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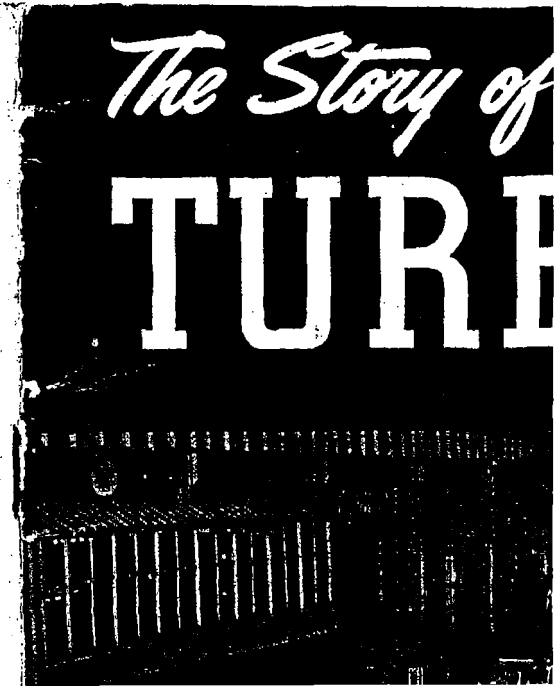
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# The Story of TURB



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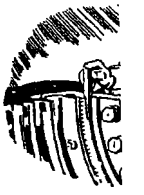
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# *The stor*
# TURI



MORE than 2000 years ago, steam turbine on the pri for automatic lawn sprinklers. while the two Ptolemies engag for power, and brought the Eg around their collective ears. Ev first practical steam engines, turbine. But when his steam forgot about the turbine.

Hero's turbine was the first power from the steam generat word is the modern General temperature, steam turbine—de thousand horsepower, providi electric power for each pound enough electricity to light and

Twenty centuries separate done with the turbine in the l 2000!

One reason why it took l turbine than the steam engin first—is that the steam engine while the turbine though sim plicated and difficult to design a the collective engineering geni ence of modern industry.

BATTLESHIPS ARE PROPELLED BY STEAM TURBIN
*(Official U.S. Navy Photo.)*

# *The story of*
# *BILLY MADIGAN*

In 1897 a young American, Charles G. Curtis, had invented a new kind of turbine, totally different from the turbine already developed by Sir Charles Algernon Parsons in England. It consisted of a series of wheels upon a common shaft, each wheel having two rows of revolving blades separated by a stationary row. Steam from a nozzle was directed against one row, then against the stationary blades which reversed the direction of the steam and sent it against the second row of blades on the wheel. What Curtis had, in embryo, was the modern steam turbine.

Charles Curtis brought his plans to General Electric. In the years that followed, some of General Electric's best engineering brains and greatest manufacturing skills were employed on the problems of the turbine.

The first Curtis turbine was built in the factory yard at Schenectady, N. Y. It didn't work.

Then another young General Electric engineer, W. L. R. Emmet, undertook the task of redesigning the turbine. He rearranged the buckets, or blades, and the proportion of bucket rows to the number of stages. By 1901 the Curtis-Emmet turbine was successfully completed. It had a capacity of 500 kilowatts and a speed of 1800 revolutions per minute. A few months later a 1500-kilowatt unit was well advanced.

