Cogeneration System: Gas Turbine Engine Test

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ME125: Engineering Measurements
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Abstract

The purpose of this lab is to examine the performance and efficiency of a gas turbine engine. Gas turbine engines are important to look at in engineering because they are a major source of electricity production. Since they are of such importance, engineers are continually trying to find ways to increase performance and efficiency of these systems. For our purposes, we looked at the effect of various electrical loads (30 kW, 40 kW, 50 kW, and 60 kW) on the performance and efficiency of the gas turbine engine. We were unable to physically run the system, so data was provided for the analysis. The cycle was analyzed as an ideal Brayton cycle to simplify the analysis of the gas turbine engine. The results of the calculations performed for the efficiencies showed the correct trend for varying electrical loads. However, the actual values calculated were incorrect as there were many various efficiencies that exceeded 100%.

Contents, Tables, & Figures

Table of Contents

List of Figures

List of Tables

Introduction

The objective of this lab is to examine the performance and efficiency of a gas turbine engine. A common application of a gas turbine engine is driving an electric generator and extracting heat from the exhaust gases to perform some other task. Gas turbine engines have many advantages for electrical generation; they are clean-burning and can be brought up to full load very quickly. Due to technical difficulties, we were unable to actually operate the gas turbine. We were provided with a set of data from a previous operating run of the gas turbine for analysis of performance and efficiency.

The actual gas power cycle is rather complex, so to reduce the analysis to a manageable level, some assumptions are made. The first set of assumptions utilized is the air-standard assumptions:

1. The working fluid is air, which continuously circulates in a closed loop and always behaves as an ideal gas.
2. All the processes that make up the cycle are internally reversible.
3. The combustion process is replaced by a heat-addition process from an external source.
4. The exhaust process is replaced by a heat-rejection process that restores the working fluid to its initial state.

Another assumption that is often utilized to simplify the analysis is that air has constant specific heats whose values are determined at room temperature (25^{o}C, or 77^{o}F). The final assumptions made to perform the analysis are:

1. The system is steady-state.
2. Neglect kinetic and potential energies.
3. There is only one inlet and one outlet in the cycle.
4. Adiabatic turbines and compressors.
5. Isobaric heat exchangers.

Apparatus and Procedure

<u>Equipment:</u>

- 79 kilowatt (kW) Gas Turbine Generator
- Waste Heat Boiler
- Absorption Chiller
- Axial Turbine
- Burner
- Compressor
- Thermocouple (°F)
- Pressure Transducers (psig)
- Barometer (in Hg)

The Gas Turbine Engine turns a shaft, which is connected to a gearbox (Figure #2), that reduces speed and transmits power (kW) to a 480 Volt, 3 phase, 60 Hz generator. The output from the generator goes to an electric load bank. Figure #4 shows the control switches for the load bank. The electrical load is measured in kilowatts (kW). The flow of electricity is monitored by an engine control panel (Figure #5). The Thermocouple (Figure #1) measures the temperature in Fahrenheit. Compressor pressure is measured in pounds per square inch gage (psig) by pressure transducers and atmospheric pressure is measured by a barometer in inch Mercury (in Hg).

