Lab 1e
Compressed Air Turbine Performance Measurement

OBJECTIVES

Warning: though the experiment has educational objectives (to learn about boiling heat transfer, etc.), these should not be included in your report.

- To measure the torque/speed, and power/speed curves of a single stage reaction turbine.
- Application of the First Law of Thermodynamics to a simple open system undergoing a steady flow process.
- Determination of the isentropic efficiency of a turbine.

EQUIPMENT

Name	*Model*	*S/N*
Hilton Experimental Turbine	F840	
Computer		

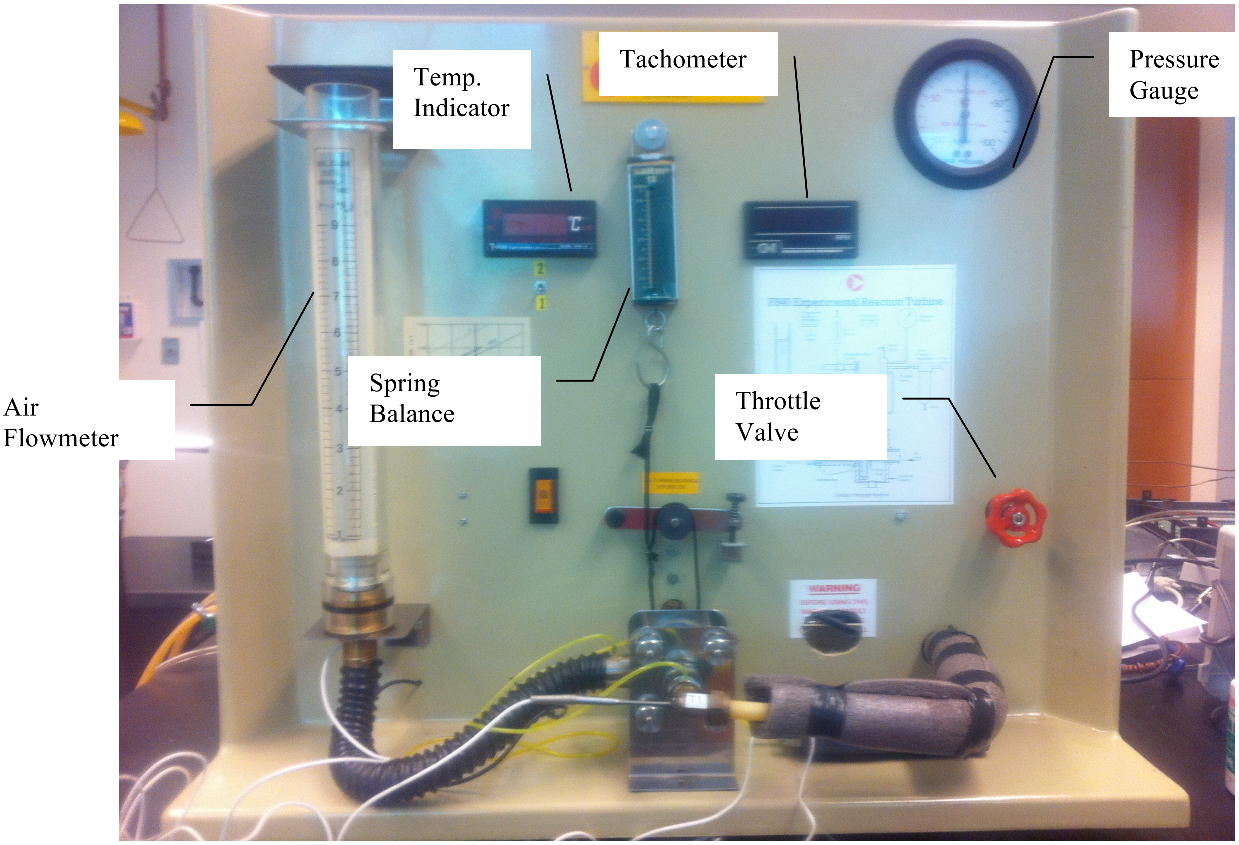

Figure 1 Bench-top Hilton Experimental Turbine

The turbine used in this experiment is the bench-top Hilton Experimental Turbine F840. It is classified as a "single stage, radial flow, reaction turbine". "Single stage" means that the expansion of the fluid from the turbine inlet pressure to the exhaust pressure takes place within on stator and its corresponding rotor. "Radial flow" indicates that the fluid enters and leaves the rotor at different radii without significant axial components in its velocity. Finally, "reaction" means that the fluid pressure drop (and consequent increase of velocity) takes place in the rotor. The fluid therefore passes through the stator at an almost constant pressure.

