers fell to disease than to the enemy. Influenza that was spread by traveling troops caused more deaths than the war itself.

Artillery was more powerful than that of the Civil War, but aiming was not much more predictable. It was used in two modes, but mostly it was mass random bombardment. If you kept your head down your chances were statistical; if you stuck it up, they were zero. Helmets were reintroduced—the first body armor used for centuries. Soldiers were often found to be physically well, but mentally unable to fight or sometimes unable to do anything at all (shell shock).

Alternately, a gun would fire a shot, observe the hit, and correct. This provided advance warning. Winston Churchill once watched a series of explosions pass in front of him without flinching. One wonders how often a soldier jumped into a crater, knowing the next round would surely be aimed elsewhere. With stable lines and no aerial bombing the ratio of shell-to-kills was huge, and capability was limited by manufacturing output.

A barbed-wire entanglement, often maintained by both sides, prevented any rapid advance. Wire entanglement had been developed during the Civil War. Barbs were invented somewhat later by cattle ranchers, and now proved very effective at snarling soldiers' uniforms. It was stated earlier that a machine gun is inefficient unless the enemy cooperates by standing in front of it, or his location is unknown. These conditions were, however, created by trench warfare. The commanders' only apparent tactic was

to have as many men as possible jump from the trenches and advance as rapidly as possible across "no-man's-land," but it inevitably involved too few men and was too slow. Even victorious machine-gunners became nauseated at the carnage their *killing machines* wrought. Recoil mechanisms meant the second bullet no longer went wild. An occasional machine-gun burst at night would discourage sneak attacks under cover of darkness.

### Poison Gas

Germany's chemical capability was far ahead of other countries. Chemicals entered the war as tear gas, vomiting gas, chlorine, phosgene, and finally mustard gas. However, each of these was quickly analyzed and reproduced, and defenses were invented. Uncooperative winds often twisted the poison back upon the perpetrators. Poison gas was probably the first *weapon of mass destruction*.

### Battleships

Britain prided herself on ruling the sea. A fleet of battleships with names such as *Invincible* was followed by an even heftier class, the *dreadnought* (literally, fear-nothing). These ships did not live up to their names (see WWII later). The Germans went to the opposite extreme. Having an inferiority complex, they designed better ships, which were consequently fewer in number and mostly kept at home for fear of being lost. The one big naval battle (Jutland, considered by some to be the biggest naval battle ever) between the two powers was inconclusive.

### Submarines

The submarine, or underwater boat, or simply *U-boat*, had advanced to become a formidable weapon. Designed to fight from below or above the surface, the U-boat could fight from the shadows of the depths with the first indication being a torpedo trail heading for your ship. The torpedos were of modern style, although limited to *straight-runners* that required contact to explode. On the surface, frequently employed to conserve torpedos, submarines used use deck guns of sufficient caliber to sink merchant ships.

Germany was the leader, generally having over a hundred U-boats in service. At times they were the only boats that dared sneak out of the Baltic. U-boats wrought havoc at the beginning of the war only to have their government bow to diplomatic pressure. Neutral vessels were to be left alone (many secretly carried war materiel). Even for hostile merchantmen (some of which were secretly armed), subs were supposed to surface, give the crews time to get into lifeboats, and take on survivors (terms ranging from suicidal to impossible). Near the end of the war Germany, in desperation, resumed unrestricted warfare, which at that point sealed her fate by drawing the U.S. into the conflict.

Countermeasures arose: mines, depth charges, sonar, and decoys. These weapons were hit-or-miss and primarily of psychological value. Sonar consisted of a hydrophone (underwater microphone) with an operator listening for an unidentified propeller. Range was limited, even when the listener was at rest and quiet. High command insisted that surface ships travel individually—preventing serial attacks but making each one a sitting duck. When convoys were finally resumed, losses dropped greatly. A U-boat might sink an escort or two, but then became a target for the others.

## ARMING THE PLANES

Legend has it a pilot had the clever idea of mounting a machine gun in front of him—and shot off his propeller. Guns were then mounted high enough to clear the prop, creating an unstable configuration whereby one pilot found himself hanging on for dear life because the plane had flipped upside-down. The French put armor on the props at critical locations. Anthony Fokker (below) perfected for Germany a method to synchronize the gun so it fired only when the prop was not in the way.



