PRODUCTION GOES TO WAR

DIVISION OF INFORMATION
War Production Board
Washington, D.C.

FOREWORD

This is a war of production—machine against machine. It is total war, and the phrase means what it says—*total*. Our way of life is based on machine production. When that way of life is called upon to defend itself, it is natural that mechanical power, which has had so large a part in its construction, should assume an equally large share in its preservation.

The ability of American industry to produce is beyond question. No one doubts that we have the men, the machines, the genius, and the skills to make anything we want to make in any quantity. Our industrial record for the past 50 years proves that we can do it.

The job now in hand is to organize our vast resources. Every skill, every man engaged in this effort must now produce toward a single goal. There is only one answer to those who seek to rule the world by force of planes and ships and tanks and guns. The answer is more planes, more ships, more tanks, and more guns.

The implements of war sufficient for the task in hand are not to be had overnight—neither for the asking, nor for the appropriating of money, nor by any means except the full unstinted concentration of the productive resources, human and material, of this productive Nation. The sustained ability to produce is itself a weapon. In this war of assembly lines it is the master weapon, governing grand strategy, military tactics, and human courage alike.

The road that reaches back from the smoking battlefronts in the Far East, in Russia, in other parts of Europe and Africa to the assembly lines in America is a long and tortuous one. But longer and more difficult still is the trail that stretches from the assembly lines on backward—to the very beginning of the ships and the tanks and the planes and the guns.

It is a road that winds back beyond the machine tools—the turret lathes, the boring mills, and the giant planers that shape the metal—to the forging of the metal itself, and from there to the steel furnaces, the smelters, and the kilns, and thence into the bowels of the earth, deep into the ore. It is a road that is lined every step of the way with high-tension cables. It is a road that is crowded with men, clangorous with the sound of hammers, and the air above it is heavy and hot with sulphur and smoke and the rumble of traveling cranes. It is all of this, but mostly it is a road that is paved with solid, sweating human hours.

It takes time to build a tank. But it takes even more time to build the giant press that forms the turret for the tank. And still more time to make the boring mill that cuts the ring of the turret to size—to an exact size—within two-thousandths of an inch of perfection.

Fortunately there is a system of work which pays dividends in time. It begins slowly, consuming man-hour after man-hour with painful deliberation. And it ends in a teeming rush.

Step by step, designers, engineers, and skilled craftsmen build man-brains and man-skills into machine tools. Tireless, inanimate material is given boundless power—power controlled to the last ounce and directed to the last fraction of a fraction. When the machine tool is built, the power of man to work with metal has been magnified.

This is the system which is the basis of our material civilization. It is mass production, based on the principle of interchangeable parts. In peacetime, it means more goods for more people, at lower prices. It is a working force for democracy. And it works in wartime, too. Just now it is working in behalf of the free people of the world—whether they live in this country, in Europe, or in the Far East.

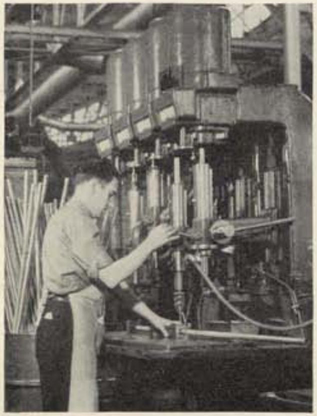
As a Nation we have contracted to become the Arsenal of Democracy. It is the biggest and most responsible contract ever written. If we are to fulfill it on schedule and in good measure, there is no time to lose. There is nothing to do but work, produce, and fight.

W. H. Harrison

Director of Production,
War Production Board.

Vertical multiple spindle machine boring cylinder barrels.

Internal grinding machine finishing plane propeller hubs.



Sensitive drill machining tube parts for aircraft frame.

Five-position drill boring bolt holes in cylinder flange.

PLANES

INTO the building of a bomber go more than 100,000 man-hours of work. There are more than 30,000 different parts and, counting duplicates, there are several hundred thousand separate pieces of metal. The engines themselves are made of 8,000 separate pieces of metal, each of which must be machined on machine tools. The carburetor of a large airplane engine is a more complicated bit of engineering than the entire engine of your automobile—one cylinder unit develops as much horsepower as an eight-cylinder automobile.

In the last war, airplane engines had to be overhauled every 50 hours. Today, because their vital parts are machined to within a few ten-thousandths of an inch, they can go 600 hours at a stretch. Such precise workmanship is making airplanes for the Army and Navy that are the finest of their types in any air force. These airplanes will be made in such numbers that the United States will have the largest air force in the world.

It is 38 years since the Wright brothers flew the first airplane at Kittyhawk, N. C., and in that time the aircraft industry in the United States has made something over 100,000 planes of all kinds, from puddle jumpers tied together with bailing wire, to an 82-ton Army bomber. Now we are in a production program that calls for, in one year, substantially more than half the total number of airplanes made since 1904. This means a complete military plane about every 8½ minutes of every day in 1942.