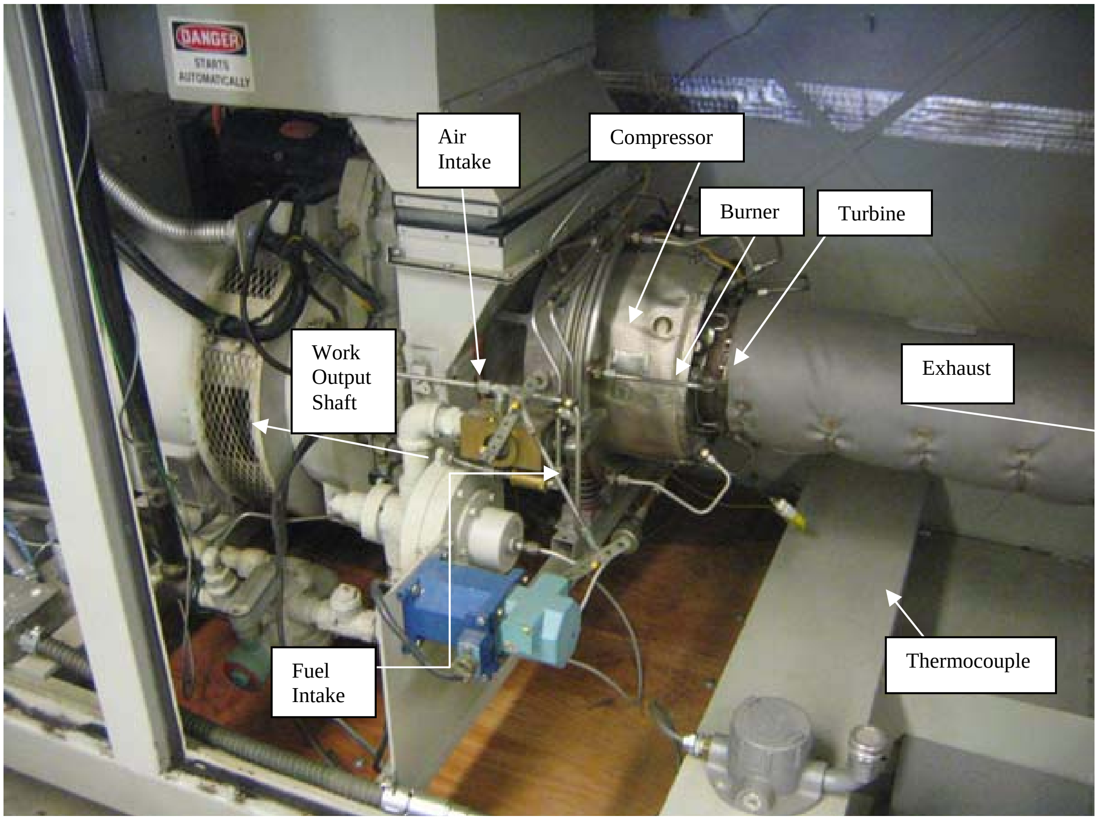

Figure #1 Gas Turbine Engine and its Components

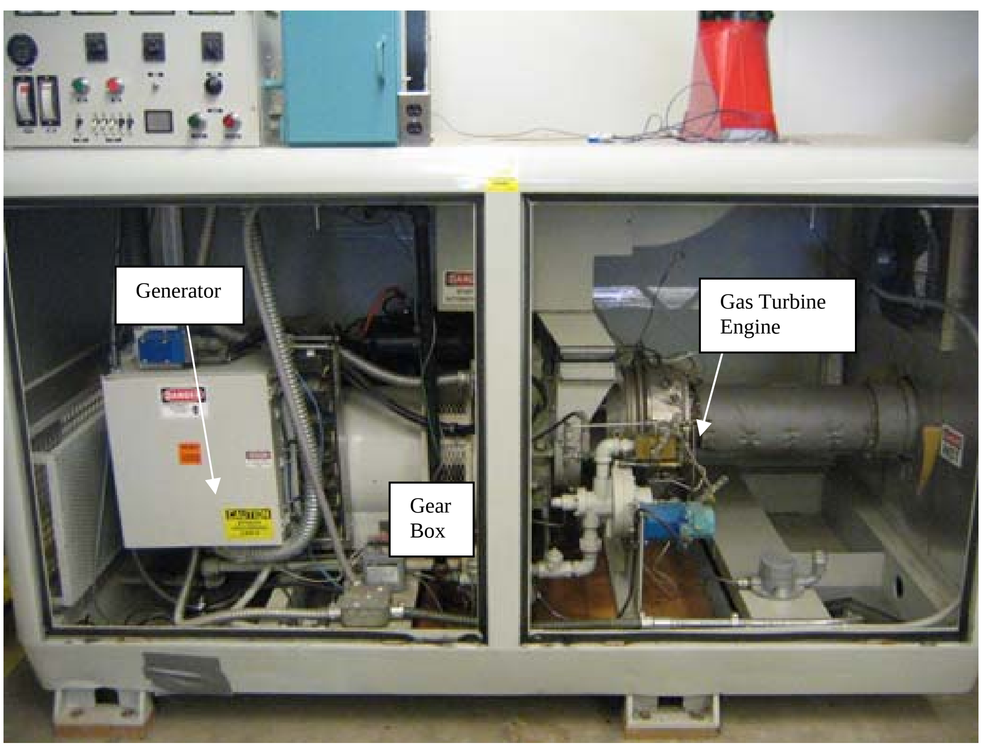

Figure #2 Gas Turbine Engine and Generator

Figure #3 Cogeneration System

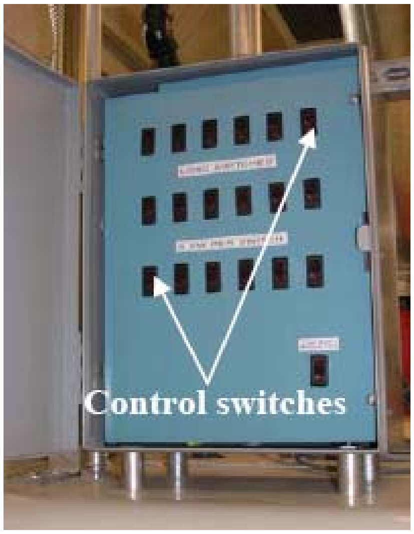

Figure #4 Load Bank **Figure #5 Engine Control Panel**

Procedures:

Due to technical difficulties with the Gas Turbine engine, it was unable to be turned on. The Gas Turbine was examined in the presence of a technician and questions were answered. Since the machine was unable to be turned on, the data was unable to be recorded; thus, the data was given to us.

Results and Discussion

Throughout this laboratory there were six variables measured periodically: T1, T2, T3, T4, T5, T6, and P2. See below for the meaning of each variable:

- T1 is the Temperature of the air entering the compressor.
- T2 is the Temperature of the air exiting the compressor.
- T3 is the Temperature of the air entering the turbine.
- T4 is the Temperature of the air exiting the turbine.
- T5 is the Temperature of the air entering the cooling cabin.
- T6 is the Temperature of the air exiting the cooling cabin.
- P2 is the Pressure of the air exiting the compressor.

The following values were measured or assumed once:

- P1 – the Pressure of the air entering the compressor.
- k – ratio of specific heats (obtained from assumed specific heats).
- Cp – assumed specific heat (assumed constant).
- m_dot – assumed mass flow rate.

These values T1, T3, P1, P2, and k were used to calculate the isentropic efficiency for both the compressor and the turbine. The efficiencies, clearly wrong, were then assumed. With this assumption the thermal efficiency, back work ratio, and the generator efficiency was then found for several loading conditions. Sample calculations can be found in the Appendix.

Pressure Ratio

Figure #6 shows how the pressure ratio was influenced by the load. See the Appendix for details on the calculation.

