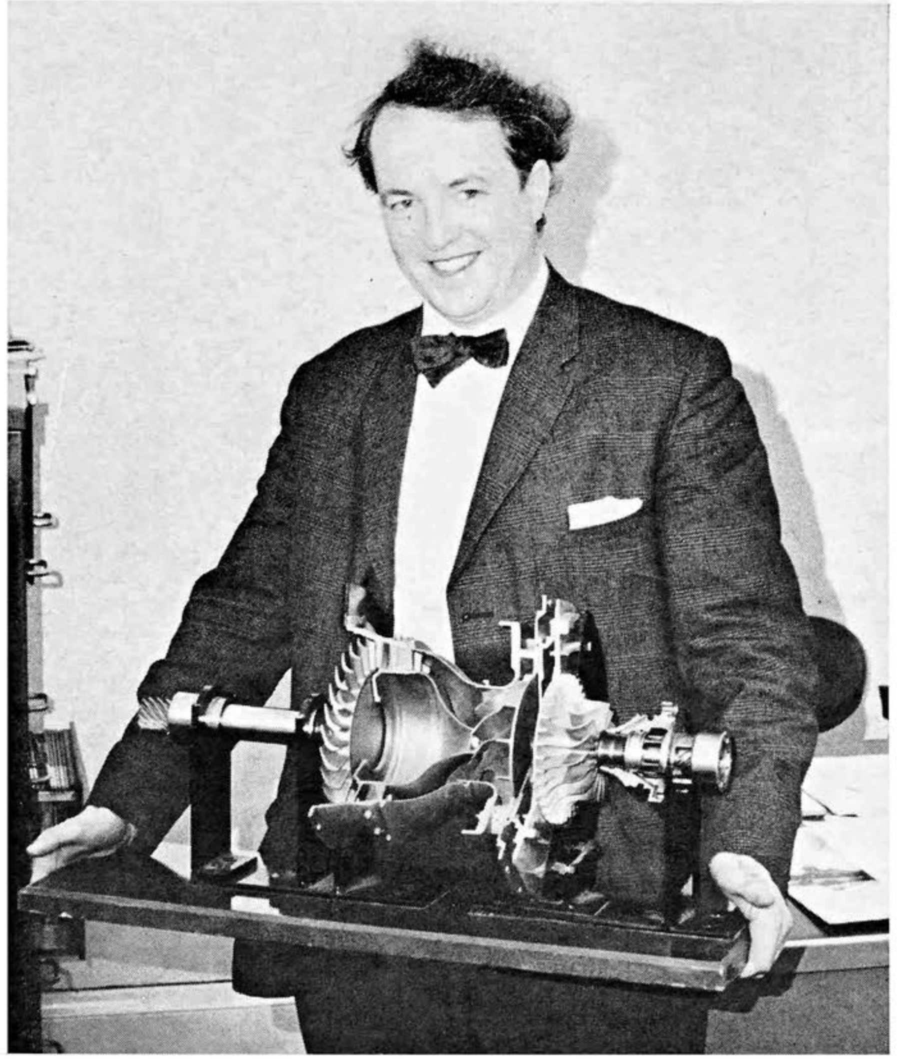


ROVER ENGINEER demonstrates the light weight and compactness of the moving parts in a gas turbine engine. This unit develops 150 bhp.

