Chapter 1
Understand Stirling Engines in Ten Minutes or Less

Power is life. It flows from power stations through wires to the cities we live in. It flows from the sun to the earth, giving us the food we eat. It is stored in the fuels we use to fly jet airplanes between continents. There are many ways of making power, from water wheels along rivers to the engines of a supersonic transport on its way to Paris. For some power needs, Stirling engines are nothing short of the perfect engine.

The inventor of Stirling engines, Robert Stirling (1790-1878), was part preacher, part inventor, and 100 percent Renaissance man. He was a minister of the Church of Scotland who was interested in the physical health and safety of his parishioners in addition to the well-being of their souls. He invented the Stirling engine (he called it an “air engine") because the steam engines of his day would often explode, killing and maiming those who were unlucky enough to be standing close by. Robert Stirling’s engines couldn’t explode, and they produced more power than the steam engines then in use.

In 1816 Stirling received his first patent for a new type of “air engine.” The engines he built, and those that followed, eventually became known as “hot air engines.” They continued to be called hot air engines until the 1940s, when other gases such as helium and hydrogen were used as the working fluid. Robert’s brother, James Stirling, also played an important role in the development of Stirling engines.

If you’d like to read more about Robert Stirling and the engines that he built, read the biography of Robert Stirling by Robert Sier entitled *Reverend Robert Stirling D.D.: A Biography of the Inventor of the Heat Economiser & Stirling Cycle Engine* (L A Mair, 1995).

The excellent book by Finkelstein and Organ titled *Air Engines: The History, Science, and Reality of the Perfect Engine* (American Society of Mechanical Engineers, 2001), has shown that Robert Stirling must have had a much more sophisticated understanding of his engines than is commonly thought. Indeed, according to the simulations done by Professor Organ of Cambridge University, if Robert Stirling had made a mistake as small as selecting the wrong diameter of wire for his engine’s regenerator, his initial engine of 1816 would have failed to run at all.

So what is a Stirling engine anyway? Stirling engines are a category of engine, just like diesel engines are a category of engine. They are closed-cycle engines, which means that the air (or other gas such as helium) is used over and over again inside the engine. The air inside the engine is never used up nor dumped into the environment as dirty exhaust.

Because the air is used over and over again, Stirling engines can be “regenerative.” This means that some of the heat used to expand the air in one cycle can be used again to expand the air in the next cycle. Stirling engines do this by moving the air across another material called a regenerator. Regenerators are widely used in industry today and are probably Robert Stirling‘s most important invention.

When the hot air in a Stirling engine flows over the cool regenerator, some of the heat from the air flows into the regenerator, heating it up. This pre-cools the air before it moves to the cold side of the engine, where it will reject more of its heat and complete the cycle. Compare this process to not having to throw away all of the heat that a conventional internal combustion engine dumps into its exhaust at the end of each cycle.

Stirling engines are continuous combustion engines. This can be a tremendous advantage when it comes to building a very clean-running engine. Strike a match and let it burn for a second, then blow it out. When did you see most of the smoke? Most of its smoke was produced not when the match was burning brightly, but when it was being lit and when it had been blown out. It is much easier to make a continuous burning process very clean than it is to make an intermittent burning process, such as those used in most gasoline and diesel engines, clean.

In a Stirling engine, one side of the engine is continuously heated while the other side is continuously cooled. First the air is moved to the hot side, where it is heated and expands, pushing up on a piston. Then the air is moved through the regenerator (where it stores some heat for the next cycle) to the cold side, where it cools off and contracts, pulling down on the piston. The temperature change inside the engine produces the pressure change needed to push on the piston and make the engine run.

Stirling engines are different from the engine in your car in several ways. First, Stirling engines are external combustion engines. This simply means the fire that heats the engine and makes it run does not occur inside the working cylinder of the engine. Most people are familiar with steam engines, which are also external combustion engines. Because the Stirling engine is an external combustion engine, it can be made to run on any fuel or heat source, from burning biomass to solar energy. Of course, the hot side of the engine has to be designed for the chosen heat source or type of fuel.

