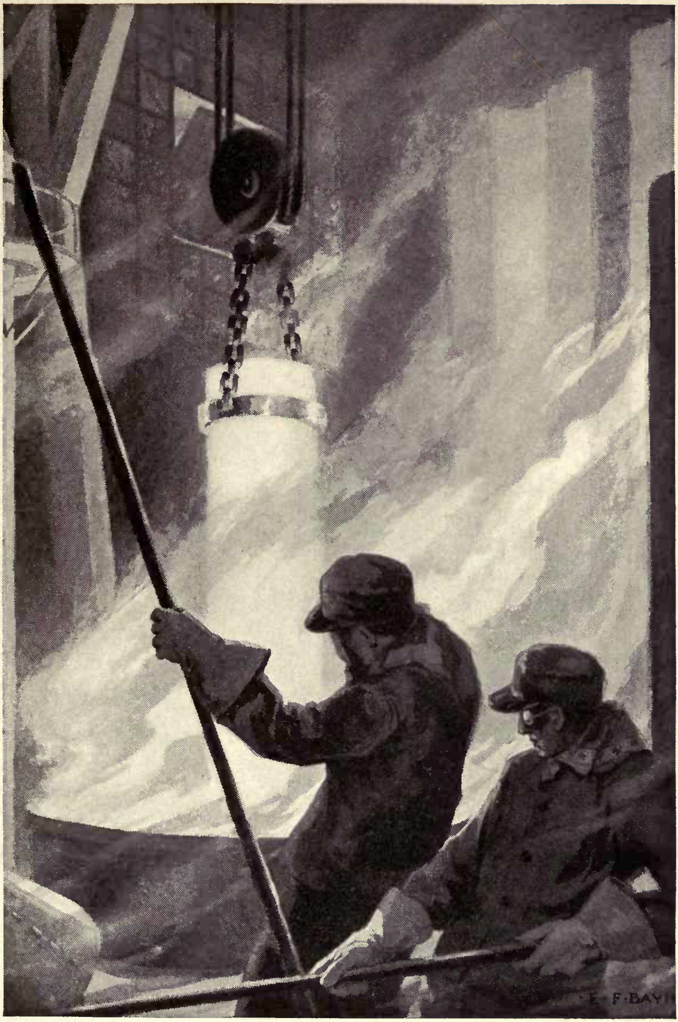
INVENTIONS OF THE GREAT WAR

A. RUSSELL BOND



Oil-tempering the lining of a Big Gun (See page 76)

INVENTIONS OF THE
GREAT WAR

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BY

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WITH MANY ILLUSTRATIONS

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PREFACE

The great World War was more than two-thirds over when America entered the struggle, and yet in a sense this country was in the war from its very beginning. Three great inventions controlled the character of the fighting and made it different from any other the world has ever seen. These three inventions were American. The submarine was our invention; it carried the war into the sea. The airplane was an American invention; it carried the war into the sky. We invented the machine gun; it drove the war into the ground.

It is not my purpose to boast of American genius but, rather, to show that we entered the war with heavy responsibilities. The inventions we had given to the world had been developed marvelously in other lands. Furthermore they were in the hands of a determined and unscrupulous foe, and we found before us the task of overcoming the very machines that we had created. Yankee ingenuity was faced with a real test.

The only way of overcoming the airplane was to build more and better machines than the enemy possessed. This we tried to do, but first we had to be taught by our allies the latest refinements of this machine, and the war was over before we had more than started our aerial program. The machine gun and its accessory, barbed wire (also an American invention), were overcome by the tank; and we may find what little comfort we can in the fact that its invention was inspired by the sight of an American farm tractor. But the tank was a British creation and was undoubtedly the most important invention of the war. On the sea we were faced with a most baffling problem. The U-boat could not be coped with by the building of swarms of submarines. The essential here was a means of locating the enemy and destroying him even while he lurked under the surface. Two American inventions, the hydrophone and the depth bomb, made the lot of the U-boat decidedly unenviable and they hastened if they did not actually end German frightfulness on the sea.

But these were by no means the only inventions of the war. Great Britain showed wonderful ingenuity and resourcefulness in many directions; France did marvels with the airplane and showed great cleverness in her development of the tank and there was a host of minor inventions to her credit; while Italy showed marked skill in the creation of large airplanes and small seacraft.

The Central Powers, on the other hand, were less originative but showed marked resourcefulness in developing the inventions of others. Forts were made valueless by the large portable Austrian guns. The long range gun that shelled Paris was a sensational achievement, but it cannot be called a great invention because it was of little military value. The great German Zeppelins were far from a success because they depended for their buoyancy on a highly inflammable gas. It is interesting to note that while the Germans were acknowledging the failure of their dirigibles the British were launching an airship program, and here in America we had found an economical way of producing a non-inflammable balloon gas which promises a great future for aerial navigation.

The most important German contribution to the war—it cannot be classed as an invention—was poison gas, and it was not long ere they regretted this infraction of the rules of civilized warfare adopted at the Hague Conference; for the Allies soon gave them a big dose of their own medicine and before the war was over, fairly deluged them with lethal gases of every variety.

Many inventions of our own and of our allies were not fully developed when the war ended, and there were some which, although primarily intended for purposes of war, will be most serviceable in time of peace. For this war was not one of mere destruction. It set men to thinking as they had never thought before. It intensified their inventive faculties, and as a result, the world is richer in many ways. Lessons of thrift and economy have been taught us. Manufacturers have learned the value of standardization. The business man has gained an appreciation of scientific research.

The whole story is too big to be contained within the covers of a single book, but I have selected the more important and interesting inventions and have endeavored to describe them in simple language for the benefit of the reader who is not technically trained.

A. RUSSELL BOND

New York, May, 1919

CONTENTS

LIST OF ILLUSTRATIONS

INVENTIONS OF THE GREAT WAR

INVENTIONS OF THE GREAT WAR

CHAPTER I

The War in and Under the Ground

FOR years the Germans had been preparing for war. The whole world knew this, but it had no idea how elaborate were their preparations, and how these were carried out to the very minutest detail. When the call to arms was sounded, it was a matter of only a few hours before a vast army had been assembled—fully armed, completely equipped, ready to swarm over the frontiers into Belgium and thence into France. It took much longer for the French to raise their armies of defense, and still longer for the British to furnish France with any adequate help. Despite the heroic resistance of Belgium, the Entente Allies were unprepared to stem the tide of German soldiers who poured into the northern part of France.

So easy did the march to Paris seem, that the Germans grew careless in their advance and then suddenly they met with a reverse that sent them back in full retreat. However, the military authorities of Germany had studied not only how to attack but also how to retreat and how to stand on the defensive. In this, as in every other phase of the conflict, they were far in advance of the rest of the world, and after their defeat in the First Battle of the Marne, they retired to a strong position and hastily prepared to stand on the defensive. When the Allies tried to drive them farther back, they found that the German army had simply sunk into the ground. The war of manœuver had given way to trench warfare, which lasted through long, tedious months nearly to the end of the great conflict.

The Germans found it necessary to make the stand because the Russians were putting up such a strong fight on Germany's eastern frontier. Men had to be withdrawn from the western front to stem the Russian tide, which meant that the western armies of the kaiser had to cease their offensive activities for the time being. The delay was fatal to the Germans, for they had opposed to them not only brave men but intelligent men who were quick to learn. And when the Germans were ready to resume operations in the West, they found that the Allies also had sunk into the ground and had learned all their tricks of trench warfare, adding a number of new ones of their own.

The whole character of the war was changed. The opposing forces were dead-locked and neither could break through the other's lines. The idea of digging into the ground did not originate with this war, but never before had it been carried out on so extensive a scale. The inventive faculties of both sides were vainly exercised to find some way of breaking the dead-lock. Hundreds of new inventions were developed. The history of war from the days of the ancient Romans up to the present time was searched for some means of breaking down the opposing lines. However, the dead-lock was not broken until a special machine had been invented, a traveling fort. But the story of that machine is told in another chapter.

At the outset the Allies dug very shallow ditches, such as had been used in previous wars. When it was found that these burrows would have to be occupied for weeks and months, the French and British imitated the Germans and dug their trenches so deep that men could walk through them freely, without danger of exposing their heads above ground; and as the ditches grew deeper, they had to be provided with a firing-step on which the riflemen could stand to fire over the top of the trenches. The trenches were zig-zagged so that they could not be flanked, otherwise they would have made dangerous traps for the defenders; for had the enemy gained one end of the trench, he could have fired down the full length of it, killing or wounding every man it contained. But zig-zagging made it necessary to capture each turn separately. There were lines upon lines of these trenches. Ordinarily there were but three lines, several hundred feet apart, with communicating trenches connecting them, and then several kilometers[1] farther back were reserve trenches, also connected by communicating trenches with the front lines.

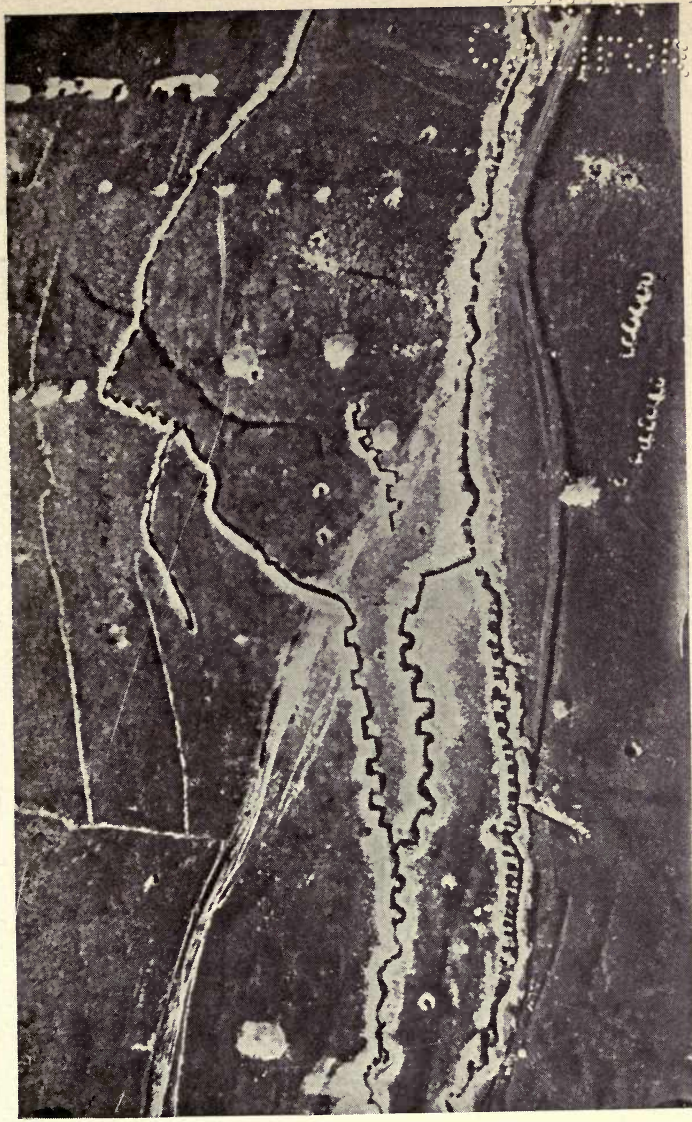
[1] A kilometer is, roughly, six tenths of a mile; or six miles would equal ten kilometers.

Men did not dare to show themselves out in the open near the battle-front for a mile or more behind the front-line trenches, for the enemy's sharp-shooters were always on the watch for a target. The men had to stay in the trenches day and night for two or more weeks at a time, and sleeping-accommodations of a very rough sort were provided for them in dugouts which opened into the trenches. The dugouts of the Allies were comparatively crude affairs, but the Germans spent a great deal of time upon their burrows.

UNDERGROUND VILLAGES

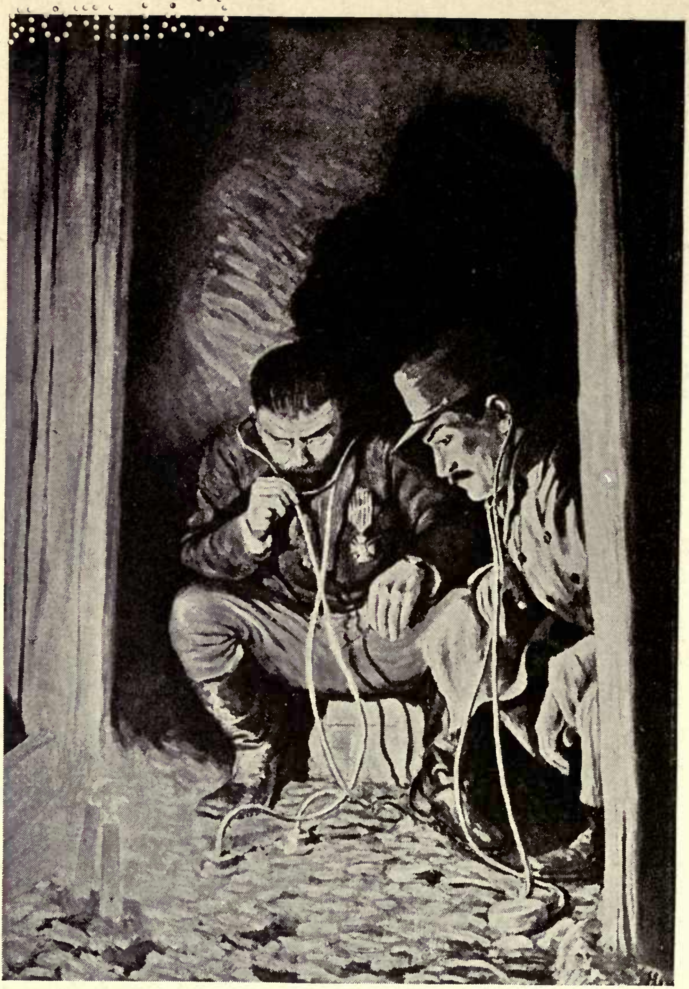
When the French first swept the Germans back out of their trenches along the Aisne, they were astonished to find how elaborate were these underground dwellings. They found that the ground was literally honeycombed with rooms and passageways. Often the dugouts were two stories in depth and extended as much as sixty feet below the level of the ground. In fact, all along this part of the front, the Germans had a continuous underground village in which thousands of men were maintained. The officers' quarters were particularly well fitted up, and every attention was given to the comfort of their occupants. There were steel door-mats at the entrances of the quarters. The walls were boarded and even papered. The bedrooms were fitted with spring beds, chiffoniers, and wash-stands, and all the rooms were lighted with electric lamps. There were spacious quarters for the men, with regular underground mess halls and elaborate kitchens. There were power-plants to furnish steam for the operation of pumps and for the lighting-plants and for other purposes.

There was a chalk formation here in which were many large natural caves. One enormous cave was said to have held thirty thousand soldiers, and in this section the Germans kept large reserve forces. By digging far into the ground, the German troops secured protection from shell-fire; in fact, the horrible noise of battle was heard only as a murmur, down in these depths. With characteristic thoroughness, the Germans built their trench system for a long stay; while the Allies, on the other hand, looked upon *their* trenches as merely temporary quarters, which would hold the enemy at bay until they could build up armies large enough



(C) Underwood & Underwood

Lines of Zig-Zag Trenches as viewed from an Airplane



Courtesy of "Scientific American"

French Sappers using Stethoscopes to detect the Mining Operations of the Enemy to drive the invaders out of the country. The construction of the trenches along some parts of the battle-line was particularly difficult, because of the problem of drainage. This was especially true in Flanders, where the trenches in many cases were below water-level, and elaborate pumping-systems had to be installed to keep them dry. Some of them were concrete-lined to make them waterproof. In the early stages of the war, before the trenches were drained, the men had to stand in water for a good part of the time, and the only way they could get about at all in the miry trenches was by having "duck-boards" in them. Duck-boards are sections of wooden sidewalk such as we find in small villages in this country, consisting of a couple of rails on which crosspieces of wood are nailed. These duck-boards fairly floated in the mud.

Some of the trenches were provided with barbed-wire barriers or gates calculated to halt a raiding-party if it succeeded in getting into the trench. These gates were swung up out of the way, but when lowered they were kept closed with a rather complicated system of bolts which the enemy would be unable to unfasten without some delay; and while he was struggling to get through the gate, he would be a target for the bullets of the defenders.

HIDING RAILROADS IN DITCHES

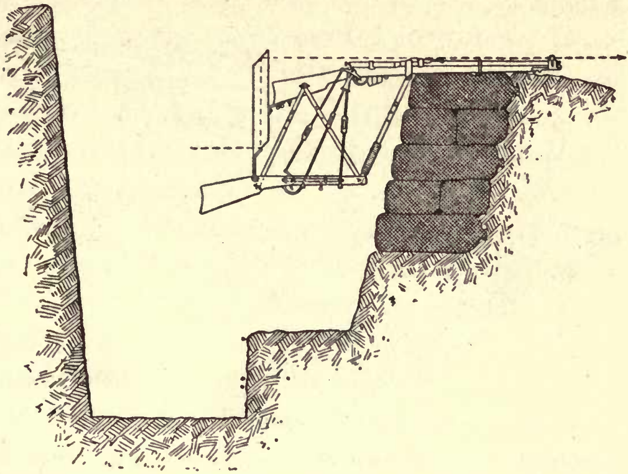
Because of the elaborate system of trenches, and the distance from the front line to that part of the country where it was safe to operate in the open, it was necessary to build railways which would travel through tunnels and communicating trenches to the front lines. These were narrow-gage railroads and a special standard form of track section was designed, which was entirely of metal, something like the track sections of toy railroads. The tracks were very quickly laid and taken up at need. The locomotives had to be silent and smokeless and so a special form of gasolene locomotive was invented to haul the little cars along these miniature railroads to the front lines. Usually the trench railroads did not come to the very front of the battle-line, but their principal use was to carry shell to the guns which were located in concealed positions. Railroad or tramway trenches could not be sharply zig-zagged but had to have easy curves, which were apt to be recognized by enemy airplanes, and so they were often concealed under a covering of wire strewn with leaves.

PERISCOPES AND "SNIPERSCOPES"

But while the armies were buried underground, it was necessary for them to keep their eyes upon each other so that each might be ready for any sudden onslaught of the other. Snipers were always ready to fire at any head that showed itself above the parapet of the trench and so the soldiers had to steal an idea from the submarines and build them periscopes with which they could look over the top of their trenches without exposing themselves. A trench periscope was a very simple affair, consisting of a tube with two mirrors, one at the top and one at the bottom, set at such an angle that a person looking into the side of the tube at the bottom could see out of the opposite side of the tube at the top.

Observation posts were established wherever there was a slight rise in the ground. Sometimes these posts were placed far in advance of the trenches and sometimes even behind the trenches where it was possible to obtain a good view of the opposing lines. Sometimes a tunnel would be dug forward, leading to an outlet close to the enemy's lines, and here an observer would take his position at night to spy with his ears upon the activities of the enemy. Observers who watched the enemy by day would often not dare to use periscopes, which might be seen by the enemy and draw a concentrated fire of rifles and even shell. So that every manner of concealment was employed to make the observation posts invisible and to have them blend with their surroundings. Observers even wore veils so that the white of their skin would not betray them.

Snipers were equally ingenious in concealing themselves. They frequently used rifles which were connected with a dummy butt and had a periscope sighting-attachment. This attachment was called a "sniperscope." The rifle-barrel could be pushed through a loophole in the parapet and the sniper standing safely below the parapet could hold the dummy butt to his shoulder and aim his rifle with perfect accuracy by means of the periscope. It was next to impossible to locate a sniper hidden in this way. One method of doing it was to examine rubbish, tin cans, or any object that had been penetrated by a bullet and note the direction taken by the bullet. This would give a line leading toward the source of the shot, and when a number of such lines were traced, they



Redrawn from Military Map Reading by permission of E. O. McKay

FIG. 1. A "sniperscope" with which a sharpshooter could take aim without showing his head above the parapet

would cross at a spot where the sniper or his gun was stationed, and a few shell would put the man out of business. Dummy heads of papier mâché were sometimes stuck above the parapet to draw the fire of enemy snipers and the bullet-holes which quickly appeared in them were studied to discover the location of the snipers.

Sometimes fixed rifles were used. These were set on stands so that they could be very accurately trained upon some important enemy

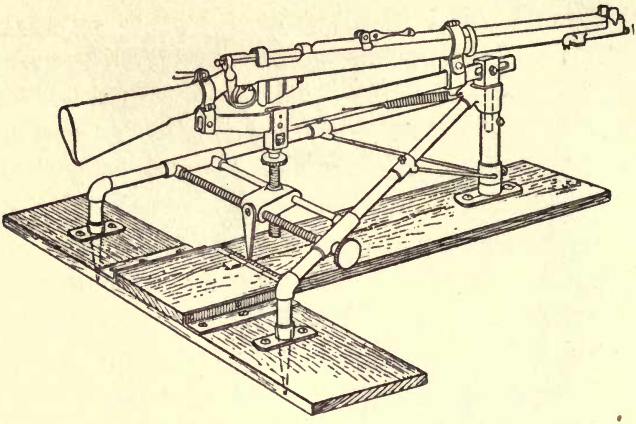


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FIG. 2. A fixed rifle stand arranged to be fired after dark

post. Then they could be fired in the dark, without aiming, to disturb night operations of the enemy. Often a brace of rifles, as many as six, would be coupled up to be fired simultaneously, and by operating a single lever each gun would throw out the empty cartridge shell and bring a fresh one into position.

STEEL BRIER PATCHES

The most important defense of a trench system consisted in the barbed-wire entanglements placed before it. Barbed wire, by the way, is an American invention, but it was originally intended for the very peaceful purpose for keeping cattle within bounds. Long ago it was used in war, but never to the extent to which it was employed in this world struggle. The entanglements were usually set up at night and were merely fences consisting of stout posts driven into the ground and strung with barbed wire running in all directions, so as to make an impenetrable tangle. Where it was possible to prepare the entanglements without disturbance and the position was an important one, the mass of barbed wire often extended for a hundred yards or more in depth. Just beyond the entanglements trip-wires were sometimes used. A trip-wire was a slack wire which was laid on the ground. Before being laid, the wire was tightly coiled so that it would not lie flat, but would catch the feet of raiders and trip them up. Each side had "gates" in the line through which this wire could quickly be removed to let its own raiding-parties through. Sometimes raiders used tunnels, with outlets beyond the barbed wire, but they had to cut their way through the metal brier patches of their opponents.

Early in the war, various schemes were devised for destroying the entanglements. There were bombs in the form of a rod about twelve feet long, which could be pushed under the wire and upon exploding would tear it apart. Another scheme was to fire a projectile formed like a grapnel. The projectile was attached to the end of a cable and was fired from a small gun in the same way that life-lines are thrown out to wrecks near shore. Then the cable would be wound up on a winch and the grapnel hooks would tear the wire from its fastenings. Such schemes, however, did not prove very practicable, and it was eventually found that a much better way of destroying barbed wire was to bombard it with high-explosive shell, which would literally blow the wire apart. But it required a great deal of shelling to destroy these entanglements, and it was really not until the tank was invented that such obstructions could be flattened out so that they formed no bar to the passage of the soldiers.

The Germans not only used fixed entanglements, but they had large standard sections of barbed wire arranged in the form of big cylindrical frames which would be carried easily by a couple of men and could be placed in position at a moment's notice to close a gap in the line or even to build up new lines of wire obstruction.

MINES AND COUNTER-MINES

In the earlier stages of the war it proved so impossible to capture a trench when it was well defended by machine-guns that efforts were made to blow up the enemy by means of mines. Tunnels were dug reaching out under the enemy's lines and large quantities of explosives were stored in them. At the moment when it was intended to make an assault, there would be a heavy cannonading to disconcert the enemy, and then the mine would be touched off. In the demoralizing confusion that resulted, the storming-party would sweep over the enemy. Such mines were tried on both sides, and the only protection against them was to out-guess the other side and build counter-mines.

If it were suspected, from the importance of a certain position and the nature of the ground, that the enemy would probably try to undermine it, the defenders would dig tunnels of their own toward the enemy at a safe distance beyond their own lines and establish listeners there to see if they could hear the mining-operations of their opponents. Very delicate microphones were used, which the listeners would place on the ground or against the walls of their tunnel. Then they would listen for the faintest sound of digging, just as a doctor listens through a stethoscope to the beating of a patient's heart or the rush of air through his lungs. When these listening-instruments picked up the noise of digging, the general direction of the digging could be followed out by placing the instrument at different positions and noting where the noise was loudest. Then a counter-mine would be extended in that direction, far enough down to pass under the enemy's tunnel, and at the right moment, a charge of TNT (trinitrotoluol) would be exploded, which would destroy the enemy's sappers and put an end to their ambitious plans.

A very interesting case of mining was furnished by the British when they blew up the important post of Messines Ridge. This was strongly held by the Germans and the only way of dislodging the enemy was to blow off the top of the ridge. Before work was started, geologists were called upon to determine whether or not the ground were suitable for mining-operations. They picked out a spot where the digging was good from the British side, but where, if counter-mines were attempted from the German side, quicksands would be encountered and tunneling of any sort would be difficult. The British sappers could, therefore, proceed with comparative safety. The Germans suspected that something of the sort was being undertaken, but they found it very difficult to dig counter-mines. However, one day their suspicions were confirmed, when the whole top of the hill was blown off, with a big loss of German lives. In the assault that followed the British captured the position and it was annexed to the British lines.

CHAPTER II

Hand-Grenades and Trench Mortars

IN primitive times battles were fought hand-to-hand. The first implements of war were clubs and spears and battle-axes, all intended for fighting at close quarters. The bow and arrow enabled men to fight at a distance, but shields and armor were so effective a defense that it was only by hand-to-hand fighting that a brave enemy could be defeated. Even the invention of gunpowder did not separate the combatants permanently, for although it was possible to hurl missiles at a great distance, cannon were so slow in their action that the enemy could rush them between shots. Shoulder firearms also were comparatively slow in the early days, and liable to miss fire, and it was not until the automatic rifle of recent years was fully developed that soldiers learned to keep their distance.

When the great European war started, military authorities had come to look upon war at close quarters as something relegated to bygone days. Even the bayonet was beginning to be thought of little use. Rifles could be charged and fired so rapidly and machine-guns could play such a rapid tattoo of bullets, that it seemed impossible for men to come near enough for hand-to-hand fighting, except at a fearful cost of life. In developing the rifle, every effort was made to increase its range so that it could be used with accuracy at a distance of a thousand yards and more. But when the Germans, after their retreat in the First Battle of the Marne, dug themselves in behind the Aisne, and the French and British too found it necessary to seek shelter from machine-gun and rifle fire by burrowing into the ground, it became apparent that while rifles and machine-guns could drive the fighting into the ground, they were of little value in continuing the fight after the opposing sides had buried themselves. The trenches were carried close to one another, in some instances being so close that the soldiers could actually hear the conversation of their opponents across the intervening gap. Under such conditions long-distance firearms were of very little practical value. What was needed was a short-distance gun which would get down into the enemy trenches. To be sure, the trenches could be shelled, but the shelling had to be conducted from a considerable distance, where the artillery would be immune to attack, and it was impossible to give a trench the particular and individual attention which it would receive at the hands of men attacking it at close quarters.

Before we go any farther we must learn the meaning of the word "trajectory." No bullet or shell travels in a straight line. As soon as it leaves the muzzle of the gun, it begins to fall, and its course through the air is a vertical curve that brings it eventually down to the ground. This curve is called the "trajectory." No gun is pointed directly at a target, but above it, so as to allow for the pull of gravity. The faster the bullet travels, the flatter is this curve or trajectory, because there is less time for it to fall before it reaches its target. Modern rifles fire their missiles at so high a speed that the bullets have a very flat trajectory. But in trench warfare a flat trajectory was not desired. What was the use of a missile that traveled in a nearly straight line, when the object to be hit was hiding in the ground? Trench fighting called for a missile that had a very high trajectory, so that it would drop right into the enemy trench.

HAND-ARTILLERY

Trench warfare is really a close-quarters fight of fort against fort, and the soldiers who manned the forts had to revert to the ancient methods of fighting an enemy intrenched behind fortifications. Centuries ago, not long after the first use of gunpowder in war, small explosive missiles were invented which could be thrown by hand. These were originally known as "flying mortars." The missile was about the size of an orange or a pomegranate, and it was filled with powder and slugs. A small fuse, which was ignited just before the device was thrown, was timed to explode the missile when it reached the enemy. Because of its size and shape, and because the slugs it contained corresponded, in a manner, to the pulp-covered seeds with which a pomegranate is filled, the missile was called a "grenade."

Grenades had fallen out of use in modern warfare, although they had been revived to a small extent in the Russo-Japanese war, and had been used with some success by the Bulgarians and the Turks in the Balkan wars. And yet they had not been taken very seriously by the military powers of Europe, except Germany. Germany was always on the lookout for any device that might prove useful in war, and when the Germans dug themselves in after the First Battle of the Marne, they had large quantities of hand-grenades for their men to toss over into the trenches of the Allies. These missiles proved very destructive indeed. They took the place of artillery, and were virtually hand-thrown shrapnel.

The French and British were entirely unprepared for this kind of fighting, and they had hastily to improvise offensive and defensive weapons for trench warfare. Their hand-grenades were at first merely tin cans filled with bits of iron and a high explosive in which a fuse-cord was inserted. The cord was lighted by means of a cigarette and then the can with its spluttering fuse was thrown into the enemy lines. As time went on and the art of grenade fighting was learned, the first crude missiles were greatly improved upon and grenades were made in many forms for special service.

There was a difference between grenades hurled from sheltered positions and those used in open fighting. When the throwers were sheltered behind their own breastworks, it mattered not how powerful was the explosion of the grenade. We must remember that in "hand-artillery" the shell is far more powerful in proportion to the distance it is thrown than the shell fired from a gun, and many grenades were so heavily charged with explosives that they would scatter death and destruction farther than they could be thrown by hand. The grenadier who cast one of these grenades had to duck under cover or hide under the walls of his trench, else the fragments scattered by the exploding missile might fly back and injure him. Some grenades would spread destruction to a distance of over three hundred feet from the point of explosion. For close work, grenades of smaller radius were used. These were employed to fight off a raiding-party after it had invaded a trench, and the destructive range of these grenades was usually about twenty-five feet.

Hand-grenades came to be used in all the different ways that artillery was used. There were grenades which were filled with gas, not only of the suffocating and tear-producing types, but also of the deadly poisonous variety. There were incendiary grenades which would set fire to enemy stores, and smoke grenades which would produce a dense black screen behind which operations could be concealed from the enemy. Grenades were used in the same way that shrapnel was used to produce a barrage or curtain of fire, through which the enemy could not pass without facing almost certain death. Curtains of fire were used not only for defensive purposes when the enemy was attacking, but also to cut off a part of the enemy so that it could not receive assistance and would be obliged to surrender. In attacks upon the enemy lines, grenades were used to throw a barrage in advance of the attacking soldiers so as to sweep the ground ahead clear of the enemy.

The French paid particular attention to the training of grenadiers. A man had to be a good, cool-headed pitcher before he could be classed as a grenadier. He must be able to throw his grenade with perfect accuracy up to a distance of seventy yards, and to maintain an effective barrage. The grenadier carried his grenades in large pockets attached to his belt, and he was attended by a carrier who brought up grenades to him in baskets, so that he was served with a continuous supply.

LONG-DISTANCE GRENADE-THROWING

All this relates to short-distance fighting, but grenades were also used for ranges beyond the reach of the pitcher's arm. Even back in the sixteenth century, the range of the human arm was not great enough to satisfy the combatants and grenadiers used a throwing-implement, something like a shovel, with which the grenade was slung to a greater distance, in much the same way as a lacrosse ball is thrown. Later, grenades were fitted with light, flexible wooden handles and were thrown, handle and all, at the enemy. By this means they could be slung to a considerable distance. Such grenades were used in the recent war, particularly by the Germans. The handle was provided with streamers so as to keep the grenade head-on to the enemy, and it was usually exploded by percussion on striking its target. These long-handled gre-

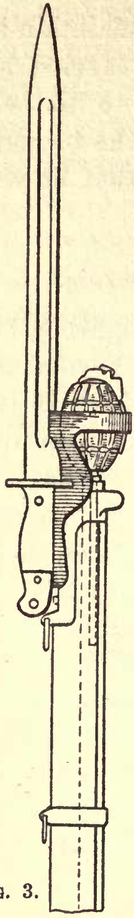


FIG. 3.

A rifle grenade fitted to the muzzle of a rifle

nades, however, were clumsy and bulky, and the grenadier required a good deal of elbow-room when throwing them.

A much better plan was to hurl them with the aid of a gun. A rifle made an excellent short-distance mortar. With it grenades could be thrown from three to four hundred yards. The grenade was fastened on a rod which was inserted in the barrel of the rifle and then it was fired out of the gun by the explosion of a blank cartridge. The butt of the rifle was rested on the ground and the rifle was tilted so as to throw the grenade up into the air in the way that a mortar projects its shell.

STRIKING A LIGHT

The lighting of the grenade fuses with a cigarette did very well for the early tin-can grenades, but the cigarettes were not always handy, particularly in the heat of battle, and something better had to be devised. One scheme was to use a safety-match composition on the end of a fuse. This was covered with waxed paper to protect it from the weather. The grenadier wore an armlet covered with a friction composition such as is used on a safety-match box. Before the grenade was thrown, the waxed paper was stripped off and the fuse was lighted by being scratched on the armlet. In another type the fuse was lighted by the twisting of a cap which scratched a match composition on a friction surface. A safety-pin kept the cap from turning until the grenadier was ready to throw the grenade.

The Mills hand-grenade, which proved to be the most popular type used by the British Army, was provided with a lever which was normally strapped down and held by means of a safety-pin. Fig. 4 shows a sectional view of this grenade. Just before the missile was thrown, it was seized in the hand so that the lever was held down. Then the safety-pin was removed and when the grenade was thrown, the lever would spring up under pull of the spring *A*.

This would cause the pin *B* to strike the percussion cap *C*, which would light the fuse *D*. The burning fuse would eventually carry the fire to the detonator *E*, which would touch off the main explosive, shattering the shell of the grenade and scattering its fragments in all direc-

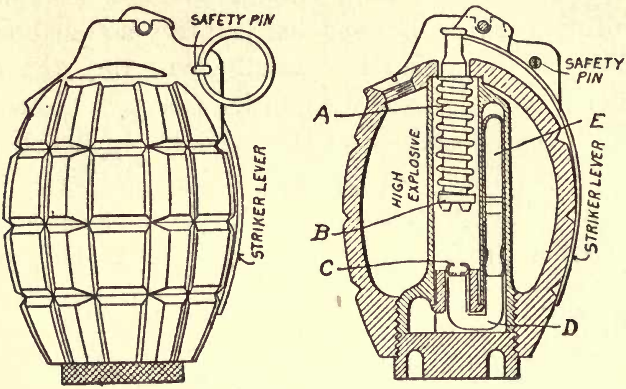


FIG. 4. Details of the Mills hand grenade

tions. The shell of the grenade was indented so that it would break easily into a great many small pieces.

There were some advantages in using grenades lighted by fuse instead of percussion, and also there were many disadvantages. If too long a time-fuse were used, the enemy might catch the grenade, as you would a baseball and hurl it back before it exploded. This was a hazardous game, but it was often done.

Among the different types of grenades which the Germans used was one provided with a parachute as shown in Fig. 5. The object of the parachute was to keep the head of the grenade toward the enemy, so that when it exploded it would expend its energies forward and would not cast fragments back toward the man who had thrown it. This was a very sensitive grenade, arranged to be fired by percussion, but it was so easily exploded that the firing-mechanism was not released until after the grenade had been thrown. In the handle of this gre-

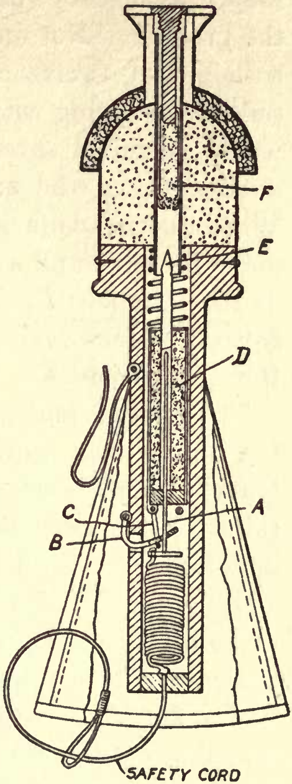


FIG. 5. A German parachute grenade

nade there was a bit of cord about twenty feet long. One end of this was attached to a safety-needle, *A*, while the other end, formed into a loop, was held by the grenadier when he threw the grenade. Not until the missile had reached a height of twelve or thirteen feet would the pull of the string withdraw the needle *A*. This would permit a safety-hook, *B*, to drop out of a ring, *C*, on the end of a striker pellet, *D*. When the grenade struck, the pellet *D* would move forward and a pin, *E*, would strike a cap on the detonator *F*, exploding the missile. This form of safety-device was used on a number of German grenades.

The British had another scheme for locking the mechanism until after the grenade had traveled some distance through the air. Details of this grenade, which was of the type adopted to be fired from a rifle, are shown in Fig. 6. The striker *A* is retained by a couple of bolts, *B*, which in turn are held in place by a sleeve, *C*. On the sleeve is a set of wind-vanes, *D*. As the grenade travels through the air, the wind-vanes cause the sleeve *C* to revolve, screwing it down clear of the bolts *B*, which then drop out, permitting the pin *A* to

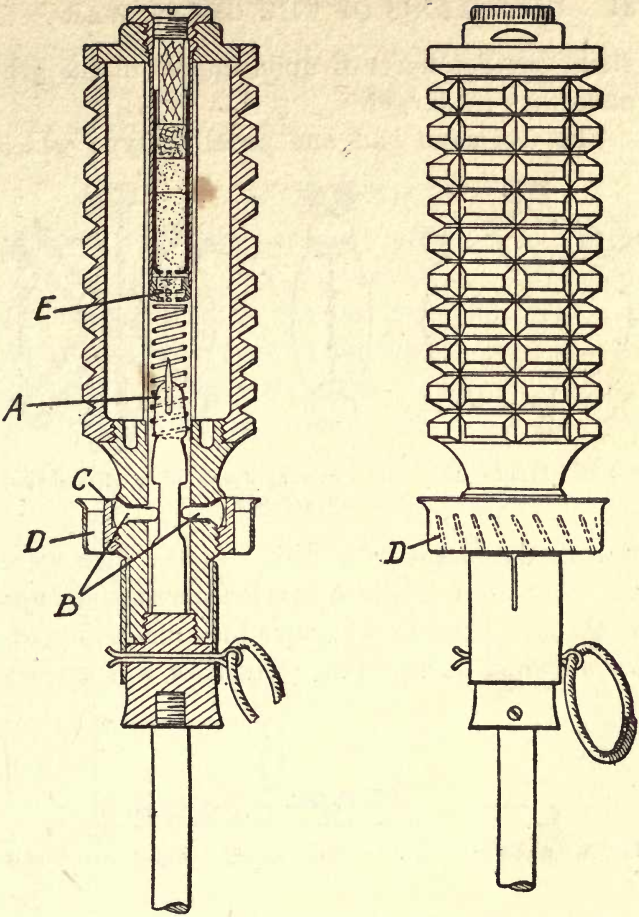


FIG. 6. British rifle grenade with a safety-device which is unlocked by the rush of air against a set of inclined vanes, *D*, when the missile is in flight

strike the detonator *E* upon impact of the grenade with its target.

The Germans had one peculiar type which

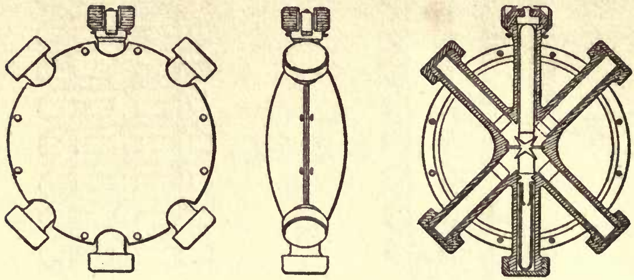


FIG. 7. Front, side, and sectional views of a disk-shaped German grenade

was in the shape of a disk. In the disk were six tubes, four of which carried percussion caps so that the grenade was sure to explode no matter on which tube it fell. The disk was thrown

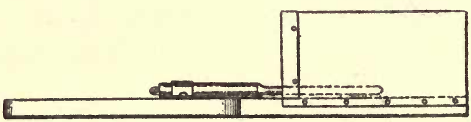


FIG. 8. A curious German hand grenade shaped like a hair brush

with the edge up, and it would roll through the air. Another type of grenade was known as the hair-brush grenade because it had a rectangular body of tin about six inches long and two and three quarter inches wide and deep, which was nailed to a wooden handle.

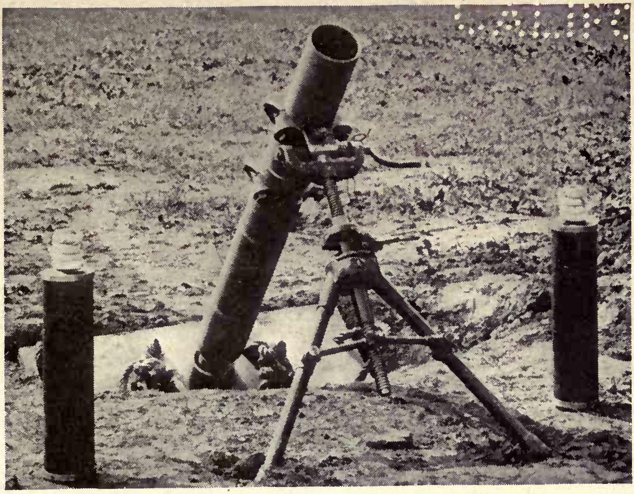
MINIATURE ARTILLERY

Hand-artillery was very effective as far as it went, but it had its limitations. Grenades could not be made heavier than two pounds in weight if they were to be thrown by hand; in fact, most of them were much lighter than that. If they were fired from a rifle, the range was increased but the missile could not be made very much heavier. TNT is a very powerful explosive, but there is not room for much of it in a grenade the size of a large lemon. Trench fighting was a duel between forts, and while the hand-artillery provided a means of attacking the defenders of a fort, it made no impression on the walls of the fort. It corresponded to shrapnel fire on a miniature scale, and something corresponding to high-explosive fire on a small scale was necessary if the opposing fortifications were to be destroyed. To meet this problem, men cast their thoughts back to the primitive artillery of the Romans, who used to hurl great rocks at the enemy with catapults. And the trench fighters actually rigged up catapults with which they hurled heavy bombs at the enemy lines. All sorts of ingenious catapults were built, some modeled after the old Roman machines. In some of these stout timbers were used as springs, in others there were powerful coil springs. It was not necessary to cast the bombs far. For distant work the regular artillery could be used. What was needed was a short-distance gun for heavy missiles and that is what the catapult was.

But the work of the catapult was not really satisfactory. The machine was clumsy; it occupied too much space, and it could not be aimed very accurately. It soon gave way to a more modern apparatus, fashioned after the old smooth-bore mortars. This was a miniature mortar, short and wide-mouthed. A rifled barrel was not required, because, since the missile was not to be hurled far, it was not necessary to set it spinning by means of rifling so as to hold it head-on to the wind.

GIANT PEA-SHOOTERS

Better aim was secured when a longer-barreled trench mortar came to be used. In the

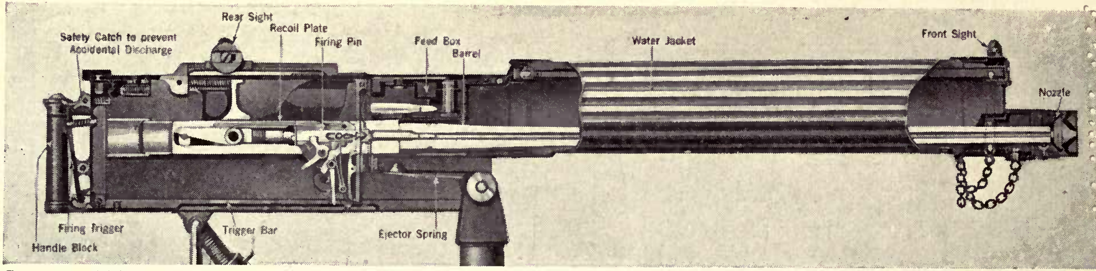


Press Illustrating Service

A 3-inch Stokes mortar and two of its shells

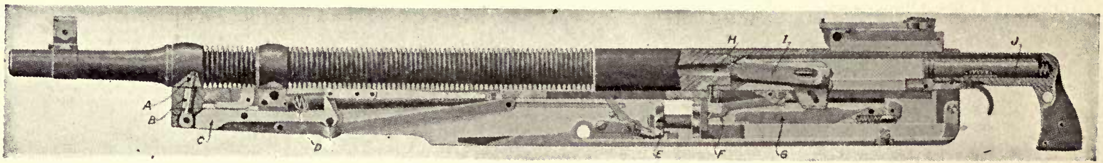
Press Illustrating Service

Dropping a shell into a 6-inch trench mortar



Courtesy of "Scientific American"

The Maxim Machine-gun Operated by the Energy of the Recoil



Courtesy of "Scientific American"

Colt Machine-gun partly broken away to show the Operating Mechanism

Gas from port *A* pushes down piston *B*, rocking lever *C*, which compresses coil-spring *D*. The cartridge fed into the gun by wheel *E*, is extracted by *F*, raised by *G* to breech *H*, and rammed in by bolt *I*. *J*, piston firing-hammer.

trench, weight was an important item. There was no room in which to handle heavy guns, and the mortar had to be portable so that it could be carried forward by the infantry in a charge. As the walls of a light barrel might be burst by the shock of exploding powder, compressed air was used instead. The shell was virtually blown out of the gun in the same way that a boy blows missiles out of a pea-shooter. That the shell might be kept from tumbling, it was fitted with vanes at the rear. These acted like the feathers of an arrow to hold the missile head-on to its course.

The French in particular used this type of mortar and the air-pump was used to compress the air that propelled the shell or aërial torpedo, or else the propelling charge was taken from a compressed-air tank. Carbon-dioxide, the gas used in soda water, is commonly stored in tanks under high pressure and this gas was sometimes used in place of compressed air. When the gas in the tank was exhausted the latter could be recharged with air by using a hand-pump. Two or three hundred strokes of the pump would give a pressure of one hundred and twenty to one hundred and fifty pounds per inch, and would supply enough air to discharge a number of shell. The air was let into the barrel of the mortar in a single puff sufficient to launch the shell; then the tank was cut off at once, so that the air it contained would not escape and go to waste.

THE STOKES MORTAR

However, the most useful trench mortar developed during the war was invented by Wilfred Stokes, a British inventor. In this a comparatively slow-acting powder was used to propel the missile, and so a thin-walled barrel could be used. The light Stokes mortar can easily be carried over the shoulder by one man. It has two legs and the barrel itself serves as a third leg, and the mortar stands like a tripod. The two legs are adjustable, so that the barrel can be inclined to any desired angle. It took but a moment to set up the mortar for action in a trench or shell-hole.

Curiously enough, there is no breech-block, trigger or fire-hole in this mortar. It is fired merely by the dropping of the missile into the mouth of the barrel. The shell carries its own propelling charge, as shown in Fig. 9. This is in the form of rings, *A*, which are fitted on a stem, *B*. At the end of the stem are a detonating cap and a cartridge, to ignite the propellant, *A*. At the bottom of the mortar barrel, there is a steel point, *E*, known as the

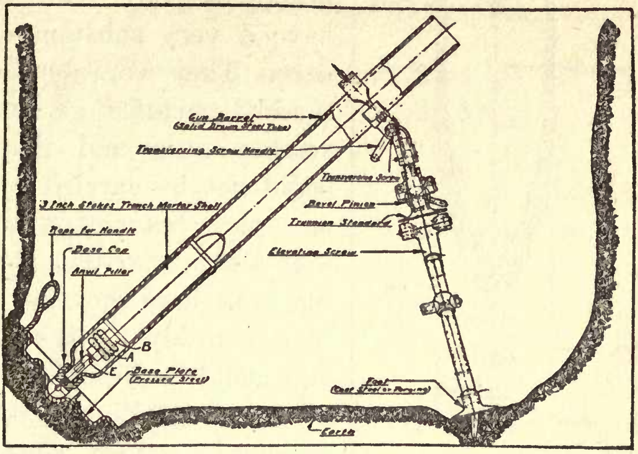


FIG. 9. Sectional view of a 3-inch Stokes mortar showing a shell at the instant of striking the anvil

"anvil." When the shell is dropped into the mortar, the cap strikes the anvil, exploding the cartridge and touching off the propelling charge, *A*. The gases formed by the burning charge hurl the shell out of the barrel to a distance of several hundred yards.

The first Stokes mortar was made to fire a 3–inch shell, but the mortar grew in size until it could hurl shell of 6–inch and even 8½–inch size. Of course, the larger mortars had to have a very substantial base. They were not so readily portable as the smaller ones and they could not be carried by one man; but compared with ordinary artillery of the same bore they were immeasurably lighter and could be brought to advanced positions and set up in a very short time. The larger shell have tail-vanes, as shown in Fig. 10, to keep them from tumbling when in flight.