TURBINES FOR PRODUCTION? *Not Yet, Says Rover*

BY JOSEPH LOWREY

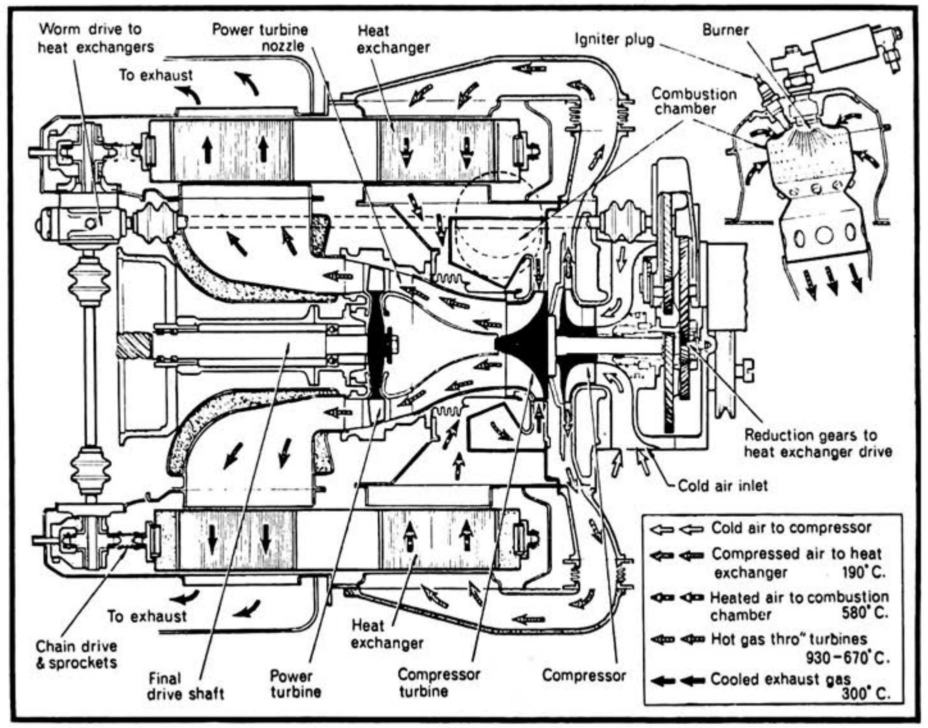
CORNING CERCOR heat-exchanger passages are only 0.020 by 0.038 in.

VISITING THE Rover car factory at Solihull, England, one no longer can discover a Gas Turbine Division. Instead, visitors are invited to a slightly separate company called Rover Gas Turbines Ltd. Those who ask about turbine cars are told that several of them are in everyday use, that work on future projects continues, but just now the chief preoccupation of the company is to earn some money instead of merely spending it on experimentation. Just about 1000 much-too-assorted Rover gas turbines now have been built and sold. Worthwhile markets for these lightweight power units have been found. The latest designs are being tooled for production at more attractive prices. Hence turbine cars are regarded by Rover as a long-term certainty, but not as the immediate money-spinner.

Perhaps the most impressive thing about visiting Noel Penny, Technical Director of Rover Gas Turbines Ltd., is when he gets up from his desk and hands the visitor a 150-bhp engine to look at! Well, not actually the whole engine, as its casing has been sectioned to let the moving parts be seen, and auxiliaries such as the starter are missing, but what is handed across is most of a real 150-bhp engine, not just a model. Complete even to its electric starter and reduction gearing, the twin-shaft engine, which can start a load from rest and deliver 146 bhp at 6000 rpm of its output shaft (the actual power turbine is running about six times as fast), weighs only a very scant 100 lb.

Power-to-weight ratio is the quality on which Rover is selling its small gas turbines today. And these engines are ideal for such tasks as running an airliner's air conditioning plant while the plane is on the ground. In this application, the turbine takes an insignificant amount of kerosene from the plane's main fuel tanks. A specific fuel consumption around 0.9 lb./bhp-hr. is used. Fuel economy is not important enough to justify impairing the engine's power-to-weight ratio with a heat exchanger. Similar considerations apply to portable fire pumps which need to develop a great deal of power for very few hours per year, or for emergency electrical generating equipment, used only when regular supply equipment fails. Both these duties require absolutely dependable starting for a neglected engine. For this the gas turbine is better than a piston engine. Some jobs have been found for which the hot exhaust of the simplest kind of gas turbine is an advantage. One engine, for example, can heat and light a hut in the Antarctic, or can turn a corn-drying blower while heating the drying air.

ROVER'S 2S/150—for 2-shaft/150 bhp—gas turbine engine was raced at Le Mans in 1965 and could be the base for future passenger car engines.



