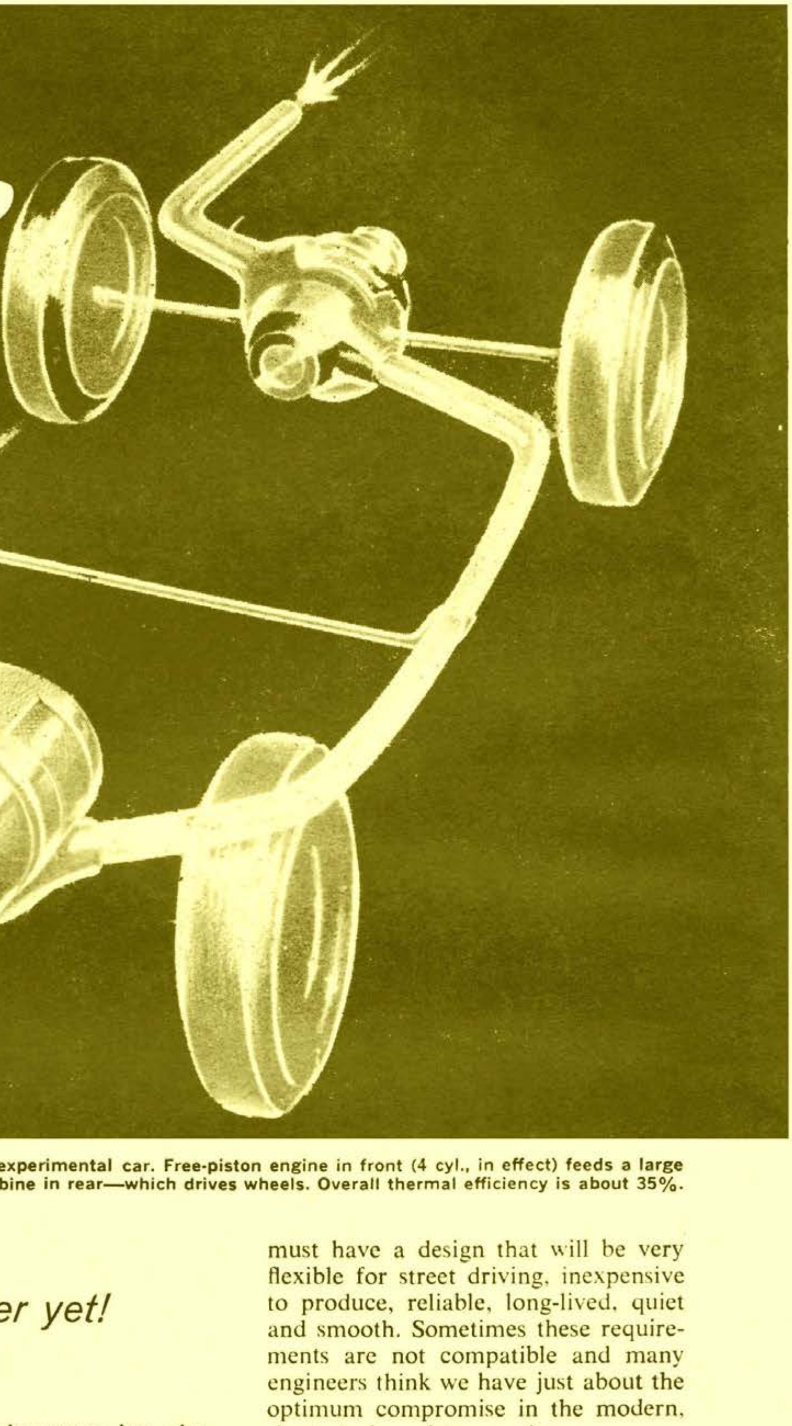
Replace the Piston Engine?



POWERPLANT LAYOUT in General Motors' XP-500 experimental car. Free-piston engine in front (4 cyl., in effect) feeds a large volume of hot gas (about 850° F.) to simple gas turbine in rear—which drives wheels. Overall thermal efficiency is about 35%.

There have been a lot of schemes, but nobody's come up with the answer yet!

BY ROGER HUNTINGTON

FOR THE LAST 60 years the world has been geared to the internal combustion engine. But it has been a very particular type of internal combustion engine—the one that uses a 4-stroke operating cycle, spark ignition, fuel-air mixture outside the cylinder in a carburetor, and a layout that utilizes pistons, connecting rods and crankshaft to convert combustion pressure into useful power.

