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ABSTRACT

These supplemental units contain four laboratory exercises that can be used to enhance the labs in "Physics for the Technologies." The four units (one mechanical, two thermal, and one electrical) are designed to enhance labs in presenting specific concepts. Each unit can be used as an example of how the concepts behind the theory apply to real-world situations. Introductory materials list the units in which they can be used as additional exercises, offer suggestions for presenting the supplementary units, list necessary equipment, and offer two options for obtaining equipment the high school may not have. Each unit consists of these components: introduction (lab objective, learning path, and main idea); teaching path with list of resource materials, class goals, and class activities; discussion (information); and laboratory (equipment, procedures, and additional exercises). Topics are as follows: mechanical bending stress, measuring heat flow using an electrical analog, electrical energy storage in capacitors, and measuring thermal power. (YLB)

PHYSICS FOR THE TECHNOLOGIES

Supplementary Units

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PHYSICS FOR THE TECHNOLOGIES
SUPPLEMENTARY UNITS

What is in these units?

The Supplementary Units contain four laboratory exercises which can be used to enhance the labs in Physics for the Technologies. Each unit contains a lab objective, discussion sections and laboratory exercises. The equipment needed to complete each lab is listed at the beginning of the exercise. (See **EQUIPMENT** section on how to obtain equipment that the local school may not have.)

Where to use the units.

The four units (one mechanical, two thermal and one electrical) are designed to enhance labs in presenting specific concepts. Each unit can be used as an example of how the concepts behind the theory apply to real-world situations. The supplementary units can be used as additional exercises in the following units:

Unit I: "Mechanical Bending Stress" a lab exercise for Force in Mechanical Systems;

Unit II: "Measuring Heat Flow Using an Electrical Analog" a lab exercise for Rate in Thermal Systems;

Unit III: "Electrical Energy Storage in Capacitors" a lab exercise for Energy in Electrical Systems;

Unit IV: "Observing Thermal Power" a lab exercise for Power in Thermal Systems.

Please keep in mind that the above listing is only a suggested use of the units. If the teacher so desires, the units can be used in other units or subunits. Also, these units are for the first year of Physics for the Technologies. Teachers who teach a two-year sequence, may wish to modify the units somewhat and use them as part of the second-year course.

Lesson Outline for each Unit

Introduction: Lab Objective, Learning Path, Main Idea

Teaching Path: Resource Materials, Class Goals, Class Activities

Discussion

Laboratory: Equipment, Procedures, Additional Exercises

SUGGESTIONS FOR USING THE SUPPLEMENTARY UNI

In order to provide a variety of learning experiences, the following suggestions may be helpful in presenting the supplementary units:

- Consider using teams of instructors to present the ideas and concepts. These teams may consist of high school faculty from academic and vocational areas, high school and technical college faculty, or high school faculty and an industry representative. If someone outside the school setting is to be invited, it is suggested that the individual be notified well in advance of the scheduled date so that he/she will have ample opportunity to prepare for the class.

- Make arrangements for high school classes to visit labs on the campus of Tri-County Technical College. Teachers wishing to take students to Tri-County Technical College should contact Dr. Jim Wood, Chairman, Industrial and Engineering Technology Division. (Telephone 646-8361, 225-2250 [Anderson County], 859-7033 [Pickens County], or 882-4412 [Oconee County] extension 2176 or 2285.) Dr. Wood can provide the name of the appropriate department head to contact in order to arrange for the visit to Tri-County.

- Plan field trips which center around the concepts being presented in the particular lesson. Local industries can provide students with the opportunity to see how the concepts being presented in the classroom are applied in the workplace. If field trips are to be used, call the industry and explain what the field trip is about, what concepts are being presented in the classroom, and tell the industry representative you would like for him to provide students with the opportunity to see how the skills being taught relate to the workplace.

- Invite outside speakers to address the class. When inviting a guest speaker, it would be helpful to the speaker to provide some preliminary information about the concepts being covered in class. Speakers may be able to bring examples of machines from the workplace which demonstrate concepts being presented in class. The <u>Guide to Area Business Speakers</u>, published by the Partnership for Academic and Career Education, is an excellent source for speakers.

EQUIPMENT

Rulers (centimenters)
Meter sticks
Deep-throat C-clamp
Wood strips
Strips of materials (metals or plastics)
DC power supply (at least 12-V.)
Voltmeter or DMM
Ammeter or VOM
Ring clamps
Turbine diffuser
Weights (1/2-kg., 1-kg., 2-kg.)
Switches (various)
Test block with wire clamps
5300 microfarad capacitor
15000 microfarad capacitor
1000-ohm resistor
12-V. lamp (100 milliamp or smaller)
Timer with minutes and seconds
Bunsen burner
Ring stands
Clamps
Turbine
Thermocouple and multimeter
Weight hanger (1-kg. type)

Laboratory exercises in these modules may require the use of equipment which the local high school science department might not have readily available. If the high school does not have the equipment, there are two ways to obtain this equipment.

Option One is to have the local industrial technology education classes construct the equipment. Blueprint drawings of needed equipment are contained in each module which requires specialized equipment.

Option Two is to request the needed equipment from the Industrial and Engineering Technology Division at Tri-County Technical College. If equipment is to be requested from Tri-County, please give two to three weeks' notice so the materials can be collected and placed in the division's office for dissemination. To request materials from Tri-County contact Dr. James Wood, Chairman, Industrial and Engineering Technology Division, Tri-County Technical College. Telephone 646-8361, 225-2250 (Anderson County), 859-7033 (Pickens County), or 882-4412 (Oconee County) extension 2176 or 2285.

UNIT I

MECHANICAL BENDING STRESS

LAB OBJECTIVE

When you've finished this lab, you should be able to do the following:

1. Measure the deflection of a beam subjected to bending stress.
2. Calculate the resistance of a beam to bending stress.

LEARNING PATH

1. Preview the lab. This will give you an idea of what's ahead.
2. Read the lab. Give particular attention to the lab objectives.
3. Do the lab "Mechanical Bending Stress."

MAIN IDEA

* A beam which is loaded by a force placed at some distance from its restrained end will deflect or bend.
* The degree of beam deflection depends on the magnitude of load applied, the material from which the beam is constructed and the distance between the load and the restrained end of the beam.

TEACHING PATH - CLASS L3

(Students should have read this lab before proceeding, mostly to familiarize them with the nature of the lab to be completed and the equipment to be used.)

RESOURCE MATERIALS

Lab 1M3: "Mechanical Bending Stress"

CLASS GOALS

See **OBJECTIVES** for Lab 1M3.

CLASS ACTIVITIES

Set up the lab and run through the procedures before the students try the lab. You'll be able to anticipate student difficulties.

1. Preview the lab for the students and explain what it is about. Show students the equipment and tell them what they are to accomplish.

2. Have the students follow the procedures outlined in the lab instructions. Encourage them to read the procedures carefully. (Reading detailed procedures and following instructions are important parts of a technician's training.)

3. Monitor student progress and provide help as needed.

4. Before coming to the next class, you should review print/ video material on "Force in Mechanical Systems." Ask students to review the objectives and main ideas in preparation for Class R, a review of the subunit, "Force in Mechanical Systems."

NOTE: Before class, cut strips of the materials which your students will use in the bending tests. These strips should be 30 cm long by 2 cm wide by 2 mm thick, with a hole to insert the weight hanger at one end. Also, cut strips of wood 10 cm long by 3 cm wide by 1 cm thick to help clamp the bending test strips to a table.

DISCUSSION

If we load a beam at a distance from its restrained (or supported) end, the beam will deflect (or bend). The bending of a loaded beam is shown in Figure 1 below.

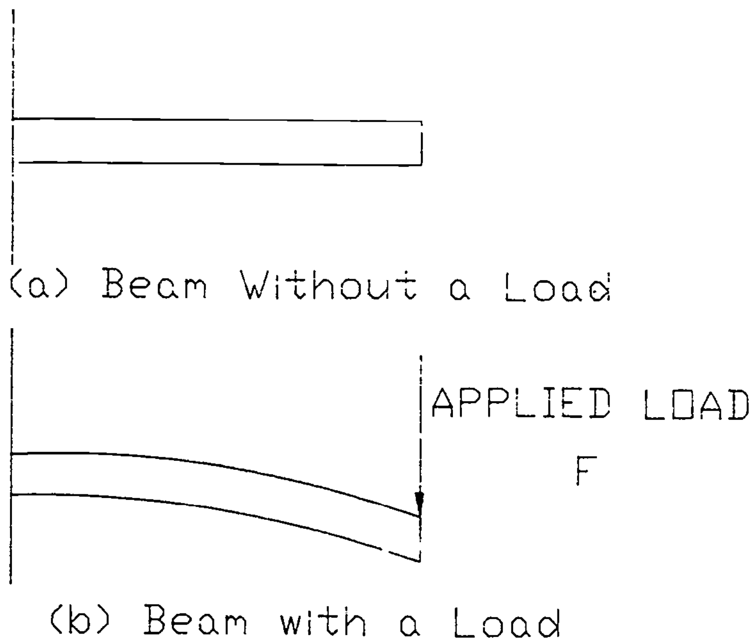


Figure 1 Beam without a load and after loading

The load placed on the beam has caused a mechanical stress in the beam material. This mechanical stress causes a tension stress in the top of the beam and a compression stress in the lower part of the beam. Somewhere between the top and bottom sides of the beam (as the stress changes from tension to compression), the stress is zero. This plane of zero beam stress is called the neutral surface. The stress profile in Figure 2 illustrates the idea of the neutral surface.