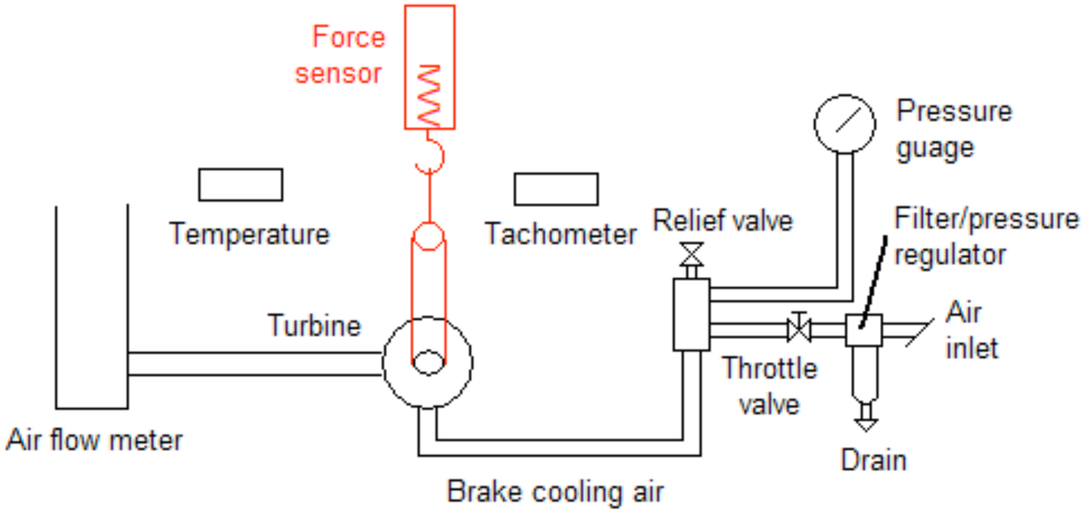

Figure 2 Reaction Turbine Schematic Diagram

<u>REQUIRED READING</u>

1- See reference [1] for operation of the turbine and this write-up for introduction and theory.

PRELAB QUESTIONS (10% of the total grade of the lab, 2.5% each)

1- What is the isentropic efficiency of a turbine?
2- What is the Turbine Pressure Ratio?
3- Describe the torque and power curves of a turbine and explain why they are useful.
4- Read carefully the instructions in this write-up and describe how you will perform measurements to obtain Shaft Power, Heat Transfer of a system and External Isentropic Efficiency of a turbine.

PROCEDURE

Note: Part 1 is designed to perform on the first day and part 2 & part 3 are combined to perform on second day.

Part 1. Investigation of torque/speed and power/speed characteristics of a single stage

1. Measure the radius of the dynamometer appropriately, so bias and precision errors can be estimated.
2. Calibrate the spring force sensor using weights. Make sure that your procedure will let you obtain bias and precision errors.
3. Adjust the throttle valve until the inlet air pressure is at the desired value - say 60 kN m^{-2} gauge (this pressure must then be constant throughout the test).
4. Unscrew the brake adjusting screw until the turbine runs close to its maximum speed but NOT exceeding 40,000 $\frac{rev}{\min}$.
5. When conditions are stable, note the speed, spring balance reading and air flow rate.
6. Rotate the brake adjusting screw until the turbine runs at about 85% of the initial speed, and when stable repeat observations.
7. Repeat in similar decrements of speed until the turbine finally stalls.
8. The test may now be repeated at other constant turbine inlet pressures.

Sample Analysis

Typical results for an Inlet pressure of 60 kN/m^2 gauge are shown.