Actually there are many other possible ways to do this same job. Unconventional engine types have intrigued engineers and inventors since the beginning of the automobile. They utilize every conceivable combination of operating cycles, ignition method, fuel mixing and forced conversion. Each system has vital advantages but also apparently more than enough disadvantages to keep it out of mass production. But that doesn't mean that the old conventional 4-cycle, spark-ignition piston engine is going to be top dog forever in the automotive field.

Certainly one of the major goals with any new engine type is reduced fuel consumption. Current engines convert only 15 to 30% of the heat energy in the fuel into useful power. There are many possible arrangements that will do a lot better. There are also some systems which will get more power out of a given size and weight of engine than we get with today's conventional car engines. This is a desirable goal, but at the same time we must have a design that will be very flexible for street driving, inexpensive to produce, reliable, long-lived, quiet and smooth. Sometimes these requirements are not compatible and many engineers think we have just about the optimum compromise in the modern, short-stroke, piston engine.

Any newcomer will have to be just as good in all these respects—and much better in some—to get a foot in the door.

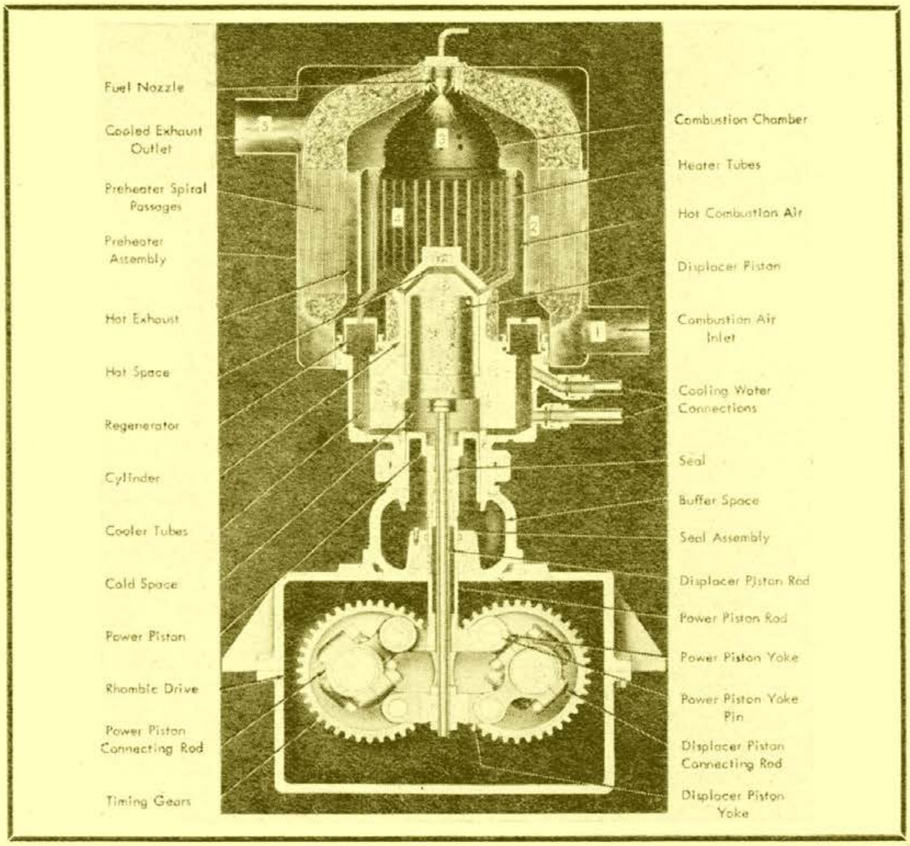
STRATIFIED CHARGE—One of the major faults of the conventionally carbureted engine is that it can't burn a very lean air-fuel mixture. When the fuel and air are mixed in a more or less homogenous mixture outside the cylinder, then fired by a single spark plug at the end of the compression stroke, a mixture leaner than about 16 or 17 parts of air to one part of fuel (by weight) won't fire. The fuel just isn't concentrated enough to get a good flame started at the plug tip. Of course an air-fuel mixture near the chemically-correct mixture is needed for maximum power, but a lot of gas could be saved at part throttle if much leaner mixtures could be used.