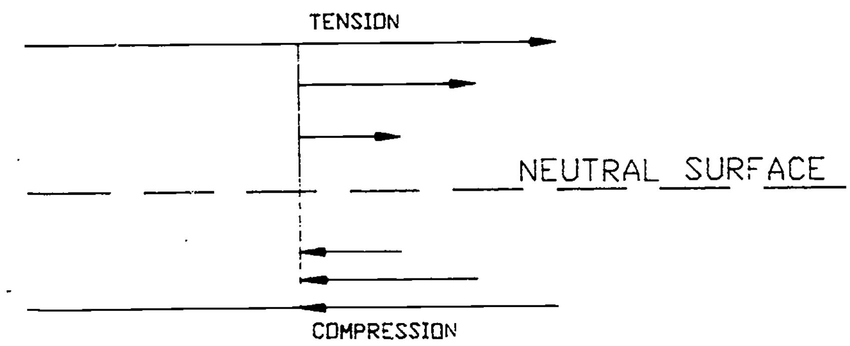


Figure 2 Stress profile in a loaded beam

Figure 3 below illustrates the parameters of a beam cross section which are used to calculate the stresses and deflection of the beam.

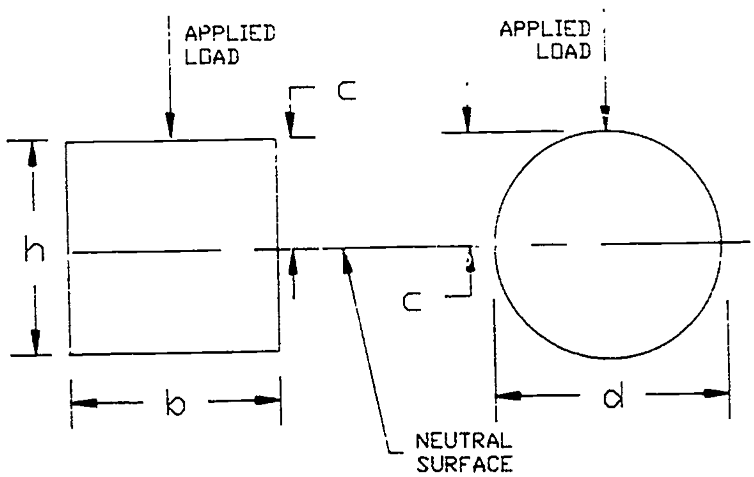


Figure 3 Beam stress and deflection parameters

MOMENT OF INERTIA OF BEAMS

The ability of a beam to resist bending stresses depends on the type of material from which the beam is constructed and the distribution of the material in the beam in relationship to the direction of the load.

The distribution of the beam material in relation to the direction of the load is quantified as the **"moment of inertia"** of the beam about the neutral surface.

Some formulae for moments of inertia of beams are

Rectangular Beam Cross Sections

$$I = \frac{b * h^3}{12} \quad (1)$$

where I = moment of inertia about the neutral surface

b = width of beam (perpendicular to load)

h = depth of beam (parallel to load)

Round Beam Cross Sections

$$I = \frac{PI * d^4}{64} \quad (2)$$

where PI = pi or 3.141592654...

BENDING STRESS IN BEAMS

The bending stress in a beam is produced by loading the beam at a distance from its restrained (or supported) end. Figure 4 below illustrates a cantilever beam loading.

Figure 4 Cantilever Beam Loading

In the cantilever beam, the effect of the loading force is to produce a moment. The moment of the cantilever beam shown in Figure 4 is

$$M = F * L \qquad (3)$$

where M = the moment on the beam

F = the force on the beam

L = the distance from the beam support to the load force PERPENDICULAR to the load force

The stress in a beam can be calculated from

$$S = \frac{M * v}{I} \qquad (4)$$

where S = stress in the beam at a distance of v from the neutral surface

v = distance from the neutral to the point at which the stress is calculated (let's call x "POSITIVE" if it is ABOVE the neutral surface and "NEGATIVE" if it is BELOW the neutral surface)

I = the moment of inertia of the beam

If the distance from the neutral surface at which we calculate the stress is c (the distance from the neutral surface to the outside surface of the beam), then we calculate the maximum stress in the beam (tension if S is + and compression if S is -) or

$$S_{max} = \frac{M * c}{I} \qquad (5)$$

DEFLECTION IN BEAMS

When a beam is loaded in cantilevered fashion, the free end of the beam will be deflected or bent downward as shown in Figure 5 below:

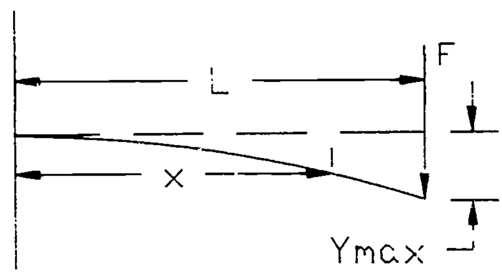


Figure 5 Deflection of a cantilevered beam

The value of the beam deflection can be calculated from the equation

$$y = \frac{M * x^2}{2E * I} \qquad (6)$$

where y = the beam deflection

M = the moment on the beam

x = the distance from the supported end of the beam to the point at which the deflection is being calculated

E = the modulus of elasticity of the material from which the beam is constructed

I = the moment of inertia of the beam

If the distance from the supported end of the beam is equal to the distance from the supported end of the beam to the load force, then the deflection will be its maximum value. This maximum value of deflection can be calculated from the equation

$$y_{max} = \frac{M * L^2}{2E * I} \qquad (7)$$

STIFFNESS OF BEAMS

The ability of a beam to resist bending is called stiffness. The stiffness of a beam is determined by calculating the spring constant of the beam from

$$k = \frac{F}{y} = \frac{\text{applied load}}{\text{deflection}} \qquad (8)$$

Substituting M from Equation 3 into Equation 7 and solving for F/y we obtain the equation for beam spring constant as

$$k = \frac{2E * I}{L^3} \qquad (9)$$

The higher the value of k, the greater the load force needed to produce the same value of beam deflection; thus, the beam is more resistant to bending or it is stiffer.

EQUIPMENT
Ruler (centimeters)
Meter stick
Weights (1/2-kg., 1-kg., 2-kg.)
Weight hanger, 1-kg. type
Deep-throat C-clamp
Wood strip (approximately 10 cm long X 3 cm wide X 1 cm thick)
Strips of material (approximately 30 cm long X 2 cm wide X 2 mm thick) (various metals and plastics should be used)

PROCEDURES

1. Secure a strip of material to the edge of a table using the C-clamp and wood strip, allowing 20 cm of the strip to hang over the edge of the table. See Figure 6 below. [**CAUTION!!!** Be careful not to put your feet under the test sample or weight hanger at any time. If the C-clamp slips, there could be some serious injuries.]

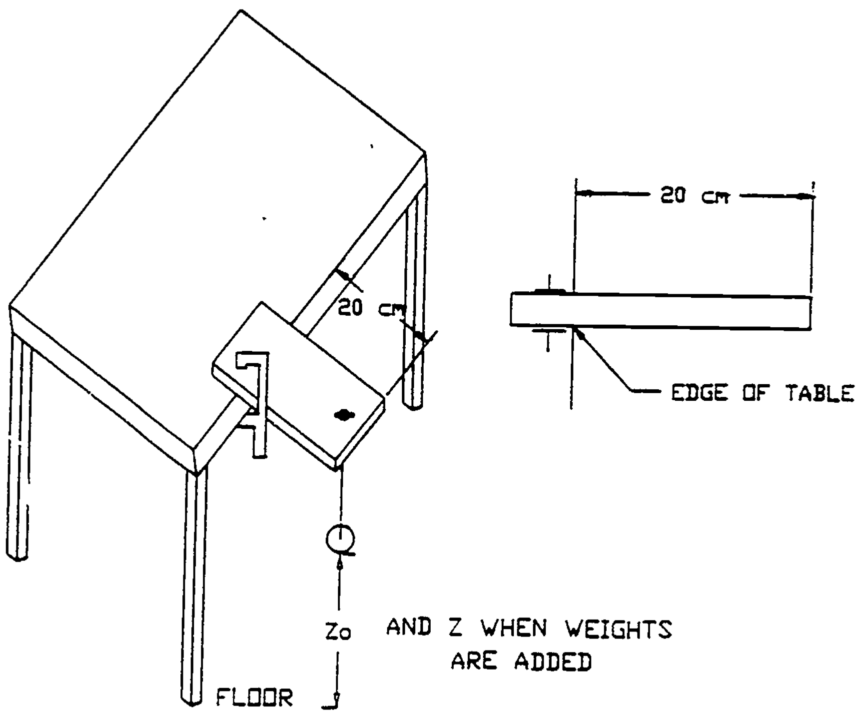


Figure 6

2. Measure and record, in Data Table 1, the distance from the edge of the wood strip to the center of the weight hanger hole. This is the variable L.

3. Measure and record, in Data Table 1, the distance from the floor to the test sample (at the weight hanger). This is the distance Z_0.

4. Measure and record, in Data Table 1, the weight hanger weight. This is the variable W_0.

5. Attach the weight hanger to the test specimen; measure and record in Data Table 1 the distance from the floor to the test sample (at the weight hanger). This is the variable Z.

6. Calculate the deflection by subtracting the loaded distance from the unloaded distance and record the difference in Data Table 1. This is the variable y_{max}.

7. Repeat Step 5 using the 1/2-kg, 1-kg and 2-kg. weights. Record the weights and deflections in Data Table 1. [**CAUTION!!!** DO NOT forget to add the weight of the hanger to that of the attached weights.] This is the Variable $F = W + W_0$.

