mation and almost a week passed before a single plane returned to test out the defenses. It, too, was shot down. "Without doubt, they (the twelve SCR-584's then on the beachhead) are largely responsible for the successful anti-aircraft defense of Anzio," said an official report.

More direct news of the prowess of the SCR-584 reached the Corporation in August, 1944, after the invasion of France, through the courtesy of the Chief of Staff, General George Marshall, who forwarded a then secret letter addressed to him by General Sir Frederick A. Pile, commanding the British defense against the buzz bombs.

"I am writing to thank you for the great assistance

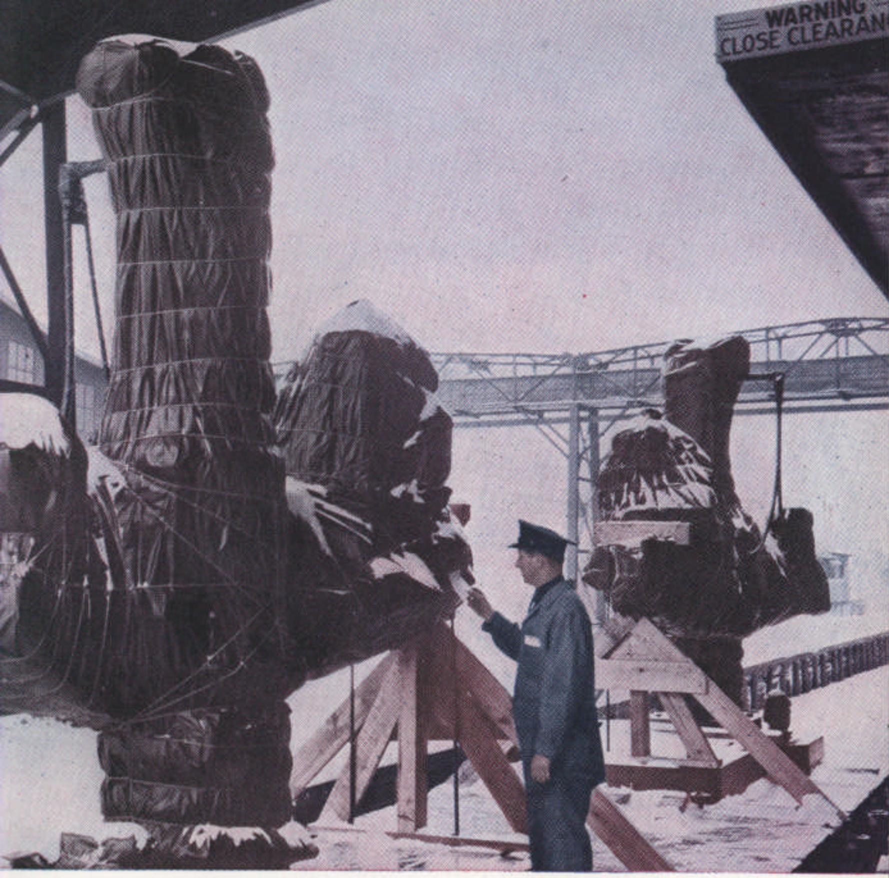
Blind-flying dive bombers, fighters and photographic planes were directed by radar from this SCR-584 trailer.

you have given us in meeting the flying bombs," the letter read. "The equipment you have sent us is absolutely first-class, and every day we are getting better results with it. We are employing the SCR-584 with the new predictor. This predictor also is an outstanding job. Finally, there is a fuse so secret that I can describe it only by its nickname in this country, "Bonzo."

"With this fuse we have cut down the number of rounds fired per flying bomb destroyed to well under 100, and the best of batteries actually are getting one bomb to every 40 rounds. Our percentage of kills is not yet high enough, but it is going up at a very nice pace and we are already far ahead of the fighter planes. . . . General Eisenhower has lent me twenty of your batteries and they are now in action on the coast. They are a grand lot of chaps and have shot down large numbers of flying bombs."

If the percentage of kills was not then high enough to suit General Sir Frederick, it quickly became so. On a later Sunday in August, 101 V-1 buzz bombs were detected approaching the coast of England. Of these only four got past the SCR-584 radar-directed defense.

"Bonzo," the very secret fuse, was the radio proximity fuse, also an American invention, from which the veil of censorship was not lifted until the Fall of 1945. Smaller than a pint milk bottle, the VT fuse contained five radio tubes, each about a third the size of a cigarette. Instead of being timed to explode



Radar-making machine tools begin to arrive at the Dodge Plant. These are radial drills in their shipping wrappers.

at a pre-determined point, a shell equipped with a VT fuse was set off by radio waves when it came within 70 feet of an enemy bomber. Another type of VT fuse used in howitzer fire was exploded by radio impulses reflected from the ground instead of from a flying target. Even men in foxholes could not escape their deadly fragmentation at about tree-top height.

Radar even enabled the British and our Air Force to backtrack the buzz bombs to their sources in

France, Belgium and Holland, then to bomb these launching installations. On D-Day, June 6th, 1944, though the French coast was heavily overcast, the German coastal defenses showed up plainly on the scopes of airborne radar sets and enabled Allied bombers to lay down a bomb barrage which paralyzed many of the Nazi defenses for a time. Every bomb dropped was directed by radar and none hit an Allied soldier though the German and our lines often were as close together as a "quarter past three," in artilleryman's language.

Thirty-nine SCR-584 sets were landed on Normandy beaches on D-Day and were so deadly in their effect that the Germans soon pulled their aircraft out except for sporadic sorties.

On the last night of the German evacuation of Boulogne, heavy guns on the Dover coast sank eleven ships out of eighteen at a range of twenty miles, ships which only radar could see.

