SACRAMENTO
STATE

Final Lab Report for Three Labs

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Date of Experiments:
Lab3: Nov. 7, 2008
Lab4: Sep. 26, 2008
Lab5: Oct. 10, 2008

Date of Report Submittal: Dec. 12, 2008

ME125: Engineering Measurements
Dr. Zhou

Abstract

Lab #3 Wind Tunnel

The objective of this lab is to re-investigate the interactions between a flowing fluid (air) and a solid object (cylinder). There is reason to believe that the vertical measurements taken in a previous laboratory have inaccuracies. This re-investigation involved calculating velocities and plotting the velocity, static and total pressure profiles against the distance between top and bottom walls. This was done in a position directly behind the cylinder. These measurements were then compared to the previous measurements and the error of the automated vertical measurement taking machine was determined. As a result to this laboratory the measurements taken by the machine were found to be in error. All three profiles (velocity, static pressure, and total pressure against vertical distance) were found to have significant error. Performing the vertical movements of the pilot tube is recommended by hand.

Lab #4 Compressor

The purpose of this experiment is to provide further experience with electronic data acquisition hardware and software by evaluating a Reciprocating Air Compressor Test System. Temperature and pressure measurements were taken by the computer at a specific receiver tank pressure. The data acquired was time dependant thus the transient data of the both the low and high pressure cylinders was recorded. The results from lab 4 (a previous lab) were valid for an ideal compression cycle. For this lab the compression cycles was analyzed to determine if the ideal compression cycle assumption was valid. As a result of this analysis the high pressure pump was found to have a cycle that was very similar to the ideal compressor cycle. The assumption of an ideal cycle for the high pressure cycle is valid and the resulting error would be minor. However, the low pressure cycle does not resemble the ideal compressor cycle so this assumption may have a large impact on the resulting calculations performed in lab 4.

Lab #5 Gas Turbine

The thermal efficiency of lab 5 will be reanalyzed using variable specific heats. The cycle was analyzed as an ideal Brayton cycle to simplify the analysis of the gas turbine engine, this assumption will still hold true for this reanalysis as well. Using constant specific heats gives significant error; because of this error, variable specific heats were used in this lab. As a result of this lab the error associated with using specific heats was found to be 19%. It is recommended that the use of variable specific heats be used whenever possible. The temperature sensor used to record the data for T3 was found to be more accurate than the sensor used to measure the temperature for T4a. The temperature sensors should be repositioned so that their accuracy will be improved.

Contents, Tables, & Figures

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Introduction

Lab #3 Wind Tunnel

The objective of this lab is to investigate the interactions between a flowing fluid (air) and a solid object (cylinder). Flow over a circular cylinder in cross-flow is one of the classic problems in fluid mechanics as it illustrates a number of important phenomena, including boundary layer effects, flow separation, and vortex-vorticity. For lab 3 the vertical motions were performed by a machine, but for this lab the motions will be performed by hand. The results were plotted and show side by side with the previous lab 3 graphs. These two types of graphs will be studied by comparing velocity and pressure profiles in the wake region. The velocity and pressure will be measured using the Pilot-static tube. The measurements obtained in the lab will be analyzed using the Bernoulli equation. The following conditions must be satisfied for the equation to be valid:

1) The equation is applied along a streamline.
2) The flow is steady.
3) The flow is incompressible; ρ = constant (Mach number is less than about 0.3).
4) The flow is inviscid (frictionless).

Lab #4 Compressor

This Lab provides a further understanding of the operation and operating characteristics of a two-stage reciprocating compressor. Pressure and piston position values were recorded for both the low pressure and the high pressure compression cycles at a receiver tank pressure of 318 psi. The actual cycles for both these compressors were graphed and compared to the ideal cycle. As a result of this comparison the ideal cycle assumption was found to hold true for one cycle but not the other.

Lab #5 Gas Turbine

The objective of this lab is to examine the efficiency of a gas turbine engine and make comparisons between previous efficiencies measured. For this laboratory the Rankine cycle was used as the ideal cycle which the actual cycle was assumed to follow. This required a number of assumptions to be made:

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.

With these assumptions in place the thermal efficiencies were recalculated for variable specific heats. As a result the error associated with using constant specific heats was found to be approximately 19%.

Apparatus and Procedure

Lab #3 Wind Tunnel

Equipment:

- Subsonic wind tunnel
- Blower
- Turbulence reducing screens
- Inlet filter
- Test cylinder
- 1/8” diameter traversing Pitot tube
- 4 inclined Manometers

The total pressure head, static pressure head and static gage pressure head are measured via inclined manometers. The velocity pressure head is calculated from the measurements of the total pressure head and static pressure head.

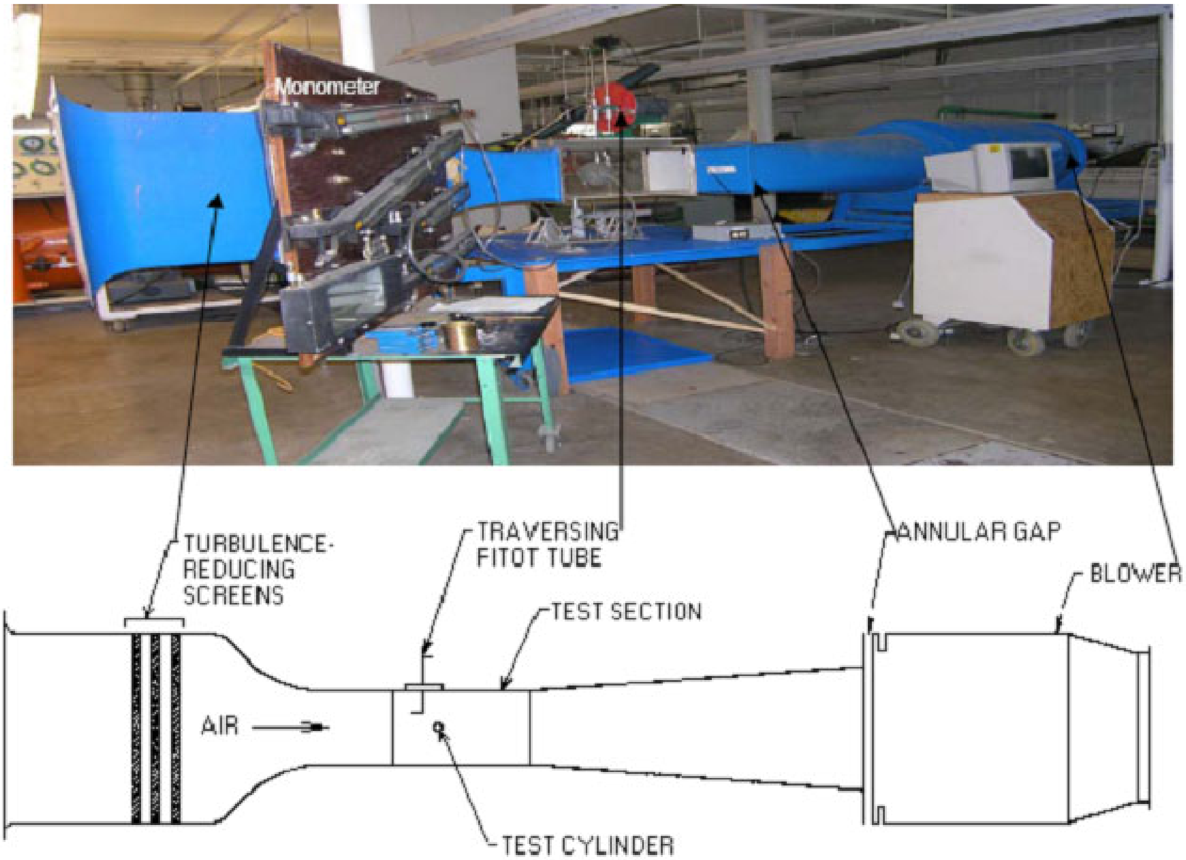


Figure #1 Schematic Diagram and Photo of Subsonic Wind Tunnel

Procedures:

1. We zeroed up the four inclined manometers.
2. Made sure the pilot tube was in the center (vertically), located at the top wall, and at Position 2 which is at the 7.75 inch mark on the scale.
3. We pressed the start button to start the blower.
4. We manually lowered the pilot tube by increments of 0.5 inches.
5. At each increment the static pressure head and total pressure head were recorded from the inclined monometers.

Lab #4 Compressor

Equipment:

- Ingersoll-Rand two-stage, double-acting, reciprocating piston compressor
- 7.5 horsepower GE Induction motor
- Thermometer (Celsius)
- Barometer
- Computer with LABTECH Notebook software
- Floppy disk
- Input Power Gage
- Annubar Flowrate (Standard Cubic Feet Per Minute)
- Tank Pressure Gauge
- Receiver Tank

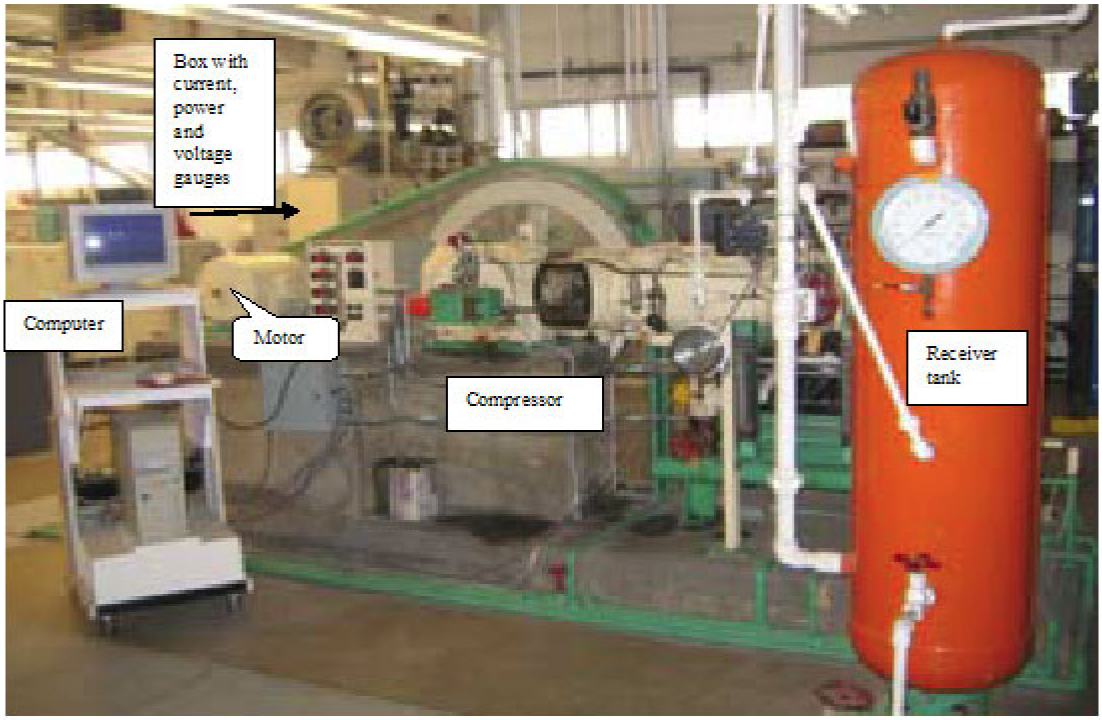


Figure #2 Reciprocating Air Compressor Test System

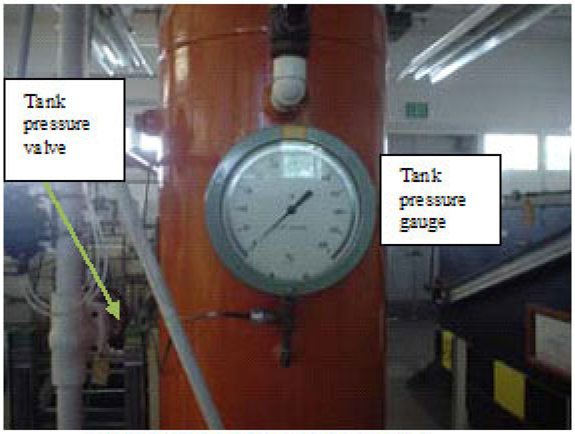


Figure #3 Tank Pressure Gauge

Procedures:

1. A transient test was run at a receiver tank pressure 318psig.
    a. We opened LABTECH Notebook, opened the file ‘comp_PV’ and pushed the *Run* button in the window.
    b. The program record data for a few seconds.
    c. The data was saved (in spreadsheet format) on the computer by going exiting out of the run-time box and then going to file and exiting out of the build time box
    d. Excel was opened, drive (C:) was opened, finally Temp folder was opened and the file was saved with the name ‘comp_PV,’
2. We then copied the data from the floppy disk on to our USB storage devices.

Lab #5 Gas Turbine

There was no data collected for this part of the lab. Only a recalculation was performed.

Results and Discussion

Lab #3 Wind Tunnel

The follow contains graphs are taken by moving the pilot tube vertically by hand and the when the machine moved the pilot tube. The machine data was taken in one of the previous laboratories and its values will be compared to those taken by hand to ascertain their validity.

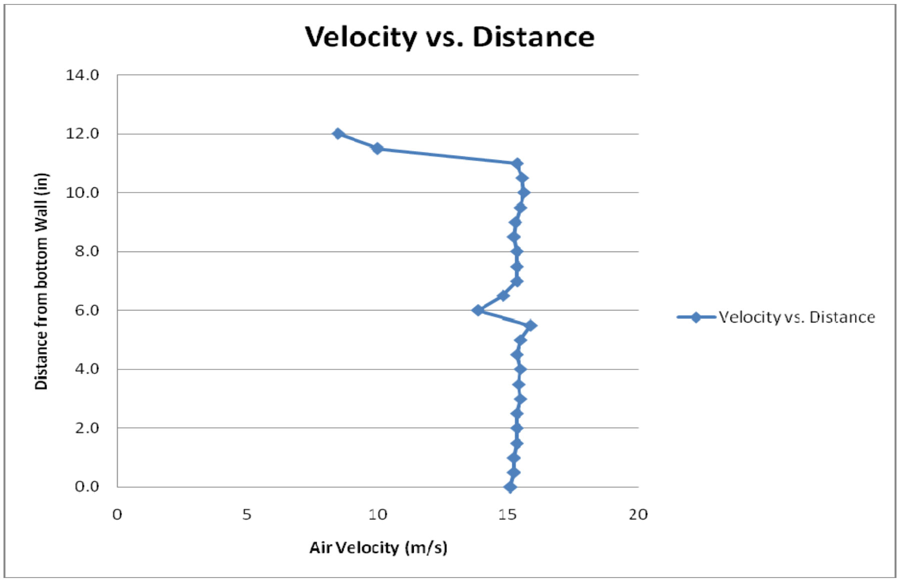


Figure #4 Velocity Against the Vertical Distance for Horizontal Location 2, By Hand

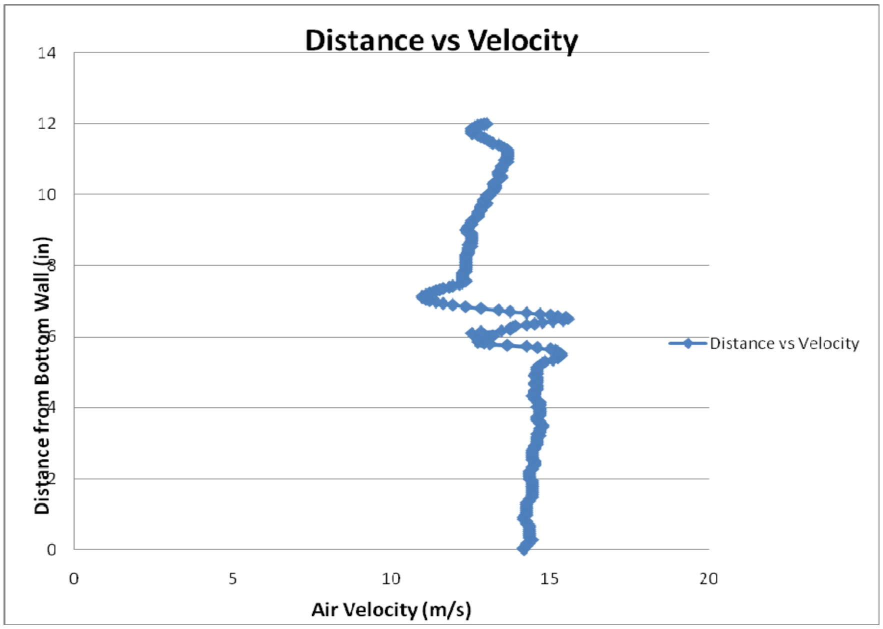


Figure #5 Velocity Against the Vertical Distance for Horizontal Location 2, By Mechanism

The velocity results obtained using the mechanism to move the pilot tube are significantly different than those taken by hand. Although the graphs share similar features, there is enough of a difference that the error in the mechanism's values will be substantial. One of the primary reasons for this error is due to the mechanisms jerky behavior at about six inches from the bottom of the wall. The jerky motions seen by the team produced a significant error. The graph taken by hand confirmed our expectations that the erratic motion of the machine graph is due to the mechanism not the cylinder. There should have been a sudden drop in air velocity near the top wall, this is due to the hole in the top wall that the pilot tube is running along. The hand taken measurements confirm this pressure drop where the measurements taken by the machine did not.

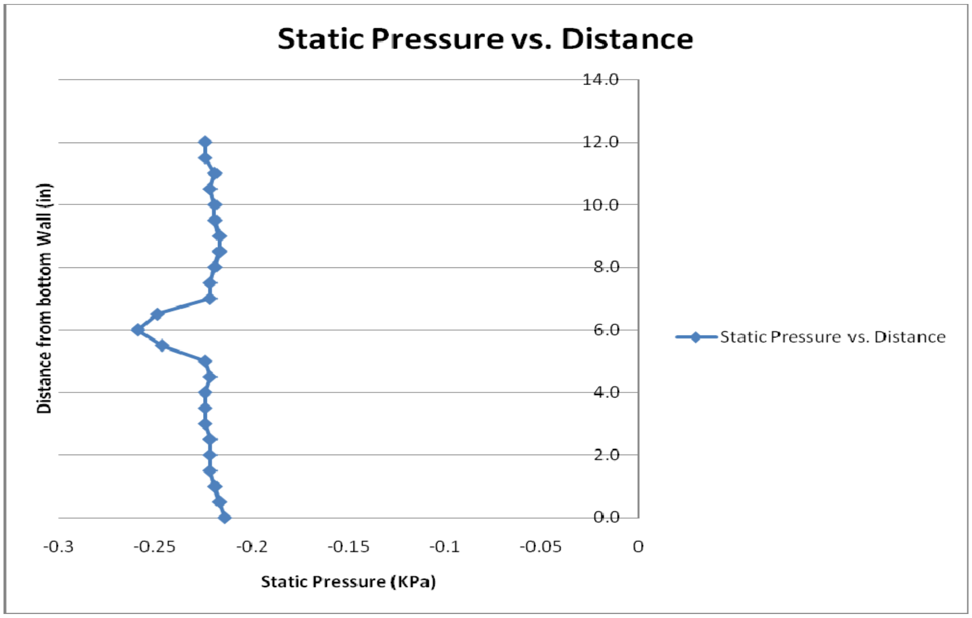


Figure #6 Static Pressure Against the Vertical Distance for Horizontal Location 2, By Hand

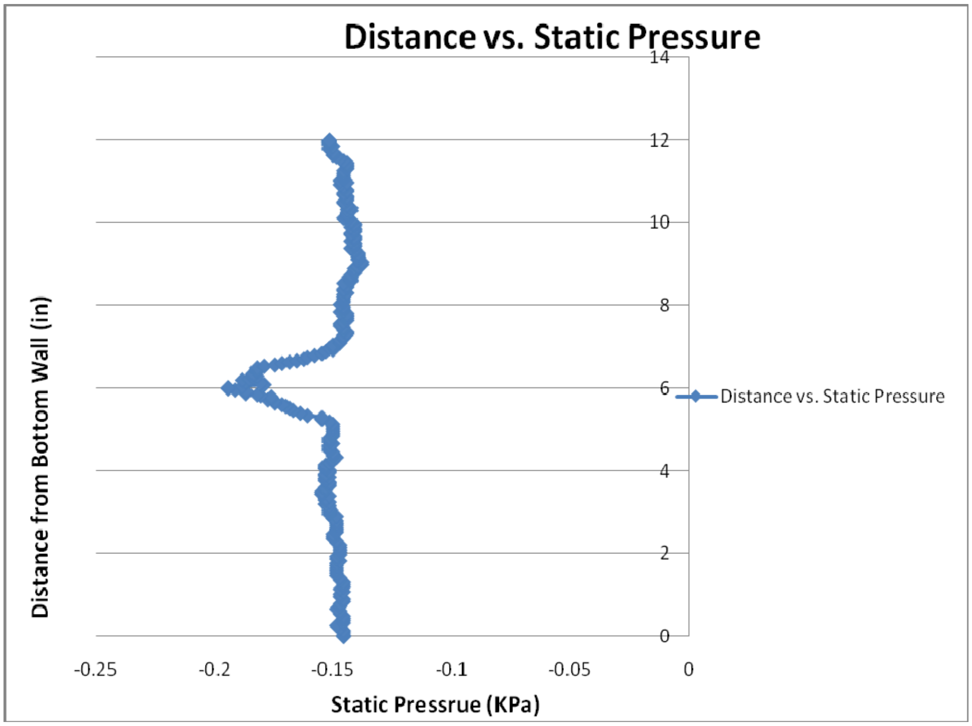


Figure #7 Static Pressure Against the Vertical Distance for Location 2, By Mechanism

The static pressure results obtained using the mechanism to move the pilot tube are nearly identical to those taken by hand. Despite the graphs similarity though, they are consistently off by 0.07KPa. This may be due to the way the measurements were taken. The results confirmed our expectations.