The American aircraft industry, when the need came, was not geared for anywhere near this many planes. Compared with the present demand, the production for World War I was indeed infinitesimal. At its outbreak, for instance, we had 55 airplanes. From a military point of view, 51 of these were classified as obsolete and four as obsolescent: our air force, zero.

Up to the end of November 1918, we produced a single type of bomber, shipping abroad slightly more than half of the total of 3,227. We produced 13,574 Liberty engines and shipped more than a third of them abroad, and produced for use here 8,000 training planes and 16,000 training engines.

U. S. Plane Program Started Slowly in the Year of Munich

Aside from this brief flurry of activity, serious production of military aircraft was not started until four years ago, when European nations looked to this country for help in attempting to overcome the lead taken by the Axis. In 1938—the year of Munich—our aircraft plants were producing about 100 military planes a month. Then France placed an unprecedented order for 200 pursuit planes. Britain followed and France doubled its order; and by 1939, the 36,000 shop employees of the industry were building warplanes at the rate of 200 a month.

Meanwhile, Congress approved a program for 5,500 aircraft for our armed forces and at the end of the year the industry which had been primarily interested in flivvers and commercial transports could count a production of more than 2,100 military planes.

Hundreds of Plants Converted to Build Parts for Aircraft

By the spring of 1940 the rate was nearing 500 a month. As impressive as this expansion record seemed, the industry and the Nation at large had to catch breath after President Roosevelt in May told Congress he would like to see this Nation "geared up to the ability to turn out at least 50,000 planes a year. Furthermore," he added, "I believe this Nation should plan at this time a program that would provide us with 50,000 military and naval planes."

This planning program began to make its tremendous demands felt in every part of the industry—assembly plants were doubled and redoubled, part makers brought in more and more shops. One single plant now uses more workers than were in the entire industry three years ago, and the total number of productive employees in over 30 plants is well above 300,000.

These newly trained men and women have joined the veteran mechanics from other industries who have brought to this field the skill to shape pieces of metal. Many of their old familiar machine tools have been adapted to this work but many new ones have had to be built because tolerances unheard of in other industries are everyday measurements in aircraft plants. Men and machines were to do a job that never had been done before: Bring quantity production to an industry dedicated to hand-building its product.

There was not only a change within the industry, but also one in its scope. Automobile makers were becoming interested in airplanes. Plans for new buildings more spacious than any others in the world began coming off drawing boards. While continuing to run automobiles off their regular production lines, the major companies took on substantial orders for aircraft engines, parts, subassemblies, and complete planes.

This was the "make-ready" program for the objectives set in 1940 for this year and next year. Meanwhile production in existing plants in the aircraft industry began to rise steadily. From 561 planes in July 1940, the rate went to over 800 in December, and the year's total was just over 6,000. In the first quarter of 1941, about 1,000 planes a month were produced, and by September this figure had been doubled. For military reasons, exact figures later than that time are not available for publication.

As new facilities came into production and old ones gained new skill, the aircraft industry added to its fast-growing family plants that once made automobiles and bodies, household refrigerators, hardware, hydraulic-control equipment, pneumatic tools, electric generating equipment, electrical equipment, rubber products, elevators, pumps, and railroad cars. Hundreds of subcontractors feed thousands of parts to these plants.

The fastest military airplane in the world with speed well in excess of 400 miles an hour is the Army's *P–38*, the Lockheed *Lightning*. This low-wing monoplane, with tricycle retractable landing gear and two 12-cylinder supercharged engines rated at 1,150 horsepower, weighs about 13,500 pounds, is armed with 37-mm. cannon and .50-caliber machine guns. Similarly armed is the Bell *Airacobra*, *P–39*, a single-place, single-engine pursuit plane that weighs about 6,000 pounds. As a middle-altitude fighter, as well as for attack on ground targets, this plane has no equal.

The Republic *Thunderbolt*, *P–47*, is the fastest single-engine airplane in the world. Heavily armored and bristling with both large- and small-caliber guns, this plane has done 680 miles an hour in a power-dive test and more than 400 miles an hour in level flight. It is powered by a 2,000 horsepower engine and has a four-blade propeller with a diameter of more than 12 feet. Comparable in weight to the *P–38*, the *P–47* is slightly smaller. Its length is 32 feet 8 inches, its height 13 feet, and its wing span 41 feet.

One of the latest Navy fighters is the Grumman *Wildcat*, a fast, maneuverable, single-engine plane. Earlier models were used by the Marines in the defense of Wake Island. Lt. Edward O'Hare, the Navy's first ace of the war, piloted a *Wildcat* when he downed five Japanese planes and disabled a sixth in a single day over the Pacific.

