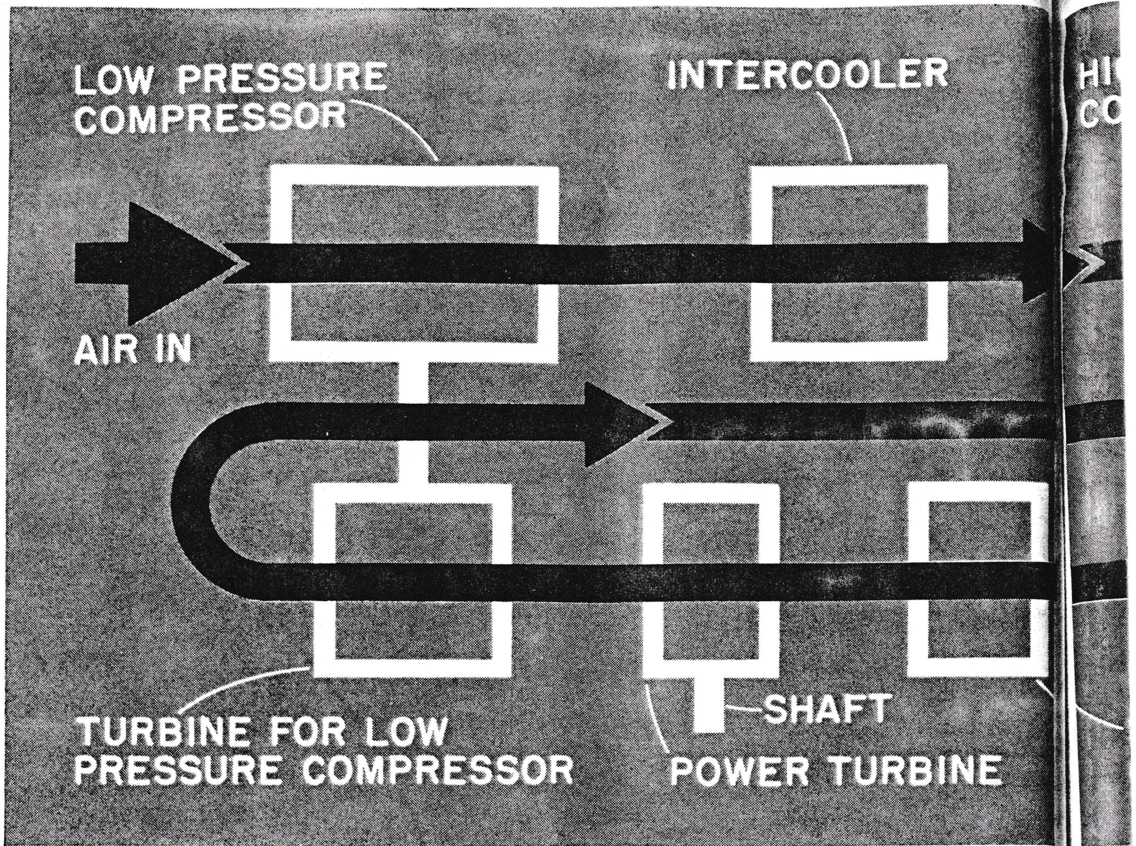
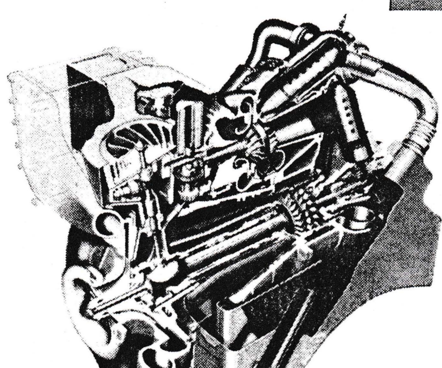


Air flow chart shows various stages of compression, heating, combustion, for a Ford 704 engine using a regenerator.

Below: Cutaway of Ford 704 engine.



ENGINE ECONOMY THROUGH REGENERATION

Fuel savings of from 20 to 50 per cent are expected from aircraft powerplants using this preheating design principle

By J. S. BUTZ JR.