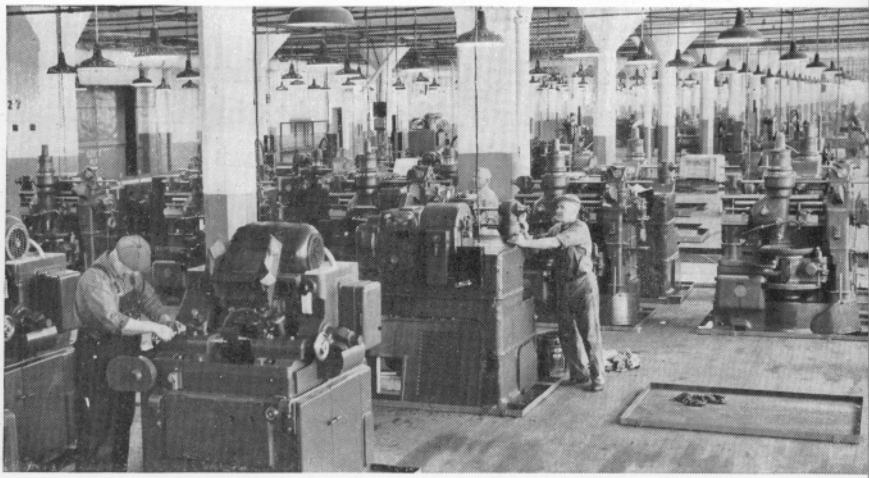
Air Marshal Tedder, Air Chief of the North African campaign, credited radar above tanks with the rout of Rommel. "Radar," he said after the war ended, "caught Rommel's fuel ships just outside Tobruk before the battle of El Alamein. Later it enabled us to strangle his Mediterranean supply line, and this led to the collapse of his armies."

* * * * *

In the course of the development of the microwave SCR-584 gun-laying radar, the Radiation Laboratory found itself faced with new mechanical problems in the vital antenna mount. While the principle was the same used in earlier radars, a much greater mechanical accuracy was demanded, and as the SCR-584 must be easily moved from place to place, there were limits of size and weight. Accuracy would depend entirely upon the gearing, size and weight would depend principally upon the gearing. A lesser weight factor was the antenna dish or paraboloid. An experimental paraboloid had been made of spun and cast aluminum, no longer to be had.

In late April of 1942, Dr. Karl T. Compton, President of Massachusetts Institute of Technology, seat of the Radiation Laboratory, phoned his friend, Mr. Keller, to ask if two Laboratory men could come to

Gears held to exquisite accuracies were cut on the gear shapers and shavers shown here.



Tool men at work. Chrysler brought in extra ones to help engineer the tooling of the radar job.

Detroit to talk with him about their paraboloid problem. Dr. L. A. DuBridge, Director of the Laboratory, and his aide, Dr. I. A. Getting, arrived the next day.

After studying the drawings they brought with them, Mr. Keller said he thought Chrysler could handle the paraboloid, stamping it out of steel at the Dodge plant. Unfamiliar with the art of forming thin sections of steel in presses, Drs. DuBridge and Getting questioned whether the necessary accuracy could be had by this method. In principle, they explained, the dish focused the radio beam as a battleship searchlight reflector focuses a million candlepower light. Mr. Keller satisfied them, however, that the piece could be made to close accuracy on automobile body presses.

They did not speak of gearing, but it so happened that Chrysler Corporation was making radar antenna mount gears for Research Enterprise, Ltd., Canadian makers of radar, and so knew something of the gearing problems involved. Chrysler merely made the gears to the specifications of the Canadian company, but Chrysler men never had ceased to wonder why it should be necessary to use so many gears to accomplish the reductions necessary in such a mechanism.

For all they could see, the required antenna mount gear reductions could be attained much more compactly and with greater accuracy in operation if an entirely different type of gearing were used. It seemed to them that many gears must compound the possibilities of error in operation, while if the same reductions could be realized with fewer gears, the instrument must become more accurate, to say nothing of being lighter, less bulky and easier to make. Mr. Keller mentioned this to his visitors.

