TURBINES For Today?

a report on the state of the art

BY TONY HOGG

INTRODUCTION

OF THE MANY *potential sources of power for the future automobile, none holds more promise or prospect of imminent appearance than the gas turbine. Two years ago,* Car Life *surveyed the turbine field and found little to indicate such propulsion would be generally available within 10 years. Still, the near-fantastic pace of research and development in this field and the millions of dollars invested to finance these efforts since that time virtually obsoletes our 2-year-old survey. With this activity in mind, a revisit to the scene is quite worthwhile. As the publicity-seeking Chrysler Corporation rapidly approaches its deadline to produce 50 turbine-powered cars for certain selected personages, an unaccountable shroud of uncertainty draws close around the project. It begins to appear doubtful whether the motoring public at large will hear more of this particular batch of cars, which now seem more leased-out prototypes than purchasable products.*

Other turbine development programs, not only at GM and Ford but also in such remotely related areas as the earthmoving industry, have proceeded with less trumpeting but with no less achievement. Among the "windmill fraternity" there is a freedom of information exchange unknown in other areas of automotive engineering and design. This fraternization among engineers from rival corporations may be frowned upon in corporate board rooms, but it nonetheless helps account for the acceleration of development throughout the industry as a whole.

Thus, while GM develops its "Ferris wheel" heat exchanger, a company such as Caterpillar Tractor Co. can work out units that operate and can be serviced under conditions of extreme dust and mud, and ultimately all will benefit. With few exceptions, everyone concerned with turbine development pays tribute to both Rover and Boeing for pioneering work.

Indeed, the state of the art has progressed during the past two years to the point where Detroit could market turbine-powered vehicles if cost were a lesser object. There also is available (p. 22) a bolt-on turbine assist unit for present day automobiles, although it uses bottled air rather than an intake compressor. This sampling of presently operating turbine vehicles demonstrates how far we have progressed and also gives the reader greater insight into problem areas yet to be satisfactorily solved.—The Editors

SERIOUS DEVELOPMENT work has taken place on the gas turbine in the last two decades, but a glance at the current turbine scene shows that as far as automobiles are concerned there is still a lot of work to be done before an acceptable turbine-powered car can be marketed. Before reviewing the latest developments, however, it is necessary to take a look at the past history of the turbine in order to find out what basic problems are involved and how they have been overcome so far.

The gas turbine is a direct development of the jet engine that was conceived by Englishman Frank Whittle, and patented by him in 1930 as a "radial-compressor-turbine-jet aero-engine." Development was slow, and it was not until 1936 that a prototype was completed. The RAF placed an order in 1939 for a jet-propelled aircraft, the Gloster single-engined machine powered by a Whittle engine built by Power Jets Ltd. Its first flight was made in May, 1941, and in accordance with an agreement in force at that time, a complete unit together with all drawings immediately was sent to America where it was handed over to the Bell Company, which built and flew the first American jet plane in October, 1942.

Although the first unit was built by Power Jets, a lot of the manufacture and machining had been undertaken by Rolls-Royce, whose experience with superchargers was particularly useful in the development of turbine blades. Also in on the act was the Rover Motor Company which, because of the circumstances of war production, was working very closely with Rolls-Royce at that time. Rover subsequently obtained permission from the British government to attempt to build a gas turbine engine in 1942.

As far as the automobile was concerned, the Rover Company took its time. It was not until 1951 that a small turbine for automotive use was produced and installed in a vehicle very similar to the production car. This machine caused quite a sensation when it first appeared, and more so in 1952 when Rover took it to the Jabbeke freeway outside Ostend in Belgium and ran it through a measured mile at 151 mph.

These initial demonstrations, together with subsequent prototypes and their attendant publicity, have given to the automobile turbine a certain luster which it probably doesn't deserve at the present stage of development. Undoubtedly, the turbine is basically less complex than the internal combustion engine and, to the layman, its principles are far more logical, mainly because the parts are simple rotating parts with nothing going up and down. Furthermore, it runs on almost any type of fuel, requires no warm-up period in even the coldest climates, has ideal torque characteristics for automobile use, requires no external cooling system, has non-toxic exhaust, weighs about 40% less, and requires no oil changes because the lubricant is not contaminated by the products of combustion. However, despite these seeming advantages, it has provoked fear and trepidation wherever automobiles are designed and built.