As a road-going engine, however, the gas turbine does need to limit the quantity of fuel that it burns just to heat the atmosphere. When Rover competed in the 1965 Le Mans 24-hour sports car road race, the firm's objective was to demonstrate the fuel economy which can result when a gas turbine is run with a heat exchanger. Results were not what Rover engineers had hoped. A stone passed through the intake filters, damaged the compressor and impaired engine performance. Nevertheless, the car took 10th place from 51 starters and 14 finishers, averaging 98.2 mph with a fuel consumption of 11.25 mi./U.S. gal. Subsequent independent tests of the same Rover-BRM 2-seat car have shown fuel economy to be best at a steady 45 mph, when 26 mpg was recorded. This deteriorated to only 17 mpg at 100 mph on a banked test track.

Despite these extremely promising results, the gas turbine car remains tantalizingly just over the horizon. Rover worked on the earliest Whittle jet engines for aircraft, then built the firm's first gas turbine car in 1949. A Rover car established a turbine speed record of 152.9 mph in 1952. A series of gas turbine cars have been in everyday road use since that time, but even today it seems that neither Rover nor any other factory is yet tooling for mass production of a turbine car. Although the pace of progress has been ▶

and remains disappointing, Rover recently has expanded its gas turbine activities to many times former experimental unit size.

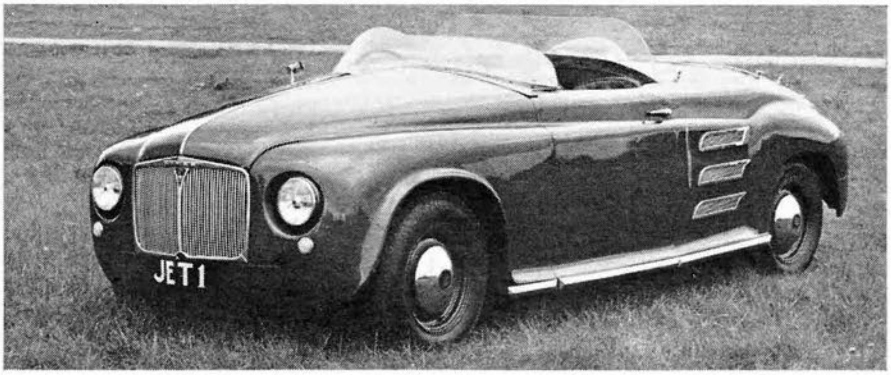
What gas turbine enthusiasts are counting on is the huge scope for future development of an engine which already is at least comparable with piston engines. Whereas reciprocating engines "burn" all their air with quite a high expansion ratio and so offer only limited possibilities for future improvements in efficiency, today's gas turbines burn only about one-third of the air which they breathe, and do so with an expansion ratio of only about 4:1. If materials capable of withstanding continuous exposure to higher temperatures become available, gas turbine power-to-weight ratios can rise as fuel consumptions decline. At the moment, Rover produces results with an extremely simple inward-flow turbine (almost the exact opposite of a centrifugal compressor) made as a one-piece investment casting of low-carbon steel, and a cast light-alloy compressor rotor. Long term possibilities include such turbine blade materials as heat-resistant ceramics, the poor tensile strength of which might be made acceptable by techniques comparable with the pre-stressing of concrete to overcome a similar inherent structural weakness.

Many of the gas turbines which Rover has sold are single-shaft units, akin to pure-jet aero engines. They have just one turbine which drives the compressor, with the turbine proportioned so that shaft horsepower can be taken from it at high speeds. Such a single-shaft turbine can drive electrical generators or centrifugal water pumps that operate only at speed. This type of turbine, however, is quite unsuited for use in a car. Rover twin-shaft turbines have their centrifugal compressor and inward-flow primary turbine rotors overhung on the end of a shaft, outboard of two bearings which are flexibly mounted to keep critical vibration speeds well below the operating range. Downstream from the compressor-driving turbine, an entirely separate axial-flow turbine (also outrigged beyond its own pair of bearings) takes power from the gas stream, and this separate turbine will start from rest, against a load if necessary, once the gas generator upstream supplies it with a blast of hot gas.