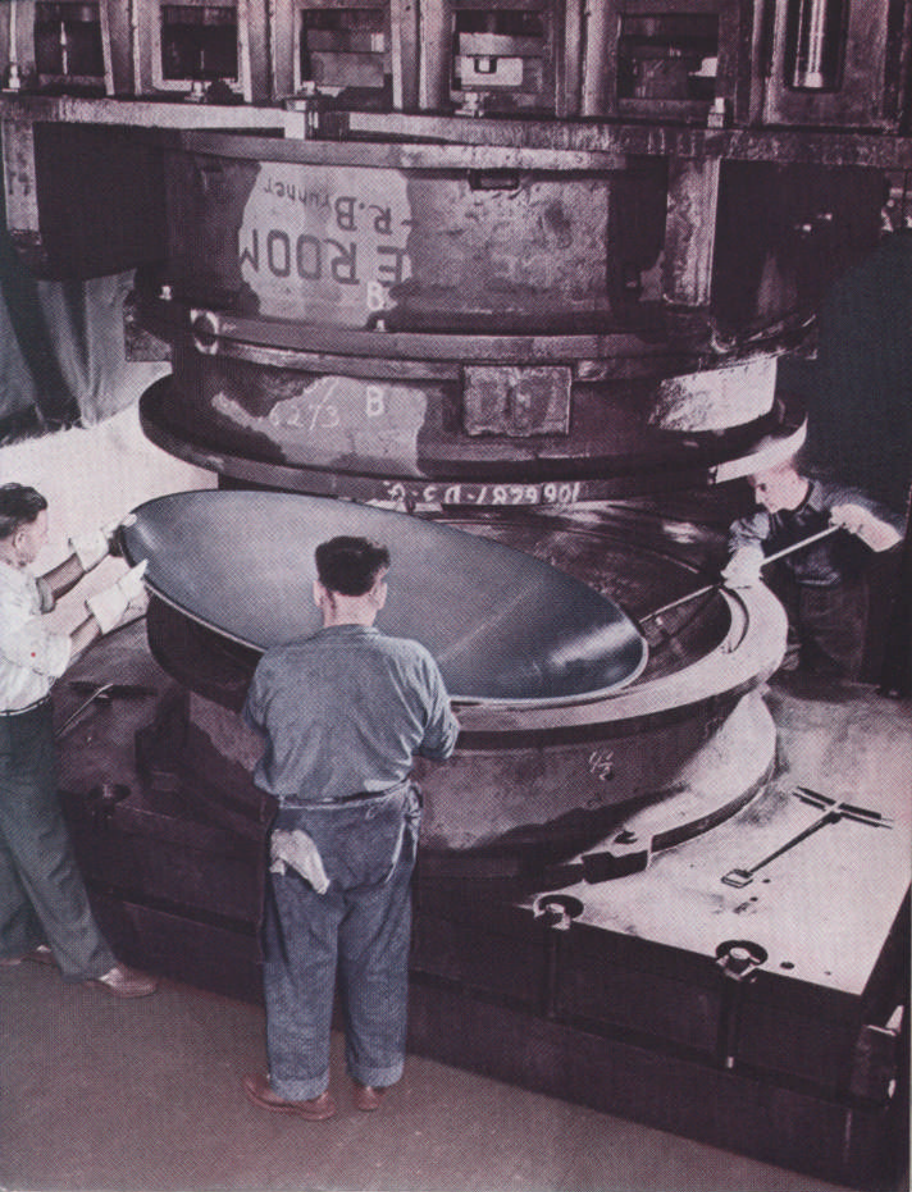
They then disclosed that they were troubled by just this problem in the SCR-584 mount and discussed gearing methods at length with Keller. The tentative solution he proposed led them, as soon as they had returned to Cambridge, to recommend to the Army that Chrysler be employed to design and build in its entirety the microwave radar antenna mount of which the paraboloid is one detail.

In essence, what Chrysler was asked to do was to work out the unsolved mechanical problems of short-wave gun-laying radar and, having done so, to manufacture the design in quantities.

The significance of this assignment lay in the fact that the antenna mount is the eyes of radar. The gun-director and the guns can act only on what it reports and no more accurately than it reports. Or in the words of the Signal Corps, the mount was an "unsolved detail and a most difficult engineering and manufacturing problem; it must be extremely accurate, for on its accuracy depends the accuracy of the computer and the fire of the guns."

The SCR-584 had been methodically planned to cope with the planes of the future—speeds up to 600-700 miles an hour and altitudes up to 60,000 feet. Such speeds demanded the long-range destruction of a hostile plane, at a distance from the radar set of not less than 8 miles, and its discovery at a greater distance than aircraft can be seen by the eye on the clearest day. Hence the need of a new short wave technic and the ultra accuracy asked of the mechanism in order to harness the short wave's precision to the guns.

An error of only a few seconds of a degree in an instrument becomes an error of many yards when the line of sight is carried out to 10,000 feet and beyond, the error increasing with the distance. What had been a tolerable error in anti-aircraft fire when the ceiling



Stamping out on an automobile fender press the radar "dish" which focuses radio beams as a searchlight reflector focuses light rays.

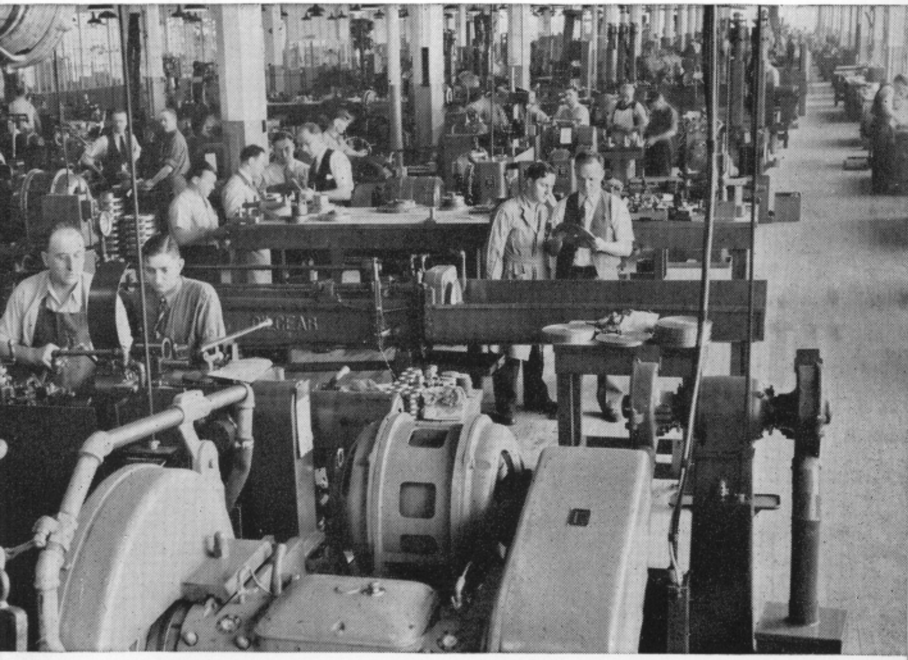
of service planes commonly was 12,000 feet and their speed around 150 miles an hour became intolerable against better planes. The radio echo makes no errors, but the least backlash in the gears would mistranslate the echo's report, so to hit a plane flying in the stratosphere at speeds approaching that of sound called for something approaching perfection in the gears which tell the guns where to aim.