The principle of the stratified charge engine is to initiate combustion in an area where the air-fuel mixture is nearly chemically correct (around 15:1). Then this will start a strong enough flame to ignite a much leaner mixture in the main combustion area.

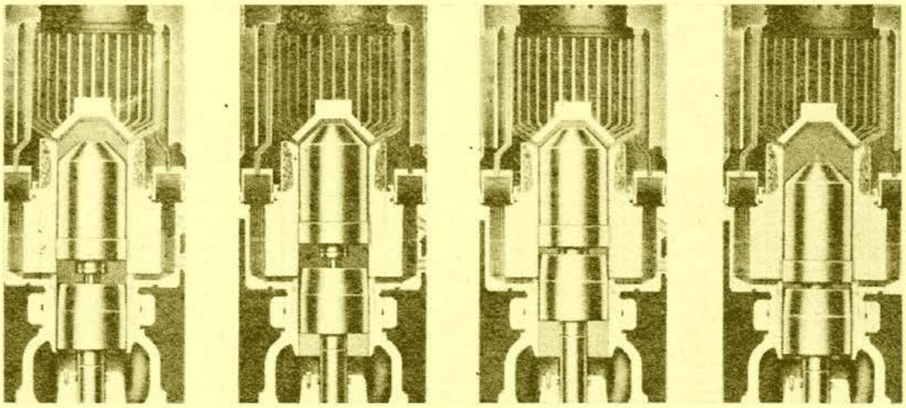
There are several ways it can be done. Probably the most successful design of this type was the Texaco Combustion Process engine, *circa* 1950. Here pure air was drawn into the cylinder through a shrouded intake valve, which gave it a violent swirling motion around the cylinder. The fuel was injected in a strong spray in the direction of swirl, pointed at the spark plug. This gave a relatively rich mixture for combustion and the flame front more or less stood still while the swirling air fed into it. Not only could this system burn a very lean air-fuel mixture, but there was no chance for detonation to occur in stagnant end gas. The Texaco engineers got their lowest specific fuel consumption at an air-fuel ratio of about 40:1—and they successfully burned a kerosene-like fuel (around 60 octane) at 10:1 compression ratio. The Achilles' Heel of the Texaco engine was the cost of the fuel injection system.

Some other stratified charge engines use a separate small cell to initiate combustion in a rich mixture. This cell connects with the main combustion chamber through a narrow throat, so the initial flame jets out into the lean mixture in the main chamber like a torch. A system like this can fire air-fuel ratios as lean as 150 or 200:1. Specific fuel consumption, in terms of pounds per horsepower-hour, can readily be cut 15 or 20%. A typical design of this type was developed by N.A. Nilov in Russia in the late '50s. It used two carburetors, a rich-mixture carburetor to feed a readily-combustible mixture to the "pre-chambers," and a lean carburetor to feed the main mixture to the cylinders through overhead poppet valves. This design did away with the cost and complication of fuel injection, but still got the benefit of the lean mixture. The small valve into the pre-chamber didn't open until late in the suction stroke (after the main cylinder was nearly charged), to prevent the mixture in the main cylinder from getting too rich.

One advantage of using fuel injection with stratified-charge engines is that it does away with the air throttle. In other words, the cylinders will draw a full charge of pure air on every suction stroke and engine load is controlled by varying the amount of fuel injected (like a diesel engine). This has



STIRLING HOT AIR engine in cross-section, showing components. Working fluid makes a closed circuit through heat exchangers from top of each piston. Bottom end has rhombic drive.

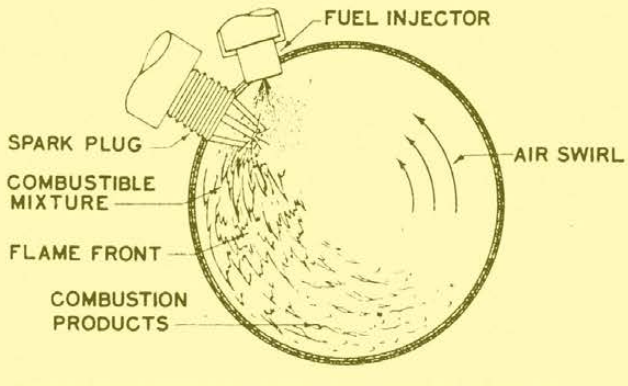


ACTUAL CYCLE of GM's Stirling engine. Space between two pistons is cool, with hot space above piston top, drawing from heater tubes at top. Although highly efficient, it has a low output. Its big advantage is absolute silence while in operation.