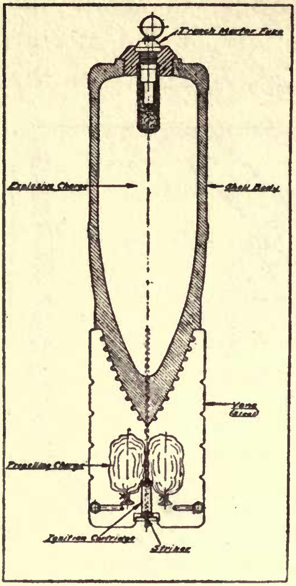


FIG. 10. A 6-inch trench mortar shell fitted with tail-vanes

CHAPTER III

Guns that Fire Themselves

MANY years ago a boy tried his hand at firing a United States Army service rifle. It was a heavy rifle of the Civil War period, and the lad did not know just how to hold it. He let the butt of the gun rest uncertainly against him, instead of pressing it firmly to his shoulder, and, in consequence, when the gun went off he received a powerful kick.

That kick made a deep impression on the lad, not only on his flesh but on his mind as well. It gave him a good conception of the power of a rifle cartridge.

Years afterward, when he had moved to England, the memory of that kick was still with him. It was a useless prank of the gun, he thought, a waste of good energy. Why could not the energy be put to use? And so he set himself the task of harnessing the kick of the gun.

A very busy program he worked out for that kick to perform. He planned to have the gun use up its exuberant energy in loading and firing itself. So he arranged the cartridges on a belt and fed the belt into the gun. When the gun was fired, the recoil would unlock the breech, take out the empty case of the cartridge just fired, select a fresh cartridge from the belt, and cock the main spring; then the mechanism would return, throwing the empty cartridge-case out of the gun, pushing the new cartridge into the barrel, closing the breech, and finally pulling the trigger. All this was to be done by the energy of a single kick, in about one tenth of a second, and the gun would keep on repeating the operation as long as the supply of cartridges was fed to it. The new gun proved so successful that the inventor was knighted, and became Sir Hiram Maxim.

A DOCTOR'S TEN-BARRELED GUN

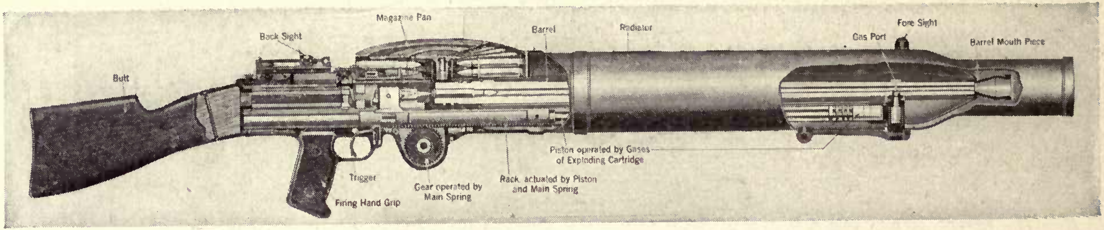
But Maxim's was by no means the first machine-gun. During the Civil War a Chicago physician brought out a very ingenious ten-barreled gun, the barrels of which were fired one after the other by the turning of a hand-crank. Although Dr. Gatling was a graduate of a medical school, he was far more fond of tinkering with machinery than of doling out pills. He invented a number of clever mechanisms, but the one that made him really famous was that machine-gun. At first our government did not take the invention seriously. The gun was tried out in the war, but whenever it went into battle it was fired not by soldiers but by a representative of Dr. Gatling's company, who went into the army to demonstrate the worth of the invention. Not until long after was the Gatling gun officially adopted by our army. Then it was taken up by many of the European armies as well.

Although many other machine-guns were invented, the Gatling was easily the best and most serviceable, until the Maxim invention made its appearance, and even then it held its own for many years; but eventually it had to succumb. The Maxim did not have to be cranked: it fired itself, which was a distinct advantage; and then, instead of being a bundle of guns all bound up into a single machine, Maxim's was a single-barreled gun and hence was much lighter and could be handled much more easily.

A GUN AS A GAS-ENGINE

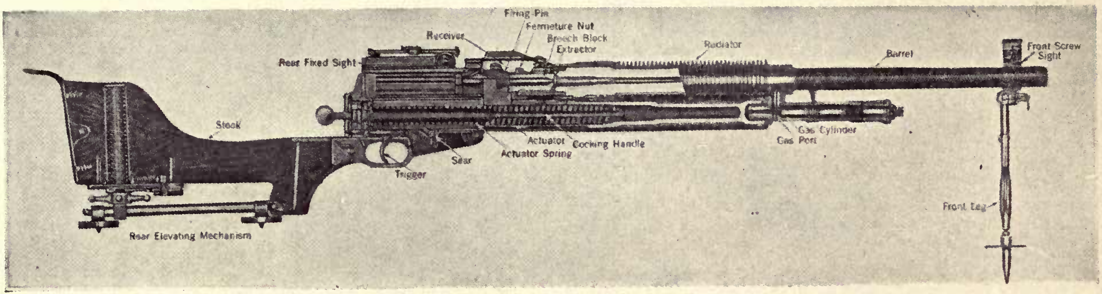
Another big advance was made by a third American, Mr. John M. Browning, who is responsible for the Colt gun. It was not a kick that set Browning to thinking. He looked upon a gun as an engine of the same order as an automobile engine, and really the resemblance is very close. The barrel of the gun is the cylinder of the engine; the bullet is the piston; and for fuel gunpowder is used in place of gasolene. As in the automobile engine, the charge is fired by a spark; but in the case of the gun the spark is produced by a blow of the trigger upon a bit of fulminate of mercury in the end of the cartridge.

Explosion is the same thing as burning. The only way that the explosion of gunpowder differs from the burning of a stick of wood is that the latter is very slow, while the former goes like a flash. In both cases the fuel turns into great volumes of gas. In the case of the gun the gas is formed almost instantly and in such quantity that it has to drive the bullet out of the barrel to make room for itself. In the cartridge that our army uses, only about a tenth



Courtesy of "Scientific American"

The Lewis Gun which produces its own cooling current

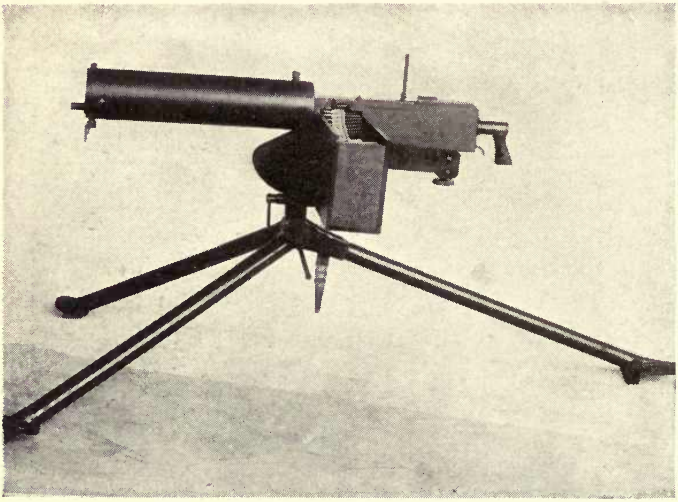


Courtesy of "Scientific American"

The Benèt-Mercié Gun operated by gas

(C) Committee on Public Information

Browning Machine Rifle, weight only 15 pounds



(C) Committee on Public Information

Browning Machine Gun, weighing 34½ pounds of an ounce of smokeless powder is used, but this builds up so heavy a pressure of gas that the bullet is sent speeding out of the gun at a rate of half a mile a second. It travels so fast that it will plow through four feet of solid wood before coming to a stop.

Now it occurred to Browning that it wouldn't really be stealing to take a little of that gas-power and use it to work the mechanism of his machine-gun. It was ever so little he wanted, and the bullet would never miss it. The danger was not that he might take too much. His problem was to take any power at all without getting more than his mechanism could stand. What he did was to bore a hole through the side of the gun-barrel. When the gun was fired, nothing happened until the bullet passed this hole; then some of the gas that was pushing the bullet before it would blow out through the hole. But this would be a very small amount indeed, for the instant that the bullet passed out of the barrel the gases would rush out after it, the pressure in the gun would drop, and the gas would stop blowing through the hole. With the bullet traveling at the rate of about half a mile in a second, imagine how short a space of time elapses after it passes the hole before it emerges from the muzzle, and what a small amount of gas can pass through the hole in that brief interval!

The gas that Browning got in this way he led into a second cylinder, fitted with a piston. This piston was given a shove, and that gave a lever a kick which set going the mechanism that extracted the empty cartridge-case, inserted a fresh cartridge, and fired it.

GETTING RID OF HEAT

The resemblance of a machine-gun to a gasolene-engine can be demonstrated still further. One of the most important parts of an automobile engine is the cooling-system. The gasolene burning in the cylinders would soon make them red-hot, were not some means provided to carry off the heat. The same is true of a machine-gun. In fact, the heat is one of the biggest problems that has to be dealt with. In a gasolene-engine the heat is carried off in one of three ways: (1) by passing water around the cylinders; (2) by building flanges around the cylinders to carry the heat off into the air; and (3) by using a fan to blow cool air against the cylinders. All of these schemes are used in the machine-gun. In Dr. Gatling's gun the cooling-problem was very simple. As there were ten barrels, one barrel could be cooling while the rest were taking their turn in the firing. In other words, each barrel received only a tenth of the heat that the whole gun was producing; and yet Gatling found it advisable to surround the barrels for about half their length with a water-jacket.

In the Maxim gun a water-jacket is used that extends the full length of the barrel, and into this water-jacket seven and a half pints of water are poured. Yet in a minute and a half of steady firing at a moderate rate, or before six hundred rounds are discharged, the water will be boiling. After that, with every thousand rounds of continuous fire a pint and a half of water will be evaporated. Now the water and the water-jacket add a great deal of weight to the gun, and this Browning decided to do away with in his machine-gun. Instead of water he used air to carry off the heat. The more surface the air touches, the more heat will it carry away; and so the Colt gun was at first made with a very thick-walled barrel. But later the

Colt was formed with flanges, like the flanges on a motor-cycle engine, so as to increase the surface of the barrel. Of course, air-cooling is not so effective as water-cooling, but it is claimed for this gun, and for other machine-guns of the same class, that the barrel is sufficiently cooled for ordinary service. Although a machine-gun may be capable of firing many hundred shots per minute, it is seldom that such a rate is kept up very long in battle. Usually, only a few rounds are fired at a time and then there is a pause, and there is plenty of time for the barrel to cool. Once in a while, however, the gun has to be fired continuously for several minutes, and then the barrel grows exceedingly hot.

EFFECT OF OVERHEATING

But what if the gun-barrel does become hot? The real trouble is not that the cartridge will explode prematurely, but that the barrel will expand as it grows hot, so that the bullet will fit too loosely in the bore. Inside the barrel the bore is rifled; that is, there are spiral grooves in it which give a twist to the bullet as it passes through, setting it spinning like a top. The spin of the bullet keeps its nose pointing forward. If it were not for the rifling, the bullet would tumble over and over, every which way, and it could not go very far through the air, to say nothing of penetrating steel armor. To gain the spinning-motion the bullet must fit into the barrel snugly enough to squeeze into the spiral grooves. Now there is another American machine-gun known as the Hotchkiss, which was used to a considerable extent by the French Army. It is a gas-operated gun, something like the Colt, and it is air-cooled. It was found in tests of the Hotchkiss gun that in from three to four minutes of firing the barrel was expanded so much that the shots began to be a little uncertain. In seven minutes of continuous firing the barrel had grown so large that the rifling failed to grip the bullet at all. The gun was no better than an old-fashioned smooth-bore. The bullets would not travel more than three hundred yards. It is because of this danger of overheating that the Colt and the Hotchkiss guns are always furnished with a spare barrel. As soon as a barrel gets hot it is uncoupled and the spare one is inserted in its place. Our men are trained to change the barrel of a colt in the dark in a quarter of a minute.

But a gun that has to have a spare barrel and that has to have its barrel changed in the midst of a hot engagement is not an ideal weapon, by any means. And this brings us to still another invention—that, too, by an American. Colonel I. N. Lewis, of the United States Army, conceived of a machine-gun that would be cooled not by still air but by air in motion. This would do away with all the bother of water-jackets. It would keep the gun light so that it could be operated by one man, and yet it would not have to be supplied with a spare barrel.

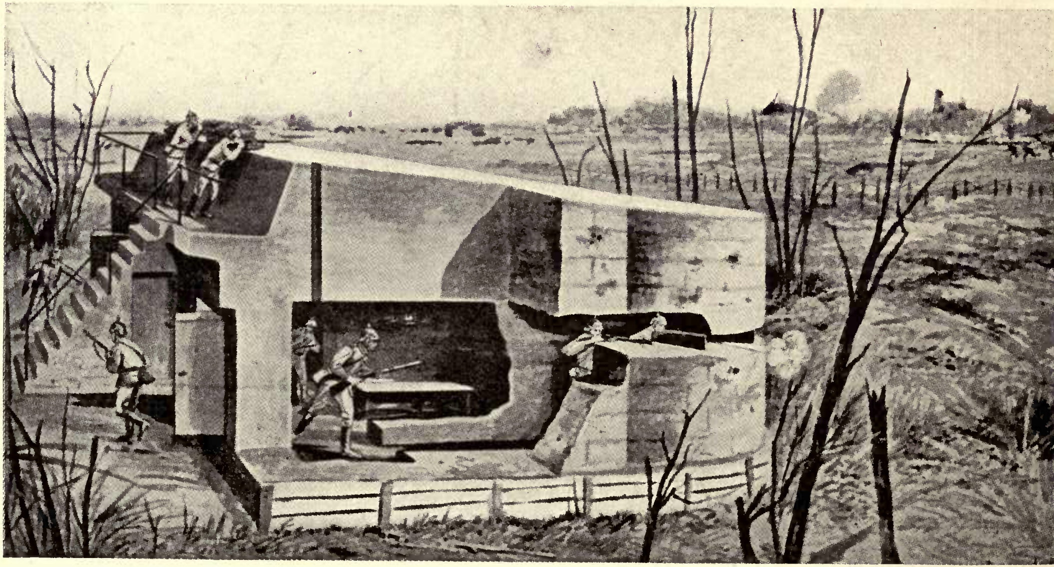
Like the Colt and the Hotchkiss, the Lewis gun takes its power from the gas that comes through a small port in the barrel, near the muzzle. In the plate facing page 44 the port may be seen leading into a cylinder that lies under the barrel. It takes about one ten-thousandth part of a second for a bullet to pass out of the barrel after clearing the port, but in that brief interval there is a puff of gas in the cylinder which drives back a piston. This piston has teeth on it which engage a small gear connected with a main-spring. When the piston moves back, it winds the spring, and it is this spring that operates the mechanism of the gun. The cartridges, instead of being taken from a belt or a clip, are taken from a magazine that is round and flat. There are forty-seven cartridges in the magazine and they are arranged like the spokes of a wheel, but in two layers. As soon as forty-seven rounds have been fired, the shooting must stop while a new magazine is inserted. But to insert it takes only a couple of seconds.

USING THE BULLET TO FAN THE GUN

The most ingenious part of the Lewis gun is the cooling-system. On the barrel of the gun are sixteen flanges or fins. These, instead of running around the gun, run lengthwise of the barrel. They are very light fins, being made of aluminum, and are surrounded by a casing of the same metal. The casing is open at each end so that the air can flow through it, but it extends beyond the muzzle of the barrel, and there it is narrowed down. At the end of the barrel there is a mouthpiece so shaped that the bullet, as it flies through, sucks a lot of air in its wake, making a strong current flow through the sixteen channels formed between the fins inside the casing. This air flows at the rate of about seventy miles per hour, which is enough to carry off all the heat that is generated by the firing of the cartridges. The gun may be regulated to fire between 350 and 750 rounds per minute, and its total weight is only 25½ pounds.

America can justly claim the honor of inventing and developing the machine-gun, although Hiram Maxim did give up his American citizenship and become a British subject. By the way, he is not to be confused with his younger brother, Hudson Maxim, the inventor of high explosives, who has always been an American to the core. Of course we must not get the impression that only Americans have invented machine-guns. There have been inventors of such weapons in various countries of Europe, and even in Japan. Our own army for a while used a gun known as the Benèt-Merciè, which is something like the Hotchkiss. This was invented by L. V. Benèt, an American, and H. A. Merciè, a Frenchman, both living in St. Denis, France.

Lewis Machine-guns in action at the front



Courtesy of "Scientific American"

An elaborate German Machine-Gun Fort

THE BROWNING MACHINE-GUN

When we entered the war, it was expected that we would immediately equip our forces with the Lewis gun, because the British and the Belgians had found it an excellent weapon and also because it was invented by an American officer, who very patriotically offered it to our government without charging patent royalties. But the army officials would not accept it, although many Lewis guns were bought by the navy. This raised a storm of protest throughout the country until finally it was learned that there was another gun for which the army was waiting, which it was said would be the very best yet. The public was skeptical and finally a test was arranged in Washington at which the worth of the new gun was demonstrated.

It was a new Browning model; or, rather, there were two distinct models. One of them, known as the heavy model, weighed only 34½ pounds, this with its water-jacket filled; for it was a water-cooled gun. Without its charge of water the machine weighed but 22½ pounds and could be rated as a very light machine-gun. However, it was classed as a heavy gun and was operated from a tripod. The new machine used recoil to operate its mechanism. The construction was simple, there were few parts, and the gun could very quickly be taken apart in case of breakage or disarrangement of the mechanism. But the greatest care was exercised to prevent jamming of cartridges, which was one of the principal defects in the other types of machine-guns. In the test this new weapon fired twenty thousand shots at the rate of six hundred per minute, with interruptions of only four and a half seconds, due partly to defective cartridges.

There was no doubt that the new Browning was a remarkable weapon. But if that could be said of the heavy gun, the light gun was a marvel. It weighed only fifteen pounds and was light enough to be fired from the shoulder or from the hip, while the operator was walking or running. In fact, it was really a machine-rifle. The regular .30-caliber service cartridges were used, and these were stored in a clip holding twenty cartridges. The cartridges could be fired one at a time, or the entire clip could be fired in two and a half seconds. It took but a second to drop an empty clip out of the gun and replace it with a fresh one. The rifle was gas-operated and air-cooled, but no special cooling-device was supplied because it would seldom be necessary to fire a shoulder rifle fast enough and long enough for the barrel to become overheated.

After the Browning machine-rifle was demonstrated it was realized that the army had been perfectly justified in waiting for the new weapon. Like the heavy Browning, the new rifle was a very simple mechanism, with few parts which needed no special tools to take them apart or reassemble them; a single small wrench served this purpose. Both the heavy and the light gun were proof against mud, sand, and dust of the battle-field. But best of all, a man did not have to have highly specialized training before he could use the Browning rifle. It did not require a crew to operate one of these guns. Each soldier could have his own machine-gun and carry it in a charge as he would a rifle. The advantage of the machine-rifle was that the operator could fire as he ran, watching where the bullets struck the ground by noting the dust they kicked up and in that way correcting his aim until he was on the target. Very accurate shooting was thus made possible, and the machine-rifle proved invaluable in the closing months of the war.

Browning is unquestionably the foremost inventor of firearms in the world. He was born of Mormon parents, in Ogden, Utah, in 1854, and his father had a gun shop. As a boy Browning became familiar with the use of firearms and when he was but fourteen years of age he invented an improved breech mechanism which was later used in the Winchester repeater. Curiously enough, it was a Browning pistol that was used by the assassin at Serajevo who killed the Archduke of Austria and precipitated the great European war, and it was with the Browning machine-gun and rifle that our boys swept the Germans back through the Argonne Forest and helped to bring the war to a successful end.

THE MACHINE-GUN IN SERVICE

Although the machine-gun has been used ever since the Civil War, it was not a vital factor in warfare until the recent great conflict. Army officials were very slow to take it up, because they did not understand it. They used to think of it as an inferior piece of light artillery, instead of a superior rifle. The Gatling was so heavy that it had to be mounted on wheels, and naturally it was thought of as a cannon. In the Franco-Prussian War the French had a machine-gun by which they set great store. It was called a *mitrailleuse*, or a gun for firing grape-shot. It was something like the Gatling. The French counted on this machine to surprise and overwhelm the Germans. But they made the mistake of considering it a piece of artillery and fired it from long range, so that it did not have a chance to show its worth. Only on one or two occasions was it used at close range, and then it did frightful execution. However, it was a very unsatisfactory machine, and kept getting out of order. It earned the contempt of the Germans, and later when the Maxim gun was offered to the German Army they would have none of it. They did not want to bother with "a toy cannon."

It really was not until the war between Russia and Japan that military men began to realize the value of the machine-gun. As the war went on, both the Russians and the Japanese bought up all the machine-guns they could secure. They learned what could be done with the aid of barbed wire to retard the enemy while the machine-guns mowed them down as they were trying to get through.

A man with a machine-gun is worth a hundred men with rifles; such is the military estimate of the weapon. The gun fires so fast that after hitting a man it will hit him again ten times while he is falling to the ground. And so it does not pay to fire the gun continuously in one direction, unless there is a dense mass of troops charging upon it. Usually the machine-gun is swept from side to side so as to cover as wide a range as possible. It is played upon the enemy as you would play the hose upon the lawn, scattering a shower of lead among the advancing hosts.

MACHINE-GUN FORTS

It used to be thought that the Belgian forts of armored steel and concrete, almost completely buried in the ground, would hold out against any artillery. But when the Germans brought up their great howitzers and hurled undreamed-of quantities of high explosives on these forts, they broke and crumbled to pieces.

Then it was predicted that the day of the fort was over. But the machine-gun developed a new type of warfare. Instead of great forts, mounting huge guns, little machine-gun forts were built, and, they were far more troublesome than the big fellows.

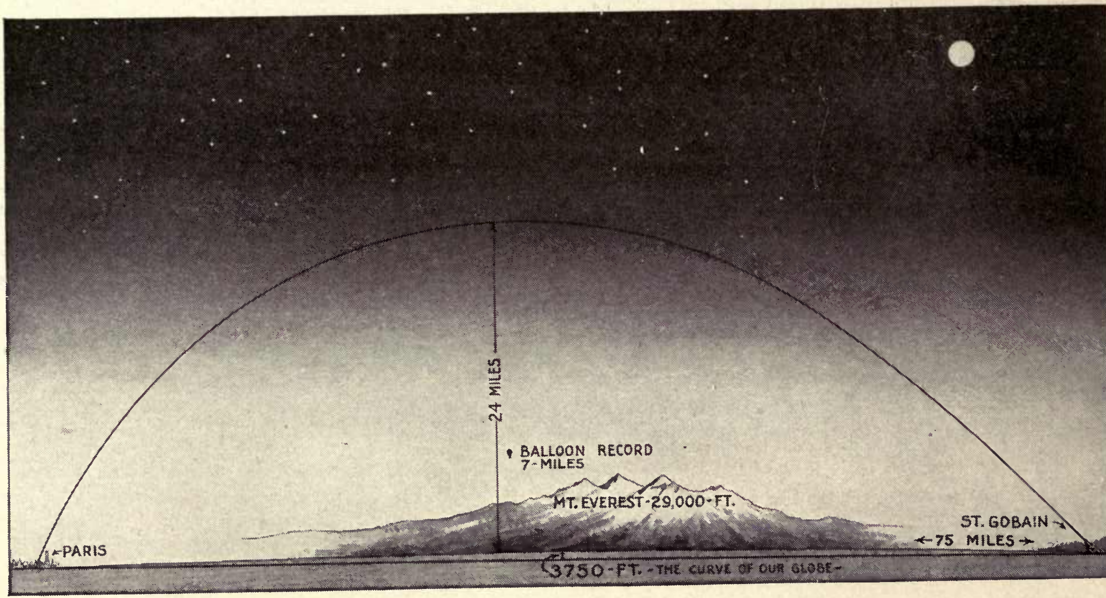
To the Germans belongs the credit for the new type of fort, which consisted of a small concrete structure, hidden from view as far as possible, but commanding some important part of the front. "Pill-boxes," the British call them, because the first ones they ran across were round in shape and something like a pill-box in appearance. These pill-boxes were just large enough to house a few men and a couple of machine-guns. Concealment was of the utmost importance; safety depended upon it. Airplanes were particularly feared, because a machine-gun emplacement was recognized to be so important that a whole battery of artillery would be turned upon a suspected pill-box.

Some of the German machine-gun forts were very elaborate, consisting of spacious underground chambers where a large garrison of gunners could live. These forts were known as *Mebus,* a word made from the initials of

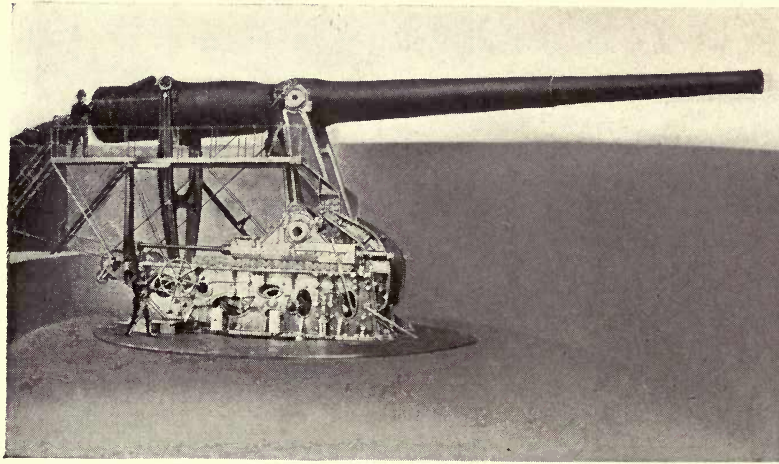
"Maschinengewehr Eisen-Bettungs Unterstand," meaning a machine-gun iron-bedded foundation.

It was the machine-gun that was responsible for the enormous expenditure of ammunition in the war. Before a body of troops dared to make a charge, the ground had to be thoroughly searched by the big guns for any machine-gun nests. Unless these were found and destroyed by shell-fire, the only way that remained to get the best of them was to crush them down with tanks. It was really the machine-gun that drove the armies into trenches and under the ground.

But a machine-gun did not have to be housed in a fort, particularly a light gun of the Lewis type. To be sure, the Lewis gun is a little heavy to be used as a rifle, but it could easily be managed with a rest for the muzzle in the crotch of a tree, and a strong man could actually fire the piece from the shoulder. The light machine-gun could go right along with a charging body of troops and do very efficient service, particularly in fighting in a town or village, but it had to be kept moving or it would be a target for the artillery. In a certain village fight a



Comparative diagram of the path of a projectile from the German Super-gun



Courtesy of "Scientific American"

One of our 16-inch Coast Defence Guns on a disappearing mount

Height of gun as compared with the New York City Hall machine-gunner kept changing his position. He would fire for a few minutes from one building and then shift over to some other. He did this no less than six times, never staying more than five minutes at a time in the same spot. But each one of the houses was shelled within fifteen minutes of the time he opened fire from it, which shows the importance that the Germans attached to machine-gun fire.

CHAPTER IV

Guns and Super-Guns

WHEN the news came that big shells were dropping into Paris from a gun which must be at least seventy miles away, the world at first refused to believe; then it imagined that some brand-new form of gun or shell or powder had been invented by the Germans. However, while the public marveled, ordnance experts were interested but not astonished. They knew that it was perfectly feasible to build a gun that would hurl a shell fifty, or seventy-five, or even a hundred miles, without involving anything new in the science of gunnery.

SHOOTING AROUND THE EDGE OF THE EARTH

But if such ranges were known to be possible, why was no such long-distance gun built before? Simply because none but the Germans would ever think of shooting around the edge of the earth at a target so far away that it would have to be as big as a whole city to be hit at all. In a distance of seventy miles, the curve of the earth is considerable. Paris is far below the horizon of a man standing at St. Gobain, where the big German gun was located. And if a hole were bored from St. Gobain straight to Paris, so that you could see the city from the gun, it would pass, midway of its course, three thousand, seven hundred and fifty feet below the surface of the earth. With the target so far off, it was impossible to aim at any particular fort, ammunition depot, or other point of military importance. There is always some uncertainty as to just where a shell will fall, due to slight differences in quality and quantity of the powder used, in the density of the air, the direction of the wind, etc. This variation is bad enough when a shell is to be fired ten miles, but when the missile has to travel seventy miles, it is out of the question to try to hit a target that is not miles in extent.

Twenty years before the war our Ordnance Department had designed a fifty-mile gun, but it was not built, because we could see no possible use for it. Our big guns were built for fighting naval battles or for the defense of our coasts from naval attacks, and there is certainly no use in firing at a ship that is so far below the horizon that we cannot even see the tips of its masts; and so our big guns, though they were capable of firing a shell twenty-seven miles, if aimed high enough, were usually mounted in carriages that would not let them shoot more than twelve or fifteen miles.

The distance to which a shell can be hurled depends to a large extent upon the angle of the gun. If the gun is tilted up to an angle of 15 degrees, the shell will go only about half as far as if it were tilted up to 43½ degrees, which is the angle that will carry a shell to its greatest distance. If the long-range German gun was fired at that angle, the shell must have risen to a height of about twenty-four miles.

BEYOND THE EARTH'S ATMOSPHERE

Most of the air that surrounds our globe lies within four miles of the surface. Few airplanes can rise to a greater height than this, because the air is so thin that it gives no support to the wings of the machine. The greatest height to which a man has ever ascended is seven miles. A balloon once carried two men to such a height.

One of them lost consciousness, and the other, who was nearly paralyzed, succeeded in pulling the safety-valve rope with his teeth. That brought the balloon down, and their instruments showed that they had gone up thirty-six thousand feet. What the ocean of air contains above that elevation, we do not know, but judging by the way the atmosphere thins out as we rise from the surface of the earth, we reckon that nine tenths of the air lies within ten miles of the surface of the earth. At twenty-four miles, or the top of the curve described by the shell of the German long-range guns, there must be an almost complete vacuum.

If only we could accompany a shell on its course, we should find a strange condition of affairs. The higher we rose, the darker would the heavens become, until the sun would shine like a fiery ball in a black sky. All around, the stars would twinkle, and below would be the glare of light reflected from the earth's surface and its atmosphere, while the cold would be far more intense than anything suffered on earth. Up at that height, there would be nothing to indicate that the shell was moving—no rush of air against the ears. We should seem detached from earth and out in the endless reaches of space.

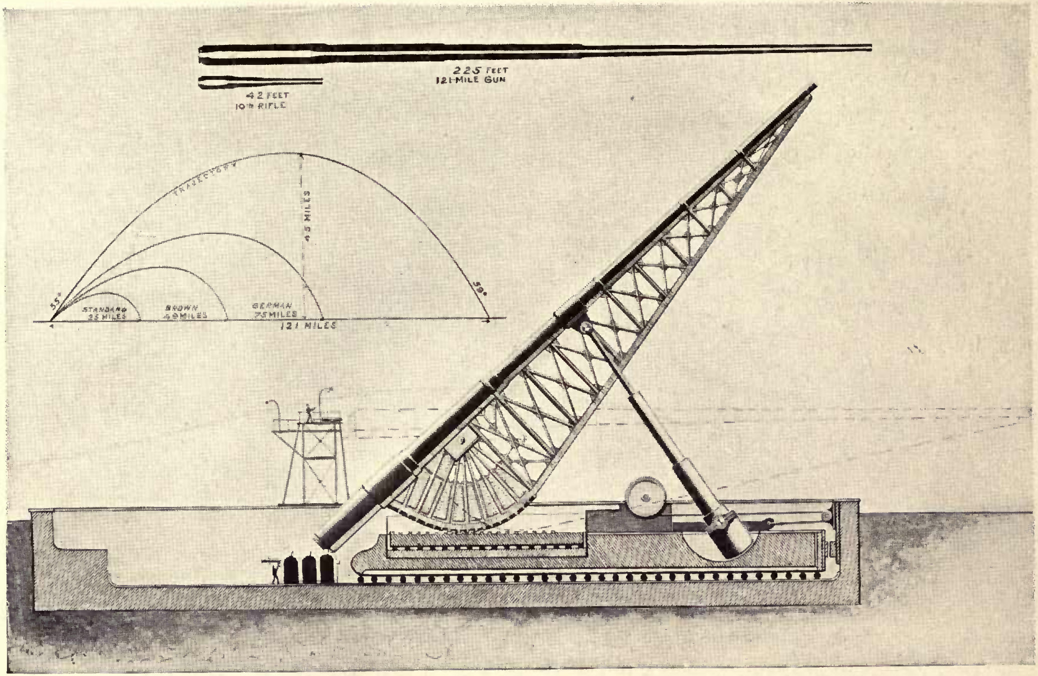
It seems absurd to think that a shell weighing close to a quarter of a ton could be retarded appreciably by mere air. But when we realize that the shell left the gun at the rate of over half a mile a second—traveling about thirty times faster than an express-train—we know that the air-pressure mounts up to a respectable figure. The pressure is the same whether a shell is moving through the air or the air is blowing against the shell. When the wind blows at the rate of 100 to 120 miles per hour, it is strong enough to lift houses off their foundations, to wrench trees out of the ground, to pick up cattle and carry them sailing through the air. Imagine what it would do if its velocity were increased to 1,800 miles per hour. That is what the shell of a big gun has to contend with. As most of the air lies near the earth, the shell of long-range guns meet with less and less resistance the higher they rise, until they get up into such thin air that there is virtually no obstruction. The main trouble is to pierce the blanket of heavy air that lies near the earth.

WAYS OF INCREASING THE RANGE

The big 16-inch guns that protect our coasts fire a shell that weighs 2,400 pounds. Nine hundred pounds of smokeless powder is used to propel the shell, which leaves the muzzle of the gun with a speed of 2,600 feet per second. Now, the larger the diameter of the shell, the greater will be its speed at the muzzle of the gun, because there will be a greater surface for the powder gases to press against. On the other hand, the larger the shell, the more will it be retarded by the air, because there will be a larger surface for the air to press against. It has been proposed by some ordnance experts that a shell might be provided with a disk at each end, which would make it fit a gun of larger caliber. A 10-inch shell, for instance, could then be fired from a 16-inch gun. Being lighter than the 16-inch shell, it would leave the muzzle of the gun at a higher speed. The disks could be so arranged that as soon as the shell left the gun they would be thrown off, and then the 10-inch shell, although starting with a higher velocity than a 16-inch shell, would offer less resistance to the air. In that way it could be made to cover a much greater range. By the way, the shell of the German long-range gun was of but 8.2-inch caliber.

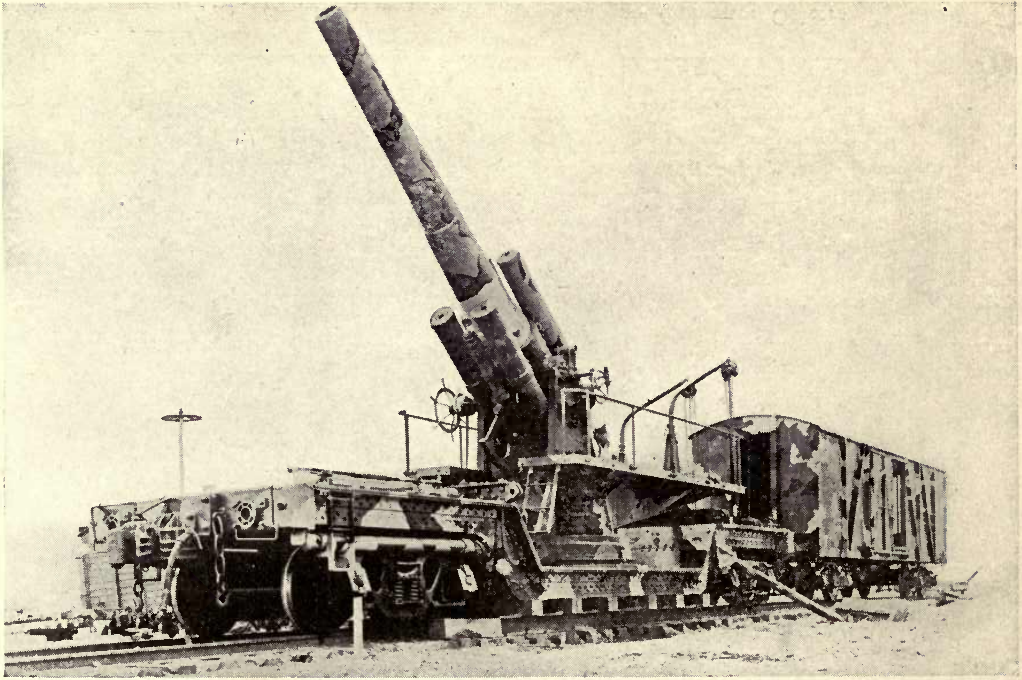
Another way of increasing the range is to lengthen the gun. Right here we must become acquainted with the word "caliber." Caliber means the diameter of the shell. A 16-inch gun, for instance, fires a shell of 16-inch caliber; but when we read that the gun is a 40- or 50-caliber gun, it means that the length of the gun is forty or fifty times the diameter of the shell. Our biggest coast-defense guns are 50-caliber 16-inch guns, which means that they are fifty times 16 inches long, or 66⅔ feet in length. When a gun is as long as that, care has to be taken to prevent it from sagging at the muzzle of its own weight. These guns actually do sag a little, and when the shell is fired through the long barrel it straightens up the gun, making the muzzle "whip" upward, just as a drooping garden hose does when the water shoots through it.

Now the longer the caliber length of a gun, the farther it will send a shell, because the powder gases will have a longer time to push the shell. But we cannot lengthen our big guns



Courtesy of "Scientific American"

The 121-Mile Gun designed by American Ordnance Officers



American 16-Inch Rifle on a Railway Mount much more without using some special support for the muzzle end of the gun, to keep it from "whipping" too much. It is likely that the long-range German gun was provided with a substantial support at the muzzle to keep it from sagging.

Every once in a while a man comes forth with a "new idea" for increasing the range. One plan is to increase the powder-pressure. We have powders that will produce far more pressure than an ordinary gun can stand. But we have to use powders that will burn comparatively slowly. We do not want too sudden a shock to start with, but we wish the powder to give off an enormous quantity of gas which will keep on pushing and speeding up the shell until the latter emerges from the muzzle. The fifty-mile gun that was proposed twenty years ago was designed to stand a much higher pressure than is commonly used, and it would have fired a 10-inch shell weighing 600 pounds with a velocity of 4,000 feet per second at the muzzle.

The Allies built no "super-guns," because they knew that they could drop a far greater quantity of explosives with much greater accuracy from airplanes, and at a much lower cost. The German gun at St. Gobain was spectacular and it did some damage, but it had no military value and it did not intimidate the French as the Germans had hoped it would.

A GUN WITH A RANGE OF A HUNDRED AND TWENTY MILES

But although we built no such gun, after the Germans began shelling Paris our Ordnance Department designed a gun that would fire a shell to a distance of over 120 miles! There was no intention of constructing the gun, but the design was worked out just as if it were actually to be built. It was to fire a shell of 10-inch caliber, weighing 400 pounds. Now, an Elswick standard 10-inch gun is 42 feet long and its shell weighs 500 pounds. Two hundred pounds of powder are used to propel the shell, which leaves the muzzle with a velocity of 3,000 feet per second. If the gun is elevated to the proper angle, it will send the shell 25 miles, and it will take the shell a minute and thirty-seven seconds to cover that distance. But the long-range gun our ordnance experts designed would have to be charged with 1,440 pounds of powder and the shell would leave the muzzle of the gun with a velocity of 8,500 feet per second. It would be in the air four minutes and nine seconds and would travel 121.3 miles. Were the gun fired from the Aberdeen Proving Grounds, near Baltimore, Maryland, its shell would travel across three states and fall into New York Bay at Perth Amboy. At the top of its trajectory it would rise 46 miles above the earth.

But the most astonishing part of the design was the length of the gun, which worked out to 225 feet. An enormous powder-chamber would have to be used, so that the powder gases would keep speeding up the shell until it reached the required velocity at the muzzle. The weight of the barrel alone was estimated at 325 tons.

It would have to be built up in four sections screwed together and because of its great length and weight it would have to be supported on a steel truss. The gun would be mounted like a roller lift-bridge with a heavy counterweight at its lower end so that it could be elevated or depressed at will and a powerful hydraulic jack would be required to raise it.

The recoil of a big gun is always a most important matter. Unless a gun can recoil, it will be smashed by the shock of the powder explosion. Usually, heavy springs are used to take up the shock, or cylinders filled with oil in which pistons slide. The pistons have small holes in them through which the oil is forced as the piston moves and this retards the gun in its recoil. But this "super-gun" was designed to be mounted on a carriage running on a set of tracks laid in a long concrete pit. On the recoil the gun would run back along the tracks, and its motion would be retarded by friction blocks between the carriage and the tracks and also by a steel cable attached to the forward end of the carriage and running over a pulley on the front wall of the pit, to a friction drum.

The engraving facing page 68 gives some idea of the enormous size of the gun. Note the man at the breech of the gun. The hydraulic jack is collapsible, so that the gun may be brought to the horizontal position for loading, as shown by the dotted lines. The cost of building this gun is estimated at two and a half million dollars and its 400-pound shell would land only about sixty pounds of high explosives on the target. A bombing-plane costing but thirty thousand dollars could land twenty-five times as big a charge of high explosives with far greater accuracy. Aside from this, the gun lining would soon wear out because of the tremendous erosion of the powder gases.

THE THREE-SECOND LIFE OF A GUN

Powder gases are very hot indeed—hot enough to melt steel. The greater the pressure in the gun, the hotter they are. It is only because they pass through the gun so quickly, that they do not melt it. As a matter of fact, they do wear it out rapidly because of their heat and velocity. They say that the life of a big gun is only three seconds. Of course, a shell passes through the gun in a very minute part of a second, but if we add up these tiny periods until we have a total of three seconds, during which the gun may have fired two hundred rounds, we shall find that the lining of the barrel is so badly eroded that the gun is unfit for accurate shooting, and it must go back to the shops for a new inner tube.

ELASTIC GUNS

We had better go back with it and learn something about the manufacture of a big gun.

Guns used to be cast as a solid chunk of metal. Now they are built up in layers. To understand why this is necessary, we must realize that steel is not a dead mass, but is highly elastic—far more elastic than rubber, although, of course, it does not stretch nor compress so far. When a charge of powder is exploded in the barrel of a gun, it expands in all directions. Of course, the projectile yields to the pressure of the powder gases and is sent kiting out of the muzzle of the gun. But for an instant before the shell starts to move, an enormous force is exerted against the walls of the bore of the gun, and, because steel is elastic, the barrel is expanded by this pressure, and the bore is actually made larger for a moment, only to spring back in the next instant. You can picture this action if you imagine a gun made of rubber; as soon as the powder was fired, the rubber gun would bulge out around the powder-chamber, only to collapse to its normal size when the pressure was relieved by the discharge of the bullet.

Now, every elastic body has what is called its elastic limit. If you take a coil spring, you can pull it out or you can compress it, and it will always return to its original shape, unless you pull it out or compress it beyond a certain point; that point is its elastic limit. The same is true of a piece of steel: if you stretch it beyond a certain point, it will not return to its original shape. When the charge of powder in a cannon exceeds a certain amount, it stretches the steel beyond its elastic limit, so that the bore becomes permanently larger. Making the walls of the gun heavier would not prevent this, because steel is so elastic that the inside of the walls expands beyond its elastic limit before the outside is affected at all.

Years ago an American inventor named Treadwell worked out a scheme for allowing the bore to expand more without exceeding its elastic limit. He built up his gun in layers, and shrunk the outer layers upon the inner layers, just as a blacksmith shrinks a tire on a wheel, so that the inner tube of the gun would be squeezed, or compressed. When the powder was fired, this inner layer could expand farther without danger, because it was compressed to start with. The built-up gun was also independently invented by a British inventor. All modern big guns are built up.

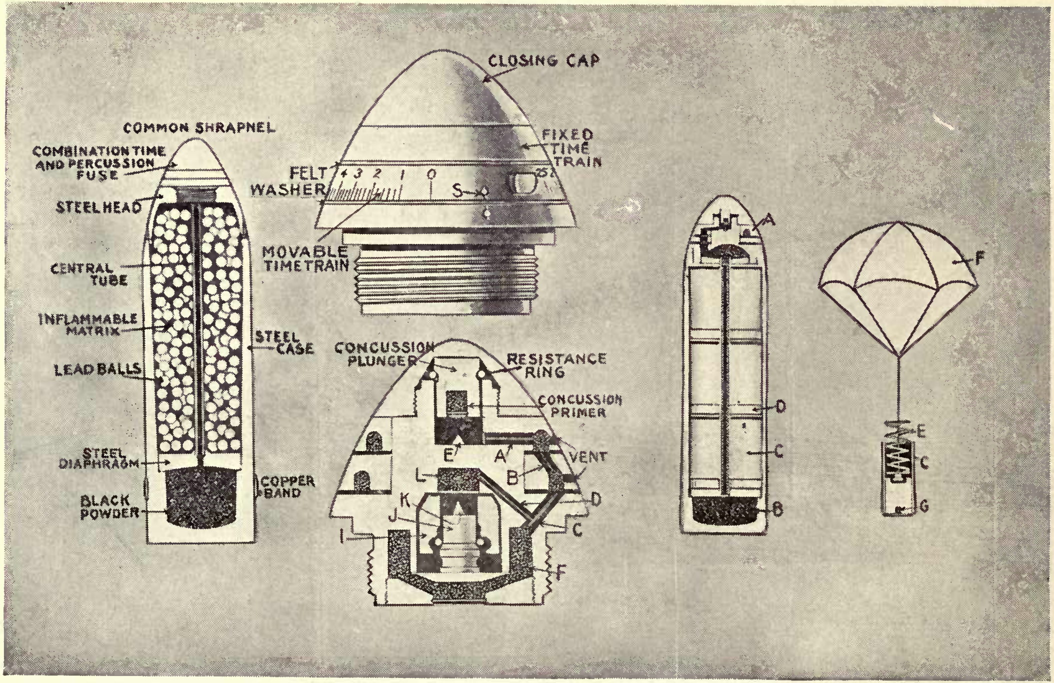
HOW BIG GUNS ARE MADE

The inside tube, known as the lining, is cast roughly to shape, then it is bored out, after which it is forged by the blows of a powerful steam-hammer. Of course, while under the hammer, the tube is mounted on a mandrel, or bar, that just fits the bore. The metal is then softened in an annealing furnace, after which it is turned down to the proper diameter and re-bored to the exact caliber. The diameter of the lining is made three ten-thousandths of an inch larger than the inside of the hoop or sleeve that fits over it. This sleeve, which is formed in the same way, is heated up to 800 degrees, or until its inside diameter is eight tenths of an inch larger than the outside diameter of the lining. The lining is stood up on end and the sleeve is fitted over it. Then it is cooled by means of water, so that it grips the lining and compresses it. In this way, layer after layer is added until the gun is built up to the proper size.

Instead of having a lining that is compressed by means of sleeves or jackets, many big guns are wound with wire which is pulled so tight as

Photograph from Underwood & Underwood

A Long-distance Sub-calibered French Gun on a Railway Mount



Courtesy of "Scientific American"

Inside of a Shrapnel Shell and Details of the Fuse Cap

Search-light Shell and one of its Candles to compress the lining. The gun-tube is placed in a lathe, and is turned so as to wind up the wire upon it. A heavy brake on the wire keeps it drawn very tight. This wire, also, is put on in layers, so that each layer can expand considerably without exceeding its elastic limit. Our big 16-inch coast-defense guns are wound with wire that is one-tenth of an inch square. The length of wire on one gun is sufficient to reach all the way from New York to Boston with fifty or sixty miles of wire left over.

GUNS THAT PLAY HIDE-AND-SEEK

A very ingenious invention is the disappearing-mount which is used on our coast fortifications. By means of this a gun is hidden beyond its breastworks so that it is absolutely invisible to the enemy. In this sheltered position it is loaded and aimed. It is not necessary to sight the gun on the target as you would sight a rifle. The aiming is done mathematically. Off at some convenient observation post, an observer gets the range of the target and telephones this range to the plotting-room, where a rapid calculation is made as to how much the gun should be elevated and swung to the right or the left.

This calculation is then sent on to the gunners, who adjust the gun accordingly. When all is ready, the gun is raised by hydraulic pressure, and just as it rises above the parapet it is automatically fired. The recoil throws the gun back to its crouching position behind the breastworks. All that the enemy sees, if anything, is the flash of the discharge.

Now that airplanes have been invented, the disappearing-mount has lost much of its usefulness. Big guns have to be hidden from above. They are usually located behind a hill, five or six miles back of the trenches, where the enemy cannot see them from the ground, and they are carefully hidden under trees or a canopy of foliage or are disguised with paint.