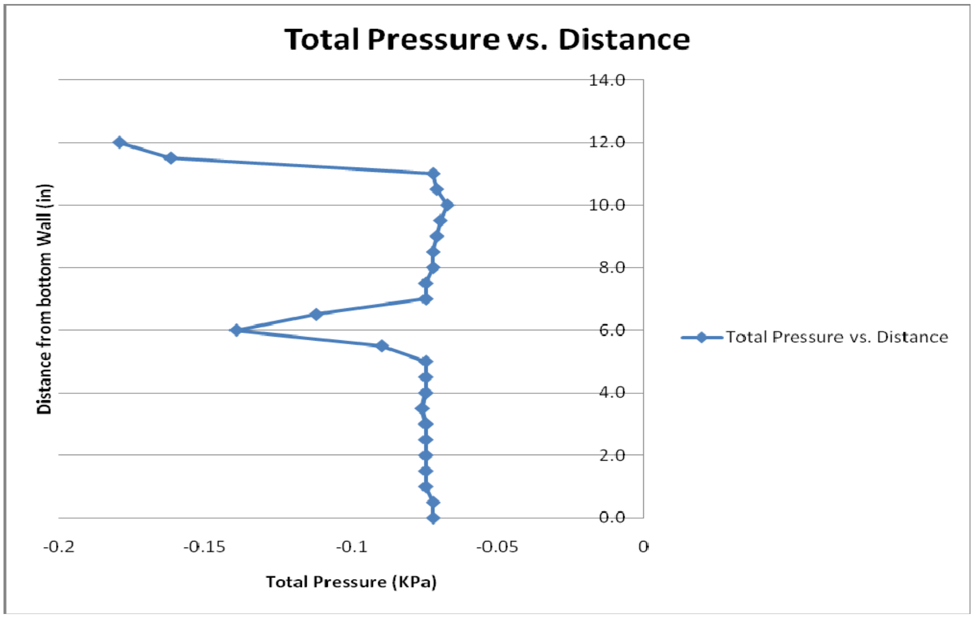


Figure #8 Total Pressure Against the Vertical Distance for Horizontal Location 2, By Hand

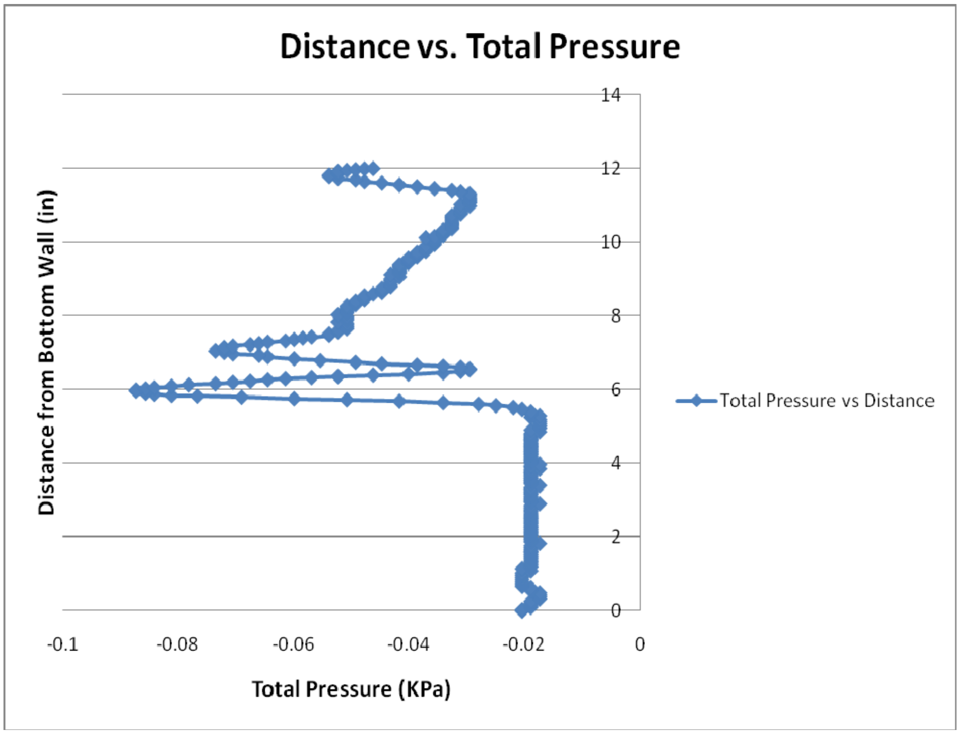


Figure #9 Total Pressure Against the Vertical Distance for Location 2, By Mechanism

The total pressure results obtained using the mechanism to move the pilot tube are significantly different than those taken by hand. Although the graphs share similar features, there is enough of a difference that the error in the mechanism's values will be substantial. One of the primary reasons for this error is due to the mechanisms jerky behavior at about six inches from the bottom of the wall. The jerky motions seen by the team produced a significant error. The graph taken by hand confirmed our expectations that the erratic motion of the machine graph is due to the mechanism not the cylinder. There should have been a sudden drop in air velocity near the top wall, this is due to the hole in the top wall that the pilot tube is running along. The hand taken measurements confirm this pressure drop where the measurements taken by the machine did so only minorly.

Lab #4 Compressor

Both the low pressure and high pressure compressors behave as usual real-world compressors. This indicates that the characteristics associated with the ideal compression cycle are present in both of the compressors used. However, instead of following idealized constant pressure or constant volume straight lines, the compressor cycles for both the low pressure and high pressure compressors exhibit a steadier transition from one part of their cycle to another. See the appendix section for sample calculations.

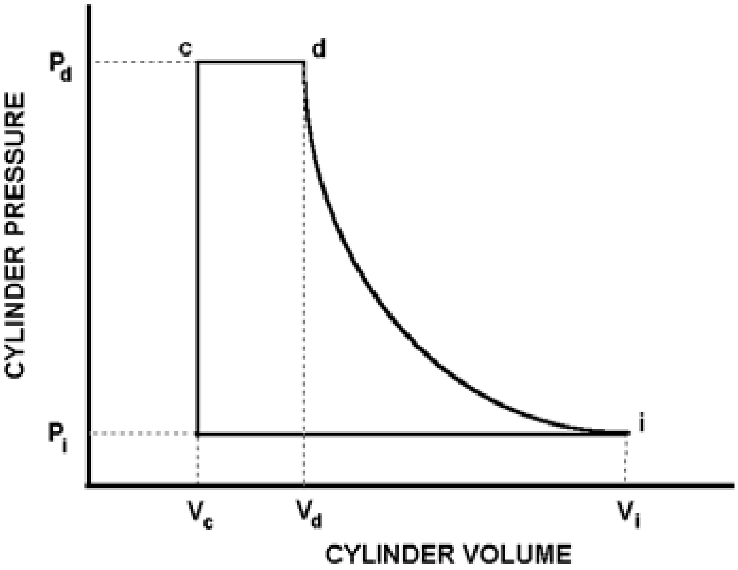


Figure #10 Ideal Compression Cycle

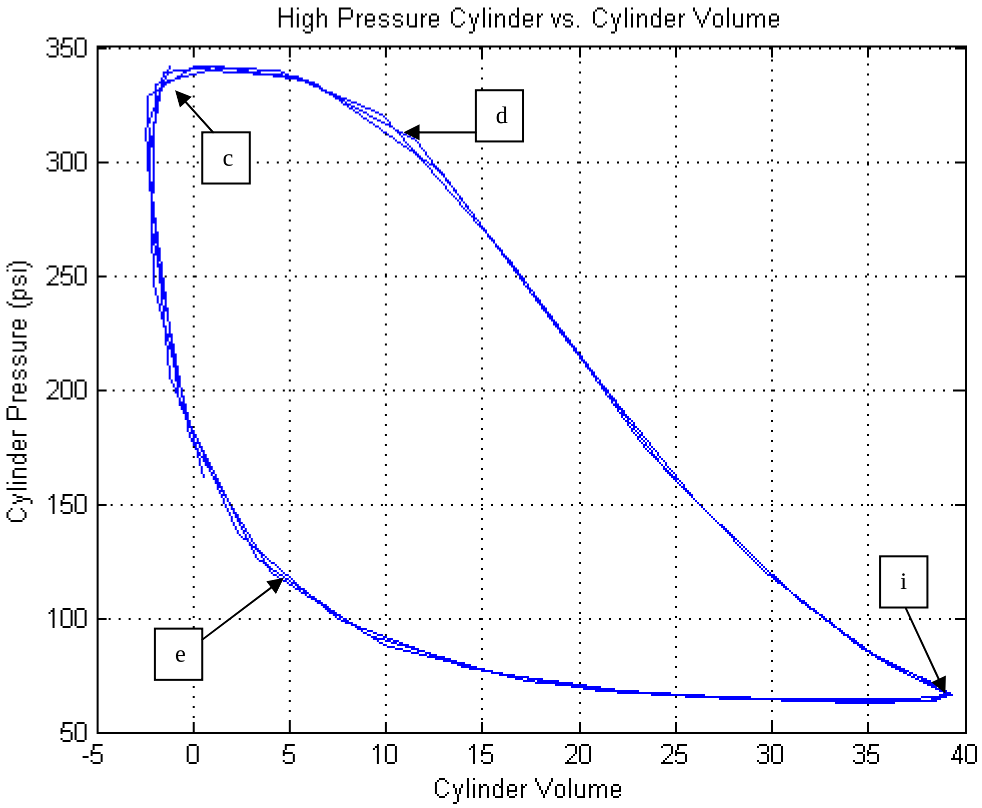


Figure #11 Pressure Against Volume for High Pressure Cylinder

The high pressure cylinder cycle follows the ideal compression cycle almost exactly. The main difference is that transitions between cycle operations are a gradual process. Because of this the various parts of the cycle can be identified with a fair amount of accuracy, therefore transition points are plotted on the graph. Because of the facts just listed previously, the idealized cycle should give a fairly accurate approximation of the actual cycle.