8. If you wish to test various samples of materials, make copies of Data Table 1 and repeat Steps 1 through 6 for each of the samples.

DATA TABLE 1

L = cm.
Z_0 = cm.
W_0 = kg.

Test	Z	Z_0	$Y_{max}=Z-Z_0$	W	W_0	$F=W-W_0$
1						
2						
3						
4						

WRAP-UP

From the weight and deflection data in Data Table 1, calculate the spring constant of the beam and enter the value in Data Table 2. This the variable k.

DATA TABLE 2

Test	F	y_{max}	$K = F/y_{max}$
1			
2			
3			
4			

ADDITIONAL EXERCISES

From the dimensions of the beams tested, calculate the moment of inertia, I, and calculate the modulus of elasticity, E, of the beam material from

$$E = \frac{k * L^3}{2\ I}$$

Record these calculated values of E in Data Table 3.

DATA TABLE 3

Test	k	L	I	$E=k*L^3 /(2I)$
1				
2				
3				
4				

Is the modulus of elasticity related to the stiffness of the beam?

UNIT II

MEASURING HEAT FLOW USING AN ELECTRICAL ANALOG

LAB OBJECTIVE

When you've finished this lab, you should be able to analyze the heat flow through any material composition or geometry using the analogy between heat conduction through a thermal resistance and electrical current flow through an electrical resistance.

LEARNING PATH

1. Preview the lab. This will give you an idea of what's ahead.
2. Read the lab. Give particular attention to the lab objectives.
3. Do the lab, "Measuring Heat Flow Using an Electrical Analog."

MAIN IDEA

* Analogues allow tests to be performed on test devices in a manner much less tedious than if the test were performed on an actual device.

TEACHING PATH - CLASS L3

RESOURCE MATERIALS

Lab 3T3: "Measuring Heat flow Using an Electrical Analog"

CLASS GOALS

See **OBJECTIVES** for Lab 3T3

CLASS ACTIVITIES

Set up the lab and run through the procedures before the students try the lab. You'll be able to anticipate student difficulties.

1. Preview the lab for the students and explain what the lab is about. Show students the equipment and tell them what they are to accomplish.

2. Have the students follow the procedures outlined in the lab instructions. Encourage students to read the Procedures carefully. (Reading detailed procedures and following instructions are important parts of a technician's training.)

3. Monitor student progress and provide help as needed.

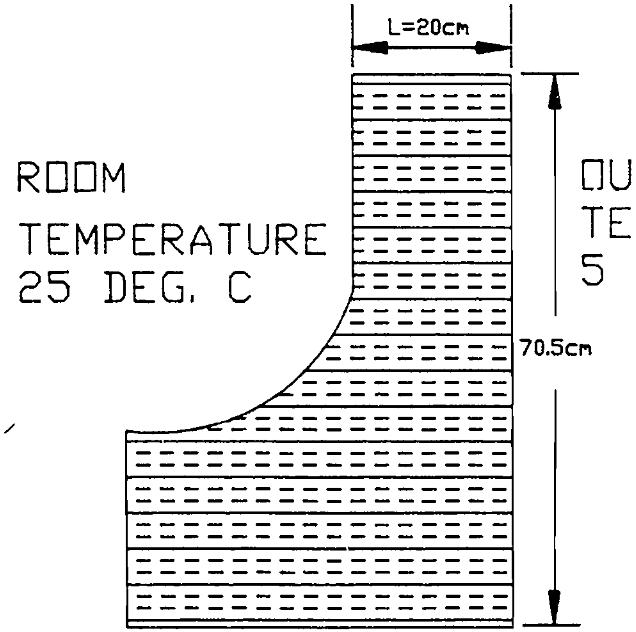
The test block can be built using the attached drawing "Corner Block Drawing". Students in the school's shop classes can make the test block using aviation snips.

Make photocopies of the "Test Block Pattern" and the "Wiring Clamp Pattern" and use these copies for a pattern by which to cut the sheet metal. **CAUTION:** When working with sheet metal, be careful not to be cut by the sharp edges.

<u>**NOTE:**</u> For temperature difference across a wall to be accurately simulated, the wire clamps must be connected to the test block to ensure uniform application of voltage.

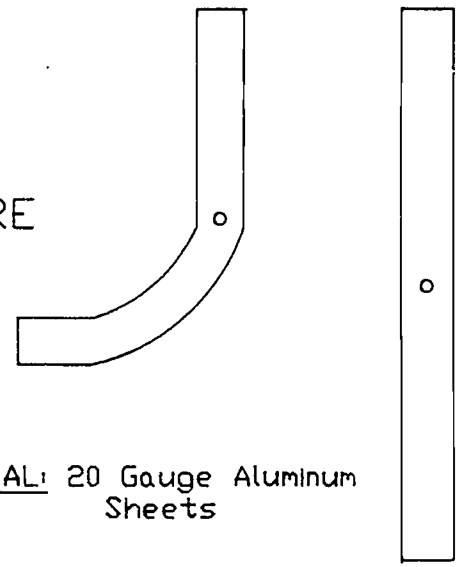
To further study the effect of geometry on heat flow rate, cut out different test blocks and wiring clamps to simulate different corner block shapes. You are only limited by your own imagination when simulating heat flow using the electrical analog.

By measuring the voltage between any point on the test block and power supply ground (-), you may determine the "temperature" at that point by using the temperature versus voltage scale factor. By placing a grid on the Test Block and measuring the voltages at the grid intersections, a temperature profile can be obtained for the corner block. Engineers use such temperature profiles to reduce the heat lost from buildings or to study the heat flow through newly designed machines without having to actually build the machine. **CAUTION:** Observe all safety procedures used when working with electrical devices.



WALL MATERIAL
k= 0.125 cal/sec-cm-cm-C/cm

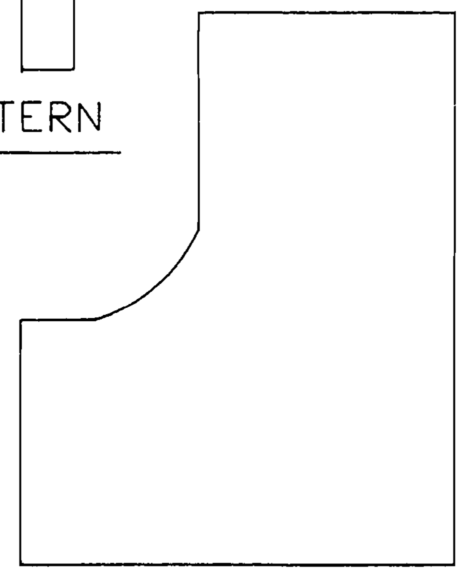
ROOM CORNER BLOCK



MATERIAL: 20 Gauge Aluminum Sheets

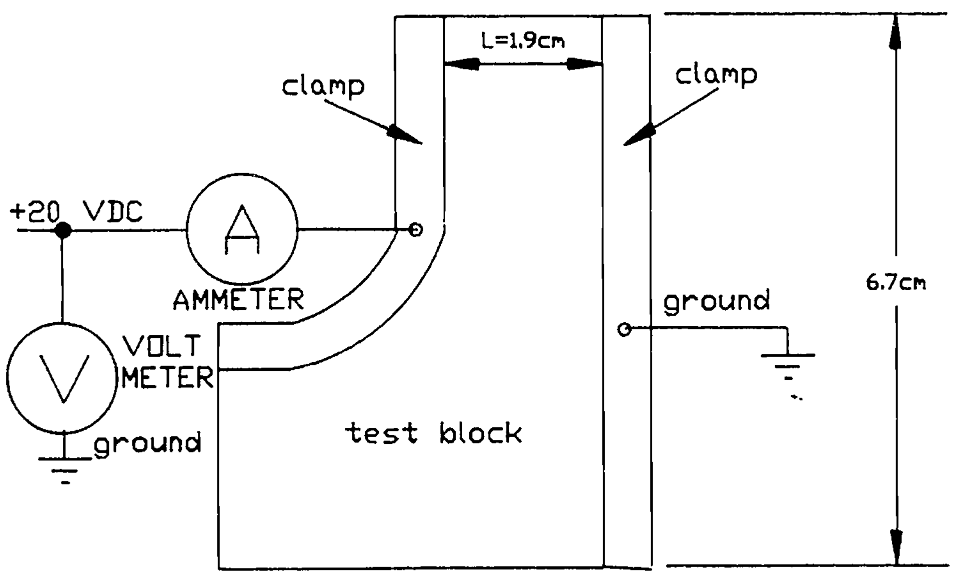
WIRING CLAMP PATTERN

NOTE:
1. Clamp wire clamps securely and uniformly to the test block
2. Solder power supply wires to clamps at 1/32 inch drilled holes



MATERIAL: 20 Gauge Aluminum Sheets

TEST BLOCK PATTERN



TEST SET UP

CORNER BLOCK DRAWING

DISCUSSION

ANALOGUES are dissimilar mechanisms which correspond in some way to each other. In plain English, analogues are physically different but operate in a similar manner.

WHAT IS AN ELECTRICAL ANALOG FOR HEAT FLOW?

Scientists and engineers have developed certain "laws" to mathematically describe or predict the operation of physical systems. These laws are expressed as formulae or equations.