The *Airacobra* and *Lightning* are flying with the RAF under the same names. The British call the Navy's *Wildcat* the *Martlet*. The Curtiss *Tommyhawk*, known to the United States air force as the *P–40*, is fighting over four continents—with the Russians in Europe, the British in Africa, the Flying Tigers in Asia, and the Americans in Australia. The newer Curtiss *Kittyhawk*, Brewster *Buffalo*, Republic *Lancer*, and North American *Mustang* are among other American-made fighters serving the United Nations.

Bombers are getting increased emphasis in production schedules and high priority ratings this year for the obvious military reason that there is a pressing need for this type of long-range offensive plane.

The program now in effect calls for large quantities of four-engine bombers. These planes weigh nearly seven times as much as some single-engine fighters, and to produce them takes considerably more man-hours, more raw materials, more engines, and more plant space.

It is generally agreed among military observers that in the heavy bomber class the enemy has nothing to compare with our Boeing *B–17*, *Flying Fortress*, or our Consolidated *B–24*. The British have been using both these four-engine bombers for some time and have renamed the latter the *Liberator*. A nautical version of the *B–24* is the Navy's flying boat *Coronado*.

In the medium bomber class, the American Army has two different planes—the *B–25* and *B–26*—whose range, speed, and bomb-carrying ability are greater than any similar bomber in any other air force. The Martin *B–26* two-engine bomber is the fastest medium bomber in the world. It has a slightly higher top speed than the *B–25*, made by North American. However, the latter bomber has speed nearly as great as famous foreign fighter planes. Brig. Gen. James Doolittle led a group of *B–25's* in the successful bombing of Tokyo in April. The Navy's two-engine bomber is the flying boat *Catalina*. One of this type, on British patrol, sighted the fleeing German battleship *Bismarck* and directed the British fleet to its position for the kill.

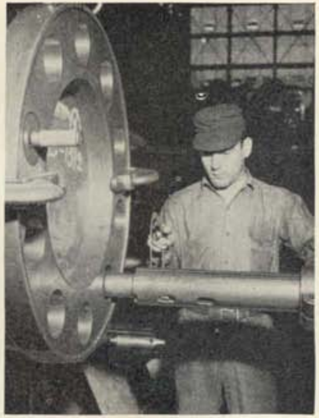
The Army's twin-engine Douglas light attack bomber *A–20*, is so fast the British use an earlier version, the *Havoc*, as a night fighter. American-built attack bombers going to the United Nations air forces also include the *Boston*, *Baltimore*, *Hudson*, and *Ventura*.

The Army and Navy use the same Douglas dive bomber, called the *A–24* by the former service and the *Dauntless* by the latter. Other dive bombers include the Vultee *Vengeance* and Curtiss *Helldiver*.

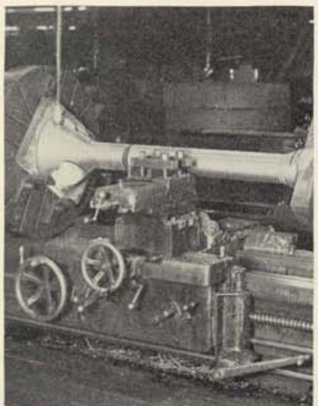
Even Better Planes Are Being Designed for Early Production

Besides fighters and bombers, the industry is building numbers of observation planes, transports, and trainers. While all these are being turned out for the use of the United Nations, newer planes are coming out of the blueprint stage. These will be faster, larger, have greater load ability, and more range than the ones already known as the "finest in the world."

Ship propeller, cast in one piece, being lifted into place.



Worker boring a large engine shaft coupling for a ship.



48-inch engine lathe machining triple expansion engine rod.

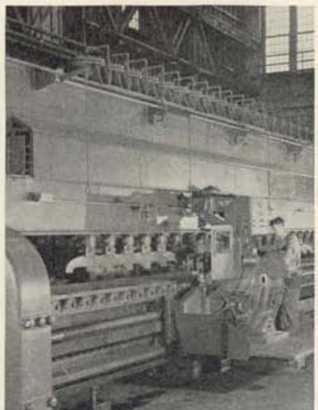


Plate planer being set up for machining ship plates.

SHIPS

THE BIGGEST, most complex single job in solid metal since man began to work with metal thousands of years ago is the building of a large ship. It takes approximately three years to build a battleship. Into the building of a Liberty Ship—an emergency cargo vessel that has been stripped of frills and standardized for rapid production—go some 500,000 man-hours and the time needed will average about three months.

The final assembly station in the building of a ship is the shipway. It is here that all the parts are built into a whole. But to talk of assembling a ship is like talking of assembling a skyscraper. Assembly is the big part of the job. But not all of it. For generators and turbines must be built. Giant shafts must be turned. Propellers must be forged and machined. Tons of plate must be cut, shaped, and scarfed. All the work is done in machine or structural shops, some in the shipyard itself, some outside. But wherever it is done, it is a job for machine tools.