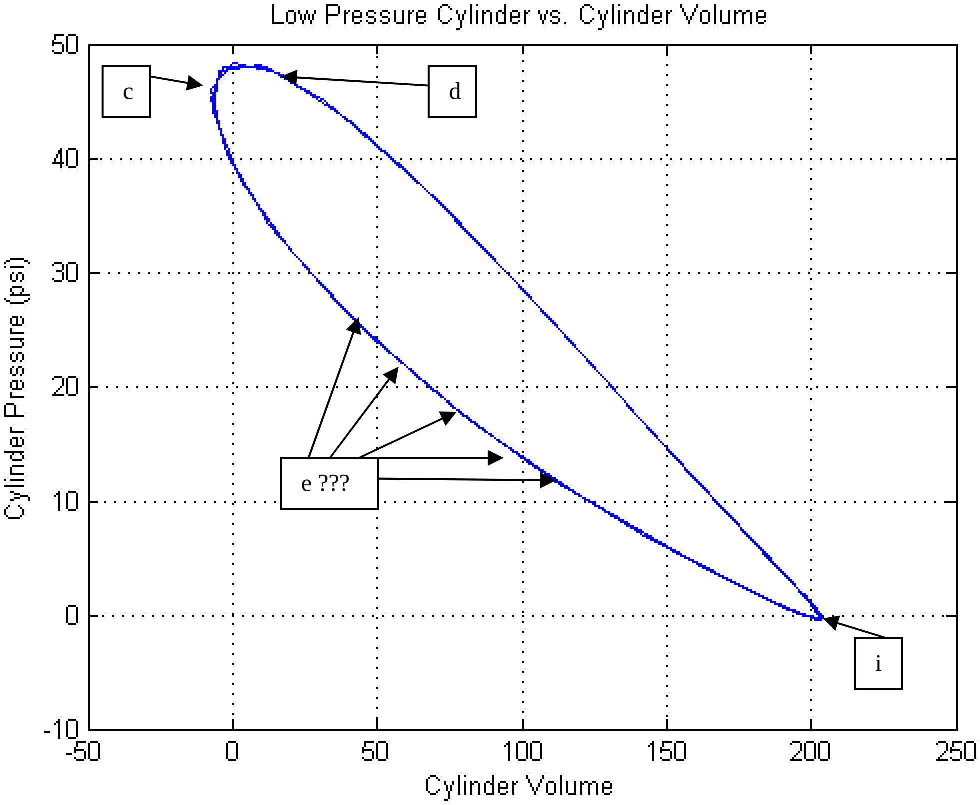


Figure #12 Pressure Against Volume for Low Pressure Cylinder

The low pressure cylinder cycle does not follow the ideal compression cycle very well at all. Although the overall cycle resembles the ideal cycle, this resemblance is minimum. Because of this, the various parts of the cycle are difficult to identify and the ones that are identifiable have severe error associated with their positions, (see the figure above). Because of the facts just listed previously, the idealized cycle will give only a rough estimate of the actual cycle taking place in this instance.

Lab #5 Gas Turbine

Recalculation of the gas cycle was done to show the inaccuracy due to the use of specific heats. The calculations will show the percentage difference of the thermal efficiencies due to assumptions of constant specific heats.

Table #1 shows the thermal efficiencies due to three different types of calculations. See the appendix for the calculations.

Table #1 Calculation Method and its Associated Thermal Efficiency

How the calculation was performed	Thermal Efficiencies
a_th1: Constant Cp	8.465%
a_th2: Variable Cp; Assuming T1 and T3 are accurate	10.269%
a_th3: Variable Cp; Assuming T1 and T4a are accurate	4.591%
a_th4: Manufacture given efficiency:	About 30%

The assumption of T1 and T3 being accurate is done because it gives a value of thermal efficiency that is the closest to the manufactures specifications. The percentage difference between a_th1 and a_th2 is found to be 19%. This is found by using the equation:
% diff = (a_th2 - a_th1) / ((a_th2 + a_th1)/ 2).

Conclusion

Lab #3 Wind Tunnel

As a result of this laboratory the velocity and pressure profiles confirmed our initial expectations. The wake present should have a profile that is very uniform and show significant differences near the wall where the pilot tube is cut to fit. The static pressure behind the cylinder is symmetrical about the midpoint of the vertical distance. The midpoint is where the cylinder is located, so it makes sense that the static pressure is symmetrical about that point. In addition the velocity and pressure profiles from Lab 3 were found to be in error. The jerkiness of the graphs was shown to be an error of the machine used not an inherent property of the air itself. The pressure drop near the wall where the pilot tube was cut did not exhibit actual values for lab 3 either. In short, make sure all the equipment works properly before trusting its readins.

Lab #4 Compressor

As a result of this lab the actual compressions cycles were found behave overall like ideal compression cycles. However, the low compression cycle does not resemble many of the characteristics present in the ideal compression cycle. The results obtained in lab 4 will have errors associated with all values dependant on the ideal cycle. To increase the accuracy of the results obtained in lab 4 there could have been correction factors used to correct all values derived from the ideal cycle assumption.

Lab #5 Gas Turbine

As a result of this laboratory the thermal efficiencies were compared and temperature sensors were evaluated. The use of constant specific heats results in an error of 19%. This error is significant so the use of variable specific heats is recommended. In addition to the errors associated with specific heats the temperature sensors were also evaluated. The temperature sensor associated with T3 was found to be more accurate than the temperature sensor associated with T4a. This conclusion was made because the thermal efficiencies calculated from both these temperature sensors (a_th2 and a_th3) showed a significant difference. The value of a_th2 was much closer to the manufactures value so its temperature sensor (T3) was found to be more accurate. It is recommended that both theses sensor be moved to different locations. Once T3 and T4a have been moved the accuracy of the thermal efficiencies should increase.

References

Allen, Tracy. Applied Sensors. Version 1.4. © 2003 Parallax.

Thermodynamics Text .

Appendix A: Sample Calculations

Lab #3 Wind Tunnel

1. The conversion of voltage to inches is calculated with the equation below:

   y = (V – V_min)/((V_max-V_min)/12) ... (eqn 5)

   6.565 = (6.2903 - 0.0149)/((11.4861 - 0.0149)/12)

2. The static pressure head is calculated with the equation below:

   hs = ht-hv ... (eqn 6)

   -0.537 = (-0.0513) - 0.4864

3. The calculation of the velocity of the air is done using the equation below:

   V = (2*rho_manometer*g*hv/rho_air)^(1/2) ... (eqn 7)

   13.9 m/s = (2*(1000kg/m^3)*(9.81m/s^2)*(0.4863in/(39.37in/m))/(1.25kg/m^3))^(1/2)

4. The total pressrue is calculated with the equation below:

   P_t = rho_manometer*g*ht ... (eqn 8)

   -0.01278 KPa = (1000kg/m^3)*(9.81m/s^2)*(-0.0513in/(39.37in/m))

5. The static pressure is calculated with the equation below:

   P_s = rho_manometer*g*hs ... (eqn 9)

   -0.13353 KPa = (1000kg/m^3)*(9.81m/s^2)*(-0.5359in/(39.37in/m))

Lab #4 Compressor

- Calculat the position of the cylinder.

position = stroke/(Vmax - Vmin)*(V - Vmin) ... (eqn 1)

0.0757 = 5/(6.9284 – (-4.9463))*(-4.7656 – (-4.9463))

- Calculate the volume displaced by the cylinders at each position:

Volume = (pi*d^2/4)* position ... (eqn 2)

0.5809 = pi*3.125^2 / 4 * 0.0757

Lab #5 Gas Turbine

Calculations Assuming T3 is More Accurate than T4a

If T1, **T3,** P1 and P2, as well as the isentropic efficiency for compressor n_c and for turbine n_t are known then the thermal efficiency can be calculated. This calculation will be done using variable specific heats. Becuase variable specific heats will be used the enthalpy's and Pr values will have to be looked up at each state.

75 percent efficiencies.
n_c = 0.75 and n_t = n_c

Enthalpys and Pr's obtained from Introduction to Thermodynamics text:
h1 = 302.20, Known because T1 is known.
Pr1 = 1.487
h3 = 1137.98, Known because T3 is known.
Pr3 = 155.5

The steps:

1. Calculate h2s and h4s (enthalpy's)

2. Calculate h2a and h4a

3. Calculate the work done by the turbine (w_t)

4. Calculate the work done compressing the air in compresser (w_c)

5. Calculate the net work done

6. Calculate the heat generated in the burner (q_in)

7. Calculate the actual thermal efficiency of the cycle (n_th)

For step 1:

- Calculate Pr2:

Pr2 = Pr1*r_p ... (eqn 1)

Pr2 = 1.487*3.4 = 5.0558

- Knowing Pr2 and P2, h2s can be found using thermo text book.

h2s = 434.8673 kJ/kg.

- Calculate Pr2:

Pr4 = Pr3/r_p ... (eqn 2)

Pr4 = 155.5/3.4

- Knowing Pr4 and P4, h4s can be found using thermo text book.

h4s = 811.9116 kJ/kg

For step 2:

- Deffinition of isentropic efficiancey of a compressor (n_c):

n_c = (h2s - h1)/(h2a - h1) ... (eqn 3)

- Rearange equation 3 to get:

h2a = (h2s - h1)/n_c + h1 ...(eqn 4)

h2a = (434.867-302.2)/(0.75) + (302.2) = 479.0897 kJ/kg

- Deffinition of isentropic efficiancey of a turbine (n_t):

n_t = (h3 - h4a)/(h3 - h4s) ... (eqn 5)

- Rearange equation 5 to get:

h4a = h3 - (h3 - h4s)*n_c ...(eqn 6)

h4a = (1138) – (1138-811.9116)*(0.75) = 893.4287 kJ/kg

For step 3:

- Deffinition of work done by turbine

w_t = h3 - h4a ... (eqn 7)

w_t = 1138 - 811.9116 = 244.5513 kJ/kg

For step 4:

- Deffinition of work done by compressor

w_c = h2a - h1 ... (eqn 8)

w_c = 479.0897 – 302.2 = 176.8897 kJ/kg

For step 5:

- Deffinition of net work

w_net = w_t - w_c ... (eqn 9)

w_net = 244.5513 - 176.8897 = 67.6616 kJ/kg

For step 6:

- Deffinition heat entering the system

q_in = h3 - h2a ... (eqn 10)

q_in = 1138 - 479.0897 = 658.8903 kJ/kg

For step 7:

- Deffinition of actual thermal efficiency n_th = (w_net)/q_in ... (eqn 11)

n_th = 67.6616/658.8903*100% = 10.269%

Calculations Assuming T4a is More Accurate than T3

If T1, **T4a**, P1 and P2, as well as the isentropic efficiency for compressor n_c and for turbine n_t are known then the thermal efficiency can be calculated. This calculation will be done using variable specific heats. Becuase variable specific heats will be used the enthalpy's and Pr values will have to be looked up at each state.

75 percent efficiencies
n_c = 0.75 and n_t = n_c

Enthalpys and Pr's obtained from Introduction to Thermodynamics text:
h1 = 302.20, Known because T1 is known.
Pr1 = 1.487
h4a = 746.81, Known because T4 is known

*See the MATLAB file in the appendix for the neumerical calculations. The neumerical portion is not shown because multiple itterations were needed.

The steps:

1. Calculate h2s (enthalpy)

2. Calculate h2a

3. Perform iterations to find h4a

4. Calculate the work done by the turbine (w_t)

5. Calculate the work done compressing the air in compresser (w_c)

6. Calculate the net work done

7. Calculate the heat generated in the burner (q_in)

8. Calculate the actual thermal efficiency of the cycle (n_th)

For step 1:

Pr2 = Pr1*r_p ... (eqn 1)

Knowing Pr2 and P2, h2a can be found.

For step 2:

Deffinition of isentropic efficiancey of a compressor (n_c):

n_c = (h2s - h1)/(h2a - h1) ... (eqn 2)

Rearange equation 2 to get:

h2a = (h2s - h1)/n_c + h1 ...(eqn 3)

For step 3:

Iteration procedure:

1st Assume h3

2nd calculate h4s

Pr4 = Pr3/r_p ... (eqn 4)

Knowing Pr4 and P4, h4s can be found.