The huge guns recently built to defend our coasts are intended to fire a shell that will pierce the heavy armor of a modern dreadnought. The shell is arranged to explode after it has penetrated the armor, and the penetrating-power is a very important matter. About thirty years ago the British built three battleships, each fitted with two guns of 16¼-inch caliber and 30-caliber length. In order to test the penetrating-power of this gun a target was built, consisting first of twenty inches of steel armor and eight inches of wrought-iron; this was backed by twenty feet of oak, five feet of granite, eleven feet of concrete, and six feet of brick. When the shell struck this target it passed through the steel, the iron, the oak, the granite, and the concrete, and did not stop until it had penetrated three feet of the brick. We have not subjected our 16-inch gun to such a test, but we know that it would go through two such targets and still have plenty of energy left. Incidentally, it costs us $1,680 each time the big gun is fired.

THE FAMOUS FORTY-TWO-CENTIMETER GUN

One of the early surprises of the war was the huge gun used by the Germans to destroy the powerful Belgian forts. Properly speaking, this was not a gun, but a howitzer; and right here we must learn the difference between mortars, howitzers, and guns. What we usually mean by "gun" is a piece of long caliber which is designed to hurl its shell with a flat trajectory. But long ago it was found advantageous to throw a projectile not at but upon a fortification, and for this purpose short pieces of large bore were built. These would fire at a high angle, so that the projectile would fall almost vertically on the target.

As we have said, the bore of a gun is rifled; that is, it is provided with spiral grooves that will set the shell spinning, so as to keep its nose pointing in the direction of its flight. Mortars, on the other hand, were originally intended for short-range firing, and their bore was not rifled. In recent years, however, mortars have been made longer and with rifled bores, so as to increase their range, and such long mortars are called "howitzers." The German 42-centimeter howitzer fired a shell that was 2,108 pounds in weight and was about 1½ yards long. The diameter of the shell was 42 centimeters, which is about 16½ inches. It carried an enormous amount of high explosive, which was designed to go off after the shell had penetrated its target. The marvel of this howitzer was not that it could fire so big a shell but that so large a piece of artillery could be transported over the highroads and be set for use in battle. But although the 42-centimeter gun was widely advertised, the real work of smashing the Belgian forts was done by the Austrian

"Skoda" howitzers, which fired a shell of 30.5-centimeter (12-inch) caliber, and not by the 42-centimeter gun. The Skoda howitzer could be taken apart and transported by three motor-cars of 100 horse-power each. The cars traveled at a rate of about twelve miles per hour. It is claimed the gun could be put together in twenty-four minutes, and would fire at the rate of one shot per minute.

FIELD-GUNS

So far, we have talked only of the big guns, but in a modern battle the field-gun plays a very important part. This fires a shell that weighs between fourteen and eighteen pounds and is about three inches in diameter. The shell and the powder that fires it are contained in a cartridge that is just like the cartridge of a shoulder rifle. These field-pieces are built to be fired rapidly. The French 75-millimeter gun, which is considered one of the best, will fire at the rate of twenty shots per minute, and its effective range is considerably over three miles. The French supplied us with all 75-millimeter guns we needed in the war, while we concentrated our efforts on the manufacture of ammunition.

GUNS THAT FIRE GUNS

During the War of the Revolution, cannon were fired at short range, and it was the custom to load them with grape-shot, or small iron balls, when firing against a charging enemy, because the grape would scatter like the shot of a shot-gun and tear a bigger gap in the ranks of the enemy than would a single solid cannon-ball. In modern warfare, guns are fired from a greater distance, so that there will be little danger of their capture. It is impossible for them to fire grape, because the ranges are far too great; besides, it would be impossible to aim a charge of grape-shot over any considerable distance, because the shot would start spreading as soon as they left the muzzle of the gun and would scatter too far and wide to be of much service. But this difficulty has been overcome by the making of a shell which is really a gun in itself. Within this shell is the grape-shot, which consists of two hundred and fifty half-inch balls of lead. The shell is fired over the lines of the enemy, and just at the right moment it explodes and scatters a hail of leaden balls over a fairly wide area.

It is not a simple matter to time a shrapnel shell so that it will explode at just the right moment. Spring-driven clockwork has been tried, which would explode a cap after the lapse of a certain amount of time; but this way of timing shells has not proved satisfactory. Nowadays a train of gunpowder is used. When the shell is fired, the shock makes a cap (see drawing facing page 77) strike a pin, *E*, which ignites the train of powder, *A*. The head of the shell is made of two parts, in each of which there is a powder-fuse. There is a vent, or short cut, leading from one fuse to the other, and, by the turning of one part of the fuse-head with respect to the other, this short cut is made to carry the train of fire from the upper to the lower fuse sooner or later, according to the adjustment. The fire burns along one powder-train *A*, and then jumps through the short cut *B* to the other, or movable train, as it is called, until it finally reaches, through hole *C*, the main charge *F*, in the shell. The movable part of the fuse-head is graduated so that the fuse may be set to explode the shell at any desired distance. In the fuse-head there is also a detonating-pin *K*, which will strike the primer *L* and explode the shell when the latter strikes the ground, if the time-fuse has failed to act.

When attacking airplanes, it is important to be able to follow the flight of the shell, so some shrapnel shell are provided with a smoke-producing mixture, which is set on fire when the shell is discharged, so as to produce a trail of smoke.

In meeting the attack of any enemy at night, search-light shell are sometimes used. On exploding they discharge a number of "candles," each provided with a tiny parachute that lets the candle drop slowly to the ground. Their brilliant light lasts fifteen or twenty minutes. Obviously, ordinary search-lights could not be used on the battle-field, because the lamp would at once be a target for enemy batteries, but with search-light shell the gun that fires them can remain hidden and one's own lines be shrouded in darkness while the enemy lines are brilliantly illuminated.

(C) Committee on Public Information

Putting on the Gas Masks to Meet a Gas Cloud Attack

(C) Kadel & Herbert
Even the Horses had to be Masked

Photograph by Kadel & Herbert
Portable Flame-throwing Apparatus

CHAPTER V

The Battle of the Chemists

SOME years ago the nations of the world gathered at the city of The Hague, in Holland, to see what could be done to put an end to war. They did not accomplish much in that direction, but they did draw up certain rules of warfare which they agreed to abide by. There were some practices which were considered too horrible for any civilized nation to indulge in. Among these was the use of poisonous gases, and Germany was one of the nations that took a solemn pledge not to use gas in war.

Eighteen years later the German Army had dug itself into a line of trenches reaching from the English Channel to Switzerland, and facing them in another line of trenches were the armies of France and England, determined to hold back the invaders. Neither side could make an advance without frightful loss of life. But a German scientist came forth with a scheme for breaking the dead-lock. This was Professor Nernst, the inventor of a well-known electric lamp and a man who had always violently hated the British. His plan was to drown out the British with a flood of poisonous gas. To be sure, there was the pledge taken at The Hague Conference, but why should that stand in Germany's way? What cared the Germans for promises now? Already they had broken a pledge in their violation of Belgium. Already they had rained explosives from the sky on unfortified British cities (thus violating another pledge of The Hague Conference); already they had determined to war on defenseless merchantmen. To them promises meant nothing, if such promises interfered with the success of German arms. They led the world in the field of chemistry; why, they reasoned, should n't they make use of this advantage?

POURING GAS LIKE WATER

It was really a new mode of warfare that the Germans were about to launch and it called for much study. In the first place, they had to decide what sort of gas to use. It must be a gas that could be obtained in large quantities. It must be a very poisonous gas, that would act quickly on the enemy; it must be easily compressed and liquefied so that it could be carried in containers that were not too bulky; it must vaporize when the pressure was released; and it must be heavier than air, so that it would not be diluted by the atmosphere but would hug the ground. You can pour gas just as you pour water, if it is heavier than air. A heavy gas will stay in the bottom of an unstoppered bottle and can be poured from one bottle into another like water. If the gas is colored, you can see it flowing just as if it were a liquid. On the other hand, a gas which is much lighter than air can also be kept in unstoppered bottles if the bottles are turned upside down, and the gas can be poured from one bottle into another; but it flows up instead of down.

Chlorine gas was selected because it seemed to meet all requirements. For the gas attack a point was chosen where the ground sloped gently toward the opposing lines, so that the gas would actually flow down hill into them. Preparations were carried out with the utmost secrecy. Just under the parapet of the trenches deep pits were dug, about a yard apart on a front of fifteen miles, or over twenty-five thousand pits. In these pits were placed the chlorine tanks, each weighing about ninety pounds. Each pit was then closed with a plank and this was covered with a quilt filled with peat moss soaked in potash, so that in case of any leakage the chlorine would be taken up by the potash and rendered harmless. Over the quilts sandbags were piled to a considerable height, to protect the tanks from shell-fragments.

Liquid chlorine will boil even in a temperature of 28 degrees below zero Fahrenheit, but in tanks it cannot boil because there is no room for it to turn into a gas. Upon release of the pressure at ordinary temperatures, the liquid boils violently and big clouds of gas are produced. If the gas were tapped off from the top of the cylinder, it would freeze on pouring out, because any liquid that turns into a gas has to draw heat from its surroundings. The greater the expansion, the more heat the gas absorbs, and in the case of the chlorine tanks, had the nozzles been set in the top of the tank they would very quickly have been crusted with frost and choked, stopping the flow.

But the Germans had anticipated this difficulty, and instead of drawing off the gas from the top of the tank, they drew off the liquid from the bottom in small leaden tubes which passed up through the liquid in the tank and were kept as warm as the surrounding liquid. In fact, it was not gas from the top of the tank, but liquid from the bottom, that was streamed out and this did not turn into gas until it had left the nozzle.

WAITING FOR THE WIND

Everything was ready for the attack on the British in April, 1915. A point had been chosen where the British lines made a juncture with the French. The Germans reckoned that a joint of this sort in the opponent's lines would be a spot of weakness. Also, they had very craftily picked out this particular spot because the French portion of the line was manned by Turcos, or Algerians, who would be likely to think there was something supernatural about a death-dealing cloud. On the left of the Africans was a division of Canadians, but the main brunt of the gas was designed to fall upon the Turcos. Several times the attack was about to be made, but was abandoned because the wind was not just right. The Germans wished to pick out a time when the breeze was blowing steadily—not so fast as to scatter the gas, but yet so fast that it would overtake men who attempted to run away from it. It was not until April 22 that conditions were ideal, and then the new mode of warfare was launched.

Just as had been expected, the Turcos were awe-struck when they saw, coming out of the German trenches, volumes of greenish-yellow gas, which rolled toward them, pouring down into shell-holes and flowing over into the trenches as if it were a liquid. They were seized with superstitious fear, particularly when the gas overcame numbers of them, stifling them and leaving them gasping for breath. Immediately there was a panic and they raced back, striving to out-speed the pursuing cloud.

For a stretch of fifteen miles the Allied trenches were emptied, and the Germans, who followed in the wake of the gas, met with no opposition except in the sector held by the Canadians. Here, on the fringe of the gas cloud, so determined a fight was put up that the Germans faltered, and the brave Canadians held them until reinforcements arrived and the gap in the line was closed.

The Germans themselves were new at the game or they could have made a complete success of this surprise attack. Had they made the attack on a broader front, nothing could have kept them from breaking through to Calais. The valiant Canadians who struggled and fought without protection in the stifling clouds of chlorine, were almost wiped out. But many of them who were on the fringe of the cloud escaped by wetting handkerchiefs, socks, or other pieces of cloth, and wrapping them around their mouths and noses.

The world was horrified when it read of this German gas attack, but there was no time to be lost. Immediately orders went out for gas-masks, and in all parts of England, and of France as well, women were busy sewing the masks. These were very simple affairs—merely a pad of cotton soaked in washing-soda and arranged to be tied over the mouth and nose. But when the next attack came, not long after the first, the men were prepared in some measure for it, and again it failed to bring the Germans the success they had counted upon.

One thing that the Germans had not counted upon was the fact that the prevailing winds in Flanders blow from west to east. During the entire summer and autumn of 1915, the winds refused to favor them, and no gas attacks were staged from June to December. This gave the British a long respite and enabled them not only to prepare better gas-masks, but also to make plans to give the Hun a dose of his own medicine.

WHEN THE WIND PLAYED A TRICK ON THE GERMANS

There were many disadvantages in the use of gas clouds, which developed as the Germans gathered experience. The gas started from their own lines in a very dense cloud, but the cloud grew thinner and thinner as it traveled toward the enemy, and lost a great deal of its strength. If the wind were higher than fifteen miles an hour, it would swirl the gas around and dissipate it before it did much harm to the opposing fighters. If the wind were light, there were other dangers. On one occasion in 1916 a cloud of gas was released upon an Irish regiment. The wind was rather fickle. It carried the gas toward the British trenches, but before

(C) Kadel & Herbert

Liquid Fire Streaming from Fixed Flame-throwing Apparatus

Courtesy of "Scientific American"

Cleaning Up a Dugout with the "Fire Broom" reaching them the cloud hesitated, the wind veered around, and soon the gas began to pour back upon the German lines. The Germans were entirely unprepared for this boomerang attack. Many of the Huns had no gas-masks on, and those who had, found that the masks were not in proper working-order. As a result of this whim of the winds, eleven thousand Germans were killed.

While chlorine was the first gas used, it was evident that it was not the only one that could be employed. British chemists had suspected that the Germans would use phosgene, which was a much more deadly gas, and in the long interval between June and December, 1915, masks were constructed which would keep out not only the fumes of chlorine but also the more poisonous phosgene. In one of their sorties the British succeeded in capturing some valuable notes on gas attacks, belonging to a German general, which showed that the Germans were actually preparing to use phosgene. This deadly gas is more insidious in its action than chlorine. The man who inhales phosgene may not know that he is gassed. He may experience no ill effects, but hours afterward, particularly if he has exercised in the meantime, he may suddenly fall dead, owing to its paralyzing action on the heart.

FREEING THE BRITISH TRENCHES OF RATS

Phosgene was not used alone, but had to be mixed with chlorine, and the deadly combination of the two destroyed all life for miles behind the trenches. However, the British were ready for it. They had been drilled to put on their masks in a few seconds' time, on the first warning of a gas attack. When the clouds of chlorine and phosgene came over No Man's Land, they were prepared, and, except for casualties among men whose masks proved defective, the soldiers in the trenches came through with very few losses. All animal life, however, was destroyed. This was a blessing to the British Tommy, whose trenches had been overrun with rats. The British had tried every known method to get rid of these pests, and now, thanks to the Germans, their quarters were most effectively fumigated with phosgene and every rat was killed. If only the "cooties" could have been destroyed in the same way, the Germans might have been forgiven many of their offenses.

The disadvantages in the use of gas clouds became increasingly apparent. What was wanted was some method of placing the gas among the opponents in concentrated form, without wasting any of it on its way across from one line to the other. This led to the use of shell filled with materials which would produce gas. There were many advantages in these shell. They could be thrown exactly where it was desired that they should fall, without the help of the fickle winds. When the shell landed and burst, the full effect of its contents was expended upon the enemy. A gas cloud would rise over a wood, but with shell the wood could be filled with gas, which, once there, would lurk among the trees for days. Chemicals could be used in shell which could not be used in a cloud attack. The shell could be filled with a liquid, or even with a solid, because when it burst the filling would be minutely pulverized. And so German chemists were set to work devising all sorts of fiendish schemes for poisoning, choking, or merely annoying their opponents.

GAS THAT MADE ONE WEEP

One of the novel shell the Germans used was known as the "tear-gas" shell. This was filled with a liquid, the vapor of which was very irritating to the eyes. The liquid vaporized very slowly and so its effect would last a long time. However, the vapor did not permanently injure the eyes; it merely filled them with tears to such an extent that a soldier was unable to see and consequently was confused and retarded in his work. The "tear-gas" shell were marked with a "T" by the Germans and were known as "T-shell."

Another type of shell, known as the "K-shell," contained a very poisonous liquid, the object of which was to destroy the enemy quickly. The effect of this shell was felt at once, but it left no slow vapors on the ground, and so it could be followed up almost immediately by an attack. Later on, the Germans developed three types of gas shell—one known as the "Green Cross," another as the "Yellow Cross," and the third as the "Blue Cross." The Green Cross shell was filled with diphosgene, or a particularly dangerous combination of phosgene in liquid form, which would remain in pools on the ground or soak into the ground and would vaporize when it became warm. Its vapors were deadly. One had always to be on his guard against them. In the morning, when the sun warmed the earth and vapors were seen to rise from the damp soil, tests were made of the vapors to see whether it was mere water vapor or diphosgene, before men were allowed to walk through it.

These vapors were heavier than air and would flow down into a trench, filling every nook and cranny. If phosgene entered a trench by a direct hit, the liquid would remain there for days, rendering that part of the trench uninhabitable except by men in gas-masks. The infected part of the trench, however, was cut off from the rest of the trench by means of gas-locks. In other words, blankets were used to keep the gas out, and usually two blankets were hung so that a man in passing from one part of the trench to another could lift up the first blanket, pass under it, and close it carefully behind him before opening the second blanket which led into the portion of the trench that was not infected.

The Germans had all sorts of fiendish schemes for increasing the discomfort of the Allies. For instance, to some of their diphosgene shell they added a gas which caused intense vomiting.

The Yellow Cross shell was another fiendish invention of the Huns. It was popularly known as "mustard gas" and was intended not to kill but merely to discomfort the enemy. The gas had a peculiar penetrating smell, something like garlic, and its fumes would burn the flesh wherever it was exposed to them, producing great blisters and sores that were most distressing. The material in the shell was a liquid which was very hard to get rid of because it would vaporize so slowly. On account of the persistence of this vapor, lasting as it did for days, these gas shell were usually not fired by the Germans on lines that they expected to attack immediately.

THE SNEEZING-SHELL

The Blue Cross shell was comparatively harmless, although very annoying. It contained a solid which was atomized by the explosion of the shell, and which, after it got into the nostrils, caused a violent sneezing. The material, however, was not poisonous and did not produce any casualties to speak of, although it was most unpleasant. A storm of Blue Cross shell could be followed almost immediately by an attack, because the effect of the shell would have been dissipated before the attackers reached the enemy who were still suffering from the irritation of their nostrils.

GAS-MASKS

As the different kinds of gas shell were developed, the gas-masks were improved to meet them. In every attack there were "duds" or unexploded shell, which the chemists of the Allies analyzed. Also, they were constantly experimenting with new gases, themselves, and often could anticipate the Germans. The Allies were better able to protect themselves against gas attacks than the Germans, because there was a scarcity of rubber in Germany for the manufacture of masks. When it was found that phosgene was going to be used, the simple cotton-wad masks had to give way to more elaborate affairs with chemicals that would neutralize this deadly gas. And later when the mustard gas was used which attacked the eyes, and the sneezing-gas that attacked the nose, it was found necessary to cover the face completely, particularly the eyes; and so helmets of rubber were constructed which were tightly fitted around the neck under the coat collar. The inhaled aid was purified by passage through a box or can filled with chemicals and charcoal made of various materials, such as cocoanut shells, peach pits, horse-chestnuts, and the like. Because the Germans had no rubber to spare, they were obliged to use leather, which made their masks stiff and heavy.

GLASS THAT WILL NOT SHATTER

One of the greatest difficulties that had to be contended with was the covering of the eyes. There was danger in the use of glass, because it was liable to be cracked or broken, letting in the deadly fumes and gassing the wearer. Experiments were made with celluloid and similar materials, but the finest gas-masks produced in the war were those made for our own soldiers, in which the goggles were of glass, built up in layers, with a celluloid-like material between, which makes a tough composition that will stand up against a very hard blow. Even if it cracks, this glass will not shatter.

The glasses were apt to become coated on the inside with moisture coming from the perspiration of the face, and some means had to be provided for wiping them off. The French hit upon a clever scheme of having the inhaled air strike the glasses in a jet which would dry off the moisture and keep the glasses clear. Before this was done, the masks were provided with little sponges on the end of a finger-piece, with which the glasses could be wiped dry without taking the masks off.

But all this time, the Allies were not merely standing on the defensive. No sooner had the Germans launched their first attack than the British and French chemists began to pay back the Hun in kind. More attention was paid to the shell than the cloud attack, and soon gas shell began to rain upon the Germans. Not only were the German shell copied, but new gases were tried. Gas shell were manufactured in immense quantities.

Then America took a hand in the war and our chemists added their help, while our factories turned out steady streams of shell. If Germany wanted gas warfare, the Allies were determined that she should have it. Our chemists were not afraid to be pitted against the German chemists and the factories of the Allies were more than a match for those of the Central Powers. When the Germans first started the use of gas, apparently they counted only their own success, which they thought would be immediate and overwhelming. They soon learned that they must take what they gave. The Allies set them a pace that they could not keep up with.

When the armistice brought the war to a sudden stop, the United States alone was making each day two tons of gas for every mile of the western front. If the war had continued, the Germans would have been simply deluged. As it was, they were getting far more gas than they could possibly produce in their own factories and they had plenty of reason to regret their rash disregard of their contract at The Hague Conference. One gas we were making was of the same order as mustard gas but far more volatile, and had we had a chance to use it against the Germans they would have found it very difficult to protect themselves against its penetrating fumes.

BATTLING WITH LIQUID FIRE

Somewhat associated with gas warfare was another form of offensive which was introduced with the purpose of breaking up the dead-lock of trench warfare. A man could protect himself against gas by using a suitable mask and clothing, but what could he do against fire? It looked as if trench defenders would have to give up if attacked with fire, and so, early in the war, the Germans devised apparatus for shooting forth streams of liquid fire, and the Allies were not slow to copy the idea.

The apparatus was either fixed or portable, but it was not often that the fixed apparatus could be used to advantage, because at best the range of the flame-thrower was limited and in few places were the trenches near enough for flaming oil to be thrown across the intervening gap. For this reason portable apparatus was chiefly used, with which a man could send out a stream for from a hundred to a hundred and fifty feet. On his back he carried the oil-tank, in the upper part of which there was a charge of compressed air. A pipe led from the tank to a nozzle which the man held in his hand, using it to direct the spray.

There was some danger to the operator in handling a highly inflammable oil. The blaze might flare back and burn him, particularly when he was lighting the stream, and so a special way of setting fire to the spray had to be devised. Of course, the value of the apparatus lay in its power to shoot the stream as far as possible. The compressed air would sent the stream to a good distance, but after lighting, the oil might be consumed before it reached the desired range. Some way had to be found of igniting the oil stream far from the nozzle or as near the limit of its range as possible. And so two nozzles were used, one with a small opening so that it would send out a fine jet of long range, while the main stream of oil issued from the second nozzle. The first nozzle was movable with respect to the second and the two streams could be regulated to come together at any desired distance from the operator within the range of the apparatus. The fine stream was ignited and carried the flame out to the main stream, setting fire to it near the limit of its range. In this way a flare-back was avoided and the oil blazed where the flame was needed. The same sort of double nozzle was used on the stationary apparatus and because weight was not a consideration, heavier apparatus was used which shot the stream to a greater distance.

But flame-throwing apparatus had its drawbacks: there was always the danger that the tank of highly inflammable oil might be burst open by a shell or hand-grenade and its contents set on fire. The fixed apparatus was buried under bags of sand, but the man who carried flame-throwing apparatus on his back had to take his chances, not knowing at what instant the oil he carried might be set ablaze, turning him into a living, writhing, human torch. Because of this hazard, liquid fire did not play a very important part in trench warfare; to set fire to the spray at its source with a well directed hand-grenade was too easy.

THE "FIRE BROOM"

There were certain situations, however, in which liquid fire played a very important part. After a line of trenches had been captured it was difficult to clear out the enemy who lurked in dugouts and underground passages. They would not surrender, and from their hidden recesses they could pour out a deadly machine-gun fire. The only way of dislodging them was to use the "fire broom." In other words, a stream of liquid fire was poured into the dugout, burning out the men trapped in it. If there were a second exit, they would come tumbling out in a hurry. If not, they would be burned to death. After the first sweep of the "broom," if there were any survivors, there would not be any fight left in them, and they would be quick to surrender before being subjected to a second dose of fire.

CHAPTER VI

Tanks

THERE is no race-horse that can keep up with an automobile, no deer that can outrun a locomotive. A bicyclist can soon tire out the hardiest of hounds. Why? Because animals run on legs, while machines run on wheels.

As wheels are so much more speedy than legs, it seems odd that we do not find this form of locomotion in nature. There are many animals that owe their very existence to the fact that they can run fast. Why has n't nature put them on wheels so that when their enemy appears they can roll away, sedately, instead of having to jerk their legs frantically back and forth at the rate of a hundred strokes a minute?

But one thing we must not overlook. Our wheeled machines must have a special road prepared for them, either a macadam highway or a steel track. They are absolutely helpless when they are obliged to travel over rough country. No wheeled vehicle can run through fields broken by ditches and swampy spots, or over ground obstructed with boulders and tree-stumps.

But it is not always possible or practicable to build a road for the machines to travel upon, and it is necessary to have some sort of self-propelled vehicle that can travel over all kinds of ground.

Some time ago a British inventor developed a machine with large wheels on which were mounted the equivalent of feet. As the wheels revolved, these feet would be planted firmly on the ground, one after the other, and the machine would proceed step by step. It could travel over comparatively rough ground, and could actually walk up a flight of stairs. We have a very curious walking-machine in this country. It is a big dredge provided with two broad feet and a "swivel chair." The machine makes progress by alternately planting its feet on the ground, lifting itself up, chair and all, pushing itself forward, and sitting down again.

Although many other types of walking-machines have been patented, none of them has amounted to very much. Clearly, nature hopelessly outclasses us in this form of propulsion.

Years ago it occured to one ingenious man that if wheeled machines must have tracks or roads for their wheels to run on, they might be allowed to lay their own tracks. And so he arranged his track in the form of an endless chain of plates that ran around the wheels of his machine. The wheels merely rolled on this chain, and as they progressed, new links of the track were laid down before them and the links they had passed over were picked up behind them. A number of inventors worked on this idea, but one man in particular, Benjamin Holt, of Peoria, Illinois, brought the invention to a high state of perfection. He arranged a series of wheels along the chain track, each carrying a share of the load of the machine, and each mounted on springs so that it would yield to any unevenness of the ground, just as a caterpillar conforms itself to the hills and dales of the surface it creeps over. In fact, the machine was called a "caterpillar" tractor because of its crawling locomotion.

But it was no worm of a machine. In power it was a very elephant. It could haul loads that would tax the strength of scores of horses. Stumps and boulders were no obstacles in its path. Even ditches could not bar its progress. The machine would waddle down one bank and up the other without the slightest difficulty. It was easily steered; in fact, it could turn around in its own length by traveling forward on one of its chains, or traction-belts, and backward on the other. The machine was particularly adapted to travel on soft or plowed ground, because the broad traction-belts gave it a very wide bearing and spread its weight over a large surface. It was set to work on large farms, hauling gangs of plows and cultivators. Little did Mr. Holt think, as he watched his powerful mechanical elephants at work on the vast Western wheat-fields, that they, or rather their offspring, would some day play a leading rôle in a war that would rack the whole world.

But we are getting ahead of our story. To start at the very beginning, we must go back to the time when the first savage warrior used a plank of wood to protect himself from the rocks hurled by his enemy. This was the start of the never-ending competition between arms and armor. As the weapons of offense developed from stone to spear, to arrow, to arquebus, the wooden plank developed into a shield of brass and then of steel; and then, since a separate shield became too bothersome to carry, it was converted into armor that the warrior could wear and so have both hands free for battle. For every improvement in arms there was a corresponding improvement in armor.

After gunpowder was invented, the idea of armor for men began to wane, because no armor could be built strong enough to ward off the rifle-bullet and at the same time light enough for a man to wear. The struggle between arms and armor was then confined to the big guns and the steel protection of forts and war-ships.

But not so long ago the machine-gun was invented, and this introduced a new phase of warfare. Not more than one rifle-bullet in a thousand finds its mark on the battle-field. The Boers in the battle of Colenso established a record with one hit in six hundred shots. In the excitement of battle men are too nervous to take careful aim and they are apt to fire either too high or too low, so that the mortality is not nearly so great as some would expect. But with the machine-gun there is not this waste of ammunition, because it fires a stream of bullets, the effect of which can readily be determined by the man who operates the volley. The difference between the machine-gun fire and rifle fire is something like the difference between hitting a tin can with a stone or with a stream of water. It is no easy matter to score a hit with the stone; but any one can train a garden hose on the can, because he can see where the water is striking and move his hose accordingly until he covers the desired spot. In the same way, with the machine-gun, it is much easier to train the stream of bullets upon the mark, and, having once found the mark, to hold the aim. That is one reason why the destruction of a machine-gun is so tremendous; another, of course, being that it will discharge so many more shots per minute than the common rifle.

In the Russo-Japanese War, the Russians played havoc with the attacking Japanese at Port Arthur by using carefully concealed machine-guns, and the German military attachés were quick to note the value of the machine-

(C) Underwood & Underwood

British Tank Climbing out of a Trench at Cambrai

(C) Underwood & Underwood

Even Trees were no Barrier to the British Tank

Press Illustrating Service

The German Tank was very heavy and cumbersome gun. Secretely they manufactured large numbers of machine-guns and established a special branch of service to handle the guns, and they developed the science of using them with telling effect. And so, when the recent great war suddenly broke out, they surprised the world with the countless number of machine-guns they possessed and the efficient use to which they put them. Thousands of British soldiers in the early days of the war fell victims to these death-dealing machines. Two or three men with a machine-gun could defy several companies of soldiers, especially when the attackers had to cut their way through barbed-wire entanglements. It was clearly evident that something must be done to defend the men against the machine-gun; for to charge against it meant, simply, wholesale slaughter.

At first the only means of combating the machine-guns seemed to be to destroy them with shell-fire; but they were carefully concealed, and it was difficult to search them out. Only by long-continued bombardment was it possible to destroy them and tear away the barbed wire sufficiently to permit of a charge. Before an enemy position was stormed it was subjected to the fire of thousands of guns of all calibers for hours and even days.

But this resulted in notifying the enemy that a charge was ere long to be attempted at a certain place, and he could assemble his reserves for a counter-attack. Furthermore, the Germans learned to conceal their machine-guns in dugouts twenty or thirty feet underground, where they were safe from the fire of the big guns, and then, when the fire let up, the weapons would be dragged up to the surface in time to mow down the approaching infantry.

It was very clear that something would have to be done to combat the machine-gun. If the necessary armor was too heavy for the men to carry, it must carry itself. Armored automobiles were of no service at all, because they could not possibly travel over the shell-pitted ground of No Man's Land. The Russians tried a big steel shield mounted on wheels, which a squad of soldiers would push ahead of them, but their plan failed because the wheels would get stuck in shell-holes. A one-man shield on wheels was tried by the British. Under its shelter a man could steal up to the barbed wire and cut it and even crawl up to a machine-gun emplacement and destroy it with a hand-grenade. But this did not prove very successful, either, because the wheels did not take kindly to the rough ground of the battle-field.

And here is where we come back to Mr. Holt's mechanical elephants. Just before the great war broke out, Belgium—poor unsuspecting Belgium—was holding an agricultural exhibit. An American tractor was on exhibition. It was the one developed by Mr. Holt, and its remarkable performances gained for it a reputation that spread far and wide. Colonel E. D. Swinton of the British Army heard of the peculiar machine, and immediately realized the advantages of an armored tractor for battle over torn ground. But in the first few months of the war that ensued, this idea was forgotten, until the effectiveness of the machine-gun and the necessity for overcoming it recalled the matter to his mind. At his suggestion a caterpillar tractor was procured, and the military engineers set themselves to the task of designing an armored body to ride on the caterpillar-tractor belts. Of course the machine had to be entirely re-designed. The tractor was built for hauling loads, and not to climb out of deep shell-holes; but by running the traction-belts over the entire body of the car, and running the forward part of the tractor up at a sharp angle the engineers overcame that difficulty.

In war, absolute secrecy is essential to the success of any invention, and the British engineers were determined to let no inkling of the new armored automobiles reach the enemy. Different parts of the machines were made in different factories, so that no one would have an idea of what the whole would look like. At first the new machine was known as a "land-cruiser" or "land-ship"; but it was feared that this very name would give a clue to spies, and so any descriptive name was forbidden. Many of the parts consisted of rolled steel plates which might readily be used in building up vessels to hold water or gasolene; and to give the impression that such vessels were being constructed the name "tank" was adopted. The necessity of guarding even the name of the machines was shown later, when rumors leaked out that the tanks were being built to carry water over the desert regions of Mesopotamia and Egypt. Another curious rumor was that the machines were snow-plows for use in Russia. To give some semblance of truth to this story, the parts were carefully labeled, "For Petrograd."

Probably never was a military secret so well guarded as this one, and when, on September 15, 1916, the waddling steel tractors loomed up out of the morning mists, the German fighters were taken completely by surprise. Two days before, their airmen had noticed some peculiar machines which they supposed were armored automobiles. They had no idea, however, that such formidable monsters were about to descend upon them.

The tanks proceeded leisurely over the shell-torn regions of No Man's Land, wallowing down into shell-holes and clambering up out of them with perfect ease. They straddled the trenches and paused to pour down them streams of machine-gun bullets. Wire entanglements were nothing to them; under their weight steel wire snapped like thread. The big brutes marched up and down the lines of wire, treading them down into the ground and clearing the way for the infantry. Even trees were no barrier to these tanks. Of course they did not attack large ones, but the smallish trees were simply broken down before their onslaughts. As for concrete emplacements for machine-guns, the tanks merely rode over them and crushed them. Those who attempted to defend themselves in the ruins of buildings found that the tanks could plow right through walls and bring them down in a shower of bricks and stone. There was no stopping these monsters, and the Germans fled in consternation before them.

There were two sizes of tanks. The larger ones aimed to destroy the machine-gun emplacements, and they were fitted up with guns for firing a shell. The smaller tanks, armed with machine-guns, devoted themselves to fighting the infantry. British soldiers following in the wake of the bullet-proof tank were protected from the shots of the enemy and were ready to attack him with bayonets when the time was ripe. But the tanks also furnished an indirect protection for the troops. It was not necessary for the men to conceal themselves behind the big tractors. Naturally, every Hun who stood his ground and fought, directed all his fire upon the tanks, leaving the British infantry free to charge virtually unmolested. The success of the tank was most pronounced.

In the meantime the French had been informed of the plans of their allies, and they set to work on a different design of tractor. It was not until six months later that their machines saw service. The French design differed from the British mainly in having the tractor belt confined to the wheels instead of running over the entire body of the tank. It was more blunt than the British and was provided at the forward end with a steel cutting-edge, which adapted it to break its way through wire entanglements. At each end there are two upward-turning skids which helped the tank to lift itself out of a hole. The larger machines carried a regular 75-millimeter (3-inch) field-gun, which is a very formidable weapon. They carried a crew of one officer and seven men.

Life in a tank is far from pleasant. The heat and the noise of machinery and guns are terrific. Naturally, ventilation is poor and the fumes and gases that accumulate are most annoying, to say the least. Sometimes the men were overcome by them. But war is war, and such discomforts had to be endured.

But the tank possessed one serious defect which the Germans were not slow to discover. Its armor was proof against machine-gun fire, but it could not ward off the shells of field-guns, and it was such a slow traveler that the enemy did not find it a very difficult task to hit it with a rapid-fire gun if the gunner could see his target. And so the Germans ordered up their guns to the front lines, where they could score direct hits. Only light guns were used for this purpose, especially those whose rifling was worn down by long service, because long range was not necessary for tank fighting.

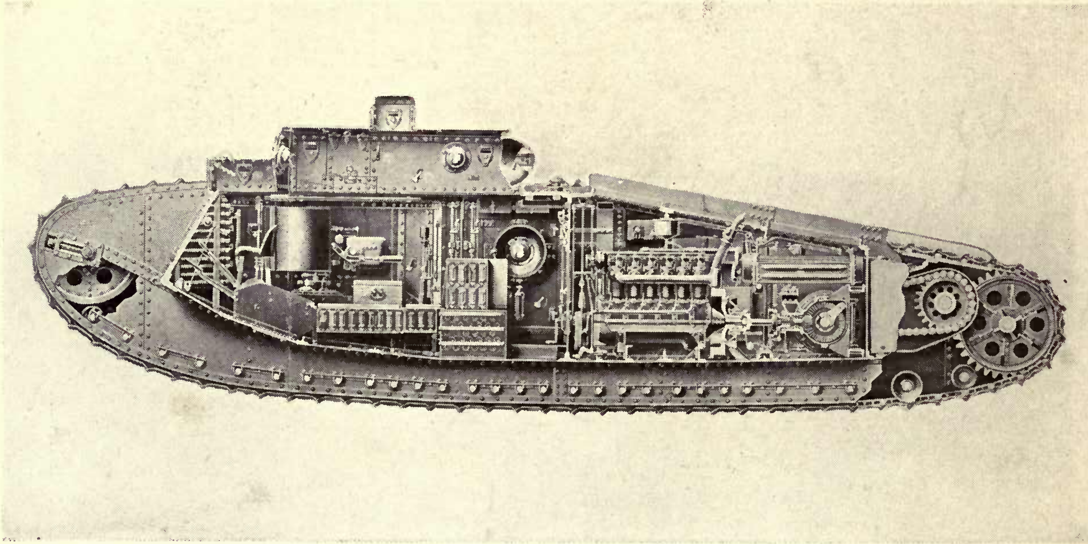
When the Germans began their final great drive, it was rumored that they had built some monster tanks that were far more formidable than anything the Allies had produced. Unlike the British, they used the tanks not to lead the army but to follow and destroy small nests of French and British that were left behind. When the French finally did capture one of the German tanks, which had fallen into a quarry, it proved to be a poor imitation. It was an ugly-looking affair, very heavy and cumbersome. Owing to the scarcity of materials for

(C) Underwood & Underwood

The Speedy British "Whippet" Tank that can travel at a speed of twelve miles per hour

(C) Underwood & Underwood

The French High-Speed "Baby" Tank



Courtesy of "Automotive Industries"

Section through our Mark VIII Tank showing the layout of the interior with the locations of the most important parts in the fighting compartment in the engine room producing high-grade armor, it had to make up in thickness of plating what it lacked in quality of steel. The tank was intended to carry a crew of eighteen men and it fairly bristled with guns, but it could not manœuver as well as the British tank; for when some weeks later a fleet of German tanks encountered a fleet of heavy British tanks, the Hun machines were completely routed.

It was then that the British sprang another surprise upon the Germans. After the big fellows had done their work, a lot of baby tanks appeared on the scene and chased the German infantry. These little tanks could travel at a speed of twelve miles an hour, which is about as fast as an ordinary man can run. "Whippets," the British called them, because they were like the speedy little dogs of that name. They carried but two men, one to guide the tank and the other to operate the machine-gun. The French, too, built a light "mosquito" tank, which was even smaller than the British tank, and fully as fast. It was with these machines, which could dart about quickly on the battlefield and dodge the shell of the field-guns, and which were immune to the fire of the machine-gun, that the Allies were able to make progress against the Germans.

When the Germans retired, they left behind them nests of machine-guns to cover the withdrawal of their armies. These gunners were ordered to fight to the very end. They looked for no mercy and expected no help. Had it not been for the light tanks, it would have been well nigh impossible to overcome these determined bodies of men without frightful losses.

Since America invented the machine-gun and also barbed wire, and since America furnished the inspiration for the tank with which to trample down the wire entanglements and stamp out the machine-guns, naturally people expected our army to come out with something better than anything produced by our allies. We did turn out a number of heavy machines patterned after the original British tank, with armor that could stand up against heavy fire, and we also produced a small and very speedy tank similar to the French "baby" tank, but before we could put these into service the war ended. The tanks we did use so effectively at St.-Mihiel and in the Argonne Forest were supplied by the French.

CHAPTER VII

The War in the Air

WE Americans are a peace-loving people, which is the very reason why we went into the war. We had to help down the power that was disturbing the peace of the world. We do not believe in conquests—at least of the type that Germany tried to force—and yet there are certain conquests that we do indulge in once in a while.

Eleven years before Germany undertook to conquer Europe two young Americans made the greatest conquest that the world has ever seen. The Wright brothers sailed up into the heavens and gained the mastery of the air. They offered their conquest to the United States; but while we accepted their offering with enthusiasm at first, we did not know what to do with the new realm after we got it. There seemed to be no particular use in flying. It was just a bit too risky to be pleasant sport, and about all we could see in it was an exhibition for the circus or the county fair.

Not so in Europe, however. Flying meant something over there—there where the frontiers have ever bristled with big guns and strong fortifications, and where huge military forces have slept on their arms, never knowing what dreadful war the morning would bring forth. The war-lovers hailed the airplane as a new instrument with which to terrorize their neighbors; the peace-lovers saw in it another menace to their homes; it gave them a new frontier to defend. And so the military powers of Europe took up the airplane seriously and earnestly and developed it.

At first military authorities had rated the airplane chiefly as a flying scout. Some bomb-dropping experiments had been made with it, but it proved very difficult to land the bombs near the target, and, besides, machines of those days were not built to carry very heavy loads, so that it did not seem especially profitable to attack the enemy from the skies. As for actual battles up among the clouds, they were dreamed of only by the writers of fiction. But wild dreams became stern realities in the mighty struggle between the great powers of the world.

EYES IN THE SKY

As a scouting-machine the airplane did prove to be far superior to mounted patrols which used to perform scout-work. In fact, it changed completely the character of modern warfare. From his position high up in the heavens the flying scout had an unobstructed view of the country for miles and he could see just what the enemy was doing. He could see whether large forces of men were collecting for an attack. He could watch the course of supply-trains, and judge of their size. He could locate the artillery of the enemy and come back with information which in former times a scout posted in a tall tree or even in a captive balloon could not begin to acquire. Surprise attacks were impossible, with eyes in the sky. The aviator could help his own batteries by signaling to them where to send their shell, and when the firing began he would spot the shots as they landed and signal back to the battery how to correct its aim so as to drop the shell squarely on the target.

The French sprang a surprise on the Germans by actually attacking the infantry from the sky. The idea of attack from overhead was so novel that armies did not realize the danger of exposing themselves behind the battle-front. Long convoys of trucks and masses of infantry moved freely over the roads behind the lines and they were taken by surprise when the French began dropping steel darts upon them. These were about the size of a pencil, with pointed end and fluted tail, so that they would travel through the air like an arrow. The darts were dropped by the hundred wherever the airmen saw a large group of the enemy, and they struck with sufficient velocity to pierce a man from head to foot. But steel darts were not used very long. The enemy took to cover and then the only way to attack him was to drop explosives which would blow up his shelter.

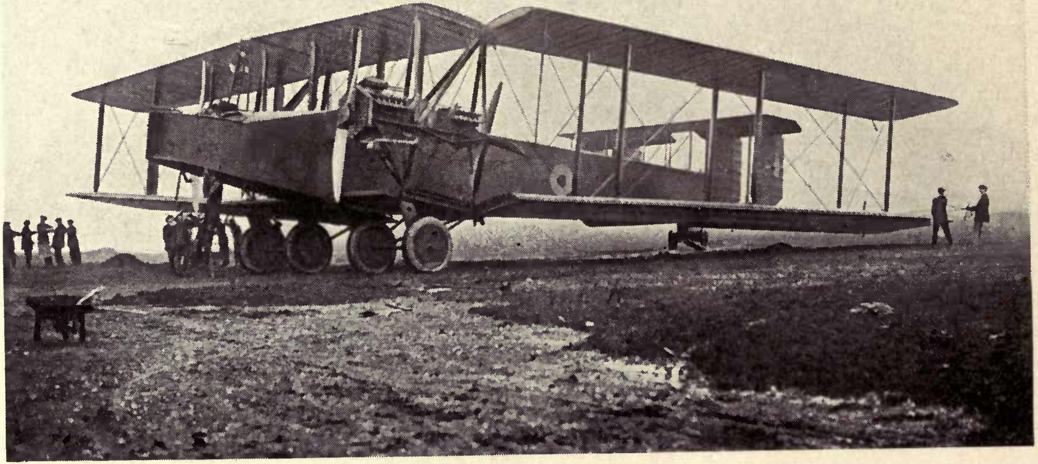
At the outset, air scouts were more afraid of the enemy on the ground than in the sky. The Germans had anti-aircraft guns that were fired with accuracy and accounted for many Allied planes. In those days, airplanes flew at comparatively low altitudes and they were well within the reach of the enemy's guns. But it was not long before the airplanes began to fight one another. Each side was very much annoyed by the flying scouts of its opponents and after a number of pistol duels in the sky the French began to arm their planes with machine-guns.

Two months after the war started the first airplane was sent crashing to earth after a battle in the sky. The fight took place five thousand feet above the earth, between a French and a German machine. The German pilot was killed and the plane fell behind the French lines, carrying with it a Prussian nobleman who died before he could be pulled out of the wreckage. The war had been carried into the skies. But if scouts were to fight one another, they could not pay much attention to scouting and spotting and it began to be realized that there were four distinct classes of work for the airplane to do—scouting, artillery-spotting, battling, and bombing. Each called for special training and its own type of machine. As air fighting grew more specialized these classes were further subdivided, but we need not go into such refinements.

AIR SCOUTS AND THEIR DANGERS

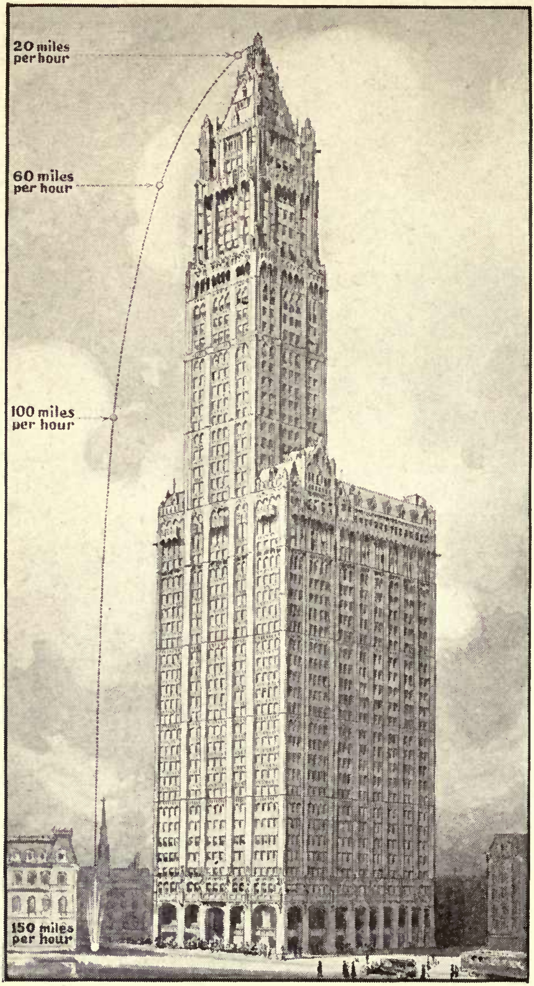
The scouting-airplane usually carried two men, one to drive the machine and the other to make observations. The observer had to carry a camera, to take photographs of what lay below, and he was usually equipped with a wireless outfit, with which he could send important information back to his own base. The camera was sometimes fitted with a stock like that of a gun, so that it could be aimed from the shoulder. Some small cameras were shaped so that they could be held in the hand like a pistol and aimed over the side of the fuselage, or body, of the airplane; but the best work was done with large cameras fitted with telescopic lenses, or "telephoto" lenses, as they are called. Some of these were built into the airplane, with the lens opening down through the bottom of the fuselage.

The scouting-airplane carried a machine-gun, not for attack, but for defense. It had to be a quick climber and a good dodger, so that it could escape from an attacking plane. Usually it did not have to go very far into the enemy country, and it was provided with a large wing-



(C) Underwood & Underwood

A Handley-Page Bombing Plane with One of its Wings Folded Back



How an object dropped from the Woolworth Building would increase its speed in falling spread, so that if anything happened to the engine, it could *volplane,* or glide back, to its own lines. As the scouting-planes were large, they offered a big target to anti-aircraft guns, and so the work of the air scout was to swoop down upon the enemy, when, of course, the machine would be traveling at high velocity, because it would have all the speed of falling added to that which its own propeller gave it.

It was really a very difficult matter to hit a rapidly moving airplane; and even if it were hit, there were few spots in which it could be mortally wounded. Hundreds of shots could go through the wings of an airplane without impairing its flying in the least. The engine, too, could be pretty well peppered with ordinary bullets without being disabled. As for the men in the machine, they furnished small targets, and even they could be hit in many places without being put entirely out of business. And so the dangers of air scouting were not so great as might at first be supposed.

One of the most vulnerable spots in the airplane was the gasolene tank. If that were punctured so that the fuel would run out, the airplane would have to come to the ground.

Worse still, the gasolene might take fire and there was nothing the aviator dreaded more than fire. There were occasions in which he had to choose between leaping to earth and burning to death, and the former was usually preferred as a quicker and less painful death. In some of the later machines the gasolene-tank could be pitched overboard if it took fire, by the throwing of a lever, and then the aviator could glide to earth in safety.