For the last decade, almost every big automobile manufacturer both here and in Europe has experimented with the turbine. The problems encountered have paralleled those faced at the turn of the century when car makers attempted to scale down the steam engine for automotive use. At that time the steam engine was a simple device, provided that all one wanted was to power a factory, generate electricity, or haul a freight train. However, efficiency and economy as an automobile power unit necessitated a totally different approach and excessive complication, which was mostly concerned with the accurate metering of fuel and water in the correct proportions according to the power required. Although latter day admirers of the Stanley may not agree, this is nevertheless true. In the case of the gas turbine, it is the problem of scaling down a power unit which was developed to lift 100 people into the air, so that it will transport one man a few miles to work with the equivalent economy and efficiency of the current automobile engine.

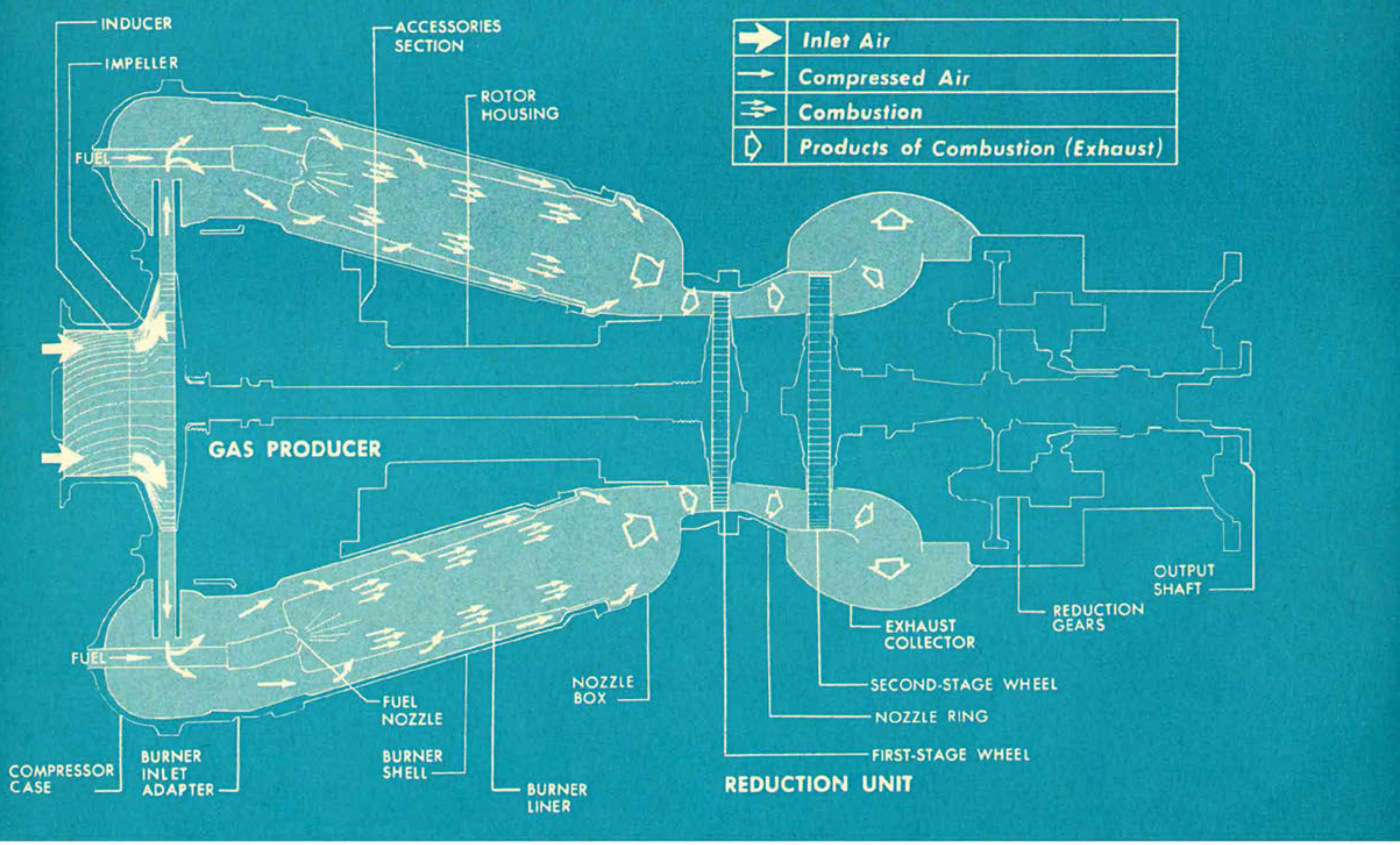
The earliest experimental turbines used a single shaft, which compressed the air and also delivered the power. These were in fact little more than jet engines because the hot gases were exhausted into the atmosphere where the heat and noise became an embarrassment. The next step was to install another turbine wheel, called the power output turbine, to harness the waste gases and convert them into shaft power. The resulting two-shaft turbine is the most common type in use today, a good example of which was the Boeing 502 described by *Car Life* (January 1963) in a Ford roadster installation. Although a very simple, compact and powerful unit, its fuel consumption worked out at 3 to 5 mpg and completely outweighed any of the advantages possessed by the turbine over the piston engine.