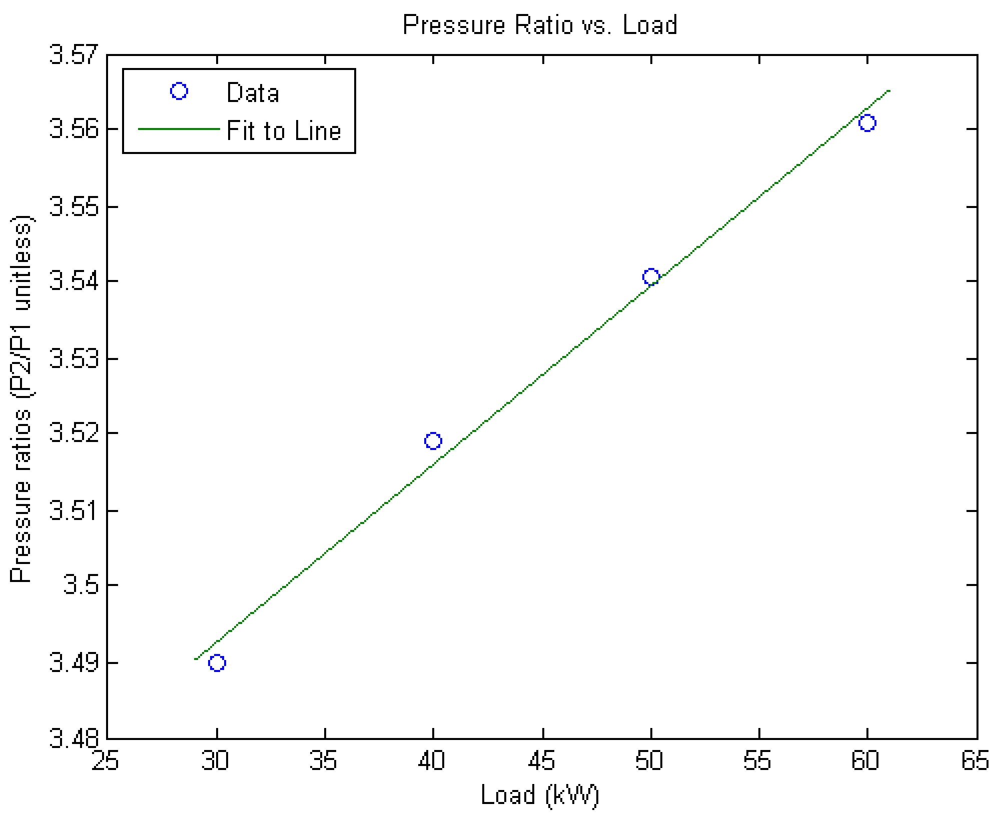

Figure #6 Graph of Pressure Ratio Against Load

This figure indicates that as the load increases so does the pressure ratio. However, this change is very small, as evident by the slope of the fit line being 0.0023444. Thus, for most cases, the pressure ratio can be assumed constant. For this experiment the actual pressure ratios were used instead of assuming the pressure ratios were of constant value.

Isentropic Efficiencies

Table #1 shows the calculated isentropic efficiencies for both the compressor and the turbine over various loading conditions. See the Appendix for details on the equations used.

Table #1 Compressor and Turbine Isentropic Efficiencies

Load (kW)	Compressor Efficiency (%)	Turbine Efficiency (%)
30	24.374%	107.672%
40	23.631%	99.113%
50	22.489%	93.048%
60	21.067%	87.197%

It is clear that the measurements above are in error. The compressor efficiencies are much too low and the turbine efficiencies are much too high (not to mention impossible in one case). Because of the above errors, there is obviously a mistake in one or more of the measurements taken. P1 and T1 are correct because these simply measure atmospheric conditions which were easily verified. It can be assumed that P2 and T4 are fairly accurate because the pressure gage is reliable and the thermocouple is placed effectively. T2 and T3 seem to be the primary candidates for error. The accuracy of T2 and T3 has more to do with their placement than the equipment itself. T2 is in contact with the wall and thus its temperature is increased due to conduction from the wall it is placed on. T3, although more accurate than T2, is sensing a higher temperature because it is receiving radiation from the flame i.e. the thermocouple can “see” the flame. In the next section a possible error for the measured values of T2 and T3 is shown.

Use of Assumed Efficiencies to Perform Calculations

The manufacturer indicates that the isentropic efficiency for both the turbine and the compressor should be close to 75%. With this assumed value, the “actual” values of T2 and T3 were calculated. See the Appendix for details on the equations used. Table #2 shows the measured and calculated temperature values; notice the difference.

Table #2 Comparing the Measured Values of T3 and T2 to the Calculated Values

Load (kW)	T2 Measured (K)	T2 Calculated (K)	T3 Measured (K)	T3 Calculated (K)
30	834.0008	474.9477	1080.5	943.7
40	858.8583	478.4210	1079.9	978.3
50	894.9046	481.8406	1099.3	1021.5
60	940.2570	483.9013	1120.5	1066.6

The measured and calculated values for T2 are significantly different. Although the calculated values are probably not accurate, they should be more accurate than the measured T2 values. The reason for the inaccuracy of the calculated T2 values is due to the fact that these values were calculated from an *assumed* efficiency; an efficiency which is probably wrong due to the fact that the machine is several decades old. Overall, not much can be said about the differences in the measured verses calculated temperature values due to the fact that they are both probably wrong.

The thermal efficiency, back work ratio, and generator efficiency were found using the calculated values of T2 and T3 (as incorrect as they may be); these findings are shown in Table #3. See the Appendix for details on the equations used.