AN OLD POWERPLANT design technique known as regeneration is attracting great interest today for use on aircraft gas turbine engines. Most aircraft engine manufacturers currently are working on regenerative turbine engine designs. The military services, especially the Army and the Navy, are studying this type of engine for a number of uses.

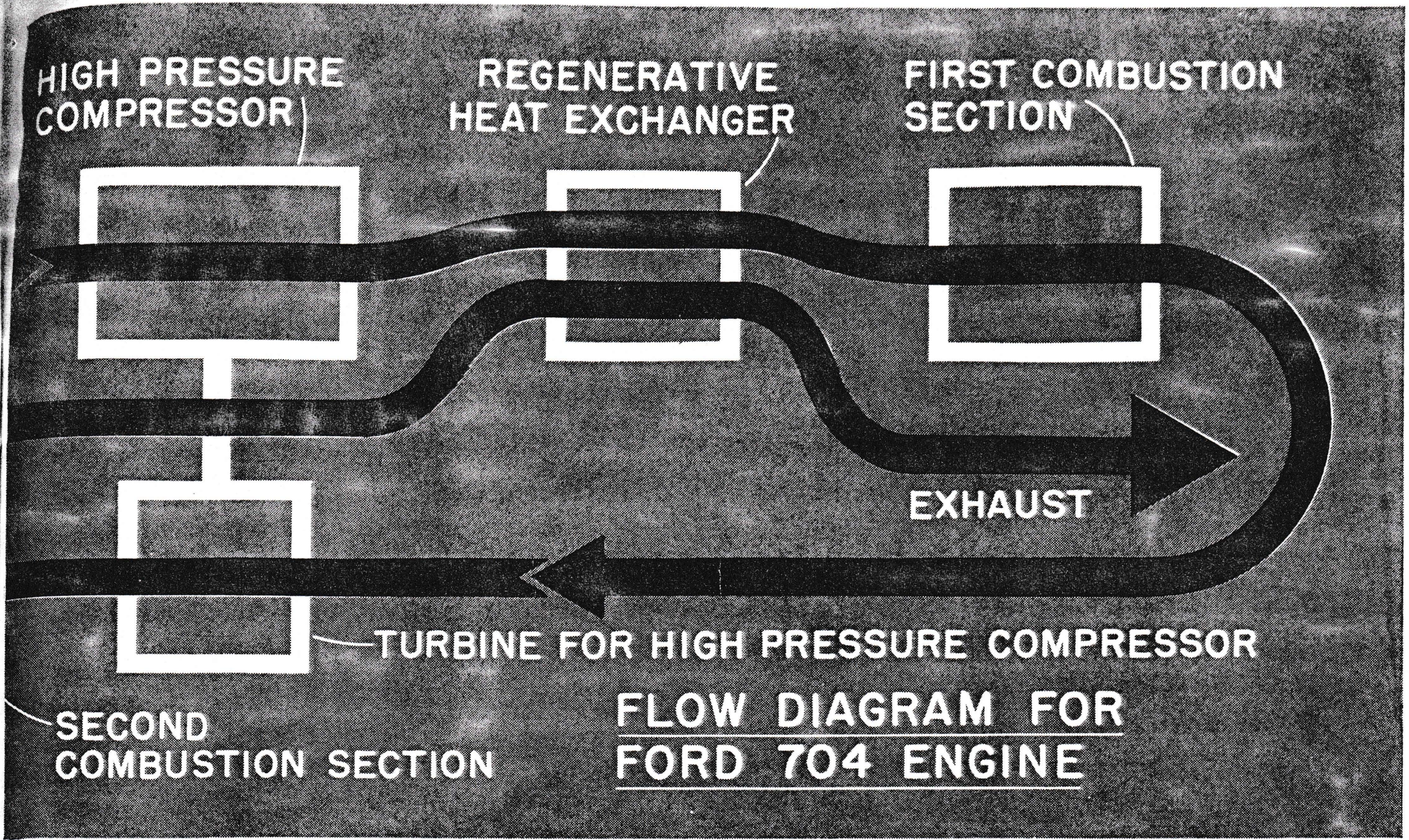
Regenerative engines hold out the possibility of making very large reductions in fuel consumption. This is the goal of the military and the engine manufacturers.