The law which describes heat flow by conduction across an object (such as shown in Figure 1) is:

$$Q = \frac{kA(T_2 - T_1)}{L}$$

where

Q = heat flow rate (thermal rate)

k = thermal conductivity of the object through which the heat is "flowing"

A = surface area of the object (at right angles to the direction of heat flow)

L = thickness of the object (in the direction of heat flow)

T_2 = temperature on the "hot" side of the object

T_1 = temperature on the "cold" side of the object

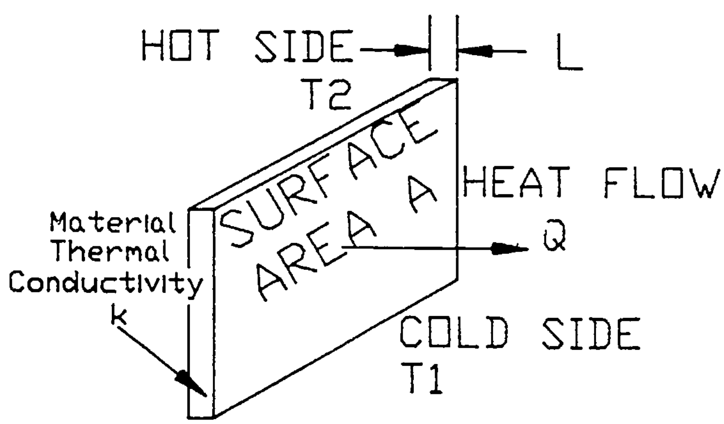


Figure 1 Conduction Heat Flow

The law which describes the flow of electrical current through an object (such as shown in Figure 2) is:

$$I = \frac{V}{R}$$

where I = current (flow of charge)

V = voltage drop across the object

R = electrical resistance of the object

This equation is known as Ohm's Law.

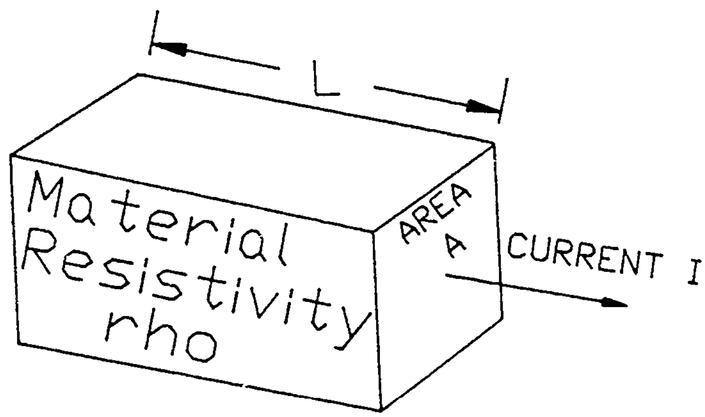


Figure 2 Electrical Current Flow

Thus, by looking at the similarities between the heat flow equation and Ohm's Law, we can determine the analog quantities as shown in Table 2.

TABLE 2

Type of Quantity	Ohm's Law	Heat Flow Equation
Rate	I	Q
Driving Force	V	$T_2 - T_1$
Resistance	R	L/kA

In fact, almost any rate "Law" can be expressed as

$$\text{Rate} = \frac{\text{Driving Force}}{\text{Resistance}}$$

ELECTRICAL ANALOG SIMULATION OF HEAT FLOW IN IRREGULAR GEOMETRIES

In objects which have regular geometries (i.e., can be easily expressed mathematically), the heat flow equation can be used to calculate the heat flow rate using simple calculations.

However, in objects whose geometries are irregular (not easy to express mathematically) calculations require computers or simplifying assumptions (which greatly reduce the accuracy of the results). Another way of determining the heat flow would be to build an <u>EXACT</u> model of the object and subject it to the conditions it would see in its actual operation. The latter method is very expensive and time-consuming, especially if the service conditions vary and/or several designs must be analyzed.

By using the analogies between electrical current flow and heat flow, heat flow rate in an actual object can be determined by using scale factors on the measured value of electrical current flowing in an electrically conducting test object.

SCALE FACTORS FOR THE ELECTRICAL ANALOG OF HEAT FLOW

Scale factor for the electrical analog of heat flow can be found by comparing the analogous parts of the heat flow equation and Ohm's Law (i.e., RATE, DRIVING FORCE, RESISTANCE). Since we will be <u>measuring</u> ELECTRICAL properties and <u>calculating</u> HEAT FLOW, let's use a scale factor "format" like

Heat Flow Quantity = Scale Factor * Electrical Quantity

-then-

$$Q = K_I * I$$

$$T_2 - T_1 = K_V * V$$

$$\frac{L}{kA} = K_R * R$$

Now let's write the equations for the scale factors for RATE, K_I, RESISTANCE, K_V, and DRIVING FORCE, K_R

$$\text{Scale Factor} = \frac{\text{Heat Flow Quantity}}{\text{Electrical Quantity}} \quad \text{-then-}$$

$$K_V = \frac{T_2 - T_1}{V}$$

-and-

$$K_R = \frac{L_Q/kA_Q}{R}$$

but remember the equation for resistance of a conductor is

$$R = \frac{rho * L_R}{A_R}$$

where rho= resistivity of the object

L_R = thickness of object (in direction of current)

A_R = cross-sectional area of object (perpendicular to direction of current)

By substituting K_R in the equation for R and rearranging we have

$$K_R = \frac{A_R L_Q}{A_Q L_R k(rho)}$$

-and-

$$K_I = \frac{Q}{I}$$

Since $Q=k * A_Q(T_2-T_1)/L_Q$ and $I = V/R$ (or $V * A_R/(rho * L_R)$, substituting these values into the K_I equation and rearranging, we have

$$K_I = \frac{k * A_Q(T_2-T_1)}{L_Q} * \frac{rho * L_R}{V * A_R} \quad \text{-or-}$$

$$K_I = \frac{A_Q L_R k(rho)}{A_R L_Q} * \frac{(T_2 - T_1)}{V}$$

-THUS-

$$K_I = \frac{K_V}{K_R}$$

Using these scale factors and the analog equations, we can determine the heat flow rate of an object by measuring the current through a test object.

SUMMARY OF ELECTRICAL ANALOG OF HEAT FLOW EQUATIONS

Let's arrange these equations simply in the order in which they will be used to determine an object's heat flow by measuring the current in our test object.

SCALE FACTOR EQUATIONS

$$K_R = \frac{A_R L_Q}{A_Q L_R k(rho)}$$

$$K_V = \frac{T_2 - T_1}{V}$$

$$K_I = \frac{K_V}{K_R}$$

ANALOG EQUATIONS

$$Q = K_I I$$

VARIABLES NEEDED TO USE THE ANALOG METHOD OF TESTING

A_R = length of straight side X thickness of TEST object

A_Q = length of straight side X thickness of ACTUAL object

L_Q = length of short side of ACTUAL object (perpendicular to A_Q)

L_R = length of short side of TEST object (perpendicular to A_R)

k = thermal conductivity of ACTUAL object

rho= resistivity of TEST object

T_2 = "hot side" temperature of ACTUAL object

T_1 = "cold side" temperature of ACTUAL object

V = voltage drop across TEST object

VALUES MEASURED FROM THE ELECTRICAL TEST OBJECT

I = current through the test object

VALUES CALCULATED FOR THE ACTUAL OBJECT

Q = heat flow through the object

MEASURING THE HEAT LOSS FROM A ROOM CORNER BLOCK

In order to make the electrical analog of heat flow useful, let's apply the technique to measuring the heat flow from part of a building wall. Figure 3 below shows the actual object to be tested:

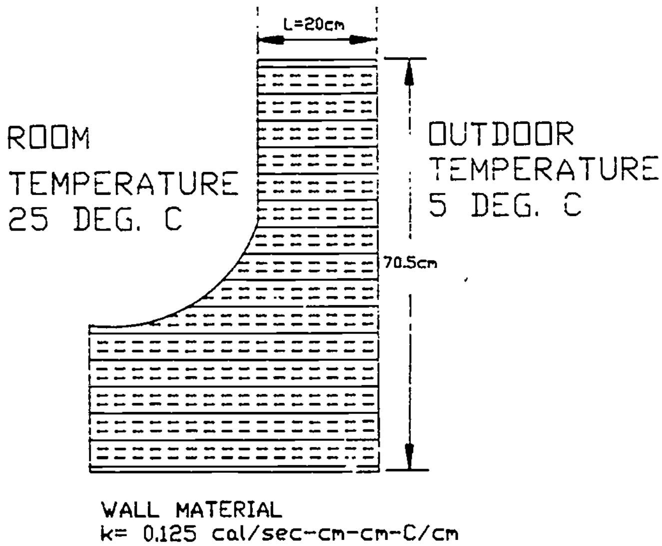


Figure 3 Room Corner Block

In Figure 3 we have shown a top view of the corner of a room in the building for which we will be measuring heat loss. In order to perform the test, we first must calculate the scale factors for the electrical analog of heat flow (We will assume the outdoor face of the corner block is 250 cm "thick" and that there is no heat loss from the two faces perpendicular to the outdoor faces, the top of the corner or the bottom of the corner). Figure 4 below shows the test block we will use to simulate the actual block in the corner of the room:

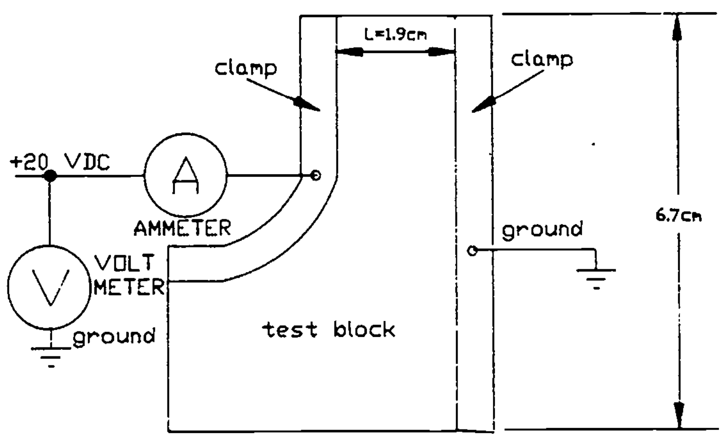


Figure 4 Test Block

VARIABLES NEEDED TO USE THE ANALOG METHOD OF TESTING

A_R = 6.7 cm * 0.0934 cm* = 0.626 cm^2

A_Q = 70.5 cm * 250 cm = 17,625 cm^2

L_Q = 20 cm

L_R = 1.9 cm

k = 2.17 watts/cm-deg C*

rho= 2.688 * 10^{-6} ohm-cm*

T_2 = 25 deg C

T_1 = 5 deg C

V = 20 volts

* Values from Handbook of Engineering Fundamentals John Wiley and Sons, Inc. publisher