3rd calculate h4a

Deffinition of isentropic efficiancey of a turbine (n_t):

n_t = (h3 - h4a)/(h3 - h4s) ... (eqn 5)

Rearange equation 5 to get:

h4a = h3 - (h3 - h4s).*n_c ...(eqn 6)

5th iterate

Perform the above opporations untill the calculated value of h4a equals the actual value of h4a.

For step 3:

Deffinition of work done by turbine

$w_t = h3 - h4a$ ... (eqn 7)

For step 4:

Deffinition of work done by compressor

$w_c = h2a - h1$ ... (eqn 8)

For step 5:

Deffinition of net work

$w_{net} = w_t - w_c$ ... (eqn 9)

For step 6:

Deffinition heat entering the system

$q_{in} = h3 - h2a$ ... (eqn 10)

For step 7:

Deffinition of actual thermal efficiency

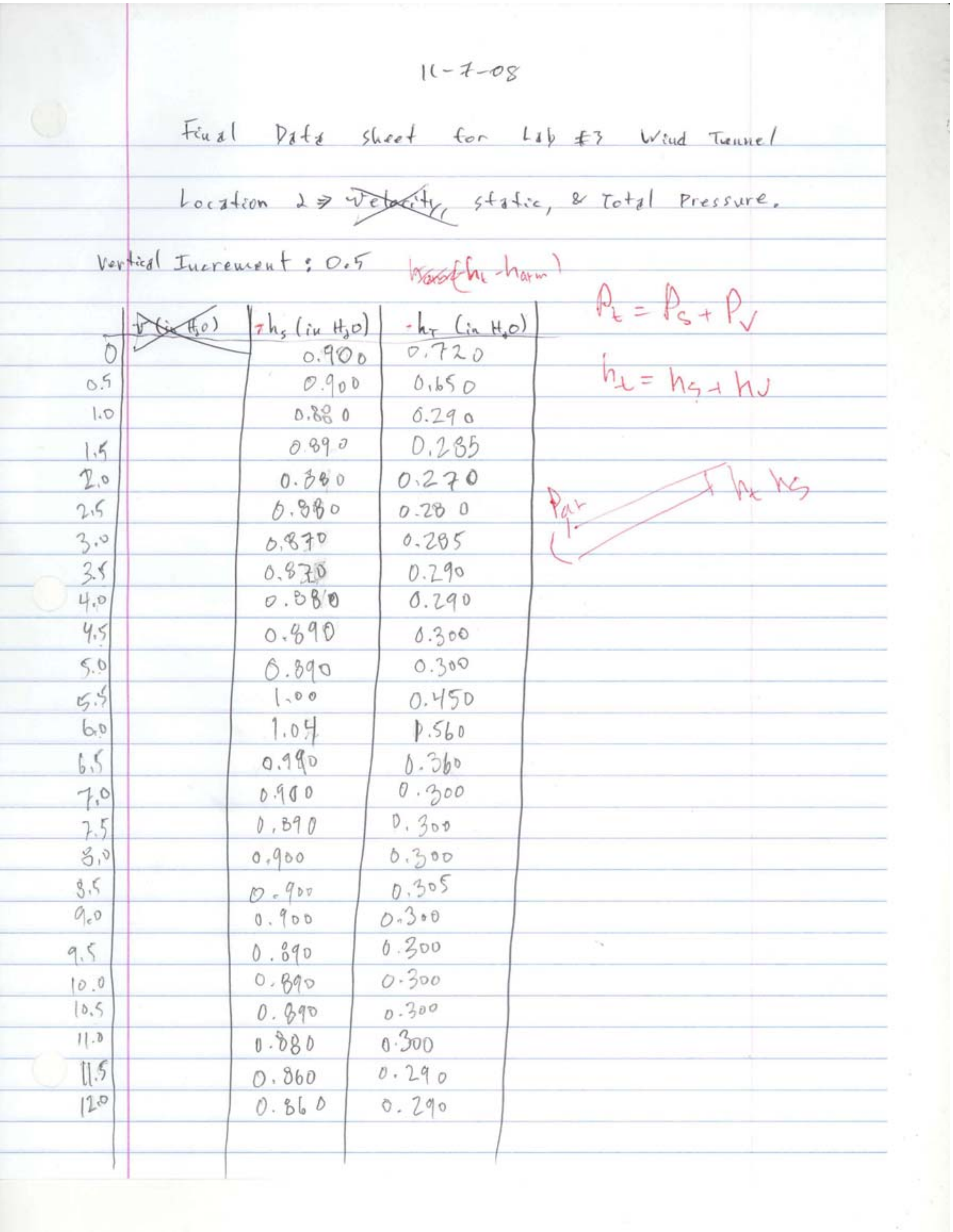
$n_{th} = (w_t - w_c)/q_{in}$ ... (eqn 11)

n_{th} = a value between 5.296% and 3.886%

n_{th} =

Appendix B: Raw Data and Calculations

Lab #3 Wind Tunnel



11-7-08

Final Data sheet for Lab #3 Wind Tunnel

Location 2 ⇒ ~~Velocity,~~ static, & Total Pressure.

Vertical Increment : 0.5

~~[illegible]~~$(h_t - h_{atm})$

$P_t = P_s + P_v$

$h_t = h_s + h_v$

	~~v (in H_2O)~~	$-h_s$ (in H_2O)	$-h_T$ (in H_2O)
0		0.900	0.720
0.5		0.900	0.650
1.0		0.880	0.290
1.5		0.890	0.285
2.0		0.880	0.270
2.5		0.880	0.280
3.0		0.870	0.285
3.5		0.870	0.290
4.0		0.880	0.290
4.5		0.890	0.300
5.0		0.890	0.300
5.5		1.00	0.450
6.0		1.04	0.560
6.5		0.990	0.360
7.0		0.900	0.300
7.5		0.890	0.300
8.0		0.900	0.300
8.5		0.900	0.305
9.0		0.900	0.300
9.5		0.890	0.300
10.0		0.890	0.300
10.5		0.890	0.300
11.0		0.880	0.300
11.5		0.860	0.290
12.0		0.860	0.290

Figure #13 Final Wind Tunnel Lab Data Sheet

Final Lab Data Sheet and Calculations for Lab #3 Wind Tunnel
11/7/2008
Measure static and total pressure at location 2
Vertical Increment: 0.5 in

VD = Vertical Distance, measued from the top (in)
hs = static pressure head, negative values (in of H2O)
ht = total pressure head, negative values (in of H2O)

VD (in)	hs (in H2O)	ht (in H2O)	hv (in H2O)	Velocity v (m/s)	Static Pressure Ps (kPa)	Total Pressure Pt (kPa)
0.0	0.90	0.720	0.18	8.471260563	-0.224257049	-0.179405639
0.5	0.90	0.650	0.25	9.983476315	-0.224257049	-0.161963424
1.0	0.88	0.290	0.59	15.33690733	-0.219273559	-0.072260605
1.5	0.89	0.285	0.61	15.53064437	-0.221765304	-0.071014732
2.0	0.88	0.270	0.61	15.59468853	-0.219273559	-0.067277115
2.5	0.88	0.280	0.60	15.466335	-0.219273559	-0.06976886
3.0	0.87	0.285	0.59	15.27178216	-0.216781814	-0.071014732
3.5	0.87	0.290	0.58	15.20637809	-0.216781814	-0.072260605
4.0	0.88	0.290	0.59	15.33690733	-0.219273559	-0.072260605
4.5	0.89	0.300	0.59	15.33690733	-0.221765304	-0.07475235
5.0	0.89	0.300	0.59	15.33690733	-0.221765304	-0.07475235
5.5	1.00	0.450	0.55	14.80788839	-0.249174498	-0.112128524
6.0	1.04	0.560	0.48	13.83351057	-0.259141478	-0.139537719
6.5	0.99	0.360	0.63	15.84827733	-0.246682753	-0.089702819
7.0	0.90	0.300	0.60	15.466335	-0.224257049	-0.07475235
7.5	0.89	0.300	0.59	15.33690733	-0.221765304	-0.07475235
8.0	0.90	0.300	0.60	15.466335	-0.224257049	-0.07475235
8.5	0.90	0.305	0.60	15.40175712	-0.224257049	-0.075998222
9.0	0.90	0.300	0.60	15.466335	-0.224257049	-0.07475235
9.5	0.89	0.300	0.59	15.33690733	-0.221765304	-0.07475235
10.0	0.89	0.300	0.59	15.33690733	-0.221765304	-0.07475235
10.5	0.89	0.300	0.59	15.33690733	-0.221765304	-0.07475235
11.0	0.88	0.300	0.58	15.20637809	-0.219273559	-0.07475235
11.5	0.87	0.290	0.58	15.20637809	-0.216781814	-0.072260605
12.0	0.86	0.290	0.57	15.07471865	-0.214290069	-0.072260605

VD (measured from bottom) (in)
12.0
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0

Figure #14 Final Wind Tunnel Lab Calculations Sheet

Lab #4 Compressor

Transient data recorded by Labtech Notebook.

LABTECH NOTEBOOK
Data file
Time is 22:31:24.25.
Date is 9-05-2008.

ran a transient test at receiver tank pressure 318psig

Pressure: Pressure in low-P cylinder (psig)
Disp. V: Travelling Distance of piston recorded in voltage
Hi Pres: Pressure in high-P cylinder (psig)

Pressur	Disp. V	Hi Pres
0.9766	-4.7656	161.6211
-0.4395	-5.5762	246.0938
0.1465	-5.6738	328.3691
3.4668	-4.9463	341.7969
9.3262	-3.5938	339.8438
16.9922	-1.8896	320.5566
26.2695	0.1465	256.5918
35.8398	2.3438	174.0723
43.1152	4.2578	120.6055
47.4121	5.8057	87.1582
48.3398	6.8018	73.4863
46.0938	7.2559	66.4063
40.8691	6.9824	63.4766
34.1797	6.0205	63.9648
27.0996	4.5557	64.6973
19.7266	2.5928	66.6504
13.0371	0.4248	72.7539
7.1777	-1.8701	88.1348
3.125	-3.667	120.1172
0.4883	-4.9951	179.1992
-0.4395	-5.625	270.9961
0.5371	-5.5615	333.7402
4.3457	-4.7021	340.332
10.7422	-3.2471	337.4023
19.1895	-1.3721	309.3262
28.6133	0.6982	236.5723