Table #3 Thermal Efficiency, Back Work Ratio, and Generator Efficiency

Load (kW)	Thermal Efficiency (%)	Back Work Ratio	Generator Efficiency (%)
30	8.465%	0.8133	89.132%
40	9.313%	0.7899	101.303%
50	10.26%	0.7616	106.461%
60	11.186%	0.7322	108.516%

The trends for the thermal and generator efficiencies are accurate. This cycle was designed to be the most efficient when at its maximum load. This means that the cogeneration system will have poorer performance when partially loaded which we see matches our results. Besides the general trend, the numbers above are pretty meaningless (generator efficiencies larger than 100 percent clearly indicate a meaningless answer). The reason for the near meaningless answers stems from the fact that the turbine and compressor efficiencies are largely inaccurate. More accurately placed temperature sensing equipment is needed so that the efficiencies will not have to be assumed.

Turbine-Generator Housing Energy Balance

The turbine-generator housing was viewed as a control volume through which energy enters and exits in the form of fluids (gas mixtures) and electricity. The energy balance for this control volume is listed below.

Energy balance:

$$\frac{d(E_{cv})}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \sum_i \dot{m}_i (h_i + \frac{v_i^2}{2} + gz_i) - \sum_e \dot{m}_e (h_e + \frac{v_e^2}{2} + gz_e)$$

In this case steady-state conditions are assumed so there is no change in energy inside the control volume over time. The mass flow rates in this case are cooling air (in and out) and air (in and out); air was assumed because dealing with the air gas mixture (going in) and the exhaust gasses (coming out) are very complicated. The changes in potential and kinetic energies are approximately zero so they can be neglected. The work out in this case is in the form of electricity. The only heat transfer that takes places is that between the gasses, which are accounted for in the mass flow rates, so heat transfer is zero.

The simplified energy balance:

$$\dot{W}_{electricity} = (\dot{m}_{air} h_{air})_{in} + (\dot{m}_{cooling\_air} h_{cooling\_air})_{in} - (\dot{m}_{air} h_{air})_{out} - (\dot{m}_{cooling\_air} h_{cooling\_air})_{out}$$

Conclusion

This lab contained problems from the beginning since the gas turbine was not operating and we were unable to run it and obtain data. The data we were provided with, to do the analysis for this lab, was bad data. The main values obtained in the lab were compressor and turbine isentropic efficiency, thermal efficiency, back work ratio, and the generator efficiency for the various electrical loads (30 kW, 40 kW, 50 kW, and 60 kW). The compressor and turbine efficiencies are (24.374%, 23.631%, 22.489%, 21.067%) and (107.672%, 99.113%, 93.048%, 87.197%) respectively. The thermal efficiency calculated for the various system loads are (8.465%, 9.313%, 10.26%, 11.186%), the back work ratios calculated are (0.8133, 0.7899, 0.7616, 0.7322), and the generator efficiencies calculated are (89.132%, 101.303%, 106.461%, 108.516%) respectively. These calculated values represent the correct trend of how the efficiencies change with the varying loads, but are highly inaccurate since it is impossible to have efficiency values larger than 100%. The unrealistic efficiency results could be a result of the data that was provided being acquired from a previous malfunctioning experiment.

The practical importance of this experiment was to gain experience with using a gas turbine engine and evaluating its performance. Since we were unable to operate it, instead we took advantage of learning from the mechanic on hand to answer any questions we had about the system. The two major application areas of gas-turbine engines are aircraft propulsion and electric power generation. In our case, the gas turbine engine was part of a cogeneration system that was producing electricity.

There are changes that can be made to improve this experiment since there was error in the results. A couple changes might be relocating the temperature sensors for T2 and T3 to acquire more accurate data since T2 was experiencing some added heat due to conduction, while T3 was experiencing some added heat due to radiation. Changing the location of these two temperature sensors would lower their temperature readings and provide more realistic performance and efficiencies.

References

https://online.csus.edu/webct/urw/lc4130001.tp0/cobaltMainFrame.dowebct

Appendix

Sample Calculations

k=1.4, Cp=1.005

For Table #1:

1. For a compressor with constant specific heats:

   T2s/T1 = (P2/P1)^((k-1)/k) ... (eqn 1).

   T2s=T1((P2/P1)^(k-1)/k))

   431.7306=302.0793 ((352.4869/101)^((1.4-1)/1.4))

2. Definition of isentropic efficiency of a compressor (n_c):

   n_c = ((T2s - T1)/(T2a - T1)) ... (eqn 2).

   0.2437=((431.7306-302.0793)/(834.0008-302.0793)

3. For a turbine with constant specific heats:

   T4s/T3 = (P1/P2)^((k-1)/k) ... (eqn 3).

   T4s=T3((P1/P2)^(k-1)k))

   756.0457=1080.5 ((101/352.4869)^((1.4-1)/1.4))

4. Definition of isentropic efficiency of a turbine (n_t):

   n_t = ((T3 - T4a)/(T3 - T4s)) ... (eqn 4).

   1.0767 = ((1080.5-731.1510)/(1080.5-756.0457)

For Table #2 and #3:

m_dot=0.844

5. Calculate the Thermal efficiency, Back work ratio, and Generator efficiency using the 4 equations below. Because n_c and n_t were both clearly wrong we make the assumption that n_t and n_c are 75%.

   n_c = 0.75; n_t = n_c;

6. Rearrange (eqn 2):

T2a = (T2s-T1)/n_c + T1 ... (eqn 5)

474.9447=((431.7306-302.0793)/0.75))+302.0793

7. Rearrange (eqn 4):

T3 = (T4a-((n_t)(T4s)))/(1-n_t) ... (eqn 6)

8. Plug (eqn 6) into (eqn 3) and solve for T4s:

T4s = 1/(((1-n_t)/((P1/P2)^((k-1)/k)))+n_t/T4a) ... (eqn 7)

660.3013=1/(((1-0.75)/ ((101/352.4869)^((1.4-1)/1.4)))+0.75)/731.1510)