SCALE FACTOR EQUATIONS

$$K_R = \frac{(6.7\ cm^2)(20\ cm)}{(70.5\ cm^2)(1.9\ cm)(2.17\ watts/cm\text{-}deg\ C)(2.668 * 10^{-6}\ ohm\text{-}cm)}$$

$$K_R = 1.715 * 10^5\ deg\ C/watt\text{-}ohm$$

$$K_V = \frac{(25\ deg\ C - 5\ deg\ C)}{20\ volts} = 1\ deg\ C/volt$$

$$K_I = \frac{1\ deg\ C/volt}{1.715 * 10^5\ deg\ C/watt\text{-}ohm} = 5.831 * 10^{-6}\ watt\text{-}ohm/volt$$

NOTE: 1 amp = 1 volt/ohm

-or-

$$K_I = 5.831 * 10^{-6}\ watt/amp$$

ANALOG EQUATIONS

$$Q(watt) = (5.831 * 10^{-6} \text{ watt/amp}) I(amp)$$

-or using milliamps(ma)

$$Q(watt) = (5.831 * 10^{-3} \text{ watt/ma}) I(ma)$$

ANALOG EQUATION TO USE IN LAB

CONCLUSIONS

Thus, by measuring the current flow, I, through the test block, we can calculate the heat flow, Q, through the corner (actual) block.

By changing the variables and test block geometry, we can recalculate the analog equation and test any other heat flow we wish.

Laboratory

EQUIPMENT

DC Power Supply
Voltmeter or DMM
Ammeter or VOM
Test Block with Wire Clamps

PROCEDURES

1. Hook the power supply to the test block as shown in Figure 1 below:

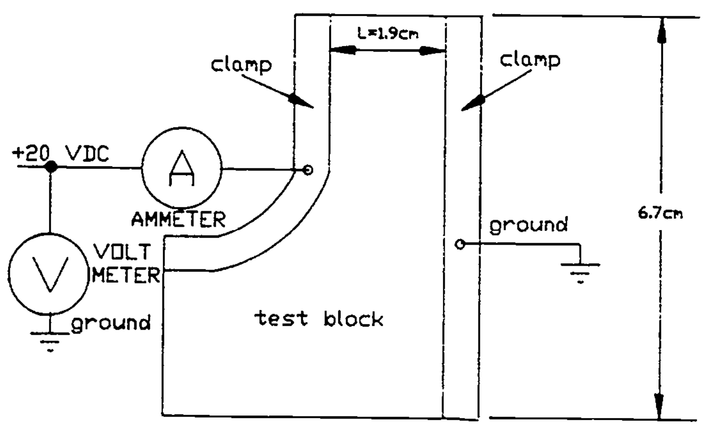


Figure 1

2. Adjust the voltage across the test block to 20 volts DC. (This simulates a 20° C temperature difference between the outside and inside walls of the corner block)

3. Measure the current through the test block and record the value below in Data Table 1:

   NOTE: You may want to simulate other temperature differences across the corner block; if so, record the current through the test block for the other voltage drops shown in Data Table 1. REMEMBER: If you change the voltage drop you MUST recalculate K_V and K_I.

DATA TABLE 1

Voltage across Test Block (volts)	Current through Test Block (milliamps)	Heat Flow (watts) K_I * I
20		
5		
10		
15		
25		
30		

WRAP-UP

Now we have seen one method scientists and engineers use to find out what will happen to a particular device they have designed without having to build a full-scale, working model.

There are many ways to SIMULATE the operation of an actual device by measuring the effects on a much smaller and less expensive test device. Two of these ways include

> Wind tunnel testing of models of aircraft and mockups to test the passenger comfort in a new automobile.

A very modern way of simulation involves using computers to make numerous calculations of the various parameters of a device to determine how the device will perform under various operating conditions. In the future, many people will be employed in these areas of Computer Aided Design (CAD) using computers to speed up the design process.

Can you think of any examples of using a simple test to determine the operation of another device?

UNIT III

ELECTRICAL ENERGY STORAGE IN CAPACITORS

LAB OBJECTIVES

When you've finished this lab, you should be able to do the following:

1. Describe the construction of a capacitor.

2. Explain how a capacitor stores energy.

3. Calculate the charge on a capacitor, given its size and the voltage across it.

4. Calculate the instantaneous voltage across a capacitor in a resistor-capacitor (RC) network.

5. Calculate the approximate time required to fully charge a capacitor in an RC circuit.

LEARNING PATH

1. Preview the lab. This will give you an idea of what's ahead.

2. Read the lab. Pay particular attention to the lab objectives.

3. Do the lab, "Electrical Energy Storage in Capacitors."

MAIN IDEAS

* Capacitors store and discharge electrical energy.

* The amount of energy stored is determined by the size of the capacitor and the electrical potential across its terminals.

* The rate of charge and discharge of the capacitor is determined by its size and the resistance of the charging or discharging path.

* A large capacitor can store enough energy to briefly light a small lamp.

TEACHING PATH - CLASS L1

Note: Students should have read this lab before proceeding, mostly to familiarize themselves with the nature of the lab to be completed and the equipment to be used.

RESOURCE MATERIALS

Lab 5E1: "Electrical Energy Storage in Capacitors"

CLASS GOALS

See **OBJECTIVES** for Lab 5E1.

CLASS ACTIVITIES

(Set up the lab and run through the procedures before students try it. You'll be able to anticipate student difficulties.)

1. Preview the lab for students and explain what it is about. Show students the equipment and tell them what they need to accomplish.

2. Have students follow the Procedures outlined in the lab carefully. (Reading detailed procedures and following instructions are important parts of a technician's training.)

3. Monitor student progress and provide help as needed.

4. Ask students to read Lab 5E2, "Converting Fluid Energy to Electrical Energy," before doing the next lab.

DISCUSSION

A simple capacitor consists of two conductive plates separated by a dielectric or nonconductive material. Each of the plates is connected to a terminal of the capacitor. The dielectric may be air, teflon, paper, mica or a number of other insulating materials. When a voltage is applied across the two terminals, an electrical charge is deposited on the plates. The amount of charge that will be deposited for a given voltage is determined by the capacitance of the capacitor and is calculated using the equation

$$Q = CV \qquad (1)$$

where Q is the charge measured in coulombs
C is capacitance in farads
V is volts

The capacitance is determined by the surface area of the plates, the distance between them, and the type of dielectric used. While some capacitors are adjustable and have variable capacitance ratings, most have a fixed value. Although the formula above specifies capacitance in farads, most common capacitor values are in picofarads (trillionths of a farad), or microfarads (millionths of a farad). They are manufactured in many sizes and styles, with ratings from just a few picofarads to many thousand microfarads. They are also rated by the amount of voltage which can exist between the terminals without the dielectric breaking down.

The amount of charge on the capacitor plates is related to the amount of current that flows into the capacitor. When the capacitor discharges, the direction of current flow reverses, in much the same manner as occurs with the charging and discharging of a battery.

If a power supply is connected directly to the capacitor terminals, the capacitor will charge almost instantly to the supply voltage. If, however, a resistor is placed in series with the capacitor, then the resistor will impede the flow of current, and it will take longer for the capacitor to fully charge to the applied voltage. A resistor in series with a capacitor forms an RC circuit. Until the capacitor is fully charged, part of the applied voltage will appear across the capacitor, and the rest will appear across the resistor.

By rearranging Equation (1), for a given charge, the voltage across a capacitor will be ssen to vary inversely with the capacitance.

$$V = \frac{Q}{C} \qquad (2)$$

Therefore, if we know the charge on a capacitor and we know its capacitance value, we can calculate the voltage across it. Thus, the voltage across a capacitor in an RC circuit can be determined if we know the voltage applied to the circuit, the value of the resistor, the value of the capacitor, and the length of time that the capacitor has been charging through the resistor. The next equation summarizes these relationships:

$$v = E(1 - e^{-t/RC}) \tag{3}$$

v = voltage across the capacitor
E = applied voltage
e = natural logarithm
t = charging time in seconds
R = series resistance in ohms
C = capacitance in farads

The exponential function ($e^{-t/RC}$) is important here. Note that when t= 0, the value of the function is 1. When this value is substituted back into Equation (3), the voltage (v) across the capacitor is zero.

$$\begin{aligned} v &= E(1 - 1) \\ &= E(0) \\ &= 0 \end{aligned}$$

This makes sense since t = 0 at the instant that the supply voltage is first applied to the circuit and therefore no charging time has elapsed.