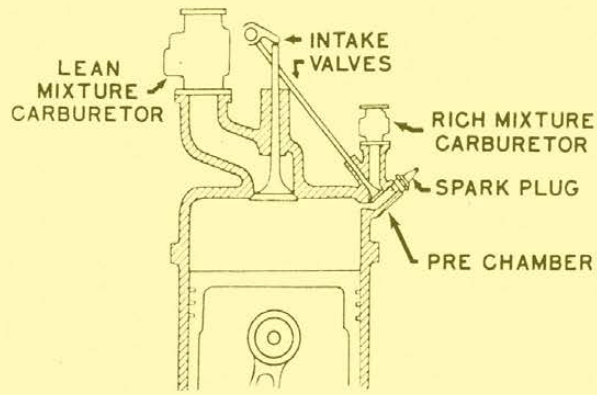
several advantages. One, the "pumping loss" caused by the pistons pulling against a high vacuum on the suction stroke (when the throttle is nearly closed) is practically eliminated. Also, combustion is more efficient when the lean mixture is fired in the full, highly-compressed air charge. Molecular dissociation and heat losses to the cooling water are reduced, due to lower gas temperatures through the cycle. One series of tests on a given design showed thermal efficiency reduced 8% when load was controlled by throttling the air supply (to half load).

ODD CYCLES—Current auto engines mostly work on the age-old 4-stroke Otto cycle. Here the "working fluid" (air-fuel mixture) is drawn in on a suction stroke, compressed on the next up-stroke, fired to a high pressure and temperature at the end of this compression stroke (at nearly constant volume), then expanded on the down-stroke to give the useful power, and finally forced out of the cylinder on the exhaust stroke. This is a very simple, practical cycle sequence for automotive engines. The popular 2-stroke and diesel cycles are relatively minor variations of it.

But engineers have long dreamed of new cycle concepts which would eliminate some of the inefficiencies inherent in burning the working fluid in the working chamber. So, how about an external combustion engine? Very high thermal efficiencies are available by ▶



TEXACO EXPERIMENTAL engine of the late '40s swirled air through shrouded valve while spraying fuel at spark plug.



STRATIFIED-CHARGE engine by Nilov had plug igniting a rich mixture in a pre-chamber, which lit the main charge.

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using air, or hydrogen, as the working fluid and doing the heating and cooling outside the cylinder. General Motors Research spent quite a lot of time and effort on an external combustion hot air engine in the late '50s—a cycle that was invented by Scotsman Robert Stirling back in 1816. The GM engineers achieved brake thermal efficiencies at part load of 39% with the Stirling engine, as compared with 35 and 32%, respectively, for equivalent modern diesel and V-8 automotive engines.

The Stirling engine uses two pistons in each cylinder that have their relative motions phased by a rhombic drive to control the pressure and temperature variations of a working fluid (air or hydrogen) that is used over and over again as the engine goes through its cycle. Without going into great detail, the principle is to pump the fluid in and out of the power chamber through heat exchanger tubes which can extract or add heat as required. The heating tubes run through a combustion chamber that is heated at more or less constant temperature by gasoline sprayed in through a nozzle. The cooling tubes run through water jackets. The load of the engine is controlled by varying the amount of working fluid. (This was done in the GMR engine by introducing hydrogen under pressure to raise the load, and bleeding it off to the atmosphere to reduce it.)

Some idea of the operating cycle of the Stirling engine can be had by studying the accompanying drawings. The power piston is at the bottom. The displacer piston is at the top and doesn't do any work, except to move gas. The hydrogen gas follows a closed circuit between the chambers above the two pistons. When the power piston comes up on the compression stroke the displacer moves quickly ahead of it to draw in cool gas and try to give constant-temperature (isothermal) compression. Then heat is added on the down stroke by having the displacer closely follow the motion of the power piston, thus drawing in hot gas above it from the heating tubes. It is this relative addition and subtraction of heat from the working fluid that gives the net useful thrust on the power piston. The same thing in principle is done with internal combustion engines; but the trouble there is that the working fluid is rejected at the end of each cycle and 35-40% of the heat energy in the fuel goes out the exhaust with it. The closed-cycle external combustion engine is much more efficient.

