How Gas Turbine Engines Work

by Marshall Brain

When you go to an airport and see the commercial jets there, you can't help but notice the huge engines that power them. Most commercial jets are powered by turbofan engines, and turbofans are one example of a general class of engines called **gas turbine** engines.

You may have never heard of gas turbine engines, but they are used in all kinds of unexpected places. For example, many of the helicopters you see, a lot of smaller power plants and even the M-1 Tank use gas turbines. In this edition of **HowStuffWorks**, we will look at gas turbine engines to see what makes them tick!

A Little Background

There are many different kinds of turbines:

- You have probably heard of a **steam turbine**. Most power plants use coal, natural gas, oil or a nuclear reactor to create steam. The steam runs through a huge and very carefully designed multi-stage turbine to spin an output shaft that drives the plant's generator.
- Hydroelectric dams use **water turbines** in the same way to generate power. The turbines used in a hydroelectric plant look completely different from a steam turbine because water is so much denser (and slower moving) than steam, but it is the same principle.
- **Wind turbines**, also known as wind mills, use the wind as their motive force. A wind turbine looks nothing like a steam turbine or a water turbine because wind is slow moving and very light, but again, the principle is the same.

A gas turbine is an extension of the same concept. In a gas turbine, a pressurized gas spins the turbine. In all modern gas turbine engines, the engine produces its own pressurized gas, and it does this by burning something like propane, natural gas, kerosene or jet fuel. The heat that comes from burning the fuel expands air, and the high-speed rush of this hot air spins the turbine.

Advantages and Disadvantages

So why does the M-1 tank use a 1,500 horsepower gas turbine engine instead of a diesel engine? It turns out that there are two big advantages of the turbine over the diesel:

- Gas turbine engines have a great **power-to-weight ratio** compared to reciprocating engines. That is, the amount of power you get out of the engine compared to the weight of the engine itself is very good.
- Gas turbine engines are **smaller** than their reciprocating counterparts of the same power.

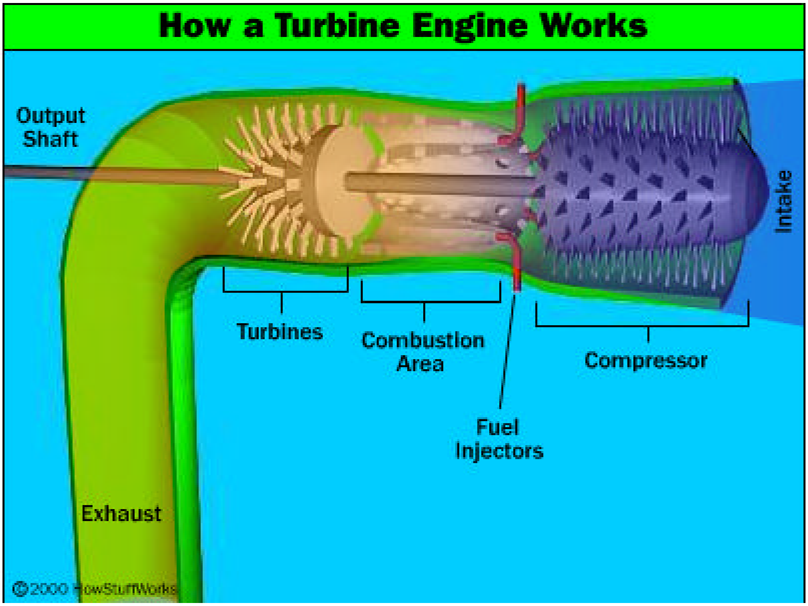
The main disadvantage of gas turbines is that, compared to a reciprocating engine of the same size, they are **expensive**. Because they spin at such high speeds and because of the high operating temperatures, designing and manufacturing gas turbines is a tough problem from both the engineering and materials standpoint. Gas turbines also tend to use more fuel when they are idling, and they prefer a constant rather than a fluctuating load. That makes gas turbines great for things like transcontinental jet aircraft and power plants, but explains why you don't have one under the hood of your car.