GAS TURBINE design in its present state involves a great many design choices. Rover believes in the simple centrifugal compressor driven by an equivalent inward-flow turbine. Company engineers think it is the most tolerant of widely varied operating conditions without stalling of airflow over the airfoil blades. The limit on the highest combustion gas temperature which components can withstand must be considered. Rover uses a compression ratio of 4:1 at maximum rpm. Additional compression would raise air temperature and would reduce the amount of fuel that could be burned per pound of air without overheating any components. This, in turn, would impair the engine's power-to-weight ratio, though the specific fuel consumption would improve. Conversely, a lower compression ratio could let more power be developed less efficiently.

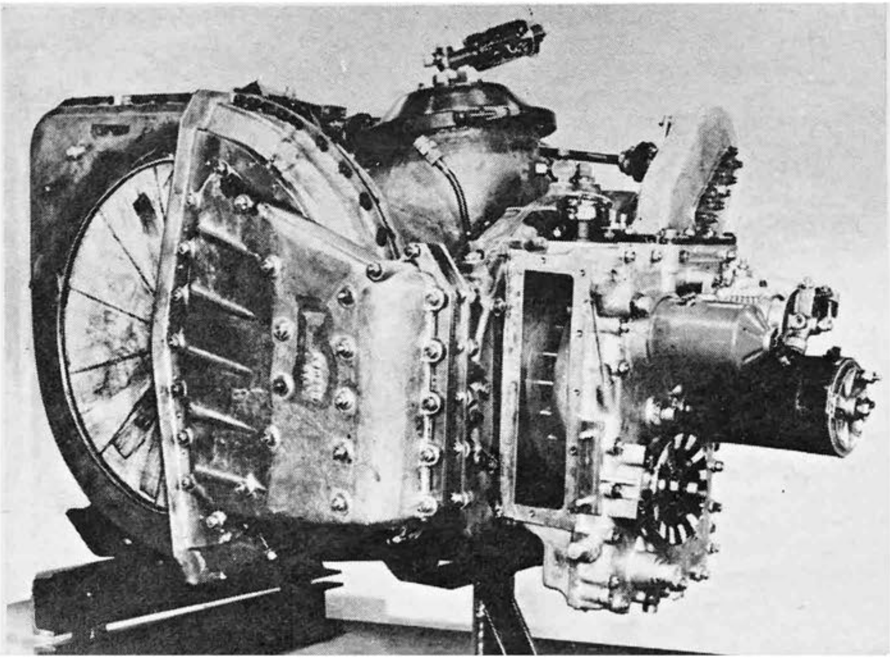
Now that a 24-hour race has proved before the public the reliability of a regenerative heat exchanger, a gas turbine engine with a fairly low compression ratio appears much more attractive. Its wastefully hot exhaust gas can be used to heat one half of a slowly-turning Cercor porous glass ceramic disc, the opposite half of which preheats air on its way from the compressor into the combustion chamber. Such a heat exchanger impairs the power-to-weight ratio of a gas turbine, because it adds weight and because it imposes some restriction upon the air flow into the combustion chamber and of exhaust gas out of the power turbine. As raced at Le Mans last year, the Rover engine developed 145 bhp, whereas two years previously it had delivered 150 bhp without a heat exchanger. At

