Today's "Free" Power Was Generated in the Twenties

There is ample evidence that the exhaust-driven turbosupercharger will someday be a very important piece of performance equipment in the American automobile field. It is widely used already on commercial diesel engines, and is starting to show up on truck, aircraft and marine gasoline engines—where maximum power with minimum size and weight is needed.

The editors of Car Life thought it might be interesting to take a look at some early turbocharger history by investigating the evolution of the famous General Electric aircraft turbo—from which modern ground vehicle designs have sprung.

The GE turbocharger was certainly one of the milestone technological developments in the 70-year evolution of the internal combustion piston engine. The whole concept of utilizing waste exhaust gases to supercharge the intake system is a natural one for this type of engine. The idea is even better for aircraft engines that have to fly in low-density air at high altitudes.

The GE turbo took many years to develop but it was perfected just in time to be a vital factor in winning the air war over Europe in the early 1940s. Since then it has successfully gone into commercial aviation—and, of course, its evolution has now involved cars and heavy-duty ground vehicles.

The story of the turbosupercharger is practically the story of one man, Dr. Sanford Moss. He was one of those rare individuals who pursued a single technical interest for a lifetime. He was fascinated by turbine machinery as a boy. His college theses for his Master's and Doctor's degrees were on gas turbines. In 1903 he operated, in the Cornell University laboratories, the first turbine wheel ever run on products of combustion in the United States. He then went to work in the General Electric research department where he spent the rest of his life working on gas turbines, steam turbines and centrifugal air compressors.

It was only the energy and enthusiasm of Sanford Moss that made the aircraft turbosupercharger a practical reality by 1940.

Actually, Moss wasn't the first to build a working aircraft turbo. In 1917 the French engineer Auguste Rateau built a crude turbine-driven centrifugal compressor for aircraft engines and successfully tested it on a dynamometer on a mountain peak in France.

At this point our National Advisory Committee for Aeronautics (NACA) became interested and asked GE to undertake development of an aircraft turbo in cooperation with engineers of the Army Air Corps in Dayton, Ohio.

This was when Dr. Moss entered the picture.

The first GE turbosupercharger was ready for dynamometer tests on a Liberty engine by the summer of 1918. In those days they didn't have...
TURBOS

any way of simulating high altitude on the ground, so the engine was taken up on Pikes Peak and tested on a special dynamometer built on the back of a truck; it was complete with instruments for measuring power, pressures, temperatures and fuel consumption. At this 14,000-ft. altitude the Liberty put out 356 bhp with the turbo and 230 without. The test was considered highly successful in every way and everyone was enthused about the future of aircraft turbos.

The next project was to set a new world aircraft altitude record with the turbo-boosted Liberty. In 1920, Maj. R. W. Schroeder climbed his biplane fighter to 36,000 ft. Just as he was about to descend his oxygen supply failed and he lost consciousness. The plane plunged out of control for six miles before Schroeder revived, just in time to pull out of the 300-mph dive. It was a close call. In 1921, Lt. John Macready hit 40,000 ft. with the turbo-Liberty. These flights brought the turbosupercharging principle a lot of good publicity, at least in technical circles. Moss and his crew of GE engineers were even then regarded as the world's top authorities on the subject.

The next 15 years were spent in detail refinement of the turbocharger unit and its installation. There were dozens of problems that had to be solved to make the thing practical for extended use. Certainly the toughest one was finding metal alloys for the turbine wheel and buckets (blades) that would have adequate strength to resist the high centrifugal stresses at exhaust gas temperatures of 1500°F and more. Remember that very little was known about high-temperature alloys in the World War I period. Engineers steered away from mechanisms that required them. The exhaust turbocharger was one of the first devices that absolutely had to have highly stressed parts operating in the 1500° range. The GE engineers hardly knew where to start. What was worse, little was known about fabricating, machining and fastening some of the known "exotic" alloys of the day.

The early turbines used more or less conventional chrome steel, with separate forgings for individual buckets and a forged disc. The buckets were machined with a kind of dovetail base that fit into corresponding slots in the outer edge of the disc, to positively lock them in place. But these chrome steel buckets would last only a few hours under the scorching heat. In 1922, a step forward was made with new chrome-silicon alloys. In the late '20s, chrome-nickel alloys were used to gain still longer life—which was now measured in hundreds of hours at 1500°F. When the engineers switched to a "17W" chrome-nickel alloy in 1933, with 19% nickel, turbine life was up to the point where military men could begin to think seriously about practical production applications of the turbo principle. Until then, turbines were used only in scattered experimental installations.