But there are disadvantages. The big one, of course, is that it can't exchange heat fast enough to get good power out of a given engine bulk and weight. GM's test engine weighed 450 lb. and developed 40 bhp at 2500 rpm. Such characteristics would be practical only for large stationary engines. But they say the uncanny silence and smoothness of this Stirling was very intriguing.

In another odd-cycle experiment, GM Research played with a unique free-piston gasifier for a gas turbine engine in the mid '50s. The free-piston unit merely generated large volumes of hot gas for the turbine. But it did this more efficiently than the rotary compressor and burner section of a normal g.t. engine. A free-piston engine has no rods or crankshaft. There are "bounce" pistons at each end that operate in closed chambers, and drive smaller pistons back and forth in an opposed manner in a conventional cylinder. When the small pistons come together they compress the air to a ratio of 30 or 40:1. Then fuel is injected in diesel fashion, and the small pistons are forced apart by the combustion pressure. This, in turn, compresses the air in the closed bounce chambers ahead of the large bounce pistons—which generates the force to return the small pistons on the next compression stroke. Very simple. An arrangement of reed or poppet valves permits the bounce pistons to charge the working cylinder through cylinder wall ports on the back-and-forth strokes. When the small pistons uncover the exhaust ports at the outer end of their strokes, this hot gas goes to drive the turbine.

Advantage? The free-piston gasifier, with its high compression ratio, works at an efficiency of 40 or 45%, so the overall piston-turbine efficiency is about 35%. Also, the exhaust gas coming from the cylinders is at a temperature of only 450 to 900° F., instead of the usual 1600° gas temperature of a turbine gasifier. This permits use of cheaper materials for the turbine blades. If desired, additional fuel could be sprayed into the exhaust gases between the gasifier and turbine to get a momentary burst of power, since these gases still have 80% of their original oxygen content (typical of diesel combustion). GM used this unique free-piston-turbine powerplant for its XP-500 show car in 1956, and got quite good results in road tests.

No CRANKSHAFT—Many engine visionaries have considered it more important to get rid of the wild linkage of pistons, connecting rods and crankshaft that are used to convert combustion pressures into useful torque. This complicated system is not only the main source of engine vibration, but the high friction created by the pistons sliding up and down in their cylinders is a big factor in the relatively low brake efficiency of the modern engines.

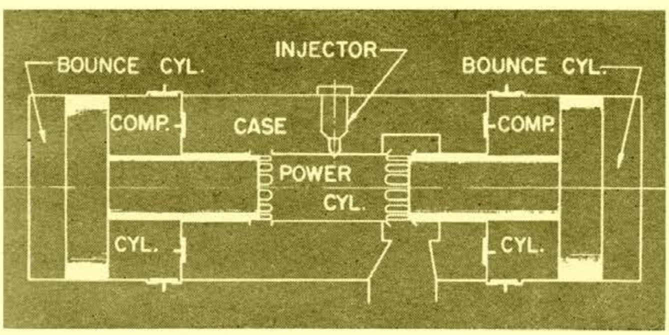
The Wankel rotary engine has a tipped rotor that rotates with an eccentric motion in a closed casing, in such a way that the combustion cavities alternately expand and contract in volume to take care of the suction, compression, expansion and exhausting phases. The air-fuel mixture is let in and out through ports in the chamber walls, and a single spark plug fires each cavity as it comes around. Actually the new Rambler-Renault rotary engine is similar in basic principle, though different in operation. Here the combustion cavities stand still, and a cam-shaped rotor moves in and out of the cavities to give the changes in volume. It also uses poppet valves to admit the mixture instead of wall ports.

Both engines feature great smoothness and high rpm ability (though the Rambler-Renault would be limited by valve gear dynamics). Small versions of the Wankel engine, with port breathing, have operated efficiently above 15,000 rpm, and the output per cubic inch of capacity, and in terms of engine size and weight, is very high. The toughest problem with these rotary engines is that they need sliding seals between the rotor tips and the chamber walls. These seals have to operate at very high linear velocities, and lubrication, wear and sealing efficiency are their biggest headaches.