The next major step to improve efficiency and economy was to incorporate a regenerator, or heat exchanger, to recapture the heat being lost in the exhaust and transfer it to the incoming air. Although the heat exchanger presents a difficult engineering problem because of the necessity of sealing off the gases at very high temperatures, it is now an essential and most effective feature of the turbine. As an example, the General Motors GT-302 turbine had a specific fuel consumption of 1.63 pounds per horsepower hour but, two years later, the GT-304 used only 0.77 pounds of fuel per horsepower hour. The main reason for this gain was the addition of a regenerator to the cycle to recover the heat and energy from the exhaust.

In a turbine which does not incorporate a heat exchanger, it is necessary to expend the energy of the fuel to heat the air from room temperature (as they say in the wine trade) to the necessary 1600°. However, an efficient heat exchanger will raise the temperature of the air to at least 1000° before the fuel is even introduced. Actually, the operating temperature of a turbine is extremely critical and a recent announcement from the Chrysler Corporation reported that an increase in operating temperature of only 400° could decrease the size and weight of a turbine by 30 to 40% and, at the same time, decrease its fuel consumption more than 20%.

At the present time, there is no standard layout for a heat exchanger. The General Motors opinion is that, to ▶

BOEING TURBINE, a straight-through design, illustrates basic principles.



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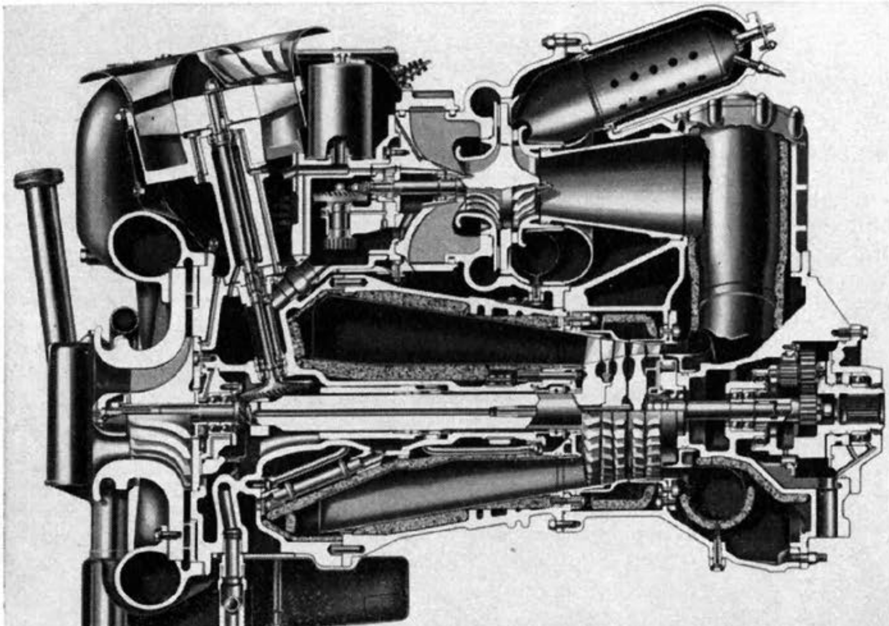
be effective, it must be mechanically operated and revolve at about 30 rpm so that it is exposed first to the exhaust gases and then to the incoming air. GM uses two units, one on either side of the turbine shaft just behind the compressor casing, which are similar in appearance to a replaceable type air filter element, and have a diameter of 22 in. Porous material alternated with thin metal plates fills the space between the metal rims, and a vertical bulkhead extends from top to bottom of the chamber in which the regenerator revolves, completely separating one side of this chamber from the other. As the regenerator revolves, it passes through the first part of the chamber where the exhaust gases are blown through it and then, after going through the seal, it moves into the second section of the chamber where the compressed air passes through it. This system works well, although the problem of sealing is acute—not only because of the high temperatures involved but also because of the difference in pressure between the two sides of the chamber.