ROVER'S TURBINES

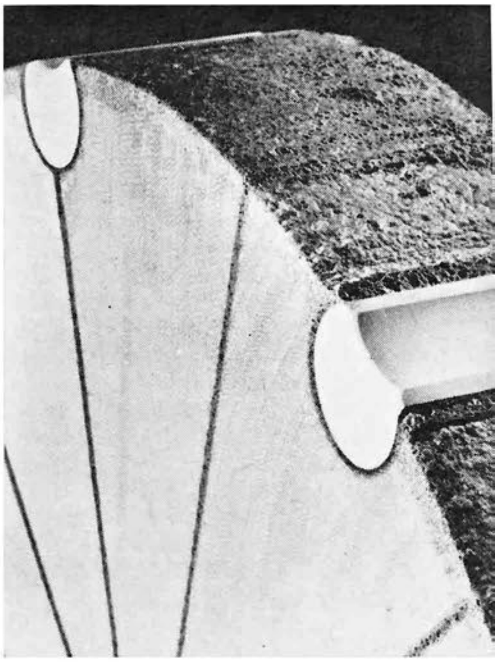


JET I, the world's first turbine car, was produced by Rover in 1949. The car, timed at 150 mph, now is a museum exhibit.

IN 1956, Rover's 4-wheel-drive turbine car appeared. Its rear axle was the prototype for the unit now on Rover 2000 cars.



REMOVAL OF the outlet duct from the "hot" half of one heat exchanger shows one of two glass-ceramic drums which return exhaust heat to the inlet side of the Rover 2S/150 gas turbine engine as raced at Le Mans.



EXPERIMENTAL rotating heat exchanger avoids use of heavy metal outer retaining ring.

full power, however, the heat exchanger had reduced the engine's fuel consumption from 0.82 to 0.57 lb./bhp-hr., a remarkable reduction of fully 30%.

So far as use of gas turbines in everyday cars is concerned, the heat exchanger is especially significant because it improves part-load fuel economy to a much greater extent than full-load economy. Running at 10% of its maximum power output as it often would on suburban roads, the gas turbine has 80% of the heating of its compressed air done by the heat exchanger, with combustion of fuel providing only the remaining 20% of the heat. Hence, at this light load, the heat-exchanger turbine engine should be almost five times as efficient as a like engine without a heat exchanger.

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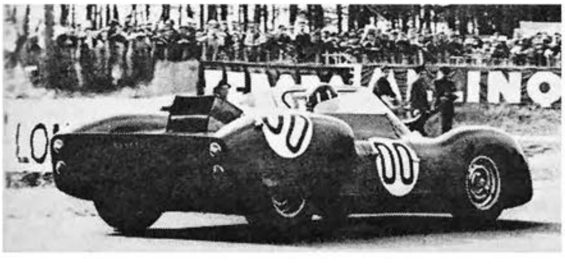
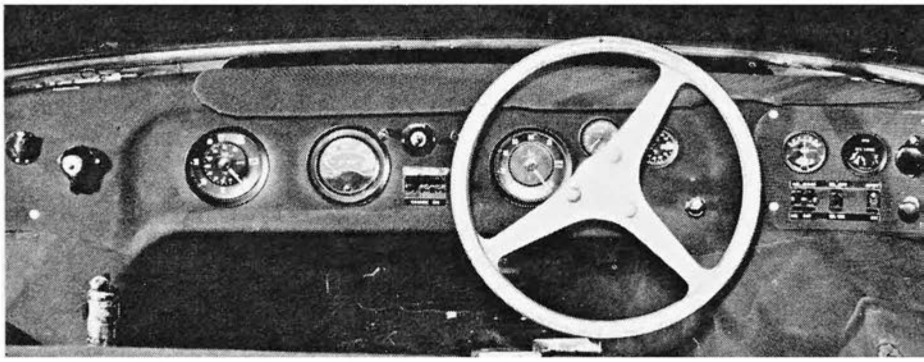
FRONT-WHEEL-drive T4, above, is in regular use today. Below, GP driver Graham Hill tests the 1963 Rover-BRM sports/racing car.





INSTRUMENT PANEL on the 1965 Rover-BRM Le Mans car showed, from left, power turbine tachometer, jet pipe temperature, gas generator and turbine revolutions, fuel pressure, oil pressure and temperature, ammeter and fuel remaining. Below, the car competes in the 24 Hours.