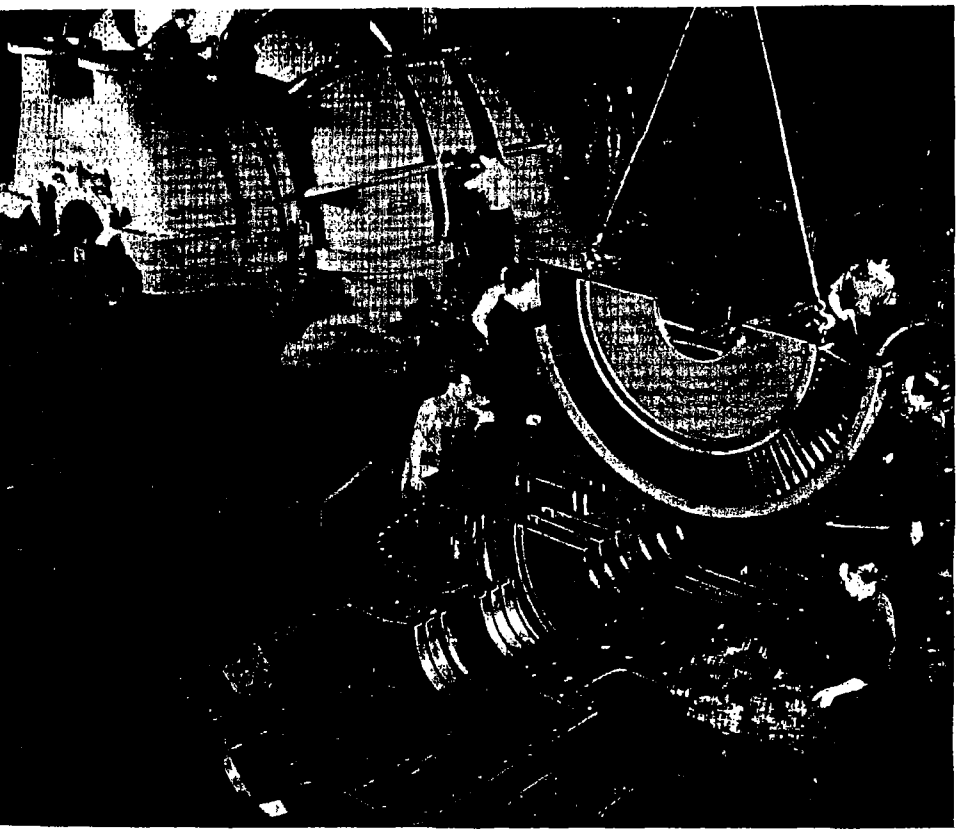
In 1901 General Electric undertook to build, for the Commonwealth Edison Company of Chicago, a 5000-kilowatt turbine for their Fiske Street Station that was to begin operating in 1903.

The year 1903 dawned, and with it came plenty of headaches. Chicago began to ask when the first factory test of the big turbine would be made. A tentative promise was given. It had to be postponed, then postponed again.

A whisper went around that General Electric was having



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TURBINES ARE DIFFICULT TO DESIGN AND BUILD

trouble with the turbine. Perhaps their engineers had been a little too cocksure.

About this time, the manager of the Schenectady Works called in one of the young foremen, William M. Madigan. "Bill," he said, "do you want to make a change?"

"Which way?" said Madigan promptly. "Up or down?"

"Up, if you can swing the job. We're in hot water over that Chicago turbine. We've promised to have steam in her by March, and she's nowhere near ready. The Company's reputation depends on keeping that promise. We've picked you to swing it. Think it over and give me your answer."

"I don't need to think it over," Madigan replied.

The following Monday the new foreman of the building, where the big turbine lay almost finished but unassembled,

began laying out his work. Early as it was, the manager was there ahead of him.

The parts of the turbine were scattered all over the shop. Two wheels were to be machined over again because of flaws. Everyone who looked at those wheels shook his head and said, "Six weeks at least." Madigan said nothing, but as he studied the job his fighting spirit rose to the challenge.

Like a general he marshalled his men, organizing their different operations. He kept the work going without pause. Repeatedly he stepped in and worked with his own hands. Everything he did was planned ahead.

The manager came down to the shop day after day. "When will you steam her, Bill?" he asked.

"March 7," was the quiet but confident reply.

"You're too optimistic," the manager said. "Madigan's crazy," everybody else said.

Nevertheless word was sent to Chicago that the turbine would receive its factory test on March 7.

March 1 arrived. By that time the turbine builders in Building 20 were working all hours. Vice presidents came in, and asked the same question that the manager had asked, "When will the turbine be steamed?" Madigan's reply was, "On March 5!" He was grimy with dirt and grease. His eyes were red from lack of sleep. But his head was as clear as ever, his confidence reassuring. The big turbine was almost assembled. A few more days of intensive, unflagging work and on March 4, three days ahead of his first promise, Madigan told the test men to let in steam. Three months later the big turbine was running steadily, day and night, in the Commonwealth Edison's Fiske Street Station.

Billy Madigan was one of the first of General Electric's turbine foremen. It is men like him whose story is almost forgotten, and yet these men, now found in any G-E plant by the hundreds, are vital to the building of great steam turbines. Generally recruited from the ranks, they belong in any story of G-E turbine production—or in any other story of American industrial achievement.