### Aeroplanes

The internal-combustion engine, possibly the most significant advance of all for the war, was of little use at the start. Airplanes were too light to carry sufficient armament, initially any at all (see sidebar above). The famous dogfights for control of airspace—involving such legends as "Red Baron" Richtofen—were mainly to determine who could use it for observation and for shooting the enemy's observation balloons. German Zeppelins had greater range and capacity, eventually bombing London, but were slow, at the mercy of bad winds, and filled with hydrogen—becoming deathtraps when incendiary bullets were introduced.

Trucks had little carrying capacity and bogged down in the muddy, cratered roads at the front. Elsewhere, railroads did most of the hauling. Early tanks (see sidebar) often could not negotiate the trench-crisscrossed battlefields. They frequently were disabled or broke down, leaving the crews stranded to await death.

### Tanks

Winston Churchill was presented with the concept of an armored, tracked vehicle that could cross the muddy, cratered no-man's-land, flatten the barbed wire barricades, and carry heavy firepower right into the enemy's lines. The idea promised a breakthrough, and Churchill forwarded the idea up the line. It was rejected.

The plans were changed to an armored water-carrier to get *badly-needed* fresh water to the troops in the front trenches. This time it was accepted. After a few "in-development-modifications," the vehicle was back to its original configuration. Thus, it is still known today as a *tank*.

### Radio

Radio was put to use, but was capable only of Morse code, not voice. The code had to be encrypted, because the other side was listening, too. This combination was too slow for battlefield orders. Encryption was often skipped, sometimes informing the enemy before, or even instead of, the intended recipient. Worse yet (for the Germans), the British recovered a code book from a drowned sailor and lay in wait for the Germans just often enough that they never caught on. Carrier pigeons were more reliable!

### THE STAGE FOR WWII

How much did WWI influence history? Consider the names later involved in WWII and other events: Clement Attlee, David Ben-Gurion, Josip Tito, Winston Churchill, Charles de Gaulle, Anthony Eden, Albert Einstein, Mahatma Gandhi, Ernest Hemingway, Rudolph Hess, Adolf Hitler, V.I. Lenin, Douglas MacArthur, Harold Macmillan, B.C. Montgomery, Benito Mussolini, George Patton, John Pershing, Erwin Rommel, Franklin D. Roosevelt (right), Harry S. Truman, Georgi Zhukov, and last, but not least, Ho Chi Minh.

### Late-war Developments

Eventually after a few years, both commands realized they were getting nowhere and turned to engineering development. The potential of the airplane was recognized, and better models were introduced, sometimes with a development time measured in weeks. Bombers with increased payload and range could damage sensitive targets behind enemy lines. Krupp of Germany built a gun that shelled Paris with shells up to 400 pounds from a range of 74 miles. This might have been the beginning of over-the-horizon warfare!

Tanks that could leap the trenches, crush barbed wire, and survive shelling long enough to attack machine-gun nests and artillery emplacements led troop advances. Field commanders eventually learned to coordinate a continuous artillery barrage moving forward with tanks right behind it and troops right behind them, rather than attacking at three different times and allowing defenders to fight them separately and regroup between assaults.

Flamethrowers were developed by the Germans. Cameras were placed on airplanes to provide immediate, accurate mapping. An aircraft carrier was built by the British.

### World War II

World War II began like WWI was supposed to, unfortunately for the French. They had constructed the Maginot Line, an elaborately constructed string of fortifications stretching from neutral Switzerland to neutral Belgium except for the Ardennes region—which they believed to be impassible to a modern army. Ignoring Belgium and the Ardennes were serious mistakes. After invading Poland, which served mostly as a trial run, Hitler ignored Belgium's neutrality and also blasted through the Ardennes with his "blitzkrieg" (lightning war), bypassing the Maginot line, where many guns could not be rotated to the rear and which was cut off and near-useless anyway. Blitzkrieg was war mechanized to an extent never seen before. *Panzer* (armored) divisions with close air support moved so fast and so relentlessly that defenders never had a chance to regroup or reinforce a weak point.

This technique required clear superiority, at least temporarily when exploiting a weak point, and it was used for a long time before stalling. By the end of the first year Germany controlled western Poland, Austria, Belgium, France, Luxembourg, Denmark, and Norway.

### Guns

Although the weapons at the start of WWII resembled those from the end of WWI, they were bigger and better, with huge improvements in some cases. Later the vacuum-tube fuze was engineered to sense the presence of metal, making anti-aircraft fire far more efficient. Calculation of ballistic tables, initially done by a roomful of people punching mechanical calculators, offered a great improvement over miss-and-correct. Later, the U.S. Navy's Dahlgren Lab would purchase the first commercially-sold electronic computers to do the job.