TURBINES

Years of experiment with "recuperative" heat exchangers akin to automotive water radiators showed that heavy and expensive units made from stainless steel soon became choked with dirt and carbon. The Corning Glass Works of Corning, N.Y., provided the breakthrough with a porous glass ceramic which hardly changes its dimensions as it gets hot. The material passes exhaust gas through half of the slowly-turning 3-in. thick disc in one direction, and compressed air through the other half of the disc from the opposite side, keeping the vital passages clear. Roller-chain driven at only 20 rpm when the gas generator is turning 65,000 rpm, two "regenerative" heat exchanger drums of 17.5-in. diameter cool exhaust gas from approximately 1300° F to 480° F, using that energy to pre-heat combustion chamber air from about 350° F to approximately 1100° F.

Despite the great advantage that a heat-exchanger has produced, the Rover gas turbines so far shown to the public would be extravagant if used in city traffic. Just to keep the gas generator half of the Le Mans engine spinning at its "idling" speed of 35,000 rpm (rather more than half the speed of 65,000 rpm which provides rated power) takes a fuel consumption of 1.5 gal. (U.S.) of kerosene per hour. This idling gas generator will, in fact, propel the 1650-lb. Rover-BRM car at 35-40 mph unless the brakes are applied.

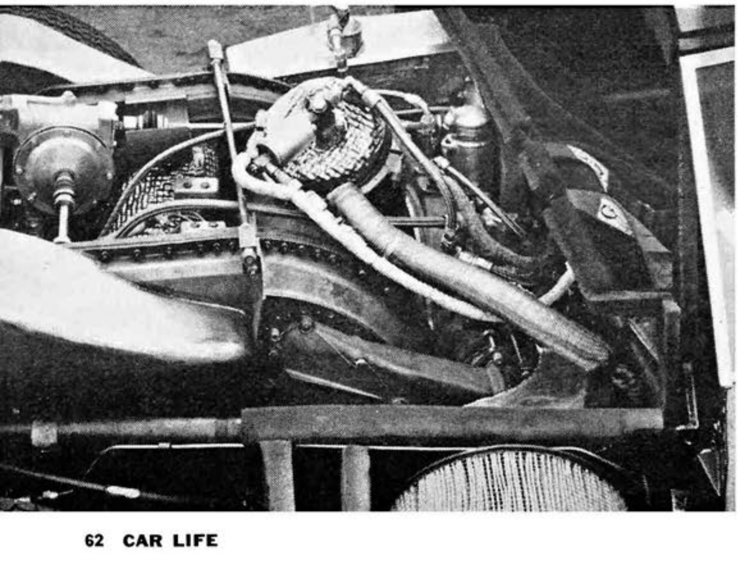
In comparison, a piston engine of 150 bhp output would probably burn about 0.5 gal. (U.S.) of gasoline per hour at idle. The exact figure would vary a good deal with the engine's state of tune. It is possible to make the gas turbine idle more economically than at 1.5 gal./hr. consumption. This can be done by reducing its idling speed toward the minimum, which provides enough compressed air to avoid stalling. But, if this is done, the lag between depressing the gas pedal and getting real acceleration from the car is increased. Drivers might possibly accept a system which produced a slower and more economical idle during long traffic hold-ups, with the engine re-set by a light touch on the gas pedal to an idling speed from which more immediate and more satisfactory acceleration was available.

More probably, Rover will find it necessary to follow a Chrysler example and equip future car power units with what is referred to as "variable geometry" which Rover tested in various forms, but did not need for the Le Mans race. The objective of variable geometry is to keep the gas generator assembly of compressor and first-stage turbine idling at a high enough speed for quick acceleration to be available on demand, but to cut down air flow through the engine (and correspondingly the fuel consumption needed to meet pumping losses) by throttling the air with variable-angle nozzle blades. Forms of variable geometry which have been tested include pre-swirl vanes in the intake duct to the centrifugal compressor, equivalent variable-angle blading at the intake to the inward-flow compressor turbine and also variable-angle blading between the compressor turbine and the separate power turbine. The limiting factors on throttling airflow through a gas turbine engine are the attainment of excessive combustion temperatures and the onset of "compressor surge" when air flow gets too far away from designed angles of incidence.