9. The thermal efficiency of an ideal Brayton cycle:

n_th,Brayton = 1 – (1/((P2/P1)^(1-1/k))) ... (eqn 8)

0.3003=1-(1/((352.4869/101)^((1.4-1)/1.4)))

10. Get T2a using equation 5:

T2a = ((T2s-T1)/n_c) + T1

474.9477=((431.7306-302.0793)/0.75)+302.0793

11. Get T3 using equations 6 and 7 to get T3:

T3 = ((T4a-((n_t)(T4s)))/(1-n_t)

943.7=(731.1510-((0.75)(660.3013)))/(1-0.75)

12. The work done by the turbine:

w_t = Cp(T3-T4a)

213.6119=1.005(943.7-731.1510)

13. The work done compressing the air in compressor:

w_c = Cp(T2a-T1)

173.7328=1.005(474.9477-302.0793)

14. The heat generated in the burner:

q_in = Cp(T3-T2a)

471.0962=1.005(943.7-474.9477)

15. The net work:

w_net = w_t - w_c

39.8791=213.6119-173.7328

16. The ideal thermal efficiency using equation 8:

n_th_ideal = 1-(1/((P2/P1)^(1-1/k)))

0.3003=1-(1/((352.4869/101)^((1.4-1)/1.4)))

17. The actual thermal efficiency:

n_th = w_net/q_in

0.0847=39.8791/471.0962

18. The back work ratio:

r_bw = w_c/w_t

0.8133=173.7328/213.6119

19. The generator efficiency:

n_gen = Load/((m_dot)(w_net))

0.8913=30/ ((0.844)(39.8791))

MATLAB File

Team KAB's Analysis of Lab 5

Programmer: Aaron Klapheck

```
% Lab #5 The Gas Turbine Engine 10-Oct-08

clear, clc, home

fprintf('The date and time: %s \n', datestr(now))
```

The date and time: 14-Oct-2008 12:36:15

Data

```
% P1 remains constant throughout this experiment:

P1 = 14.69;     % P1 is atmospheric pressure in psi.

% The following data changes with time.
% There are a total of 9 variables being measured. The 9 variable are
% being measured by the computer. The computer takes multiple measurements
% at each "steady state" so
% the values being measured are then averaged at each of the four
% steady-states. The data can be distinguished from each other according to
% the different engine loads.
%
% Units:
% Voltage in Volts (V)
% Current in Amps (A)
% Temperature in degrees Fahrenheit (F)
% Pressure in pounds per square inch gauge pressure (psig)
%
% T's and P's:
% T1 is the Temperature of the air entering the compressor
% T2 is the Temperature of the air exiting the compressor
% T3 is the Temperature of the air entering the turbine
% T4 is the Temperature of the air exiting the turbine
% T5 is the Temperature of the air entering the cooling cabin
% T6 is the Temperature of the air exiting the cooling cabin
% P2 is the Pressure of the air exiting the compressor

Load_30 = [ 84.3712     76.1905 107.4481      1040.8212      1487.1918      854.3895
 36.5574 270.1465       43.3455

            84.1270     76.0684 107.8144      1039.7559      1485.061       856.5202
 36.4353 271.2454       43.5897
```

```
          84.3712    76.1905 107.3260    1042.9518 1487.1918     856.5202     36.6184
 270.8791       43.4676

          84.3712    76.1905 107.8144      1039.7559     1482.9304     858.6508
 36.4963 270.5128       43.1013

          84.1270    76.3126 107.8144      1040.8212     1480.7998     857.5855
 36.4353 271.0623       42.9792

          84.1270    76.4347 107.9365      1044.0171     1482.9304     856.5202
 36.4353 270.3297       43.2234

          83.7607    76.4347 107.9365      1041.8865     1488.2571     857.5855
 36.2521 269.7802       43.4676

          83.6386    76.3126 107.8144      1039.7559     1489.3224     855.4549
 36.5574 270.8791       43.2234

          83.7607    76.1905 107.9365      1044.0171     1483.9958     854.3895
 36.4353 270.1465       43.5897];


Load_40 = [ 86.5690    77.2894 113.3089      1083.4341     1485.061      903.3944
 37.0458 269.7802       56.8987

          86.5690    77.7778 113.5531      1085.5647     1482.9304     901.2638