The exact performance of the new engines is not certain at present. Their state of development is a closely guarded secret. Regenerative engines suitable for aircraft have been tested. But most manufacturers are in the component testing phase. Few, if any, major aircraft engine companies have tested complete regenerative gas turbine engines.

However, enough work has been done for most engine specialists to predict that the use of regeneration will cut fuel consumption from 20 to 50 per cent compared to the most modern turboprop and turboshaft engines now in development. The possibility of such a reduction is enough to make both the government and industry consider the development of several sizes of regeneration engines.

Basically, in regenerative design the hot exhaust stream from the gas turbine engine is ducted forward and used to heat the engine air just before it enters the combustion chamber. This preheating means that less fuel needs to be burned in the combustion chamber to bring the engine air stream up to the required turbine inlet temperature and the required thrust level.

Regeneration is an old idea. The jet engineer pioneers in England and Germany in the late 1930's and

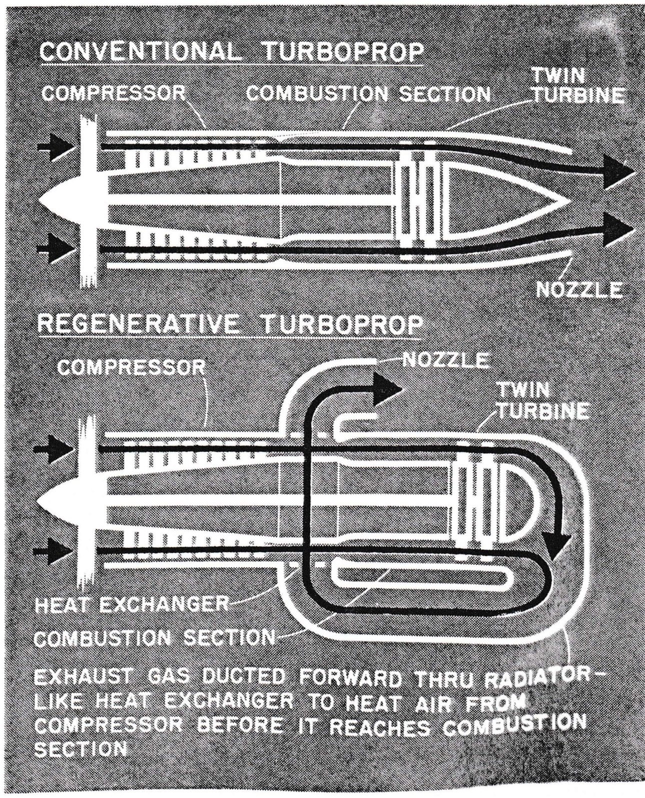


the early 1940's considered the use of regeneration as a means of lowering fuel consumption. The inefficiency of dumping a high temperature exhaust out of any heat engine has been well understood for many years. Regeneration devices known as super-heaters and economizers improve the efficiency of most steam powerplants by using excess heat to raise the temperature of the water entering the boiler. Even on a pure jet which provides its propulsive power or thrust by a high temperature air stream, the fuel consumption of the engine, under some operating conditions, can be improved by using some of the hot exhaust to heat the incoming air.

Naturally, there are disadvantages to go with the advantages of regeneration. The main ones are added weight and complexity. It takes more parts and more weight to duct the exhaust air around into some sort of heat exchanger to preheat the combustion chamber air.

In the earliest days of jet engines it was generally agreed that the added weight and complexity of regeneration were not worth the trouble. Most manufacturers concentrated on the simplest types of engines. By the end of World War II, however, regeneration was being seriously considered as a possible means to bring the fuel consumption of jet engines down to the level of reciprocating engines. Allison had a Navy contract to build a T-36, a regenerative turboprop which ran in 1946. Eventually, the program was cancelled in the economy wave following the war. Even though this engine was promising in several respects, it did not have the potential of the regenerative engines which are being proposed today.