In this system, the air enters the heat exchanger at 350°F and emerges on the other side at 1200°F. The heated air then goes through the combustors where fuel is burned to bring it up to 1650°F, and the hot gases then expand through the turbines. In the next stage, the gases return through the heat exchanger where temperature is reduced to little over 500°F, providing a relatively cool and silent exhaust. In this way, the heat exchanger serves the dual function of heating the incoming air and reducing the exhaust temperature to the point where it is no longer a problem.

Obviously, the heat exchanger or regenerator is the first essential of any efficient turbine power unit, but it adds a very considerable amount of complication to the unit. Another interesting complication is a method of varying the angle of attack of the gases on the power output turbine in order to achieve maximum economy, acceleration and braking. A nozzle blade that pivots, upon activation by an automatic control hooked up to the accelerator pedal, directs the gas flow to the turbine blades at the angle of maximum efficiency throughout the full operating range.

Not only does the variable nozzle system (such as Chrysler uses) have certain advantages when the vehicle is under power but also, by reversing the nozzles, a considerable engine braking effect can be obtained. Furthermore, this effect exists throughout the speed range, to the point where a small reverse torque can result when the power output turbine is stalled.

CUTAWAY VIEW of Ford's 704 turbine shows (from left across bottom) supercharging compressor, supercharging turbine, power turbine and reduction gears. Combustor (upper right) empties into high pressure compressor.



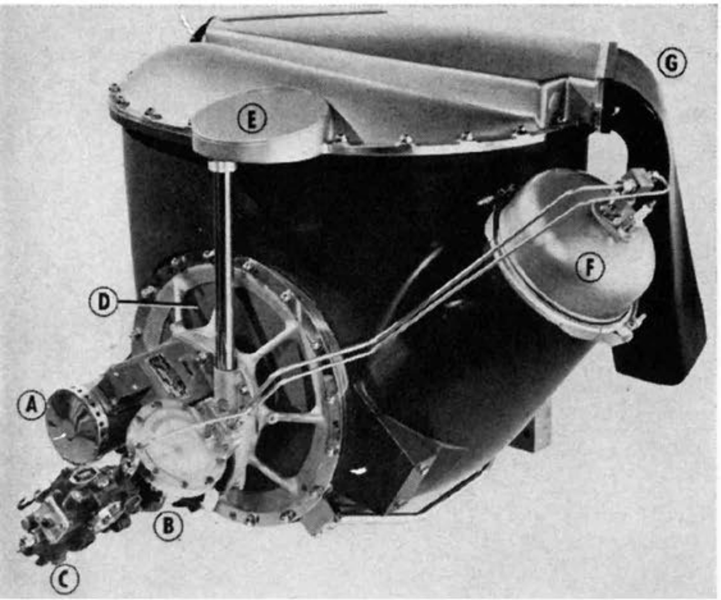
On the less serious side of turbine development, one of the joys is the exceptional and rather precise speeds attained by some of the components. As an example, the compressor of the Chrysler CR2A unit revolves at 44,610 rpm and the power output turbine has a permissible maximum of 45,730 rpm. The consequences of exceeding these speeds by perhaps another 15 rpm are almost beyond the imagination.

Actually, the Chrysler Corporation is quite conservative as far as rpm are concerned, since the Rover 2S/140 reaches 65,000 rpm. However, the laurels must go to Ford with its blithe description of the compressor of its model 704, that "at design speed, the unit rotates at 91,500 rpm." Returning to more sedate speeds, Chrysler advises that for the accessories "a vertical shaft connected to a gearbox rotates the regenerator core through a pinion and large ring gear, with the required overall reduction of 2800 to 1." Despite these rather frightening speeds, it is significant that all turbine manufacturers are quick to reassure that the external casing of their units is sufficiently strong to contain any flying particles, in the event of a serious mechanical derangement.