 37.0458 271.0623       57.2650

          86.3248    77.2894 113.7973      1088.7607     1485.061      902.3290
36.8626  269.7802       57.6313

          86.2027    77.7778 113.5531      1085.5647     1481.8651     905.5251
 36.8016 270.6960    57.3871

          86.4469    77.7778 113.5531      1086.6301     1486.1265     900.1984
 36.9847 269.7802       57.5092

          86.8132    77.4115 113.5531      1084.4994     1481.8651     902.3290
36.8626  269.9634       57.5092

          86.3248    77.4115 113.4310    1088.7607 1483.9958     904.4597     36.6795
 270.5128       57.3871

          86.3248    77.7778 113.3089      1087.6953     1488.2571     902.3290
36.8016  269.9634       57.6313

          86.6911    77.6557 113.7973      1085.5647     1482.9304     900.1984
 36.9847 270.6960    57.6313];



Load_50 = [ 89.8657    78.3883 119.4139      1150.5494     1519.1514     963.0526
 37.4121 270.3297       71.5507

          89.4994    78.6325 119.1697      1148.4188     1523.4127     957.7259
 37.0458 269.9634       71.5507

          89.1331    78.5104 119.5360    1152.6802 1523.4127     960.9219     37.0458
 270.5128       71.1844

          89.2552    78.8767 119.2918      1150.5494     1522.3474     964.1178
 37.1679 270.1465       71.4286

          89.1331    78.8767 119.2918      1153.7455     1512.7595     959.8565
 37.1679 270.6960    71.3065
```

```
            88.7668     78.6325 119.6581       1150.5494      1514.8901      957.7259
 37.3510 270.3297       71.5507

            88.8889     78.6325 119.2918       1151.6149      1518.0862      963.0526
 37.2900 269.9634       71.5507];



Load_60 = [ 90.8425     78.0220 122.2222       1230.4489      1564.9603      1023.7759
 37.5342 270.3297       85.4701

            90.3541     78.0220 122.2222       1234.7101      1556.4377      1017.3840
 37.4121 270.5128       85.4701

            90.4762     78.0220 122.4664       1233.6448      1554.3071      1021.6453
 37.5952 270.1465       84.9817

            90.4762     78.3883 122.1001       1232.5795      1560.6991      1023.7759
 37.5342 270.5128       85.7143

            90.2320     77.8999 122.5885       1232.5795      1550.0459      1023.7759
 37.4731 271.0623       85.9585];


T1 = [mean(Load_30(:,1)); mean(Load_40(:,1)); mean(Load_50(:,1)); mean(Load_60(:,1))];

T5 = [mean(Load_30(:,2)); mean(Load_40(:,2)); mean(Load_50(:,2)); mean(Load_60(:,2))];

T6 = [mean(Load_30(:,3)); mean(Load_40(:,3)); mean(Load_50(:,3)); mean(Load_60(:,3))];

T2 = [mean(Load_30(:,4)); mean(Load_40(:,4)); mean(Load_50(:,4)); mean(Load_60(:,4))];

T3 = [mean(Load_30(:,5)); mean(Load_40(:,5)); mean(Load_50(:,5)); mean(Load_60(:,5))];

T4 = [mean(Load_30(:,6)); mean(Load_40(:,6)); mean(Load_50(:,6)); mean(Load_60(:,6))];

P2 = [mean(Load_30(:,7)); mean(Load_40(:,7)); mean(Load_50(:,7)); mean(Load_60(:,7))];

V = [mean(Load_30(:,8)); mean(Load_40(:,8)); mean(Load_50(:,8)); mean(Load_60(:,8))];

I = [mean(Load_30(:,9)); mean(Load_40(:,9)); mean(Load_50(:,9)); mean(Load_60(:,9))];


% Convert all units to metric


% Kelvin = (Fahrenheit - 32)5/9 + 273.15


Load = [30; 40; 50; 60];            % kW

T1 = (T1 - 32)./1.8 + 273.15;       % K

T2a = (T2 - 32)./1.8 + 273.15       % K

T3 = (T3 - 32)./1.8 + 273.15        % K
```

```
T4a = (T4 - 32)./1.8 + 273.15;      % K

T5 = (T5 - 32)./1.8 + 273.15;       % K

T6 = (T6 - 32)./1.8 + 273.15;       % K

P2 = (P2 + P1).*6.89;               % kPa

P1 = 101;  % kPa - atmopheric pressure is 101 kPa
```

```
T2a =

  834.0008
  858.8583
  894.9046
  940.2570


T3 =

  1.0e+003 *

    1.0805
    1.0799
    1.0993
    1.1205
```