This refinement of the critical turbine component also pushed GE engineers into more intensive development of other parts of the system. The efficiency of centrifugal superchargers had been improved a lot since the early gear-driven aircraft installations of the mid 1920s. Compressor efficiency was critical in getting optimum performance out of the turbo principle. Developments such as spiral diffusers and curved inlet vanes had raised centrifugal compressor efficiencies by 10 to 15% in the decade between 1925 and 1935. This was vital to turbochargers that had to operate at impeller tip speeds of 1200 ft./sec. and more.

Another complicating factor was that the high compression ratios required for high-altitude supercharging (between 2 and 3:1) would raise the air temperature 200 or 250° even with an efficient compressor. This not only reduced power because of the reduced density, but the high charge temperature would invite combustion detonation in the engine. It was obvious that any successful turbo installation would require some sort of "intercooler" between the turbo-compressor and engine to cool down the hot charge. Dr. Moss and his crew tried all kinds of ideas in the '25-'35 period. They finally settled on a simple cellular-core heat exchanger, something like a car radiator, that would take the hot engine air through one section and cool it with cold outside air flowing at right angles. This type of heat exchanger is relatively bulky and some of the more compact designs gave excessive air flow restrictions.

The exhaust waste gate is another development of this period. This was simply a flap valve in the exhaust duct that could by-pass some of the exhaust at lower altitudes, to keep from over-boosting the engine. In other words, the turbocharger unit was designed specifically to give design output pressure at the design altitude with full exhaust flow. Then this pressure could be held constant at lower altitudes by merely by-passing part of the exhaust gas and slowing down the turbine. The waste gate valve was controlled automatically by a hydraulic cylinder and linkage, sensitive to compressor outlet pressure. By 1930 it was general practice to use the turbocharger unit with an engine that had its own built-in supercharger. This was, in effect, two-stage supercharging. The turbo unit was designed to maintain sea-level pressure in the pipe between the turbo and engine (plus a small increment to allow for restriction across the intercooler), then the engine blower would boost it another 5-10 lb./sq. in. over sea-level atmospheric pressure.

GE had all this hardware and know-

FATHER of modern turbosupercharging was Dr. Sanford Moss of GE Research.

WORLD ALTITUDE record was set at 40,000 ft. in 1921 by Lt. John Macready (shown with Dr. Moss), using Liberty engine with early GE turbocharger.
how in 1935. But the turbosupercharger still hadn't found its niche, so to speak. It was still an experimental curiosity, and Washington was dragging its feet on appropriations for military aircraft development so there wasn't much money for wild new ideas. As a matter of fact, much of Moss' turbosupercharger work was financed directly out of the GE coffers, without any government contract, but with the hope that some future commercial application could be found.

The big breakthrough came in 1937, during development of the famous Boeing B-17 4-engine "Flying Fortress" bomber. Its original concept, dating back to 1933, was for a plane that could carry very heavy bomb loads for long distances. There was no particular aim for very high working altitudes. The early prototypes had 2-speed geared superchargers. However, as the project moved along and war clouds gathered over Europe, it became clear to our top military men that the B-17 bomber was the key to American air defense. They agreed that it should have some very special ace-in-the-hole that would make it the best long-range bomber in the world. Thus the concept of super altitudes moved into American air war strategy. Altitude was to be the B-17's ace. The Army Air Corps men wanted a bomber that could haul a big bomb load at 35,000 ft. altitude, in smooth, clear air, above the enemy fighters and anti-aircraft guns, and drop those bombs with pinpoint accuracy—"in a pickle barrel," they said.

They could never have hoped for this without GE turbosupercharger hardware on the shelf. The 2-speed geared superchargers of the day had critical altitudes under 20,000 ft. GE's turbo was the only known device at the time with the potential to do the job. There were still some question marks on its reliability and longevity, but Washington decided to gamble everything on the GE turbo to give American fighting planes altitude superiority over the rest of the world. It was felt that altitude superiority was fighting superiority in air warfare and was just as important as a fast climb, short take-off run, tight turning circle, high load capacity or long range. The Air Corps took the first step on the new road in 1937 when it ordered the fast-developing Boeing B-17 switched to GE turbosuperchargers.