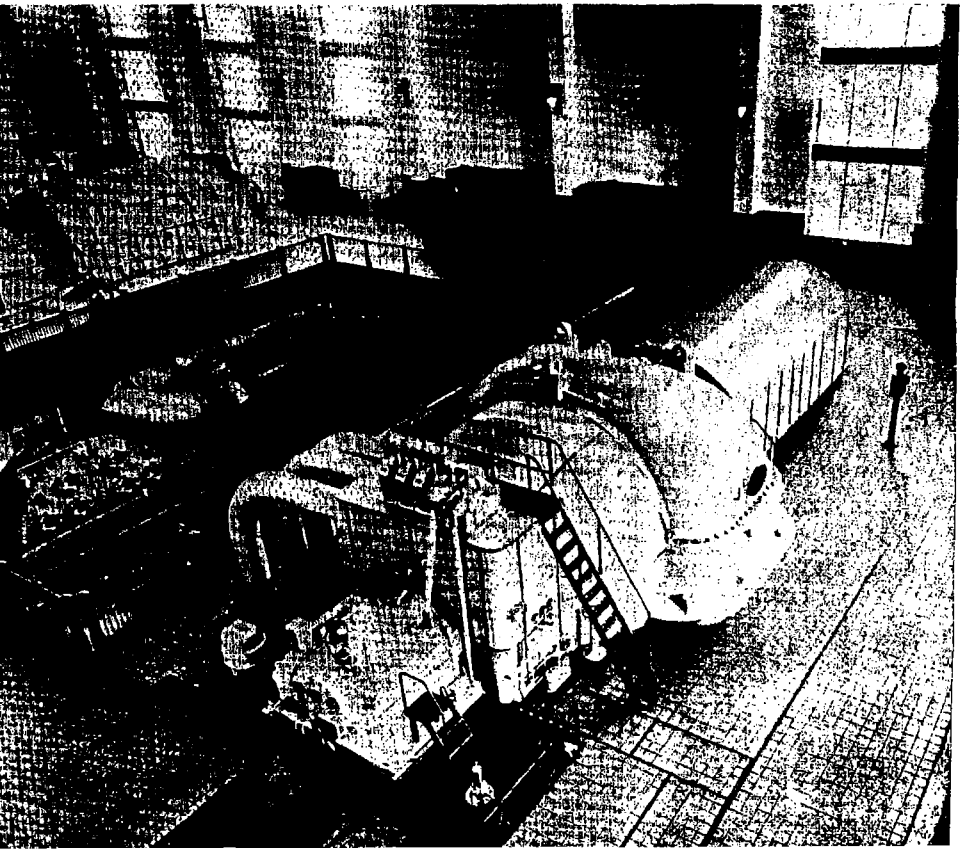


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Nearly 40 years later, another group of General Electric men and women was called upon to produce turbines under an even more exacting schedule. With the spirit of Billy Madigan, they worked quietly and competently, giving up holidays and vacations; and once again an apparently impossible schedule was met with impossibly good margins.

Four great U.S. battleships were launched and commissioned within a single year: the *North Carolina*, the *Washington*, the *South Dakota* and the *Massachusetts*—all equipped with G-E propulsion turbines, and all ahead of schedule. During that time many hundreds of turbines were produced for other ships, and many more for industries. These certainly were a considerable factor in making America more powerful on land and sea.

HOME OF THE TURBINE—A MODERN POWER STATION



# *The story of RESEARCH and ENGINEERING*

THE 5000-KILOWATT TURBINE generator which General Electric built for the Commonwealth Edison required only one-tenth of the space and weighed one-eighth as much as the reciprocating engines it replaced. And the cost was but one-third!

The superiority of these turbines was so marked that General Electric was kept busy trying to fill the demand. But there were some men who were not satisfied. These were the scientists, engineers, inventors—men like Curtis, and Emmet, and Oscar Junggren. Junggren obtained numerous patents on turbine details, many of which are still in use. One of these called for increasing bucket lengths and increasing pitch diameters from stage to stage, a design which was adopted eventually for most turbines. With painstaking, scientific thoroughness, these men, and the G-E turbine engineers who followed them—such men as Smith, Warren, Dickinson, and many others—embarked upon an almost infinite series of improvements on what was already in many respects man's most perfect machine.