Making gigantic parts fit to a thousandth part of an inch is just about the hardest job in building a ship. Some of the gears that go into an engine have to be cut in air-conditioned rooms, since the pieces of metal from which they are made are so large that change of a few degrees in temperature will cause them to contract or expand enough to throw measurements off balance. Temperature rise may change the size of a small rod so slightly that it would hardly make any difference, but the same change in the tremendous gears of a ship may be more than enough to ruin the job. So the temperature in cutting rooms must be stabilized.

Even if there were only a few of these huge parts to fit to near-perfection, the demand on time and machines would be considerable. But there are many such parts. Into a ship go turbines as high as a room, gears larger than an entire motor truck, propeller blades taller than a man, valves big enough for a man to walk through.

Landlubber Industries Turn to Producing Parts for Vessels

Many of the facilities now making equipment for ships are either new or converted from some landlubber industry. Manufacturers of paper machinery are machining shafting; makers of oil-well machinery are building deck equipment such as winches, windlasses, and steering gears; stove makers are producing lifeboats; marble-cutting equipment is doing rough preliminary work on shafting.

The size of the shipbuilding program alone would mean a tremendous expansion of a going industry. But the United States did not have a fully going shipbuilding industry to begin with. It was only on its way at the time the need for merchant shipping began to be felt in the summer of 1940. Shipbuilding in American yards practically stopped after the World War program was ended early in 1922.

This old program was quite sizable. It hit a peak of 5,051,759 deadweight tons in 1919—after the Armistice had been signed—and accounted for an aggregate of 14,525,939 deadweight tons during the five-year period from 1917 to 1922. But during the next five years, our yards delivered only 699,767 deadweight tons—96 ships. In the following five years, 602,823 tons—66 ships. In the next three years, 1934 to 1936, a total of 16 ships was built. This meant America's shipbuilding industry was at keel bottom. With the impetus given by the Merchant Marine Act of 1936, the industry began to stir, slowly. By 1940 it was able to build 56 ships in 12 months—more than any year since 1922.

Last year 1,100,000 deadweight tons of shipping were delivered and plans were made for approximately 6,000,000 tons for delivery in 1942. This schedule—20 percent larger than last war's peak—was replaced by one for 8,000,000 tons set by the President as the new 1942 objective.

Merchant ships of 2,000 tons or more flying the American flag in 1941 totaled a little over 10,000,000 tons. The President, in ordering 8,000,000 tons, asked shipyards to build in one year nearly as much tonnage as the merchant fleet had in it last fall. This merchant shipping program was in addition to a naval ship program which was even greater.

In July 1940, there were about 60 ways available for merchant ships. The present plans call for nearly 300 ways, some being added to old yards and some being built in 20-odd completely new yards.

Concentration in the merchant shipping program is on the 416-foot Liberties and each one delivered adds 10,500 deadweight tons to America's merchant marine. Others in the program include three main types of standard cargo vessels, ranging up to 12,600 tons; two types of large tankers, averaging about 16,500 tons; troop ships, smaller cargo ships, barges, tugs, and the like.

New Assembly Methods Save Much Time in Building Liberties

In designing the Liberty Ship thought was given to minimum cost, rapidity of construction, and simplicity of operation. In order to get engines for the Liberties in the numbers needed, a less advanced type of propulsion machinery is used. It is a triple-expansion, reciprocating engine of 2,500 horsepower and it can drive the ship at 11 knots. Extensive use is made of welding to save time and steel. Assembly work is possible by a modification of fabrication methods. Delay in procurement is reduced by centralizing purchases of materials and equipment. A Liberty Ship carries a complement of 44 officers and men and costs upward of $1,600,000.

TANKS

POUND-FOR-POUND, tanks being made with American skill surpass any similar type in mobility and mechanical reliability. Hard-hitting, tough, capable of outrunning and outlasting other models, American tanks didn't just happen to be good. Superiority was built into them by hundreds of precision tools. Each part is made to exact measurements and machine tools used to make them are of a special nature and size.

Thirty to 50 percent of the weight of any tank is armor plate. To build a tank, hard, thick steel that cannot be pierced by a rifle or machine-gun bullet must be pressed and drilled and turned and reamed and milled to exact dimensions. Into a tank go steel, nickel, brass, copper, aluminum, rubber, leather, glass, cotton, plastic, tin, lead, and many other products. In its skeleton are rolled plates, castings, forgings, rivets, bolts, wire, tubing, ball and roller bearings, gears, electric motors, instruments, batteries, and valves.

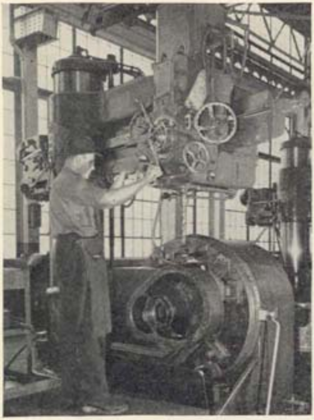
In a light tank are 14,000 individual pieces; in a medium tank, 25,000; in a heavy tank, 40,000. These must be machined, subassembled, and assembled. Many of the metal parts must be machined on boring mills, radial drilling machines, milling machines, and similar tools of much larger size than found in ordinary shops. A transmission cover alone is as heavy as the average automobile. Armor castings and forgings are so tough that tungsten-carbide tools have to be used in nearly all turning and boring operations. Cutters of high-speed steel containing a high cobalt content must be used in milling and similar operations.