THE SELF-HEALING GASOLENE-TANK

One of the contributions which we made to military aëronautics was a gasolene-tank that was puncture-proof. It was made of soft rubber with a thin lining of copper. There are some very soft erasers on the market through which you can pass a lead pencil and never find the hole after it has passed through, because the rubber has closed in and healed the wound. Such was the rubber used in the gasolene-tank. It could be peppered with bullets and yet would not leak a drop of gasolene, unless the bullet chanced to plow along the edge of the tank and open a long gash.

The Germans used four different kinds of cartridges in their aircraft guns. The first carried the ordinary bullet, a second type had for its bullet a shell of German silver filled with a phosphor compound. This was automatically ignited through a small opening in the base of the shell when it was fired from the gun and it left a trail of smoke by which the gunner could trace its course through the air and correct his aim. At night the bright spot of light made by the burning compound would serve the same purpose. Such a bullet, if it hit an ordinary gasolene-tank, would set fire to its contents. The bullet would plow through the tank and out at the opposite side and there, at its point of exit, is where the gasolene would be set on fire. Such incendiary bullets were repeatedly fired into or through the rubber tanks and the hole would close behind the bullet, preventing the contents from taking fire. The two other types of bullets referred to were an explosive bullet or tiny shell which would explode on striking the target and a perforating steel bullet which was intended to pierce armor or penetrate into vital parts of an airplane engine.

Machines with which artillery-spotting was done were usually manned by a pilot and an observer, so that the latter could devote his entire attention to noting the fire of the guns and signaling ranges without being hampered by having to drive the machine. These machines were usually of the pusher type, so that the observer could have an unobstructed view. They did not have to be fast machines. It was really better for them to move slowly. Had it been possible for them to stop altogether and hover over the spot that was being shelled, it would have been a distinct advantage. That would have given the observer a chance to note with better accuracy the fall of the shell. Like the scout, the spotter had to be a fast climber, so that it could get out of the range of enemy guns and run away from attacking planes.

GIANTS OF THE SKY

The largest war-planes were the bomb-dropping machines. They had to be capable of carrying heavy loads of explosives. They were usually slow machines, speed being sacrificed in carrying-capacity.

The Germans paid a great deal of attention to big bomb-dropping machines, particularly after their Zeppelins proved a failure. Their huge Gothas were built to make night raids on undefended cities. The Italians and the British retaliated with machines that were even larger. At first the French were inclined to let giant planes alone. They did not care to conduct long-distance bombing-raids on German cities because their own important cities were so near the battle-front that the Germans could have done those places more harm than the French could have inflicted. Later they built some giant machines, although not so large as those of the Italians and the British.

The large triplane Capronis built by the Italians held a crew of three men. They were armed with three guns and carried 2750 pounds of explosives. That made a useful load of 4000 pounds. The machine was driven by three engines with a total of 900 horse-power.

The big British plane was the Handley-Page, which had a wing-spread of 125 feet and could carry a useful load of three tons. These enormous machines conducted their raids at night because they were comparatively slow and could not defend themselves against speedy battle-planes. The big Italian machines used "search-light" bombs to help them locate important points on the ground beneath. These were brilliant magnesium torches suspended from parachutes so that they would fall slowly and give a broad illumination, while the airplane itself was shielded from the light by the parachute.

But these giants were not the only bombing-machines. There were smaller machines that operated over the enemy's battle-line and dropped bombs on any suspicious object behind the enemy lines. These machines had to be convoyed by fast battle-planes which fought off hostile airmen.

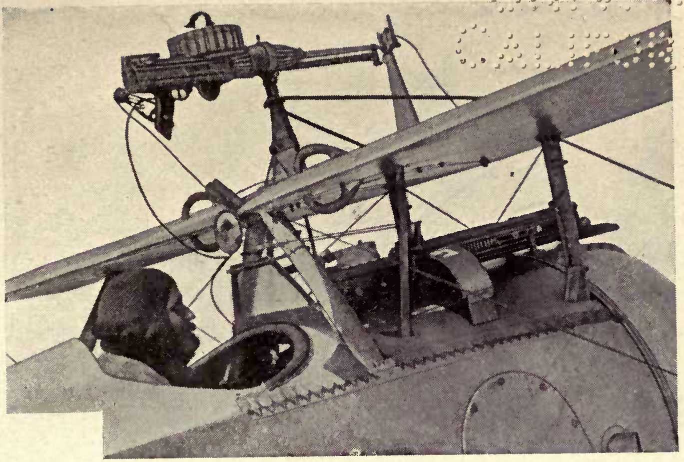
HOW FAST IS A HUNDRED AND FIFTY MILES PER HOUR?

In naval warfare the battle-ship is the biggest and heaviest ship of the fleet, but in the air the battle-planes are the lightest and the smallest of the lot. They are one-man machines, as a rule, little fellows, but enormously speedy. Speed is such an important factor in aërial warfare that there was a continuous struggle between the opposing forces to produce the faster machine. Airplanes were constantly growing speedier, until a speed of 150 miles per hour was not an uncommon rate of travel. It is hard to imagine such a speed as that, but we may gain some idea if we consider a falling object. The observation platform of the Woolworth Building, in New York, is about 750 feet above the ground. If you should drop an object from this platform you would start it on a journey that would grow increasingly speedy, particularly as it neared the ground. By the time it had dropped from the sixtieth story to the fifty-ninth it would have attained a speed of nearly 20 miles per hour. (We are not making any allowances for the resistance of the air and what it would do to check the speed.) As it passed the fiftieth story it would be traveling as fast as an express-train, or 60 miles per hour. It would finally reach the ground with a speed equal to that of a fast battle-plane—150 miles per hour.

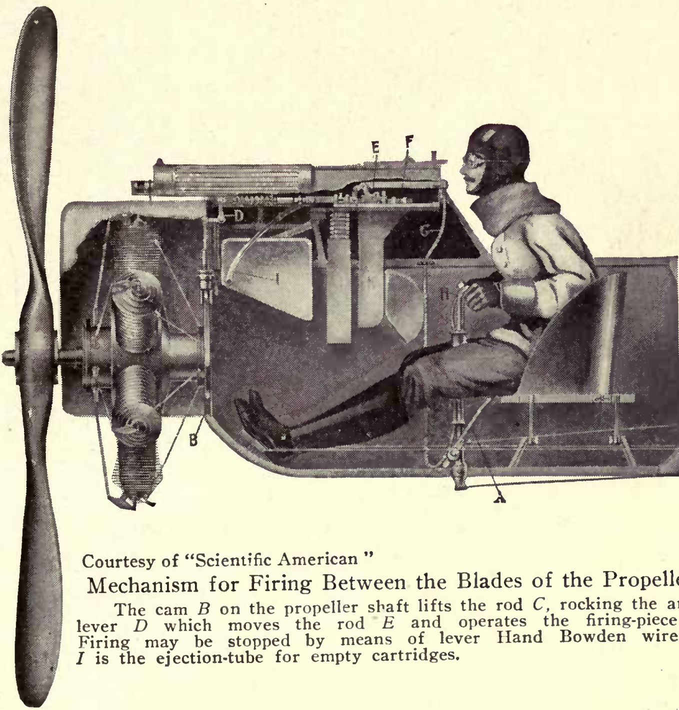
The battle-plane was usually fitted with a single machine-gun that was fixed to the airplane, so that it was brought to bear on the target by aiming the entire machine. In this the plane was something like a submarine, which must point its bow at its intended victim in order to aim its torpedo. The operator of the battle-plane simply drove his machine at the enemy and touched a button on his steering-lever to start his machine-gun going.

SHOOTING THROUGH THE PROPELLER

Now, the fleetest machines and the most easily manœuvered are those of the tractor type, that is, the ones which have the propeller in front; but having the propeller in front is a handicap for a single-seater machine, for the gun has to be fired through the propeller and the bullets are sure to hit the propeller-blades. Nevertheless the French did fire right through the propeller, regardless of whether or not the blades were hit; but at the point where they came in line with the fire of the gun they were armored with steel, so that there was no danger of their being cut by the bullets. It was calculated that not more than one bullet in eighteen would strike the propeller-blade and be deflected from its course, which was a very trifling loss; nevertheless, it was a loss, and on this account a mechanism was devised which would time the operations of the machine-gun so that the shots would come only when the propeller-blades were clear of the line of fire.



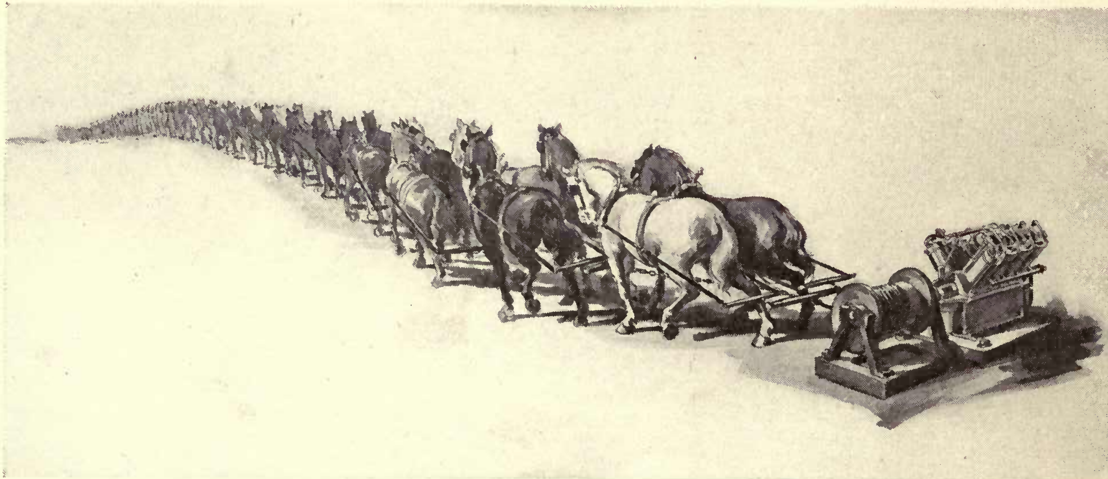
Machine Gun mounted to Fire over the Blades of the Propeller



Courtesy of "Scientific American"

Mechanism for Firing Between the Blades of the Propeller

The cam *B* on the propeller shaft lifts the rod *C*, rocking the angle lever *D* which moves the rod *E* and operates the firing-piece *F*. Firing may be stopped by means of lever Hand Bowden wire *G*. *I* is the ejection-tube for empty cartridges.



It would take a Hundred Horses to Supply the Power for a Small Airplane

A cam placed on the propeller-shaft worked the trigger of the machine-gun. This did not slow up the fire of the machine-gun. Quite the contrary. We are apt to think of the fire of the machine-guns as very rapid, but they usually fire only about five hundred rounds per minute, while an airplane propeller will make something like twelve hundred revolutions per minute. And so the mechanism was arranged to pull the trigger only once for every two revolutions of the propeller.

FIGHTING AMONG THE CLOUDS

There was no service of the war that began to compare with that of the sky fighter. He had to climb to enormous heights. Air battles took place at elevations of twenty thousand feet. The higher the battle-plane could climb, the better, because the man above had a tremendous advantage. Clouds were both a haven and a menace to him. At any moment an enemy plane might burst out of the clouds upon him. He had to be ready to go through all the thrilling tricks of a circus performer so as to dodge the other fellow and get a commanding position. If he were getting the worst of it, he might feign death and let his machine go tumbling and fluttering down for a thousand feet or so, only to recover his equilibrium suddenly and dart away when the enemy was thrown off his guard. He might escape into some friendly cloud, but he dared not hide in it very long, lest he get lost.

It is a peculiar sensation that comes over an aviator when he is flying through a thick mass of clouds. He is cut off from the rest of the world. He can hear nothing but the terrific roar of his own motor and the hurricane rush of the wind against his ears. He can see nothing but the bluish fog of the clouds. He begins to lose all sense of direction. His compass appears to swing violently to and fro, when really it is his machine that is zig-zagging under his unsteady guidance. The more he tries to steady it, the worse becomes the swing of the compass. As he turns he banks his machine automatically, just as a bicyclist does when rounding a corner. He does this unconsciously, and he may get to spinning round and round, with his machine standing on its side. In some cases aviators actually emerged from the clouds with their machines upside down. To be sure, this was not an alarming position for an experienced aviator; at the same time, it was not altogether a safe one. A machine was sometimes broken by its operator's effort to right it suddenly. And so while the clouds made handy shelters, they were not always safe harbors.

To the battle-plane fell the task of clearing the air of the enemy. If the enemy's battle-planes were disposed of, his bombing-planes, his spotters, and his scouts could not operate, and he would be blind. And so each side tried to beat out the other with speedier, more powerful, and more numerous battle-planes. Fast double-seaters were built with guns mounted so that they could turn in any direction.

THE FLYING TANK

The Germans actually built an armored battle-plane known as the flying tank. It was a two-seater intended mainly for attacking infantry and was provided with two machine-guns that pointed down through the floor of the fuselage. A third gun mounted on a revolving wooden ring could be used to fight off hostile planes. The bottom and sides of the fuselage or body of the airplane from the gunner's cock-pit forward were sheathed with plates of steel armor. The machine was a rather cumbersome craft and did not prove very successful. A flying tank was brought down within the American lines just before the signing of the armistice.

AMERICA'S HELP

Our own contribution to the war in the air was considerable, but we had hardly started before the armistice brought the fighting to an end. Before we entered the war we did not give the airplane any very serious consideration. To be sure, we built a large number of airplanes for the British, but they were not good enough to be sent to the front; they were used merely as practice planes in the British training-schools. We knew that we were hopelessly outclassed, but we did not care very much. Then we stepped into the conflict.

"What can we do to help?" we asked our allies, and their answer gave us a shock.

"Airplanes!" they cried. "Build us airplanes—thousands of them—so that we can drive the enemy out of the air and blind his armies!"

It took us a while to recover from our surprise, and then we realized why we had been asked to build airplanes. The reputation of the United States as a manufacturer of machinery had spread throughout the world. We Americans love to take hold of a machine and turn it out in big quantities. Our allies were sure that we could turn out first-class airplanes, and many of them, if we tried.

Congress made an appropriation of six hundred and forty million dollars for aëronautics, and then things began to hum.

A BIRTHDAY PRESENT TO THE NATION

The heart of an airplane is its engine. We know a great deal about gasolene-engines, especially automobile engines; but an airplane engine is a very different thing. It must be tremendously powerful, and at the same time extremely light. Every ounce of unnecessary weight must be shaved off. It must be built with the precision of a watch; its vital parts must be true to a ten-thousandth part of an inch. It takes a very powerful horse to develop one horse-power for a considerable length of time. It would take a hundred horses to supply the power for even a small airplane, and they would weigh a hundred and twenty thousand pounds. An airplane motor of the same power would weigh less than three hundred pounds, which is a quarter of the weight of a single horse. It was this powerful, yet most delicate, machine that we were called upon to turn out by the thousand. There was no time to waste; a motor must be designed that could be built in the American way, without any tinkering or fussy hand-work.

Two of our best engineers met in a hotel in Washington on June 3, 1917, and worked for five days without once leaving their rooms. They had before them all the airplane knowledge of our allies. American engine-builders offered up their trade secrets. Everything was done to make this motor worthy of America's reputation. There was a race to have the motor finished by the Fourth of July. Sure enough, on Independence Day the finished motor was there in Washington—the "Liberty motor," a birthday present to the nation.

Of course that did not mean that we were ready at once to turn out Liberty motors by the thousand. The engine had to undergo many tests and a large number of alterations before it was perfectly satisfactory and then special machinery had to be constructed before it could be manufactured in quantity. It was Thanksgiving Day before the first manufactured Liberty was turned out and even after that change upon change was made in this little detail and that. It was not until a year after we went to war that the engine began to be turned out in quantity.

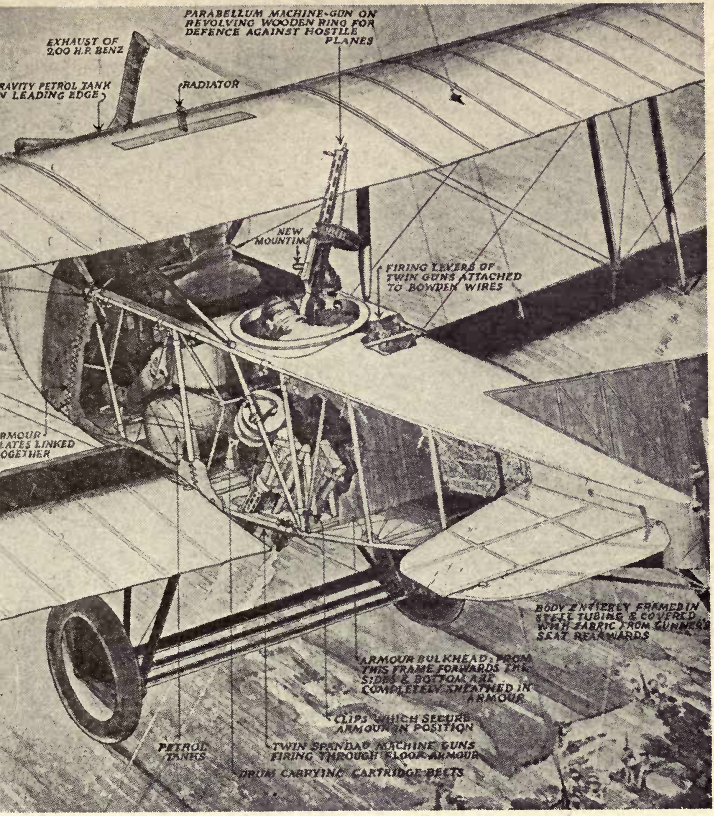
There was nothing startlingly new about the engine. It was a composite of a number of other engines, but it was designed to be turned out in enormous quantities, and it was remarkably efficient. It weighed only 825 pounds and it developed over 420 horse-power. Some machines went up as high as 485 horse-power. An airplane engine weighing less than 2 pounds per horse-power is wonderfully efficient. Of course the Liberty was too heavy for a light battleplane (a heavy machine, no matter how powerful, cannot make sharp turns), but it was excellent for other types of airplanes and large orders for Liberty engines were made by our allies. Of course we made other engines as well, and the planes to carry them. We built large Caproni and Handley-Page machines, and we were developing some remarkably swift and powerful planes of our own when the Germans thought it about time to stop fighting.

FLYING BOATS

So far we have said nothing about the seaplanes which were used in large numbers to watch for submarines. These were big flying boats in which speed was not a very important matter. One of the really big machines we developed, but which was not finished until after the war, was a giant with a 110-foot span and a body or hull 50 feet long. During the war seaplanes carried wireless telephone apparatus with which they could call to destroyers and submarine-chasers when they spotted a submarine. They also carried bombs which they could drop on U-boats, and even heavy guns with which they could fire shell.

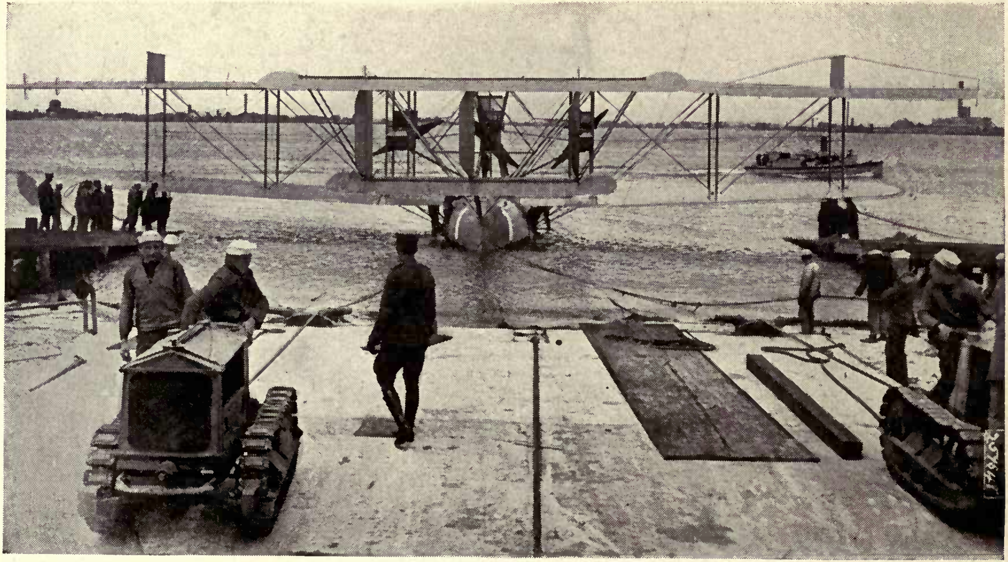
A still later development are the giant planes of the N. C. type with a wing-spread of 126 feet and driven by four Liberty motors. They carry a useful load of four and a half tons.

Early in the war, large guns were mounted on airplanes, but the shock of the recoil proved too much for the airplane to stand. However,



C) Underwood & Underwood

The Flying-tank — an Armored German Airplane designed for firing on troops on the march



(C) Underwood & Underwood

An N-C (Navy-Curtiss) Seaplane of the type that made the first flight across the Atlantic an American inventor produced a gun which had no recoil. This he accomplished by using a double-end gun, which was fired from the middle. The bullet or shell was shot out at the forward end of the gun and a dummy charge of sand was shot out at the rear end. The sand spread out and did no damage at a short distance from the gun, but care had to be taken not to come too close. These non-recoil guns were made in different sizes, to fire 1½-inch to 3-inch shell.

THE AUTOMATIC SEAPLANE

Another interesting development was the target airplane used for the training of aërial gunners. This was a small seaplane with a span of only 18½ feet, driven by a 12-horse-power motor, the whole machine weighing but 175 pounds. This was sent up without a pilot and it would fly at the rate of forty to fifty miles per hour until its supply of gasolene gave out, when it would drop down into the sea. It afforded a real target for gunners in practice machines.

Early in the war an American inventor proposed that seaplanes be provided with torpedoes which they could launch at an enemy ship. The seaplane would swoop down out of the sky to within a short distance of the ship, drop its projecticle, and fly off again, and the torpedo would continue on its course until it blew up the vessel. It was urged that a fleet of such seaplanes protected by a convoy of fast battle-planes could invade the enemy harbors and destroys its powerful fleet. It seemed like a rather wild idea, but the British actually built such torpedo-planes and tested them. However, the German fleet surrendered before it was necessary to blow it up in such fashion.

AIRPLANES AFTER THE WAR

With the war ended, all the Allied powers have large numbers of airplanes on their hands and also large numbers of trained aviators. Undoubtedly airplanes will continue to fill the skies in Europe and we shall see more and more of them in this country. Even during the war they were used for other purposes than fighting. There were ambulances on wings—machines with the top of the fuselage removable so that a patient on a stretcher could be placed inside. A French machine was furnished with a complete hospital equipment for emergency treatment and even for performing an operation in case of necessity. The flying hospital could carry the patient back to the field or base hospital after treatment.

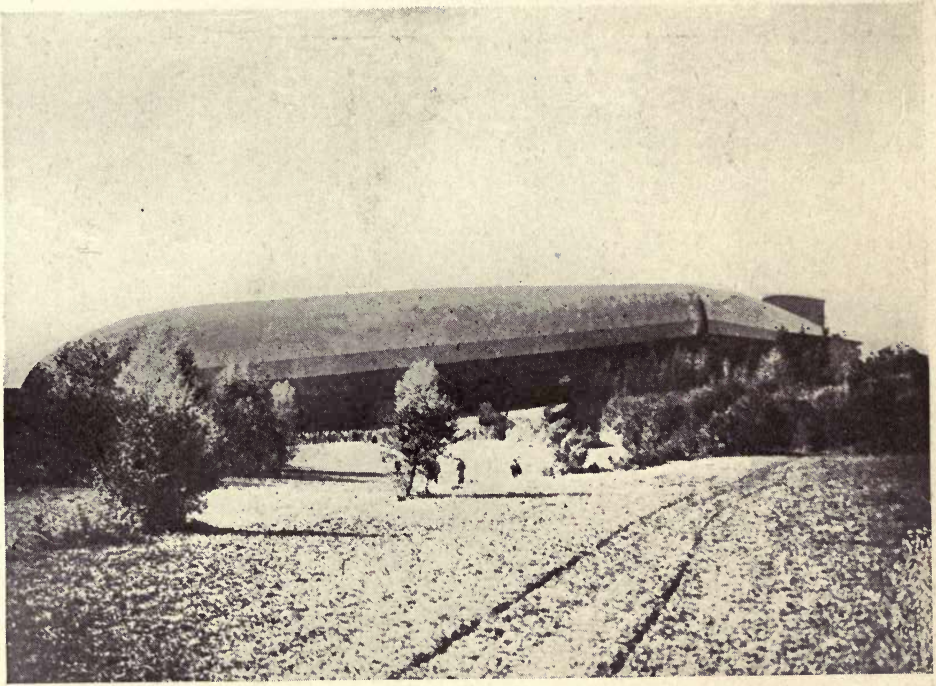
Mail-carrying airplanes are already an old story. In Europe the big bombing-machines are being used for passenger service between cities. There is an air line between Paris and London. The airplanes carry from a dozen to as many as fifty passengers on a single trip. In some cities here, as well as abroad, the police are being trained to fly, so that they can police the heavens when the public takes to wings. Evidently the flying-era is here.

CHAPTER VIII

Ships that Sail the Skies

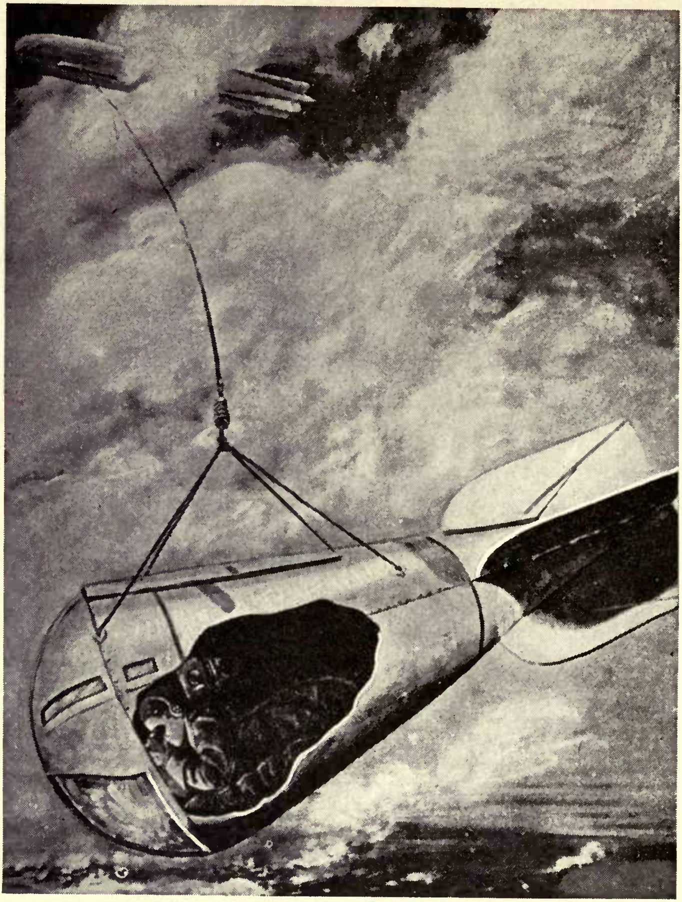
SHORTLY after the Civil War broke out, Thaddeus S. C. Lowe, an enthusiastic American aëronaut, conceived the idea of sending up scout balloons to reconnoiter the position of the enemy. These balloons were to be connected by telegraph wires with the ground, so that they could direct the artillery fire. The idea was so novel to the military authorities of that day that it was not received with favor. Balloons were looked upon as freak inventions, entirely impracticable for the stern realities of war; and as for telegraphing from a balloon, no one had ever done that before.

But this enthusiast was not to be daunted, and he made a direct appeal to President Lincoln, offering to prove the practicability of this means of scouting. So he took his balloon to Washington and made an ascent from the grounds of the Smithsonian Institution, while



(C) Underwood & Underwood

A big German Zeppelin that was forced to come down on French soil



Courtesy of "Scientific American"

Observation Car lowered from a Zeppelin sailing above the clouds the President came out on the lawn south of the White House to watch the demonstration. In order to test him, Mr. Lincoln took off his hat, waved his handkerchief, and made other signals. Lowe observed each act through his field-glasses and reported it to the President by telegraph. Mr. Lincoln was so impressed by the demonstration that he ordered the army to use the observation balloon, and so with some reluctance the gas-bag was introduced into military service, Professor Lowe being made chief aëronautic engineer. Under Lowe's direction the observation balloons played an important part in the operations of the Union Army.

On one occasion a young German military attaché begged the privilege of making an ascent in the balloon. Permission was given and when the German officer returned to earth he was wildly enthusiastic in praise of this aërial observation post. He had had a splendid view of the enemy and could watch operations through his field-glasses which were of utmost importance. Realizing the military value of the aircraft, he returned to Germany and urged military authorities to provide themselves with captive balloons. This young officer was Count

Ferdinand von Zeppelin, who was destined later to become the most famous aëronautic authority in the world and who lived to see Germany equipped with a fleet of balloons which were self-propelling and could travel over land and sea to spread German frightfulness into England. He also lived to see the virtual failure of this type of war-machine in the recent great conflict, and it was possibly because of his deep disappointment at having his huge expensive airships bested by cheap little airplanes that Count von Zeppelin died in March, 1917. However, he was spared the humiliation of seeing a fleet of Zeppelins lose their way in a fog and fall into France, one of them being captured before it could be destroyed, so that all its secrets of construction were learned by the French.

THE WEIGHT OF HYDROGEN

Before we describe the Zeppelin airships and the means by which they were eventually overcome, we must know something about the principles of balloons. Every one knows that balloons are kept up in the air by means of a very light gas, but somehow the general public fails to understand why the gas should hold it up.

Some people have a notion that there is something mysterious about hydrogen gas which makes it resist the pull of gravity, and that the more hydrogen you crowd into the balloon the more weight it will lift. But hydrogen has weight and feels the pull of gravity just as air does, or water, or lead. The only reason the balloon rises is because it weighs less than the air it displaces. It is hard to think of air as having weight, but if we weigh air, hydrogen, coal-gas, or any other gas, in a vacuum, it will tip the scales just as a solid would. A thousand cubic feet of air weighs 80 pounds. In other words, the air in a room ten feet square with a ceiling ten feet high, weighs just about 80 pounds. The same amount of coal-gas weighed in a vacuum would register only 40 pounds; while an equal volume of hydrogen would weigh only 5½ pounds. But when we speak of volumes of gas we must remember that gas, unlike a liquid or a solid, can be compressed or expanded to almost any dimensions. For instance, we could easily fill our room with a ton of air if the walls would stand the pressure; or we could pump out the air, until there were but a few ounces of air left. But in one case the air would be so highly compressed that it would exert a pressure of about 375 pounds on every square inch of the wall of the room, while in the other case its pressure would be almost infinitesimal. But 80 pounds of air in a room of a thousand cubic feet would exert the same pressure as the atmosphere, or 15 pounds on every square inch. And when we say that a thousand cubic feet of hydrogen weighs only a little over 5 pounds, we are talking about hydrogen at the same pressure as the atmosphere.

Since the hydrogen is sixteen times lighter than air, naturally it will float in the air, just as a piece of wood will float in water because it is lighter than the same volume of water. If we surrounded the thousand cubic feet of hydrogen with a bag so that the gas will not diffuse into the air and mix with it, we shall have a balloon which would float in air provided the bag and the hydrogen it contains do not weigh more than eighty pounds. As we rise from the surface of the earth, the air becomes less and less dense, or, in other words, it becomes lighter, and the balloon will keep on rising through the atmosphere until it reaches a point at which its weight, gas-bag and all, is exactly the same as that of an equal volume of air.

But there are many conditions that affect the height to which the balloon will ascend. The higher we rise, the colder it is apt to become, and cold has a tendency to compress the hydrogen, collapsing the balloon and making it relatively heavier. When the sun beats upon a balloon, it heats the hydrogen, expanding it and making it relatively lighter, and if there is no room for this expansion to take place in the bag, the bag will burst. For this reason, a big safety-valve must be provided and the ordinary round balloon is open at the bottom so that the hydrogen can escape when it expands too much and the balloonist carries ballast in the form of sand which he can throw over to lighten the balloon when the gas is contracted by a sudden draft of cold air.

Although a round balloon carries no engine and no propeller, it can be guided through the air to some degree. When an aëronaut wishes to go in any particular direction, he sends up his balloon by throwing out ballast or lowers it by letting out a certain amount of gas, until he reaches a level at which he finds a breeze blowing in the desired direction. Such was the airship of Civil War times, but for military purposes it was not advisable to use free balloons, because of the difficulty of controlling them. They were too liable to fall into the hands of the enemy. All that was needed was a high observation post from which the enemy could be watched, and from which observations could be reported by telegraph. The balloon was not looked upon as a fighting-machine.

ZEPPELIN'S FAILURES AND SUCCESSES

But Count Zeppelin was a man of vision. He dreamed of a real ship of the air—a machine that would sail wherever the helmsman chose, regardless of wind and weather. Many years elapsed before he actually began to work out his dreams, and then he met with failure after failure. He believed in big machines and the loss of one of his airships meant the waste of a large sum of money, but he persisted, even though he spent all his fortune, and had to go heavily in debt. Every one thought him a crank until he built his third airship and proved its worth by making a trip of 270 miles. At once the German Government was interested and saw wonderful military possibilities in the new craft. The Zeppelin was purchased by the government and money was given the inventor to further his experiments.

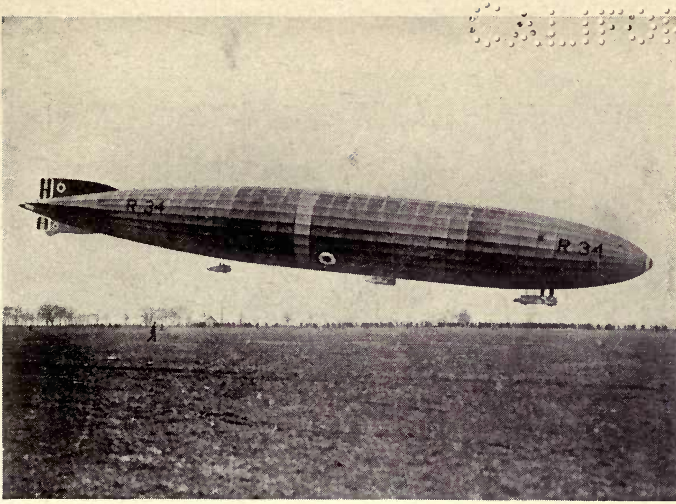
That was not the end of his failures. Before the war broke out, thirteen Zeppelins had been destroyed by one accident or another. Evidently the building of Zeppelin airships was not a paying undertaking, although they were used to carry passengers on short aërial voyages. But the government made up money losses and Zeppelin went on developing his airships.

Of course, he was not the only one to build airships, nor even the first to build a dirigible. The French built some large dirigibles, but they failed to see any great military advantage in ships that could sail through the air, particularly after the airplane was invented, and so it happened that when the war started the French were devoting virtually all their energies to the construction of speedy, powerful airplanes. As for the British, they did not pay much attention to airships. The idea that their isles might be attacked from the sky seemed an exceedingly remote possibility.

RIGID, SEMI-RIGID, AND FLEXIBLE BALLOONS

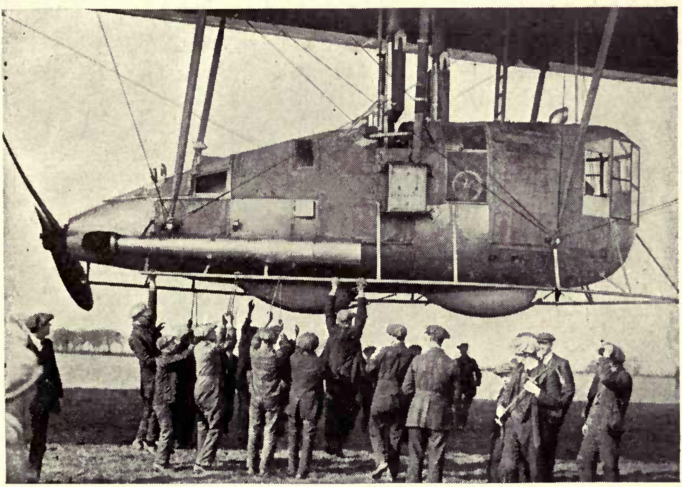
Count Zeppelin always held that the dirigible balloons must be rigid, so that they could be driven through the air readily and would hold their shape despite variations in the pressure of the hydrogen. The French, on the other hand, used a semi-rigid airship; that is, one in which a flexible balloon is attached to a rigid keel or body. The British clung to the idea of an entirely flexible balloon and they suspended their car from the gas-bag without any rigid framework to hold the gas-bag in shape. In every case, the balloons were kept taut or distended by means of air-bags or ballonets. These air-bags were placed inside the gas-bags and as the hydrogen expanded it would force the air out through valves, but the hydrogen itself would not escape. When the hydrogen contracted, the air-bags were pumped full of air so as to maintain the balloon in its fully distended condition. Additional supplies of compressed hydrogen were kept in metal tanks.

In the Zeppelin balloon, however, the gas was contained in separate bags which were placed in a framework of aluminum covered over with



(C) Underwood & Underwood

Giant British Dirigible built along the lines of a Zeppelin



(C) Underwood & Underwood

One of the engine cars or "power eggs" of a British Dirigible

Photograph by International Film Service

Crew of the C-5 (American Coastal Dirigible) starting for Newfoundland to make a Transatlantic Flight fabric. Count Zeppelin did not believe in placing all his eggs in one basket. If one of these balloons burst or was injured in any way, there was enough buoyancy in the rest of the gas-bags to hold up the airship. As the Zeppelins were enormous structures, the framework had to be made strong and light, and it was built up of a latticework of aluminum alloy. Aluminum itself was not strong enough for the purpose, but a mixture of aluminum and zinc and later another alloy known as duralumin, consisting of aluminum with three per cent of copper and one per cent of nickel, provided a very rigid framework that was exceedingly light. Duralumin is four or five times as strong as aluminum and yet weighs but little more.

The body of the Zeppelin is not a perfect circle in section, but is made up in the form of a polygon with sixteen sides, and the largest of the Zeppelins used during the war contained sixteen compartments, in each of which was placed a large hydrogen gas-bag. A super-Zeppelin, as the latest type is called, was about seventy-five feet in diameter and seven hundred and sixty feet long, or almost as long as three New York street blocks. In its gas-bags it carried two million cubic feet of hydrogen and although the whole machine with its fuel, stores, and passengers weighed close to fifty tons, it was so much lighter than the air it displaced that it had a reserve buoyancy of over ten tons.

KEEPING ENGINES CLEAR OF THE INFLAMMABLE HYDROGEN

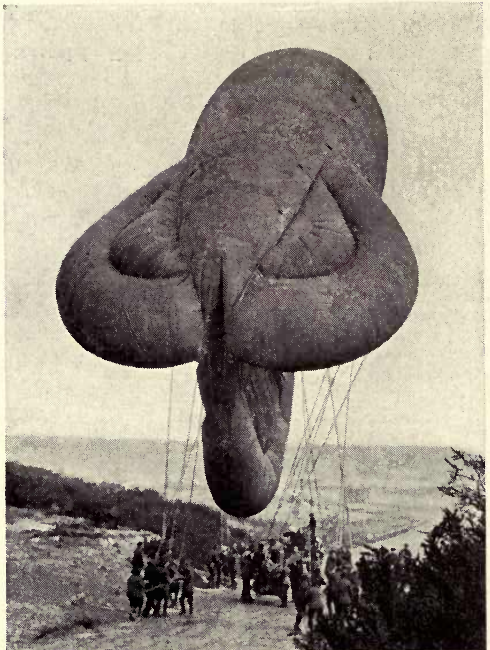
As hydrogen is a very inflammable gas, it is extremely dangerous to have an internal-combustion engine operating very near the gas-bags. In the super-Zeppelins the engines were placed in four cars suspended from the balloon. There was one of these cars forward, and one at the stern, while near the center were two cars side by side. In the rear car there were two engines, either of which could be used to drive the propeller. By means of large steering rudders and horizontal rudders, the machine could be forced to dive or rise or turn in either direction laterally. The pilot of the Zeppelin had an elaborate operating-compartment from which he could control the rudders, and he also had control of the valves in the ballonets so that by the touch of a button he could regulate the pressure of gas in any part of the dirigible.

There were nineteen men in the crew of the Zeppelin—two in the operating-compartment, and two in each of the cars containing engines, except for the one at the stern in which there were three men. The other men were placed in what was known as the "cat walk" or passageway running inside the framework under the gas-bags. These men were given various tasks and were supposed to get as much sleep as they could, so as to be ready to replace the other men at need.

The engine cars at each side of the balloon were known as power eggs because of their general egg shape. At the center of the Zeppelin the bombs were stored, and there were electromagnetic releasing-devices operated from the pilot's room by which the pilot could drop the bombs whenever he chose. The Zeppelin also carried machine-guns to fight off airplanes. Gasolene was stored in tanks which were placed in various parts of the machine, any one of which could feed one or all of the engines, and they were so arranged that they could be thrown overboard when the gasolene was used up, so as to lighten the load of the Zeppelin. Water ballast was used instead of sand, and alcohol was mixed with the water to keep it from freezing. The machine which came down in French territory and was captured before it could be destroyed by the pilot, found itself unable to rise because in the intense cold of the upper air the water ballast had frozen, and it could not be let out to lighten the load of the Zeppelin.

THE ZEPPELIN'S TINY ANTAGONISTS

The one thing above all others that the Zeppelin commander feared was the attack of airplanes. In the early stages of the war, it was considered unsafe for airplanes to fly by night because of the difficulty of making a landing in the dark. Later this difficulty was overcome by the use of search-lights at the landing-fields. The airplane would signal its desire to land and the search-lights would point out the proper landing-field for it. So that after the first few months of the war Zeppelins were subjected to the danger of airplane attack. Of course, on a dark night it was very difficult for an airplane to locate a Zeppelin, because the huge machine could not be seen and the throb of its engines was drowned out by the engines of the airplane

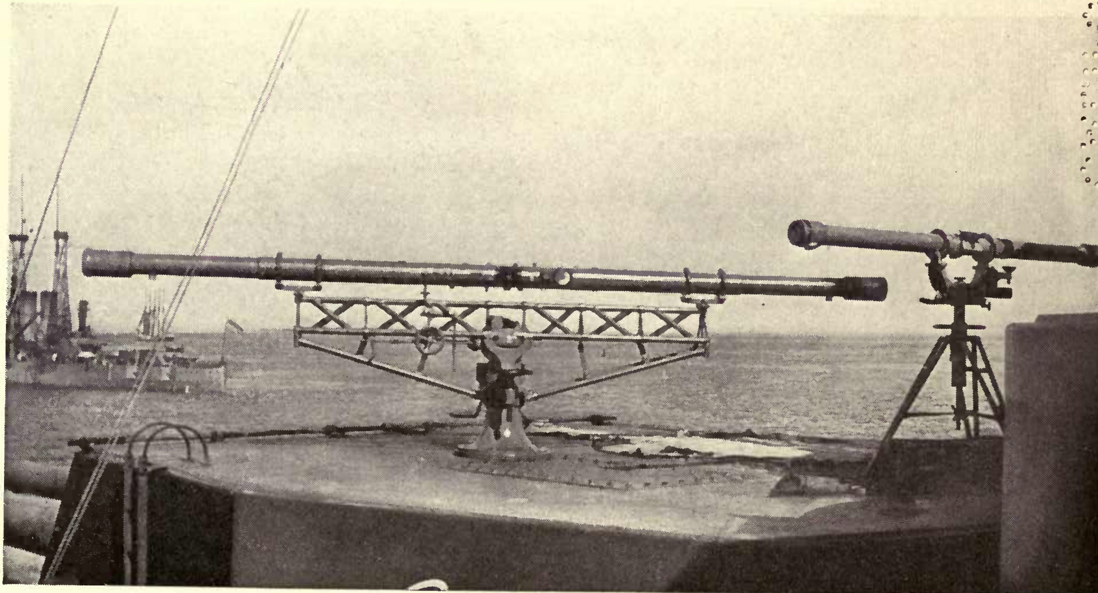


Photograph from Kadel & Herbert

The Curious Tail of a Kite Balloon

British Official Photograph from Kadel & Herbert

Observers in the Basket of an Observation-Balloon



Photograph by Kadel & Herbert

Enormous Range-finders mounted on a Gun Turret of an American Warship itself. Nevertheless, Zeppelins were occasionally located and destroyed by airplanes.

The danger of the Zeppelin lay in the fact that it was supported by an enormous volume of very inflammable gas and the airplane needed but to set fire to this gas to cause the destruction of the giant of the air. And so the machine-guns carried by airplanes were provided with explosive, flaming bullets. A burst of flame within the gas-bag would not set the gas on fire, because there would be no air inside to feed the fire, but surrounding the gas-bag there was always a certain leakage of hydrogen which would mix with the air in the compartment and this would produce an explosive mixture which needed but the touch of fire to set it off. The Zeppelin was provided with a ventilating-system to carry off these explosive gases, but they could never be disposed of very effectively, and, as a consequence, a number of Zeppelins were destroyed by the tiny antagonists that were sent up by the British and the French. To fight off these assailants the Germans provided their Zeppelins with guns which would fire shrapnel shell. It is difficult for a Zeppelin to use machine-guns against an airplane because the latter would merely climb above the Zeppelin and would be shielded by the balloon itself. And so the Germans put a gun emplacement on top of the balloon both forward and aft. There was a deck extending along the top of the balloon which was reached by a ladder running up through the center of the airship. But it was impossible to ward off the fleet little antagonists, once the dirigible was discovered. True, a Zeppelin could make as much as seventy miles per hour, but the fastest airplanes could travel twice as fast as that.

SUSPENDING AN OBSERVER BELOW THE ZEPPELIN

One ingenious scheme that was tried was to suspend an observation car under the Zeppelin. The car was about fourteen feet long and five feet in diameter, fitted with a tail to keep it headed in the direction it was towed. It had glass windows forward and there was plenty of room in it for a man to lie at full length and make observations of things below. The car with its observer could be lowered a few thousand feet below the Zeppelin, so that the observer could watch proceedings below, while the airship remained hidden among the clouds.

The observer was connected by telephone with the chart-room of the Zeppelin and could report his discoveries or even act as a pilot to direct the course of the ship.

But despite everything that could be done, the Zeppelin eventually proved a failure as a war-vessel because it was so very costly to construct and operate and could so easily be destroyed, and the Germans began to build huge airplanes with which bombing-raids could be continued.

Strange to say, however, although the Germans were ready to admit the failure of their big airship, when the war stopped the Allies were actually building machines patterned after the Zeppelin, but even larger, and expected to use them for bombing-excursions over Germany. This astonishing turn of the tables was due to the fact that America had made a contribution to aëronautics that solved the one chief drawback of the Zeppelin.

A BALLOON GAS THAT WILL NOT BURN

When we entered the war against Germany, our allies placed before us all their problems and among them was this one of the highly inflammable airship. Could we not furnish a substitute for hydrogen that would not burn? It was suggested to us that helium would do if we could produce that gas cheaply and in sufficient quantity. Now, helium has a history of its own that is exceedingly interesting.

Every now and then the moon bobs its head into our light and we have a solar eclipse. But our satellite is not big enough to cut off all the light of the big luminary and the fiery atmosphere of the sun shows us a brilliant halo all around the black disk of the moon. Long ago, astronomers analyzed this flaming atmosphere with the spectroscope, and by the different bands of light that appeared they were able to determine what gases were present in the sun's atmosphere. But there was one band of bright yellow which they could not identify. Evidently this was produced by a gas unknown on earth, and they called it "helium" or "sun" gas.

For a quarter of a century this sun gas remained a mystery; then one day, in 1895, Sir William Ramsay discovered the same band of light when studying the spectrum of the mineral cleveite. The fact that astronomers had been able to single out an element on the sun ninety million miles away before our chemists could find it right here on earth, produced a mild sensation, but the general public attached no special importance to the gas itself. It proved to be a very light substance, next to hydrogen the lightest of gases, and for years it resisted all attempts at liquefaction. Only when Onnes, the Dutch scientist, succeeded in getting it down to a temperature of 450 degrees below zero, Fahrenheit, did the gas yield to the chill and condense into a liquid. The gas would not burn; it would not combine with any other elements, and apparently it had no use on earth, and it might have remained indefinitely a lazy member of the chemical fraternity had not the great world conflict stirred us into frenzied activity in all branches of science in our effort to beat the Hun.

Because the gas had no commercial value, there was only a small amount of helium to be found in the whole world. Not a single laboratory in the United States had more than five cubic feet of it and its price ranged from $1,500 to $6,000 per cubic foot. At the lowest price it would cost $3,000,000,000 to provide gas enough for one airship of Zeppelin dimensions and it seemed absurd even to think of a helium airship.