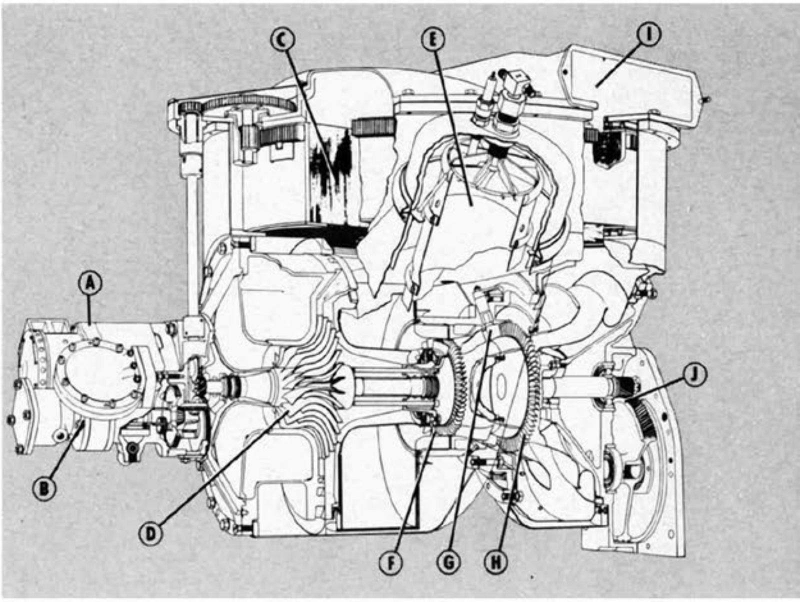
One problem arising from these extremely high shaft speeds is the necessity for perfect balance. The turbine blades, or buckets as they are called in the trade, are subjected to constant temperatures approaching 1700°F and the bucket material must be able to withstand the heat—to resist even minute warping or distortion—because a tiny bit of imbalance at 91,500 rpm is way out of balance. This general problem accounts for much of the high initial cost of a gas turbine; it can only be solved by the use of exotic alloys, which are not only expensive but also difficult to work.

At the same time, strict quality control is a necessity because of the high speeds and forces that are inherent in turbine operation. This quality control is very expensive, although in a Detroit-type production line it could become practically an automatic process with the cost spread over a vast number of units.

Returning to the exotic alloys required for the hot parts of the unit, a certain amount of controversy exists. The metallurgy of the gas turbine actually is a subject in itself. However, all the successful alloys employ either nickel or cobalt, with nickel taking pride of place. Nickel is a strategic material and 65% of the world's supply comes from Canada. The policy in Detroit has always been to avoid mass production of anything that depends on strategic materials, since a Korean-type emergency can easily halt production. With this in mind, Chrysler's effort under the direction of George J.



CHRYSLER KETTLE turbine has starter-generator (A); fuel pump and control system (B and C); combustor (F) and exhaust duct (G).



TWO-SHAFT layout of Chrysler turbine shows compressor impeller (D); variable second-stage nozzle (G), and second stage power turbine (H).

Heubner Jr. has been directed toward finding alloys which are compounded of common materials and eliminating reliance on nickel. On the other hand, both Ford and GM seem quite confident of the nickel supply situation and appear to be more interested in finding materials that are somewhat cheaper.