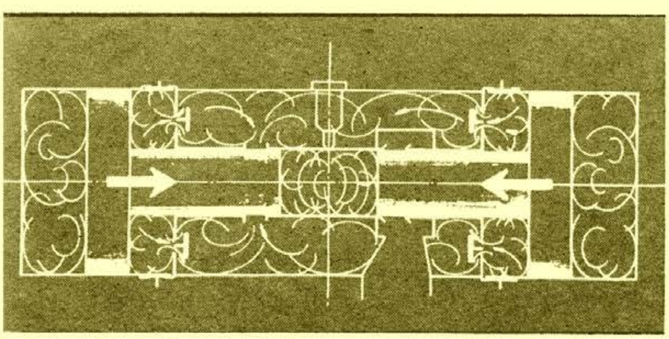
The NSU people in Germany, who have adapted the Wankel design for production cars, are facing another problem: Tax authorities are considering the displacement equal to the total swept cavity volume of the three lobes instead of one lobe cavity, as the NSU says it should be. This will hurt the engine in terms of tax per horsepower.

Another type of rotary engine has the crankshaft on the center of a barrel-shaped engine, with several cylinders operating axially around the outside of the barrel. The pistons bear against a cam or "swashplate" that appears to have a wobbling motion as it rotates. Thus axial piston thrust also gives a rotational component that exerts torque on the crankshaft. Such an engine is very smooth and quite compact, due to the barrel shape. But the pistons usually have to thrust through sliding slipper bearings, which wear and give friction. Also, there are all the old problems of piston inertia and lubrication and valve gear. Thus, this layout has little to recommend it over current engine designs. Herrmann and Mitchell have been the big exponents of the barrel engine, and they generated quite a lot of interest in the '30s. Operating prototypes have run successfully in airplanes and boats. But Detroit never paid it much attention.

And so it goes. These engines are only a small fraction of the weird and wild ideas that have been tried to improve the age-old spark-ignition piston auto engine. Someday one of them might score. ■

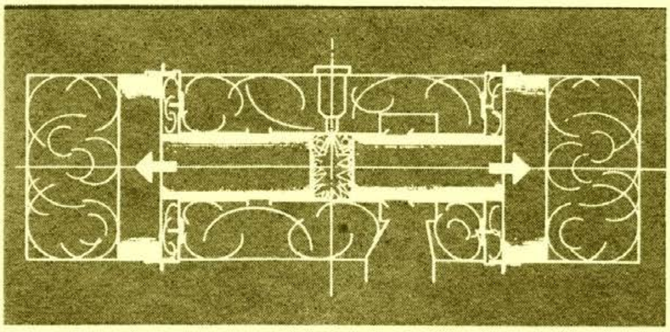


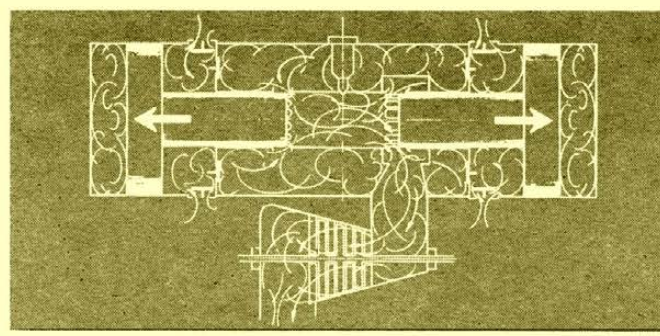
1) CYCLE SEQUENCE of GM's free-piston gasifier: starting position with intake and exhaust ports open, valves closed.



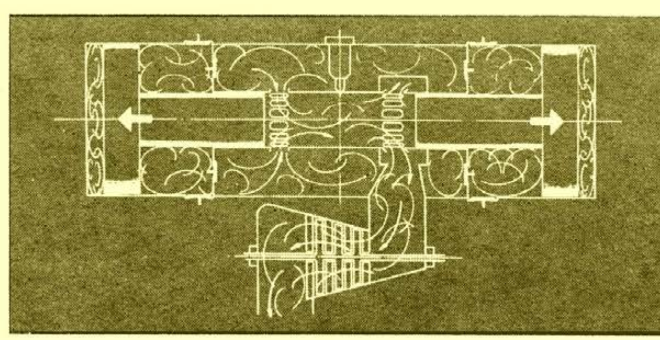
2) PISTONS MOVE inward, closing ports and compressing air.

3) FUEL IS injected into power cylinder and power stroke begins.





4) PISTONS CONTINUE upward travel. Air in bounce cylinders is compressed for return stroke; compressor, exhaust ports are open.



5) INTAKE PORTS open, case air scavenges cylinder and goes to turbine.

6) PRESSURE IN bounce cylinder moves pistons inward for next cycle.