The Gas Turbine Process

Gas turbine engines are, theoretically, extremely simple. They have three parts:

- **Compressor** - Compresses the incoming air to high pressure
- **Combustion area** - Burns the fuel and produces high-pressure, high-velocity gas
- **Turbine** - Extracts the energy from the high-pressure, high-velocity gas flowing from the combustion chamber

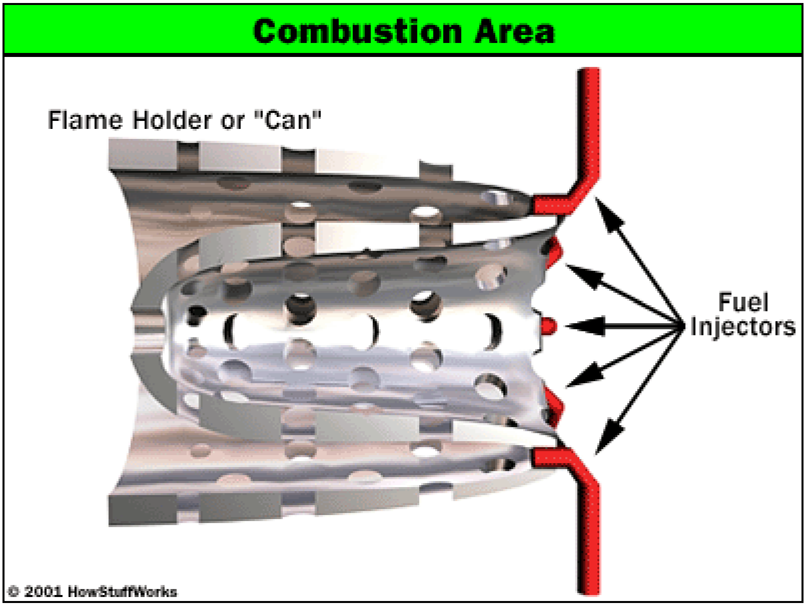
The following figure shows the general layout of an **axial-flow** gas turbine -- the sort of engine you would find driving the rotor of a helicopter, for example:



In this engine, air is sucked in from the right by the compressor. The compressor is basically a cone-shaped cylinder with small fan blades attached in rows (eight rows of blades are represented here). Assuming the light blue represents air at normal air pressure, then as the air is forced through the compression stage its pressure rises significantly. In some engines, the pressure of the air can rise by a factor of 30. The high-pressure air produced by the compressor is shown in dark blue.

Combustion Area

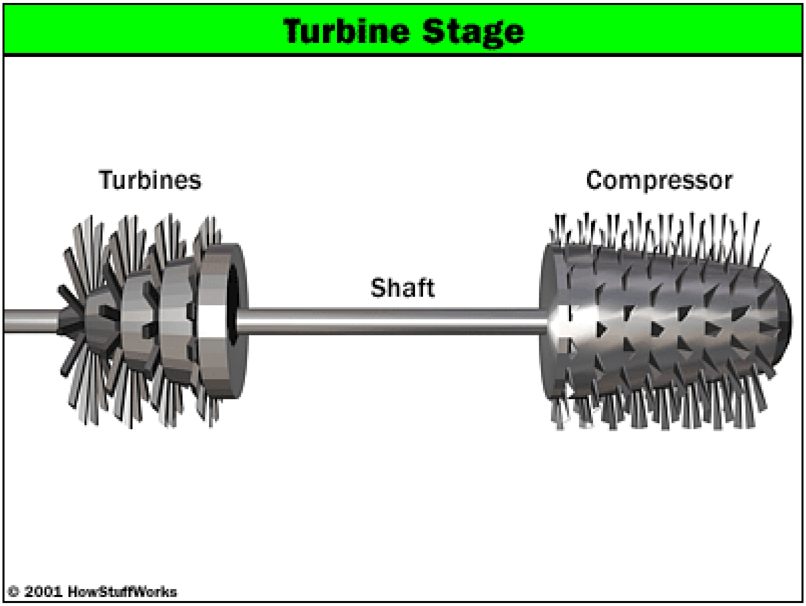
This high-pressure air then enters the combustion area, where a ring of fuel injectors injects a steady stream of fuel. The fuel is generally kerosene, jet fuel, propane or natural gas. If you think about how easy it is to blow a candle out, then you can see the design problem in the combustion area -- entering this area is high-pressure air moving at hundreds of miles per hour. You want to keep a flame burning continuously in that environment. The piece that solves this problem is called a "flame holder," or sometimes a "can." The **can** is a hollow, perforated piece of heavy metal. Half of the can in cross-section is shown below:



The **injectors** are at the right. Compressed air enters through the perforations. Exhaust gases exit at the left. You can see in the previous figure that a **second set of cylinders** wraps around the inside and the outside of this perforated can, guiding the compressed intake air into the perforations.

The Turbine

At the left of the engine is the **turbine** section. In this figure there are two sets of turbines. The first set directly drives the compressor. The turbines, the shaft and the compressor all turn as a single unit:



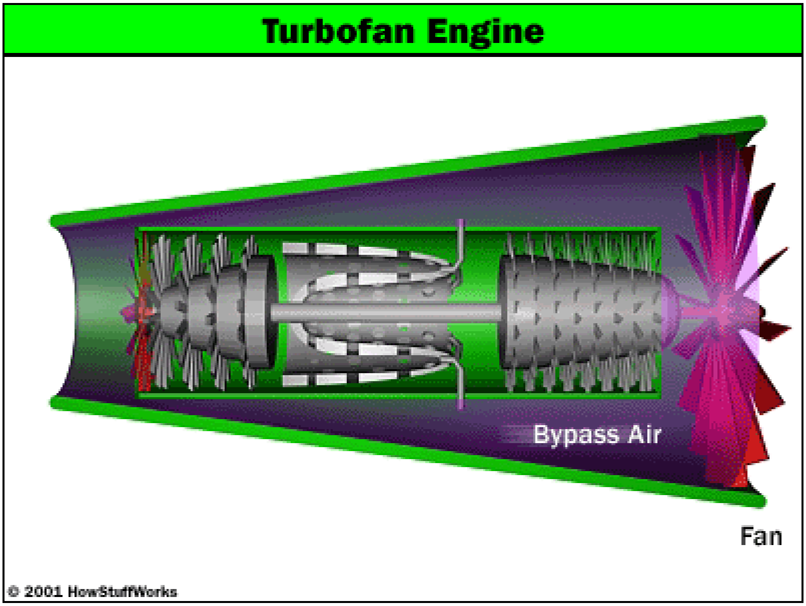
At the far left is a final turbine stage, shown here with a single set of vanes. It drives the output shaft. This final turbine stage and the output shaft are a completely stand-alone, freewheeling unit. They spin freely without any connection to the rest of the engine. And that is the amazing part about a gas turbine engine -- there is enough energy in the hot gases blowing through the blades of that final output turbine to generate 1,500 horsepower and drive a 63-ton M-1 Tank! A gas turbine engine really is that simple.

In the case of the turbine used in a tank or a power plant, there really is nothing to do with the exhaust gases but vent them through an exhaust pipe, as shown. Sometimes the exhaust will run through some sort of heat exchanger either to extract the heat for some other purpose or to preheat air before it enters the combustion chamber.

The discussion here is obviously simplified a bit. For example, we have not discussed the areas of bearings, oiling systems, internal support structures of the engine, stator vanes and so on. All of these areas become major engineering problems because of the tremendous temperatures, pressures and spin rates inside the engine. But the basic principles described here govern all gas turbine engines and help you to understand the basic layout and operation of the engine.