The effects of this research, invention, and manufacturing are almost startling. World War II has made demands upon the production of power that surpass those of any previous time in our history. During 1943, the power produced by the public utilities and made available to build weapons for our fighting forces was six times that of another war year —1918. The coal required to produce this amount was only twice that of 1918. In other words, the turbine of 1943 was made so efficient that it produced three times as much power per pound of coal.

There's but one reason for figures like these, and for engineering and research like this—to make electricity more plentiful and more useful for everybody. In less than 25 years

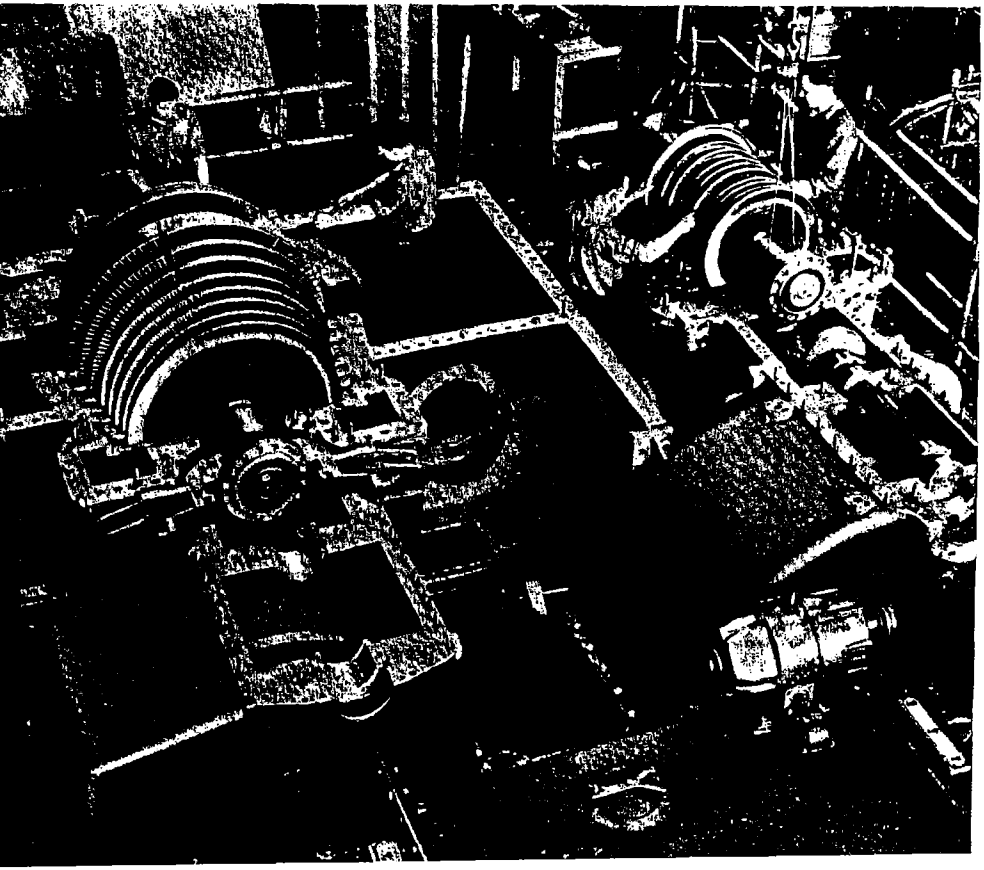


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a series of inventions and improvements helped to multiply the U.S.'s electric power six times. Not all of these improvements were in the turbine itself. Boilers kept pace with developments in the turbine. Furnaces are fed carefully and scientifically; fire walls are water-cooled and generators are now hydrogen-cooled, to cut down wind resistance as they speed at 1800 or 3600 revolutions per minute.

Boilers, generators, and switchgear are the body of a powerhouse; the turbine is its heart. And it is due, in no small part to a little group of painstaking scientists and engineers and workmen, who have made the turbine their life work, that in a land where 65 per cent of all our electric power is produced by steam turbines, we are so *powerful* today.

HIGH-SPEED PROPULSION TURBINES—THE HEART OF A SHIP



# *Home of the HURRICANE*

EVERY boy who has ever built a windmill has rediscovered for himself the ancient principles of the turbine. A steam turbine is a series of windmill vanes set in wheels mounted on a shaft in such a way that steam—in lieu of wind—can be directed against these blades to drive the wheels, and turn the shaft. It's that simple—in principle.