Graph pressure ratios as a function of load

```
P_ratio = P2/P1;

fprintf('\nPressure ratios for an increasing load: %g %g %g %g \n \n', P_ratio)

FitToLine = polyfit(Load, P_ratio, 1);

fprintf('Notice the rate of pressure ratio increase is very small: %g \n \n',
FitToLine(1,1))

x = [29:0.01:61];

FitToLine = polyval(FitToLine, x);


plot(Load, P_ratio, 'o', x, FitToLine), ...

    xlabel('Load (kW)'), title('Pressure Ratio vs. Load'), ...
```

```
ylabel('Pressure ratios (P2/P1 unitless)'), ...
legend('Data', 'Fit to Line', 'Location', 'NorthWest')
```

Pressure ratios for an increasing load: 3.48997 3.51912 3.54061 3.56095

Notice the rate of pressure ratio increase is very small: 0.0023444

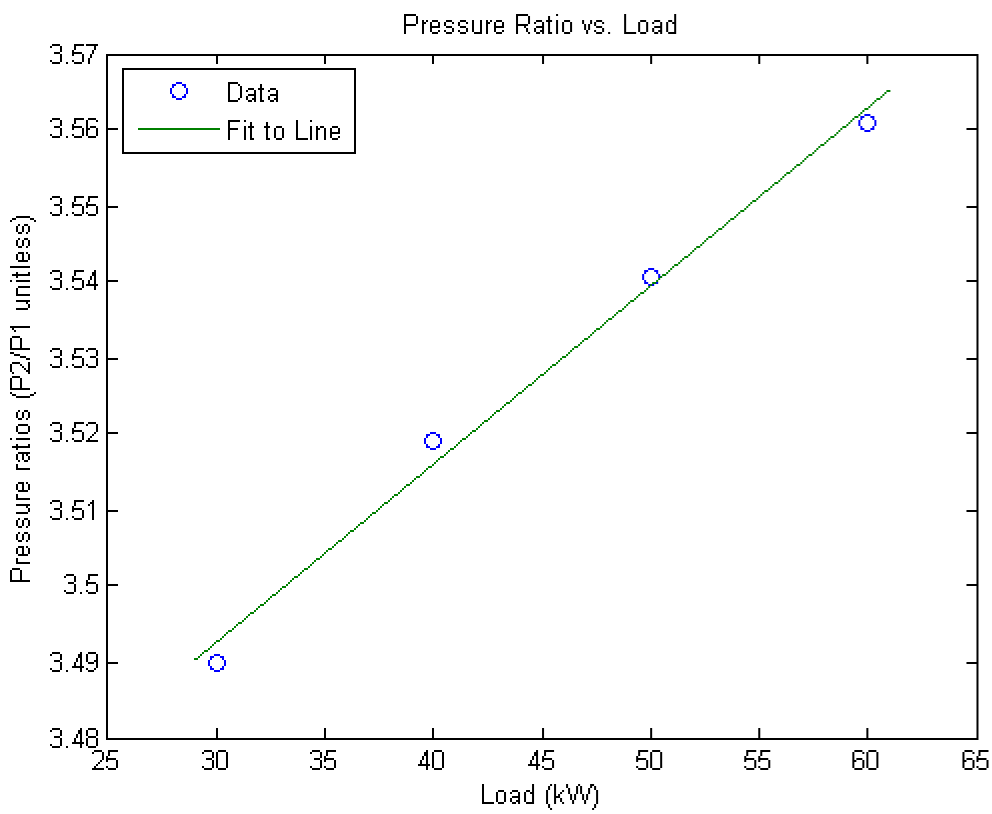

Figure # 7 Graph of Pressure Ratio Against Load

Calculations

```
% Assume specific heat is constant(k = c_p/c_v).
k = 1.4; % assuming T = 300K is constant (which it is not).
Cp = 1.005; % kJ/(kg*K) Assuming T = 300K is approximately constant.
m_dot = 0.844; % kg/s. This value is assumed.
```

```
% 1st. Calculate the isentropic efficiency of the turbine and the
% compressor using the 4 equations below.
%
% For a compressor with constant specific heats:
%   T2s/T1 = (P2/P1)^((k-1)/k) ... (eqn 1).
% Definition of isentropic efficiancy of a compressor (n_c):
%   n_c = ((T2s - T1)/(T2a - T1)) ... (eqn 2).
% For a turbine with constant specific heats:
%   T4s/T3 = (P1/P2)^((k-1)/k) ... (eqn 3).
% Definition of isentropic efficiancy of a turbine (n_t):
%   n_t = ((T3 - T4a)/(T3 - T4s)) ... (eqn 4).

fprintf('%%%%%%% Get n_c using equations 1 and 2 %%%%%% \n')
T2s = T1.*(P2./P1).^((k-1)/k);
n_c = ((T2s - T1)./(T2a - T1));
[num2str(round(100000.*n_c)./1000), ['%';'%';'%';'%']]

fprintf('%%%%%%% Get n_t using equations 3 and 4 %%%%%% \n')
T4s = T3.*(P1./P2).^((k-1)/k);
n_t = ((T3 - T4a)./(T3 - T4s));
[num2str(round(100000.*n_t)./1000), ['%';'%';'%';'%']]




% 2nd. Calculate the Thermal efficiency, Back work ratio, and Generator
% efficiency using the 4 equations below. Because n_c and n_t were both
% clearly wrong we make the assumption that n_t and n_c are 75%.
n_c = 0.75; n_t = n_c;
%
% Rearange (eqn 2): T2a = (T2s-T1)/n_c + T1 ... (eqn 5)
% Rearange (eqn 4): T3 = (T4a-n_t*T4s)/(1-n_t) ... (eqn 6)
% Plug (eqn 6) into (eqn 3) and solve for T4s:
%   T4s = 1./(((1-n_t)/((P1/P2)^((k-1)/k)))+n_t/T4a) ... (eqn 7)
% The thermal efficiency of an ideal Brayton cycle:
```

```
%   n_th,Brayton = 1 - 1/((P2/P1)^(1-1/k)) ... (eqn 8)


fprintf('%%%%%% Get T2a using equation 5 %%%%%% \n')

T2a = (T2s-T1)./n_c + T1


fprintf('%%%%%% Get T3 using equations 6 and 7 %%%%%% \n')

T4s = 1./((((1-n_t)./((P1./P2).^((k-1)/k)))+n_t)./T4a);

T3 = (T4a-n_t.*T4s)./(1-n_t)



fprintf('%%%%%% The work done by the turbine %%%%%% \n')

w_t = Cp.*(T3-T4a)


fprintf('%%%%%% The work done compressing the air in compresser %%%%%% \n')

w_c = Cp.*(T2a-T1)


fprintf('%%%%%% The heat generated in the burner %%%%%% \n')

q_in = Cp.*(T3-T2a)


fprintf('%%%%%% The net work %%%%%% \n')

w_net = w_t - w_c


fprintf('%%%%%% The ideal thermal efficiency using equation 8 %%%%%% \n')

n_th_ideal = 1-1./((P2./P1).^(1-1/k));

[num2str(round(100000.*n_th_ideal)./1000), ['%';'%';'%';'%']]


fprintf('%%%%%% The actual thermal efficiency %%%%%% \n')

n_th = w_net./q_in;

[num2str(round(100000.*n_th)./1000), ['%';'%';'%';'%']]


fprintf('%%%%%% The back work ratio %%%%%% \n')

r_bw = w_c./w_t


fprintf('%%%%%% The generator efficiency %%%%%% \n')
```

```
    n_gen = Load./(m_dot.*w_net);
    [num2str(round(100000.*n_gen)./1000), ['%';'%';'%';'%']]
```