Other Variations

Large jetliners use what are known as **turbofan** engines, which are nothing more than gas turbines combined with a large fan at the front of the engine. Here's the basic (highly simplified) layout of a turbofan engine:



You can see that the core of a turbofan is a normal gas turbine engine like the one described in the previous section. The difference is that the final turbine stage drives a shaft that makes its way back to the front of the engine to power the **fan** (shown in red in this picture). This **multiple concentric shaft approach**, by the way, is extremely common in gas turbines. In many larger turbofans, in fact, there may be two completely separate compression stages driven by separate turbines, along with the fan turbine as shown above. All three shafts ride within one another concentrically.

The purpose of the fan is to dramatically increase the amount of air moving through the engine, and therefore increase the engine's **thrust**. When you look into the engine of a commercial jet at the airport, what you see is this fan at the front of the engine. It is huge -- on the order of 10 feet (3 m) in diameter on big jets, so it can move a lot of air. The air that the fan moves is called "**bypass air**" (shown in purple above) because it bypasses the turbine portion of the engine and moves straight through to the back of the nacelle at high speed to provide thrust.

A **turboprop** engine is similar to a turbofan, but instead of a fan there is a conventional **propeller** at the front of the engine. The output shaft connects to a **gearbox** to reduce the speed, and the output of the gearbox turns the propeller.

Thrust Basics

The goal of a turbofan engine is to produce **thrust** to drive the airplane forward. Thrust is generally measured in pounds in the United States (the metric system uses Newtons, where 4.45 Newtons equals 1 pound of thrust). A "pound of thrust" is equal to a force able to accelerate 1 pound of material 32 feet per second per second (32 feet per second per second happens to be equivalent to the acceleration provided by gravity). Therefore, if you have a jet engine capable of producing 1 pound of thrust, it could hold 1 pound of material suspended in the air if the jet were pointed straight down. Likewise, a jet engine producing 5,000 pounds of thrust could hold 5,000 pounds of material suspended in the air. And if a rocket engine produced 5,000 pounds of thrust applied to a 5,000-pound object floating in space, the 5,000-pound object would accelerate at a rate of 32 feet per second per second.

Thrust is generated under Newton's principle that "every action has an equal and opposite reaction." For example, imagine that you are floating in space and you weigh 100 pounds on Earth. In your hand you have a baseball that weighs 1 pound on Earth. If you throw the baseball away from you at a speed of 32 feet per second (21 mph / 34 kph), your body will move in the opposite direction (it will **react**) at a speed of 0.32 feet per second. If you were to continuously throw baseballs in that way at a rate of one per second, your baseballs would be generating 1 pound of continuous thrust. Keep in mind that to generate that 1 pound of thrust for an hour you would need to be holding 3,600 pounds of baseballs at the beginning of the hour. If you wanted to do better, the thing to do is to throw the baseballs harder. By "throwing" them (with of a gun, say) at 3,200 feet per second, you would generate 100 pounds of thrust.

Jet Engine Thrust

In a turbofan engine, the baseballs that the engine is throwing out are **air molecules**. The air molecules are already there, so the airplane does not have to carry them around at least. An individual air molecule does not weigh very much, but the engine is throwing a lot of them and it is throwing them at very high speed. Thrust is coming from two components in the turbofan:

- The **gas turbine** itself - Generally a nozzle is formed at the exhaust end of the gas turbine (not shown in this figure) to generate a high-speed jet of exhaust gas. A typical speed for air molecules exiting the engine is 1,300 mph (2,092 kph).
- The **bypass air** generated by the fan - This bypass air moves at a slower speed than the exhaust from the turbine, but the fan moves a lot of air.

As you can see, gas turbine engines are quite common. They are also quite complicated, and they stretch the limits of both fluid dynamics and materials sciences. If you want to learn more, one worthwhile place to go would be the library of a university with a good engineering department. Books on the subject tend to be expensive, but two well-known texts include "Aircraft Gas Turbine Engine Technology" and "Elements of Gas Turbine Propulsion."

There is a surprising amount of activity in the home-built gas-turbine arena, and you can find other people interested in the same topic by participating in newsgroups or mailing lists on the subject.

For more information on gas turbine engines and related topics, check out the links on the following page.