At the other extreme, the voltage (v) across the capacitor can equal the supply voltage (E) only when the exponential function has the value zero:

$$\begin{aligned} v &= E(1 - 0) \\ &= E(1) \\ &= E \end{aligned}$$

But for what value of (t) does the exponential function have a value of zero ?

$$e^{-t/RC} = 0 \tag{4a}$$

$$\frac{1}{(e^{t/RC})} = 0 \tag{4b}$$

$$e^{t/RC} = \frac{1}{0}\text{, but division by zero is undefined.} \tag{4c}$$

Although the solution to Equation (4c) is undefined, note in Equation (4b) that as (t) increases, the exponential function $e^{t/RC}$ increases, therefore, its reciprocal decreases. As (t) approaches infinity, the exponential function approaches infinity, and its reciprocal does indeed approach zero. Thus, we can conclude that as time passes, the voltage (v) across the capacitor approaches the supply voltage but in theory, never exactly reaches it.

Since the resistance and capacitance values also affect the time required to charge the capacitor, it is convenient to think of the product (RC) as being a <u>time constant</u>. When (t) equals (RC), in seconds, we say that one time constant has elapsed. When (t) equals two times (RC), we say that two time constants have elapsed, and so forth. Note that in Eq.(4b), the base (e) is raised to the power (t/RC). Consider the following values for this equation:

Let $f(t) = \frac{1}{(e^{t/RC})}$.

Then

when t = RC	f(t) = 0.368
t = 2(RC)	f(t) = 0.135
t = 3(RC)	f(t) = 0.050
t = 4(RC)	f(t) = 0.018
t = 5(RC)	f(t) = 0.006
t = 6(RC)	f(t) = 0.002

Our expectation is confirmed; as (t) increases, Equation (4b) approaches zero. Now, let's plug the above results back into Equation (3).

$$v = E(1 - e^{-t/RC})$$

Then

when t = RC	v = 0.632(E)	or	63.2% of E
t = 2(RC)	v = 0.865(E)	or	86.5% of E
t = 3(RC)	v = 0.950(E)	or	95.0% of E
t = 4(RC)	v = 0.982(E)	or	98.2% of E
t = 5(RC)	v = 0.993(E)	or	99.3% of E
t = 6(RC)	v = 0.998(E)	or	99.8% of E

We see that (v) is in fact approaching (E).

Note also that the time required to fully charge is independent of the value of (E). In practice, it is convenient to say that the capacitor is fully charged after 5 time constants, because the voltage across the capacitor (v) has reached more than 99% of the applied voltage (E). This generalization simplifies the computation of charging time for any RC circuit.

Example

How long does it take to fully charge a 10-microfarad capacitor through a 1000-ohm resistor?

Solution

The time constant for the RC circuit is (R * C) or

1000 ohms * 10 * 10^{-6} microfarads, which is 10 * 10^{-3}

or

10 milliseconds.

The time required to fully charge is 5 time constants, or 50 milliseconds.

EQUIPMENT

5300-microfarad capacitor with a rating of 12 V. or greater
15000-microfarad capacitor with a rating of 12 V. or greater
1000-ohm resistor
12-V. lamp [100-milliamp (1.2-watt) or smaller]
Two switches (pushbutton, toggle, or slide)
Voltmeter
12-V. DC power supply
Timer or watch with minutes and seconds indicator

Optional:

The accuracy of the results in this lab depends on the accuracy of the capacitor and resistor values. The actual value of capacitors may differ by as much as 20% above or below the rated capacitance. Resistors may vary by as much as 10%. If the actual values of these components is not known, then it may be desirable to obtain a capacitor tester and an ohmmeter. Calculations should be done using the actual measured values. Otherwise, evaluation of the numerical results must take into account possible errors due to differences between rated and actual values.

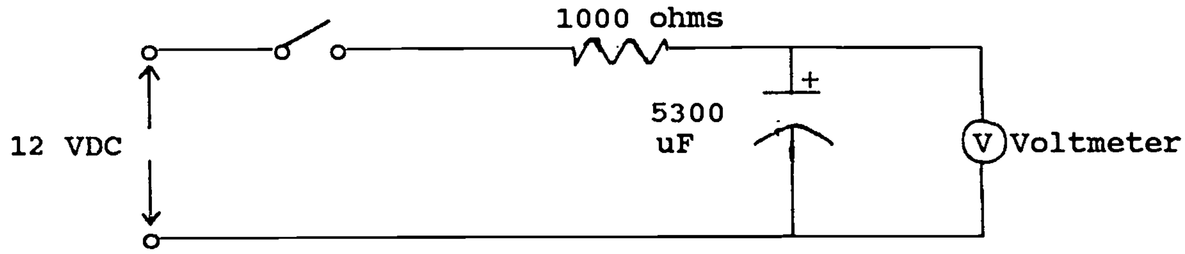
PROCEDURE

WARNING ! ! ! ! ! ! ! !

Capacitors of the type required in this lab are polarized. This means the terminals are marked for proper connection to the positive and negative leads of the power supply. Reversing the terminals will result in improper readings and **MAY RESULT IN A VIOLENT RUPTURE OF THE CAPACITOR !**

PART I

1. Construct the circuit shown in Figure 1 below, being careful to observe the polarity of the capacitor. Make certain that the switch is in the OFF position and that the power supply is also OFF.



2. Calculate the time constant (RC) for the circuit. Fill in all but the last column of the data table below.

# time constants	time in seconds (R * C)	percent charge	capacitor voltage (% * E)	measured voltage
1		63%		
2		87%		
3		95%		
4		98%		
5		99%		

3. With the switch open, turn on the power supply. The voltage across the capacitor should read zero because there is no path for charging current.

4. Close the switch and record the voltage across the capacitor after 1, 2, 3, 4 and 5 time constants in the last column of the data table.

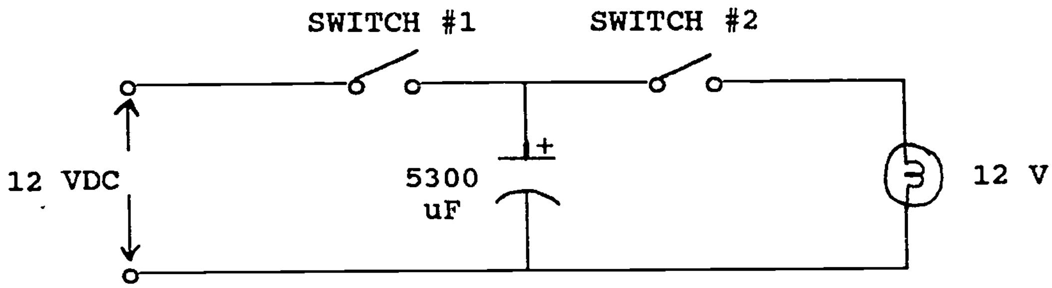
5. Compare your observations with the expected readings.

6. Repeat steps 1 through 5, substituting the 15000-microfarad capacitor for the 5300-microfarad.

# time constants	time in seconds (R * C)	percent charge	capacitor voltage (% * E)	measured voltage
1		63%		
2		87%		
3		95%		
4		98%		
5		99%		

PART II

1. After making certain that both switches and the power supply are turned off, construct the circuit below.



2. Close switch #1. Note that the capacitor is immediately charged to 12 volts.

3. Open switch #1 and immediately close switch #2. The lamp should light briefly as the energy stored in the capacitor is discharged. Note that the voltage across the capacitor has dropped to zero.

4. Repeat steps 1 through 3, substituting the 15000-microfarad capacitor for the 5300-microfarad.

5. Compare the brightness of the lamp for the two different capacitor values. It should be apparent that the higher value capacitor stores more energy.

UNIT IV

MEASURING THERMAL POWER

LAB OBJECTIVE

When you've finished this lab, you should be able to explain the effect of thermal power input on a system's mechanical power output.

LEARNING PATH

1. Preview the lab. This will give you an idea of what's ahead.
2. Read the lab and pay particular attention to the lab objectives.
3. Do the lab, "Measuring Thermal Power."

MAIN IDEA

* Turbines are used to convert thermal power into mechanical power.

TEACHING PATH - CLASS L1

RESOURCE MATERIALS

Lab 6T1: "Measuring Thermal Power"

CLASS GOALS

See **OBJECTIVES** for Lab 6T1

CLASS ACTIVITIES

(Set up the lab and run through the procedures before the students try the lab. You'll be able to anticipate student difficulties.)

1. Preview the lab for the students and explain what the lab is about. Show students the equipment and tell them what they are to accomplish.

2. Have the students follow the procedures outlined in the lab instructions and encourage students to read the procedures carefully. (Reading detailed procedures and following instructions are important parts of a technician's training.)