### Tanks

Britain invented the tank, but lagged far behind nearly everyone else in development. German tanks had armor-plating and were nearly unstoppable. However, this advantage eventually led to the development of armor-piercing shells.

### Ships

The pride of the surface navies was the battleship. The meeting of the venerable British *HMS Hood* and the newer German *Bismarck* was the naval battle of the century. However, the Brits failed to realize that the first long-range shots would arrive as much vertically as horizontally and armored the sides adequately but not the decks. A shell penetrated its magazine, and the *Hood* sank almost immediately. The *Bismarck* escaped, but only temporarily. Eventually, a torpedo from a plane barely hit her, jamming the rudder. She circled helplessly, taking more and more hits, until she sank. Britain's coast had been pounded, but this was expected and facilities had been moved inland. Germany's surface fleet retreated to the Baltic, and the value of the battleship was called into question.

Germany relied instead on the U-boat. Invention of the *Schnorkel* tube made a submarine nearly invisible during the necessary surfacing to run the diesel engines

to recharge the batteries. Mines actuated by magnetic influence made some areas hazardous for subs. "ASDIC" active sonar greatly improved sub detection. The turning point came when the Allies were able to sink U-boats faster than Germany could make new ones.

When Germany developed mines with magnetic sensors, England countered with coils of wire around its ships to cancel the magnetic signature (degaussing).

### Airplanes

The biggest change was in airplanes, to the extent that some commanders claimed (correctly) that control of the airspace was of supreme importance. Planes were now metal-skinned with internal bracing, flying much faster with much longer ranges, and carrying the war to the heartland and civilians. They could carry a load of bombs, each of which exceeded the payload of a WWI plane. They carried defensive armament and the B-17 was called the "flying fortress."

Destruction rained from the skies. Incendiary bombs sometimes created firestorms with 150 mph winds (hurricane force), which not only burned entire cities but suffocated any surviving inhabitants by using all the oxygen. Flying was hazardous duty with flak guns filling the sky with shrapnel and faster fighters going after the slower bombers as in a turkey shoot. Bombing was shifted to nighttime, but cities were "blacked out," and, with little guidance, the bombers mostly cratered empty land. The Allies found that on some raids the ratio of enemy-killed to pilots-lost was less than one, and bombers shifted back to daytime. By now fighters with greater ranges could escort them. On the other hand, traffic accidents during the blackouts sometimes claimed more lives than the raids. Eventually radar on the planes negated the protection of clouds or darkness anyway.

Superchargers removed the altitude ceiling previously imposed by thinning air. The problem then became keeping the crew from freezing or from unconsciousness. Fuel injection, invented by Daimler-Benz, meant that planes could make any maneuver, including flying upside down. "Dive bombing" had improved accuracy by aiming the plane itself at the target and releasing the bomb at the last instant, if the plane survived the flak. The Norden optical bombsight provided sufficient accuracy to allow heavy bombers to remain at high altitude.

### Radio

Radio had really come into its own with voice transmission. This required encryption (see later) or deception because the enemy was listening too. But the time scale of battle was now greatly shortened; reaction could be virtually instantaneous, rather than waiting for orders to arrive. Jamming was introduced as a countermeasure, but was limited by how close the jammers could be placed to the enemy's transmitters or receivers (the latter being more efficient, but generally more difficult). Jammers needed to be maintained, a risky task as *radio-direction-finding* could immediately pinpoint their locations. Similarly, fleets could keep in touch even when scattered beyond the horizon, but any transmission would gave away one's location.

### SHOT DOWN BY AN ENEMY THAT WASN'T THERE

There were no German planes shot down in the first battle directed by radar— because there weren't any there. The Brits had not taken into account the back lobes of their new radar. Friendly planes close behind the radar appeared as distant enemy aircraft. In the confusion, a few planes fell to friendly fire.

### New Weapons

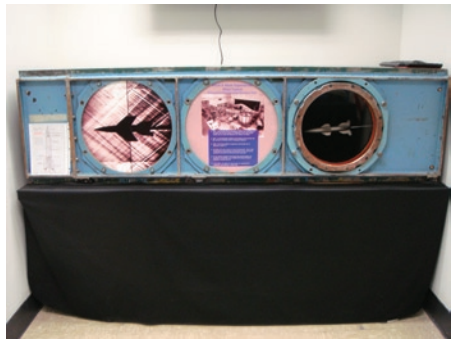
Hitler continually promised "radically new weapons" that would clinch his domination. Although an impressive number were developed, few appeared in sufficient time or quantity or usefulness to make a significant difference. Furthermore, the Allies came up with a few of their own.