37.1582	2.6807	164.5508
43.9941	4.5313	114.502
47.9004	6.0791	82.2754
48.0469	6.9873	71.2891
45.1172	7.2705	66.4063
39.9414	6.8896	63.9648
33.0566	5.8252	62.9883
25.2441	4.1016	64.4531
17.627	1.958	67.8711
11.5723	-0.1074	75.6836
6.543	-2.1338	92.5293
2.6367	-3.8965	125.7324
0.1465	-5.1758	193.3594
-0.4395	-5.6787	298.3398
1.123	-5.4297	339.3555
5.127	-4.5166	342.041
11.8652	-2.998	334.7168
21.1914	-0.9473	294.9219
29.9805	1.001	224.3652
39.0625	3.1543	151.3672
44.9707	4.8486	107.666
48.0957	6.2207	79.834
47.7051	7.0898	68.3594
44.1895	7.2314	65.918
38.0371	6.626	64.4531
31.6406	5.542	64.209
24.1699	3.8184	64.209
16.6016	1.6113	67.627
10.3516	-0.5908	78.8574
5.4688	-2.6221	99.6094
2.0508	-4.2236	137.4512
-0.0488	-5.3223	205.8105
-0.293	-5.708	313.9648
1.7578	-5.3125	341.3086
6.543	-4.2041	342.041
13.4766	-2.6465	331.7871
22.4609	-0.6787	286.6211
32.1777	1.499	205.8105
40.5273	3.54	140.625
46.1426	5.2588	99.3652
48.3398	6.46	77.1484
47.3633	7.1631	67.1387
43.1641	7.1924	64.4531
37.0605	6.499	64.4531
29.834	5.1758	64.9414
22.7051	3.4424	64.9414
15.625	1.3184	68.6035
9.3262	-0.9863	80.8105
4.6387	-2.9785	105.957
1.3672	-4.5313	150.6348

-0.2441	-5.4492	226.5625
-0.1465	-5.6885	320.5566
2.2949	-5.1855	339.8438
7.5684	-3.9844	340.0879
15.625	-2.1826	326.416
24.3652	-0.2588	270.9961
33.5938	1.8066	192.3828
41.7969	3.877	130.6152
46.7773	5.5029	93.2617
48.3887	6.665	74.707
46.7773	7.207	67.1387
42.334	7.1143	63.4766
35.6445	6.2695	63.4766
28.2715	4.8193	65.1855
20.8984	2.9102	66.4063
14.3555	0.8496	70.5566
8.5449	-1.3379	83.7402
3.8574	-3.3594	112.0605
0.9277	-4.8047	163.3301
-0.4395	-5.5957	252.1973
0.1465	-5.6641	328.6133
3.125	-5.0098	341.5527
9.1797	-3.6084	339.1113
17.8223	-1.6797	316.6504
26.6602	0.2734	254.3945
35.4004	2.2852	178.2227
42.7734	4.1895	123.291
47.4609	5.8301	86.4258
48.291	6.9092	71.7773
45.9961	7.2852	67.3828
41.2598	7.041	64.209
34.5703	6.1035	62.9883
26.8066	4.4922	63.4766
19.4824	2.5146	66.6504
12.8418	0.332	73.7305
7.2754	-1.8555	88.8672
3.3203	-3.5938	116.9434
0.4883	-5.0146	177.7344
-0.4395	-5.6592	274.9023
0.6348	-5.5664	336.1816
4.0527	-4.79	341.3086
10.2539	-3.374	336.9141
19.1895	-1.3916	308.5938
28.5156	0.6738	237.5488
37.3535	2.7393	164.3066
44.1895	4.5947	114.2578
47.8027	5.9961	83.0078
48.1445	6.958	69.8242
45.3613	7.2705	65.6738
39.6973	6.8555	65.1855

32.8125	5.7764	64.209
25.6836	4.2041	63.2324
18.4082	2.1777	65.6738
11.5723	-0.1416	75.9277
6.3965	-2.2314	94.4824
2.4902	-3.9941	128.9063
0.1465	-5.21	193.3594
-0.4395	-5.7031	291.2598
1.123	-5.4541	337.6465
5.3711	-4.4824	343.0176
12.1582	-2.9297	334.7168
20.5078	-1.0889	298.8281
29.9805	1.0107	224.3652
39.0137	3.1592	151.6113
45.166	4.9414	106.4453
48.1934	6.3037	79.1016
47.8516	7.0801	68.3594
44.4824	7.2656	64.4531
38.3789	6.6992	63.9648
31.3477	5.4932	65.4297
23.8281	3.7451	64.6973
16.9922	1.748	66.4063
10.7422	-0.4346	75.9277
5.4688	-2.627	99.1211
1.9043	-4.2822	140.1367
-0.0977	-5.3613	210.9375
-0.3418	-5.7227	309.5703
1.6113	-5.3662	338.3789
6.543	-4.2188	340.5762
13.8184	-2.583	331.7871
22.8027	-0.6006	283.9355
31.8359	1.4111	208.252
40.0391	3.4082	142.8223
46.0938	5.2344	99.3652
48.3887	6.4893	77.1484
47.2656	7.1777	68.1152
43.4082	7.2021	63.9648
37.5	6.5625	63.2324
29.8828	5.1758	64.4531
22.4121	3.3594	65.6738
15.4297	1.2354	69.5801
9.668	-0.8545	79.3457
4.8828	-2.8564	102.7832
1.3672	-4.5264	151.3672
-0.2441	-5.459	230.7129
-0.0977	-5.6738	324.2188
2.2949	-5.1807	340.5762
7.4707	-3.9893	338.623
15.5762	-2.1875	327.1484
24.707	-0.1807	270.0195

33.9844	1.9092	190.6738
41.4551	3.7793	132.0801
46.6309	5.4297	93.75
48.4375	6.6699	73.9746
46.6797	7.2217	67.3828
42.1875	7.0996	63.9648
36.0352	6.3232	62.9883
28.7598	4.9316	63.2324
20.8984	2.9346	65.6738
14.1113	0.7813	71.5332
8.3496	-1.377	84.4727
4.1016	-3.2227	109.6191
1.0254	-4.707	159.1797
-0.4395	-5.5664	251.709
0.1953	-5.625	330.8105
3.3203	-4.9463	341.0645
8.8867	-3.6719	338.3789
16.7969	-1.9092	320.3125

MATLAB File

Programmer: Aaron Klapheck

```
% Lab #4 The Reciprocating Air Compressor 20-Nov-08

% Analyzing KAB_COMP_PV.xls.

clear, clc, home

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

```
The date and time: 12-Dec-2008 16:09:28
```

Get data from the KAB_COMP_PV.xls file

```
% Constant data.


P_atm = 30;     % Atmospheric Pressure in inches of Hg (inHg).

T_room = 23;    % Room temperature in degrees Celcius (C).

N = 150;        % Angular acceleration in revolutions per minute (rpm).

d_low = 7;      % Diameter of low pressure piston in inches (in).

d_high = 3.125; % Diameter of high pressure piston in inches (in).

stroke = 5;     % Distance the piston travels in one direction measured
```

```
                % in inches (in) aka stroke.



% The following data was recorded over a perid of a few seconds. This data

% is time dependant and shows how the Pressure and Volume change over a

% number of complete cycles. The receiver tank pressure is at 318 psi.



numeric = [0.9766      -4.7656 161.6211

-0.4395  -5.5762 246.0938

0.1465   -5.6738 328.3691

3.4668   -4.9463 341.7969 % HP min

9.3262   -3.5938 339.8438

16.9922  -1.8896 320.5566

26.2695  0.1465  256.5918

35.8398  2.3438  174.0723

43.1152  4.2578  120.6055

47.4121  5.8057  87.1582

48.3398  6.8018  73.4863 % LP min

46.0938  7.2559  66.4063

40.8691  6.9824  63.4766 % HP max

34.1797  6.0205  63.9648

27.0996  4.5557  64.6973

19.7266  2.5928  66.6504

13.0371  0.4248  72.7539

7.1777   -1.8701 88.1348

3.125    -3.667  120.1172

0.4883   -4.9951 179.1992 % LP max

-0.4395  -5.625  270.9961

0.5371   -5.5615 333.7402

4.3457   -4.7021 340.332

10.7422  -3.2471 337.4023

19.1895  -1.3721 309.3262

28.6133  0.6982  236.5723
```

37.1582	2.6807	164.5508
43.9941	4.5313	114.502
47.9004	6.0791	82.2754
48.0469	6.9873	71.2891
45.1172	7.2705	66.4063
39.9414	6.8896	63.9648
33.0566	5.8252	62.9883
25.2441	4.1016	64.4531
17.627	1.958	67.8711
11.5723	-0.1074	75.6836
6.543	-2.1338	92.5293
2.6367	-3.8965	125.7324
0.1465	-5.1758	193.3594
-0.4395	-5.6787	298.3398
1.123	-5.4297	339.3555
5.127	-4.5166	342.041
11.8652	-2.998	334.7168
21.1914	-0.9473	294.9219
29.9805	1.001	224.3652
39.0625	3.1543	151.3672
44.9707	4.8486	107.666
48.0957	6.2207	79.834
47.7051	7.0898	68.3594
44.1895	7.2314	65.918
38.0371	6.626	64.4531
31.6406	5.542	64.209
24.1699	3.8184	64.209
16.6016	1.6113	67.627
10.3516	-0.5908	78.8574
5.4688	-2.6221	99.6094
2.0508	-4.2236	137.4512
-0.0488	-5.3223	205.8105
-0.293	-5.708	313.9648
1.7578	-5.3125	341.3086

6.543	-4.2041	342.041
13.4766	-2.6465	331.7871
22.4609	-0.6787	286.6211
32.1777	1.499	205.8105
40.5273	3.54	140.625
46.1426	5.2588	99.3652
48.3398	6.46	77.1484
47.3633	7.1631	67.1387
43.1641	7.1924	64.4531
37.0605	6.499	64.4531
29.834	5.1758	64.9414
22.7051	3.4424	64.9414
15.625	1.3184	68.6035
9.3262	-0.9863	80.8105
4.6387	-2.9785	105.957
1.3672	-4.5313	150.6348
-0.2441	-5.4492	226.5625
-0.1465	-5.6885	320.5566
2.2949	-5.1855	339.8438
7.5684	-3.9844	340.0879
15.625	-2.1826	326.416
24.3652	-0.2588	270.9961
33.5938	1.8066	192.3828
41.7969	3.877	130.6152
46.7773	5.5029	93.2617
48.3887	6.665	74.707
46.7773	7.207	67.1387
42.334	7.1143	63.4766
35.6445	6.2695	63.4766
28.2715	4.8193	65.1855
20.8984	2.9102	66.4063
14.3555	0.8496	70.5566
8.5449	-1.3379	83.7402
3.8574	-3.3594	112.0605

0.9277	-4.8047	163.3301
-0.4395	-5.5957	252.1973
0.1465	-5.6641	328.6133
3.125	-5.0098	341.5527
9.1797	-3.6084	339.1113
17.8223	-1.6797	316.6504
26.6602	0.2734	254.3945
35.4004	2.2852	178.2227
42.7734	4.1895	123.291
47.4609	5.8301	86.4258
48.291	6.9092	71.7773
45.9961	7.2852	67.3828
41.2598	7.041	64.209
34.5703	6.1035	62.9883
26.8066	4.4922	63.4766
19.4824	2.5146	66.6504
12.8418	0.332	73.7305
7.2754	-1.8555	88.8672
3.3203	-3.5938	116.9434
0.4883	-5.0146	177.7344
-0.4395	-5.6592	274.9023
0.6348	-5.5664	336.1816
4.0527	-4.79	341.3086
10.2539	-3.374	336.9141
19.1895	-1.3916	308.5938
28.5156	0.6738	237.5488
37.3535	2.7393	164.3066
44.1895	4.5947	114.2578
47.8027	5.9961	83.0078
48.1445	6.958	69.8242
45.3613	7.2705	65.6738
39.6973	6.8555	65.1855
32.8125	5.7764	64.209
25.6836	4.2041	63.2324

18.4082	2.1777	65.6738
11.5723	-0.1416	75.9277
6.3965	-2.2314	94.4824
2.4902	-3.9941	128.9063
0.1465	-5.21	193.3594
-0.4395	-5.7031	291.2598
1.123	-5.4541	337.6465
5.3711	-4.4824	343.0176
12.1582	-2.9297	334.7168
20.5078	-1.0889	298.8281
29.9805	1.0107	224.3652
39.0137	3.1592	151.6113
45.166	4.9414	106.4453
48.1934	6.3037	79.1016
47.8516	7.0801	68.3594
44.4824	7.2656	64.4531
38.3789	6.6992	63.9648
31.3477	5.4932	65.4297
23.8281	3.7451	64.6973
16.9922	1.748	66.4063
10.7422	-0.4346	75.9277
5.4688	-2.627	99.1211
1.9043	-4.2822	140.1367
-0.0977	-5.3613	210.9375
-0.3418	-5.7227	309.5703
1.6113	-5.3662	338.3789
6.543	-4.2188	340.5762
13.8184	-2.583	331.7871
22.8027	-0.6006	283.9355
31.8359	1.4111	208.252
40.0391	3.4082	142.8223
46.0938	5.2344	99.3652
48.3887	6.4893	77.1484
47.2656	7.1777	68.1152