Since 1950, however, engine technology has improved tremendously. It is possible now to build much better turboprops, of both the (*Continued on page* 89)



Diagramatic comparison of conventional and regenerative powerplants.

Regenerative Engines

(Continued from page 45)

conventional and regenerative types. The fuel consumption improvement which can be provided now through regeneration has grown from the five per cent or so of 1950 to 20 or 30 per cent today, depending upon who makes the estimate. The greater attractiveness of regeneration today is due largely to improved heat exchanger design.

These percentage figures add up to one big point about regenerative gas turbines. They will use less fuel than any gasoline-powered reciprocating engine ever built, including the turbo-compound engine. Regenerative engines will use only slightly more fuel than the best diesel engines.

In terms of absolute numbers, a good conventional turboprop engine of recent design will consume about .65 pounds of fuel every hour for each horsepower it produces. In other words an engine of this type producing 500 hp will use 325 pounds of fuel every hour. This is just about the same rate of fuel consumption expected from a gasoline-powered, reciprocating aircraft engine used on light aircraft. From the fuel consumption standpoint, the Wright turbo-compound was about the best gasoline burning, reciprocating engine ever built for aircraft. It has a minimum specific fuel consumption (SFC) of .38 pounds of fuel per horsepower per hour.

However, the best diesel engines used in the automotive industry and elsewhere have an SFC of about .4. Therefore a diesel producing 500 hp will burn only 200 pounds of fuel per hour, compared to 325 pounds per hour for the turboprop and reciprocating aircraft engines just discussed.

When engine designers say that they can reduce the fuel consumption of conventional turboprops 20 to 30 per cent by going to regeneration they mean they can build 500 hp engines which burn somewhere between 260 and 225 pounds of fuel per hour.

The other big consideration about engines used for propulsion is basic engine weight. The advantage of low fuel consumption can be wiped out by high engine weight because of what designers call a "weight spiral." This is caused by the increased aircraft size and weight required to carry the greater engine load.

The great attraction of conventional turboprop engines is that they put the "weight spiral" into reverse. They are much smaller and lighter than the turbo-compound and other reciprocating engines. Their frontal area in a nacelle also is much smaller so they add less drag to the airplane. These factors are very powerful elements in aircraft design and they result in smaller lighter airplanes to carry a given payload, at a given speed over a given range, in most instances.

A crucial question with regenerative gas turbine engines then is weight. Two points are clear on this weight question.

First, the regenerative turboprop is going to be much lighter than any piston engine. A large reciprocating aircraft engine will weigh about 1.0 pound per horsepower or a little less. The best piston engines for light aircraft can't do this well

(Continued on page 90)

(Continued from page 89)

because the weight of accessories tends to remain fixed. The size of starters, generators, etc. remains nearly constant and doesn't change much over wide ranges of engine output. So light plane piston engines generally weigh about 1.5 pounds or more per horsepower. It is generally agreed that a regenerative gas turbine engine for aircraft can weigh under 1.0 pound per horsepower.

The second point is that the regenerative gas turbine will always weigh more than the conventional gas turbine. The heat exchanger system and extra ducting will add weight to a regenerative engine. In the 500 hp class the conventional turboprop of the most modern design weighs around .45 pounds per horsepower.

While the regenerative engine will weigh more than the conventional gas turbine it is not expected to weigh twice as much. Some designers believe it will weigh less than 25 per cent more. If they are right and the conventional turboprop fuel consumption can be cut by more than 20 per cent, the regenerative engine undoubtedly will be very useful. It would be especially attractive on a longer range aircraft which normally stays aloft many hours. Low fuel consumption is more important than low engine weight on such aircraft. However, on short-range aircraft that land at frequent intervals and do not carry large fuel loads, low engine weight assumes greater importance.

Engine simplicity, one of the major advantages of the gas turbine, will not be affected to a great extent by the addition of regeneration. It is generally predicted that they will have less than one-third of the parts in a piston engine.

Regenerative engines are being considered by the military for two main uses today.

The Navy believes these engines have great potential for powering anti-submarine warfare (ASW) aircraft. The ASW mission involves long hours of flight in search for submarines. In the past this search was made at low altitudes, but hopefully the equipment used in the sub hunt can be improved so that the search aircraft can fly at higher altitudes which will lower fuel consumption and improve search range.