From beginning to end, the building of a tank is a task for machine tools. Without them, tanks would remain thin lines on drafting paper—with the right type of tools, they become the backbone of our armored forces.

About 25,000 Parts Assembled to Build Modern Medium Tank

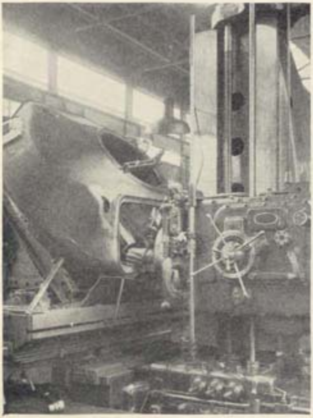
Up to several years ago there were almost as many tanks sitting as World War monuments in public squares as there were in fighting trim in the Army. Even these relics bore no battle scars, because no American-made tank fought in France. We used British heavy tanks and French light tanks and the total number was less than 300—not enough to equip one of our modern armored divisions.

The tank program on which we set our production schedules in this country was based on a 1919 campaign that fortunately didn't have to be fought. We did, it is true, make a few tanks. Up to the Armistice we built

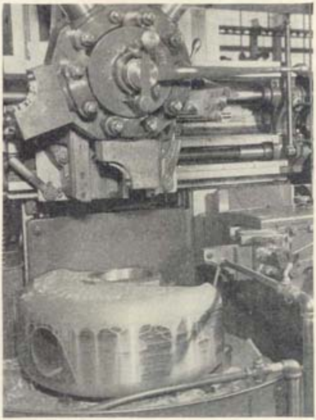


Radial drill machining a part for a tank transmission.

Vertical boring mill turning a turret ring for a tank.



Horizontal boring mill milling hole for front turret plate.



Vertical turret lathe machining a transmission housing.

a total of 64 light tanks. And they *were* light tanks—they weighed only $7\frac{1}{2}$ tons. The vehicles we call light tanks today are nearly twice as heavy as those old ones. Production of the World War light tanks continued to the end of March 1919, at which time we had 778. For actual battle participation we got all our light tanks from the French, 227 of them.

Back in those days we called 30-ton tanks "heavies." Today we call vehicles of this weight "mediums." Our modern heavy tank weighs around 56 tons. The World War 30-ton tank program called for the joint endeavor of American and British industry. To reach the Allied goal of 1,500 vehicles, the British were to supply the armor plate and we were to build the motors and driving mechanisms. Up to the Armistice we had completed about half of our share. But the 30-tonners used in battle by our troops came from the British who supplied 64 vehicles.

During the next 15 years, 30 tanks were built in the United States. Meanwhile all of the World War models had become obsolete and by the time war broke out again in Europe the Army had in service only a few light tanks and a small number of 18-ton medium tanks, known as the *M–2*.

In production was an improved model of the medium tank, known as the *M–2A1*, with heavier armor bringing its weight to 20 tons. These tanks, and the earlier types, came from Army arsenals where they were built by hand.

The need for modern mechanized fighting equipment, so forcefully demonstrated by the armored forces abroad, meant an end had to be put to this slow, tedious production method. American industry was asked to produce in great numbers a vehicle that is not a tractor, a truck, or a locomotive. It is something in between, with a nature and a function all its own. Joining in the program to produce this distant cousin of their civilian products are the locomotive, automotive, and farm-equipment industries. Helping them are plants that once made railroad cars, automobile and trailer bodies, automobile motors, Diesel engines, airplane motors, tractors, oil-well drilling equipment, type-foundry equipment, shoe machines, compressed-air equipment. Together they created a new industry to build monsters that cost $1 a pound and weigh up to 112,000 pounds.

First tank to be born of this new industry was the *M–3* light, weighing $13\frac{1}{2}$ tons and equipped with five machine guns and a 37-mm. gun—a highly destructive fighting unit that can move at speeds up to 35 miles per hour and has the tactical equivalent of 40 men on foot. It was on April 30, 1940, that the first delivery was made, and since then other production lines have started and more are being set up. Later models are going into production.

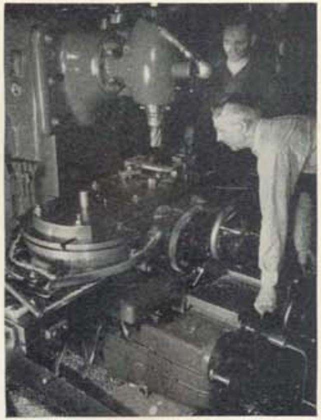
The first medium tank, *M–3*—a refinement of the *M–2A1*—was delivered in April 1941, and already it has been augmented by a later model, the *M–4*. With its seven men, four machine guns, a 37-mm. tank gun, and a 75-mm. cannon, it is a rolling battery of artillery.