Calculations--Using Test No. 4

Torque (M) = Force × radius
= 0.75 × 0.0145Nm

M = 0.0109 Nm

Shaft Power (Ps) = Torque × angular velocity
= 0.0109 × 2π/60 × 16800 Watts

Ps = 19.2 Watts

Table 1 Derived Results (Inlet pressure 60 kN/m^2 gauge)

Test No.	1	2	3	4	5	6	7
Speed $n/10^3$Rev $\min^{-1}$	36	29	23	16.8	11	6.4	0
Torque $M/10^{-3}$Nm	3.62	5.8	8.0	10.9	13.0	14.5	17.4
Shaft Power Ps/Watts	13.6	17.6	19.2	19.2	15.0	9.7	0

These results are shown graphically in Figure 3, together with results obtained with inlet pressures of 40 and 20 kN m 2 gauge.

Table 2 Sample of Observation Sheet

OBSERVATION SHEET

HILTON EXPERIMENTAL REACTION TURBINE F840

Type of Test: T/n and P/n

Atmospheric Pressure: 770 mm Hg

Date:

Ambient Temperature: 20°C

TEST No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Inlet Pressure $\frac{p_1}{\text{kN m}^{-2}\text{ g}}$	60	60	60	60	60	60	60											
Inlet Temperature $\frac{t_1}{^\circ\text{C}}$																		
Exhaust Temperature $\frac{t_2}{^\circ\text{C}}$																		
Rotational Speed $\frac{n}{10^3\text{ rev min}^{-1}}$	36	29	23	16.8	11	6.4	0											
Brake Band Force $\frac{F}{N}$	0.25	0.4	0.55	0.75	0.9	1.0	1.2											
Air Flow Rate (corrected) $\frac{\dot{m}}{\text{g s}^{-1}}$	5.5	5.5	5.5	5.5	5.5	5.5	5.5											

Comments

Both curves, see Figure 3, are typical of a reaction turbine.

The torque is derived from the product of the tangential force due to the momentum change of the air as it flows through the rotor, and the radius at which it acts. The tangential force is the product of the mass flow rate and the change in the tangential component of the air velocity across the rotor. Since both the mass flow rate and radius are constant, it follows that the torque is proportional to the change of tangential component and this decreases as speed increases. (Refer to velocity diagram in references.)

Superimposed on this is the effect of fluid friction which increases with speed and reduces the torque transmitted to the shaft.

The combination of the above effects produces the characteristic shape of the torque/speed curve.

Since the shaft power is the product of torque (M) and speed (w), it is obvious that power will be zero when M = 0 and when w = 0 and will rise to a peak value between these speeds.

Part 2. Application of the First Law of Thermodynamics to a simple open system undergoing a steady flow process.

1. Set the throttle valve to give an inlet pressure of 80 kN m^{-2} gauge.
2. Adjust the brake load so that the turbine develops its maximum power (refer to M/n graph in previous - experiment), usually about 24,000 rev min^{-1}.

3. Hold the inlet pressure and speed steady until the inlet and exhaust air temperatures are quite steady.
4. Observe and record all instruments and the brake band force.

The test should be repeated at other conditions.

Sample Analysis

Typical Observations

Ambient temperature	21^0C
Inlet pressure	(P_i) 80 kN m^{-2} gauge
Inlet temperature	(T_1) 20.7^0C
Exhaust temperature	(T_2) 16. 7^0C
Rotational speed	(n) 25,000 rev min^{-1}
Brake band force	(F) 0.78 N
Air flow rate (corrected)	(m) 6.5 g s-I
Shaft Power	(p_s) = M¾
	=Fr¾
	= 29.6 Watts

Assuming that Cp for air at the mean temperature (20.7 + 16.7 ^0C)/2 is 1.004 KJ/Kg

Change of specific enthalpy $(h_2-h_1) = Cp\,(T_2-T_1) = -4.016$KJ/Kg

Applying the Ist Law in the form of the steady flow equation,

$$Q = m(h_2-h_1) + Ps$$
$$= 3.5\ W$$

Comments

This result shows that during the passage of the air through the turbine, work was transferred to the surroundings at the rate of 29.6 Watts, the enthalpy of the air fell by 26.1 Watts and heat was transferred from the surroundings to the system at the rate of 3.5 Watts.

