APPLYING THERMODYNAMICS TO GAS TURBINES AND JET PROPULSION

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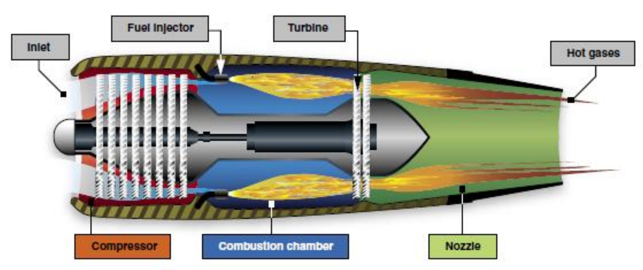
Introduction

Known generally as gas turbines, these internal combustion engines convert energy of a fuel into some form of useful power. In order to make the power produced from this fuel useable, though, a combination of compressor, combustion chamber, and turbine is used to produce work. Jet engines are a good example of a gas turbine.

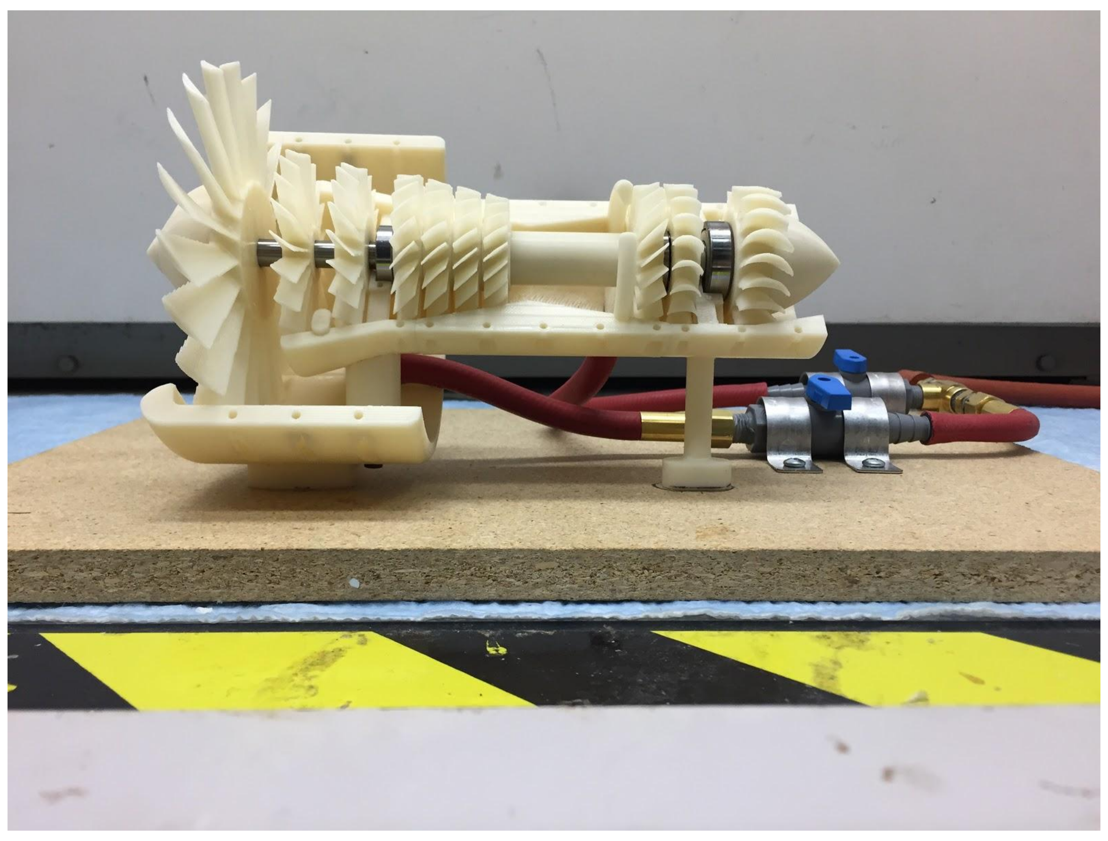


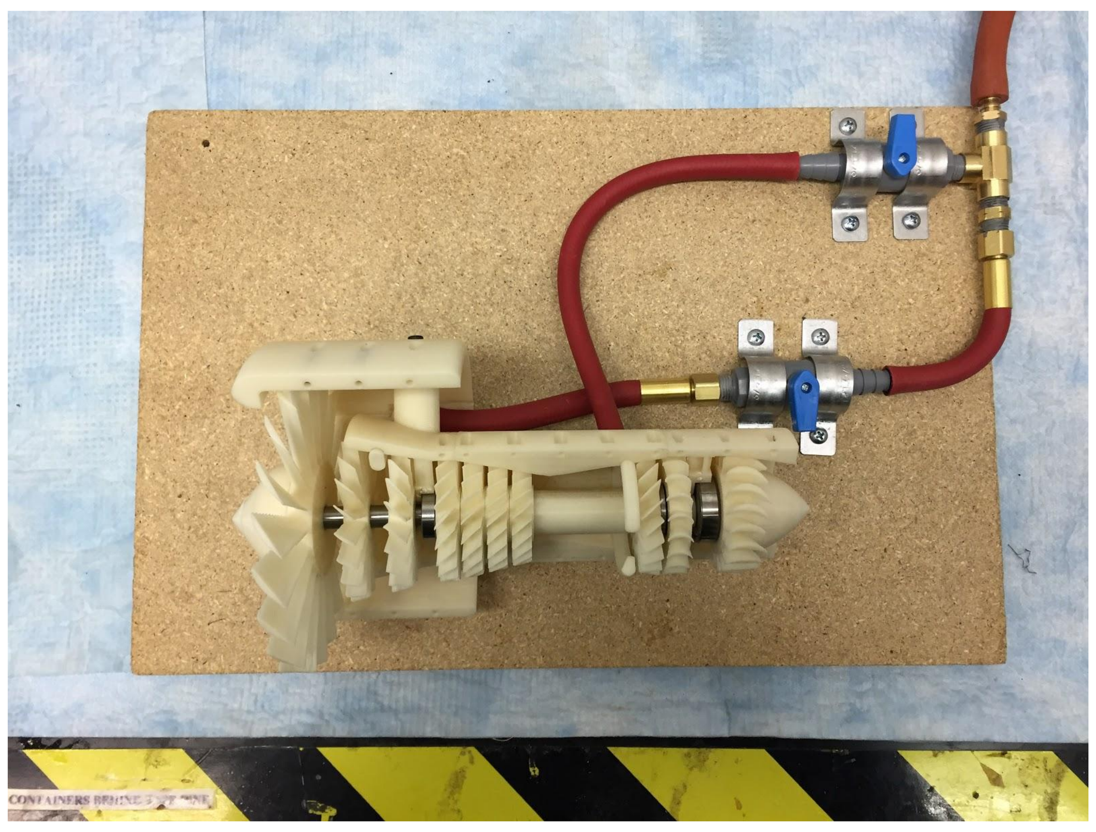
After an inlet of air is compressed by counter rotating blades, fuel injectors introduce jet fuel which is combusted. The turbine then transfers a portion of that work back into running the compressor, while the rest is propelled through a nozzle creating thrust.

The purpose of our project was to apply our knowledge of Thermodynamics 221 to understand the thermodynamic cycle that goes into the theory of jet engine propulsion. As apart of this, we were able to 3D-print and assemble a jet engine model that uses compressed air to simulate the combustion and operation of a turbine.

3-D Model

The model was printed with Acrylonitrile butadiene styrene (ABS) by using Polylactic acid (PLA) as the support material. The files used to print the model were found online as open source. The model functions with a main rotor blade, two low pressure compressor blades, and the outermost exhaust turbine fixed to a steel shaft which rotates about two ball bearings that sit in housings along the main chamber. Independent of this, a second axle--printed in ABS--has two needle roller bearings pressed in on both sides creating the second axis of rotation where the high compressor and power turbine blades rest. In order to simulate the turbine in motion, compressed air is used to simulate the combustion that would take place during the 2-3 isobaric fuel combustion. A single connection inlet is split into two inlets on the turbine. The first inlet exists in front of the second low pressure compressor, while the second is set just before the power turbine. When initiating start-up, the ball valve leading to the second inlet should be open, while the valve leading to the first is closed. Once the high compressor and turbine axis has enough inertia, the first inlet valve is opened and the second valve inlet is closed to allow for the jet to run at full capacity.