George Slider and L. P. Smith of Chrysler Engineering were sent to Cambridge April 29, 1942, to see what had been done up to then. The Radiation Laboratory people showed them the layout drawings and a wooden model of an experimental antenna mount which had been made by a neighboring Massachusetts factory and was then on test at Camp Davis.

All agreed that it was impractical for use or manufacture. It was too heavy and cumbersome; it had not been designed for production; two long trains of spur gears, with no interchangeability of parts, defeated close accuracy. The Army was talking about 3,000 units and the manufacturers were not equipped to build even a hundred.

Slider and Smith were asked to stay over and meet General Colton, director of the Signal Corps' Radio Reflection division, the next day, May first. General Colton felt that the antenna mount should be redesigned from scratch, explained the Army's urgent need of thousands of SCR-584 radar sets for anti-aircraft gun-laying, and its concern about this "unsolved detail and most difficult engineering and manufacturing problem."

Manufacture must begin by the following April. This meant that all tools must be on order by Labor Day and installed by February. All the tooling would



The short wave beam makes no errors, but radar is no more accurate than its gears, here being machined.

be hard to find, the most critical a group of special boring mills built to order. Tool makers in normal times ask three months for the design of such a machine tool.

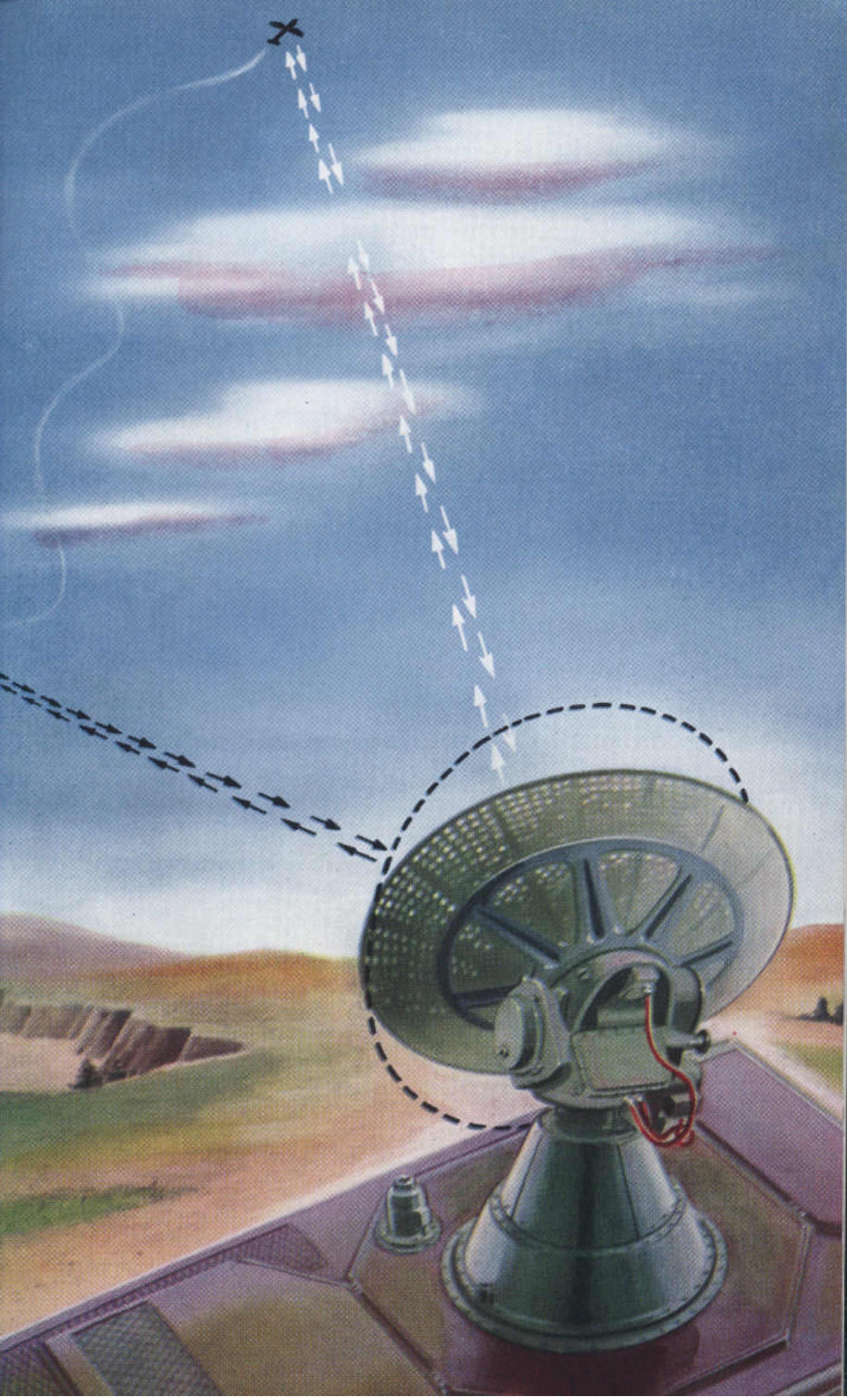
In other words, the Army was asking Chrysler to solve a difficult unsolved mechanical problem and then to manufacture within eleven months and against all the extraordinary obstacles incident to war, a complex mechanism not even defined on paper as yet.