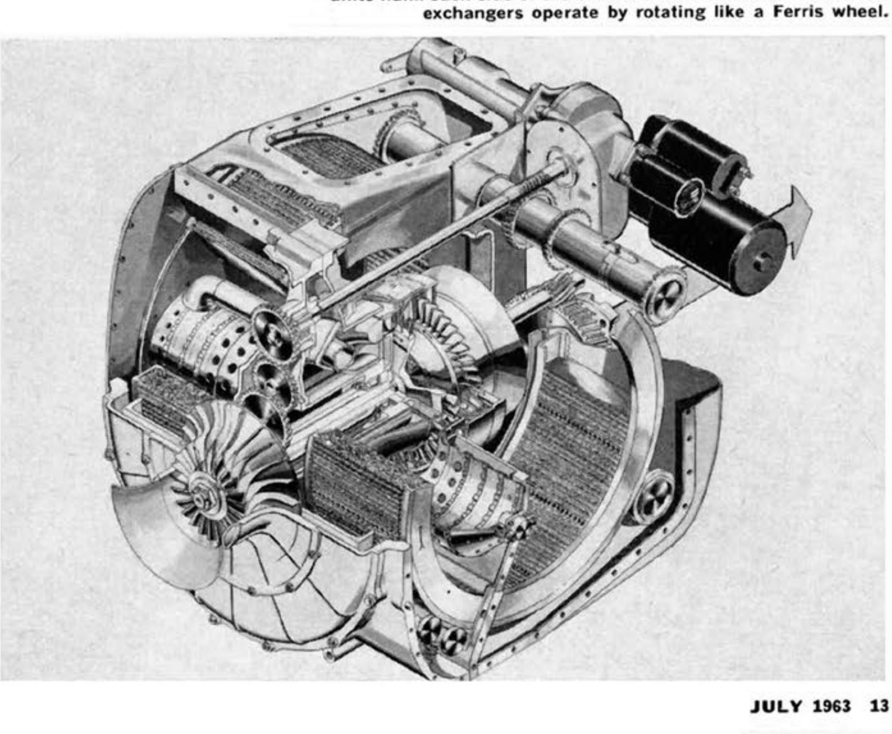
In discussing the problems of the gas turbine, it is easy to assume that once they are solved to any appreciable extent, the turbine car will become commonplace. This is not the case at all. There is always a tendency to think that anything that is new must be better, but the turbine will have to be much better before it can hope to unseat the internal combustion engine as the accepted method of automobile propulsion. Some of the world's best engineering brains have been applied constantly to both the development and, more important still, the mass production of the IC engine. Furthermore, a considerable percentage of automobile industry capital is invested in mass producing this engine. Therefore, any significant switch to turbines would be undertaken with great caution and would produce problems of such magnitude as to make the introduction of an entirely new car (Detroit has not forgotten the Edsel) quite insignificant.

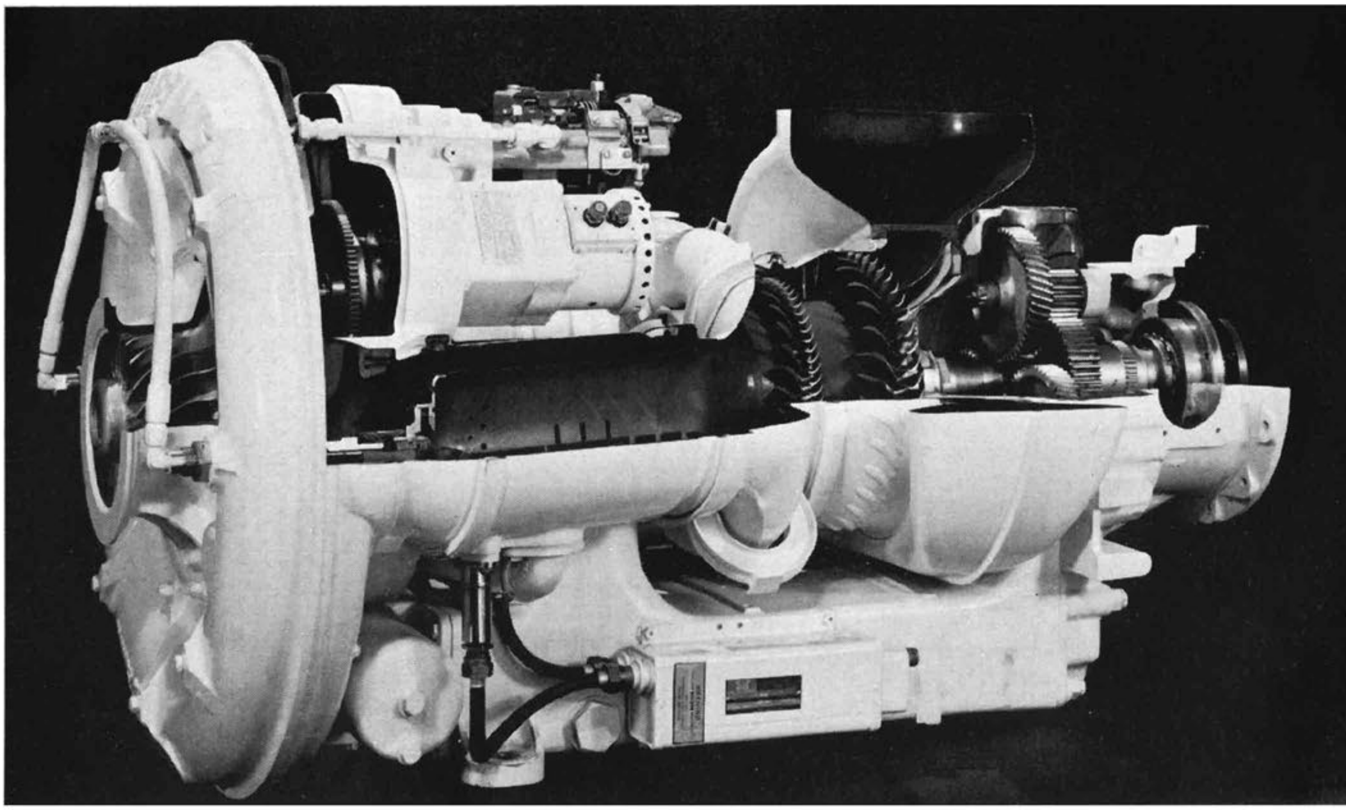
As a result, automobile manufacturers are approaching the problem carefully and are avoiding commitment to offering a turbine car at any particular time. They all like to give the impression that they are well ahead in the field, which is to a great extent true. Only Chrysler in America and Rover in England have shown any enthusiasm for marketing a turbine car, and neither has indicated that it has any plans for a production line.