AMERICAN CHEMISTS TO THE RESCUE

Just before the war it was discovered that there is a considerable amount of helium in the natural gas of Oklahoma, Texas, and Kansas, and Sir William Ramsey suggested that our chemists might study some method of getting helium from this source. The only way of separating it out was to liquefy the gases by subjecting them to extreme cold. All gases turn to liquid if they are cooled sufficiently, and then further cold will freeze them solid. But helium can stand more cold than any other and this fact gave the clue to its recovery from natural gas. The latter was frozen and one after another the different elements condensed into liquid, until finally only helium was left. This sounds simple, but it is a difficult matter to get such low temperature as that on a large scale and do it economically. To be of any real service in aëronautics helium would have to be reduced in cost from fifteen hundred dollars to less than ten cents per cubic foot. Several different kinds of refrigerating-machinery were tried and finally just before the war was brought to a close by the armistice we had succeeded in producing helium at the rate of eight cents per cubic foot, with the prospect of reducing its cost still further. A large plant for recovering helium was being built. The plant will have been completed before this book is published, and it will be turning out helium for peaceful instead of military airships.

The reduction in the cost of helium is really one of the most important developments of this war. By removing the fire risk from airships we can safely use these craft for aërial cruises or for quick long-distance travel over land and sea. For, even in time of peace, sailing under millions of cubic feet of hydrogen is a serious matter. Although no incendiary bullets are to be feared, there is always the danger of setting fire to the gas within the exhaust of the engines. Engines have had to be hung in cars well below the balloon proper. But with helium in the gas-bags the engines can be placed inside the balloon envelop and the propellers can operate on the center line of the car.

In the case of one Zeppelin, the hydrogen was set on fire by an electric spark produced by friction on the fabric of one of the gas-bags, and so even with the engine exhausts properly screened there is danger. The helium airship, however, would be perfectly safe from fire and passengers could smoke on deck or in their cabins within the balloon itself without any more fear of fire than they would have on shipboard. Wonderful possibilities have been opened by the production of helium on a large and economical scale, and the airship seems destined to play an important part in transportation very soon. As this book is going to press, we learn of enormous dirigibles about to be built in England for passenger service, which will have half again as great a lifting-power as the largest Zeppelins. The final chapter of the story of dirigibles is yet to be written, but in concluding this chapter it is interesting to note that the world's greatest aëronautic expert got his first inspiration from America and finally that America has now furnished the one element which was lacking to make the dirigible balloon a real success.

CHAPTER IX

Getting the Range

EVERY person with a good pair of eyes in his head is a range-finder. He may not know it, but he is, just the same, and the way to prove it is to try a little range-finding on a small scale.

Use the top of a table for your field of operations, and pick out some spot within easy reach of your hand for the target whose range you wish to find. The target may be a penny or a small circle drawn on a piece of white paper. Take a pencil in your hand and imagine it is a shell which you are going to land on the target. It is not quite fair to have a bird's-eye view of the field, so get down on your knees and bring your eyes within a few inches of the top of the table. Now close one eye and making your hand describe an arc through the air, like the arc that a shell would describe, see how nearly you can bring the pencil-point down on the center of the target. Do it slowly, so that your eye may guide the hand throughout its course. You will be surprised to find out how far you come short, or overreach the mark. You will have actually to grope for the target. If by any chance you should score a hit on the first try, you may be sure that it is an accident.

Have a friend move the target around to a different position, and try again. Evidently, with one eye you are not a good range-finder; but now use two eyes and you will score a hit every time. Not only can you land the pencil on the penny, but you will be able to bring it down on the very center of the target.

The explanation of this is that when you bring your eyes to bear upon any object that is near by, they have to be turned in slightly, so that both of them shall be aimed directly at that object. The nearer the object, the more they are turned in, and the farther the object, the more nearly parallel are the eyes. Long experience has taught you to gage the distance of an object by the feel of the eyes—that is, by the effort your muscles have to make to pull the eyes to a focus—and in this way the eyes give you the range of an object. You do not know what the distance is in feet or inches, but you can tell when the pencil-point has moved out until it is at the same focus as the target.

The experiment can be tried on a larger scale with the end of a fishing-rod, but here you will probably have to use a larger target. However, there is a limit to which you can gage the range. At a distance of, say, fifteen or twenty feet, a variation of a few inches beyond or this side of the target makes scarcely any change in the focus of the eyes. That is because the eyes are so close together. If they were farther apart, they could tell the range at much greater distances.

SPREADING THE EYES FAR APART

Now the ordinary range-finder, used in the army and in the navy, is an arrangement for spreading the eyes apart to a considerable distance. Of course the eyes are not actually spread, but their vision is. The range-finder is really a double telescope. The barrel is not pointed at an object, but it is held at right angles to it. You look into the instrument at the middle of the barrel and out of it at the two ends. A system of mirrors or prisms makes this possible. The range-finder may be a yard or more in length, which is equivalent to spreading your eyes a yard or more apart. Now, the prisms or object-glasses at the ends of the tube are adjustable, so that they will turn in until they focus directly on the target whose range you wish to find, and the angle through which these glasses are turned gives a measure of the distance of the target. The whole thing is calculated out so that the distance in feet, yards, or meters, or whatever the measure may be, is registered on a scale in the range-finder. Ordinarily only one eye is used to look through the range-finder, because the system of mirrors is set to divide the sight of that one eye and make it serve the purposes of two. That leaves the other eye free to read the scale, which comes automatically into view as the range-finder is adjusted for the different ranges.

On the battle-ships enormous range-finders are used. Some of them are twenty feet long. With the eyes spread as far apart as that and with a microscope to read the scale, you can imagine how accurately the range can be found, even when the target is miles away. But on land such big range-finders cannot conveniently be used; they are too bulky. When it is necessary to get the range of a very distant object, two observers are used who are stationed several hundred yards apart. These observers have telescopes which they bear upon the object, and the angle through which they have to turn the telescope is reported by telephone to the battery, where, by a rapid calculation, it is possible to estimate the exact position of the target. Then the gun is moved up or down, to the right or to the left, according to the calculation. The observers have to creep as near to the enemy as possible and they must be up high enough to command a good view of the target. Sometimes they are placed on top of telegraph poles or hidden up a tall tree, or in a church steeple.

GETTING THE OBSERVER OFF THE GROUND

This was the method of getting the range in previous wars and it was used to a considerable extent in the war we have just been through. But the great European conflict brought out wonderful improvements in all branches of fighting; and range-finding was absolutely revolutionized, because shelling was done at greater ranges than ever before, but chiefly because the war was carried up into the sky.

A bird's-eye observation is much more accurate than any that can be obtained from the ground. Even before this war, some observations were taken by sending a man up in a kite, particularly a kite towed from a ship, and even as far back as the Civil War captive balloons were used to raise an observer to a good height above the ground. They were the ordinary round balloons, but the observation balloon of to-day is a very different-looking object. It is a sausage-shaped gas-bag that is held on a slant to the wind like a kite, so that the wind helps to hold it up. To keep it head-on to the wind, there is a big air-bag that curls around the lower end of the sausage. This acts like a rudder, and steadies the balloon. Some balloons have a tail consisting of a series of cone-shaped cups strung on a cable. A kite balloon will ride steadily in a wind that would dash a common round balloon in all directions. Observers in these kite balloons are provided with telephone instruments by which they can communicate instantly with the battery whose fire they are directing. But a kite balloon is a helpless object;

it cannot fight the enemy. The hydrogen gas that holds it up will burn furiously if set on fire. In the war an enemy airplane had merely to drop a bomb upon it or fire an incendiary bullet into it, and the balloon would go up in smoke. Nothing could save it, once it took fire, and all the observers could do was to jump for their lives as soon as they saw the enemy close by. They always had parachutes strapped to them, so they could leap without an instant's delay in case of sudden danger. At the very first approach of an enemy airplane, the kite balloon had to be hauled down or it would surely be destroyed, and so kite balloons were not very dependable observation stations for the side which did not control the air.

As stated in the preceding chapter, just before the fighting came to an end, our army was preparing to use balloons that were not afraid of flaming bullets, because they were to be filled with a gas that would not burn.

MAKING MAPS WITH A CAMERA

Because airplanes filled the sky with eyes, everything that the army did near the front had to be carefully hidden from the winged scouts. Batteries were concealed in the woods, or under canopies where the woods were shot to pieces, or they were placed in dugouts so that they could not be located. Such targets could seldom be found with a kite balloon. It was the task of airplane observers to search out these hidden batteries. The eye alone was not depended upon to find them. Large cameras were used with telescopic lenses which would bring the surface of the earth near while the airplane flew at a safe height. These were often motion-picture cameras which would automatically make an exposure every second, or every few seconds.

When the machine returned from a photographing-expedition, the films were developed and printed, and then pieced together to form a photographic map. The map was scrutinized very carefully for any evidence of a hidden battery or for any suspicious enemy object. As the enemy was always careful to disguise its work, the camera had to be fitted with color-screens which would enable it to pick out details that would not be evident to the eye. As new photographic maps were made from day to day, they were carefully compared one with

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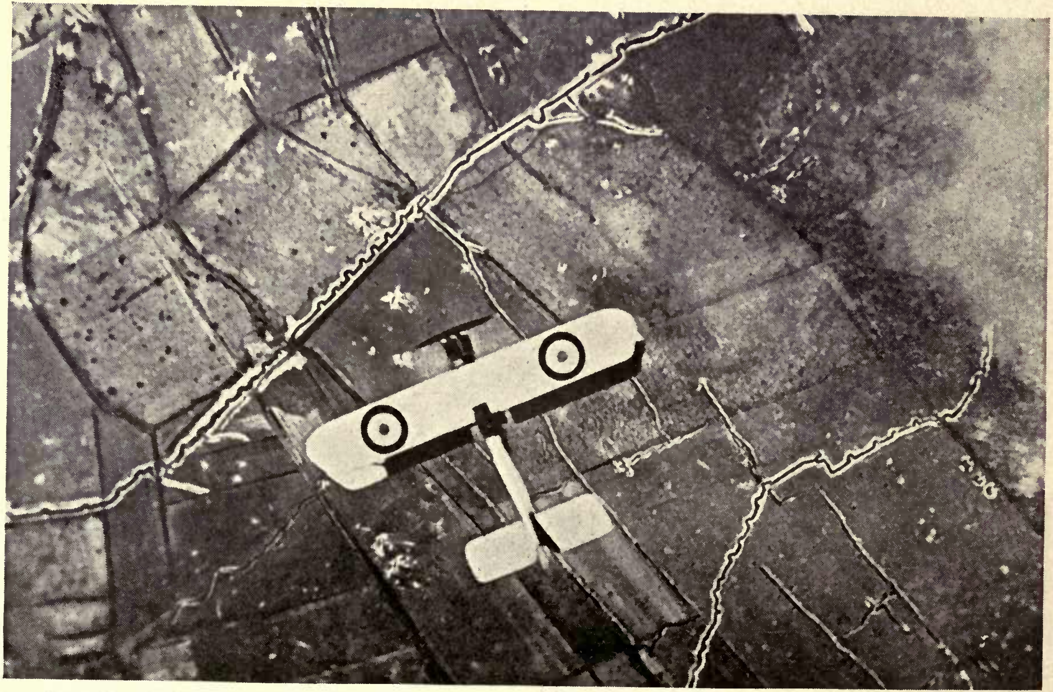
British Anti-aircraft Section getting the Range of an Enemy Aviator



A British Aviator making Observations over the German Lines the other so that it might be seen if there was the slightest change in them which would indicate some enemy activity. As soon as a suspicious spot was discovered, its position was noted on a large-scale military map and the guns were trained upon it.

CORRECTING THE AIM

It is one thing to know where the target is and another to get the shell to drop upon it. In the firing of a shell a distance of ten or twenty miles, the slightest variation in the gun will make a difference of many yards in the point where the shell lands. Not only that, but the direction of the wind and the density of the air have a part to play in the journey of the shell. If the shell traveled through a vacuum, it would be a much simpler matter to score a hit by the map alone. But even then there would be some differences, because a gun has to be "warmed up" before it will fire according to calculation. That is why it is necessary to have observers, or "spotters" as they are called, to see where the shell actually do land and tell the gun-pointers whether to elevate or depress the gun, and how much to "traverse" it—that is, move it sideways. This would not be a very difficult matter if there were only one gun firing, but when a large number of guns are being used, as was almost invariably the case in the war, the spotter had to know which shell belonged to the gun he was directing.

One of the most important inventions of the war was the wireless telephone, which airplanes used and which were brought to such perfection that the pilot of an airplane could talk to a station on the earth without any difficulty, from a distance of ten miles; and in some cases he could reach a range of fifty miles. With the wireless telephone, the observer could communicate instantly with the gun-pointer, and tell him when to fire. Usually thirty seconds were allowed after the signal sent by the observer before the gun was fired, and on the instant of firing, a signal was sent to the man in the airplane to be on the lookout for the shell. Knowing the position of the target, the gun-pointer would know how long it would take the shell to travel through the air, and he would keep the man in the airplane posted, warning him at ten seconds, five seconds, and so forth, before the shell was due to land.

In order to keep the eyes fresh for observation and not to have them distracted by other sights, the observer usually gazed into space until just before the instant the shell was to land. Then he would look for the column of smoke produced by the explosion of the shell and report back to the battery how far wide of the mark the shell had landed. A number of shell would be fired at regular intervals, say four or five per minute, so that the observer would know which shell belonged to the gun in question.

There are different kinds of shell. Some will explode on the instant of contact with the earth. These are meant to spread destruction over the surface. There are other shell which will explode a little more slowly and these penetrate the ground to some extent before going off; while a third type has a delayed action and is intended to be buried deep in the ground before exploding, so as to destroy dugouts and underground positions. The bursts of smoke from the delayed-action shell and the semi-delayed-action shell rise in a slender vertical column and are not so easily seen from the sky. The instantaneous shell, however, produces a broad burst of smoke which can be spotted much more readily, and this enables the man in the airplane to determine the position of the shell with greater accuracy. For this reason, instantaneous shell were usually used for spotting-purposes, and after the gun had found its target, other shell were used suited to the character of the work that was to be done.

MINIATURE BATTLE-FIELDS

Observation of shell-fire from an airplane called for a great deal of experience, and our spotters were given training on a miniature scale before they undertook to do spotting from the air. A scaffolding was erected in the training-quarters over a large picture of a typical bit of enemy territory. Men were posted at the top of this scaffolding so that they could get a bird's-eye view of the territory represented on the map, and they were connected by telephone or telegraph with men below who represented the batteries. The instructor would flash a little electric light here and there on the miniature battle-field, and the observers had to locate these flashes and tell instantly how far they were from certain targets. This taught them to be keen and quick and to judge distance accurately.

Airplane observing was difficult and dangerous, and often impossible. On cloudy days the observer might be unable to fly at a safe height without being lost in the clouds. Then dependence had to be placed upon observers stationed at vantage-points near the enemy, or in kite balloons.

SPOTTING BY SOUND

When there is no way of seeing the work of a gun, it is still possible to correct the aim, because the shell can be made to do its own spotting. Every time a shell lands, it immediately announces the fact with a loud report. That report is really a message which the shell sends out in all directions with a speed of nearly 800 miles per hour—1,142 feet per second, to be exact. This sound-message is picked up by a recorder at several different receiving-stations. Of course it reaches the nearest station a fraction of a second before it arrives at the next nearest one. The distance of each station from the target is known by careful measurement on the map, and the time it takes for sound to travel from the target to each station is accurately worked out. If the sound arrives at each station on schedule time, the shell has scored a hit; but if it reaches one station a trifle ahead of time and lags behind at another, that is evidence that the shell has missed the target and a careful measure of the distance in time shows how far and in what direction it is wide of the mark. In this way it was possible to come within fifty or even twenty-five yards of the target.

This sound-method was also used to locate an enemy battery. It was often well nigh impossible to locate a battery in any other way. With the use of smokeless powder, there is nothing to betray the position of the gun, except the flash at the instant of discharge, and even the flash was hidden by screens from the view of an airplane. Aside from this, when an airplane came near enough actually to see one of these guns, the gun would stop firing until the airplane had been driven off. But a big gun has a big voice, and it is impossible to silence it. Often a gun whose position has remained a secret for a long time was discovered because the gun itself "peached."

The main trouble with sound-spotting was that there were usually so many shell and guns going off at the same time that it was difficult if not impossible to distinguish one from another. Sometimes the voice of a hidden gun was purposely drowned by the noise of a lot of other guns. After all, the main responsibility for good shooting had to fall on observers who could actually see the target, and when we think of the splendid work of our soldiers in the war, we must not forget to give full credit to the tireless men whose duty it was to watch, to the men on wings who dared the fierce battle-planes of the enemy, to the men afloat high in the sky who must leap at a moment's notice from under a blazing mass of hydrogen, and finally to the men who crept out to perilous vantage-points at risk of instant death, in order to make the fire of their batteries tell.

CHAPTER X

Talking in the Sky

IN one field of war invention the United States held almost a monopoly and the progress Americans achieved was epoch-making.

Before the war, an aviator when on the wing was both deaf and dumb. He could communicate with other airplanes or with the ground only by signal or, for short distances, by radio-telegraphy, but he could not even carry on conversation with a fellow passenger in the machine without a speaking-tube fitted to mouth and ears so as to cut out the terrific roar of his own engine. Now the range of his voice has been so extended that he can chat with fellow aviators miles away. This remarkable achievement and many others in the field of radio-communication hinge upon a delicate electrical device invented by Deforest in 1906 and known as the "audion." For years this instrument was used by radiotelegraphers without a real appreciation of its marvelous possibilities, and, as a matter of fact, in its earlier crude form it was not capable of performing the wonders it has achieved since it was taken over and developed by the engineers of the Bell Telephone System.

THE AUDION

Although the audion is familiar to all amateur radio-operators, we shall have to give a brief outline of its construction and operation for the benefit of those who have not had the opportunity to dabble in wireless telegraphy. The audion is a small glass bulb from which the air is exhausted to a high degree of vacuum. The bulb contains three elements. One is a tiny filament which is heated to incandescence by a battery, so that it emits negatively charged electrons. The filament is at one side of the bulb and at the opposite side there is a metal plate. When the plate and the filament are connected with opposite poles of a battery, there is a flow of current between them, but because only negative electrons are emitted by the filament, the current will flow only in one direction—that is, from the plate to the filament.

If the audion be placed in the circuit of an alternating-current generator, it will let through only the current running in one direction. Thus it will "rectify" the current or convert alternating current into direct current.

But the most important part of the audion, the part for which Deforest is responsible, is the third element, which is a grid or flat coil of platinum wire placed between the filament and the plate. This grid furnishes a very delicate control of the strength of the electric current between plate and filament. The slightest change in electric power in the grid will produce large changes of power in the current flowing through the audion. This makes it possible to magnify or amplify very feeble electric waves, and the extent to which the amplifying can be carried is virtually limitless, because a series of audions can be used, the current passing through the first being connected with the grid of the next, and so on.

TALKING FROM NEW YORK TO SAN FRANCISCO

There is a limit to which telephone conversations can be carried on over a wire, unless there is some way of adding fresh energy along the line. For years all sorts of experiments were tried with mechanical devices which would receive a telephone message and send it on with a fresh relay of current. But these devices distorted the message so that it was unintelligible. The range of wire telephony was greatly increased by the use of certain coils invented by Pupin, which were placed in the line at intervals; but still there was a limit to which conversation could be carried on by wire and it looked as if it would never be possible to telephone from one end of this big country of ours to the other. But the audion supplied a wonderfully efficient relay and one day we awoke to hear San Francisco calling, "Hello," to New York.

Used as a relay, the improved audion made it possible to pick up very faint wireless-telegraph messages and in that way increased the range of radio outfits. Messages could be received from great distances without any extensive or elaborate aërials, and the audion could be used at the sending-station to magnify the signals transmitted and send them forth with far greater power.

Having improved the audion and used it successfully for long-distance telephone conversation over wires, the telephone company began to experiment with wireless telephony. They believed that it might be possible to use radiotelephony in places where wires could not be laid. For instance, it might be possible to talk across the Atlantic.

But before we go farther, just a word of explanation concerning radiotelegraphy and radiotelephony for the benefit of those who have not even an elementary knowledge of the subject.

SIMPLE EXPLANATION OF RADIOTELEGRAPHY

Suppose we should set up two stakes in a pond of water, at some distance from each other, and around each we set a ring-shaped cork float. If we should move one of these floats up and down on its stake, it would produce ripples in the water which would spread out in all directions and finally would reach the opposite stake and cause the float there to bob up and down in exactly the same way as did the float moved by hand. In wireless telegraphy the two stakes are represented by antennæ or aërials and the cork floats are electric charges which are sent oscillating up and down the antennæ. The oscillations produced at one aërial will set up electro-magnetic waves which will spread out in all directions in the ether until they reach a receiving-aërial, and there they will produce electric oscillations similar to the ones at the transmitting-antenna.

Telegraph signals are sent by the breaking up of the oscillations at the transmitting-station into long and short trains of oscillations corresponding to the dots and dashes of ordinary wire telegraphy. In other words, while the sending-key is held down for a dash, there will be a long series of oscillations in the antenna, and for the dot a short series, and these short and long trains of waves will spread out to the receiving-aërial where they will reproduce the same series of oscillations. But only a small part of the energy will act on the receiving-aërial because the waves like those on the pond spread in all directions and grow rapidly weaker. Hence the advantage of an extremely delicate instrument like the audion to amplify the signals received.

The oscillations used in wireless telegraphy these days are very rapid, usually entirely too rapid, to affect an ordinary telephone receiver, and if they did they would produce a note of such high pitch that it could not be heard. So it is customary to interrupt the oscillations, breaking them up into short trains of waves, and these successive trains produce a note of low enough pitch to be heard in the telephone receiver. Of course the interruptions are of such high frequency that in the sending of a dot-and-dash message each dot is made up of a great many of the short trains of waves.

Now in radiotelephony it is not necessary to break up the oscillations, but they are allowed to run continuously at very high speed and act as carriers for other waves produced by speaking into the transmitter; that is, a single speech-wave would be made up of a large number of smaller waves. To make wireless telephony a success it was necessary to find some way of making perfectly uniform carrier-waves, and then of loading on them waves of speech. Of course, the latter are not sound-waves, because they are not waves of air, but they are electro-magnetic waves corresponding exactly to the sound-waves of air and at the receiving-end they affect the telephone receiver in the same way that it is affected by the electric waves which are sent over telephone wires. The telephone engineers found that the audion could be used to regulate the carrier-waves and also to superpose the speech-waves upon them, and at the receiving-station the audion was used to pick up these waves, no matter how feeble they might be, and amplify them so that they could be heard in a telephone receiver.

TALKING WITHOUT WIRES

Attempts at long-distance talking without wires were made from Montauk Point, on the tip of Long Island, to Wilmington, Delaware, and they were successful. This was in 1915. The apparatus was still further improved and then the experiment was tried of talking from the big Arlington station near Washington to Darien, on the Isthmus of Panama. This was a distance of twenty-one hundred miles, and speech was actually transmitted through space over that great distance. That having proved successful, the next attempt was to talk from Arlington to Mare Island and San Diego, on the Pacific Coast, a distance of over twenty-five hundred miles. This proved a success, too, and it was found possible even to talk as far as Honolulu.

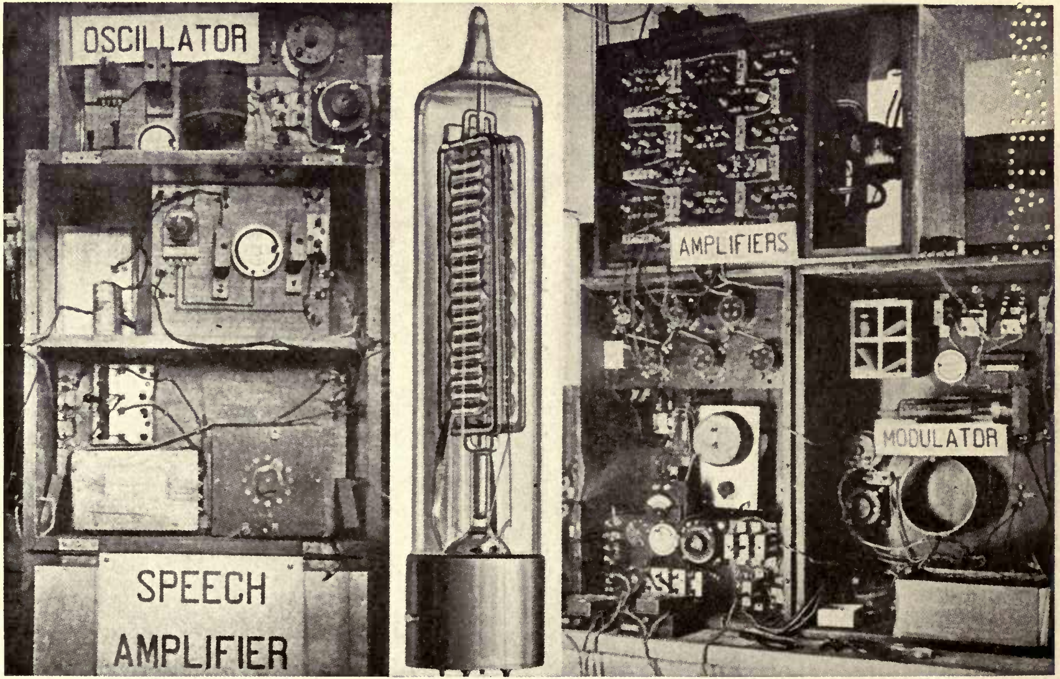
The engineers now felt confident that they could talk across the Atlantic to Europe, and so in October of 1915 arrangements were made to conduct experiments between Arlington and the Eiffel Tower in Paris. Although the war was at its height, and the French were straining every effort to hold back the Germans at that time, and although there were constant demands for the use of radio-telegraphy, the French showed such an appreciation of science that they were willing to lend their aid to these experiments. The Eiffel Tower could be used only for short periods of time, and there was much interference from other high-powered stations. Nevertheless, the experiment proved perfectly successful, and conversation was carried on between our capital and that of France, a distance of thirty-six hundred miles. At the same time, an operator in Honolulu, forty-five hundred miles away, heard the messages, and so the voice at Arlington carried virtually one third of the way around the globe. After that achievement, there was a lull in the wireless-telephone experiments because of the war.

(C) G. V. Buck

Radio Head-gear of an Airman

(C) G. V. Buck

Carrying on Conversation by Radio with an Aviator Miles Away



(C) American Institute of Electrical Engineers

Long Distance Radio Apparatus at the Arlington (Va.) Station, with enlarged view of the Type of Vacuum Tube used.

But there soon came an opportunity to make very practical use of all the experimental work. As soon as there seemed to be a possibility that we might be drawn into the war, the Secretary of the Navy asked for the design of apparatus that would make it possible for ships to converse with one another and with shore stations. Of course all vessels are equipped with wireless-telegraph apparatus, but there is a decided advantage in having the captain of one ship talk directly with the captain of another ship, or take his orders from headquarters, with an ordinary telephone receiver and transmitter. A special equipment was designed for battleships and on test it was found that ships could easily converse with one another over a distance of thirty-five miles and to shore stations from a distance of a hundred and seventy-five miles. The apparatus was so improved that nine conversations could be carried on at the same time without any interference of one by the others.

When it became certain that we should have to enter the war, there came a call for radio-telephone apparatus for submarine-chasers, and work was started on small, compact outfits for these little vessels.

RADIOTELEPHONES FOR AIRPLANES

Then there was a demand for radiotelephone apparatus to be used on airplanes. This was a much more complicated matter and called for a great deal of study. The way in which problem after problem arose and was solved makes an exceedingly interesting narrative. It seemed almost absurd to think that a delicate radiotelegraph apparatus could be made to work in the terrific noise and jarring of an airplane. The first task was to make the apparatus noise-proof. A special sound-proof room was constructed in which a noise was produced exactly imitating that of the engine exhaust of an airplane engine. In this room, various helmets were tried in order to see whether they would be proof against the noise, and finally a very suitable helmet was designed, in which the telephone receiver and transmitter were installed.

By summer-time the work had proceeded so far that an airplane equipped with transmitting-apparatus could send spoken messages to an operator on the ground from a distance of two miles. The antenna of the airplane consisted of a wire with a weight on the lower end, which hung down about one hundred yards from the body of the machine. But a trailing antenna was a nuisance in airplane manœuvers, and it was also found that the helmet which was so satisfactory in the laboratory was not just the thing for actual service in an airplane. It had to fit very tightly around the ears and the mouth, and as the airplane went to high altitudes where the air-pressure was much lower than at the ground level, painful pressures were produced in the ears which were most annoying. Aside from that, in actual warfare airplanes have to operate at extreme heights, where the air is so rare that oxygen must be supplied to the aviators, and it was difficult to provide this supply of oxygen with the radio helmet tightly strapped to the head of the operator. But after considerable experiment, this difficulty was overcome and also that of the varying pressures on the ears.

Another great difficulty was to obtain a steady supply of power on the airplane to operate the transmitting-apparatus. It has been the practice to supply current on airplanes for wireless-telegraph apparatus by means of a small electric generator which is revolved by a little propeller. The propeller in turn is revolved by the rush of air as it is carried along by the plane. But the speed of the airplane varies considerably. At times, it may be traveling at only forty miles per hour, and at other times as high as one hundred and sixty miles per hour, so that the little generator is subjected to great variations of speed and consequent variations of voltage. This made it impossible to produce the steady oscillations that are required in wireless telephony. After considerable experiment, a generator was produced with two windings, one of which operated through a vacuum tube, somewhat like an audion, and to resist the increase of voltage produced by the other winding.

Then another trouble developed. The sparks produced by the magneto in the airplane motor set up electro-magnetic waves which seriously affected the receiving-instrument. There was no way of getting rid of the magneto, but the wires leading from it to the engine were incased in metal tubes which were grounded at frequent intervals, and in that way the trouble was overcome to a large extent. The magnetos themselves were also incased in such a way that electro-magnetic waves would not be radiated from them.

Instead of using trailing wires which were liable to become entangled in the propeller, the antenna was extended from the upper plane to the tail of the machine, and later it was found that by using two short trailing antennæ one from each tip of the wings, the very best results could be obtained. Still another development was to embed the antenna wires in the wings of the plane.

It was considered necessary, if the apparatus was to be practicable, to be able to use it over a distance of two thousand yards, but in experiments conducted in October, 1917, a couple of airplanes were able to talk to each other when twenty-three miles apart, and conversations were carried on with the ground from a distance of forty-five miles. The conditions under which these distances were attained were unusual, and a distance of three miles was accepted as a standard for communication between airplanes. The apparatus weighed only fifty-eight pounds and it was connected with both the pilot and the observer so that they could carry on conversations with each other and could both hear the conversation with other airplanes or the ground. As a matter of fact, airplanes with standard apparatus are able to talk clearly to a distance of five miles and even to a distance of ten miles when conditions are favorable, and they can receive messages from the ground over almost any distance.

A similar apparatus was constructed for submarine-chasers with a standard range of conversation of over five miles. Apparatus was manufactured in large quantities in this country and all our submarine-chasers were equipped with it, as well as a great many of our airplanes and seaplanes, and we furnished radio-apparatus sets to our allies which proved of immense value in the war. This was particularly so in the case of submarine detection, when it was possible for a seaplane or a balloon to report its findings at once to submarine-chasers and destroyers, and to guide them in pursuit of submarines.

The improved audion holds out a wonderful future for radiotelephony. For receiving, at least, no elaborate aërial will be needed, and with a small loop of wire, an audion or two, and simple tuning-apparatus any one can hear the radio gossip of the whole world.

TELEGRAPHING TWELVE HUNDRED WORDS PER MINUTE

Some remarkable advances were made in telegraphy also. During the war and since, messages have been sent direct from Washington to all parts of the world. In the telegraph room operators are connected by wire with the different radio stations along the coast and they can control the radio transmitters, sending their messages without any repeating at the radio stations. Long messages are copied off on a machine something like a type-writer, which, however, does not make type impressions, but cuts perforations in a long sheet of paper. The paper is then run through a transmitter at a high speed and the message is sent out at a rate of as much as twelve hundred words a minute. At the receiving-station, the message is received photographically on a strip of paper. The receiving-instrument has a fine quartz thread in it, which carries a tiny mirror. A beam of light is reflected from the mirror upon the strip of sensitized paper. The radio waves twist the quartz thread ever so slightly, which makes the beam of light play back and forth, but of course the motion is greatly magnified. In this way a perfect record is made of the message in dots and dashes, which are translated into the corresponding letters of the alphabet.

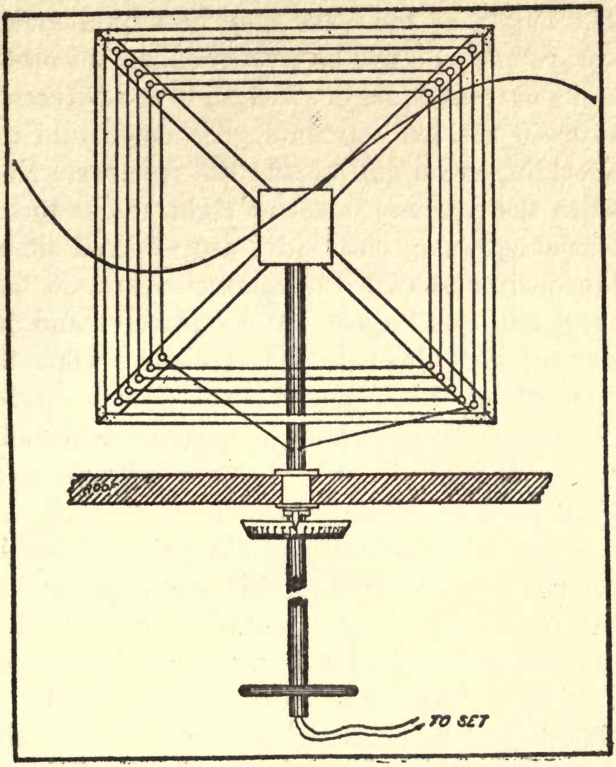
DETECTING RADIO SPIES

There is another radio invention which we contributed during the war, that proved of utmost service in thwarting German spies and which is going to prove equally valuable in time of peace. Although a war invention, its peace-time service will be to save lives. It is a very simple matter to rig up a wireless-telegraph system that will send messages to a considerable distance, and simpler still to rig up a receiving-set. European governments have always discouraged amateur radiotelegraphy, but in this country restrictions used to be so slight that almost any one could set up and use a radio set, both for receiving and for transmitting. When we entered the war we were glad that amateurs had been encouraged to play with wireless, because we had hundreds of good radio operators ready to work the sets which the army and the navy needed.

But this was a disadvantage, too. Many operators were either Germans or pro-Germans and were only too willing to use their radio experience in the interest of our enemies. It was a simple matter to obtain the necessary apparatus, because there was plenty of it to be had everywhere. They could send orders to fellow workers and receive messages from them, or they could listen to dispatches sent out by the government and glean information of great military and naval importance. The apparatus could easily be concealed: a wire hung inside a chimney, a water-pipe, even a brass bedstead could be used for the receiving-aërial. It was highly important that these concealed stations be located, but how were they to be discovered?

THE WIRELESS COMPASS

This problem was solved very nicely. The audion had made it possible to receive radio signals on a very small aërial. In place of the ordinary stationary aërial a frame five feet square was set up so that it could be turned to any point of the compass. A few turns of copper-bronze wire were wound round it. This was called the "wireless compass." It was set up on the roof of the radio station and concealed within a cupola. The shaft on which it was mounted extended down into the operating-room and carried a wheel by which it could be turned. On the shaft was a circular band of aluminum engraved with the 360 degrees of the circle, and a couple of fixed pointers indicated true north and south. Now when a signal was received by the aërial, if it struck the frame edgewise the radio waves would reach one side before they would the other. Taking a single wave, as shown by the drawing, Fig. 11, we see that while the crest of the wave is sweeping over one side of the frame, the trough of the wave is passing the other side. Two currents are set up in the radio compass, one in the wires at the near side of the compass, and another in the wires at the far side of the compass. As these currents are of the same direction, they oppose each other and tend to kill each other off, but one of the currents is stronger than the other because the crest of the wave is sweeping over that side, while the



Courtesy of the "Scientific American"

FIG. 11. The radio compass turned parallel to an oncoming electro-magnetic wave

trough of the wave is passing over the other. The length of the wave may be anything, but always one side will be stronger than the other, and a current equal in strength to the difference between the two currents goes down into the operating-room and affects the receiver. Now when the compass is set at right angles to the oncoming wave, both sides are affected simultaneously and with the same strength, so that they kill each other off completely, and no current goes down to the receiver. Thus the strength of the signal received can be varied from a maximum, when the compass is parallel to the oncoming waves, to zero, when it is at right angles to them.

To find out where a sending-station is, the compass is turned until the loudest sound is heard in the receiver and then the campass dial shows from what direction the signals are coming. At the same time, another line on the signals will be found by a second station with another compass. These directions are traced on a map; and where they meet, the sending-station must be located.

With this apparatus it was possible to locate the direction of the station within a degree.

After the station had been located as closely as possible in this way, a motor-truck was sent out in which there was a concealed radio compass. The truck would patrol the region located by the fixed compasses, and with it the position of the concealed station could be determined with perfect accuracy. The building would be raided and its occupants jailed and the radio equipment confiscated.

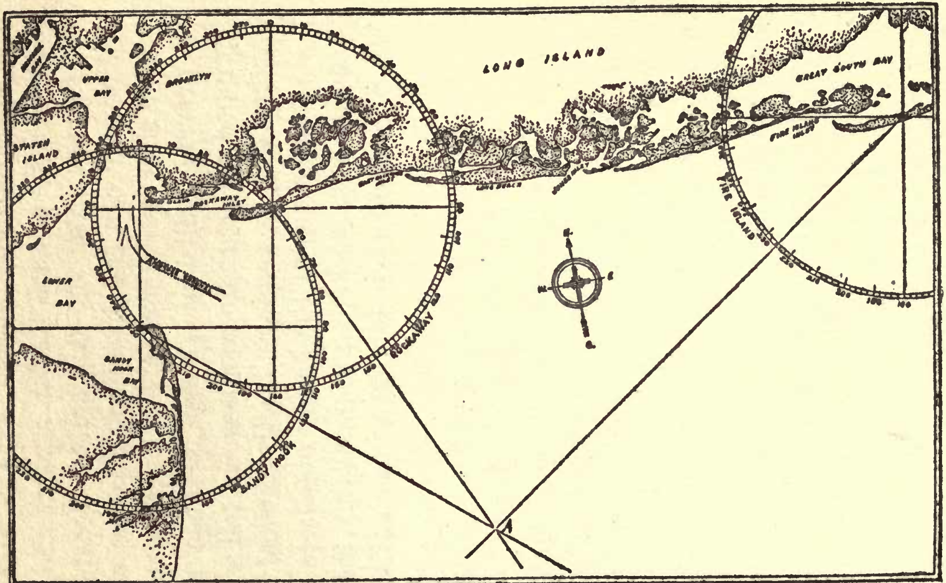
Even receiving-sets were discovered with the portable compass, but to find them was a far more difficult task. For the receiving of messages from distant points without a conspicuous aërial an audion would have to be used and this would set up feeble oscillations which could be picked up under favorable conditions by the portable compass.

PILOTING SHIPS INTO PORT

And now for the peace-time application of all this. If the compass could be used to find those who tried to hide, why could it not also be used to find those who wished to be found?

Every now and then a ship runs upon the rocks because it has lost its bearings in the fog. But there will be no excuse for such accidents now. A number of radio-compass stations have been located around the entrance and approach to New York Harbor. Similar stations have been, or soon will be, established at other ports. As soon as a ship arrives within fifty or a hundred miles of port she is required to call for her bearings. The operator of the control station instructs the ship to send her call letters for thirty seconds, and at the same time notifies each compass station to get a bearing on the ship. This each does, reporting back to the control station. The bearings are plotted on a chart and inside of two minutes from the time the ship gives her call letters, her bearing is flashed to her by radio from the control station.

The chart on which the plotting is done is covered with a sheet of glass. Holes are pierced through the glass at the location of each compass station. See Fig. 12. On the chart, around each station, there is a dial marked off in the 360 degrees of the circle. A thread passes through the chart and the hole in the glass at each station. These threads are attached to weights under the chart. When a compass station reports a bearing, the thread of that station is pulled out and extended across



Courtesy of the "Scientific American"
FIG. 12. Approaches to New York Harbor showing location of three radio compass stations and how position of a ship sending signals from A may be determined

the corresponding degree on the dial. The same is done as each station reports and where the threads cross, the ship must be located.

Not only can the direction-finder be used to pilot a ship into a harbor, but it will also serve to prevent collisions at sea, because a ship equipped with a radio compass can tell whether another ship is coming directly toward her.

And so as one of the happy outcomes of the dreadful war, we have an apparatus that will rob sea-fogs of their terrors to navigation.

CHAPTER XI

Warriors of the Paint-Brush

WHEN the great European war broke out, it was very evident that the Entente Allies would have to exercise every resource to beat the foe which had been preparing for years to conquer the world. But who ever imagined that geologists would be called in to choose the best places for boring mines under the enemy: that meteorologists would be summoned to forecast the weather and determine the best time to launch an offensive; that psycologists would be employed to pick out the men with the best nerves to man the machine-guns and pilot the battle-planes? Certainly no one guessed that artists and the makers of stage scenery would play an important part in the conflict.

But the airplane filled the sky with eyes that at first made it impossible for an army to conceal its plans from the enemy. And then there were eyes that swam in the sea—cruel eyes that belonged to deadly submarine monsters, eyes that could see without being seen, eyes that could pop up out of the water at unexpected moments, eyes that directed deadly missles at inoffensive merchantmen. They were cowardly eyes, too, which gave the ship no opportunity to strike back at the unseen enemy. A vessel's only safety lay in the chance that out in the broad reaches of the ocean it might pass beyond the range of those lurking eyes. It was a game of hide-and-seek in which the pursuer and not the pursued was hidden. Something had to be done to conceal the pursued as well, but in the open sea there was nothing to hide behind.

HIDING IN PLAIN SIGHT

There is such a thing as hiding in plain sight. You can look right at a tree-toad without seeing him, because his colors blend perfectly with the tree to which he is clinging. You can watch a green leaf curl up and shrivel without realizing that the curled edge is really a caterpillar, cunningly veined and colored to look just like a dying leaf; and out in the woods a speckled bird or striped animal will escape observation just because it matches the spotted light that comes through the underbrush. Nature is constantly protecting its helpless animals with colored coats that blend with the surroundings.

Long ago clumsy attempts at concealment were made when war-vessels were given a coat of dark-gray paint which was supposed to make them invisible at a distance. Actually the paint made them more conspicuous; but, then, concealment did not count for very much before the present war.

It was the eyes of the submarines that brought a hurry call for the artists, and up to them was put the problem of hiding ships in plain sight. A new name was coined for these warriors of the paint-brush: *camoufleurs* they were called, and their work was known as *camouflage.*

MATCHING THE SKY

Of course, no paint will make a ship absolutely invisible at a short distance, but a large vessel may be made to disappear completely from view at a distance of six or seven miles if it is properly painted.

To be invisible, a ship must reflect as much light and the same shade of light as do its surroundings. If it is seen against the background of the sea, it must be of a bluish or a greenish tint, but a submarine lies so low in the water that any object seen at a distance is silhouetted against the sky, and so the ship must have a coat of paint that will reflect the same colors as does the sky. Now, the sky may be of almost any color of the rainbow, depending upon the position of the sun and the amount of vapor or dust in the air. Fortunately in the North Sea and the waters about the British Isles, where most of the submarine attacks took place, the weather is hazy most of the time, and the ship had to be painted of such a color that it would reflect the same light as that reflected by a hazy sky. With a background of haze and more or less haze between the ship and the periscope of the U-boat, it was not a very difficult matter to paint a ship so that it would be invisible six or seven miles away. One shade of gray was used to conceal a ship in the North Sea and an entirely different shade was used for the brighter skies of the Mediterranean.

In this way, the artists made it possible for

(C) International Film

A Giant Gun Concealed Among Trees Behind the French Lines

(C) Committee on Public Information

Observing the Enemy from a Papier-Mâché Replica of a Dead Horse ships to sail in safety much nearer the pursuer who was trying to find them, and by just so much they reduced his powers of destruction. But still the odds were too heavy against the merchantman. Something must be done for him when he found himself within the seven-mile danger-zone. Here again the artists came to the rescue.

Before merchant ships were armed, a submarine would not waste a torpedo on them, but would pound them into submission with shell. Even after ships were provided with guns, submarines mounted heavier guns and unless a ship was speedy enough to show a clean pair of heels, the pursuing U-boat would stand off out of range of the ship's guns and pour a deadly fire into it. But the ships, too, mounted larger guns and the submarines had to fall back upon their torpedoes.

GETTING THE RANGE FOR THE TORPEDO

In order to fire its torpedo with any certainty, the U-boat had to get within a thousand yards of its victim. A torpedo travels at from thirty to forty miles per hour. It takes time for it to reach its target and a target which is moving at, say, fifteen knots, will travel five hundred yards while a thirty-knot torpedo is making one hundred yards. And so before the U-boat commander could discharge his torpedo, he had to know how fast the ship was traveling and how far away it was from him. He could not come to the surface and make deliberate observations, but had to stay under cover, not daring even to keep his eye out of water, for fear that the long wake of foam trailing behind the periscope would give him away. All he could do, then, was to throw his periscope up for a momentary glimpse and make his calculations very quickly; then he could move to the position he figured that he should occupy and shoot up his periscope for another glimpse to check up his calculations. On the glass of this periscope, there were a number of graduations running vertically and horizontally. If he knew his victim and happened to know the height of its smokestacks or the length of the boat, he noted how many graduations they covered, and then by a set formula he could tell how far he was from the boat. At the same time he had to work out its rate of travel and note carefully the course it was holding before he could figure where his torpedo must be aimed.

There was always more or less uncertainty about such observations, because they had to be taken hastily, and the camoufleurs were not slow to take advantage of this weakness. They increased the enemy's confusion by painting high bow-waves which made the ship look as if it were traveling at high speed. They painted the bow to look like the stern, and the stern to look like the bow, and the stacks were painted so that they appeared to slant in the opposite direction, so that it would look as if the vessel were headed the other way. U-boats came to have a very wholesome respect for destroyers and would seldom attack a ship if one of these fast fighting-craft was about, and so destroyers were painted on the sides of ships as scarecrows to frighten off the enemy.

MAKING STRAIGHT LINES LOOK CROOKED

We say that "seeing is believing," but it is not very hard to deceive the eye. The lines in Fig. 13 look absolutely parallel, and they are; but cross-hatch the spaces between them, with the hatching reversed in alternate spaces, as in

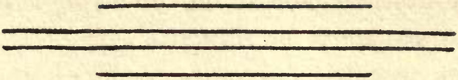
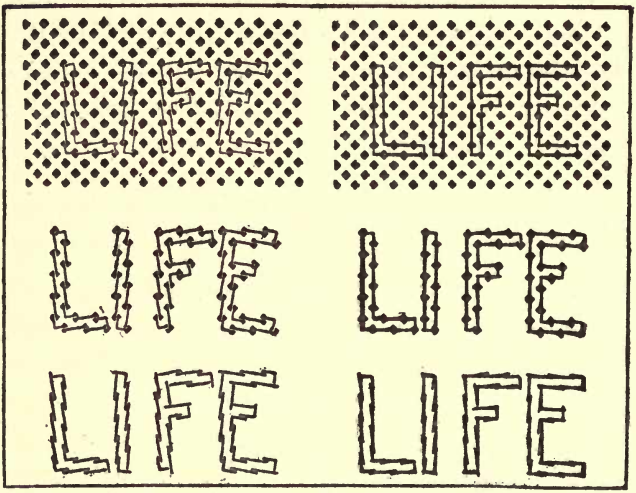


Fig. 13. Parallel lines that look straight

Fig. 14. Parallel lines that do not look straight



Courtesy of the Submarine Defense Association

Fig. 15. Letters that look all higgledy-piggledy, but are really straight

Fig. 14, and they no longer look straight. Take the letters on the left, Fig. 15. They look all higgledy-piggledy, but they are really straight and parallel, as one can prove by laying a straight-edge against them, or by drawing a straight line through each letter, as shown at the right, Fig. 16. Such illusions were used on ships. Stripes were painted on the hull that tapered slightly, from bow to stern, so that the vessel appeared to be headed off at an angle, when it was really broadside to the watcher at the other end of the periscope.

There are color illusions, too, that were tried. If you draw a red chalk-mark and a blue one on a perfectly clean blackboard, the red line will seem to stand out and the blue one to sink into the black surface of the board, because your eye has to focus differently for the two colors, and a very dazzling effect can be had with alternating squares of blue and red. Other colors give even more dazzling effects, and some of them, when viewed at a distance, will blend into the very shade of gray that will make a boat invisible at six miles. When U-boat commanders took observations on a ship painted with a "dazzle" camouflage, they saw a shimmering image which it was hard for them to measure on the fine graduations of their periscopes. Some ships were painted with heavy blotches of black and white, and the enemy making a hasty observation would be apt to focus his attention on the dark masses and overlook the white parts. So he was likely to make a mistake in estimating the height of the smoke-stack or in measuring the apparent length of a vessel.