The Chrysler engineers returned via Schenectady, New York, where, at the General Electric plant, they were joined the next morning by H. L. Weckler, Vice President and General Manager of Chrysler Corporation; Fred Lamborn, Vice President and General Manager of the Dodge division; and Fred Slack of the Corporation's Engineering division. General Electric had been commissioned to make some of the electronic elements of the SCR-584 and to assemble, test and make final delivery of the complete radar unit to the Signal Corps.

The Chrysler group were back in Detroit Sunday morning with the design already roughed out. They were hardly at their desks Monday morning when the Signal Corps issued a letter of intent to the Corporation for the design of the mount and the semi-trailer to house it; and General Colton was phoning Mr. Keller to express the Army's hope that Chrysler could begin work at once on what then was described only as "a highly confidential development."

Chrysler's achievements in radar were basically two; first, the design, an original piece of engineering

Clear or stormy, night or day, high or low, there is no place in the skies to hide from the SCR-584 radar.



posing many problems without known parallel applications, and therefore requiring creative solutions. Of these creative solutions, the most important was the devising of an unique method of gearing.

Most readers know what a gear is, usually a toothed wheel, called a "spur" gear, which meshes or mates with another toothed wheel. Reduction is a primary purpose of gears, and simple enough. Suppose your car motor turns over 3,600 times a minute. Obviously, your car wheels can not revolve at this speed. In order to harness the motor's power to the wheels, the former's revolutions are stepped down by means of gears to the drive shaft which, in turn, is geared into the rear axle.

Little gears meshing into bigger gears accomplish this stepping-down. For example, a small gear meshing into one four times its diameter necessarily must revolve four times while the larger one turns once.

Assembly of the unlubricated spinner motor which rotates at the rate of 1,750 times a minute.

In an automobile and in most geared machinery the reduction problem is a simple one best achieved with conventional spur gears. But when the reduction is, say, more than 1,000 to 1, as in the SCR-584 radar mount, this method would call for a long and bulky train of gears beyond the weight and size limitations fixed by the Signal Corps for a mobile radar, and too inaccurate for the direction of guns.

A gear is round. Any full circle, whether the earth's equator or the circumference of a dime, is divisible into 360 degrees of measurement; and since a degree contains 60 minutes, a circle of any size has 21,600 minutes of measurement.

The permissible accumulated error or backlash of the gear train of the antenna mount was fixed by the Signal Corps at 3.375 minutes (1 angular mil). This means that if ten gears were used to accomplish the required reduction, the average error must not exceed 3/10ths of a minute—and 3/10ths of a minute means 1/64,800th part of the gear's circumference. Ten gears then were too many for such accuracy, quite apart from their weight and bulk, and no fewer number of spur gears could produce the reduction called for.

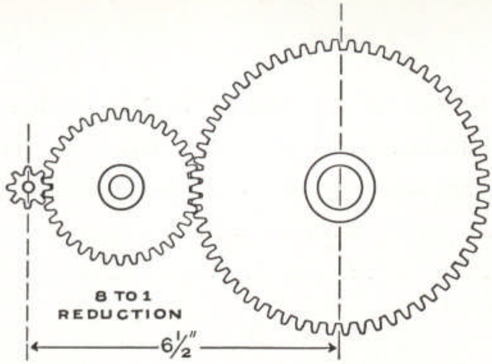
The Signal Corps specified a motor turning 3,600 times a minute. A slow moving motor would have erased the reduction problem, but slow motors happen to be big and heavy, ruling them out. For the paraboloid dish to do its job of scanning the skies properly, its drive shaft should not turn more than 8 times a minute in azimuth (horizontally) and less than 4 times a minute in elevation (up and down). To step 3,600 down to 8 and to 4 called for reductions of 472 to 1 and 1080 to 1 respectively.

Chrysler engineers did this within a very small space by inventing a method of gearing never before used in any mechanism, so far as they know.

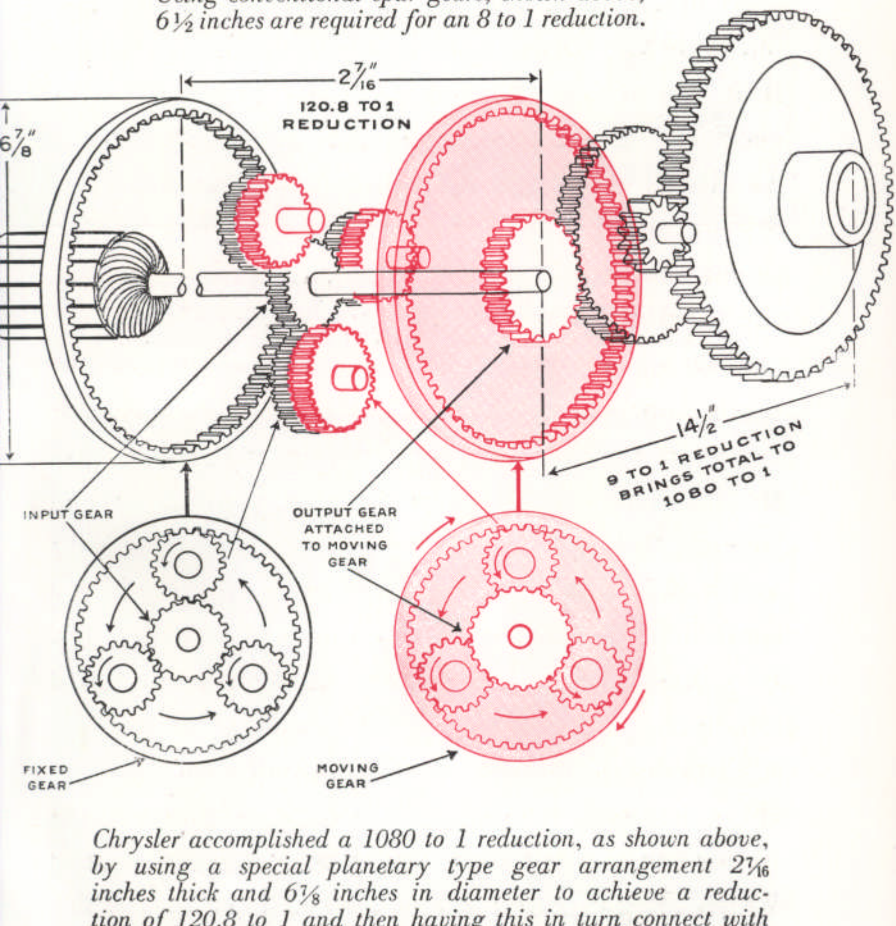
At first glance, this gear train appears to be a simple planetary train, known to any engineer. Such a train has three sections. The central member is a sun gear. The second member is made up of planet gears, usually three, revolving around the sun gear and driven by it. The planets mesh in turn with and revolve inside of a larger gear, with teeth cut inside, the third member and called the annulus.