THE Army is looking at regenerative engines although its requirements are completely different from the Navy's. Army aircraft normally fly relatively short missions in moving troops and supplies around a battlefield, so they are more sensitive to high engine weight than any ASW aircraft. The Army is interested in long ferry capability, but high efficiency on the short-range mission is considered the most important.

On lengthy airborne operations a very large percentage of the available aircraft must be used to carry fuel for those employed in moving troops and equipment. Therefore, any small decrease in the fuel consumption of the Army aircraft is magnified many times when large-scale air movements are concerned.

Some Army studies of regenerative engines are quite encouraging. A typical estimate is that the ferry range of the turbo-shaft powered Chinook helicopter could be increased 25 per cent through the use of regenerative engines.

During the 1950's most research and development work on regenerative gas turbines took place in the automobile industry.

During the last half of the 1950's all of the major auto firms road tested regenerative engines. Most of the new powerplants had a lower fuel consumption than the ordinary car engine during highway driving. There was real hope of getting the consumption down further to the diesel level. In addition, regenerative engines were generally quiet-running, their exhaust was cool enough for a person to hold their hand in, and the problem of rather slow acceleration was overcome.

ONE of the most important moves in the automobile industry in the past five years or so has been the development of gas turbine powerplants which are more complex than the simple regenerative engine. The major example of this work is the Ford 704 engine which not only has a regenerator system, it uses an "intercooler" and a "reheat burner" both of which help improve the efficiency of the engine. The function of these two units is described below:

Intercooler—One the 704 engine the compressor is divided into two units, the low pressure and the high pressure sections.

An intercooler which resembles a radiator is placed between the compressor sections. It cools the air down so that the high pressure section can be smaller, operate at a lower tip speed and absorb less power from the engine.

As the air stream leaves the high-pressure compressor section, it passes through a regenerator, of the stationary tube type, before entering the main combustion chamber. The regenerator heats the air and increases engine efficiency in the manner of all regenerators as described previously.

After the air stream passes through the main combustion chamber, where fuel is burned, it enters the first of three turbine stages. This first stage drives the high-pressure section of the compressor. Immediately after passing through this turbine the air stream enters the reheat burner.

Reheat Burner. This device takes advantage of the fact that it is more efficient, in engines with several turbine stages, to burn fuel and add heat in front of each turbine wheel rather than adding heat just once in a single combustion chamber.

As the hot engine air passes through any turbine stage, it does work and is cooled down. So if two or three turbines are placed together, the air stream is progressively cooled and has a low capacity to do work by the time it has reached the third turbine.

On the 704 engine, after the air leaves the reheat burner it passes through the second turbine which drives the engine output shaft leading to the transmission and the auto wheels. After that the air stream drives the turbine which turns the low-pressure compressor. Finally, the air stream goes through the regenerator and is exhausted overboard.

Obviously, the Ford 704 engine is much

(Continued on page 91)

(*Continued from page 90*)

more complex and heavier than a simple regenerative gas turbine. It is similar in concept to some heavy, industrial gas turbine engines which are stationary and do not have the weight problems of powerplants used for propulsion.

When Ford decided to develop the complex engine for automotive use, it had the major challenge of folding all of this machinery into a small package that would fit under the hood of a passenger car. Also the total weight had to be kept low.

The packaging and weight goals were met and the complete 704 engine has been operating on the test stand developing its maximum power of 300 hp for more than two years. A good indication of the success of the engine is a contract awarded to Ford over a year ago, by the Navy's Bureau of Ships, for the development of a 600-hp engine of the same basic design as the 704. This engine will be available to all of the armed services.

The main advantage of the 704 and the new 600 hp engine is that their fuel consumption at both full and part throttle is equivalent to the diesel engine's. In respect to partial power operation, both the 704 and the diesel engine are greatly superior to the simple regenerative gas turbine. A heavy weight advantage also lies with the 704. It produces 300 hp for a total weight of about 650 pounds while a diesel of the same power weighs around 2,700 pounds.