A JOKE ON THE PHOTOGRAPHER

Early in the submarine campaign one of our boats was given a coat of camouflage, and when the vessel sailed from its pier in the North River, New York, the owners sent a photographer two or three piers down the river to photograph the ship as she went by. He took the picture, but when the negative was developed, much to his astonishment he found that the boat was not all on the plate. In the finder of his camera, he had mistaken a heavy band of black paint for the stern of the ship, quite overlooking the real stern, which was painted a grayish white. The artist had fooled the photographer and at a distance of not more than two or three hundred yards!

SEEING BEYOND THE HORIZON

The periscope of a submarine that is running awash can be raised about fifteen feet above the water, which means that the horizon as viewed from that elevation is about six miles away, and if you draw a circle with a six-mile radius on the map of the Atlantic, you will find that it is a mere speck in the ocean; but a U-boat commander could see objects that lay far beyond his horizon because he was searching for objects which towered many feet above the water. The smoke-stacks of some vessels rise a hundred feet above the water-line, and the masts reach up to much greater altitudes. Aside from this, in the early days of the war steamers burned soft coal and their funnels belched forth huge columns of smoke which was visible from twenty to thirty miles away.

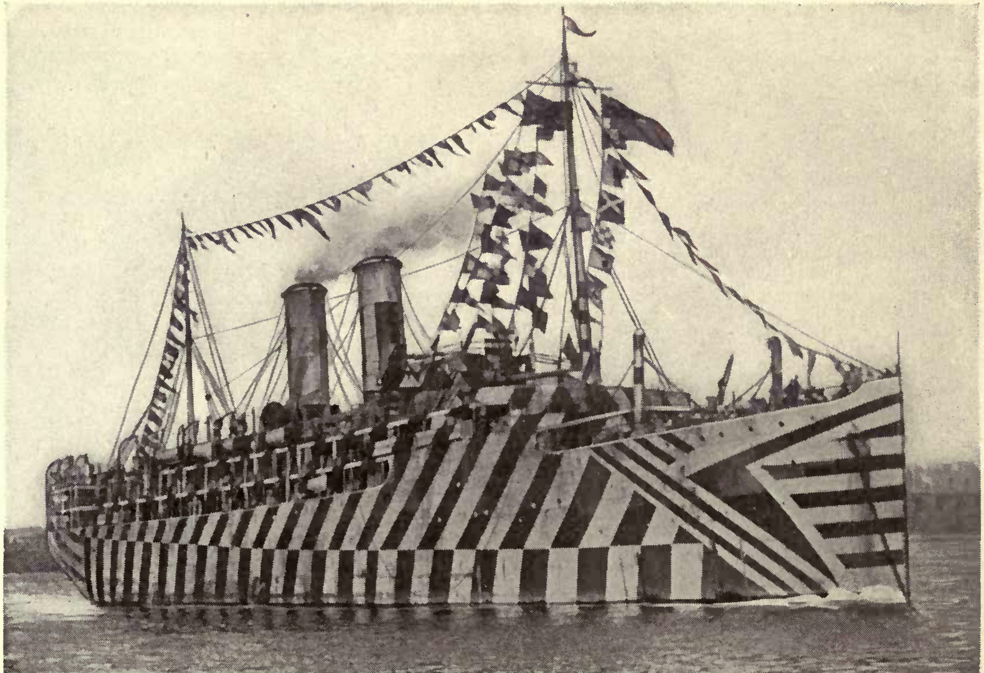
When this was realized, efforts were made to cut down the superstructure of a ship as much as possible. Some vessels had their stacks cut down almost to the deck-line, and air-pumps were installed to furnish the draft necessary to keep their furnaces going. They had no masts except for slender iron pipes which could be folded down against the deck and could be erected at a moment's notice, to carry the aërials of the wireless system. Over the ship from stem to stern was stretched a cable, familiarly known as a "clothes-line," upon which were laid strips of canvas that completely covered the superstructure of the ship. These boats lay so low that they could not be seen at any great distance, and it was difficult for the U-boats to find them. They were slow boats; too slow to run away from a modern submarine, but because of their lowly structure, they managed to elude the German U-boats. When they were seen, the U-boat commanders were afraid of them. They were suspicious of anything that looked out of the ordinary, and preferred to let the "clothes-line ships" go.

THE BRITISH MYSTERY SHIPS

The Germans had some very unhealthy experiences with the "Q-boats" or "mystery ships" of the British. These were vessels rigged up much like ordinary tramp steamers, but they were loaded with wood, so that they

(C) Committee on Public Information — From Western Newspaper Union

Camouflaged Headquarters of the American 26th Division in France



(C) Underwood & Underwood

A Camouflaged Ship in the Hudson River on Victory Day would not sink, and their hatches were arranged to fall open at the touch of a button, exposing powerful guns. They also were equipped with torpedo-tubes, so that they could give the U-boat a dose of its own medicine. These ships would travel along the lanes frequented by submarines, and invite attack. They would limp along as if they had been injured by a storm or a U-boat attack, and looked like easy prey. When a submarine did attack them, they would send out frantic calls for help, and they had so-called 'panic'' parties which took to the boats. Meantime, a picked crew remained aboard, carefully concealed from view, and the captain kept his eye upon the enemy through a periscope disguised as a small ventilator, waiting for the U-boat to come within range of certain destruction. Sometimes the panic party would lure the submarine into a favorable position by rowing under the stern as if to hide around the other side of the ship. At the proper moment, up would go the white ensign—the British man-of-war flag—the batteries would be unmasked, and a hail of shell would break loose over the Hun. Many a German submarine was accounted for by such traps.

Submarines themselves used all sorts of camouflage. They were frequently equipped with sails which they would raise to disguise themselves as peaceful sloops, and in this way they were able to steal up on a victim without discovery. Sometimes they would seize a ship and hide behind it in order to get near their prey.

CAMOUFLAGE ON LAND

But the call for the wielders of the paint-brush came not only from the sea. Their services were needed fully as much on land, and the making of land camouflage was far more interesting because it was more varied and more successful. Besides, it called for more than mere paint; all sorts of tricks with canvas, grass, and branches were used. Of course, the soldiers were garbed in dust-colored clothing and shiny armor was discarded. The helmets they wore were covered with a material that cast no gleam of light. In every respect, they tried to make themselves of the same shade as their surroundings. Like the Indians, they painted their faces. This was done when they made their raids at night. They painted their faces black so that they would not show the faintest reflection of light.

A PAPER HORSE

The most interesting camouflage work was done for the benefit of snipers or for observers at listening-posts close to the enemy trenches. It was very important to spy on the enemy and discover his plans, and so men were sent out as near his lines as possible, to listen to the conversation and to note any signs of unusual activity which would be likely to precede a raid. These men were supplied with telephone wires which they dragged over No Man's Land, and by which they could communicate their discoveries to headquarters. Some very ingenious listening-posts were established. In one case a papier-mâché duplicate of a dead horse was made, which was an exact facsimile of an animal that had been shot and lay between the two lines. One night, the carcass of the horse was removed and the papier-mâché replica took its place. In the latter a man was stationed with telephone connection back to his own lines. Here he had an excellent chance to watch the enemy.

On another occasion a standing tree, whose branches had been shot away, was carefully photographed and an exact copy of it made, but with a chamber inside in which an observer could be concealed. One night while the noise of the workmen was drowned by heavy cannonading, this tree was removed and its facsimile was set up instead, and it remained for many a day before the enemy discovered that it was a fake tree-trunk. It provided a tall observation post from which an observer could direct the fire of his own artillery.

FOOLING THE WATCHERS IN THE SKY

In the early stages of the war, it seemed impossible to hide anything from the Germans. They had eyes everywhere and were able to anticipate everything the Allies did. But the spies that infested the sky were the worst handicap. Even when the Allies gained control of the air, the control was more or less nominal because every now and then an enemy observer would slip over or under the patrolling aëroplanes and make photographs of the Allies' lines. The photographs were carefully compared with others previously taken, that the slightest change in detail might be discovered. Airplane observers not only would be ready to drop bombs on any suspicious object or upon masses of troops moving along the roads, but would telephone back to their artillery to direct its fire upon these targets. Of course, the enemy knew where the roads were located and a careful watch was kept of them.

The French did not try to hide the roads, but they concealed the traffic on the roads by hanging rows of curtains over them. As these curtains hung vertically and were spaced apart, one would suppose that they would furnish little concealment, but they prevented an observer in an aëroplane from looking down the length of a road. All the road he could see was that which lay directly under his machine, because there he could look between the curtains; if he looked obliquely at the road, the curtains would appear to overlap one another and would conceal operations going on under them.

In one case, the Germans completely covered a sunken road with canvas painted to represent a road surface. Under this canvas canopy, troops were moved to an important strategic point without the slightest indication of such a movement.

HIDING BIG GUNS

Nature's tricks of camouflage were freely used in the hiding of the implements of war on land. Our big guns were concealed by being painted with leopard spots and tiger stripes, the color and nature of the camouflage depending upon the station they were to occupy. In many cases, they were covered with branches of trees or with rope netting overspread with leaves. So careful was the observation of the air scouts that even the grass scorched by the fire of the gun had to be covered with green canvas to prevent betrayal of the position of the gun.

ROADS THAT LED NOWHERE

In the making of an emplacement for a gun it was of the utmost importance that no fresh upturned earth be disclosed to the aërial observers. Even foot-paths leading to it had to be concealed. Plans were carefully made to cover up all traces of the work before the work was begun. Where it was impossible to conceal the paths, they were purposely made to lead well beyond the point where the emplacement was building, and, still further to deceive the enemy, a show of work was sometimes undertaken at the end of the path. Wherever the sod had to be upturned, it was covered over with green canvas. The earth that was removed had to be concealed somewhere and the best place of concealment was found to be some old shell-hole which would hold a great deal of earth without any evidence that would be apparent to an observer in an aëroplane. If no shell-hole were handy, the excavated material had to be hauled for miles before a safe dumping-ground could be found. As far as possible everything was sunk below the earth level. Big pits were dug in which the mortars were placed, or if a shell-hole were empty, this was used instead.

SHADOWLESS BUILDINGS

Any projection above the ground was apt to cast a shadow which would show up on the observer's photographs. This was a difficulty that was experienced in building the hangars for airplanes. The roofs of these sheds were painted green so as to match the sod around them, but as they projected above their surroundings, they cast shadows which made them clearly evident to the enemy. This was overcome by the building of shadowless hangars; that is, hangars with roofs that extended all the way to the ground at such an angle that they would cause no shadow except when the sun was low. In some cases, aëroplanes were housed in underground hangars, the approach to which was concealed by a canvas covering. As for the machines themselves, they scorned the use of camouflage. Paint was little protection to them. Some attempt was made to use transparent wings of *cellon,* a material similar to celluloid, but this did not prove a success.

THE PHOTOGRAPHIC EYE

Although camoufleurs made perfect imitations of natural objects and surroundings, they were greatly concerned to find that the flying observers could see through their disguises. To the naked eye the landscape would not show the slightest trace of any suspicious object, but by the use of a color-screen to cut out certain rays of light, a big difference would be shown between the real colors of nature and the artist's copies of them. For instance, if a roof painted to look like green grass were viewed through a red color-screen, it would look brown; while the real grass, which apparently was of exactly the same shade as the roof, would look red. It had not been realized by the artists who had never studied the composition of light, that there is a great deal of red in the green light reflected by grass, and that if they were to duplicate this shade of green, they must put a certain amount of red paint in their imitation grass roofs. Air scouts did not depend upon their eyes alone, but used cameras so that they could study their photographs at their leisure and by fitting the cameras with different color-screens, they could analyze the camouflage and undo the patient work of the artist.

A CALL FOR THE PHYSICIST

To meet this situation, another man was summoned to help—the physicist, who looks upon color merely as waves of ether; who can pick a ray of light to pieces just as a chemist can analyze a lump of sugar. Under his expert guidance, colors of nature were imitated so that they would defy detection. Aside from this, the physicist helped to solve the tricks of the enemy's camoufleurs.

But the physicist had barely rolled up his sleeves and got into the fray when the armistice was signed which put an end to the shams as well as to the realities of the great war. While the work of camouflage was not completed, we owe an inestimable debt to the men who knew how to fake scenery and to their learned associates who count the wave lengths of light, and although their trade was a trade of deception and shams, there was no sham about the service they rendered.

MAKING SHIPS VISIBLE

While in war safety lies in invisibility, in peace the reverse is true. Now that the war is over, it may seem that the work of the camoufleurs can find no useful application; but it was impossible to learn how to make objects invisible without also learning how to make them conspicuously visible. As a consequence, we know now how to paint a ship so that it will show up more clearly in foggy weather, thereby reducing the danger of collision. We know, too, how to paint light-ships, buoys, etc., so that they will be much more conspicuous and better guides to mariners, and how to color railroad signals and road signs so that they will be more easily seen by locomotive engineers and automobile drivers.

CHAPTER XII

SUBMARINES

IT was an American invention that dragged America into the war—an American invention in the hands of barbarians and put to unspeakably barbarous use.

After seeing how the Huns used the submarine we are not so sure that we can take much pride in its invention. But if any blame attaches to us for developing the submarine, we made amends by the way in which we fought the German U-boat and put an end to German frightfulness on the sea. Of course, the credit for Germany's defeat is not for a moment claimed by Americans alone, but it must be admitted that we played an important part in overcoming the menace of the U-boat.

There is no question that the submarine was an American invention. To be sure, we can look into ancient books and find suggestions for navigating under the surface of the sea, but the first man who did actually build a successful submarine was David Bushnell, back in the Revolutionary War. After him came Robert Fulton, who carried the invention farther. He built and operated a submarine for the French Government, and, in more recent years, the submarine became a practical vessel of war in the hands of John P. Holland and Simon Lake, both Americans. However, we are not interested, just now, in the history of the submarine, but rather in the development of this craft during the recent war.

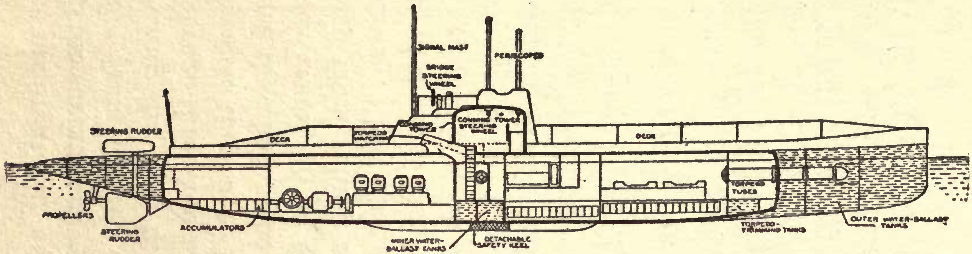
With Great Britain as an enemy, Germany knew that she was hopelessly outclassed on the sea; but while "Britannia ruled the waves," she did not rule the depths of the sea, and so Germany decided to claim this realm for her own. Little attention did she pay to surface vessels. Except in the Dogger Bank engagement and the Battle of Jutland, the German first-class vessels did not venture out upon the open sea, and even the lighter craft merely made occasional raids under cover of fog or darkness, only to cut and run as soon as the British vessels appeared. The submarine boat, or *unterseeboot* as the Germans called it, was virtually the only boat that dared go out into the high seas; consequently, the Germans specialized upon that type of craft and under their close attention it grew into a highly perfected war-vessel. But the Germans were not the only ones to develop the submarine, as we shall see.

CONSTRUCTION OF THE U-BOATS

When the great war broke out, the German U-boat was a comparatively small craft, less than 150 feet long, with its main hull only 12 feet in diameter. It could make a speed of 12 knots on the surface and only 9 when submerged. But as the war progressed, it grew larger and larger, until it attained a length of over 300 feet and its speed was increased to 12 knots when submerged and 18 knots on the surface.

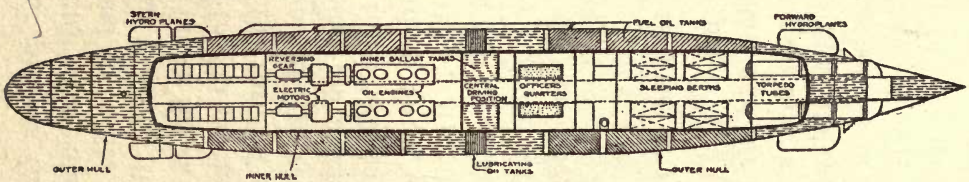
Figs. 16 to 18 show the construction of one of the early U-boats. The later boats were built after the same general plan, but on a bigger scale.

It is not always safe to judge a thing by its name; to do so is apt to lead to sad mistakes. One would naturally suppose, from its name, that a submarine is a boat that lives under water, like a fish. But it is not a fish; it is



Courtesy of the "Scientific American"

FIG. 16. Sectional view of one of the earlier German U-Boats



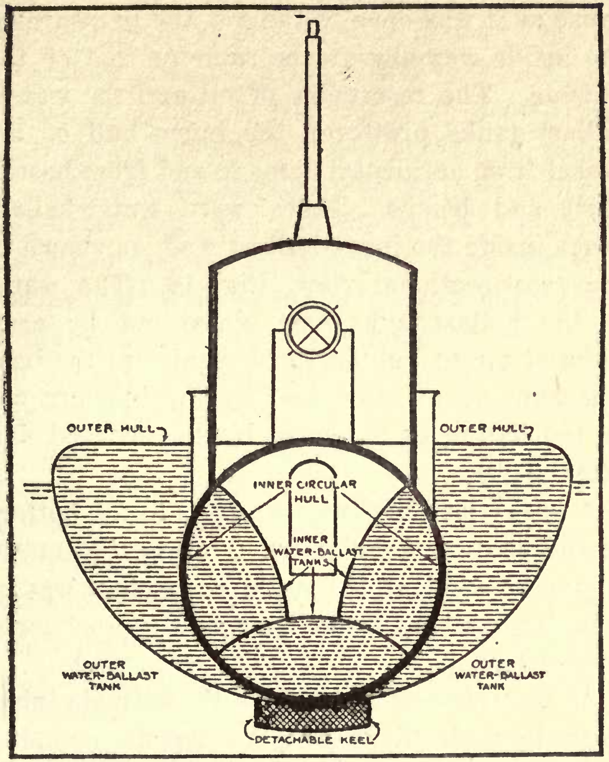
Courtesy of the "Scientific American"

FIG. 17. Sectional plan view of a German U-Boat of the type used at the beginning of the war

an air-breathing animal that prefers to stay on the surface, only occasionally diving under to hide from danger or to steal upon its prey. During the war, the German U-boats did not average three hours per day under the surface! Because they were intended to run on the surface they had to be built in the form of a surface vessel, so as to throw off the waves and keep from rolling and pitching too much in a seaway. But they also had to be built to withstand the crushing weight of deep water, and as a cylinder is much stronger than a structure of ordinary boat shape, the main hull was made circular in section and of heavy plating, strongly framed, while around this was an outer hull of boat shape, as shown in Fig. 18.

PUTTING HOLES IN A TANK TO KEEP IT FULL

The space between the inner and outer hulls was used for water ballast and for reservoirs of oil to drive the engines; and, strange as it may seem, the oil-tanks were always kept full by means of holes in the bottom of them. As the oil was consumed by the engines, water would flow into the reservoir to take its place, and the oil, being lighter than water, would float



Courtesy of the "Scientific American"

FIG. 18. Transverse section through conning-tower, showing the interior (circular) pressure-resisting hull and the lighter exterior hull, which is open to the sea

on top. The false hull was of light metal, because as it was open to the sea, the pressure on the inside was always the same as that on the outside. The reservoirs of oil and the water-ballast tanks protected the inner hull of the vessel from accidental damage and from hostile shell and bombs. There were water-ballast tanks inside the inner hull as well, as shown in the cross-sectional view, Fig. 18. The water in the ballast-tanks was blown out by compressed air to lighten the U-boat and the boat was kept on an even keel by the blowing out or the letting in of water in the forward and after tanks.

A heavy lead keel was attached to the bottom of the boat, to keep it from rolling too much. In case of accident, if there were no other way of bringing the boat to the surface, this keel could be cast loose.

At the forward end, where the torpedo-tubes were located, there was a torpedo-trimming tank. Torpedoes are heavy missiles and every time one was discharged the boat was lightened, and the balance of the submarine was upset. To make up for the loss of weight, water had to be let into the torpedo-trimming tank.

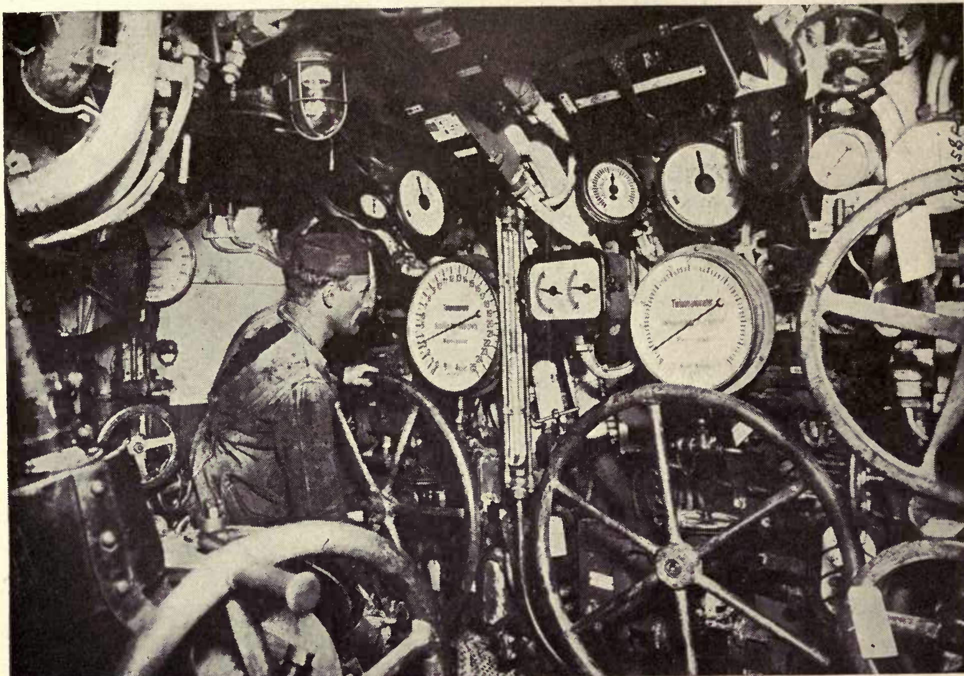
A submarine cannot float under-water without swimming; in other words, it must keep its propellers going to avoid either sinking to the bottom of the sea or bobbing up to the surface. To be sure, it can make itself heavier or lighter by letting water into or blowing water out of its ballast-tanks, but it is impossible to regulate the water ballast so delicately that the submarine will float submerged; and should the boat sink to a depth of two hundred feet or so, the weight of water above it would be sufficient to crush the hull, so it is a case of sink or swim. Usually enough ballast is taken on to make the submarine only a little lighter than the water it displaces; and then to remain under, the vessel must keep moving, with its horizontal rudders tilted to hold it down. The horizontal rudders or hydroplanes of the U-boat are shown in Fig. 17, both at the bow and at the stern.

The main hull of the vessel was literally filled with machinery. In the after part of the boat were the Diesel oil-engines with which the U-boat was propelled when on the surface. There were two engines, each driving a propeller-shaft. It was impossible to use the engines when the vessel was submerged, not because of the gases they produced—these could easily have been carried out of the boat—but because every internal-combustion engine consumes enormous quantities of air. In a few minutes the engines would devour all the air in the hull of the submarine and would then die of suffocation. And so the engines were used only when the submarine was running awash or on the surface, and then the air consumed by them would rush down the hatchway like a hurricane to supply their mighty lungs.

ENGINES THAT BURN HEAVY OIL

The oil-engines were strictly a German invention. In the earlier days of the submarine gasolene-engines were used, but despite every precaution, gasolene vapors occasionally would leak out of the reservoirs and accumulate in pockets or along the floors of the hull, and it needed but a spark to produce an explosion that would blow up the submarine. But Rudolph Diesel, a German, invented an engine which would burn heavy oils.

In the Diesel engine there are no spark-plugs and no magneto: the engine fires itself with-



(C) Underwood & Underwood

Complex Mass of Wheels and Dials inside a German Submarine

Photograph by International Film Service

Surrendered German Submarines, showing the Net Cutters at the Bow out electrical help. Air is let into the cylinder at ordinary atmospheric pressure, or fifteen pounds per square inch. But it is compressed by the upward stroke of the piston to about five hundred pounds per square inch. When air is compressed it develops heat and the sudden high compression to over thirty times its normal pressure raises the temperature to something like 1000 degrees Fahrenheit. Just as this temperature is reached, a jet of oil is blown into the cylinder by air under still higher pressure. Immediately the spray of oil bursts into flame and the hot gases of combustion drive the piston down. Because of the intense heat almost any oil, from light gasolene to heavy, almost tarlike oils, can be used. As heavy oils do not throw off any explosive vapors unless they are heated, they make a very safe fuel for submarines.

To drive the U-boat when no air was to be had for the engines, electric motors were used. There was one on each propeller-shaft and the shafts could be disconnected from the oil-engines when the motors were driving. The motors got their power from storage batteries in the stern of the submarine and under the floors forward. The motors when coupled to and driven by the engines generated current which was stored in the storage batteries. The submarine could not run on indefinitely underwater. When its batteries were exhausted it would have to come to the surface and run its engines to store up a fresh charge of electricity. The electric motors gave the boat a speed of about nine knots.

In addition to the main engines and motors, there was a mass of auxiliary machinery. There were pumps for compressing air to blow the ballast-tanks and to discharge the torpedoes. There was a special mechanism for operating the rudder and hydroplanes, and all sorts of valves, indicators, speaking-tubes, signal lines, etc. The tiny hull was simply crammed with mechanism of all kinds and particularly in the early boats there was little room for the accommodation of the officers and crew. The officers' quarters were located amidships, and forward there were the folding berths of the crews. In the later boats more space was given the men. The large U-boats carried a crew of forty and as the hazards of submarine warfare increased, more attention had to be paid to the men.

FAT MEN NOT WANTED

Oddly enough, small, slender men were preferred for submarine duty, not because of lack of space, but because it was apt to be very cold in a submarine, particularly in the winter-time. The water cooled off the boat when the submarine was traveling submerged, and the motors gave off little heat; while when the vessel was running on the surface the rush of wind to supply the engines kept the thermometer low. This meant that the men had to pile on much clothing to keep warm, which made them very bulky. The hatchway was none too large and a fat man, were he bundled up with enough clothing to keep him warm, would have a hard time squeezing through.

In the center of the vessel was the main hatchway, leading up to the conning-tower, which was large enough to hold from three to five men. This was the navigating-room when the vessel was running submerged, and above it was the navigating-bridge, used when the submarine was on the surface. In the conning-tower there was a gyroscopic compass; a magnetic compass would not work at all inside the steel hull of the U-boat. And here were the periscopes or eyes of the submarine, rising from fifteen to twenty feet above the roof of the conning-tower. There were usually two periscopes. They could be turned around to give the man at the wheel a view in any direction and they were used sometimes even when the vessel was running on the surface, to give a longer range of vision.

THE BLINDNESS OF THE SUBMARINE

Now, a submarine cannot see anything under-water. The commander cannot even see the bow of his boat from the conning-tower, and until he gets near enough to the surface to poke his periscope out of water he is absolutely blind and must feel his way about with compass and depth-gage. It was always an anxious moment for the U-boat commander, when he was coming up, until his periscope broke out of the water and he could get his bearings; and even that was attended with danger, for his periscope might be seen. Of course a periscope is a very insignificant object on the broad sea, but when a submarine is moving its periscope is followed by a wake which is very conspicuous, and so the U-boat ran a chance of being discovered and destroyed before it could dive again to a safe depth. Later, telescoping periscopes were used, which could be raised by means of a hand-lever. The submarine would run along just under the surface and every now and then it would suddenly raise its periscope for an observation and drop it down again under cover if there was danger nigh. This was much simpler and quicker than having a six- or eight-hundred-ton boat come up to the surface and dive to safety. He might even collide with a vessel floating on the surface, but to lessen this danger submarines were furnished with ears or big microphone diaphragms at each side of the hull by which a ship could be located by the noise of its propellers.

In the bow were the torpedo-tubes and the magazine of torpedoes. At first there were only two torpedo-tubes, but later the number was increased to four. These were kept constantly loaded, so that the projectiles could be launched in rapid succession, if necessary, without a pause for the insertion of a fresh torpedo. In some submarines tubes were provided in the stern also so that the boat could discharge a torpedo at its enemy while running away from him.

Each tube was closed at the outer end by a cap and at the inside end by a breech-block. The tube was blown clear of water by means of compressed air, and of course the outer cap was closed when the breech was open to let in a torpedo. Then the breech was closed, the cap opened, and the torpedo was discharged from the tube by a blast of air.

THE TORPEDO

A torpedo is really a motor-boat, a wonderfully constructed boat, fitted with an engine of its own that is driven by compressed air and which drives the torpedo through the water at about forty miles per hour. The motor-boat is shaped like a cigar and that used by the Germans was about fifteen feet long and fourteen inches in diameter. We used much larger torpedoes, some of them being twenty-two feet long. Ours have a large compressed-air reservoir and will travel for miles; but the Germans used their torpedoes at short ranges of a thousand yards and under, cutting down the air-reservoir as much as possible and loading the torpedo with an extra large explosive charge.

We found in the Diesel engine that when air is highly compressed it becomes very hot. When compressed air is expanded, the reverse takes place, the air becomes very cold. The air that drives the motor of the torpedo grows so cold that were no precautions taken it would freeze any moisture that might be present and would choke up the engine with the frost. And so an alcohol flame is used to heat the air. The air-motor is started automatically by release of a trigger as the torpedo is blown out of the torpedo-tube. By means of gearing, the motor drives two propellers. These run in opposite directions, so as to balance each other and prevent any tendency for the torpedo to swerve from its course. The torpedo is steered by a rudder which is controlled by a gyroscope, and it is kept at the proper depth under water by diving-rudders which are controlled by a very sensitive valve worked by the weight of the water above it. The deeper the water, the greater the weight or pressure; and the valve is so arranged that, should the torpedo run too far under, the pressure will cause the diving-rudders to tilt until the torpedo comes up again; then if the torpedo rises too high, the valve will feel the reduction of pressure and turn the rudders in the other direction.

The business end of a torpedo is a "war-head" packed with about four hundred pounds of TNT. At the nose of the torpedo is a firing-pin, with which the war-head is exploded. Ordinarily, the firing-pin does not project from the torpedo, but there is a little propeller at the forward end which is turned by the rush of water as the torpedo is driven on its course. This draws out the firing-pin and gets everything ready for the TNT to explode as soon as the firing-pin is struck. But the firing-pin is not the only means of exploding the torpedo. Inside there is a very delicate mechanism that will set off the charge at the least provocation. In one type of torpedo a steel ball is provided which rests in a shallow depression and the slightest shock, the sudden stopping or even a sudden swerve of the torpedo, would dislodge the ball and set off the charge. Hence various schemes, proposed by inventors, for deflecting a torpedo without touching the firing pin, would have been of no value at all.

GUNS ON SUBMARINES

As torpedoes are expensive things, the U-boats were supplied with other means of destroying their victims. The Germans sprang a surprise by mounting guns on the decks of their submarines. At first these were arranged to be lowered into a hatch when the boat was running submerged, but later they were permanently mounted on the decks so that they would be ready for instant use. They were heavily coated with grease and the bore was swabbed out immediately when the boat came to the surface, so that there was no danger of serious rust and corrosion. The 3-inch gun of the early months of the war soon gave way to heavier pieces and the latest U-boats were supplied with guns of almost 6–inch caliber and there was a gun on the after deck as well as forward.

The U-boats depended upon radiotelegraphy to get their orders and although they did not have a very wide sending-range, they could receive messages from the powerful German station near Berlin. The masts which carried the radio aërials could be folded down into pockets in the deck. From stem to stern over the entire boat a cable was stretched which was intended to permit the U-boat to slide under nets protecting harbor entrances, and in later boats there were keen-toothed knives at the bow which would cut through a steel net. During the war German and Austrian U-boats occupied so much attention that the public did not realize the part that the Entente Allies were playing under the sea. America, Great Britain, France, and Italy made good use of submarines, operating them against enemy vessels, blockading enemy ports, and actually fighting enemy submarines.

A STEAM-DRIVEN SUBMARINE

The British in particular did splendid work with the submarine and developed boats that were superior to anything turned out by the Germans. For instance, they developed a submarine which is virtually a submersible destroyer. It is 340 feet long and it can make a speed of 24 knots on the surface. The most remarkable part of this boat is that its engines are driven by steam. Its boilers are fired with oil fuel. There are two smoke-stacks which fold down when it submerges. Of course when running under-water the vessel is driven by electricity and it makes a speed of 10 knots. It carries three 4–inch guns, two forward and one aft, and its displacement submerged is 2700 tons as against 800 tons for the largest German submarines.

A SUBMARINE THAT MOUNTS A TWELVE-INCH GUN

Still more remarkable is the big "super-submarine" designed by the British to bombard the forts of the Dardanelles, but unfortunately it was built too late to be used there. This submarine carries a gun big enough for a battleship. It is of 12-inch caliber and weighs 50 tons. Of course a big gun like that could not be fired athwart the submarine. It might bowl the little vessel over, even though it was a 1700-ton submarine. The gun is mounted to fire fore and aft, with a deviation of only a few degrees to one side or the other, so that the shock of the recoil is taken by the length instead of the beam of the submarine. It fires a shell weighing 620 pounds and a full charge is not used, so that the extreme range is only about 15,000 yards. This submarine monitor would have been a very difficult target for the Turkish gunners to hit.

When the war came to an end and the German submarines surrendered to the Entente Allies at Harwich, there was considerable public curiosity as to whether or not an examination of the U-boats would disclose any wonderful secrets. But they contained nothing that the Allies did not already know, and one British officer stated that the plans of the German submarines had often fallen into their hands long before a U-boat of the same type was captured!

CHAPTER XIII

Getting the Best of the U-Boat

THE U-boat commander who sallied forth from the harbor of Wilhelmshaven in the early days of the war had nothing to fear. He was out to murder, not to fight. His prey was always out in the open, while he could kill without exposing more than his eye above water. Not even a sporting chance was allowed his victims, particularly when he chose unarmed merchantmen for his targets. He could come up boldly to the surface and shell a ship into submission. This was cheaper than torpedoing the vessel, because torpedoes are expensive. If the ship were speedy it might run away; or if the U-boat came up too close to its intended prey, the latter might run it down. That happened occasionally and it was the only danger that the *Herr Kommandant* had to fear.

If a destroyer suddenly appeared, the U-boat could dive into the shelter of the sea. If the water were not too deep, it could lie on the bottom for two or more days if need be. There was plenty of air in the hull to sustain life for many hours and then the compressed air used for blowing the ballast-tanks could be drawn upon. In the U-boat there were potash cartridges to take up the carbon-dioxide, and tanks of pure oxygen to revitalize the air. If the submarine were damaged, it was not necessary for it to come to the surface to effect repairs. There were air-locks through which a diver could be let out of the boat. He was fitted with oxygen and potash cartridges, so that he did not need to be connected by an air-hose with the boat, but could walk around it freely to mend injured rudders or to clear the propeller of entanglements.

Even the small submarines of those early days were capable of taking long voyages. Setting his course at a comfortable pace of 10 knots, the U-boat commander could count on enough fuel to carry him 1600 miles, and if need be he could slow down to 8 knots and by using certain of his water-ballast tanks for additional oil-reservoirs, extend his cruising-radius to nearly 3000 miles. The big 800-ton

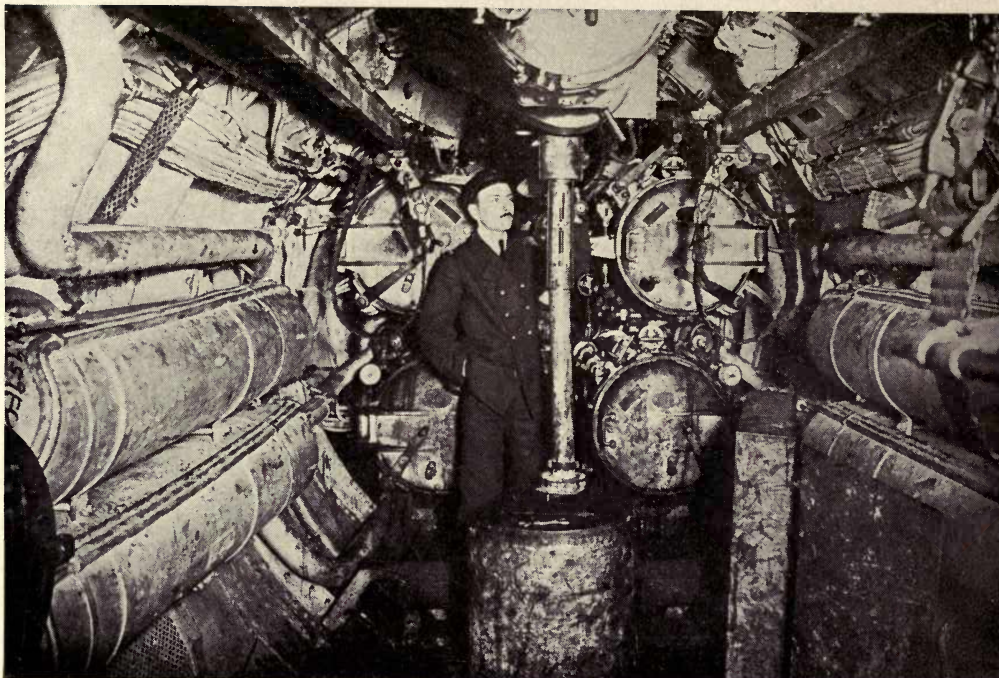
U-boats that were built later had a radius of 5000 miles at an 8-knot speed. And so when the British closed the English Channel with nets and mines, *Herr Kommandant* was not at all perturbed; he could sail around the British Isles if he chose and make war upon trans-atlantic shipping. When harbors were walled off with nets, he could remain outside and sink vessels that were leaving or entering them.

SUBMARINE-CHASERS

A real menace came when the U-boat commander popped his periscope out of the sea and saw several little motor-boats bearing down upon him. They seemed harmless enough, but a moment's inspection showed them to be armed with guns fully as powerful as those he carried. It was useless to discharge a torpedo at so speedy and small a foe. A torpedo has to have a fairly deep covering of water, else its course will be disturbed by surface waves; and the submarine-chasers drew so little water that a torpedo would pass harmlessly under them. It was useless for the U-boat commander to come up and fight them with his guns. They would have been upon him before he could do that, and their speed and diminutive size made them very difficult targets to hit. Besides, he dared not risk a duel of shell, for he knew that if the precious inner hull of his boat were punctured, he could not seek refuge under water; and if he could not hide, he was lost. The little armed mosquito craft swarmed about the harbor entrances, ready to dash at any submarine that showed itself. They could travel twice as fast as the submarine when it was submerged and half again as fast as when it was running on the surface.

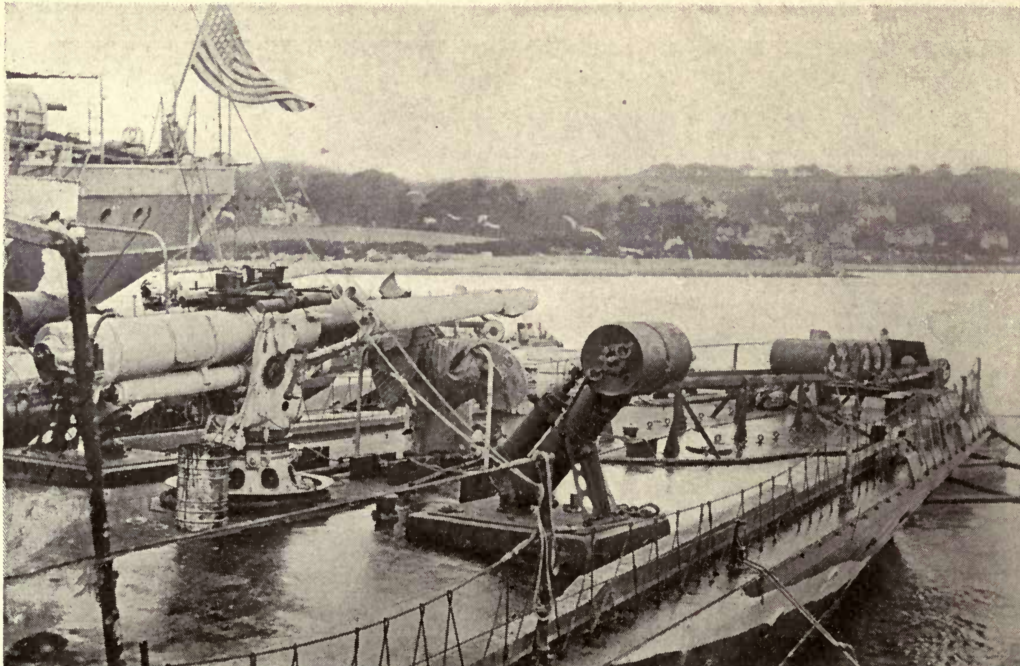
Submarines had to take to cover when these chasers were about. *Herr Kommandant* did not even dare to take a look around through his periscope, because the streak of foam that trailed in its wake would betray him and immediately the speedy motor-boats would take up the chase; and they had a disagreeable way of dropping bombs which, even if they did not sink the submarine, might produce such a concussion as to spring its seams. His foes had discovered one of his most serious defects. He was blind under-water and they were making the most of this handicap.

Groping along under-water by dead-reckon-



(C) Underwood & Underwood

Forward End of a U-boat. Note the Four Torpedo Tubes Behind the Officer



(C) Press Illustrating Service

A Depth-bomb Mortar and a Set of "Ash Cans" at the Stern of an American Destroyer ing was not any too safe a procedure near land, because he was liable at any moment to crash into an uncharted rock or maybe into the wreck of some submarine victim. He could not correct his bearings without coming to the surface, and, in the black depths of the sea, a slight miscalculation might send him to his doom. As was explained in the previous chapter, he had to keep moving, because he could not remain suspended under water.

He was more helpless than a ship sailing in the densest of fogs. A ship can stop and listen to sound-signals, or even to the beating of the surf on the shore, or it can take soundings to locate its position; and yet it is no uncommon occurrence for a ship to run ashore in a fog. How much easier it is for a submarine to lose its bearings when obliged to travel by dead-reckoning, particularly in the disconcerting excitement of the chase! To avoid the danger of collision with surface vessels, the commander chose to run at a depth of sixty-five feet. That was the upper limit of his safety-zone. A depth of over two hundred feet was his lower limit, because, as stated before, the water-pressure at that depth would crush in his hull or at least start its seams. If the bottom were smooth and sandy, and not too deep, he could settle gently upon it and wait for darkness, to make his escape.

But while he lay on a sandy bottom, he was still in danger. Trawlers were sweeping the bottom with nets. He might be discovered; and then if he did not come up and surrender, a bomb would let in the sea upon him.

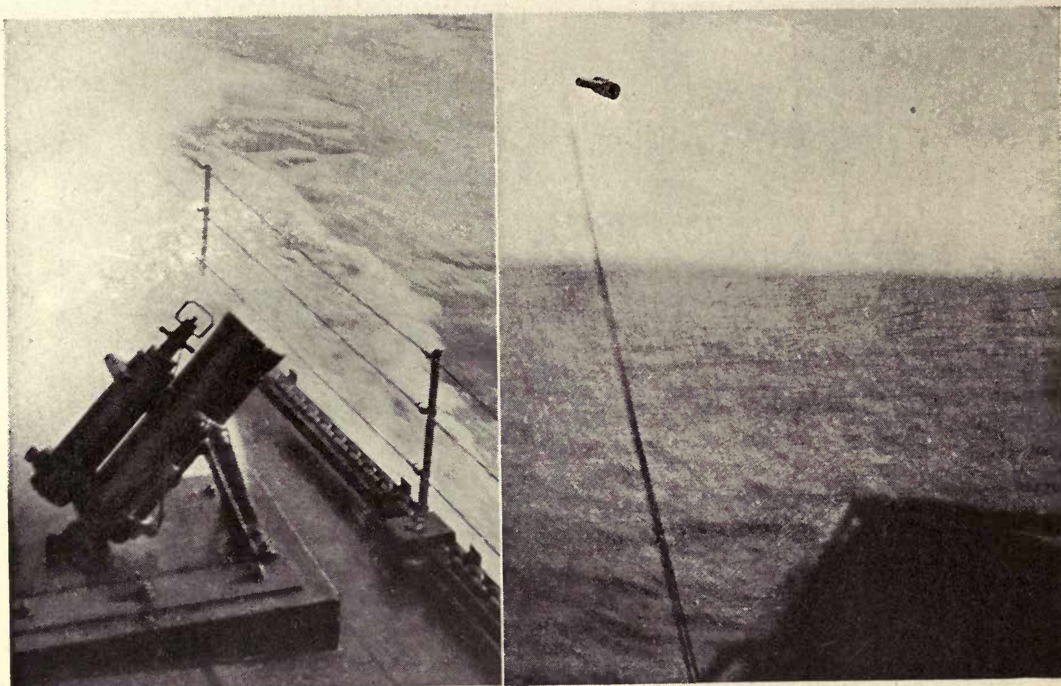
A HINT FROM NATURE

While he could not see under water, his adversaries could. They had taken a hint from nature. The fish-hawk has no difficulty in spying his submarine prey. Flying high above the water, he can see his victims at a considerable depth, and wait his chance to pounce upon an unwary fish that comes too near the surface. It is said that the British trained sea-gulls to hunt submarines. Sea-gulls will follow a ship far out to sea for the sake of feeding on refuse that is thrown overboard. British submarines encouraged the birds to follow them, by throwing out bait whenever they came to the surface. Of course the birds could see the submarine even when it was submerged, and if they pursued it, they were always rewarded with plenty of food. The gulls drew no fine distinction between Hun and Briton, and so it came that *Herr Kommandant* often groped his way along in the dark sea, totally oblivious of the fact that he was attended by an escort of feathered folk who kept the British chasers informed of his presence.

In this connection it is interesting to note that the British trained sea lions to hunt submarines. The animals were taught at first to swim to a friendly submarine, locating it by the sound of its propellers. They were always rewarded with fish. These sea lions were muzzled so that they could not go fishing on their own account. Then they learned to locate enemy submarines and pointed them out by swimming directly toward them and diving down to them.

But there were human eyes, as well, that spied upon the U-boat. Fast seaplanes patrolled the waters, searching constantly for any trace of submarine. Its form could be vaguely outlined to a depth of from fifty to seventy-five feet, unless the sea were choppy, and once it was discovered, chasers or trawlers were signaled to destroy it with bombs or to entangle it in nets. Often a submarine would be discovered by a leak in its oil-tank which would leave a telltale trail. Sometimes when the U-boat itself could not be discerned, there would be slight shimmer, such as may be seen above a hot stove, caused by refraction of light in its wake. This was easily recognized by trained observers.

Even better aërial patrols were the small dirigibles known as Blimps. They are a cross between a balloon and an airplane, for they have the body and the power-plant of an airplane, but the planes are replaced by a gas-bag. Blimps could cruise leisurely and search the sea thoroughly. They could stop and hover directly over a submarine and drop explosives upon it with great accuracy. And so *Herr Kommandant* could take no comfort in hiding under a blanket of waves unless the blanket were so thick as to conceal his form completely from the eyes overhead. This made it imperative to leave the shallower waters near shore and push out into the deep sea, where the small chasers could not pursue him. But he could not shake off his pursuers. Stream-trawlers



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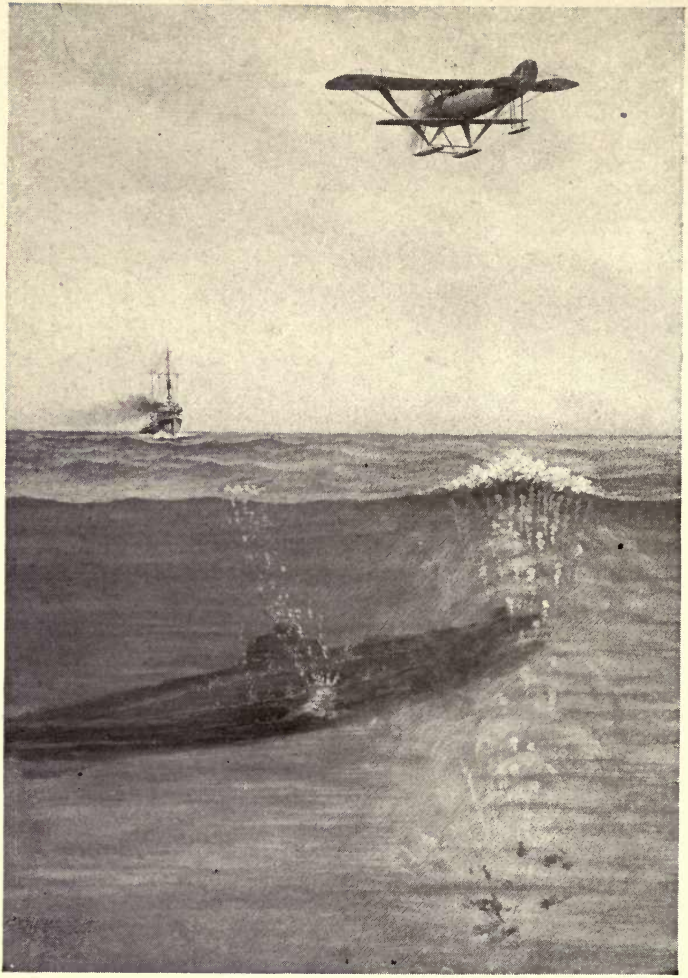
A Depth-bomb Mortar in Action and a Depth-bomb snapped as it is being hurled through the air



Courtesy of "Scientific American"

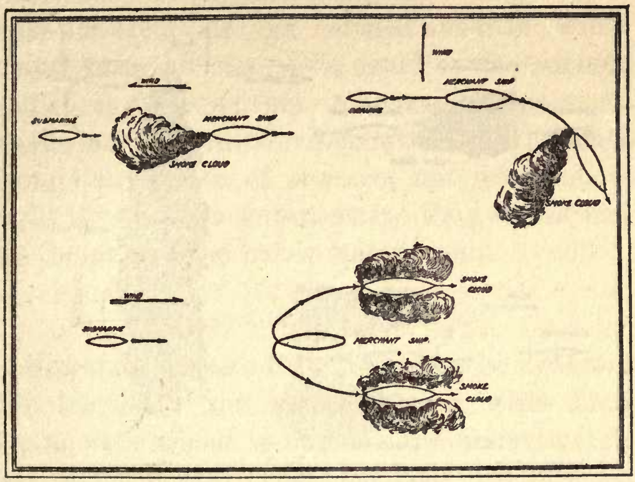
Airplane Stunning a U-boat with a Depth-bomb are built to ride the heaviest gales and they took up the chase out into the ocean.