3. Monitor student progress and provide help as needed.

CONSTRUCTING THE TURBINE

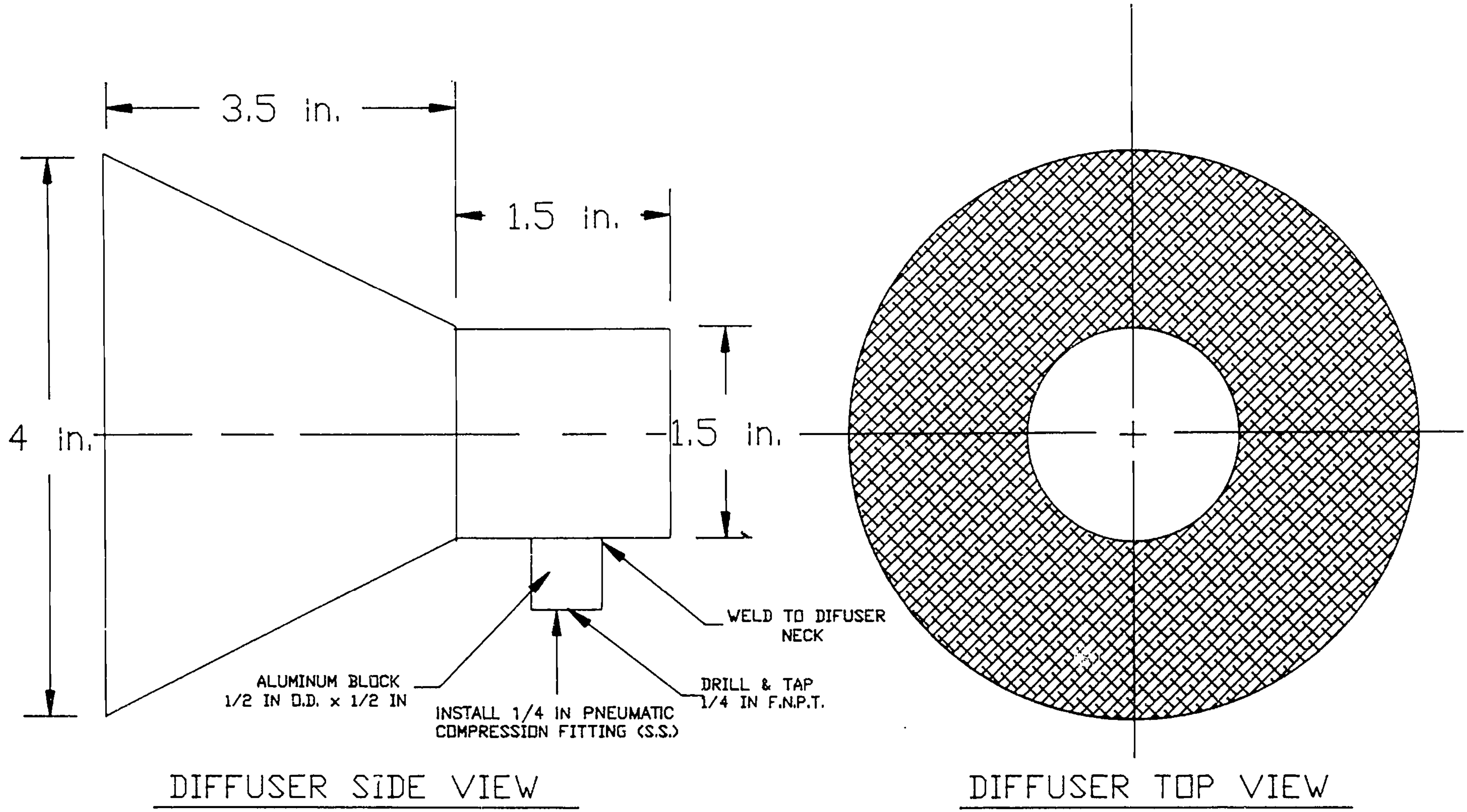
The turbine can be built using the attached drawing "TURBINE ASSEMBLY DRAWING". The turbine diffuser can be built using the attached drawing "TURBINE DIFFUSER DRAWING". Students in the school's shop classes can make the turbine using aviation snips. The diffuser will require advanced sheet metal working skills and skills in Gas Tungsten Arc Welding (GTAW or TIG).

Make photocopies of the "TURBINE TOP VIEW" and use the copy for a pattern by which to cut the sheet metal. None of the dimensions are critical. [**CAUTION:** When working with sheet metals, be careful not to get cut by the sharp edges.]

To further study the operation of turbines, try bending the blades on several turbines to different angles to show the effect of blade angle on thermal power efficiency.

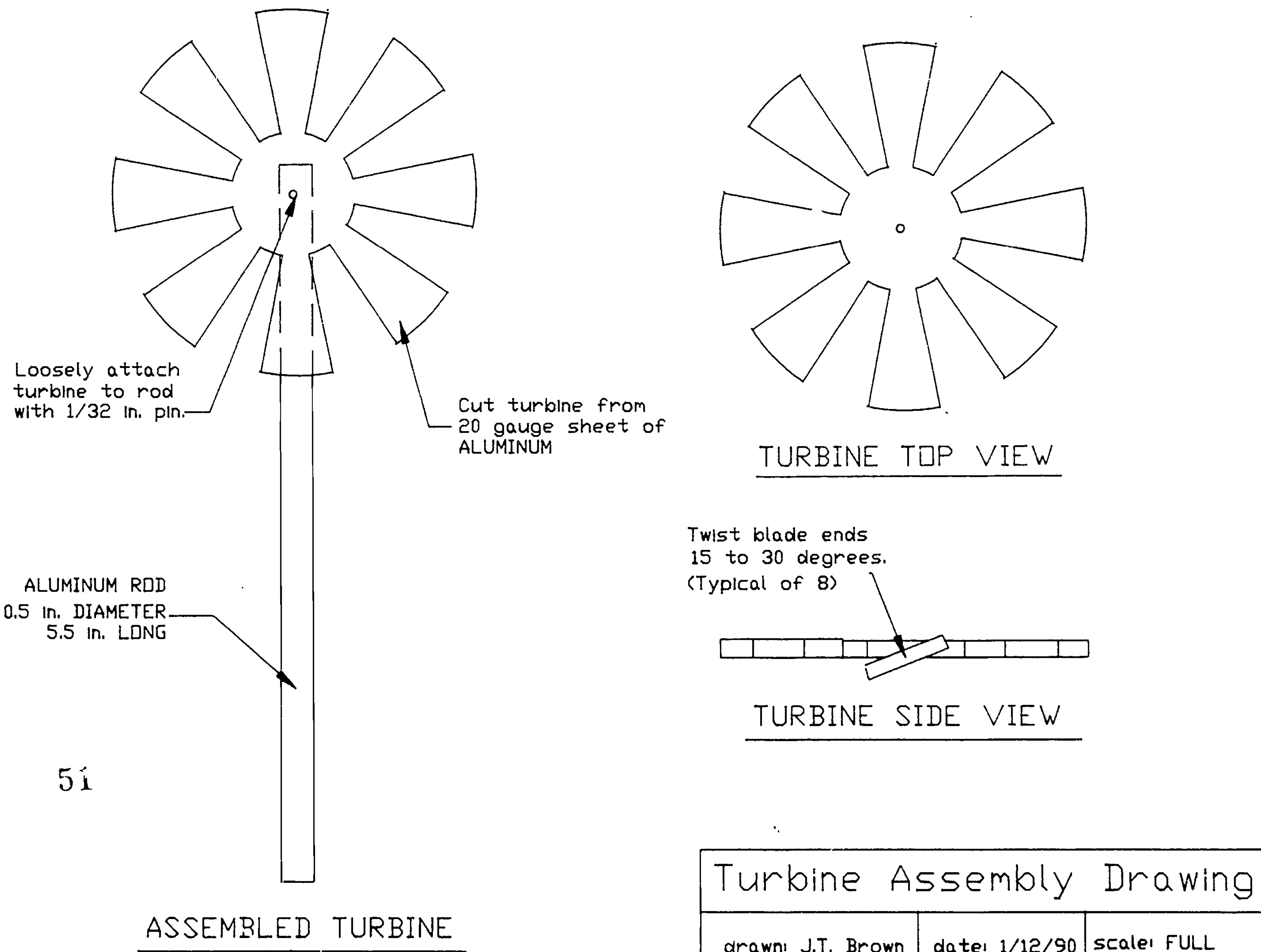
Any "turbine-like" device will work as long as it is not subject to deterioration by heat. [**NOTE:** Children's pinwheels will constitute a fire hazard.]

If a Bunsen burner is not available, consider substitutions such as: hurricane lamps or electric lamps (globe having a 1.5 to 2 inch opening in the top.) [**CAUTION:** Follow standard safety procedures when working with a Bunsen burner.]



NOTES:
1. Material 16 gauge aluminum
2. Weld and grind ALL seams
3. ALL exposed edges to be folded, welded and ground to eliminate cutting hazards

Turbine Diffuser Drawing		
drawn: J.T. Brown	date: 2/9/90	scale: FULL



Loosely attach turbine to rod with 1/32 in. pin.
Cut turbine from 20 gauge sheet of ALUMINUM
ALUMINUM ROD 0.5 in. DIAMETER 5.5 in. LONG
ASSEMBLED TURBINE
TURBINE TOP VIEW
Twist blade ends 15 to 30 degrees. (Typical of 8)
TURBINE SIDE VIEW
Turbine Assembly Drawing
drawn: J.T. Brown
date: 1/12/90
scale: FULL

DISCUSSION

A gas turbine is a device which extracts the thermal power from a gas stream and converts it into mechanical power. Gas turbines are used in industry to generate emergency electrical power. A gas turbine is the heart of the engines used to power jet aircraft.

HOW DOES A GAS TURBINE WORK?

Figure 1 shows the turbine used in a gas turbine. The turbine consists of a series of blades placed around the periphery of a wheel. The turbine wheel is attached to a shaft which turns with it.

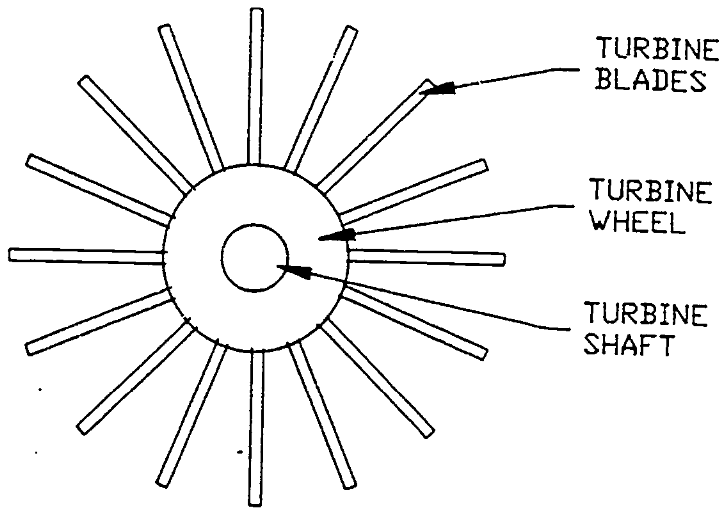


Figure 1 Turbine blades and wheel

Figure 2 shows the operation of a gas turbine. Hot gases passing over the turbine blades transfer power to the blades. The blades then move because of the power they receive. Since the blades are attached to the turbine wheel, they can only move so as to turn the wheel and its shaft. The rotating shaft then has mechanical power because of the thermal power imparted to it by the hot gases passing over the turbine blades.