```
43.4082  7.2021  63.9648

37.5     6.5625  63.2324

29.8828  5.1758  64.4531

22.4121  3.3594  65.6738

15.4297  1.2354  69.5801

9.668    -0.8545 79.3457

4.8828   -2.8564 102.7832

1.3672   -4.5264 151.3672

-0.2441  -5.459  230.7129

-0.0977  -5.6738 324.2188

2.2949   -5.1807 340.5762

7.4707   -3.9893 338.623

15.5762  -2.1875 327.1484

24.707   -0.1807 270.0195

33.9844  1.9092  190.6738

41.4551  3.7793  132.0801

46.6309  5.4297  93.75

48.4375  6.6699  73.9746

46.6797  7.2217  67.3828

42.1875  7.0996  63.9648

36.0352  6.3232  62.9883

28.7598  4.9316  63.2324

20.8984  2.9346  65.6738

14.1113  0.7813  71.5332

8.3496   -1.377  84.4727

4.1016   -3.2227 109.6191

1.0254   -4.707  159.1797

-0.4395  -5.5664 251.709

0.1953   -5.625  330.8105

3.3203   -4.9463 341.0645

8.8867   -3.6719 338.3789

16.7969  -1.9092 320.3125];


% P_low is the pressure in the low pressure cylinder (negative values)(psi)
```

```
% P_high is the pressure in the high pressure cylinder (psi)

% D is the displacement of the cylinder (Volts)


P_low = numeric(1:60,1);

D = numeric(1:60,2);

P_high = numeric(1:60,3);


% The following min's and maxes come form the one range of a piston stroke.

% (piston fully up to piston fully down). Measured in voltage

LP_min = 6.8018;

LP_max = -4.9951;

HP_min = -4.9463;

HP_max = 6.9824;
```

Calculate the Volume of both cylinders

```
position_LP = stroke./(LP_max-LP_min).*(D-LP_min);

position_HP = stroke./(HP_max-HP_min).*(D-HP_min);

V_low =  (pi.*d_low.^2./4).*position_LP;

V_high = (pi.*d_high.^2./4).*position_HP;
```

Graph of Volume vs. Low Pressure

```
plot(V_low, P_low), grid, xlabel('Cylinder Volume'), ...

    ylabel('Cylinder Pressure (psi)'), ...

    title('Low Pressure Cylinder vs. Cylinder Volume')
```

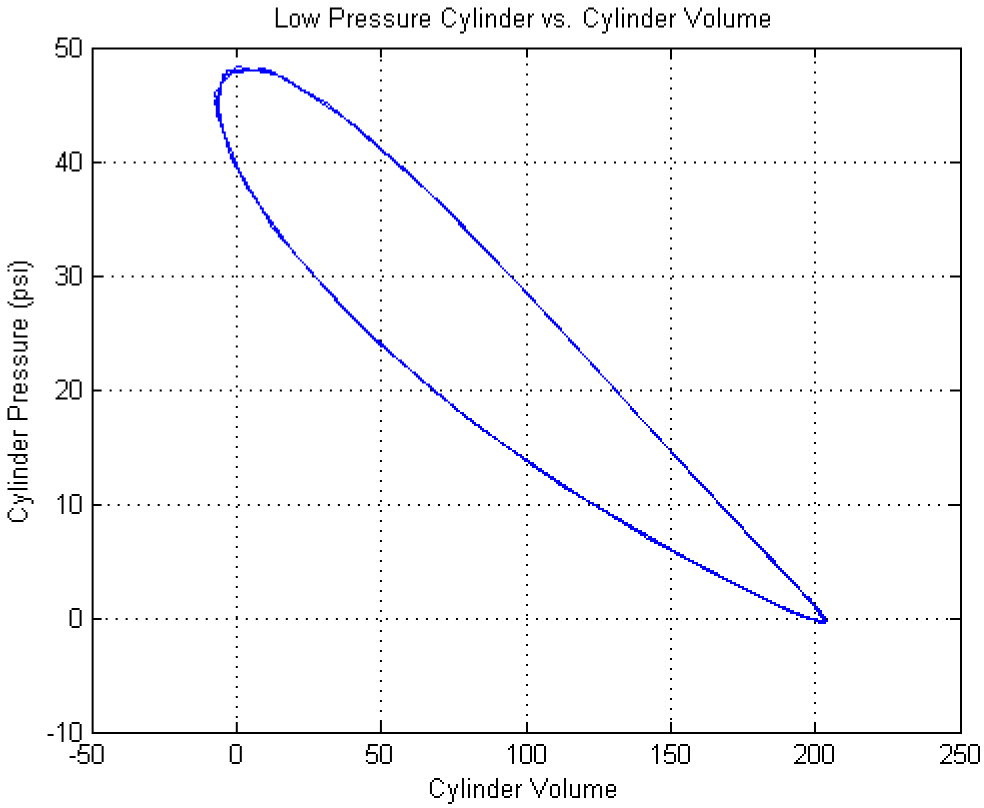


Figure #15 Pressure Against Volume for Low Pressure Cylinder

Graph of Volume vs. High Pressure

```
plot(V_high, P_high), grid, xlabel('Cylinder Volume'), ...

    ylabel('Cylinder Pressure (psi)'), ...

    title('High Pressure Cylinder vs. Cylinder Volume')
```

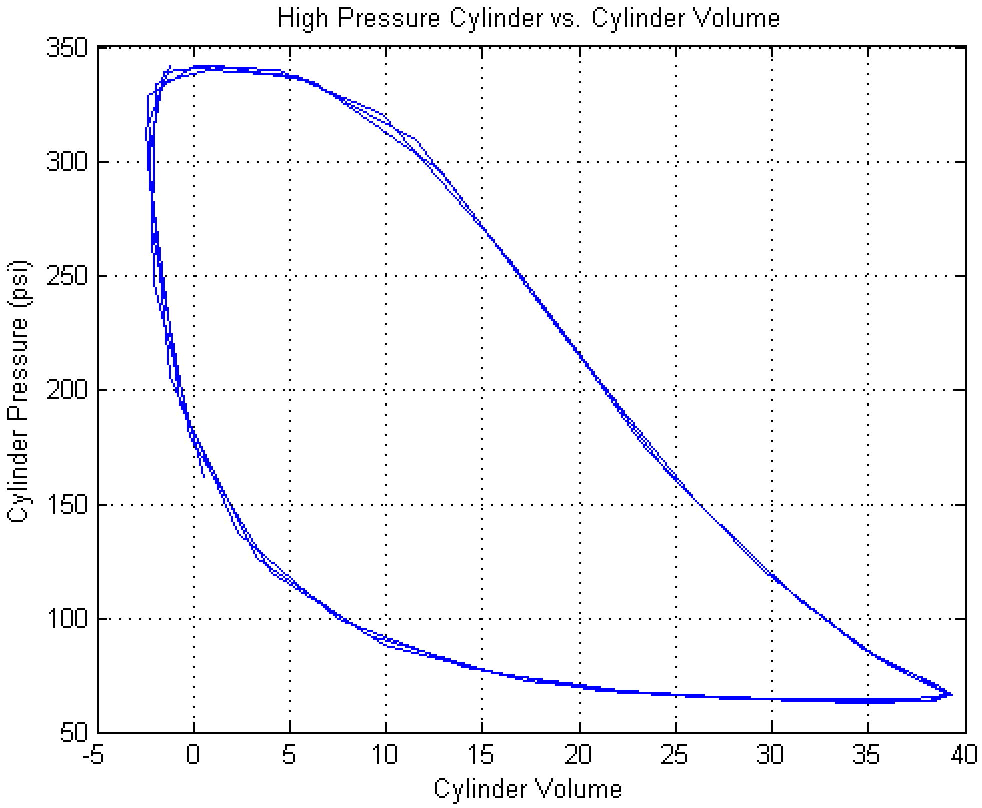


Figure #16 Pressure Against Volume for High Pressure Cylinder

Lab #5 Gas Turbine

MATLAB file

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: 12-Dec-2008 16:48:04
```

Data

```
% P1 remains constant throughout this experament:


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
```

Calculations with Constant Specific Heats

```
% 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
% compresser using the 4 equations below.
%
% For a compressor with constant specific heats:
%   T2s/T1 = (P2/P1)^((k-1)/k) ... (eqn 1).
% Deffinition of isentropic efficiancey 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).
% Deffinition of isentropic efficiancey 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%
```