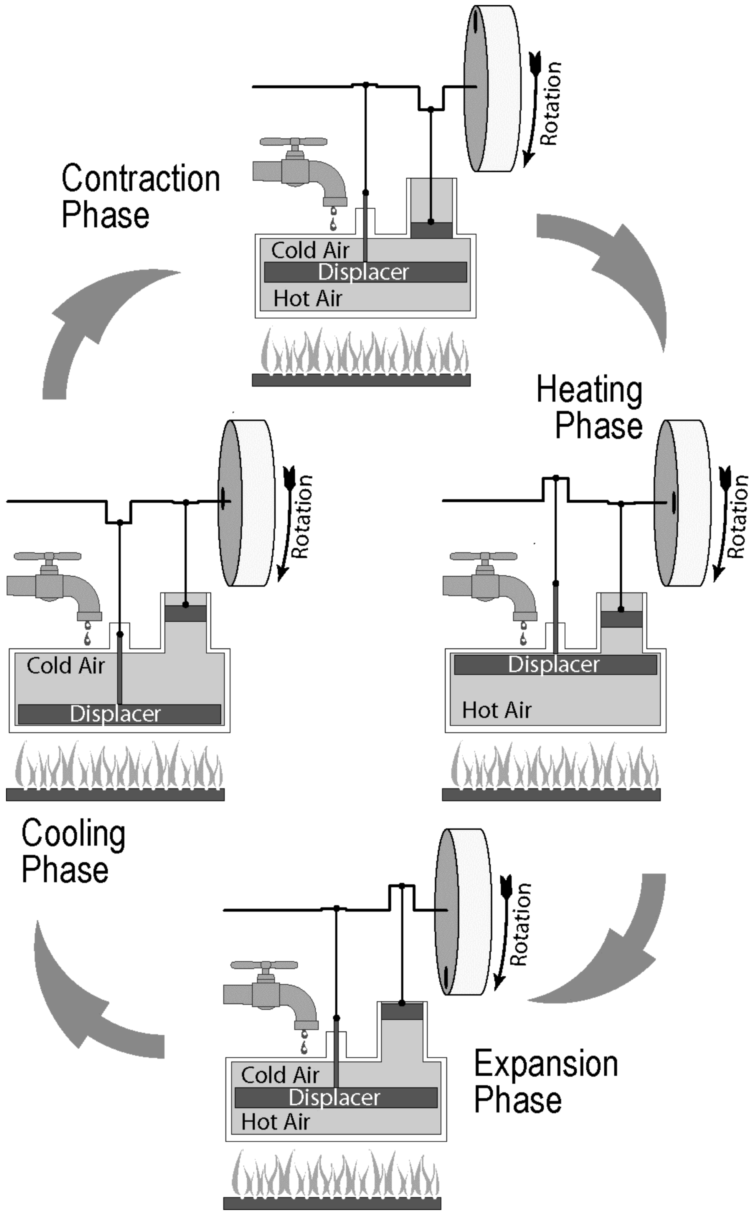

Fig.1-1: Stirling engines work by moving air (or another gas such as helium) between the hot side and the cold side.

Another way Stirling engines differ from car engines is that they have no valves. The pressure changes inside the engine are created by moving the air back and forth between the hot side of the engine and the cold side. Any fuel that will keep the hot side hot can be used to power a Stirling engine.

Fuel is a third factor in the differences between Stirling engines and a typical car engine. Stirling engines have been powered by many kinds of fuel, including gasoline, diesel, propane, sunshine and salad oil.

Because they save some of their heat from each cycle in their regenerators, Stirling engines can be exceedingly efficient. Their efficiency can approximate that of the Carnot cycle, which is the maximum theoretically possible efficiency for any heat engine. Incidentally, Robert Stirling developed and built his engine many years before Sadi Carnot (1796-1832) wrote about the ideal heat engine.[1]

What makes a good engine anyway? Does it do the work you want it to do? Do you like the way it performs its task? Does it satisfy the goals you had in mind when you purchased the engine? Can you afford it? These are the questions that should be used to judge an engine.

Some engine developers don’t ask the right questions. I read about a Stirling engine that achieved a record high thermodynamic efficiency while being fueled by sunshine. The developers forgot that efficiency is only important if you have to pay for the fuel.

While it sometimes might be important to get the maximum amount of power out of the smallest solar collector area possible, most of the time it would make sense to design an engine with a large solar collector and a small initial purchase price, since sunshine is free.

Engineers have a specific term for describing the “goodness" of any machine. This term is “figure of merit.” The figure of merit is simply the thing that you are trying to optimize when you are developing something. If a low initial purchase price is very important, then the figure of merit is low purchase price. If high

[1] Unfortunately, engine efficiency is a slippery term. It has different meanings to engineers than it does to the general public, and even among engineers there is discussion of thermodynamic efficiency, mechanical efficiency, and electrical efficiency. Sometimes an engineer will claim a very high level of efficiency for an engine, without being very specific about which type of efficiency he or she is referring to.