This result is reasonable since the exhaust casing which has a relatively large area compared with the turbine contained air at a temperature below that of the surroundings. The direction and magnitude of the heat transfer is therefore as expected.

Part 3. Determination of the isentropic efficiency of a turbine.

1. Adjust the throttle and brake load so that the turbine runs at about 50% of no load speed with the desired inlet pressure, say 60KN m^{-2} gauge.
2. Hold conditions steady until the inlet and exhaust temperature have stabilized.
3. Record all observations.

4. Repeat at other conditions.

Sample Analysis

Typical Observations

Ambient temperature	22^{o}C	
Atmospheric pressure	(Pa)	765 mm Hg
Inlet pressure	(Pi)	80 kN m^{-2} gauge
Inlet temperature	(T_1)	22^{o}C
Exhaust temperature	(T_2)	18 ^{o}C
Rotational speed	(n)	24,000 rev min^{-1}
Brake band force	(F)	0.8 N
Air flow rate (corrected)	(m)	6.5 gm s^{-1}

Calculations

Shaft Power (Ps) = M¾

= Fr¾

= 0.8 × 0.0145 × 2π/60 × 24900 Watts

Ps = 29.15 Watts

Absolute Temperature at Inlet T_1 = 22 + 273 K

= 295 K

Atmospheric Pressure =755/750 × 100 kN m^{-2}

=100.6 kN m^{-2}

Absolute Pressure at Inlet P_1 =100.6 + 80 kN m^{-2}

=180.6 kN m^{-2}

Absolute Pressure at Exhaust P_2 =100.6 kN m^{-2}

(Neglecting resistance of pipe and flowmeter)

Turbine Pressure Ratio r_p = $P_{1/}$ P_2

=1.795

Exhaust Temperature after

Isentropic expansion T_2’ $= \frac{T_1}{r_p^{(k-1)/k}}$ (k is specific heat ratio = 1.4)

=249.5K

Isentropic Enthalpy Change rate ΔH =mCp(T_1- T_2’)

=297 Watts

External Isentropic Efficiency η_s =Actual Power/ Isentropic Enthalpy Change Rate

= 29.15/297

= 9.8%

The actual and states may be plotted on T-s diagram as show in Figure 6.

Comments

An isentropic efficiency of 9.8% is as expected for a small turbine.

REFERENCES

[1] http://www.engineering.uiowa.edu/~expeng/laboratories/lab_references/Lab%20Resource%201e.pdf