The first heavy tank was delivered December 8, 1941—the day after the attack on Pearl Harbor. Its 56 tons is hell in motion.

Tank Chassis Used to Mount Artillery for More Mobility

Besides tanks themselves, the Army uses many tank chassis to mount field guns. Development of this type of mover makes it possible to give artillery a mobility unheard of in the last war. Tractor-type mounts are built with the same precision that makes our tanks unequalled, and they come from the same production lines.


Milling operation on a 37-mm. antiaircraft gun carriage.


Axle brackets for a gun carriage being set for milling.


Skilled hands adjusting a gun carriage part on a lathe.


Assembling the many machined parts that make up a gun.

GUNS

It was the need for guns in quantity which led to the principle of manufacturing interchangeable parts, which is the principle of mass production.

Eli Whitney, the inventor of the cotton gin, found that he could gain speed in the manufacture of rifles by taking care to see that each operation which he performed on each part was identical—each barrel cut to the same length, turned to the same circumference, bored to the same caliber. He fashioned each hammer, each trigger, and each stock to the exact dimensions of the one which went before it. In this way he was able to make separate parts in quantity and produce his rifles in volume lots.

Whitney's method of manufacture would be impossible without the precise work of machine tools. Without the principle of interchangeable parts, it would be futile to think of making thousands of antiaircraft guns. If precise work is necessary for the manufacture of ordinary guns, it is many times more necessary for the manufacture of that highly intricate mechanism known as an antiaircraft gun.

An antiaircraft gun, in fact, is much more than a gun. It is a unit made up of four main sections: the gun itself, the recoil mechanism, the carriage and mount, and the fire-control equipment. Each of these requires exacting skills and the complexity of manufacture is indicated by the wide variety of companies now making them. Plants turning out parts for antiaircraft guns include those that normally make agricultural machinery, firearms, automobiles, optical instruments, electrical appliances, oil burners, tires, sound reproducers, sewing machines, textile machinery, cameras, surveying instruments, elevators, printing presses, pumps, safes, and other machinery with movable heavy parts.

Many New Facilities Needed to Produce Antiaircraft Guns

Before any of these plants could begin to produce gun parts, they had to do a comprehensive retooling job. Some are now completely tooled-up and at work; others are completing their "make-ready" program needed to fill the quota set by the President. When the new goals were announced, immediate action was taken to step up substantially the production in plants already making parts for guns and to find additional facilities.

Where there were facilities in place, it was necessary to train more men and women, increase the number of hours worked, and step up the flow of materials into the plants. But the number of plants with complete facilities was small compared with the ones needed to produce the guns ordered by the President. The most important job, at first, was setting up new facilities. So far as antiaircraft guns were concerned, facilities meant machine tools. There was a problem of floor space, too, and some construction was necessary. Even more pressing was the need for gun-making equipment.

Flawless Performance of Guns Depends on Precise Workmanship

The gears and surfaces and moving parts that make up an antiaircraft gun must be perfect to within one ten-thousandth of an inch in some instances. Many tools capable of such close tolerances are being built in machine shops, but even under ideal conditions it takes months to complete the more complex ones. To get enough for the accelerated program it was necessary to convert a large number of existing tools not already working on war orders.

Antiaircraft artillery was produced only in limited numbers in this country prior to June 1940, when funds for a modest expansion of production were first made available. The principal manufacturing sources were Army and Navy arsenals which received some help from civilian plants and technicians. So far as American industry was concerned, antiaircraft guns were strangers when the war program was started.

In this respect they differed from planes and ships which had small, but active, industries of their own. To get into war production at shipyards and aircraft plants it was necessary to expand tremendously the going facilities, but to get guns in anywhere near war quantities it was necessary to create an entirely new industry. The new guns had to be built by companies new to gun building. It was almost the same situation that faced the novice rider who was given for his first mount a horse that had never been broken in.

Even in the hands of experienced ordnance men an antiaircraft gun is no snap to make. It must send projectiles as far as the substratosphere at targets hurtling through space at 300 miles an hour or faster. Firing must be rapid and extremely accurate, for in many instances planes are within range for only a few seconds. Perfection must be built into the gun so that it functions flawlessly and automatically. Otherwise it will fail in its function of providing protection for ships, troops, industrial centers, and cities.