%%% Get n_c using equations 1 and 2 %%%

ans =

24.374%

23.631%

22.489%

21.067%

%%% Get n_t using equations 3 and 4 %%%

ans =

107.672%

99.113%

93.048%

87.197%

%%% Get T2a using equation 5 %%%

T2a =

474.9477

478.4210

481.8406

483.9013

%%% Get T3 using equations 6 and 7 %%%

T3 =

```
  1.0e+003 *

    0.9437
    0.9783
    1.0215
    1.0666

%%% The work done by the turbine %%%

w_t =

  213.6119
  222.6664
  233.4326
  244.6669

%%% The work done compressing the air in compresser %%%

w_c =

  173.7328
  175.8827
  177.7861
  179.1559

%%% The heat generated in the burner %%%

q_in =

  471.0962
  502.3689
  542.3466
  585.6516
```

```
%%% The net work %%%

w_net =

   39.8791
   46.7837
   55.6465
   65.5110

%%% The ideal thermal efficiency using equation 8 %%%

ans =

30.031%
30.197%
30.318%
30.432%

%%% The actual thermal efficiency %%%

ans =

 8.465%
 9.313%
 10.26%
11.186%

%%% The back work ratio %%%

r_bw =

    0.8133
    0.7899
    0.7616
```

```
    0.7322

%%% The generator efficiency %%%

ans =

 89.132%
101.303%
106.461%
108.516%
```

Figure #8 Data Given

Mechanical Engineering Co-Gen Lab										
Data file: Temperature - Gas Turbine										
Time is 12:53:12.54.										
Date is 3-21-2008.										
T-1	T-5	T-6	T-2	T-3	T-4	Compr Pr	Volts	Current	Hand Pro	Air In D
Fahrenheit	Fahrenheit	Fahrenheit	Fahrenheit	Fahrenheit	Fahrenheit	psi_g	Volts	Amps		Inches W
84.3712	76.1905	107.4481	1040.8212	1487.1918	854.3895	36.5574	270.1465	43.3455	92.9487	2.2832
84.127	76.0684	107.8144	1039.7559	1485.061	856.5202	36.4353	271.2454	43.5897	91.5751	2.3596
84.3712	76.1905	107.326	1042.9518	1487.1918	856.5202	36.6184	270.8791	43.4676	92.033	2.0879
84.3712	76.1905	107.8144	1039.7559	1482.9304	858.6508	36.4963	270.5128	43.1013	92.4908	2.2069
84.127	76.3126	107.8144	1040.8212	1480.7998	857.5855	36.4353	271.0623	42.9792	93.4066	2.3809
84.127	76.4347	107.9365	1044.0171	1482.9304	856.5202	36.4353	270.3297	43.2234	92.4908	2.1642
83.7607	76.4347	107.9365	1041.8865	1488.2571	857.5855	36.2521	269.7802	43.4676	92.4908	2.4389
83.6386	76.3126	107.8144	1039.7559	1489.3224	855.4549	36.5574	270.8791	43.2234	91.5751	2.268
83.7607	76.1905	107.9365	1044.0171	1483.9958	854.3895	36.4353	270.1465	43.5897	92.9487	2.3412
86.569	77.2894	113.3089	1083.4341	1485.061	903.3944	37.0458	269.7802	56.8987	96.1539	2.268
86.569	77.7778	113.5531	1085.5647	1482.9304	901.2638	37.0458	271.0623	57.265	95.696	1.9749
86.3248	77.2894	113.7973	1088.7607	1485.061	902.329	36.8626	269.7802	57.6313	96.6117	2.2863
86.2027	77.7778	113.5531	1085.5647	1481.8651	905.5251	36.8016	270.696	57.3871	95.696	1.9933
86.4469	77.7778	113.5531	1086.6301	1486.1265	900.1984	36.9847	269.7802	57.5092	95.696	2.0482
86.8132	77.4115	113.5531	1084.4994	1481.8651	902.329	36.8626	269.9634	57.5092	95.696	2.213
86.3248	77.4115	113.431	1088.7607	1483.9958	904.4597	36.6795	270.5128	57.3871	96.6117	2.2802
86.3248	77.7778	113.3089	1087.6953	1488.2571	902.329	36.8016	269.9634	57.6313	95.696	2.3382
86.6911	77.6557	113.7973	1085.5647	1482.9304	900.1984	36.9847	270.696	57.6313	94.3223	2.0879
89.8657	78.3883	119.4139	1150.5494	1519.1514	963.0526	37.4121	270.3297	71.5507	98.9011	2.4176
89.4994	78.6325	119.1697	1148.4188	1523.4127	957.7259	37.0458	269.9634	71.5507	99.359	2.4939
89.1331	78.5104	119.536	1152.6802	1523.4127	960.9219	37.0458	270.5128	71.1844	101.1905	2.1764
89.2552	78.8767	119.2918	1150.5494	1522.3474	964.1178	37.1679	270.1465	71.4286	99.359	2.3718
89.1331	78.8767	119.2918	1153.7455	1512.7595	959.8565	37.1679	270.696	71.3065	100.2747	2.4633
88.7668	78.6325	119.6581	1150.5494	1514.8901	957.7259	37.351	270.3297	71.5507	98.9011	2.3901
88.8889	78.6325	119.2918	1151.6149	1518.0862	963.0526	37.29	269.9634	71.5507	99.8169	1.9841
90.8425	78.022	122.2222	1230.4489	1564.9603	1023.7759	37.5342	270.3297	85.4701	102.1062	2.4572
90.3541	78.022	122.2222	1234.7101	1556.4377	1017.384	37.4121	270.5128	85.4701	101.1905	2.3107
90.4762	78.022	122.4664	1233.6448	1554.3071	1021.6453	37.5952	270.1465	84.9817	102.1062	2.3443

90.4762	78.3883	122.1001	1232.5795	1560.6991	1023.7759	37.5342	270.5128	85.7143	102.5641	2.2924
90.232	77.8999	122.5885	1232.5795	1550.0459	1023.7759	37.4731	271.0623	85.9585	103.022	2.3199