APPENDIX.A FIGURES

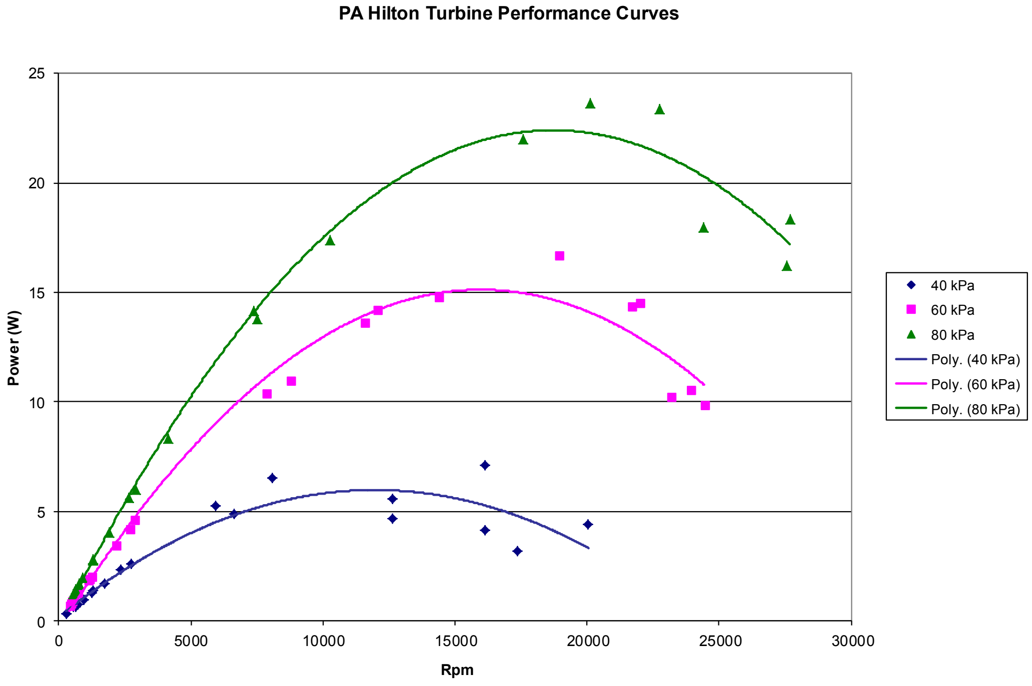

Figure 3 Example performance curves for Reaction Turbine

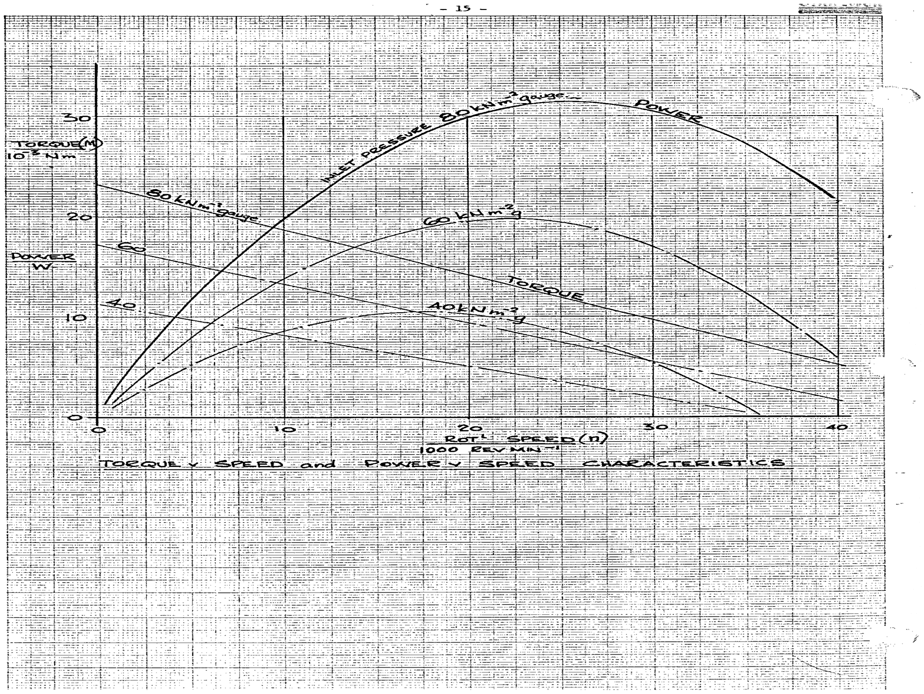

Figure 4 Torque and Power curves versus speed