There was a decided advantage for the U-boat in moving out to sea. It had a wider field of activity and could more easily escape from its pursuers. But on the other hand, its prey also had an advantage. Out in the open ocean they were not obliged to follow the usual ship lanes and it was more difficult for a submarine to intercept them. There it took more U-boats to blockade a given area.

A GAME OF HIDE-AND-SEEK

Then, it ceased to be quite so one-sided a game when merchantmen began to carry guns. That made it necessary for the submarine commander to creep up on his victims stealthily, and depend upon his torpedoes. He had to get within a thousand yards of the ship and preferably within five hundred yards, in order to be sure of hitting it. If the ship could travel faster than he could, he had to do this without betraying his presence. But ship-captains soon learned that their safety lay in zig-zagging. When *Herr Kommandant* reached the point from which he had planned to attack, he would raise his telescopic periscope out of the water, expecting to see his victim within good torpedo range, only to find it sailing safely on another tack. Again, he would have to take observations and make another try, probably with no better luck. It was a game of hide-and-seek in which the merchant ship had a good chance of making its escape, particularly when blotches of camouflage paint made it difficult for him to get the range, as described in Chapter XI.

Slower ships could be attacked without all this manœuvering, provided the submarine's guns outranged those of the ship. And so U-boats were provided with larger and larger guns, which made it possible for them to stand off and pound the merchantmen while out of reach of the vessel's guns. But ships found a way of hiding on the surface of the sea. A vessel would spout forth volumes of dense black smoke which would obliterate it from view. (See Fig. 19.) If the wind was quartering, the ship would change its course and dodge behind the sheltering pall of smoke. Not only was the smoke produced on the vessel itself, but smoke-boxes were cast overboard to form a screen behind the vessel. These smoke-boxes contained a mixture of coal-tar and phosphorus and other chemicals which would produce incomplete combustion. They were ig-

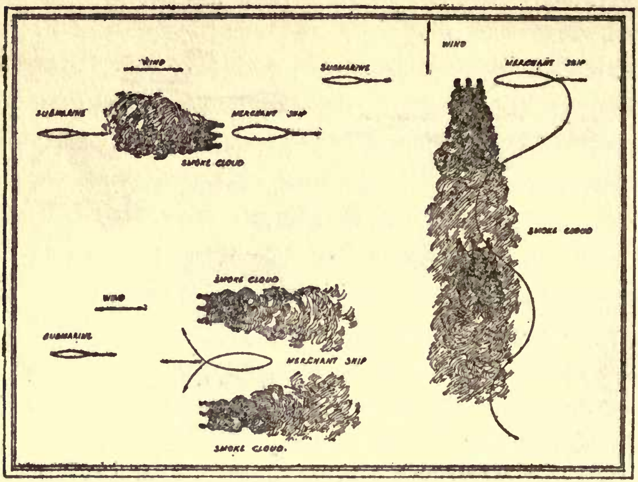


Courtesy of the Submarine Defense Association

FIG. 19. How a ship hid behind smoke produced on its own stern, with different directions of wind

nited by the rubbing of a phosphorus compound on a priming-composition, and then cast adrift to pour out dense volumes of heavy smoke. (See Fig. 20.) Behind this screen, the ship could dodge and zig-zag and if her speed were greater than that of the submarine, her chances of escape were very good.

Another annoyance that *Herr Kommandant* experienced was, when he lifted his periscopic



Courtesy of the Submarine Defense Association

FIG. 20. How a ship hid behind a screen of smoke produced by throwing smoke boxes overboard

eye above water, to find it so smeared with a sticky substance that he could not see. His foes had strewn the water with tar-oil that had spread in a thin film over a surface miles in extent. This blinded him at first, but before long he was equipped with a jet for washing off the periscope glass and that little annoyance was overcome.

But the craft most dreaded by the U-boat commander were the destroyers. These light, high-powered, heavily armed vessels could travel twice as fast as he could on the surface and three times as fast as he could submerged. Shells were invented which would not ricochet from the surface of the sea, but would plow right through the water, where they struck and hit the submarine below water-level.

DEATH-DEALING "ASH CANS"

However, it was not shell-fire that he dreaded, but the big "ash cans" loaded with TNT which were timed to explode far under water, and which would crush his boat or start its seams. It was not necessary for these bombs to hit the U-boat. When they went off they would send out a wave of pressure that would crush the boat or start its seams even if it were a hundred feet and more from the point of the explosion. Within limits, the deeper the explosion the wider would its destructive area be.

The timing-mechanism of some depth bombs consisted merely of a float on the end of a cord. When the bomb was thrown overboard this float remained on the surface until the cord was pulled out to its full length, when there would be a yank on the firing-trigger and the charge would explode. In other depth bombs there was a valve operated by the pressure of the water. When the bomb sank to the depth for which the valve was set, the pressure of the water would force the valve in, exploding a cartridge which set off the charge. So powerful were these depth bombs that the destroyer had to travel at high speed to get out of range of the explosion.

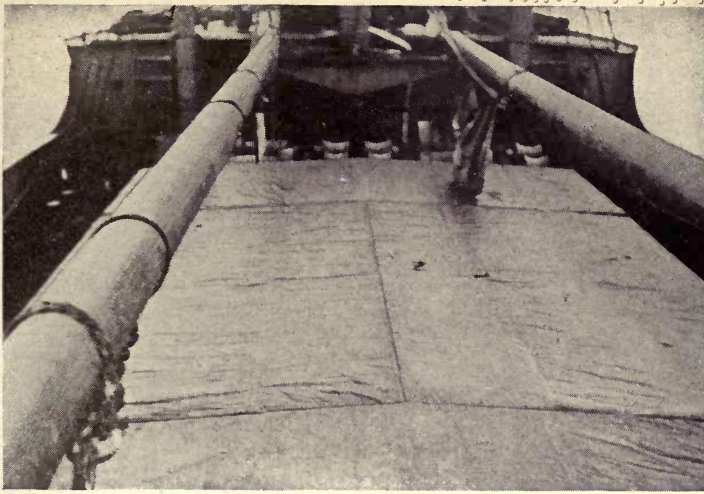
Depth bombs were rolled off the stern of the destroyer and also thrown out from the sides of the vessel by means of mortars. Some of the mortars were Y-shaped and held a depth bomb in each arm of the Y. When a blank 3-inch shell was exploded at the base of the gun, both bombs would be hurled from the ship, one to port and the other to starboard. In this way the destroyer could drop the bombs in a "pattern" of wide area. *Herr Kommandant* gained a wholesome respect for these terriers of the sea. It was suicide to show himself anywhere near a destroyer. In a moment the speedy boat would be upon him, sowing depth bombs along his course. His chances of escaping through this hail of high explosives were remote indeed.

The ships that he was most eager to destroy were either too speedy for him to catch, unless they happened to come his way, or else they were herded in large convoys protected by these dreaded destroyers. The convoy proved a most baffling problem for *Herr Kommandant.* He dared not attack the convoy by daylight. In a fog he might take a chance at picking off one of the ships, but even that was very risky. He could trail the convoy until dusk and then under cover of darkness draw near enough to discharge a torpedo, but in the daytime he must keep his distance because there were eyes in the sky watching for him. At the van and rear of the convoy there were kite balloons high in the sky, with observers constantly watching for periscopes, and for U-boats that might be lurking under the surface.

As the destroyers gained in experience, the difficulties of the U-boat attack grew greater and its work grew more and more perilous.

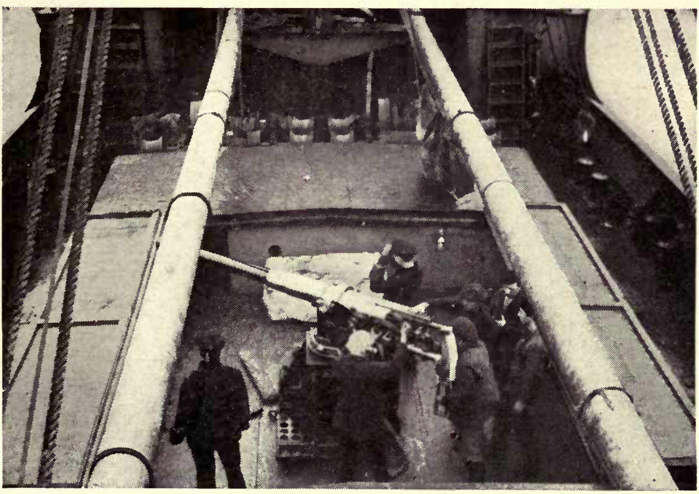
The crew grumbled and grew mutinous. The morale of the men was shaken. We can imagine the horror of plunging hurriedly into the depths of the sea, and rushing along blindly under the surface, dodging this way and that, while terrific explosions of depth bombs stagger the submarine and threaten to crush it, and there is the constant expectation that the next explosion will tear the thin shell of the U-boat and let in the black hungry water. The tables were turned. Now, if never before, *Herr Kommandant,* the hunter, knew what it felt like to be hunted.

It takes an exceptional man to go through such a harrowing experience with unshattered nerves. On at least one occasion, a submarine that was being depth-bombed came suddenly to the surface. The hatch flew open and the crew rushed out, holding up their hands and crying, "*Kamerad.*" The U-boat was uninjured, but the shock of a depth-bomb explosion had put the electric-lighting system out of commission, and the crew, unnerved by the explosion and terrified by the darkness, had overpowered their officers and brought the boat to the surface.

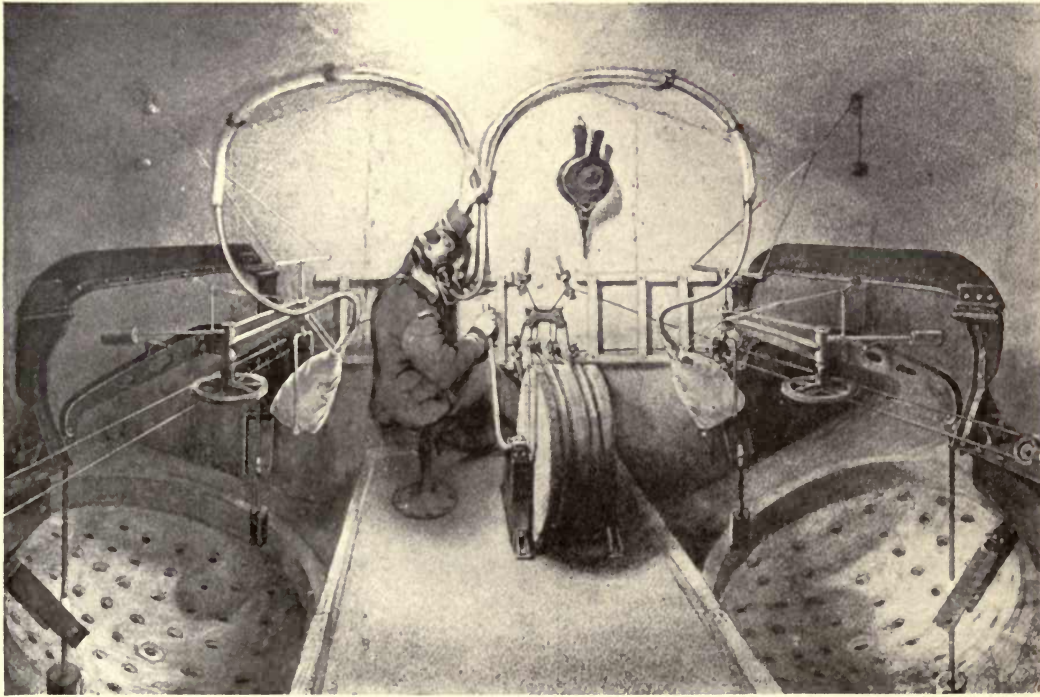


(C) Underwood & Underwood

The False Hatch of a Mystery Ship and —



The same Hatch opened to disclose the 3-Inch Gun and Crew



A French Hydrophone Installation with which the presence of Submarines was detected

EYES IN THE SEA

There were other craft that *Herr Kommandant* had to look out for. His were not the only submarines in the sea. His foes also were possessed of submarines. They could not see under water any better than he could, but they could fight on the surface as well as he, and they could creep up on him even as he crept up on his prey. As a French submarine commander puts it: "The U-boats used to enjoy the advantage of remaining themselves invisible while all the surface and aërial craft which were sent in pursuit of them were boldly outlined against the sky and visible to them. This is one of the reasons we used submarines to ambush U-boats." Submarines were also used to accompany the convoys, so that the U-boat commander had to watch not only for the eyes of the ship's lookouts and the eyes in the kite balloons, but also for the periscope eyes that swam in the sea.

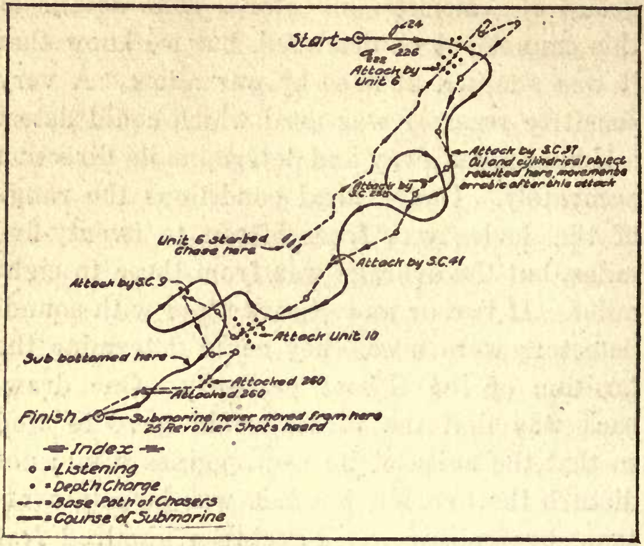
TRAILING U-BOATS BY SOUND

The troubles of the submarine-commander were multiplying. All over the world inventors were plotting his destruction. As long as we depended upon our eyes to ferret him out, the sea was a safe refuge, provided he dived deep enough, but when we began to use our ears as well, he found himself in a very serious predicament. Although light is badly broken up in its passage through water, sound-waves will travel through water much better than in air. The first listening-devices used were crude affairs and did not amount to much, particularly when the U-boats muffled their motors and engines so that they were virtually noiseless. But the French invented a very sensitive sound-detector. It consisted of a lot of tiny diaphragms set in a big hemisphere. There were two of these hemispheres, one at each side of the boat. When sound-waves struck these hemispheres, the diaphragms would respond. At the focus of each hemisphere there was a megaphone receiver; one of these carried the sound to the operator's right ear and the other to his left. He would turn a megaphone around until he found the diaphragm that produced the loudest sound. This gave him the direction of the sound-wave. Then the boat would be steered in that direction. He knew that it was aimed properly when the sound coming to his right ear was just as loud as that which came into his left ear.

A still better hydrophone was developed by a group of American inventors. The details of this cannot yet be disclosed, but we know that it was adopted at once by our allies. A very sensitive receiver was used which could detect a U-boat miles away and determine its direction accurately. Under ideal conditions the range of the device was from fifteen to twenty-five miles, but the average was from three to eight miles. If two or more boats fitted with sound-detectors were used, they could determine the position of the U-boat perfectly. One drawback was that the vessel would have to stop so that the noise of its own engines would not disturb the listener, but this was largely overcome by trailing the detector a hundred feet or more from the stern of the ship. The sounds were then brought in by an electric cable to the listener in the ship.

These sound-detectors were placed on Allied submarines as well as surface vessels and they were actually tried out on balloons and dirigibles, so that they could follow a U-boat after it had submerged too deeply to be followed by sight.

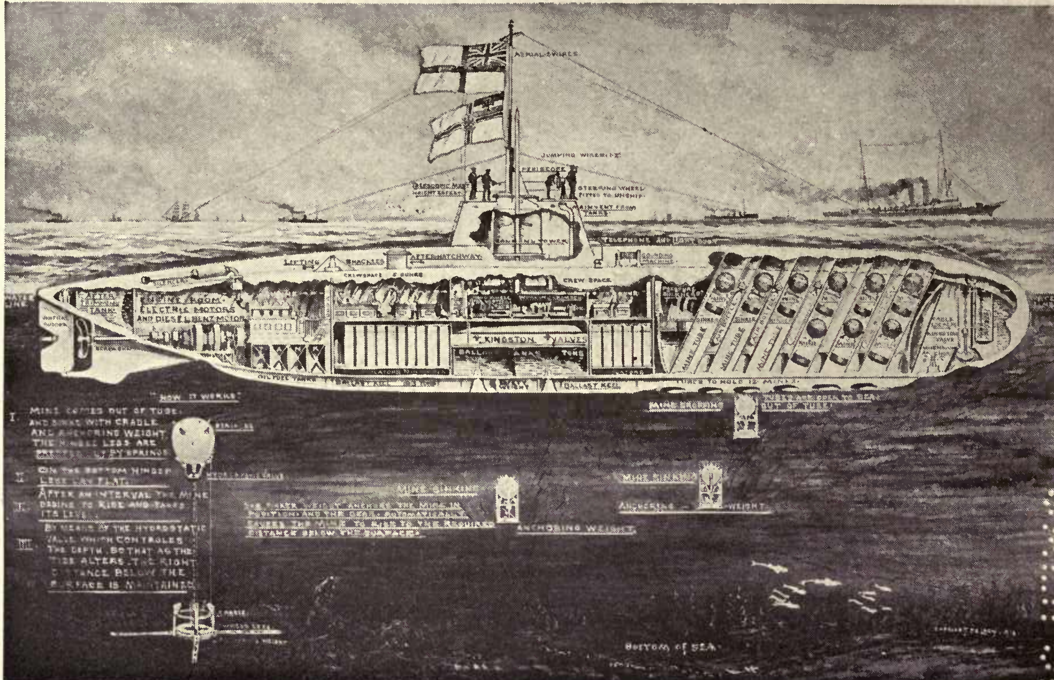
Many U-boats were chased to their doom by the aid of the American hydrophone. Fig.



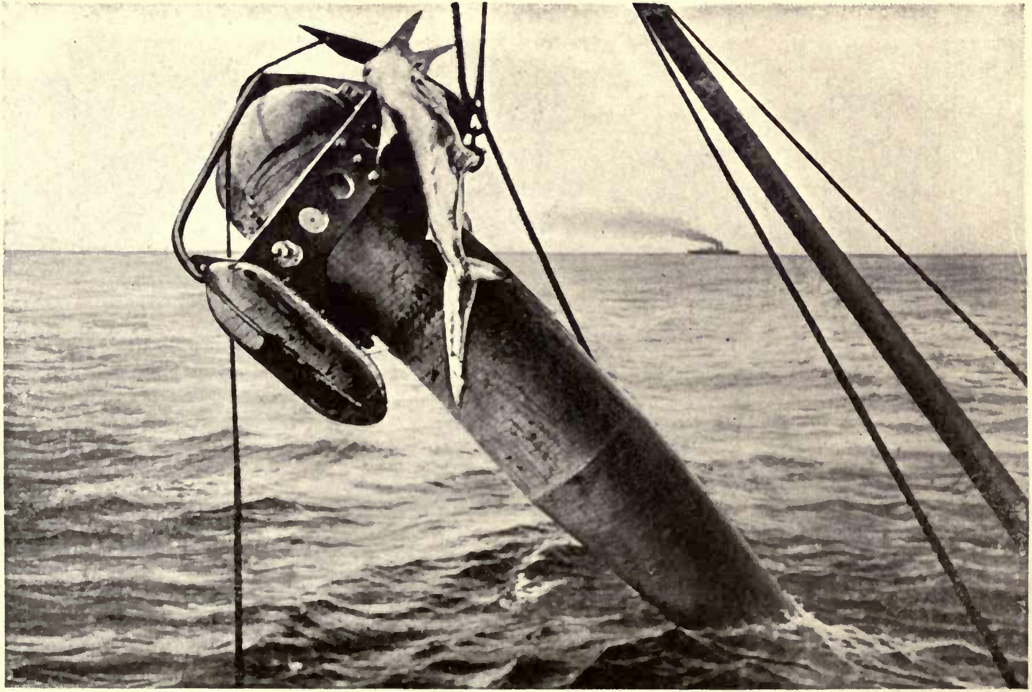
Courtesy of the "Scientific American"

FIG. 21. Chart of an actual pursuit of a U-boat which ended in the destruction of the submarine

21 illustrates a very dramatic chase. The full line shows the course of the U-boat as plotted out by hydrophones and the broken line the course of the submarine-chasers. The dots rep-



Section of a captured Mine-laying U-boat, showing how the mines were laid



(C) Underwood & Underwood

A Paravane hauled up with a Shark caught in its jaws resent patterns of depth bombs dropped upon the U-boat. Try as he would, the *Herr Kommandant* could not shake off his pursuers. At one time, as the listeners stopped to take observations, they heard hammering in the U-boat as if repairs were being made. The motors of the submarine would start and stop, showing clearly that it was disabled. More depth bombs were dropped and then there was perfect silence, which was soon broken by twenty-five revolver-shots. Evidently the crew, unable to come to the surface, had given up in despair and committed suicide.

The Adriatic Sea was an ideal place for the use of the hydrophone. The water there is so deep that submarines dared not rest on the bottom, but had to keep moving, and so they could easily be followed. Across the sea, at the heel of the boot of Italy, a barrage of boats was established. U-boats would come down to this barrage at night and, when within two or three miles of the boats, dive and pass under them. But when hydrophones were used that game proved very hazardous. Our listeners would hear them coming when they were miles away. Then they would hear them shift from oil- to electric-drive and plunge under the surface. Darkness was no protection to the U-boats. The sound-detector worked just as well at night as in the daytime and a group of three boats would drop a pattern of bombs that would send the U-boat to the bottom.

On one occasion after an attack it was evident that the submarine had been seriously injured. Its motors were operating, but something must have gone wrong with its steering-gear, or its ballast-chambers may have been flooded, because it kept going down and soon the listeners heard a crunching noise as it was crushed by the tremendous pressure of the water.

And so U-boat warfare grew more and more terrible for *Herr Kommandant.* The depths of the sea were growing even more dangerous than the surface. On every hand he was losing out. He had tried to master the sea without mastering the surface of the sea. But he can never really master who dares not fight out in the open. For a time, the German did prevail, but his adversaries were quick to see his deficiencies and, by playing upon these, to rob the terror of the sea of his powers. And as *Herr Kommandant* looks back at the time when he stepped into the lime-light as the most brutal destroyer the world has ever seen, he cannot take much satisfaction in reflecting that the sum total of his efforts was to spread hatred of Germany throughout the world, to summon into the conflict a great nation whose armies turned the tide of victory against his soldiers, and finally to subject his navy, second only to that of Great Britain, to the most humiliating surrender the world has ever seen.

CHAPTER XIV

"Devil's Eggs"

IN modern warfare a duel between fixed forts and floating forts is almost certain to end in a draw. Because the former are fixed they make good targets, while the war-ship, being able to move about, can dodge the shell that are fired against it. On the other hand, a fort on land can stand a great deal of pounding and each of its guns must be put out of action individually, before it is subdued, while the fort that is afloat runs the risk of being sunk with a few well-directed shots.

But fortifications alone will not protect a harbor from a determined enemy. They cannot prevent hostile ships from creeping by them under cover of darkness or a heavy fog. To prevent this, the harbor must be mined, and this must be done in such a way that friendly shipping can be piloted through the mine-field, while hostile craft will be sure to strike the mines and be destroyed.

The mines may be arranged to be fired by electricity from shore stations, in which case they are anchored at such a depth that ships can sail over them without touching them. If a hostile vessel tried to dash into the harbor, the touch of a button on shore would sink it when it passed over one of the mines. But the success of electrically fired mines would depend upon the "seeing." In a heavy fog they would prove no protection.

Another way of using electric mines is to have telltale devices which a ship would strike and which would indicate to the operator on shore that a vessel was riding over the mines and would also let him know over which particular mines it was at the moment passing. No friendly vessel would undertake to enter the harbor in a fog or after dark and the operator would not hesitate to blow up the invader even if he could not see him.

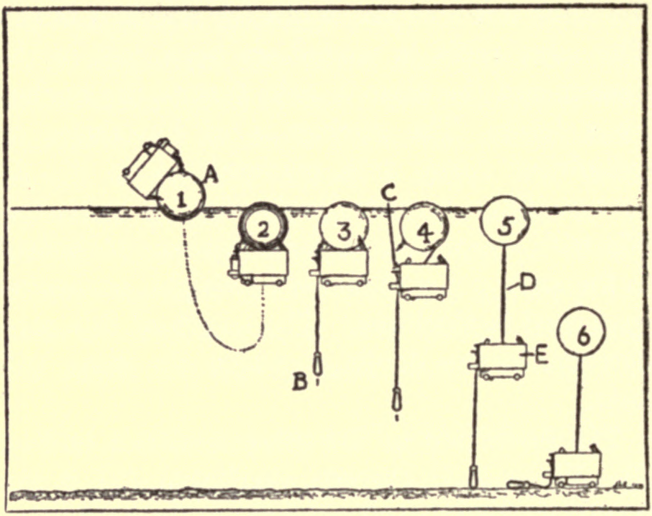
However, the ordinary method of mining a harbor is to lay fields of anchored mines across the channels and entrances to the harbor—sensitive mines that will blow up at the slightest touch of a ship's hull—and leave tortuous passages through the fields for friendly shipping. Of course pilots have to guide the ships through the passages and lest enemy spies learn just where the openings are the mine-fields must be shifted now and then.

The mines are, therefore, made so that they can be taken up by friendly mine-sweepers who know just how to handle them, and planted elsewhere. These are defensive mines, but there are other mines that are not intended to be moved. They are planted in front of enemy harbors to block enemy shipping and they are made so sensitive or of such design that they will surely explode if tampered with.

THE MINE THAT DOES ITS OWN SOUNDING

A favorite type of mine used during the war was one which automatically adjusted itself to sink to the desired depth. Submerged mines are more dangerous to the enemy because they cannot be seen and avoided. They should float far enough under the surface to remain hidden and yet not so deep that a shallow-draft ship can pass over them without hitting them. As the sea bottom may be very irregular, it is impossible to tell how long the anchor cable should be without sounding the depth of the water at every point at which a mine is planted. But the automatic anchor takes care of this. Very ingeniously it does its own sounding and holds the mine down to the depth for which it is set. The mine cable is wound up on a reel in the anchor and the mine is held fast to the anchor by a latch. The anchor is of box-shape or cylindrical form, with perforations in it. At first it sinks comparatively slowly, but as it fills with water it goes down faster. Attached to the anchor is a plummet or weight, connected by a cord to the latch. The length of this cord determines the depth at which the mine will float.

The operation of the mine is shown in Fig. 22. When it is thrown overboard (1) it immediately turns over so that the buoyant mine *A* floats on the surface (2). While the anchor is slowly filling and sinking, the plummet *B* runs out (3). If the mines are to float at a depth of, say, ten feet, this cord must be ten feet long. As soon as it runs out to its full length (4) it springs a latch, *C*, releasing the mine *A*. Then the mine cable *D* pays out, as the anchor *E* sinks, until the plummet *B* strikes bottom (5). As soon as the plummet cord slackens a spring-pressed pawl is released and locks the mine-cable reel, so that as the anchor



Courtesy of the "Scientific American"

FIG. 22. How the mine automatically adjusts itself to various depths of water

continues to sink it draws the mine down with it, until it touches bottom (6), and as the anchor was ten feet from the bottom when the plummet touched bottom and locked the reel, the mine must necessarily be dragged down to a depth of ten feet below the surface.

The mine itself, or the "devil's egg" as it is called, is usually a big buoyant sphere of metal filled with TNT or some other powerful explosive; and projecting from it are a number of very fragile prongs which if broken or even cracked will set off the mine. There is a safety-lever or pin that makes the mine harmless when it is being handled, and this must be withdrawn just before the mine is to be launched. In some mines the prongs are little plungers that are withdrawn into the mine-shell and held by a cement which softens after the mine is submerged and lets the plungers spring out. When the plungers are broken, water enters and, coming in contact with certain chemicals, produces enough heat to set off a cartridge which fires the mine.

PICKING INFERNAL MACHINES OUT OF THE SEA

The enemy mine-fields were often located by seaplanes and then mine-sweepers had to undertake the extremely hazardous task of raising the mines or destroying them. If they were of the offensive type, it was much better to destroy them. But occasionally, when conditions permitted, mine-sweepers undertook to raise the mines and reclaim them for future use against the enemy. The work of seizing a mine and making it fast to the hoisting-cable of the mine-sweeper was usually done from a small rowboat. Raising the first mine was always the most perilous undertaking, because no one knew just what type of mine it was and how to handle it with safety, or whether there was any way in which it *could* be made harmless. There were some mines, for instance, that contained within them a small vial partly filled with sulphuric acid. The mine carried no prongs, but if it were tilted more than twenty degrees the acid would spill out and blow up the mine. Such a mine would be exceedingly difficult if not impossible to handle from a boat that was rocked about by the waves.

After the first mine of the field was raised and its safety-mechanism studied, the task of raising the rest was not so dangerous. A water telescope was used to locate the mine and to aid in hooking the hoisting-cable into the shackle on the mine. The hook was screwed to the end of a pole and after the mine was hooked, the pole was unscrewed and the cable hauled in, bringing up the "devil's egg" bristling with death. Care had to be taken to keep the bobbing boat from touching the delicate prongs until the safety-device could be set.

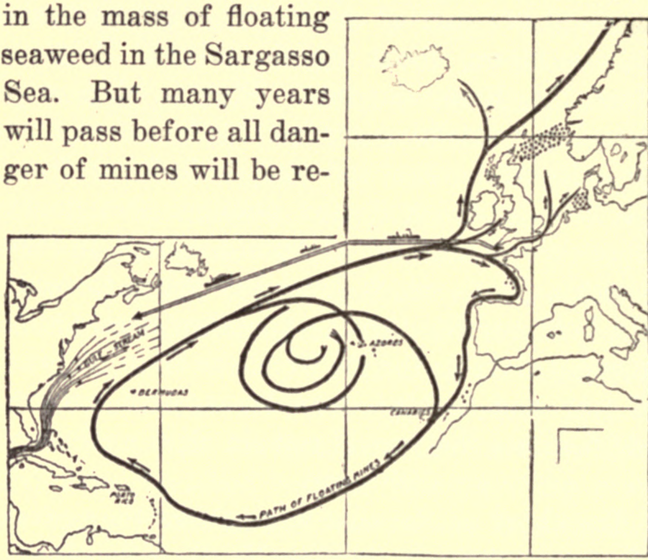
However, this painstaking and careful method of raising mines was not often employed. Shallow-draft mine-sweepers would run over the mine-field, dragging a cable between them. The cable would be kept down by means of hydrovanes or "water kites" deep enough to foul the anchor cables of the mines. The "water kites" were V-shaped structures that were connected to the cable in such a way that they would nose down as they were dragged through the water and carry the cable under. The action is just the reverse of a kite, which is set to nose up into the wind and carry the kite up when it is dragged through the air. By means of the cable the anchor chain of the mine was caught and then the mine with its anchor was dragged up. If the mine broke loose from its anchor it could be exploded with a rifle-shot if it did not automatically explode on fouling the cable.

FLOATING MINES

When England entered the war she mined her harbors because, although she had the mastery of the sea, she had to guard against raids of enemy ships carried out in foggy and dark weather. But the mines were no protection against submarines. They would creep along the bottom under the mines. Then cable nets were stretched across the harbor channels to bar the submarines, but the U-boats were fitted with cutters which would tear through the nets, and it became necessary to use mines set at lower depths so that the submarines could not pass under them; and nets were furnished with bombs which would explode when fouled by submarines. In fact, mines were set adrift with nets stretched between them, to trap submarines. Floating mines were also used by the Germans for the destruction of surface vessels and these were usually set adrift in pairs, with a long cable connecting them, so that if a vessel ran into the cable the mines would be dragged in against its hull and blow it up.

The laws of war require that floating mines be of such a design that they will become inoperative in a few hours; otherwise they might drift about for weeks or months or years and be a constant menace to shipping. Sometimes anchored mines break away from their moorings and are carried around by ocean currents or are blown about by the winds. A year after the Russo-Japanese War a ship was blown up by striking a mine that had been torn from its anchorage and had drifted far from the field in which it was planted. No doubt there are hundreds of mines afloat in the Atlantic Ocean which for many years to come will hold out the threat of sudden destruction to ocean vessels; for the Germans knew no laws of war and had no scruples against setting adrift mines that would remain alive until they were eaten up with rust.

The chart on the next page shows the course of ocean currents in the North Atlantic as plotted out by the Prince of Monaco, from which it may be seen that German mines will probably make a complete circuit of the North Atlantic, drifting down the western coast of Europe, across the Atlantic, around the Azores, and into the Gulf Stream, which will carry them back to the North Sea, only to start all over. (See Fig. 23.) Some of them will run up into the Arctic Ocean, where they will be blown up by striking icebergs and many will be trapped in the mass of floating seaweed in the Sargasso Sea. But many years will pass before all danger of mines will be removed. In the meantime, the war has left a tremendous amount of work to be done in raising anchored mines and destroying them.



Courtesy of the "Scientific American"

Fig. 23. Ocean currents of the North Atlantic showing the probable path of drifting mines

EGG-LAYING SUBMARINES

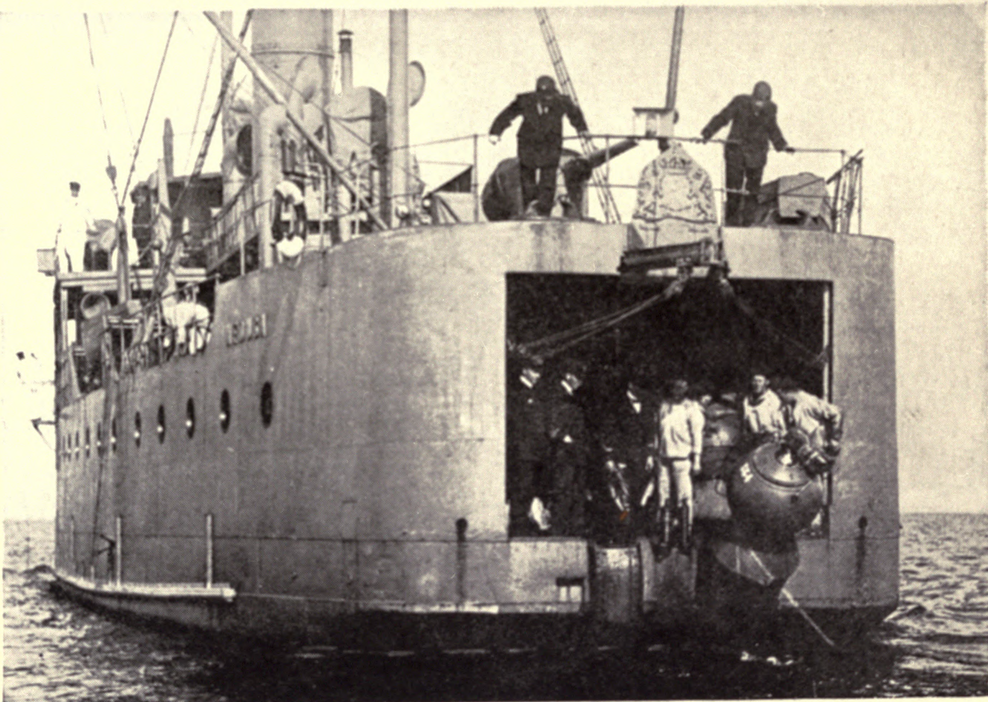
Early in the war the British were astonished to find enemy mine-fields in their own waters, far from any German ports. They could not have been planted by surface mine-layers, unless these had managed to creep up disguised as peaceful trawlers. This seemed hardly likely, because these fields appeared in places that were well guarded. Then it was discovered that German U-boats were doing this work. Special mine-laying U-boats had been built and one of them was captured with its cargo of "devil's eggs."

A sectional view of the mine-laying U-boat is shown opposite page 272. In the after part of the boat were mine-chutes in each of which three mines were stored. A mine-laying submarine would carry about a score of mines. These could be released one at a time. The mine with its anchor would drop to the bottom. As soon as it struck, anchor-arms would be tripped and spread out to catch in the sand or mud, while the mine cable would be released and the mine would rise as far as the cable would allow it. The U-boat commander would have to know the depth of water in which the mines were to be laid and adjust the cables to this depth in advance. This could not be done while the U-boat was submerged. With the mines all set for the depth at a certain spot, the U-boat commander had to find that very spot to lay his "eggs," otherwise they would either lie too deep to do any harm to shipping, or else they would reach up to the surface, where they might be discovered by the Allied patrols. As he had to do his navigating blindly, by dead-reckoning, it was very difficult for him to locate his mine-fields properly.

But the Germans did not have a monopoly on submarine mine-laying. The British also laid mines by submarine within German harbors and channels, right under the guns of Heligoland, and many a U-boat was destroyed by such mines within its home waters.

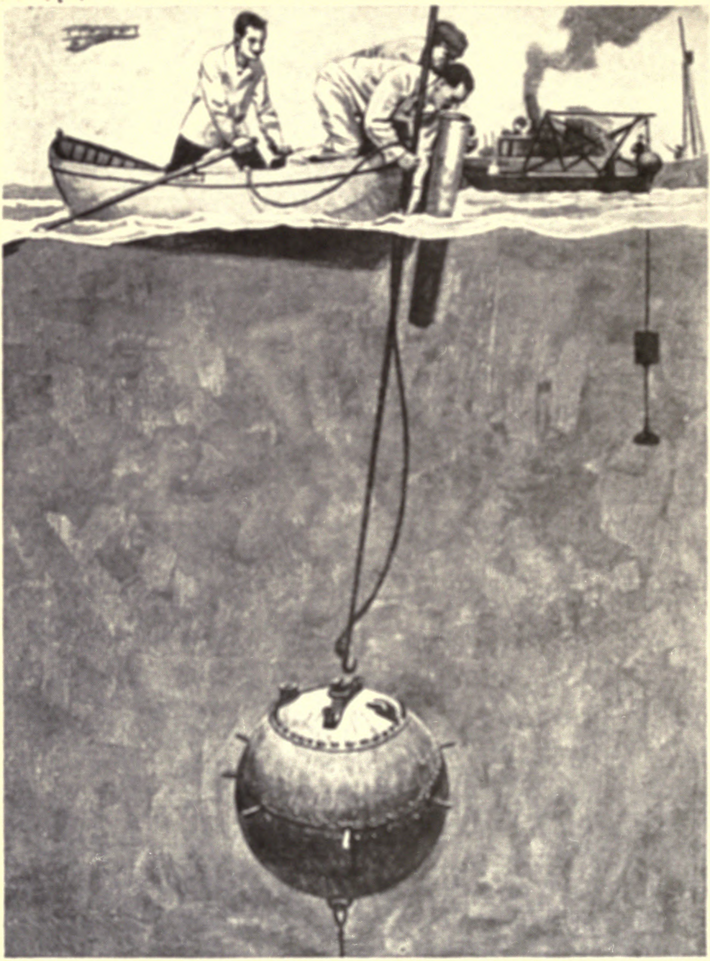
PARAVANES

On the other hand, the Allies had a way of sailing right through fields of enemy mines with little danger. Our ships were equipped with "paravanes" which are something like the "water kites" used by mine-sweepers, and



(C) Press Illustrating Service

A Dutch Mine-sweeper engaged in clearing the North Sea of German Mines



Courtesy of "Scientific American"

Hooking Up Enemy Anchored Mines

they are still used in the waters of the war zone. Paravanes are steel floats with torpedo-shaped bodies and a horizontal plane near the forward end. At the tail of the paravane, there are horizontal and vertical rudders which can be set to make the device run out from the side of the vessel that is towing it, and at the desired depth below the surface. Two paravanes are used, one at each side of the ship, and the towing-cables lead from the bow of the vessel. Thus there are two taut cables that run out from the ship in the form of a V and at such a depth that they will foul the mooring-cable of any mine that might be encountered. The mine cable slides along the paravane cable and in this way is carried clear of the ship's hull. When it reaches the paravane it is caught in a sharp-toothed jaw which cuts the mine cable and lets the mine bob up to the surface. The mine is then exploded by rifle or machine-gun fire.

In some forms of paravane there is a hinged jaw which is operated from the ship to shear the cable. The jaw is repeatedly opened and closed by a line that runs to a winch on the ship. This winch winds up the line until it is taut and then the line is permitted to slip, letting the jaw open, only to close again as the winch keeps on turning and winding up the line.

Guarded by steel sharks on each side, their jaws constantly working, a ship can plow right through a field of anchored mines with little danger. To be sure, the bow might chance to hit a mine, when, of course, there would be an explosion; but the ship could stand damage here better than anywhere else and unless the bow actually hit the mine, one or other of the paravanes would take care of it and keep it from being dragged in against the hull of the vessel.

PENNING IN THE U-BOATS

According to German testimony, mines were responsible for the failure of the U-boat. However, it was not merely the scattered mine-fields sown in German waters that brought the U-boat to terms, but an enormous mine-field stretching across the North Sea from the Orkney Islands to the coast of Norway. Early in the war, U-boats had been prevented from entering the English Channel by nets and mines stretched across the Straits of Dover. As the submarine menace grew, it was urged that a similar net be stretched across the North Sea to pen the

U-boats in. But it seemed like a stupendous task. The distance across at the narrowest point is nearly two hundred and fifty miles. It would not have been necessary to have the net come to the surface. It could just as well have been anchored so that its upper edge would be covered with thirty feet of water. Surface vessels could then have sailed over it without trouble and submarines could not have passed over it without showing themselves to patrolling destroyers. It would not have been necessary to carry the net to the bottom of the sea. A belt of netting a hundred and fifty feet wide would have made an effective bar to the passage of U-boats. As U-boats might cut their way through the net, it was proposed to mount bombs or mines on them which would explode on contact and destroy any submarine that tried to pass. However, laying a net two hundred feet long even when it is laid in sections, is no small job, but when the net is loaded with contact mines, the difficulty of the work may be well imagined.

And yet had it been thought that the net would be a success it would have been laid anyhow, but it was argued that seaweed would clog the meshes of the net and ocean currents would tear gaps in it. Even if it had not been torn away, the tidal currents would have swept it down and borne it under so far that U-boats could have passed over it in safety without coming to the surface.

A WALL OF MINES

When America entered the war, we were very insistent that something must be done to block the North Sea, and we proposed that a barrage of anchored mines be stretched across the sea and that these mines be set at different levels so as to make a "wall" that submarines could not dive under. This would do away with all the drawbacks of a net. Ocean currents and masses of seaweed could not affect individual mines as they would a net. Furthermore, an American inventor had devised a new type of mine which was peculiarly adapted to the proposed mine barrage. It had a firing-mechanism that was very sensitive and the mine had twice the reach of any other.

At length the British mine-laying forces were prevailed upon to join with us in laying this enormous mine. It was one of the biggest and most successful undertakings of the war. It was to be two hundred and thirty miles long and twelve miles wide on the average, reaching from the rocky shores of the Orkney Islands to Norway. There was plenty of deep water close to the coast of Norway and it was against international law to lay mines within three miles of the shores of a neutral nation, so that the U-boats might have had a clear passage around the end of the barrage. But as it was also against the law for the U-boats to sail through neutral waters, Norway laid a mine-field off its coast to enforce neutrality, and this was to join with that which the British and we were to lay. Most of the mine-laying was to be done by the United States and we were to furnish the mines.

The order to proceed with the work was given in October, 1917, and it was a big order. A hundred thousand mines were to be made and to preserve secrecy, as well as to hurry the work as much as possible, it was divided among five hundred contractors and subcontractors. The parts were put together in one plant and then sent to another, where each mine was filled with three hundred pounds of molten TNT. To carry them across the ocean small steamers were used, so that if one should be blown up by a submarine the loss of mines would not be very great. There were twenty-four of these steamers, each carrying from twelve hundred to eighteen hundred mines and only one of them was destroyed by a submarine. The steamers delivered their loads on the west coast of Scotland and the mines were taken across to the east coast by rail and motor canal-boats. Here the mines were finally assembled, ready for planting. Seventy thousand mines were planted, four fifths of them by American mine-layers and the rest by the British.

MINE RAILROADS ON SHIPS

To handle the mines the ships were specially fitted with miniature railroads for transporting the mines to the launching-point, so that they could be dropped at regular intervals without interruption. Each anchor mine was provided with flanged wheels that ran on rails. The mines were carried on three decks and each deck was covered with a network of rails, switches, and turn-tables, while elevators were provided to carry the mines from one deck to another. The mines, like miniature railroad cars, were coupled up in trains of thirty or forty and as each mine weighed fourteen hundred pounds, steam winches had to be used to haul them. At the launching-point the tracks ran out over the stern of the boat and here a trap was provided which would hold only one mine at a time. By the pulling of a lever the jaws of the trap would open and the mine would slide off the rails and plunge into the sea.

The mines were dropped every three hundred feet in lines five hundred feet apart, as it was unsafe for the mine-layers to steam any closer to one another than that. The mines were of the type shown in Fig. 22 and automatically adjusted themselves to various depths. The depth of the water ran down to twelve hundred feet near the Norwegian coast. Never before had mines been planted at anywhere near that depth.

It was dangerous work, because the enemy knew where the mines were being planted, as neutral shipping had to be warned months in advance. The mine-layers were in constant danger of submarine attack, although they were convoyed by destroyers to take care of the U-boats. There was even danger of a surface attack and so battle-cruisers were assigned the job of guarding the mine-layers. The mine-layers steamed in line abreast, and had one of them been blown up, the shock would probably have been enough to blow up the others as well. Enemy mines were sown in the path of the mine-layers, so the latter had to be preceded by mine-sweepers. Navigation buoys had to be planted at the ends of the lines of mines and the enemy had a habit of planting mines near the buoys or of moving the buoys whenever he had a chance. But despite all risks the work was carried through.

The barrier was not an impassable one. With the mines three hundred feet apart, a submarine might get through, even though the field was twenty-five miles broad, but the hazards were serious. Before the first lines of mines had been extended half-way across, its value was demonstrated by the destruction of several U-boats, and as the safety-lane was narrowed down the losses increased. It is said that altogether twenty-three German submarines met their doom in the great mine barrage. U-boat commanders balked at running through it, and U-boat warfare virtually came to a standstill.

According to Captain Bartenbach, commander of submarine bases in Flanders, three U-boats were sunk by anchored mines for every one that was destroyed by a depth bomb.

CHAPTER XV

SURFACE BOATS

THE war on the submarine was fought mainly from the surface of the sea and from the air above the sea, and naturally it resulted in many interesting naval developments.

As described in Chapter XIII, the first offensive measure against the U-boat was the building of swarms of speedy motor-boats which drove the invaders away from harbors and into the open sea. To follow the U-boats out into rough water larger submarine-chasers were built, but even they could not cope with the enemy far from the harbors.