Our present models are the result of continuous studies by the ordnance departments of the Army and Navy and the experience gained from the use of antiaircraft weapons during the early stages of the present war abroad. Some foreign types have been extensively tested, and improved models of two of them, the Swedish Bofors 40-mm. and the Swiss Oerlikon 20-mm., are now in production. Other types include the 37-mm. and 90-mm. guns. The 20-mm. Oerlikon (slightly under an inch in diameter) is used as defense against dive bombers, augmenting the larger weapons that shoot to higher altitudes. Projectiles that can tear a hole a foot square in attacking planes are fired from the Oerlikons at a high rate. Its range is much greater than that of heavy machine guns. Improved production methods allow the Oerlikons to be made in increasingly larger quantities.

The 37-mm. gun is an automatic weapon developed primarily for use by ground troops against low-flying aircraft. It fires a projectile slightly under an inch and a half in diameter that weighs approximately a pound and a quarter. Instant changes in aim can be made by observing the path of tracer-type slugs fired from the guns. Some of the 37-mm. projectiles are armor-piercing and others explode upon striking any part of a plane, causing considerable damage, often knocking it out of action. If these projectiles miss, they explode automatically in the air. This feature adds to the coverage of the fire and also prevents projectiles from exploding among friendly troops after falling to earth.

Mounted on a mobile carriage, the gun can be towed at high speed. To go into action, it is lowered to the ground, taking the weight from the wheels, and this operation consumes only 15 seconds.

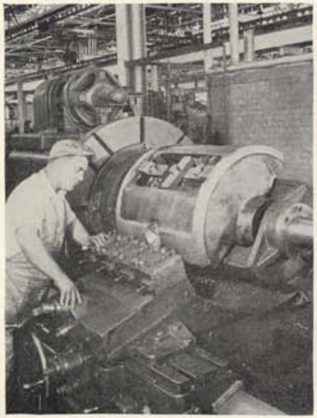
Like the 37-mm. gun, the 40-mm. Bofors is used against low-flying aircraft. It fires a high-explosive projectile, just over an inch and a half in diameter, weighing slightly more than two pounds, to a maximum vertical range higher than that of the 37-mm. type. The Bofors also uses tracer-type self-destroying ammunition. This is the gun that the British used at Dunkirk and it is credited with greatly reducing the effectiveness of German aircraft over that area, making the withdrawal successful.

Automatic Features Give Antiaircraft Battery Great Punch

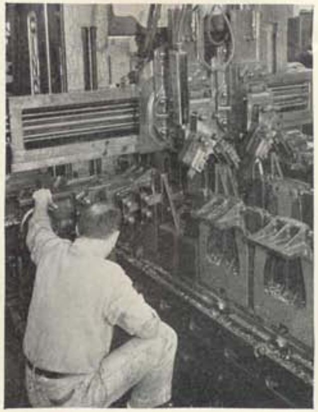
The 90-mm. gun, a picture of which appears on the defense-series 2-cent stamps, has replaced the 3-inch size as the standard antiaircraft gun for the Coast Artillery. Usually it is used in batteries of four, controlled by a director with which each gun is connected and which automatically transmits to dials the correct angles of elevation and direction. The gun crew has only to feed the loader and follow the dial pointers. Data needed to direct the action of batteries may come from radio locators, listening posts, or other sources. In the case of batteries protecting civilian areas, the far-flung system of air-raid warning will be used. This gun is a considerable improvement over the 3-inch type, giving batteries greater range and more punch. Its rate of fire is slightly lower than that of the 3-inch gun, but the projectile of the 90-mm. is slightly more than 3½ inches in diameter and heavier, weighing about 21 pounds. It is used against high-flying aircraft.

Man grown old in service bringing skill to the machine.

Youth operating a special heavy-duty milling machine.



Attentive operator watching multiple tool lathe turning.



Worker lining up tank parts to be machined on a planer.

MACHINES AND MEN

A MACHINE TOOL may be defined as a power-driven machine, not portable by hand, whose purpose is to cut metal in the form of chips. However large or small a machine tool, however complex or simple it may be, you may be sure that it employs one or more of five principles—turning, boring, planing, milling, or grinding—to do its work.

Turning is accomplished by revolving a piece of metal on centers. As the work turns, cutting tools are applied precisely and the chips are removed. The principle of the lathe has been known and used by man for thousands of years.

Machines that cut round holes in metal use the principle of boring. Some tools, like drills, make new holes in solid metal. Others, such as reamers and boring-cutters, are used to finish up or enlarge a hole that has already been made. Boring may be done by a single drill or on a great multiple-spindle machine that cuts more than 100 holes at a time.

The principle used in planing metal is the same as that used in planing wood. In this case, however, the work moves backward and forward under a rigid cutting tool. When the cutting tool moves over the metal, the operation is called shaping, and the machine tool is called a shaper.

A milling machine is equipped with a rotating cutter which has many teeth. As the work moves under the driven teeth, the metal comes off in the form of chips. The action of a milling machine resembles that of a circular saw, but the cutter itself, instead of being a thin disc, is usually a cylinder with many projecting cutting teeth.