Theory and Fundamental Principles

Ideal Closed Loop Brayton Cycle

1-2 Adiabatic Reversible Compression

Process 1-2 is an adiabatic reversible compression. This step operates through a compressor in which pressure of the working fluid, air, is elevated without heat addition or rejection. As a result, this step is isentropic where both the temperature and enthalpy increase. An input of work is necessary for this process to proceed.

-$P_2>P_1$ -$H_2>H_1$ -$V_2<V_1$

-$T_2>T_1$ -$Q=0$ -$S_2=S_1$ -$W>0$ $W_C=n(H_2-H_1)$

2-3 Isobaric Expansion

Process 2-3 is an isobaric expansion with heat addition. The heat exchanger, later modeled by a combustion chamber, is where heat from the surroundings enter the system. At constant pressure the temperature is increased to its maximum point, a limit based upon the system material. The maximum temperature which correlates to an increase in enthalpy is important for determining the work output and thermal efficiency.

-$P_3=P_2$ -$H_3>H_2$ -$V_3>V_2$

-$T_3>T_2$ -$Q_H>0$ $Q_H=n(H_3-H_2)$ -$S_3>S_2$ -$W<0$

3-4 Adiabatic Reversible Expansion

Process 3-4 is an adiabatic reversible expansion that serves as the main work producing step. The elevated pressure and temperature allow air to expand through a turbine that is located on the same rotational shaft as the compressor. Pressure, temperature, and enthalpy are decreased as work is produced. The work is harnessed for power, where a fraction is used to run the compressor. There is no heat gain or loss in the process and is therefore not only adiabatic, but isentropic.

-$P_4<P_3$ -$H_4<H_3$ -$V_4>V_3$

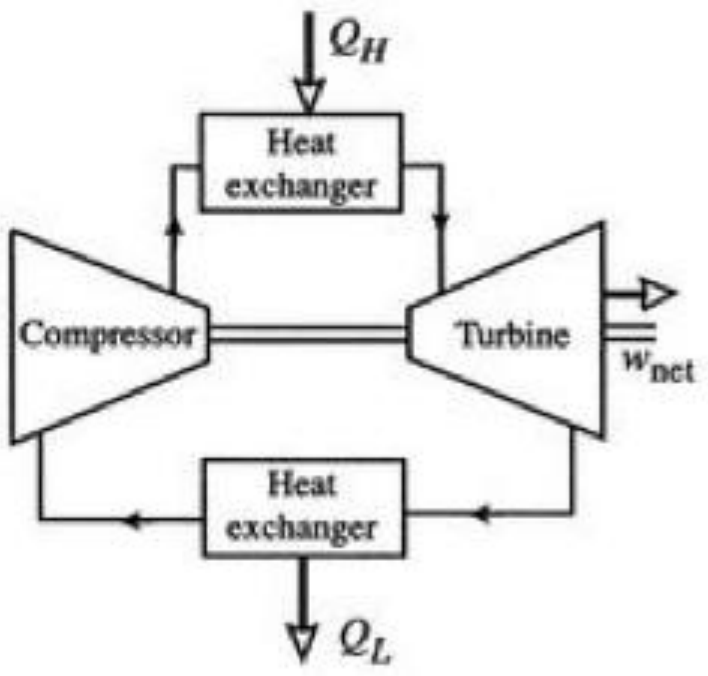
-$T_4<T_3$ -$Q=0$ -$S_4=S_3$ -$W<0$ $W_T=n(H_4-H_3)$

