Stirling Engine Efficiency

The potential efficiency of a Stirling engine is high. It is comparable to the efficiency of a diesel engine, but is significantly higher than that of a spark-ignition (gasoline) engine.

One of the most efficient Stirling engines ever made was the MOD II automotive engine, produced in the 1980′s. It reached a peak thermal efficiency of 38.5%. Compare this to a modern spark-ignition (gasoline) engine, which has a peak efficiency of 20-25%.

Despite its greater fuel economy, the MOD II engine was discontinued due to high development cost, and concerns that it would not compete with Internal Combustion engines (gasoline and diesel) in terms of responsiveness.

Below are reports by NASA describing the development and performance of the MOD II engine.

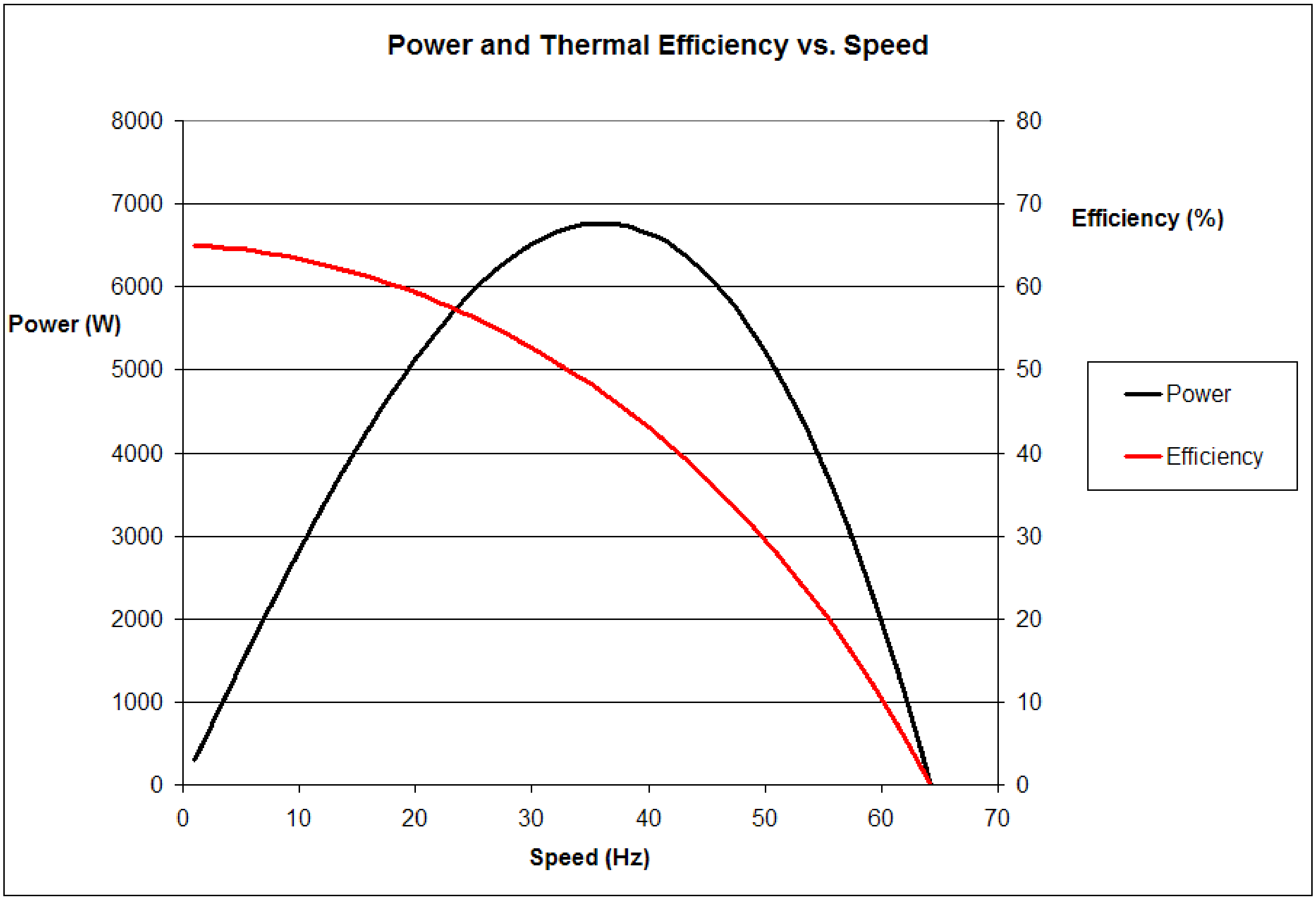
Report 1

Report 2

A Stirling engine can only achieve high efficiency if a regenerator is used. A regenerator is a metallic medium which "stores" and "releases" heat (which would otherwise be lost) as the working gas inside the engine shuttles back and forth between the hot side and the cold side.

The efficiency of a Stirling engine is affected by losses *outside* the engine such as imperfect heat transfer between the heat source and engine, and losses *inside* the engine such as pumping and various thermal losses.