As far as aircraft engines are concerned, the use of elaborate cycles such as the 704's is questioned by some designers. They cite the fact that for many aircraft missions fuel economy at power settings below cruise is of little importance.

Other aircraft gas turbine designers favor the use of at least some of the ideas employed in the 704.

Engines for ASW airplanes and Army aircraft apparently are ready to pass from the study phase into development. It isn't certain yet just what type of cycle will be used on them. Lightplanes, even extremely small ones, may benefit from the new design philosophies as soon as any other class of aircraft. A 75-hp regenerative gas turbine weighing 75 pounds has been developed by the Williams Development Corp. of Walled Lake, Mich. During the past three years the engine has been tested on stands in boats and in a jeep under Army contract. Improved versions producing 150 hp and 500 hp are under development under Navy and commercial contract.

Gas turbine engine technology seems to be growing faster today than ever. The changes apparently will be felt in land, sea and air transportation. ✈

Cessna 140

(*Continued from page 30*)

valve. The positions on the selector valve are: "Both Off," "Right Tank, 12.5 Gal.," "Left Tank, 12.5 Gal." It is important to remember that the fuel valve handle indicates the setting of the valve by its position above the dial.

Total fuel carried aboard the Cessna 140 is 25 gallons. There are two 12½ gallon tanks, one in each wing with direct reading fuel gauges in the cabin at the wing root. Fuel is fed by gravity from each wing to the selector valve, and then a single fuel line runs forward to the fuel strainer on the firewall and thence to the carburetor.

The elevator trim control, located near the fuel selector valve, is quite effective for relieving control wheel pressures during flight. The tab is actuated by rotating a small wheel. Flaps on the 140 can be raised or lowered during normal flying whenever the airspeed is less than 82 mph. In design, they are much smaller and not of the "hi-lift" type used on Cessna 170-Bs, and later models. They do induce some drag for steepening the glide angle, but in my opinion do not markedly improve the takeoff performance of the 140.

Starting the 85- or 90-hp Continental follows normal procedure. If the engine is cold (50 degrees F. or below), it should be primed three or four strokes.

Taxiing the Cessna 140 is pleasant, as it has good ground control characteristics with the steerable tail wheel and effective hydraulic brakes. Visibility over the nose is improved using a stagger-taxi pattern; out of the side windows, however, it is somewhat limited and requires leaning forward to lower the eye level below the top of the window when watching for wing clearance. By the time the 140 has been taxied into the takeoff position, the engine usually is up to takeoff temperatures due to the tight engine cowling. Mags are checked at 1,800 rpm and the drop on the right mag should not exceed 50 rpm on the left mag. At a full throttle static check, either engine (85 or 90 hp) should turn up 2,100 rpm or more when equipped with a metal prop.

Prior to takeoff, the trim tab should be set to "Takeoff" position, carburetor heat "Cold," release brakes and place heels on the floor to prevent the brakes from dragging, and check the flap control to make sure that the flaps are retracted and locked into the "Up" position.

After squaring the airplane down the runway, full throttle is fed in and the Cessna 140 accelerates at a good rate. The shortest takeoff run is obtained by keeping the tail low during the takeoff phase. In this attitude the 140 breaks ground at about 40 mph and the best rate-of-climb can then be attained by building up an airspeed of 73 mph. For a longer climbout at full throttle, Cessna recommends an airspeed between 80 or 90 mph for sufficient cooling of the engine. Takeoff performance of the 140 loaded to a gross around 1,450 pounds and powered with an 85-hp engine, checked out as follows on a day when the outside air was 40 degrees F.:

Elevation of hard surface runway	Ground run required to get airborne	Rate-of-climb, Flaps up, Full throttle
626 ft.	600 ft.	650 fpm
1,100 ft.	700 ft.	575 "
2,000 ft.	775 ft.	525 "

Upon reaching cruising altitude and as the nose of the aircraft is lowered to level flight, the airspeed builds up rapidly to about 100 mph. With a touch of trim, it is easy to get the Cessna 140 on the step, and at 2,400 rpm (about 75 per cent power) it will true out at 105 mph. Using

(*Continued on page 92*)