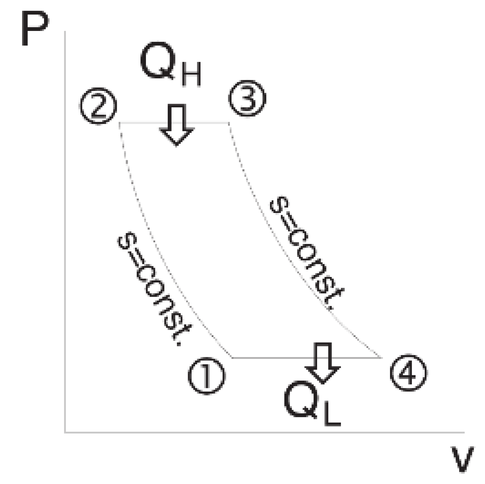
4-1 Isobaric Heat Rejection

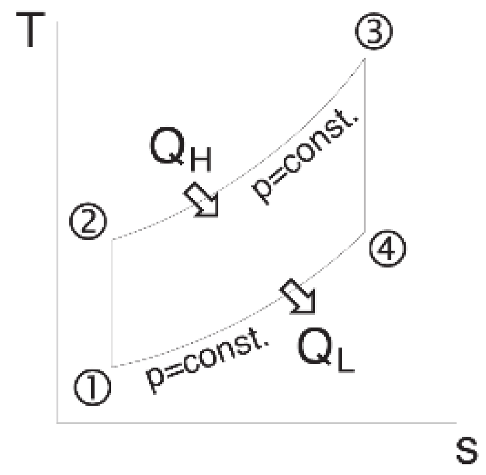
Process 4-1 is an isobaric heat rejection. This step completes the cycle by decreasing temperature and volume to its original state. As a result, the remaining thermodynamic functions return to their original states.

-$P_1=P_4$ -$H_1>H_4$ -$V_1<V_4$

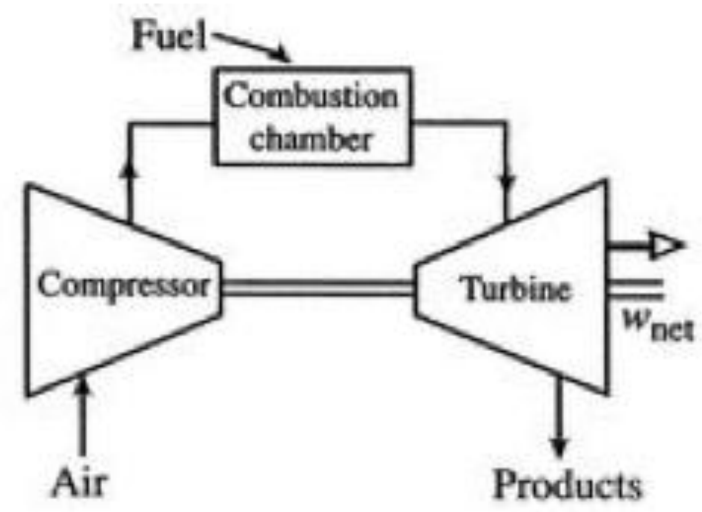
-$T_1<T_4$ -$Q_C<0$ $Q_C=n(H_4-H_1)$ -$S_1<S_4$ -$W>0$







Ideal Open Loop Brayton Cycle



1-2 Adiabatic Reversible Compression

-$P_2>P_1$ -$H_2>H_1$ -$V_2<V_1$

-$T_2>T_1$ -$Q=0$

-$S_2=S_1$ -$W>0$ -$W_C=n(H_2-H_1)$

2-3 Isobaric Fuel Combustion

-$P_3=P_2$ -$H_3>H_2$ -$V_3>V_2$

-$T_3>T_2$ -$Q_H>0$ -$S_3>S_2$ -$W<0$

3-4 Adiabatic Reversible Expansion

-$P_4<P_3$ -$H_4<H_3$ -$V_4>V_3$

-$T_4<T_3$ -$Q=0$

-$S_4=S_3$ -$W<0$ $W_T=n(H_4-H_3)$

Conclusion

In summation, the energy provided that brings electricity to our homes, powers our cars, and makes our planes fly is produced and harnessed through a set of thermodynamic processes. The changes between temperature, pressure, and volume are all correlated to one another, and can be manipulated to produce mechanical work. However, thermodynamic cycles in application can be incredibly complex. The jet engine is a small example of just how complicated such applications may be. For example, compression and expansion steps that are modeled by adiabatic and isentropic processes are never completely accurate. However, this project provides a small glimpse into the application of thermodynamic theory to reality.

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The open source STL files that were made for the jet engine were made by Gerry Hamilton .