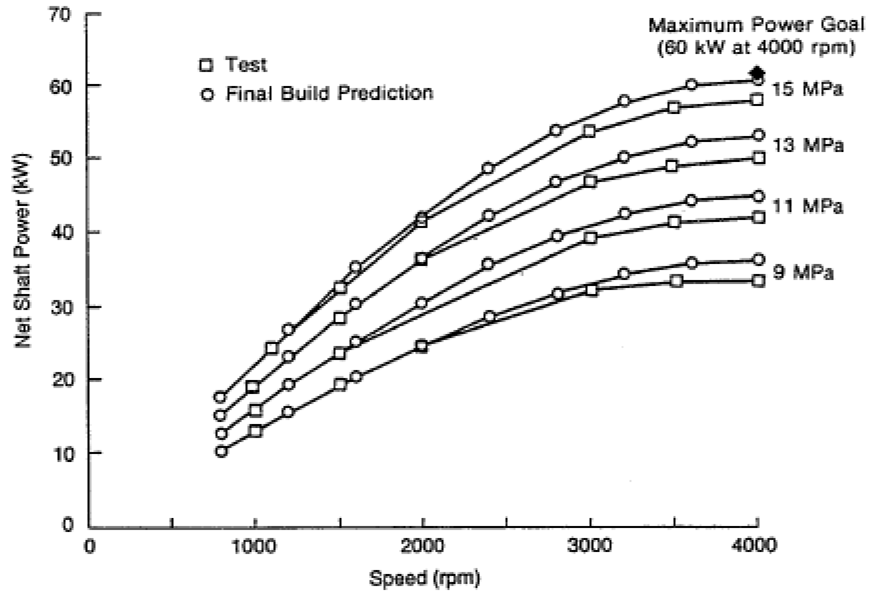
Due to the complex interaction between the various losses, the efficiency of a Stirling engine changes with operating speed. The figure below shows the predicted thermal efficiency and power of a sample engine configuration, using air as the working gas. This figure was created using simulation results from the Stirling engine software program I created.



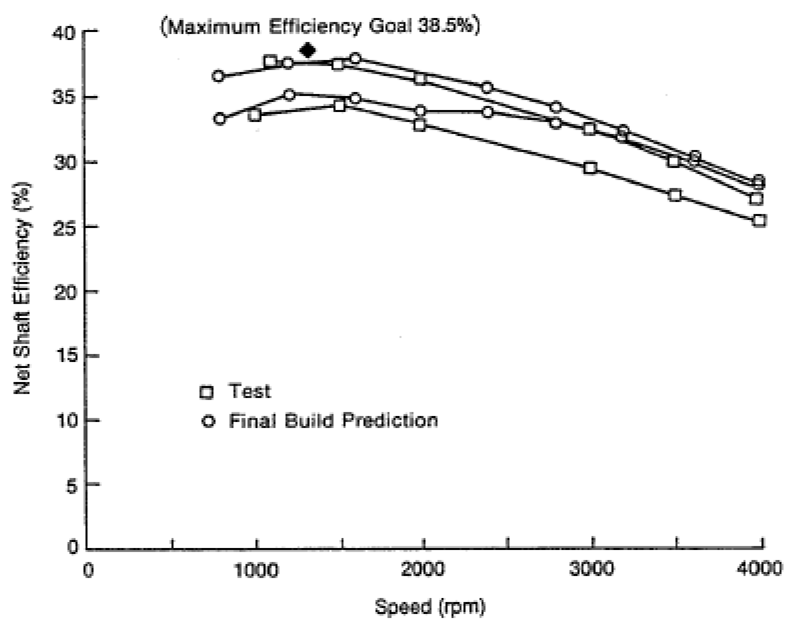
You'll notice that the thermal efficiency decreases as the engine speed increases. This is because pumping (flow) losses increase as speed increases, and less output power is produced relative to the heat input (therefore efficiency decreases). It is interesting to note that power increases until a peak is reached and then it decreases. This is because power output is directly related to speed, but as speed increases the pumping losses become overwhelmingly large, which causes the net power to decrease, eventually going to zero.

This prediction in efficiency and power is somewhat idealized, since it doesn't take into account heater efficiency (for example). The software model assumes that the heater is 100% efficient, meaning all the heat from the heat source goes into the engine. But in reality, some heat is always lost to the surroundings. This is why it's good to have a preheater (also known as a recuperator) in a real engine which increases the heater efficiency by recovering some of the waste heat from the exhaust gases.

The figure below shows the thermal efficiency and power for the MOD II engine (taken from page 56 of the second report, listed above).



a) **Mod II Power**



b) **Mod II Efficiency**

In the bottom graph you can see that the peak thermal efficiency occurs at around 1200 rpm, and then decreases from there. This is in contrast to the prediction from the software program in which the thermal efficiency decreases from the start.

It’s possible that the main reason the peak efficiency is at 1200 rpm, is because the heater efficiency is reduced at lower speeds. This would imply that at lower speeds more heat is lost to the surroundings. This makes sense if one imagines an engine running at very low speed over a flame. The flame keeps burning no matter if the engine is running or not, so it makes sense that the thermal efficiency is lowest when the engine is running at a very low speed, since less of the flame energy is being used by the engine (and more is lost to the surroundings). So by extension, one can argue that at low speeds it is more difficult to maintain high heater efficiency (even with a recuperator) because less heat energy is used by the engine, and more heat is unavoidably lost to the surroundings.

One final (perhaps surprising) point to make is that the type of working gas inside a Stirling engine has little effect on the thermal efficiency. This is something I read in the literature and discovered myself while simulating different working gases, using my software program.

However, the type of working gas used has a great effect on the power density of the engine. So for example, hydrogen as the working gas results in a much higher power density than air, even though the thermal efficiency is almost the same.