MOTOR TORPEDO-BOATS

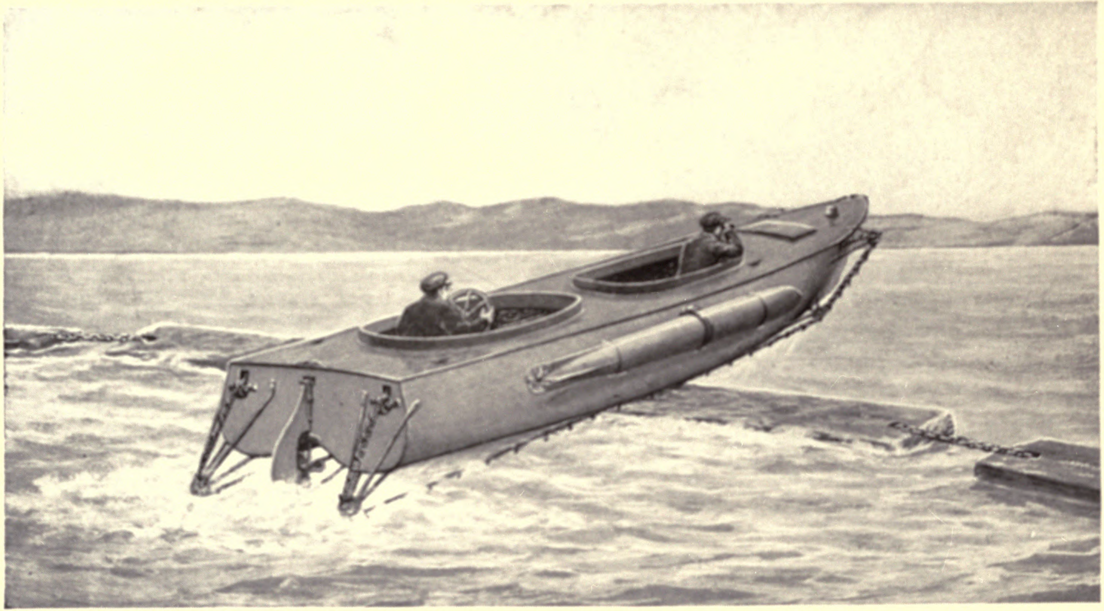
The Italians made excellent use of speedy motor-boats in the protected waters of the Adriatic Sea. One type of motor-boat was equipped with two torpedo-tubes in the bow. Small 14-inch torpedoes were used, but as each torpedo carried two hundred pounds of high explosive, the motor-boat was a formidable vessel if it crept in close enough to discharge one of these missiles at its foe.

On one occasion, a patrol of these little boats sighted a couple of Austrian dreadnoughts headed down the coast, surrounded by a screen of ten destroyers. Favored by the mist, two of the motor-boats crept through the screen of destroyers, and torpedoed the battle-ships. Then they made good their escape. A destroyer that pursued one of the boats decided that the game was not worth while when it was suddenly shaken up by the explosion of a depth bomb dropped from the motor-boat.

THE SEA TANK

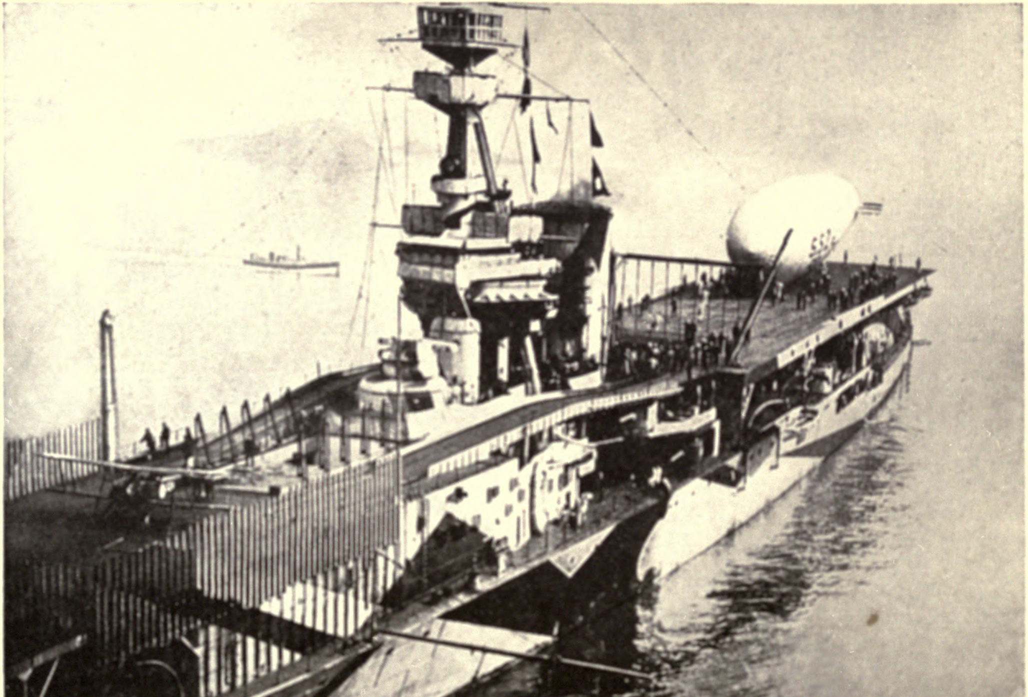
The Italians showed a great deal of naval initiative. They were forever trying to trap the Austrian fleet or to invade its harbors. Like all other naval powers, the Austrians protected their harbors with nets and mines. It was impossible for submarines to make an entrance and the ports were too well fortified to permit an open attack on the surface. Nevertheless, the Italians did break through the harbor defenses on one or two occasions and sank Austrian war-vessels. Again it was with a small boat that they did the trick.

The nets which the Austrians stretched across their harbor entrance were supported on wooden booms or logs which served as floats. These booms offered an effective bar to small boats which might attempt to enter the harbor under cover of darkness. But the Italians found a way to overcome this obstruction. They built a flat-bottomed motor-boat which drew very little water. Running under the boat were two endless chains, like the treads of a tank. In fact, the boat came to be known as a "sea tank." The chains were motor-driven and had spiked sprockets, so that when a boom was encountered they would bite into the wood and pull the boat up over the log, or maybe they would drag the log down under the boat. At any rate, with this arrangement it was not very difficult to pass the boom and enter the harbor. At the rear the chains were carried back far enough to prevent the propeller from striking when the boat had passed over the log.



Courtesy of "Scientific American"

An Italian "Sea-tank" climbing over a Harbor Boom



(C) Underwood & Underwood

Deck of a British Aircraft Mothership or "Hush-ship"

THE AWKWARD "EAGLES"

A curious boat that we undertook to furnish during the war was a cross between a destroyer and a submarine-chaser. After the submarine had been driven out to sea its greatest foe was undoubtedly the destroyer, and frantic efforts were made to turn out as many destroyers as possible. But it takes time to build destroyers and so a new type of boat was designed, to be turned out quickly in large numbers. A hundred and ten "Eagles" (as these boats are called) were ordered, but the armistice was signed before any of them were put into service; and it is just as well that such was the case, for in their construction everything was sacrificed to speed of production. As a consequence they are very ugly boats, with none of the fine lines of a destroyer, and they roll badly, even when the sea is comparatively peaceful. They are five-hundred-ton boats designed to make eighteen knots, which would not have been fast enough to cope with U-boats, because the latter could make as high a speed as that themselves, when traveling on the surface, and the two 4-inch guns of the Eagles would have been far outranged by the 5.9-inch guns of the larger U-boats.

SEAPLANE TOWING-BARGES

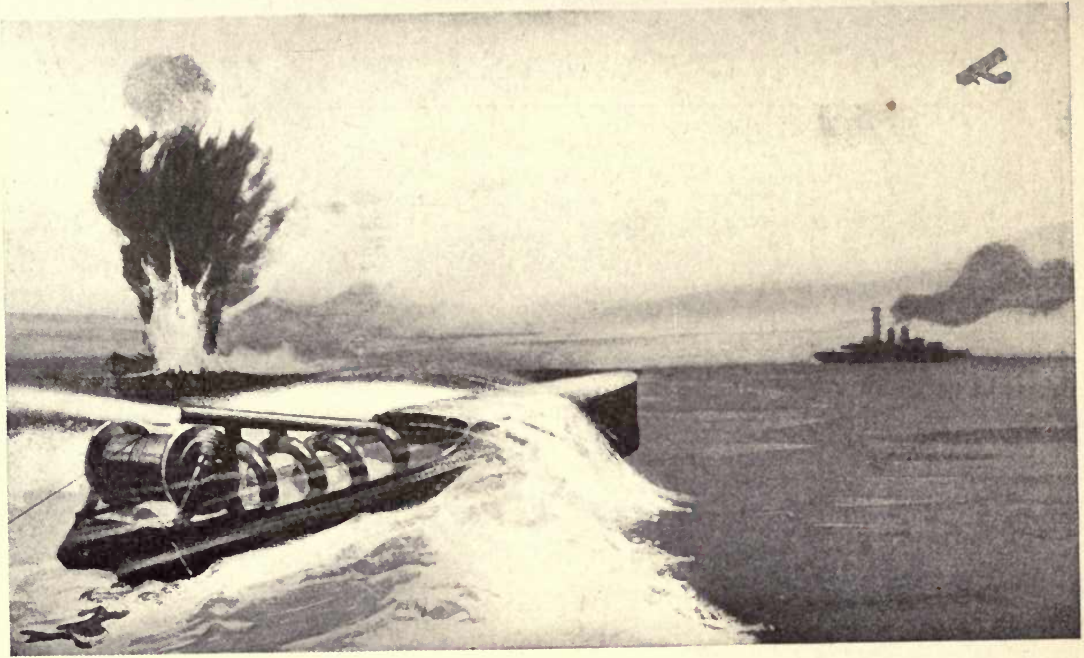
When the war on the U-boat was carried up into the sky, many new naval problems cropped up, particularly when German submarines chose to work far out at sea. Big seaplanes were used, but they consumed a great deal of fuel in flying out and back, cutting down by just so much their flying-radius at the scene of activities. A special towing-barge was used. These barges had trimming-tanks aft, which could be flooded so that the stern of the barge would submerge. A cradle was mounted to run on a pair of rails on the barge. The body of the seaplane was lashed to this cradle and then drawn up on the barge by means of a windlass. This done, the water was blown out of the trimming-tanks by means of compressed air and the barge was brought up to an even keel. The barge with its load was now ready to be towed by a destroyer or other fast boat to the scene of operations. There water was again let into the trimming-tanks and the seaplane was let back into the water. From the water the seaplane arose into the air in the usual way.

Unfortunately, when the sea is at all rough it is exceedingly difficult for a seaplane to take wing, particularly a large seaplane. A better starting-platform than the sea had to be furnished. At first some seaplanes were furnished with wheels, so that they could be launched from platforms on large ships; and then, to increase the flying-radius, seaplanes were discarded in favor of airplanes. Once these machines were launched, there was no way for them to get back to the ship. They had to get back to land before their fuel was exhausted.

On the large war-vessels a starting-platform was built on a pair of long guns. Then the war-ship would head into the wind and the combined travel of the ship and of the airplane along the platform gave speed enough to raise the plane off the platform before it had run the full length of the guns. But as long as aviators had no haven until they got back to land, there were many casualties. Eager to continue their patrol as long as possible, they would sometimes linger too long before heading for home and then they would not have enough fuel left to reach land. Many an aviator was lost in this way, and finally mother-ships for airplanes had to be built.

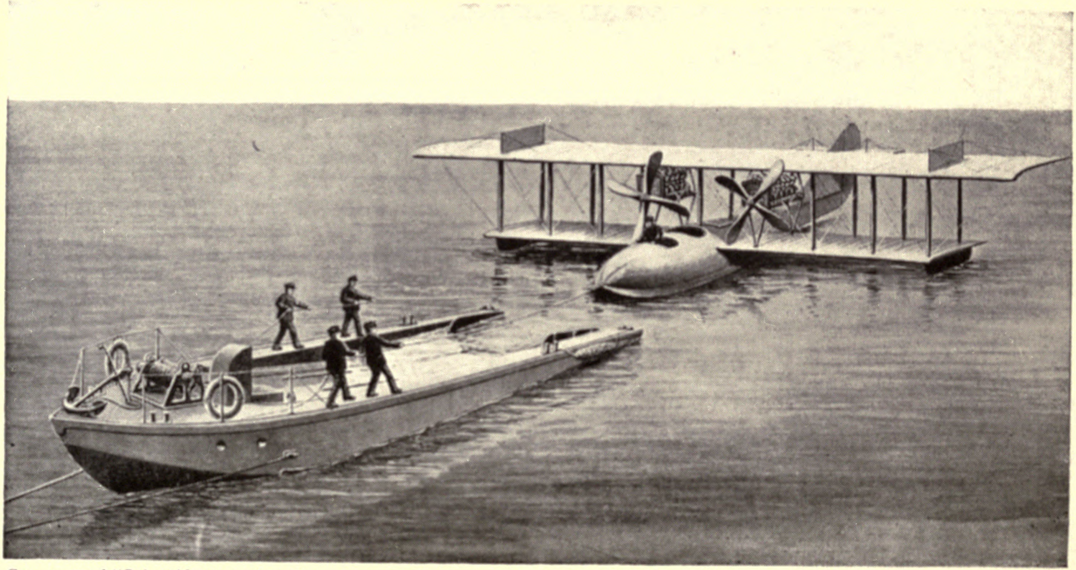
THE "HUSH SHIPS"

The British Navy had constructed a number of very fast cruisers to deal with any raiders the Germans might send out. These cruisers were light vessels capable of such high speeds that they could even overtake a destroyer. They were 840 feet long and their turbines developed 90,000 horse-power. The construction of these vessels was for a long time kept a profound secret and it was not until the German fleet surrendered that photographs of them were allowed to be published. Because of this secrecy the boats were popularly known as "hush-ships." They were not armored; it was not necessary to load them down with armor plate, because their protection lay in speed and they were designed to fight at very long range. In fact, they were to carry guns that would out-range those of the most powerful dreadnoughts. Our largest naval guns are of 16-inch caliber, but the "hush ships" were each to carry two



Courtesy of "Scientific American"

Electrically Propelled Boat or Surface Torpedo, Attacking a Warship, under Guidance of an Airplane Scout



Courtesy of "Scientific American"

Hauling a Seaplane up on a Barge so that it may be Towed at High Speed by a Destroyer

18-inch guns. The guns were monsters weighing 150 tons each and they fired a shell 18 inches in diameter and 7 feet long to a distance of 30 miles when elevated to an angle of 45 degrees. The weight of the shell was 3600 pounds and it carried 500 pounds of high explosive or more than is carried in the largest torpedoes.

At the 32-mile range the shell would pass through 12 inches of face-hardened armor and at half that range it would pass through armor 18 inches thick, and there is no armor afloat any heavier than this.

MOTHER-BOATS FOR AIRPLANES

Armed with such powerful guns as these, the "hush ships" would have been very formidable indeed; but when the guns were mounted on one of the cruisers, the *Furious,* they were found too powerful for the vessel. It was evident that the monsters would very seriously rack their own ship. So the guns were taken off the cruiser and it was turned into a mother-ship for airplanes. A broad, unobstructed deck was built on the ship which provided a runway from which airplanes could be launched, and this runway was actually broad enough to permit airplanes to land upon it. Under the runway were the hangars in which the airplanes were housed. Other "hush ships" were also converted into airplane mother-boats and there were special boats built for this very purpose, although they were not able to make the speed of the "hush ships." One of these special boats had funnels that turned horizontally to carry off the furnace smoke over the stern and leave a perfectly clear flying-deck, 330 feet long.

TORPEDO-PROOF MONSTERS

As for the 18-inch guns, they were put to another use. Early in the war the British had need for powerful shallow-draft vessels which could operate off the Flanders coast and attack the coast fortifications that were being built by the Germans. The ships that were built to meet this demand were known as monitors, because like the famous "monitor" of our Civil War they carried a single turret. These monitors were very broad for their length and were very slow. At best they could make only seven knots and in heavy weather they could not make more than two or three knots.

To be made proof against torpedoes these boats were formed with "blisters" or hollow rounded swells in the hull at each side which extended out to a distance of twelve to fifteen feet. The blisters were subdivided into compartments, so that if a torpedo struck the ship it would explode against a blister at a considerable distance from the real hull of the ship and the force of the explosion would be expended in the compartments. The blisters were the salvation of the monitors. Often were the boats struck by torpedoes without being sunk.

Unfortunately, this form of protection could not be applied to ordinary vessels, because it would have interfered seriously with navigation. The blisters made the monitors very difficult to steer and hampered the progress of a ship, particularly in a seaway.

With ships such as these the British bombarded Zeebrugge from a distance of twenty to twenty-five miles. Of course, the range had to be plotted out mathematically, as the target was far beyond the horizon of the ship, and the firing had to be directed by spotters in airplanes.

At first guns from antiquated battle-ships were used in the monitors; then larger guns were used, until finally two of the monitors inherited the 18–inch guns of the *Furious*. A single gun was mounted on the after deck of each vessel and the gun was arranged to fire only on the starboard side. No heavily armored turret was provided, but merely a light housing to shelter the gun.

AN ELECTRICALLY STEERED MOTOR-BOAT

The British war-vessels that operated in the shallow waters off the coast of Flanders were a constant source of annoyance to the Germans. Because of the shallow water it was seldom possible for a submarine to creep up on them. A U-boat required at least thirty-five feet of water for complete submergence and it did not dare to attack in the open. This led the Germans to launch a motor-boat loaded with high explosive, which was steered from shore. The motor-boat carried a reel of wire which connected it with an operator on shore. There was no pilot in the boat, but the helm was controlled electrically by the man at the shore station. As it was diffcult for the helmsman to see just what his boat was doing, or just how to steer it when it was several miles off, an airplane flew high above it and directed the helmsman, by radiotelegraphy, how to steer his boat. Of course, radiotelegraphy might have been used to operate the steering-mechanism of the boat, but there was the danger that the radio operators of the British might send out disturbing waves that would upset the control of the motorboat, and so direct wire transmission was used instead. Fortunately, when the Germans tried this form of attack, an alert British lookout discovered the tiny motor-boat. The alarm was given and a lucky shot blew up the boat with its charge before it came near the British vessel.

CHAPTER XVI

Reclaiming the Victims of the Submarine

NEARLY fifteen million tons of shipping lie at the bottom of the sea, sunk by German U-boats, and the value of these ships with their cargo is estimated at over seven billion dollars. In one year, 1917, the loss was nearly a million dollars a day.

Of course these wrecks would not be worth anything like that now, if they were raised and floated. Much of the cargo would be so damaged by its long immersion in salt water that it would be absolutely valueless, but there are many kinds of merchandise that are not injured in the least by water. Every ship carries a certain amount of gold and silver; and then the ship's hull itself is well worth salving, provided it was not too badly damaged by the torpedo that sank it. Altogether, there is plenty of rich treasure in the sea awaiting the salvor who is bold enough to go after it.

To be sure, not all of the U-boat's victims were sunk in deep water. Many torpedoed vessels were beached or succeeded in reaching shallow water before they foundered. Some were sunk in harbors while they lay at anchor, before the precaution was taken of protecting the harbors with nets. The Allies did not wait for the war to end before trying to refloat these vessels. In fact, during the war several hundred ships were raised and put back into service. A special form of patch was invented to close holes torn by torpedoes. Electric pumps were built which would work under water and these were lowered into the holds of ships to pump them out. The salvors were provided with special gas-masks to protect them from poisonous fumes of decayed matter in the wrecks.

Our own navy has played an important part in salvage. Shortly after we entered the war, all the wrecking-equipment in this country was commandeered by the government and we sent over to the other side experienced American salvors, provided with complete equipment of apparatus and machinery.

The majority of wrecks, however, are found in the open sea, where it would have been foolish to attempt any salvage-operations because of the menace of submarine attack. On at least one occasion a salvage vessel, while attempting to raise the victims of a submarine, fell, itself, a prey to a Hun torpedo. Now that this menace has been removed, such vessels as lie in comparatively shallow water, and in positions not subject to sudden tempests, can be raised by the ordinary methods; or if it is impracticable to raise them, much of their cargo can be reclaimed. However, most of the torpedoed ships lie at such depths that their salvage would ordinarily be despaired of.

IN THE DEPTHS OF THE SEA

It will be interesting to look into conditions that exist in deep water. Somehow the notion has gone forth that a ship will not surely sink to the very bottom of the deep sea, but on reaching a certain level will find the water so dense that even solid iron will float, as if in a sea of mercury, and that here the ship will be maintained in suspension, to be carried hither and yon by every chance current. Indeed, it makes a rather fantastic picture to think of these lost ships drifting in endless procession, far down beneath the cold green waves, and destined to roam forever like doomed spirits in a circle of Dante's Inferno.

But the laws of physics shatter any such illusion and bid us paint a very different picture. Liquids are almost incompressible. The difference in density between the water at the surface of the sea and that at a depth of a mile is almost insignificant. As a matter of fact, at that depth the water would support only about half a pound more per cubic foot than at the surface. The pressure, however, would be enormous. Take the *Titanic,* for instance, which lies on the bed of the ocean in water two miles deep. It must endure a pressure of about two long tons on every square inch of its surface. Long before the vessel reached the bottom her hull must have been crushed in. Every stick of wood, every compressible part of her structure and of her cargo, must have been staved in or flattened. As a ship sinks it is not the water but the ship that grows progressively denser. The *Titanic* must have actually gained in weight as she went down, and so she must have gathered speed as she sank.

We may be certain, therefore, that every victim of Germany's ruthless U-boats that sank in deep water lies prone upon the floor of the sea. It matters not how or where it was sunk, whether it was staggered by the unexpected blow of the torpedo and then plunged headlong into the depths of the sea, or whether it lingered, mortally wounded, on the surface, quietly settling down until the waves closed over it. Theoretically, of course, a perfect balance might be reached which would keep a submerged vessel in suspension, but practically such a condition is next to impossible. Once a ship has started down, she will keep on until she reaches the very bottom, whether it be ten fathoms or ten hundred.

A SUBMARINE GRAVEYARD

Instead of the line of wandering specters, then, we must conjure up a different picture, equally weird—an under-world shrouded in darkness; for little light penetrates the deep sea. Here in the cold blackness, on the bed of the ocean, the wrecks of vessels that once sailed proudly overhead lie still and deathly silent—some keeled over on their sides, some turned turtle, and most of them probably on even keel. Here and there may be one with its nose buried deep in the mud; and in the shallower waters we may come across one pinned down by the stern, but with its head buoyed by a pocket of air, straining upward and swaying slightly with every gentle movement of the sea, as if still alive.

This submarine graveyard offers wonderful opportunities for the engineer, because the raising of wrecked vessels is really a branch of engineering. It is a very special branch, to be sure, and one that has not begun to receive the highly concentrated study that have such other branches as tunneling, bridge-construction, etc. Nevertheless it is engineering, and it has been said of the engineer that his abilities are limited only by the funds at his disposal. Now he has a chance to show what he can do, for there are hundreds of vessels to be salved where before there was but one. The vast number of wrecks in deep water will make it pay to do the work on a larger and grander scale than has been possible heretofore. Special apparatus that could not be built economically for a single wreck may be constructed with profit if a number of vessels demanding similar treatment are to be salved.

The principal fields of German activities were the Mediterranean Sea and the waters surrounding the British Isles. Although the submarine zone covered some very deep water, where the sounding-lead runs down two miles without touching bottom, obviously more havoc could be wrought near ports where vessels were obliged to follow a prescribed course, and so most of the U-boat victims were stricken when almost in sight of land. In fact, as was pointed out in a previous chapter, it was not until efficient patrol measures made it uncomfortable for the submarines that they pushed out into the open ocean to pursue their nefarious work. The *Lusitania* went down only eight miles from Old Head of Kinsale, in fifty fathoms of water.

If we draw a line from Fastnet Rock to the Scilly Islands and from there to the westernmost extremity of France, we enclose an area in which the German submarines were particularly active. The soundings here run up to about sixty fathoms in some places, but the prevailing depth is less than fifty fathoms. In the North Sea, too, except for a comparatively narrow lane along the Norwegian coast—which, by the way, marked the safety lane of the German blockade zone—the chart shows fifty fathoms or under. If our salvors could reach down as far as that, most of the submarine victims could be reclaimed. But fifty fathoms means 300 feet, which is a formidable depth for salvage work. Only one vessel has ever been brought up from such a depth and that was a small craft, one of our submarines, the *F-4,* which sank off the coast of Hawaii four years ago.

DIFFERENT WAYS OF SALVING A WRECK

There are four well-known methods of raising a vessel that is completely submerged. Of course, if the ship is not completely submerged, the holes in her hull may be patched up, and then when her hull is pumped out, the sea itself will raise the ship, unless it be deeply embedded in sand or mud. If the vessel is completely submerged, the same process may be resorted to, but first the sides of the hull must be extended to the surface to keep the water from flowing in as fast as it is pumped out. It is not usual to build up the entire length of the ship. If the deck is in good condition, it may suffice to construct coffer-dams or walls around several of the hatches. But building up the sides of a ship, or constructing coffer-dams on the ship's deck is a difficult task, at best, because it must be done under water by divers.

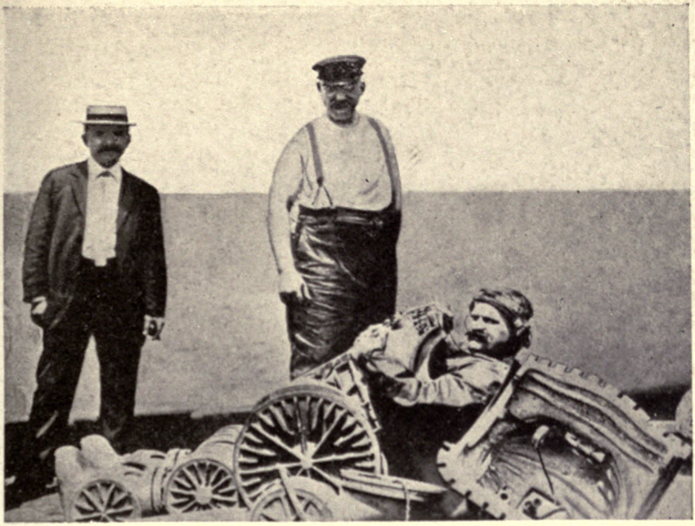
A record for this type of salvage work was established by the Japanese when they raised the battle-ship *Mikasa* that lay in some eighty feet of water. Her decks were submerged to a depth of forty feet. It is doubtful that this salvage work could be duplicated by any other people of the world. The wonderful patriotism and loyalty of the Japanese race were called forth. It is no small task to build a large coffer-dam strong enough to withstand the weight of forty feet of water, or a pressure of a ton and a quarter per square foot, even when the work is done on the surface. Perfect discipline and organized effort of the highest sort were required. Labor is cheap in Japan and there was no dearth of men for the work. Over one hundred divers were employed. In addition to the coffer-dam construction much repair work was necessary. Marvelous acts of devotion and heroism were performed. It is rumored that in some places it was necessary for divers to close themselves in, cut their air supply-pipes and seal themselves off from the slightest chance of escape; and that there were men who actually volunteered to sacrifice their lives in this way for their beloved country and its young navy. Where, indeed, outside of the Land of the Rising Sun could we find such patriotic devotion!

A second salvage method consists in building a coffer-dam not on the ship but around it, and then pumping this out so as to expose the ship as in a dry-dock. Such was the plan followed out in recovering the *Maine*. Obviously, it is a very expensive method and is used only in exceptional cases, such as this, in which it was necessary to make a post-mortem examination to determine what caused the destruction of the vessel. Neither of these methods of salvage will serve for raising a ship sunk in deep water.

RAISING A SHIP ON AIR

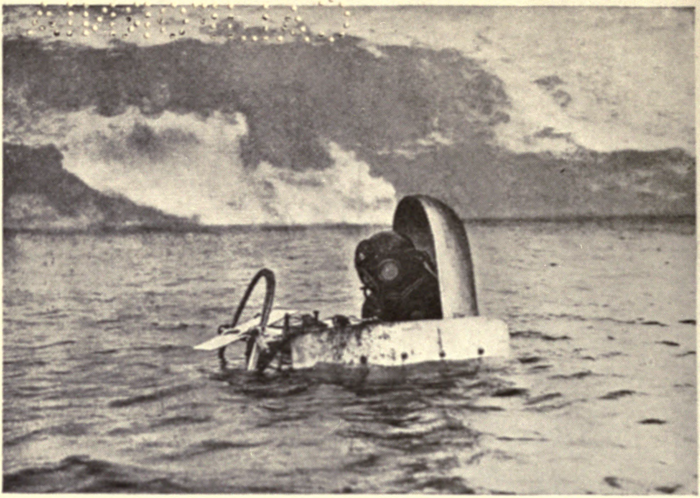
A salvage system that has come into prominence within recent years consists in pumping air into the vessel to drive the water out, thus making the boat light enough to float. This scheme can be used only when the deck and bulkheads of the boat are strongly built and able to stand the strain of lifting the wreck, and when the hole that sank the vessel is in or near the bottom, so as to allow enough air-space above it to lift the boat. The work of the diver in this case consists of closing hatches and bulkhead doors, repairing holes in the upper part of the hull, and generally strengthening the deck. It must be remembered that a deck is built to take the strain of heavy weights bearing down upon it. It is not built to be pushed up from beneath, so that frequently this method of salving is rendered impracticable because the deck itself cannot stand the strain.

A more common salvage method consists in passing cables or chains under the wreck and attaching them to large floats or pontoons. The slack in the chains is taken up when the tide is low, so that on the turn of the tide the wreck will be lifted off the bottom. The partially raised wreck is then towed into shallower water, until it grounds. At the next low tide, the

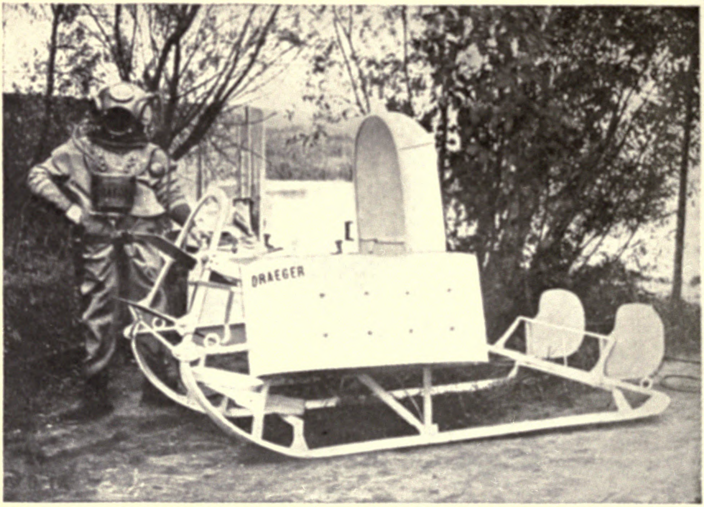


Climbing into an Armored Diving Suit

Lowering an Armored Diver into the Water



A Diver's Sea Sled ready to be towed along the bed of the sea



The Sea Sled on Land showing the forward horizontal and after vertical rudders slack of the chains is again taken in, and at flood-tide the wreck is towed nearer land. The work proceeds step by step, until the vessel is moved inshore far enough to bring its decks awash; when it may be patched up and pumped out. Where the rise of the tide is not sufficient to be of much assistance, hydraulic jacks or other lifting-apparatus are used.

SALVING THE U. S. SUBMARINE F-4

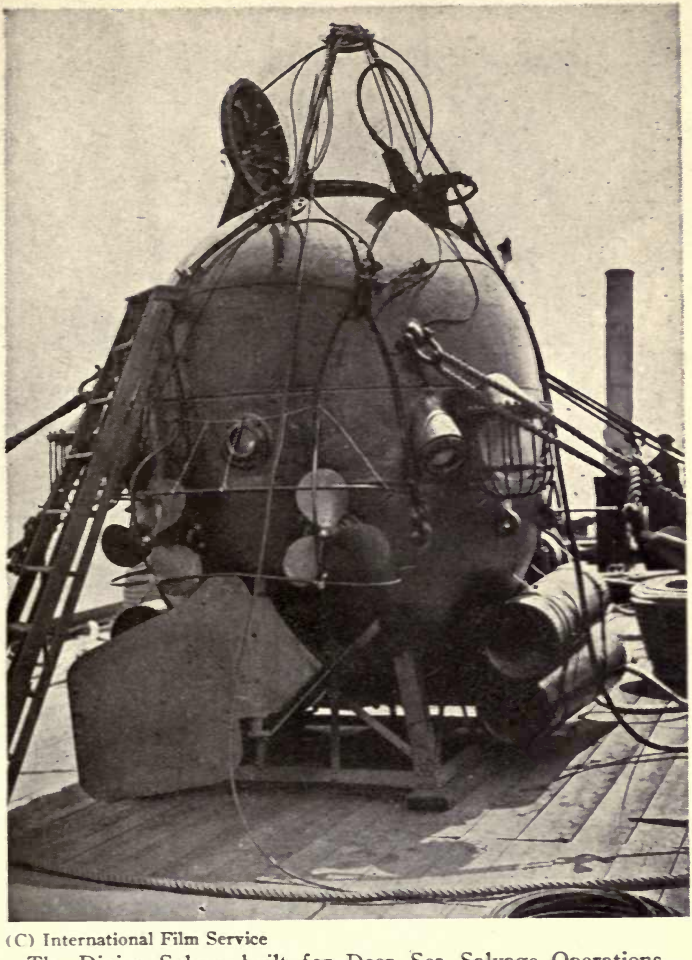
If the salvor could always be assured of clear weather, his troubles would be reduced a hundredfold, but at best it takes a long time to perform any work dependent upon divers, and the chances are very good when they are operatiug in an unsheltered spot, that a storm may come up at any time and undo the result of weeks and months of labor. This is what happened when the submarine *F-4* was salved. After a month of trying effort the submarine was caught in slings hung from barges, lifted two hundred and twenty-five feet, and dragged within a short distance of the channel entrance of the harbor, where the water was but fifty feet deep. But just then a violent storm arose, which made the barges surge back and forth and plunge so violently that the forward sling cut into the plating of the submarine and crushed it. The wreck had to be lowered to the bottom and the barges cut free to save them from being smashed. At the next attempt to raise the *F-4* pontoons were again used, but instead of being arranged to float on the surface, they were hauled down to the wreck and made fast directly to the hull of the submarine. Then when the water was forced out of the pontoons with compressed air, they came up to the surface, bringing the submarine with them. In this way all danger of damage due to sudden storms was avoided because water under the surface is not disturbed by storms overhead; and when the wreck was floated, the pontoons and submarine formed a compact unit.

While this method of salvage seems like a very logical one for work in the open sea, one is apt to forget how large the pontoons must be to lift a vessel of any appreciable size. Not only must they support their own dead weight, together with that of the sunken vessel, but some allowance must usually be made for dragging the wreck out of the clutches of a sandy or muddy bottom. Imagine the work of building pontoons large enough to raise the *Lusitania*. They would have to have a combined displacement greater than that of the vessel itself, and they would have to be so large that they would be very unwieldy things to handle in a seaway. It is for this reason that submarine pontoons are not often used to take the entire weight of the vessel. So far they have been employed mainly to salve small ships and then only to take a portion of the weight, the principal work being done by large wrecking-cranes. Instead of horizontal pontoons it has been suggested that vertical pontoons be employed, so as to provide a greater lifting-power without involving the use of enormous unwieldy units.

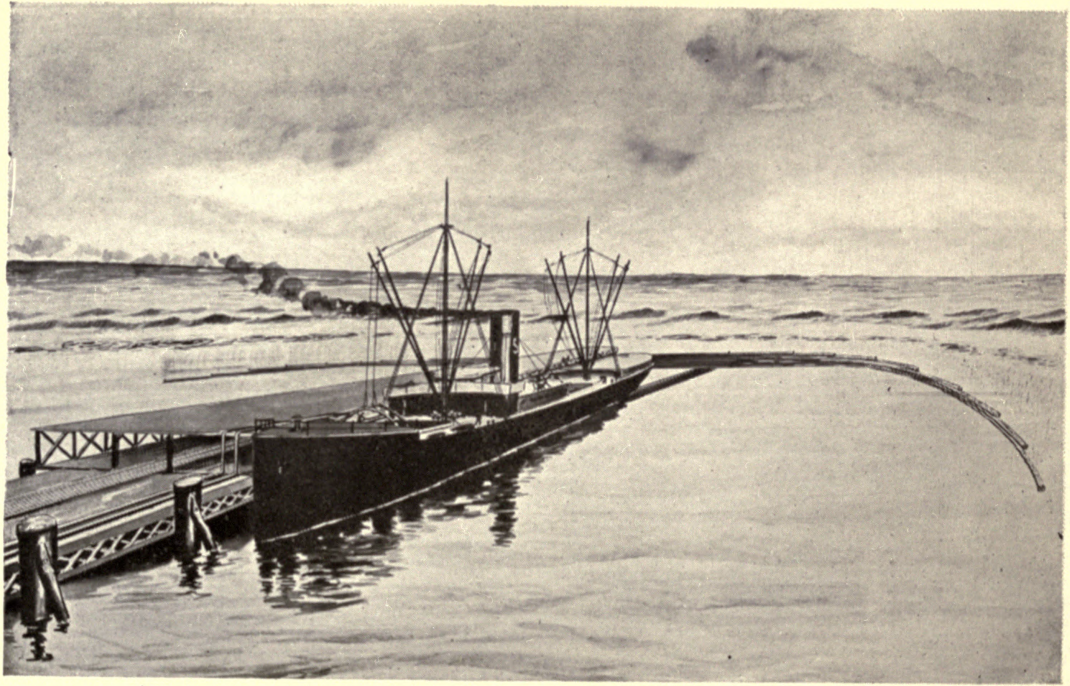
Ships are not built so that they can be picked up by the ends. Such treatment would be liable to break their backs in the middle. Were they built more like a bridge truss, the salvor's difficulties would be materially lessened. It would be a much simpler matter to raise a vessel with pontoons were it so constructed that the chains of the pontoon could be attached to each end of the hull. But because a ship is built to be supported by the water uniformly throughout its length, the salvor must use a large number of chains, properly spaced along the hull, so as to distribute the load uniformly and see that too much weight does not fall on this or that pontoon.

The main problem, however, is to get hold of the wreck and this requires the services of divers, so that if there were no other limiting factor, the depth to which a diver may penetrate and perform his duties sets the mark beyond which salvage as now conducted is impossible.

A common diver's suit does not protect the diver from hydraulic pressure. Only a flexible suit and a thin layer of air separates him from the surrounding water. This air must necessarily be of the same pressure as the surrounding water. The air that is pumped down to the diver not only serves to supply his lungs, but by entering his blood transmits its pressure to every part of his anatomy. As long as the external pressure is equalized by a corresponding pressure within him, the diver experiences no serious discomfort. In fact, when the pressure is not excessively high he finds it rather exhilarating to work under such conditions; for, with every breath, he takes in an abnormal amount of oxygen. When



(C) International Film Service
The Diving Sphere built for Deep Sea Salvage Operations



The Pneumatic Breakwater — Submerged Air Tubes protecting a California Pier from Ocean Storms he returns to the surface he realizes that he has been working under forced draft. He is very much exhausted and he is very hungry. It takes a comparatively short time to build up the high internal pressure, which the diver must have in order to withstand the pressure of the water outside, but it is the decompression when he returns to the surface that is attended with great discomfort and positive danger. If the decompression is not properly effected, the diver will suffer agonies and even death from the so-called "Caisson Disease."

A HUMAN SODA-WATER BOTTLE

We know now a great deal more than we used to know about the effect of compressed air on the human system, and because of this knowledge divers have recently descended to depths undreamed of a few years ago. When a diver breathes compressed air, the oxygen is largely consumed and exhaled from the lungs in the form of carbon-dioxide, but much of the nitrogen is dissolved in the blood and does not escape. However, like a bottle of soda-water, the blood shows no sign of the presence of the gas as long as the pressure is maintained. But on a sudden removal of the pressure, the blood turns into a froth of nitrogen bubbles, just as the soda-water froths when the stopper of the bottle is removed. This froth interrupts the circulation. The release of pressure is felt first in the arteries and large veins. It takes some time to reach all the tiny veins, and serious differences of pressure are apt to occur that often result in the rupture of blood-vessels. The griping pains that accompany the "Caisson Disease" are excruciating. The only cure is to restore the blood to its original pressure by placing the patient in a hospital lock, or boiler-like affair, where compressed air may be admitted; and then to decompress the air very slowly.

It is possible to relieve the pressure in a bottle of soda-water so gradually that the gas will pass off without the formation of visible bubbles, and that is what is sought in decompressing a diver. After careful research it has been found that the pressure may be cut down very quickly to half or even less of the original amount, but then the diver must wait for the decompression to extend to the innermost recesses of his being and to all the tiny capillaries of his venous system.

In the salvage of the *F-4* a diver went down 306 feet, and remained on the bottom half an hour. The pressure upon him was 135 pounds per square inch, or about 145 tons on the surface of his entire body. Some idea of what this means may be gained if we consider that the tallest office building in the world does not bear on its foundations with a greater weight than 215 pounds to the square inch or only about 50 per cent more than the crushing pressure this diver had to endure.

It took the diver a very short time to go down. On coming up he proceeded comparatively rapidly until he reached a depth of 100 feet. There he found the bottom rung of a rope ladder. On it he was obliged to rest for several minutes before proceeding to the next rung. The rungs of this ladder were 10 feet apart, and on each rung the diver had to rest a certain length of time, according to a schedule that had been carefully worked out. At the top rung, for instance, only 10 feet from the surface, he was obliged to wait forty minutes. In all, it took him an hour and forty-five minutes to come up to the surface. The decompression was complete and he suffered no symptoms of the "Caisson Disease." But he was so exhausted from his efforts that he was unfit for work for several days. Yet the operations that he performed at the depth of 300 feet would not have taken more than a few minutes on the surface.

A SUBMARINE REST-CHAMBER

The Germans have paid a great deal of attention to deep-diving operations, and no doubt while their U-boats were sinking merchant ships German salvors were anticipating rich harvests after hostilities ended. One scheme they developed was a submarine rest-chamber which could be permanently located on the bottom of the sea close to the point where the salvage operations were to take place. This chamber consists of a large steel box which is supplied with air from the surface and in which divers may make themselves comfortable when they need a rest after arduous work. Entrance to the chamber is effected through a door in the floor. The pressure of the air inside prevents the water from rising into the chamber and flooding it. From this submarine base the divers may go out to the wreck, either equipped with the ordinary air-tube helmets or with self-regenerating apparatus which makes them independent of an air-supply for a considerable period of time. When the diver has worked for an hour or two, or when he is tired, he may return to this chamber, remove his helmet, eat a hearty meal, take a nap if he needs it, and then return to the salvage work without going through the exhausting operation of decompressing.

CUTTING METAL UNDER WATER WITH A TORCH

The work of the diver usually consists of far more than merely passing lines under a sunken hull. It is constantly necessary for him to cut away obstructing parts. He must sometimes use blasting-power. Pneumatic cutting-tools frequently come into play, but the Germans have lately devised an oxy-hydrogen torch for under-water use, with which the diver can cut metal by burning through it. This is accomplished by using a cup-shaped nozzle through which a blast of air is projected under such pressure that it blows away the water over the part to be cut. The oxygen and hydrogen jets are then ignited electrically, and the work of cutting the metal proceeds in the hole in the water made by the air-blast. A similar submarine torch has recently been developed by an American salvage company. It was employed successfully in cutting drainage-holes in the bulkheads of the *St. Paul,* which was raised in New York Harbor in the summer of 1918.

EXPLORING THE SEA BOTTOM IN A DIVER'S SLED

The diver's sled is still another interesting German invention. It is a sled provided with vertical and horizontal rudders, which is towed by means of a motor-boat at the surface. The diver, seated on the sled, and provided with a self-contained diving-suit, can direct the motor-boat by telephone and steer his sled up and down and wherever he chooses. And so without any physical exertion, he can explore the bottom of the sea and hunt for wrecks.

ARMORED DIVING-SUITS

From time to time attempts have been made to construct a diver's suit that will not yield to the pressure of the sea, so that the diver will not be subjected to the weight of the water about him, but can breathe air at ordinary atmospheric pressure. Curious armor of steel has been devised, with articulated arms and legs, in which the diver is completely encased. With the ordinary rubber suit, the diver usually has his hands bare, because he is almost as dependent upon the sense of touch as a blind man. But where the pressure mounts up to such a high degree that a metal suit must be used, no part of the body may be exposed. If a bare hand were extended out of the protecting armor it would immediately be mashed into a pulp and forced back through the opening in the arms of the suit. The best that can be done, then, is to furnish the arms of the suit with hooks or tongs or other mechanical substitutes for hands which will enable the diver to make fast to the wreck or various parts of it.

But if a diver feels helpless in the bag of a suit now commonly worn, what would he do when encased in a steel boiler; for that is virtually what the armored suit is! A common mistake that inventors of armor units have made is to fail to consider the effects of the enormous hydraulic pressure on the joints of the suit. In order to make them perfectly tight, packings must be employed, and these are liable to be so jammed by the hydraulic pressure that it is well nigh impossible to articulate the limbs. Again, the construction of the suit should be such that when a limb is flexed it would not displace any more water than when in an extended position, and vice versa. A diver may find that he cannot bend his arm, because in doing so he would expand the cubical content of his armor by a few cubic inches, and to make room for this increment of volume it would be necessary for him to lift several hundred pounds of water. The hydraulic pressure will reduce the steel suit to its smallest possible dimensions, which may result either in doubling up the members or extending them rigidly.

But these difficulties are not insuperable. There is no reason why a steel manikin cannot be constructed with a man inside to direct its movements.

THE SALVOR'S SUBMARINE

Other schemes have been devised to relieve the diver of abnormally high air-pressure.

One plan is to construct a large spherical working-chamber strong enough to withstand any hydraulic pressure that might be encountered. This working-chamber is equipped with heavy glass ports through which the workers can observe their surroundings in the light of an electric search-light controlled from within the chamber. The sphere is to be lowered to the wreck from a barge, with which it will be in telephonic communication and from which it will be supplied with electric current to operate various electrically driven mechanisms. By means of electromagnets this sphere may be made fast to the steel hull of the vessel and thereupon an electric drill is operated to bore a hole in the ship and insert the hook of a hoisting-chain. This done, the sphere would be moved to another position, as directed by telephone and another chain made fast. The hoisting-chains are secured to sunken pontoons and after enough of the chains have been attached to the wreck the pontoons are pumped out and the wreck is raised.

It is a pity that ship-builders have not had the forethought to provide substantial shackles at frequent intervals firmly secured to the framing. A sunken vessel is really a very difficult object to make fast to and the Patent Office has recorded many very fantastic schemes for getting hold of a ship's hull without the use of divers. One man proposes the use of a gigantic pair of ice-tongs; and there have been no end of suggestions that lifting-magnets be employed, but no one who has any idea of how large and how heavy such magnets must be would give these suggestions any serious consideration.

But, after all, the chief obstacle to salvage in the open sea is the danger of storms; months of preparation and thousands of dollars' worth of equipment may be wiped out in a moment.

FIGHTING THE WAVES WITH AIR

However, there has been another recent development which may have a very important bearing on this problem of deep-sea salvage work. It has often been observed that a submerged reef, twenty or thirty feet below the surface, may act as a breakwater to stop the storming waves. An inventor who studied this phenomenon arrived at the theory that the reefs set up eddies in the water which break up the rhythm of the waves and convert them into a smother of foam just above the reef. Thereupon he conceived the idea of performing the same work by means of compressed air. He laid a pipe on the sea bottom, forty or fifty feet below the surface, and pumped air through it. Just as he had expected, the line of air bubbles produced exactly the same effect as the submerged reef. They set up a vertical current of water which broke up the waves as soon as they struck this barrier of air.

The "pneumatic breakwater," as it is called, has been tried out on an exposed part of the California coast, to protect a long pier used by an oil company. It has proved so satisfactory that the same company has now constructed a second breakwater about another pier near by. There is no reason why a breakwater of this sort should not be made about a wreck to protect the workers from storms. Where the water is very deep, it would not be necessary to lay the compressed-air pipe on the bottom, but it could be carried by buoys at a convenient depth.

Summing up the situation, then, there are two serious bars to the successful salvage of ships sunk in the open sea—the wild fury of the waves on the surface; and the silent, remorseless pressure of the deep. The former is the more to be feared; and if the waves really can be calmed, considerably more than half the problem is solved. As for the pressure of the sea, it can be overcome, as we have seen, either by the use of special submarine mechanisms, or of man-operated manikins or even of unarmored divers. We have reached a very interesting stage in the science of salvage, with the promise of important developments. Fifty fathoms no longer seems a hopeless depth.

Even in times of peace the sea exacts a dreadful toll of lives and property. Before the war the annual loss by shipwreck around the British Isles alone was estimated at forty-five million dollars. But the war, although it was frightfully destructive to shipping, may in the long run save more vessels than it sank; for it has given us sound-detectors which should remove the danger of collisions in foggy weather, and the wireless compass, which should keep ships from running off the course and on the rocks. And now, if salvage engineering develops as it should, the sea will be made to give up not only much of the wealth it swallowed during the war, but also many of the rich cargoes of gold and silver it has been hoarding since the days of the Spanish galleon.

INDEX