Grinding is usually the first and the final machine-tool operation that metal parts receive. Grinding machines clean the surfaces of castings and forgings, and grinders also polish and buff the finished parts until they meet the last fraction of the required dimension. Grinding employs the age-old principle of applying metal to a revolving abrasive wheel.

There are many machine tools which are modifications of one of the five basic principles and some two kinds of machining may be employed in the same machine, such as turning and boring. In addition, there is a wide range of special attachments and tooling which adapt a standard machine to do some particular job to the best advantage. And there are also many kinds of highly special machines designed and built for single purposes.

Near-Perfect Fittings Make Mass Production of Weapons Possible

Machine tools are the master tools of industry. There are more than 250 different kinds of them, and they all perform, basically, one job: They work metal to the shape and size that the blueprint calls for. Whether they drill or bore or cut or plane or grind, their function is the same. They are to industry what the sculptor's chisel is to art. Their raw material is a casting or a forging that has been formed to the rough dimensions of the finished job. Starting with this, machine tools create in metal the exact piece—the gear, the bolt, the shaft, or the bearing—which is specified.

Machine tools are precision tools. They work on constant and intimate terms with tolerances as fine as one-thousandth of an inch—approximately one-third of a human hair. It is this kind of accuracy which makes mass production possible. Because of it, a man on an assembly line can take at random any one of a thousand pistons, place it in any one of a thousand cylinder blocks, and know that the fit of cylinder and piston is right. Valves and valve seats, wheels and wheel hubs, propellers and propeller shafts are thus made separately, in enormous volume, and their assembly is a matter of routine.

One of the biggest jobs that machine tools constantly perform is the making of more machine tools. They are the only machines which reproduce themselves. But it is a paradox that they—the machines of mass production—are difficult to produce by mass-production methods. Except for small standard lathes and drilling machines, most machine tools are built to order—to perform one special operation. This means *individual* production. And individual production means time.

In a turret lathe, for example, there are more than 3,000 parts. There are six times as many gears as there are in an automobile transmission. A very large machine tool may weigh several hundred tons and take more than a year to build.

These are purely mechanical difficulties. The *human* difficulty is that to any machine-tool craftsman worth his salt, a half an inch is a long day's journey. Even an eighth or a sixteenth is a good stout walk. As a fraternity, machine-tool craftsmen feel at home in the cloistered regions below one ten-thousandth of an inch. Once there, however, they move about with care. For a thousandth of an inch the wrong way in an airplane cylinder might cost a battle. And a 90-mm. barrel that is untrue by even the fraction of a hair may cost a ship or a salient position.

Beyond certain limits, then, the machine-tool builder cannot hurry. His business is to save time for industry. To those who clamor for speed and more speed, he has one unassailable answer: *It takes time to save time.*

The records show, however, that, mass production or no mass production, the machine-tool builder is a past master in the art of saving time. In 1900 he was removing metal at the rate of one-fourth pound per minute. Today as much as 17 pounds per minute curl away from the edge of his cutting tools—and the accuracy of the work has increased tenfold. He can shave a 2-inch bar of steel down to a diameter of 1.85 inches almost 80 times faster than he could 40 years ago.

He has constantly improved the productivity of his machines, giving them more speed, more power, more rigidity, better lubrication. New cutters are made of hard steel alloys containing such metals as tungsten, tantalum, and titanium. His cutters today remove hard steel at an astounding rate. On brass and aluminum the cutting speed is tripled.

These are the normal improvements of peacetime, but under press of a national emergency the entire industry really moved into high gear. As a result, machine-tool output today is more than five times as large as it was in 1939. Last year's value was approximately $840,000,000—this year's value may reach an annual rate of $2,000,000,000 by fall. Every day sees mounting machine-tool capacity being translated into war munitions.

Important as machines are in this war, they do not replace men. On the contrary, the more war becomes mechanized, the more it calls for manpower behind the lines. For every man at the front today, we need many times one at home. For every army on the battlefield, there must be more armies behind the lines—in the factories, on the farms, in the mines, the shipyards, the steel mills, the laboratories, the hospitals.

Armies of Skilled Workmen Must Back Up Fighting Forces

It is a far cry from the day of the self-sufficient soldier of the Roman legion, who moved into battle with only his sword and shield. Today's mechanized armies cannot function without the full support of the men in industry who provide them with weapons, ammunition, transportation . . . with all of the technical equipment to carry through the complex operations of modern war.

The increase is spread over all civilian activity—over every man, woman, and child—but a heavy share of the increase falls to skilled men in industry—to machine-tool builders and machine-tool operators and engineers, who are charged with the job of keeping the production lines moving faster and more surely than they have ever moved before.

THERE are a good many ways we can lose this war, but there is only one way to win it: Every man of us must keep his sleeves rolled up all the time. Every machine must work all the way around the clock.

We have come to the place where every hour is zero hour, where a day lost can mean a month of fighting later on. Let us not waste a day or a minute. Let us use every man and every machine. Let's use them *now!*

W. M. Nelson

Chairman, War Production Board.

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