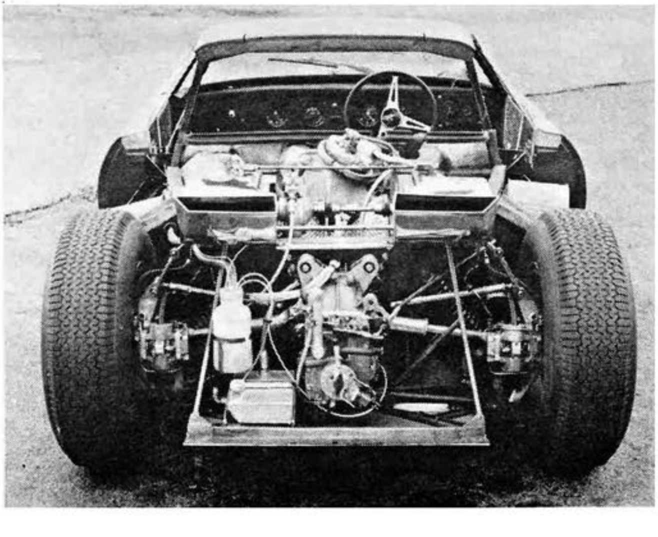
DELAY IN response to the gas pedal is a point about which Rover turbine engineers are sensitive. They claim the problem is exaggerated. Whichever turbine engined models an outsider has driven, his experience is invariably out of date, but the lag always is real, and usually occurs on releasing the gas pedal as well as on depressing it. Thrust comes from the kinetic energy of a hot gas stream impinging upon the power turbine blades and, when fuel flow rate is increased by depressing the gas pedal, the initial response is modest due to extra heat expanding the gas which already is flowing. Real thrust comes only when the gas generator has speeded up to pump many times more gas into the power turbine. Conversely, when the gas pedal is released, a cooler gas stream reduces the thrust somewhat, but a good deal of power continues to be delivered until the gas generator slows down and delivers less gas.

For an expert driver of turbine cars, lag in responses to the gas pedal can be moderated by using disc brakes in conflict with the engine, starting to accelerate prematurely and checking the car with its brakes until the way ahead is actually clear. It can be claimed that drivers of piston-engined cars suffer a rather similar lag when kicking down for full acceleration with an automatic transmission. The engine must wind up its speed in indirect gear before it delivers full power. Today's drivers are not, however, accustomed to delayed response equivalent to the extra 3 sec. which is added to Rover-BRM acceleration times if the driver does not speed up the gas generator in advance of releasing the

LE MANS ROVER-BRM engine displays combustion chamber and fuel nozzles, center, and exchanger cross shafts.



SUSPENSION WAS similar to BRM Grand Prix car, but the engine was unique in the history of Le Mans racing.



brakes. As Rover engineers say, the gas turbine has to be better than the piston engine if it is to supplant the piston engine.

Variable geometry does offer considerable improvement in throttle response, as Chrysler has demonstrated. In particular, changed blading angles, which cut down air flow through the unit, kill unwanted thrust quickly when the gas pedal is released.

IT ALSO seems that Rover gas turbine engineers have been rather disinterested in applying to the cars existing know-how on automatic transmissions. Their separate power turbines present output torque characteristics equivalent to those of a hydraulic torque converter of about 2:1 stall torque ratio, enabling gas turbine cars to be driven (and raced at Le Mans) without change-speed gearing. This, however, puts them where piston-engined cars with automatic transmissions were nearly 20 years ago, in that a car geared for high speeds has rather poor acceleration from rest. Turbine cars with automatic change-speed gearing have been run on the road, in one instance using the epicyclic part of a Borg-Warner model 35 transmission with suitably modified control arrangements.