In this type of windmill the vanes are high-grade alloy steel, the wind—i.e. high-pressure, high-temperature steam—blows at 1200 miles an hour, and the wheels turn at 600 miles an hour. In some of the newest turbines the wheels turn faster than the speed of sound; the buckets travel at a greater velocity than a bullet from a small-caliber rifle!

These high pressures are a major reason for the efficiency of the modern steam turbines, but they are also a major source of problems to the turbine engineer. It is hard to grasp the magnitude of the forces at work inside the turbine shell. A hundred-mile-an-hour wind is a tropical hurricane. It will destroy buildings, uproot trees, hurl heavy objects through the air. But the blast that blows upon the curved blades that are a turbine's buckets has *twelve times* the velocity of the hurricane!

Why such high pressures? A fall in steam pressure exerts a force in much the same way as falling water. In a waterwheel, the power depends on two things: the quantity of water that flows through the wheel and the distance the water falls. So if one dam is built twice as high as another on the same stream, twice the power will be generated.

In the same way the higher the pressure of the steam is raised, the farther it can drop in the turbine, and the greater the amount of power the turbine will give. That is why in the past 20 years, turbine pressures in the most advanced stations have been increased from 325 pounds per square inch



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TURBINE BUCKETS AND WHEELS

in 1920 to 1300 pounds in 1940, to 2300 pounds in 1941.

In a modern turbine steam enters at 1200 pounds per square inch pressure. It emerges 1/30 of a second later at an actual minus pressure—in a vacuum. In spite of the fact that it has traveled only a few feet—the modern turbine is only 15 or 20 feet long—in a split second, a great deal has happened to this steam. It has passed through from 17 to 20 bucket wheels and an equal number of nozzles, and pushed against some 5000 buckets—no wonder we speak of the steam that emerges from the turbine as being "exhausted."

Twelve hundred pounds per square inch pressure is too great a height from which to drop superheated steam to 70 degrees F. and a few pounds per square inch pressure in a fraction of a second—no machine could stand the shock. So we let it down easy "stage by stage" through a series of nozzles and bucket wheels. The steam bursts from one set of

nozzles, strikes against the row of buckets on one wheel, loses some of its velocity and pressure, passes into another row of nozzles, then against another bucket wheel, and so on. At the high-pressure end, the buckets are small since the force of the steam is so great that it can exert a very great force on a very small surface—just as the explosive force of a powder charge can drive a small bullet with terrific striking power. At the low-pressure end the buckets are as long and the wheels as big as the laws of centrifugal force will allow—frequently 12 feet in diameter. Moreover the pitch changes, like that of a variable speed propeller on a plane as it climbs from the dense air of sea level up into the thin cold air of the substratosphere.

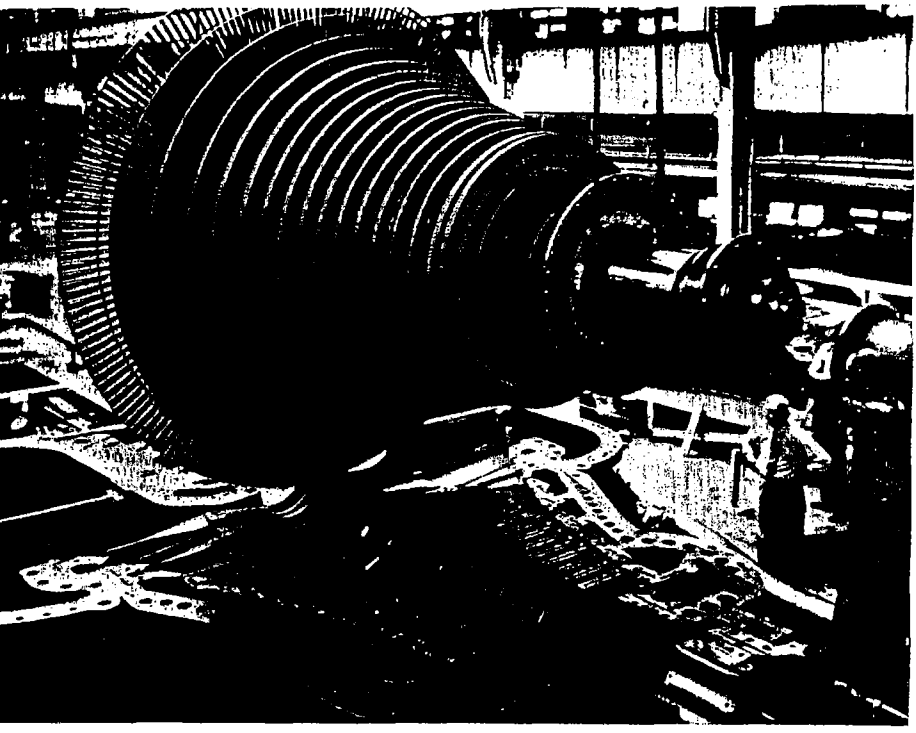
On page one we pointed out that the turbine had to wait upon a fairly high stage of technical development because it was hard to build. By now you should know at least one reason why this was true—high pressures and high speeds are two reasons—the turbine is just naturally a high-speed machine. It had to wait until engineers and scientists could develop materials to withstand these pressures and speeds. For example, a single bucket in a modern turbine traveling at six hundred miles an hour has a centrifugal force (of 90,000 pounds) trying to pull it from its attachment on the bucket wheel and shaft.