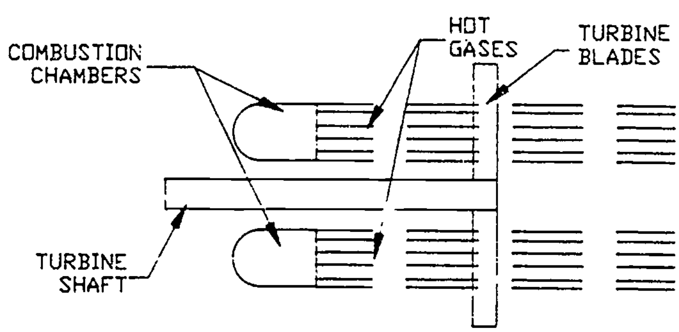


Figure 2 Gas turbine operation

Figure 3 shows a single turbine blade with the force imparted to it by the hot gases passing over the blade.

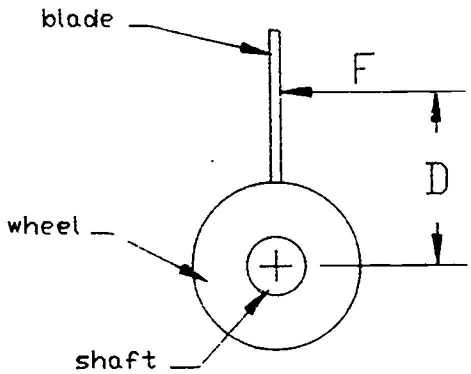


Figure 3 Forces on a turbine blade

Since the force of the blades is at a distance from the center of the turbine shaft, the gases produce a torque on the shaft. The turbine shaft will turn at a certain speed so that the power imparted to the shaft by the hot gases can be determined from the formula

$$POWER = TORQUE * SPEED \qquad (1)$$

-or-

$$P = T * S$$

where P = power imparted to the shaft in watts,

S = speed of the turbine blades in **REVOLUTIONS PER SECOND** and

T = torque produced by the hot gas on <u>ALL</u> of the turbine blades in newton-meters or

$$T = F * D \qquad (2)$$

where F = force produced by the hot gases on <u>ALL</u> of the turbine blades in newtons and

D = distance this force acts from the center of the turbine shaft in meters.

APPLICATIONS FOR GAS TURBINES

Figure 4 shows the internal construction of a jet engine.

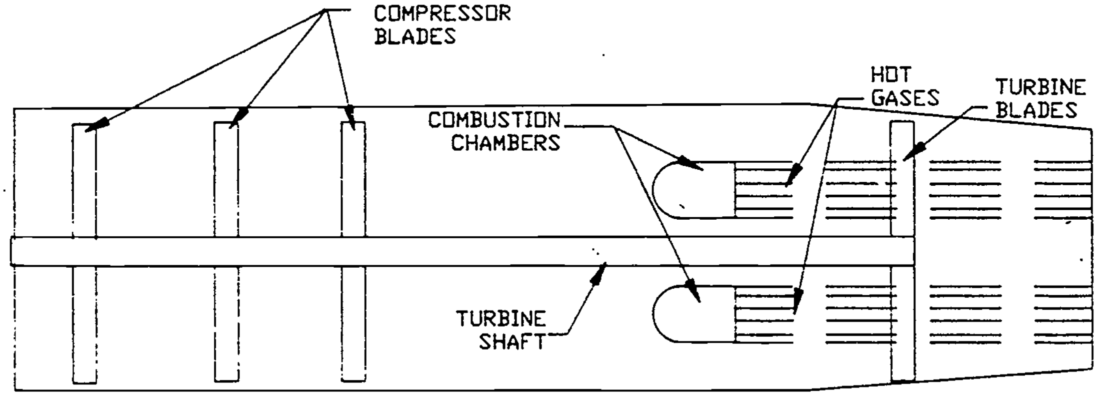


Figure 4 Internal construction of a jet engine

In the jet engine, hot gases turn the turbines, which then turn compressors, which provide high pressure air, which is used to burn the fuel to produce the hot gases to drive the turbines. In some jet engines, other turbines turn fans which push more air through the engine and outside of the combustion chamber to increase the thrust (force of the exhaust gases), which then moves the airplane.

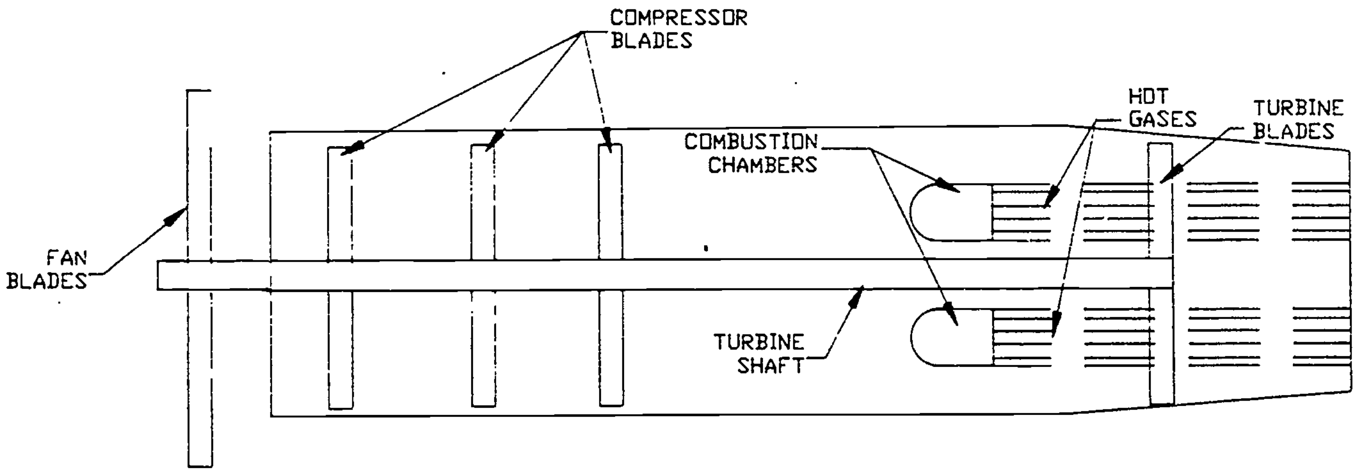


Figure 5 Fans added to a jet engine

The next time you hear a jet airplane fly overhead, remember that thermal power is the source of power which causes the airplane to fly.

EQUIPMENT

Bunsen Burner
Ring Stand
Clamps
Ring Clamp
Turbine
Turbine Diffuser
Thermocouple and multimeter
Stop watch or clock with a second hand

PROCEDURES

1. Mount the turbine and diffuser on the ring stand above the Bunsen burner.

2. Insert the thermocouple into the compression fitting on the diffuser and tighten the nut enough to grip the thermocouple.

3. Light the Bunsen burner and turn it to its lowest intensity flame. [CAUTION: Do not allow the flame to impinge on the turbine/diffuser to prevent damage to the turbine/diffuser]

4. Count the number of turbine revolutions per minute (RPM) and record this value in Data Table 1.

5. Measure the Gas Inlet Temperature from the thermocouple and record this value in Data Table 1.

6. Turn the Bunsen burner to a slightly higher flame intensity and record the temperature/RPM readings in Data Table 1.

7. Repeat Step 4 until the Bunsen burner has been turned to its maximum flame intensity. (Try to obtain 10 test points)

8. Turn the Bunsen burner off, and allow the turbine to cool before disassembling the apparatus.

DATA TABLE 1

Gas Inlet Temperature	Turbine RPM Reading

WRAP-UP

1. The turbine has a frictional resistance which the thermal power must overcome. This resistance means that the thermal power (P) must impart a torque (T) to the turbine to cause it to rotate at a certain speed (S). The formula which shows this effect is

$$P = T * S \qquad (3)$$

2. Let's assume that the torque required to turn our turbine is constant. (This is approximately correct at the relatively slow speeds obtained in this lab exercise). Then, the ratio of the power developed at one test point to the power developed at another test point is

$$\frac{P_1}{P_2} = \frac{S_1}{S_2} \qquad (4)$$

where P_1 = Power developed at Test Point 1
S_1 = Turbine speed at Test Point 1
P_2 = Power developed at Test Point 2
S_2 = Turbine speed at Test Point 2.

3. Now, by setting the lowest Bunsen burner flame intensity as test point 2, we can calculate the power ratio between the other test points by calculating the speed ratios between those same test points.

4. Using the turbine speed at the lowest Bunsen burner flame intensity as S_2, calculate the power ratios for all of the test points and tabulate this data in Data Table 2.

DATA TABLE 2

POINT	S_1 (RPM)	S_2 (RPM)	$P_1/P_2 = S_1/S_2$
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

5. How does the thermal power imparted to the turbine affect the speed of the turbine? What can you infer about the mechanical power output at the turbine shaft? How is thermal power related to Gas Inlet Temperature?