Such a gear train is a commonplace of engineering, though not widely used. As any of the three members can be made the input gear, any one made the output, this train may be used as an overdrive, underdrive or reverse. But as its limit of reduction normally is three and a half to one, simple planetary gearing could not scratch the surface of a reduction of more than 1,000 to 1, and so would have been disregarded by most engineers.

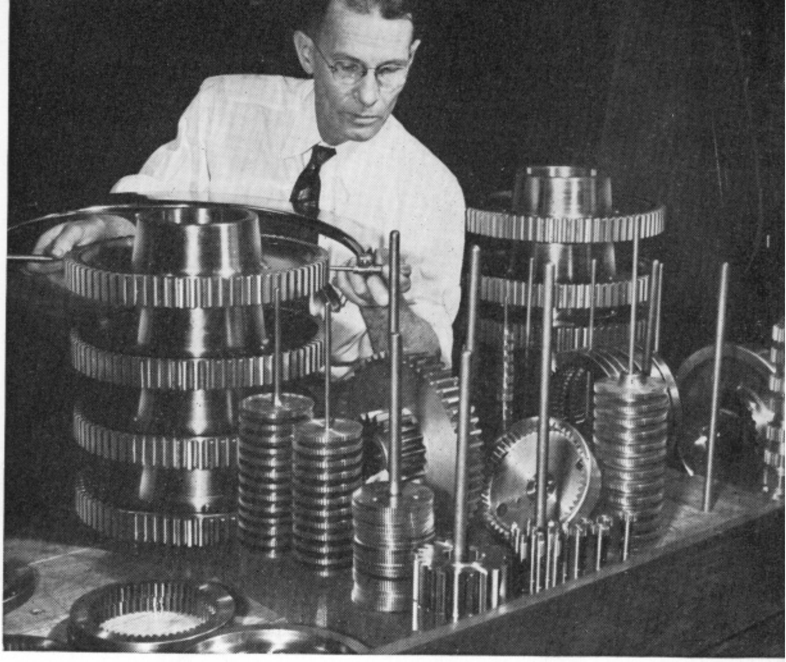
Chrysler designed a train beginning with the same three members, a sun gear driven by the motor at the motor's speed; three planets in a carrier or spider to which all the planet shafts are attached and which



Using conventional spur gears, shown above, 6½ inches are required for an 8 to 1 reduction.



Chrysler accomplished a 1080 to 1 reduction, as shown above, by using a special planetary type gear arrangement 2 7/16 inches thick and 6 7/8 inches in diameter to achieve a reduction of 120.8 to 1 and then having this in turn connect with three conventional spur gears with an additional reduction of almost 9 to 1. Thus, the entire reduction from driving center to output center was achieved in a space of 14½ inches.



Inspector gauging the large 14½-inch gears which move the radar "dish" as it scans the heavens.

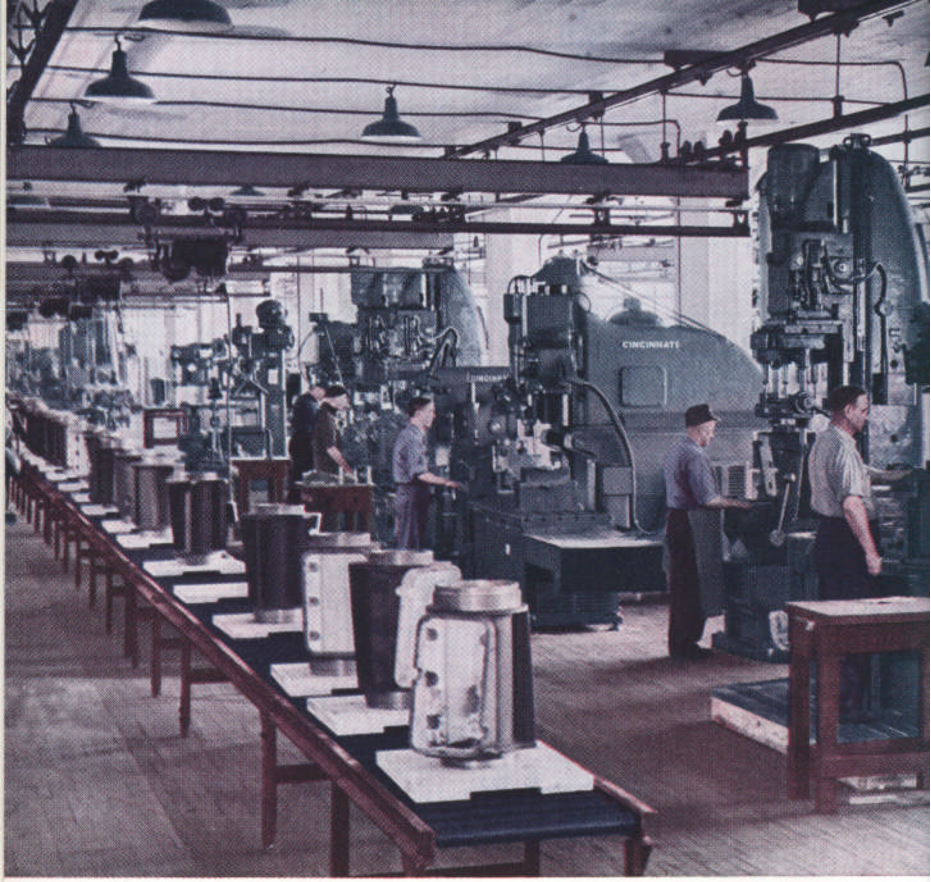
forces them to move together instead of individually; and the larger gear inside which they turn.