If speed and pressure, enormous as they are, were the turbine engineer's only problems his job would be relatively simple. But superimposed upon these, and complicating all his other problems tremendously, is the problem of high temperatures—for high temperature is the inseparable companion of high steam pressure.

While the steam is passing through the turbine, dropping from 200 pounds to a few pounds per square inch pressure in 1/30 of a second, with equal rapidity the temperature is dropping from 900 degrees Fahrenheit to 70 degrees. You think of steam that emerges from a boiling kettle as being hot—that is steam at 212 degrees F. Nine hundred degrees is the temperature of iron when it glows dull red. In this raging inferno the high-pressure buckets at one end of the



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SHAFT FITTED WITH WHEELS AND BUCKETS BEING LOWERED INTO TURBINE SHELL

turbine run red hot, while a few feet away the large buckets in the last stages run at six hundred miles an hour through a storm of tepid rain—so fast that the drops of condensed steam cut like a sand blast. The pressure in the last stages of the turbine is actually less than that of the air outside—for the condensers convert the rapidly cooling steam to water—and in so doing create a vacuum. Thus are the last final ounces of power wrung from the exhausted steam.

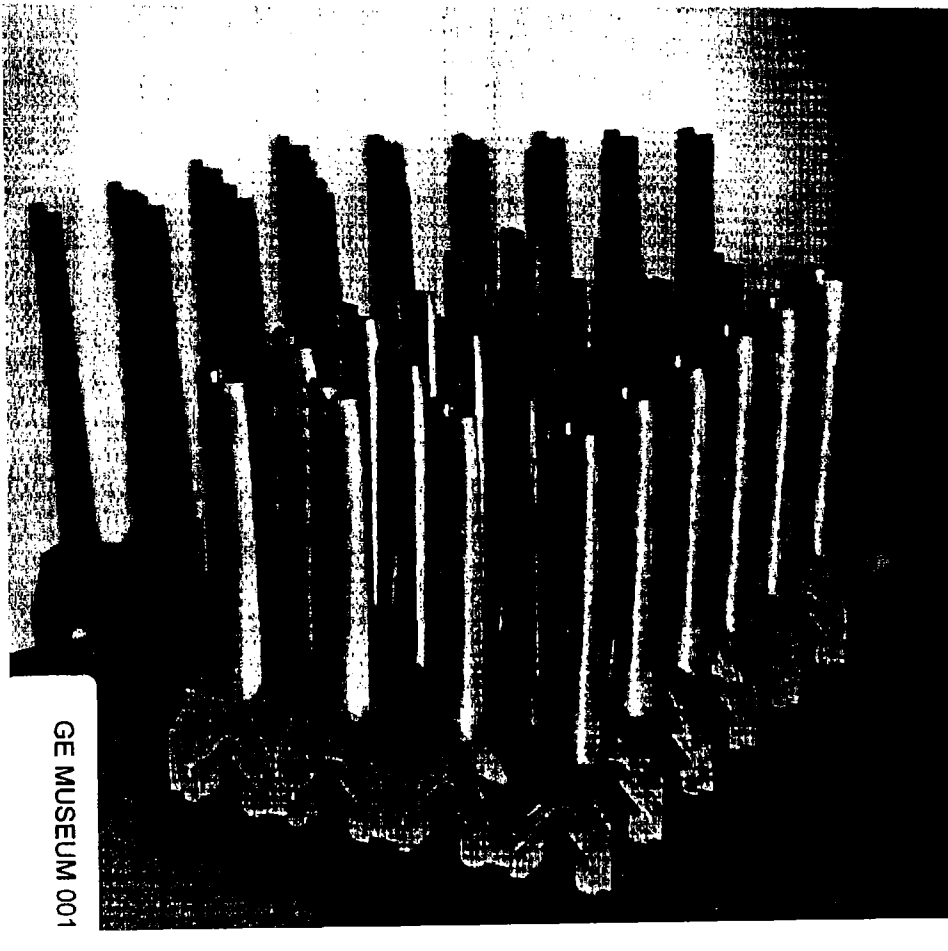
Scientists and engineers worked for many years to develop and design materials to withstand these conditions. Because all scientific development begins with measurement, they began to measure the effect of the steam passage upon various shapes and sizes of buckets and nozzles. Since a single turbine may have as many as 5000 buckets it is easy to see why these observations soon ran into thousands.