Chrysler's intentions are to build 50 to 75 turbine-powered cars which will be delivered into the hands (possibly leased) of selected customers later this year if all goes well. The whole program is purely experimental and is obviously aimed at obtaining the maximum amount of publicity. Rover has made no specific promises although its turbine program is quite advanced, especially where smaller units are concerned. The tiny Rover TP/60 turbine-propeller engine of only 60 bhp has been used successfully in light planes.

In marketing a turbine car, Rover has certain advantages over any American manufacturer. First of all, the firm has existed in the precarious, limited-production, quality car market since 1904, although its internationally accepted Land-Rover extended it into a different class after World War II. Secondly, the English automobile market is comparatively wealthy and, by our standards, is incredibly diversified —encompassing everything from the custom-bodied Rolls-Royce through an immense range of sports and *gran turismo* cars, of all sizes and shapes right down to the marginal egg cars. If the market can absorb such a wide variety of different vehicles, it is reasonable to suppose that it can absorb some ►

LIKE LARGE replaceable air filter elements, circular regenerator units flank each side of the General Motors turbine. These heat exchangers operate by rotating like a Ferris wheel.





SIMPLEST AND one of earliest, Boeing turbine has neither regenerator nor variable vanes.

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Rover turbine cars, even if expensive.

By concentrating development work on small, light turbines for industrial use, the Rover Company put itself in a good position for marketing a car. The alternative approach is that of Ford, which is concentrating on the 704 model of 300 bhp designed with the trucking industry in mind. With the steady expansion of the Interstate Highway System, Ford is interested in turbine-powered trucks that will never leave this system, fed from conventional trucks at various points, and carrying the maximum permissible payload at the maximum permissible speed for 24 hours a day. In this way, the undoubted advantages of the turbine can be utilized and the high initial cost can be paid off.

It is probable that Ford's approach is the most practical one and it would seem likely that the first appearance of turbines on the road in any quantity will be in commercial vehicles where the cost of the power unit is a comparatively minor part of the cost of the whole rig. Then, as soon as the turbine car becomes practical, Ford will have a well developed turbine up its sleeve which can be scaled down for automobile use.

It is comparatively easy to draw up a long list of the advantages of the gas turbine over the reciprocating engine for automobile use but, on the other hand, it is just as easy to draw up an equally long list of the disadvantages. However, the disadvantages are mainly concerned with the problems of mass production which, in this day and age, are the main limiting factor in any advanced automobile engineering and design work. Therefore, it is reasonable to assume that eventually the gas turbine will be an acceptable form of automotive power but, meanwhile, the internal combustion engine will continue to serve us well, as it has done for the last 70 years. ■

NEW VOLVO turbine of 250 bhp uses ceramics in heat exchanger.