### Radar

RADAR (Radio Detection and Ranging) saved Britain. When the German planes arrived, they inevitably found British planes lying in wait. The Brits not only had a complete line of coastal radars, but also had the foresight to link them all to a central location with telephone lines. The Battle of Britain (air battle) was directed from a single location, probably the first modern central command. Hitler tried to deny the significance of radar, slowing his scientists' development of the weapon and sacrificing his pilots. Later, aluminum foil was dropped as a countermeasure.

### Rockets

Small rockets had been in use off and on, but Germany built big ones, big enough to reach England. The V-1 *buzz bomb* was not a true rocket, but a pilotless drone powered by a ramjet. The flapping of the one-way valves in the intake gave the characteristic sound that warned the populace to take cover. The V-2 was a true rocket. It was supersonic, so there was usually no warning. The psychological effect of instantaneous, random explosions was devastating. The Germans were working on a much larger version to reach North America, which fortunately did not reach fruition.



Test chamber of a German wind tunnel which was liberated by the U.S. after WWII. The tunnel remained in use into the 1990s at the White Oak Laboratory, Silver Spring, MD, where the author worked. Photo: D. Marren

## War in the Pacific

The war in the Pacific was quite different, a fight for islands, beginning at Oahu (Pearl Harbor; see sidebar). Battleship guns could cover the territory, but the Japanese had turned the islands into veritable fortresses with caves and tunnels. Intense hand-to-hand fighting was required. Amphibious landings were not new, but became the order-of-the-day. The flamethrower, now with jellied gasoline that stuck to everything and burned longer, was a particularly effective (and gruesome) weapon. *Frogmen* using SCUBA (self-contained underwater breathing apparatus) infiltrated to scout both underwater and onshore defenses.

The military coined the acronym *snafu* (situation normal—all fouled up). Pearl Harbor was arguably the biggest *snafu* and military disaster ever. Investigations continue still. A warning from the newly-installed radar was dismissed as friendly planes. Intelligence reports on possible attacks were ambiguous or, worse yet, sent by routine mail and not received in time.

Another military base on Oahu was attacked before Pearl. A midget submarine had been caught some hours before. It was a well-known custom to give most of the sailors shore leave on Sunday morning.

Planes were parked closely together on the strip with no ammunition, as sabotage was thought to be the primary threat. One that was able to get moving was a new model, and the pilot, not yet having been briefed, couldn't understand the controls and never got it off the ground.

The battleships were lined neatly in a row. The *Arizona*'s magazine blew up, and it sank in ruins, with most of the crew on board already dead. Two others capsized before they could be flooded. The remaining five were sunk in place (later to be raised and put back into action). Of the ships that were able to get underway, the second sank in the channel, blocking the rest. Fortunately, the aircraft carriers were at sea.

One-third of the Pacific Fleet was out of commission in a matter of hours. The next day a similar raid on a portion of the fleet in the Philippines achieved a similar result. No precautions had been taken, because the brass could not imagine a second attack.

Because the battleships were prey to aircraft, their survival often depended on who had the most carriers in the area. Indeed, some commanders gauged success/failure by which side was able to keep more carriers operational. When the *USS Yorktown* returned to Pearl Harbor after a direct bomb hit and a second glancing one, the Japanese expected it to be out of service for several months. But Pearl was ready, and repairs were done in three days. The impact on the Japanese, both physically and psychologically, was incalculable.

Submarines often accompanied battle groups and were an additional menace, but they, too, were subject to discovery and attack from the air. War was now a truly three-dimensional business, stopping just short of space.

As Japanese fortunes ebbed and trained pilots became scarce, they turned to a suicide tactic—the *kamikaze* (divine wind). A plane was loaded with explosives and the pilot taught just enough to guide it into a ship. The tactic was difficult to counter—the frontal profile of an aircraft is necessarily kept to a minimum, so it would be hard to spot and hard to hit. Any friendly fighters would have to locate the attacker early, because the Zeros were faster and would probably be in a dive. The entire payload would be delivered, plus kinetic energy, plus fuel, as long as the plane was controllable. Furthermore, there was the psychological impact, which probably outweighed the actual effectiveness.

*End Part 2 (to be continued).*


*USS Missouri*: America's last battleship, she was scene of the Japanese surrender in 1945 and, after being re-equipped with missiles, used her new firepower during Operation Desert Storm in 1991, above right. Photos: U.S. Navy

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