The planets turn both on their own axes and in the much wider circle of the outside gear. Therefore, the spider must be moving more slowly than the sun gear. This plus the difference between the 17 teeth of the sun gear and the 19 teeth of the planets creates a reduction, but one of only two and a half to one in all.

By "imagineering", Chrysler engineers increased this reduction to 121 to 1 within almost the same space. They did it by means of two added steps. First, they made the planet gears compound. That is to say, two gears were cut, one above the other, on each blank. Adapting an old but largely forgotten principle, sometimes spoken of as the "odd tooth", they gave the upper planets 19 teeth, the lower only 18. Only the upper mesh with the sun gear and the third member.

Now they added a fourth member, a second annulus gear a little smaller than its mate—54 teeth instead of 55. The lower planet teeth mesh into this fourth gear and turn inside it. The motor's power is transmitted by the sun gear through the planets to the third member, the normal annulus gear. But this gear can't turn, being clamped to a base. As it can't move, it becomes a fulcrum, passing the power on by leverage through the lower planets to the lower, movable, annulus or output gear.

The reduction which began faintly in the simple planetary train is compounded to 121 to 1 by the one



The pedestal starts down the machine line. Boring, drilling and milling machines in the foreground.

tooth difference between the upper and lower planets. The greatest reduction is had by the least differential in teeth, and the least differential is one tooth obviously. With each complete revolution of the planets inside the fixed annulus, the output annulus moves only the distance of one of its 54 teeth.

Exactly how this works can be explained only trigonometrically, meaning that it is a compound process of a complexity which defies simplification. Yet the actual gear train is beautifully clean and simple in its lines. It looks so easy to the eye, but the layman who tries to trace the evaporation of 121 to 1 between the entrance and exit of the power, finds the train as exasperating as a tough mechanical puzzle.

Its deceptive innocence can be illustrated this way: The sun gear lifts easily out of the planets, is easily put back. The upper annulus lifts easily out of mesh with the planets, is replaced as easily. The planets in their spider lift easily out of the lower annulus—but try to replace them! Unless you know the formula, trying to put these back into mesh is as futile as trying to solve the combination lock of a vault at random, and for the same reason. Unless he has memorized the location points, even an engineer can not rejoin these two members.

Complex as it is in formula, it is simplicity itself and troubleproof in service. Compound planet gears, though rare, are not new. What is unique in the design to the best of Chrysler's belief, is the combination of dual planet gears with a fourth member, a second annulus gear.

Having created a reduction of 121 to 1 between the input and the output gears, the rest is easy: 1080 being only about nine times 121, spur gearing in two steps gives this final reduction in elevation; 472 being only about four times 121, this final reduction in azimuth is accomplished by spur gears in one step.

By means of the same new gearing principle, Chrysler Engineering later was to take approximately a ton of weight out of the gear boxes of the huge T-92 and T-93 mobile guns which it designed and built for Ordnance.

The Corporation's second contribution to the microwave radar program was an engineered production tool-up and process of manufacture whereby this complex instrument, including gears held to a precision beyond anything known in commercial manufacture, was made in quantities, quickly and economically—for the mount was a problem of manufacture even more than one of design. Accustomed to making gears to fine accuracy, Chrysler planned its production to accomplish the delicate limits required.

There are many more gears in the mount than those previously described. The returning radio echo gives the direction, speed, distance, altitude and course of a hostile plane. This information must be transmitted identically to the gun-director. Chrysler so designed the mount that this data is picked up directly from the main radar shafts, independently of the driving gears. By means of watch-like gears, the information is conveyed mechanically to seven selsyn or duplicating devices which pass it on electronically to the gun-director.

The selsyns can report the data no more accurately than it reaches them, so there can be no backlash whatever in the selsyn gears. Absolutely precise gears, however, would not function. The Chrysler solution was split gears, an ingenuity in which the tension of steel springs set inside the two halves of a gear insure that it keeps its teeth lightly clamped to the teeth of its mating gear at all times. This is possible only when the loads involved are very light—flypower instead of horsepower, as an engineer would express it.

Another major problem was an unlubricated air seal on the spinner motor which revolves 1,750 times a minute. The air seal is necessary because moisture within the hollow radio frequency transmission lines would absorb the short wave impulses. The seal holds six pounds of pressure built up by a small compressor. Because oil or grease also would absorb radio frequencies, the seal could not be lubricated. Chrysler

The elevation housing machine line. Machine tools in the foreground are boring mills.