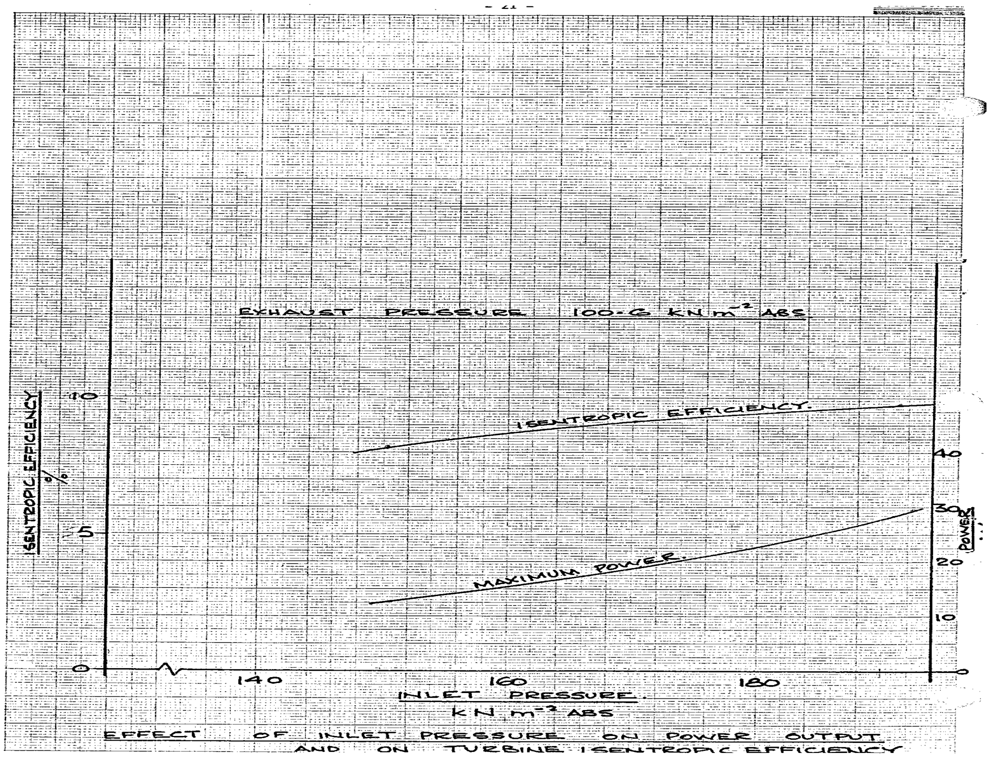

Figure 5 Effect of inlet pressure on power output

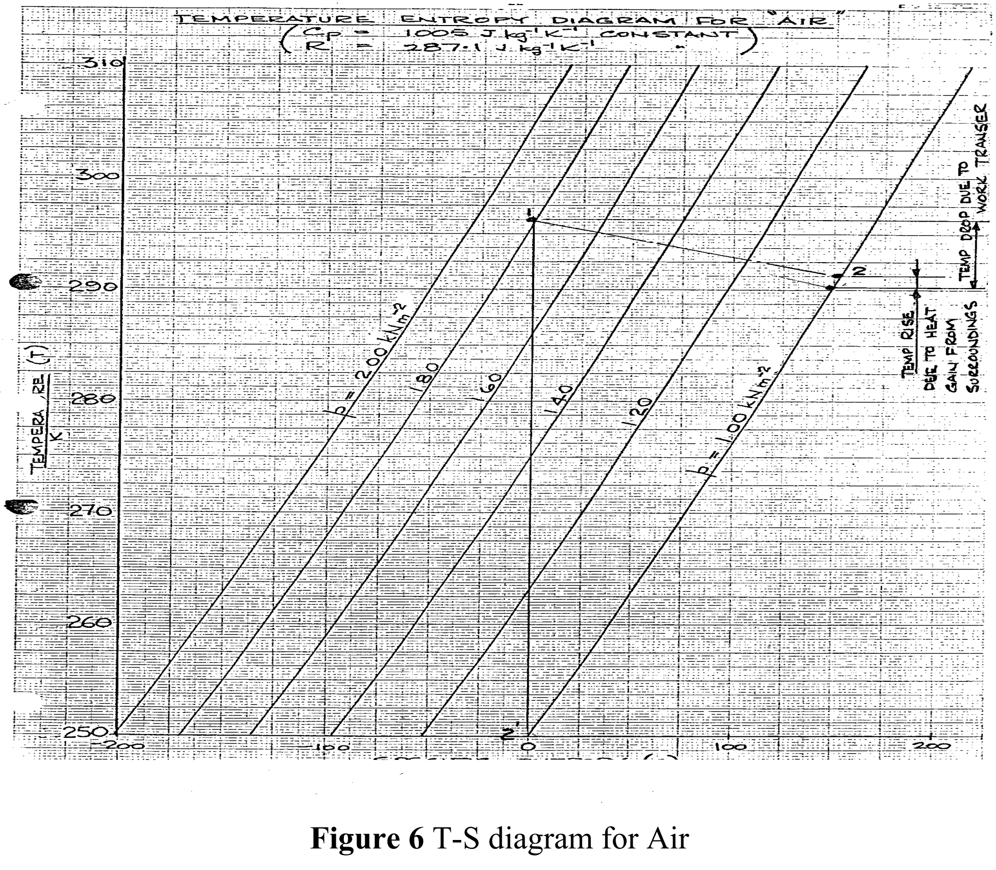

Figure 6 T-S diagram for Air