The rest is history. In the next few years over 300,000 of the Type B turbo units were produced and were used on more than 80% of the American fighting planes in World War II. Basic planes using them included the B-17, B-24 and B-29 bombers, and the twin-engine P-38 and the P-47 fighter planes. All these planes owed much of their outstanding success to altitude capability. The GE turbo was the key.

This Type B turbosupercharger unit used in World War II was a very interesting piece of precision machinery. It was big—23 in. across by 14 in. deep—and weighed 140 lb. The supercharger impeller and turbine wheel were both 12 in. in diameter. The unit had its own oil pump and storage sump to lubricate the ball bearings on the shaft. The impeller was cast in aluminum alloy and the turbine buckets were now cast in new cobalt high-temperature alloys and welded to the forged
TURBOS

disc. (An example of the forced-draft progress in metallurgy and fabrication in WWI.) A typical model of the Type B design would handle about 4000 cu. ft. of air per min. and compress this 2.8 times at a rated speed of 24,000 rpm. GE always rated the outlet pressure at 31.67 in. of mercury (Hg.) absolute. This was the standard sea level atmospheric pressure of 29.92 in. Hg. plus 1.75 in. to allow for pressure drop across the intercooler and ducting. The rated compression ratio of 2.81 would give this outlet pressure up to an altitude of around 25,000 ft., where the normal atmospheric pressure is a little over 11 in. Hg.

It is also interesting to note that the expansion ratio across the turbine was roughly the same as the pressure rise ratio across the compressor. In other words at 25,000 ft. altitude, with the exhaust waste gate closed and the exhaust all going through the turbine, the pressure in the exhaust manifold (upstream of the turbine) was between 25 and 30 in. Hg.—dropping to 11 in. across the turbine buckets. This required very effective expanding seals in the exhaust ducting to prevent leaks. The efficiency of the turbine was somewhat less than that of the compressor; but since it was working at much higher fluid temperatures (around 1500°F) there was always a big excess of bhp available to drive the compressor. There was no need to spend money shooting for maximum turbine efficiency. That was the beauty of the whole concept. With engine-driven compressors, any drop in compressor efficiency absorbs bhp directly from the crankshaft.

It's interesting to trace typical temperatures and pressures through the system at 25,000 ft. altitude. For instance, the ambient air temperature at 25,000 ft. is -30°F. The compressor would raise this to 182°F at 31.67 in. Hg. pressure. The intercooler radiator would then pull this back down to 90°F. It would drop another 30°F through the carburetor, due to fuel evaporation, and then the engine compressor would raise the mixture back to around 134°F and 40 in. Hg. pressure in the engine manifold. Result: Sea level horsepower at 25,000 ft. altitude.

Certainly the biggest disadvantage of the GE turbosupercharger system was the large weight and bulk of the installation in the aircraft. The intercooler and all its ducting added several hundred pounds of extra weight. And space requirements were so critical that the turbo had to be placed behind the cockpit, 8-10 ft. from the engine, on the P-47 fighter. There was no room at all for a turbo on the P-39 and P-51. It was best adapted to multi-engine bombers and the twin-engine P-38 fighter, where the engines were in separate “nacelles.” Late in the war, Rolls-Royce developed a 2-speed, 2-stage altitude supercharging system, with aftercooler, that was built right into its Merlin V-12 engines, adding only 150 lb. or so to the weight. This had a critical altitude of 27,000 ft. This was probably a better compromise for compact fighter planes. However, the GE turbo system, using waste exhaust gases to drive the compressor, gave much better fuel economy (which is a vital factor in aircraft range) and the engine performance in relation to fuel octane was better. And, most important: The GE system was ready to go in 1940, when the Allies really needed it. It was one of the most important factors in the air war. None of the other countries could come close to duplicating it in the three or four years available.

So that's the story: GE went into production of improved turbos for commercial aircraft after the war. And, of course, today's small units for ground vehicle engines drew their inspiration from the early GE work.

POSTWAR MODEL BH turbocharger was built for commercial transport aircraft; it was bulkier but more efficient. Total weight was over 200 lb. CHROME-NICKEL alloys were used for forged buckets of 1931 Type F-2E turbo. Cast cobalt alloy buckets came later.