Calculations with Variable Specific Heats Using T1 and T3

```
% Only use the data from the 30KW load.

T1 = [mean(Load_30(:,1))];
T5 = [mean(Load_30(:,2))];
T6 = [mean(Load_30(:,3))];
```

```
T2 = [mean(Load_30(:,4))];

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

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

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

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

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



% Convert all units to metric


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


Load = 30;                          % kW

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

T2a = (T2 - 32)./1.8 + 273.15      % K   Assume wrong, therefore unknown.

T3 = (T3 - 32)./1.8 + 273.15       % K   Assume wrong, therefore unknown.

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

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

P1 = 101  % kPa - atmopheric pressure is 101 kPa

% P3 = P2, P4 = P1.


% pressure ratio (r_p)

r_p = 3.4



%%%% Getting the Answer %%%%

% If T1, T3, P1 and P2, as well as the isentropic efficiency for

% compressor n_c and for turbine n_t are known then the thermal efficiency

% can be calculated. This calculation will be done using variable specific

% heats. Becuase variable specific heats will be used the enthalpy's and Pr

% values will have to be looked up at each state.


n_c = 0.75; n_t = n_c; % 75 percent efficiencies.
```

```
% Enthalpys and Pr's obtained from Introduction to Thermodynamics text:

h1 = 302.20;                  % Known because T1 is known.

Pr1 = 1.487;

h3 = 1137.98;                 % Known because T3 is known.

Pr3 = 155.5;



% The steps:

% 1. Calculate h2s and h4s (enthalpy's)

% 2. Calculate h2a and h4a

% 3. Calculate the work done by the turbine (w_t)

% 4. Calculate the work done compressing the air in compresser (w_c)

% 5. Calculate the net work done

% 6. Calculate the heat generated in the burner (q_in)

% 7. Calculate the actual thermal efficiency of the cycle (n_th)




% The equations:

%

% For step 1:

%   Pr2 = Pr1*r_p ... (eqn 1)

%   Knowing Pr2 and P2, h2s can be found.

%   Pr4 = Pr3/r_p ... (eqn 2)

%   Knowing Pr4 and P4, h4s can be found.

%

% For step 2:

%   Deffinition of isentropic efficiancey of a compressor (n_c):

%   n_c = (h2s - h1)/(h2a - h1) ... (eqn 3)

%   Rearange equation 3 to get:

%   h2a = (h2s - h1)/n_c + h1 ...(eqn 4)

%   Deffinition of isentropic efficiancey of a turbine (n_t):

%   n_t = (h3 - h4a)/(h3 - h4s) ... (eqn 5)

%   Rearange equation 5 to get:
```

```
%   h4a = h3 - (h3 - h4s).*n_c ...(eqn 6)
%
% For step 3:
%   Deffinition of work done by turbine
%   w_t = h3 - h4a ... (eqn 7)
%
% For step 4:
%   Deffinition of work done by compressor
%   w_c = h2a - h1 ... (eqn 8)
%
% For step 5:
%   Deffinition of net work
%   w_net = w_t - w_c ... (eqn 9)
%
% For step 6:
%   Deffinition heat entering the system
%   q_in = h3 - h2a ... (eqn 10)
%
% For step 7:
%   Deffinition of actual thermal efficiency
%   n_th = (w_net)/q_in ... (eqn 11)



fprintf('%%%%%% Get Pr2 using equation 1 %%%%%% \n')
Pr2 = Pr1.*r_p
h2s = (441.61-431.43)*(5.0558-4.915)/(5.332-4.915) + (431.43)

fprintf('%%%%%% Get Pr4 using equation 2 %%%%%% \n')
Pr4 = Pr3./r_p
h4s = (821.95-800.03)*(45.735-43.35)/(47.75-43.35) + (800.03)

fprintf('%%%%%% Get h2a using equation 4 %%%%%% \n')
h2a = (h2s - h1)/n_c + h1
```

```
fprintf('%%%%%% Get h4a using equation 6 %%%%%% \n')
h4a = h3 - (h3 - h4s).*n_c


fprintf('%%%%%% Get w_t using equation 7 %%%%%% \n')
w_t = h3 - h4a


fprintf('%%%%%% Get w_c using equation 8 %%%%%% \n')
w_c = h2a - h1


fprintf('%%%%%% Get w_net using equation 9 %%%%%% \n')
w_net = w_t - w_c


fprintf('%%%%%% Get q_in using equation 10 %%%%%% \n')
q_in = h3 - h2a


fprintf('%%%%%% Get n_th using equation 11 %%%%%% \n')
n_th = (w_net)/q_in;
[num2str(round(100000.*n_th)./1000), ['%']]
```

```
T1 =

  302.0793


T2a =
```

```
  834.0008


T3 =

  1.0805e+003


T4a =

  731.1510


P2 =

  947.1628


P1 =

   101


r_p =

    3.4000

%%% Get Pr2 using equation 1 %%%

Pr2 =

    5.0558
```

```
h2s =

  434.8673

%%% Get Pr4 using equation 2 %%%

Pr4 =

   45.7353


h4s =

  811.9116

%%% Get h2a using equation 4 %%%

h2a =

  479.0897

%%% Get h4a using equation 6 %%%

h4a =

  893.4287

%%% Get w_t using equation 7 %%%

w_t =

  244.5513

%%% Get w_c using equation 8 %%%
```

```
w_c =

  176.8897

%%% Get w_net using equation 9 %%%

w_net =

   67.6616

%%% Get q_in using equation 10 %%%

q_in =

  658.8903

%%% Get n_th using equation 11 %%%

ans =

10.269%
```

Calculations with Variable Specific Heats Using T1 and T4a

```
% pressure ratio (r_p)

r_p = P2/P1 %3.4



%%%% Getting the Answer %%%%

% If T1, T4a, P1 and P2, as well as the isentropic efficiency for

% compressor n_c and for turbine n_t are known then the thermal efficiency

% can be calculated. This calculation will be done using variable specific
```

```
% heats. Becuase variable specific heats will be used the enthalpy's and Pr
% values will have to be looked up at each state.

n_c = 0.75; n_t = n_c; % 75 percent efficiencies.

% Enthalpys and Pr's obtained from Introduction to Thermodynamics text:
h1 = 302.20;                    % Known because T1 is known.
Pr1 = 1.487;
h4a = 746.81;                   % Known because T4 is known



% The steps:
% 1. Calculate h2s (enthalpy)
% 2. Calculate h2a
% 3. Perform iterations to find h4a
% 4. Calculate the work done by the turbine (w_t)
% 5. Calculate the work done compressing the air in compresser (w_c)
% 6. Calculate the net work done
% 7. Calculate the heat generated in the burner (q_in)
% 8. Calculate the actual thermal efficiency of the cycle (n_th)



% The equations:
%
% For step 1:
%   Pr2 = Pr1*r_p ... (eqn 1)
%   Knowing Pr2 and P2, h2a can be found.
%
% For step 2:
%   Deffinition of isentropic efficiancey of a compressor (n_c):
%   n_c = (h2s - h1)/(h2a - h1) ... (eqn 2)
%   Rearange equation 2 to get:
```

```
%   h2a = (h2s - h1)/n_c + h1 ...(eqn 3)
%
% For step 3:
%   Iteration procedure:
%       1st Assume h3
%       2nd calculate h4s
%           Pr4 = Pr3/r_p ... (eqn 4)
%           Knowing Pr4 and P4, h4s can be found.
%       3rd calculate h4a
%           Deffinition of isentropic efficiancey of a turbine (n_t):
%           n_t = (h3 - h4a)/(h3 - h4s) ... (eqn 5)
%           Rearange equation 5 to get:
%           h4a = h3 - (h3 - h4s).*n_c ...(eqn 6)
%       5th iterate
%           Perform the above opporations untill the calculated value of
%           h4a equals the actual value of h4a.
%
% For step 3:
%   Deffinition of work done by turbine
%   w_t = h3 - h4a ... (eqn 7)
%
% For step 4:
%   Deffinition of work done by compressor
%   w_c = h2a - h1 ... (eqn 8)
%
% For step 5:
%   Deffinition of net work
%   w_net = w_t - w_c ... (eqn 9)
%
% For step 6:
%   Deffinition heat entering the system
%   q_in = h3 - h2a ... (eqn 10)
%
% For step 7:
```

```
%   Deffinition of actual thermal efficiency

%   n_th = (w_net)/q_in ... (eqn 11)




fprintf('%%%%%% Get Pr2 using equation 1 %%%%%% \n')

Pr2 = Pr1.*r_p

h2s = (441.61-431.43).*(5.0558-4.915)./(5.332-4.915) + (431.43)



fprintf('%%%%%% Get h2a using equation 3 %%%%%% \n')

h2a = (h2s - h1)/n_c + h1



fprintf('%%%%%% Get h4a %%%%%% \n')


fprintf('%% First iteration %%')

h3_1 = 1137.98

Pr3_1 = 155.5

Pr4_1 = Pr3_1./r_p

h4s_1 = (821.95-800.03).*(45.735-43.35)./(47.75-43.35) + (800.03)

h4a_1 = h3_1 - (h3_1 - h4s_1).*n_c

% Value too high.


fprintf('%% Second iteration %%')

h3_2 = 977.92;

Pr3_2 = 89.28;

Pr4_2 = Pr3_2./r_p;

h4s_2 = 692;

h4a_2 = h3_2 - (h3_2 - h4s_2).*n_c;

% Value too high.


fprintf('%% Third iteration %%')

h3_3 = 932.9
```

```
Pr3_3 = 75.29

Pr4_3 = Pr3_3./r_p

h4s_3 = 665

h4a_3 = h3_3 - (h3_3 - h4s_3).*n_c

% Value too low.


fprintf('%% Fourth (Final) iteration %%')

h3_4 = 955.38

Pr3_4 = 82.05

Pr4_4 = Pr3_4./r_p

h4s_4 = (702.52-691.82).*(26.258-25.85)./(27.29-25.85) + (691.82)

h4a_4 = h3_4 - (h3_4 - h4s_4).*n_c

% Value too high.



fprintf('%%%%%% Get w_t using equation 7 %%%%%% \n')

w_t = [h3_3 - h4a_3, h3_4 - h4a_4]



fprintf('%%%%%% Get w_c using equation 8 %%%%%% \n')

w_c = [h2a - h1, h2a - h1]



fprintf('%%%%%% Get w_net using equation 9 %%%%%% \n')

w_net = w_t - w_c



fprintf('%%%%%% Get q_in using equation 10 %%%%%% \n')

q_in = [h3_3 - h2a, h3_4 - h2a]



fprintf('%%%%%% Get n_th using equation 11 %%%%%% \n')

n_th = (w_net)./q_in;

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

```
r_p =

    9.3778

%%% Get Pr2 using equation 1 %%%

Pr2 =

   13.9449


h2s =

  434.8673

%%% Get h2a using equation 3 %%%

h2a =

  479.0897

%%% Get h4a %%%
% First iteration %
h3_1 =

  1.1380e+003


Pr3_1 =

  155.5000
```

```
Pr4_1 =

   16.5816


h4s_1 =

  811.9116


h4a_1 =

  893.4287

% Second iteration %% Third iteration %
h3_3 =

  932.9000


Pr3_3 =

   75.2900


Pr4_3 =

    8.0285


h4s_3 =

   665
```

```
h4a_3 =

  731.9750

% Fourth (Final) iteration %
h3_4 =

  955.3800


Pr3_4 =

   82.0500


Pr4_4 =

    8.7493


h4s_4 =

  694.8517


h4a_4 =

  759.9837

%%% Get w_t using equation 7 %%%

w_t =
```

```
  200.9250  195.3963

%%% Get w_c using equation 8 %%%

w_c =

  176.8897  176.8897

%%% Get w_net using equation 9 %%%

w_net =

   24.0353   18.5065

%%% Get q_in using equation 10 %%%

q_in =

  453.8103  476.2903

%%% Get n_th using equation 11 %%%

ans =

5.296       3.886%
```