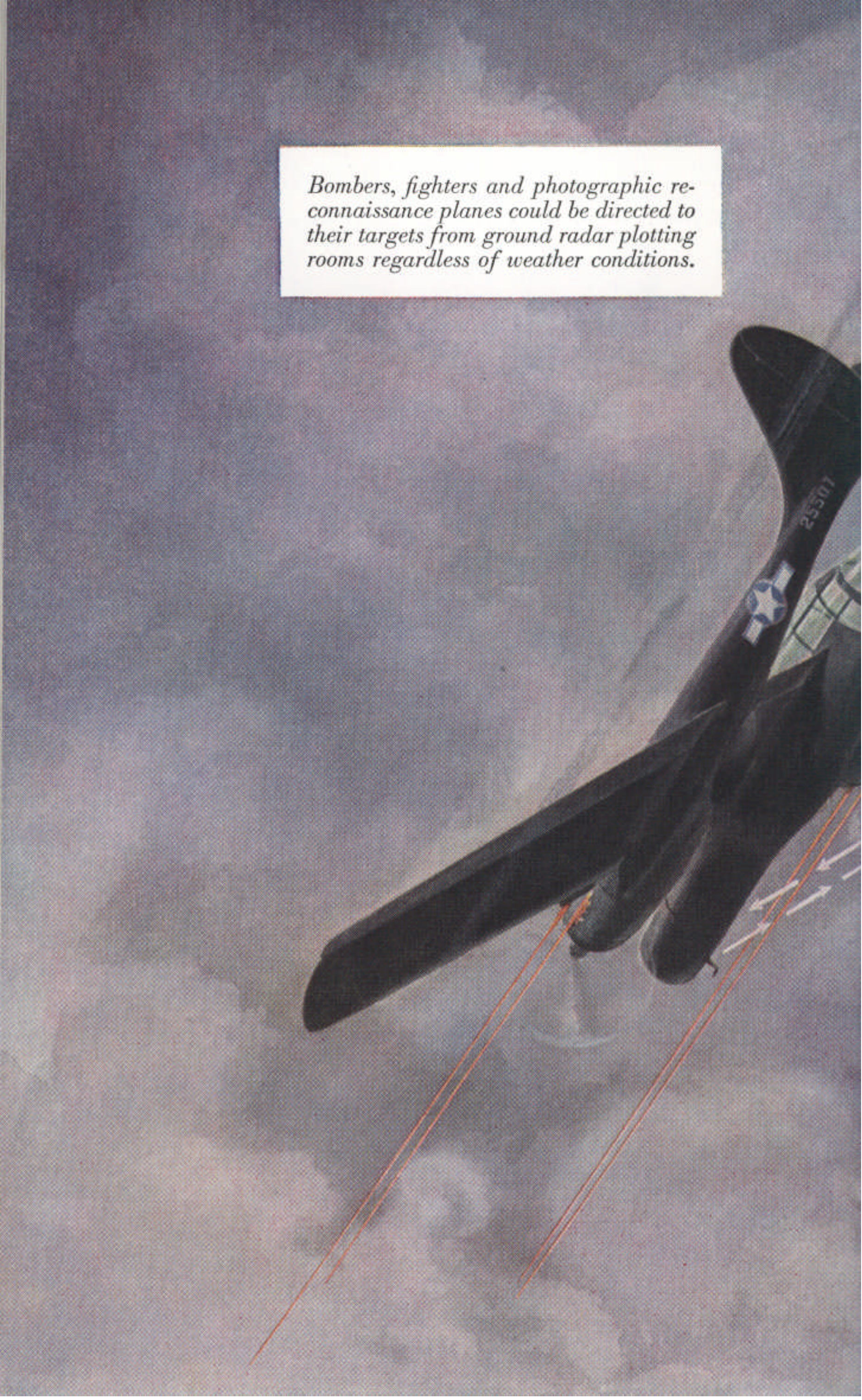
The radar "dish" oscillates up and down, right and left. Here the elevation gear housing is being assembled.

had had experience with air seals on its fluid drive, though not unlubricated. The answer was found in Superfinish, a Chrysler development. Friction was minimized by Superfinishing the bellows and seal to 95% optical flat surfaces, a microscopically smooth finish. Even the carbon disc between the housing seal and sleeve was Superfinished.

The heavy steel castings of the pedestal support appeared to be just another set of castings of which nothing but strength need be asked, yet the accuracy of the paraboloid reflector and, ultimately, of the guns, began with these innocent-looking pieces. Their dimensions had to be exact, just as the accuracy of your watch begins with the precision of its backplate.

As Chrysler Engineering designing the wiring for quantity production, the mount was wired as it moved along the assembly line, with complete interchangeability, easy replaceability, and color coding of the wires for the easy distinguishing of one electrical circuit from another. The electrical industry usually cords its wires. Chrysler used the tape it had used in recent years on all car wiring, a synthetic, satisfying the Signal Corps that the tape would lose none of its qualities at 40 degrees below zero. It is self-quenching in case of fire from short circuits; it is impervious to moisture and to most acids, has a higher strength than the best rubber and an elasticity almost as good, while rubber of these characteristics would shatter at 40 below. The nearly automatic machines which wound the tape on radar wiring circuits are a Chrysler development.

When the Signal Corps in the Fall 1943 ordered the "tropicalization" of the radar wiring to protect it against fungus growths and insect damage, the Chrysler wiring already had been so treated, the same problem having arisen earlier on tanks and military trucks. The acids and strong alkalis commonly used in soldering are a contributing cause of the fungoid growths which attack insulation in regions of high humidity and temperature. Chrysler eliminated this accessory-before-the-fact by going to a special, mild, resin-based flux. An insecticide in the lacquer



Bombers, fighters and photographic reconnaissance planes could be directed to their targets from ground radar plotting rooms regardless of weather conditions.