So far, six turbine cars have been tested by Rover engineers. Four are still in active use. Known widely by its British registration number JET 1, the first car now is an exhibit in the London Science Museum. It has an engine with an 8.75-in. diameter centrifugal compressor, mounted ahead of the rear wheels in a sedan chassis to which open 2-seat bodywork is fitted. It was followed in 1953 by a test car based upon the then-current Rover sedan. This model used an engine with a 6.5-in. diameter compressor located at various times in front and rear positions. This model seldom was seen in public.

Inability to reduce thrust quickly led to some excitement in corners during public road driving of early rear-wheel-driven Rover turbine cars. The factory's young engineers had acquired experience in fast driving in "4 x 4" Land-Rovers, so the T3 turbine car prototype of 1956 was built with four-wheel drive. In addition to the neat rear-engined T3 coupe, which the public has seen at motor shows or on the road, there also exists a skeleton version of the same car. This machine normally runs only on test tracks, driven by Rover engineers.

Some embarrassment was caused by early showings of the T4 prototype, because these took place before the public had seen the Rover 2000 Sedan from which its bodywork was derived. Unlike the piston-engined production car, the T4 has front-wheel drive from a far-forward turbine engine, and independent rear wheel suspension instead of a "dead" de Dion axle tube. This four-seat sedan could have been tooled for quantity production. The prototype still is in regular use.

For the 1963 Le Mans 24-hour race, the Rover-BRM 2-seater was very hurriedly built. A multiple-tube frame based on the BRM Grand Prix design was used. The engine now incorporating a compressor of only 5.625-in. rotor diameter, was mounted just ahead of the rear wheels. This car was rebuilt for the 1965 race. The heat-exchanger engine and improved streamlining were incorporated. There are no plans to run the Rover-BRM in the 1966 Le Mans race. Its sponsors believe that despite the damaged compressor, last year's participation proved the reliability and economy of the heat-exchanger engine.

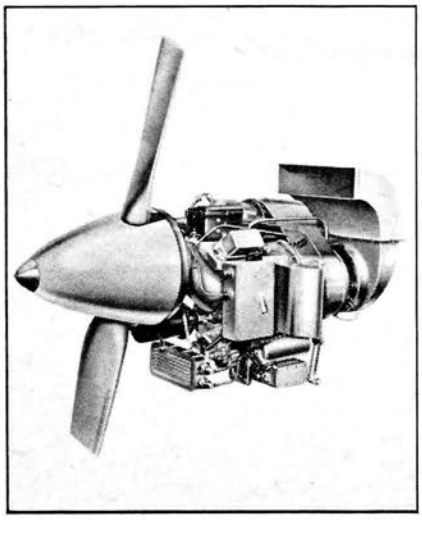
What comes next? As yet Rover engineers are not talking, perhaps because they now believe themselves ready to design a turbine car for production. This involves investment of a large amount of capital in tooling. On a world scale Rover is not a very large company, so a production go-ahead probably will require the partnership of another company inside or outside Britain.

As a basis for a production engine, the 2S/150 unit raced at Le Mans (its designation means two shafts, 150 bhp) obviously is sound. The heat exchangers would be essential. So would some form of variable geometry to reduce air flow through the fast-idling engine. Another necessity is a transmission giving at least two forward ratios. Some space could be saved if an annular combustion chamber encircling the engine is ready to replace the single combustion can above the engine that is now used. Castings which require little or no machining already are used for the main moving parts, and the welded-up engine casing could be tooled for manufacture from pressings.

ADVANTAGES which such a gas turbine engine could offer in the very near future would be very light weight for power, absolute smoothness, reliability, durability, slow but completely certain starting in the most extreme heat or cold, exhaust gas which is not toxic or smog-provoking, and good economy of low-cost fuel during high-speed driving.

Disadvantages probably would be rather heavy fuel consumption in town, and some measure of lag in response to the gas pedal. Folk who, after long years of disappointment with the turbine car, say, "It will never happen," could quite possibly be proved wrong by 1970. ■

ROVER'S 235-lb. turboprop engine is world's smallest.



TINY TURBOPROP engine, developing 60 bhp at cruise, was tested in a Currie Wot biplane in 1961 as a by-product of Rover engineering.