Then, not so many years ago, some General Electric engineers had a brilliant idea—a wind tunnel for turbines.

The idea was a natural, for like a modern airplane, the modern turbine is highly streamlined—*only the streamlining is inside*. The turbine is in effect an airplane turned inside out. All its gleaming surfaces, smooth curves, as carefully designed as a plane's wings and fuselage, are concealed within the turbine shell. But not even a Thunderbolt in its 700-mile-an-hour power dive has to withstand the pressures created inside the turbine by the 1200-mile-an-hour blast of steam.

So the turbine wind tunnel is a wind tunnel in reverse. Jets of cool, manageable, compressed air, instead of steam, are passed through the turbine's nozzles and buckets. By this

TURBINE BUCKETS MUST WITHSTAND A COMBINED WIND AND RAIN STORM 12 TIMES THE VELOCITY OF A HURRICANE



GE MUSEUM 001

means thousands of observations are quickly and easily taken and recorded, automatically, by precision instruments.

Other tests have been made over a period of many years of the effects of high temperatures upon the various steel alloys used in turbine construction. Some of these test bars have been cooking for more than 10 years in special electric furnaces, and their "creep" or permanent expansion of growth under high temperatures and stresses carefully recorded.

With high temperatures, high pressures, and high speeds, you might think that the turbine engineer had enough trouble to contend with. But there was another that gave trouble for many years, and that was vibration of internal parts. Vibration cracked buckets and wheels and wrecked turbines, sometimes within a few hours, sometimes only after years of operation. And this vibration was caused by taking such terrific amounts of power from relatively light machinery—in some cases as much as 400 horsepower out of a bucket weighing but a pound or two. The basic solution of this problem is another achievement of engineering and research, and of another turbine engineer, Wilfred Campbell.

Though many small turbines are used directly as sources of power, it is the generator that makes the power of the turbine generally available through electric light and power. One of the most important improvements in the generator has been the introduction of hydrogen gas into the generator shell to cool the generator and its windings. Since generator rotors usually spin at 1800 or 3600 revolutions per minute, the resistance of the air used in cooling may cause a substantial power loss. Hydrogen, being lighter than air, cuts down this resistance by almost 90 per cent. It also improves the cooling of the machine, and helps prevent oxidation. Since hydrogen was first used in filling a generator the majority of large generators have been cooled in this way.

The major problems of the turbine are four—high temperatures, high pressures, high speeds, and internal vibration. And their solution lies in engineering, research and manufacturing skill.

# THE STEAM TURBINE

It is not long ago as historians count time that James Watt harnessed steam to serve mankind. Yet today its most important service is one of which Watt never dreamed—providing the harnessed hurricanes in giant steam turbines that spin their whirling buckets faster than the speed of sound to drive the electric generators that bring modern magic to our homes.

The modern steam turbine is indeed a wonderful tribute to the genius of the scientist and engineer, to the skilled craftsmanship of the worker, to the courage and capacity of the company that builds it and of the utility that buys it. So efficient have these made this most favored form of power production that a kilowatt-hour—enough electricity to keep a reading lamp burning all through a long winter night—may now be generated from less than a pound of coal. Because of this and because of the ease with which it may be handled, electricity has become as universal an element of modern life as fire, water, earth, and air were in the ancient world.

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