# Principles of Engineering

## A High School Course

## Emphasizing Mathematics, Science, and Technology

- Principles of Engineering
- Auto Safety
- Structures
- Machine Automation and Control
- Energy

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# PRINCIPLES OF ENGINEERING

## A HIGH SCHOOL COURSE

### EMPHASIZING MATHEMATICS, SCIENCE, AND TECHNOLOGY

# POE : An Exemplary Curriculum for Achieving MST Learning Standards

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The "Principles of Engineering" [POE] curriculum was designed to address all seven of the MST [Mathematics, Science, and Technology] Learning Standards that were approved by the New York State Board of Regents in July, 1996. Specifically, it addresses many of the key ideas and performance indicators within each learning standard. More importantly, the new paradigm of "MST Integration" was the primary design criterion of the engineering concepts [big ideas] and case studies approach to the POE curriculum.

Another feature of the POE curriculum and instructional model is the AAAS Project 2061 recommendation of "less is more". Thus, the most significant linkages or "best fit" between the POE curriculum and the MST Learning Standards are many of the key ideas of Standards I, V, VI, and VII. The key ideas of the other three standards are addressed in the curriculum as needed.

The focus of POE on engaging students in engineering design and related mathematical analysis and scientific inquiry is directly matched to the key ideas of Standard I. Standard V : Technology Studies, describes key ideas which are all embedded in the POE curriculum. The key ideas [Systems Thinking, Modeling, and Optimization] of Standard VI are also central to POE. In fact, they are three of the six major concepts that are studied and applied to all the case studies and student projects.

Standard VII : Interdisciplinary Problem Solving is also directly related to two of the central themes [ Technology and Society Interactions and Engineering Ethics]. All the units of study and related case studies also provide many opportunities for addressing the connections between the disciplines and to use the skills and strategies of problem solving and decision making. Some have described the study of technology as a natural way of integrating concepts from all the disciplines.

The POE curriculum guide "An MST Approach to Technology Education" includes in Appendix A, a paper which provides additional background information concerning how the POE course is related to the MST Framework and Learning Standards. Given the high degree of correlation between the technological content and learning activities of the POE course and the MST Learning Standards, it is being presented as *one way* of implementing the one year/unit of Technology Studies that may be required of all students in grades 9-12.

# Principles of Engineering:

## An Introduction to Engineering Concepts through a series of Case Studies

## With Emphasis on Achieving MST Learning Standards

### Table of Contents


**I. Introduction to The Engineering Concepts**
Decision Making, Design as a Process, Modeling Techniques, Optimization Techniques, Systems Analysis, Engineering Ethics, Technology Assesment, The Information Society

**II. Auto Safety**
Factors involved in Crashes, Preventing Crashes, Preventing Injuries

**III. Structures**
Emergency Buildings, Bridge Building Contest, Model of an Emergency Structure

**IV. Machine Automation and Control**
Methods Of Automating, Automation Systems, Programming for Automation

**V. Energy**
Electrical Generation, Building a low Energy Solar house, Building a Solar Electric powered Car.

This textbook is designed to introduce students to major engineering concepts and how they are applied to the study and search for solutions to real world problems. The eight chapters deal with major engineering concepts and how people interact with technology. Each chapter will feature the study of relevant problems, related systems and specific case studies as described in the following table of contents :

## Table of Contents

Chapter I : Decision-Making in the Technological World

This introductory chapter will present various aspects of the engineering approach to decision-making (criteria, constraints, models and optimization) in the context of real world situations that require a decision. On a personal level, decision problems will include those that are related to being an intelligent consumer of technology (selecting products, foods , health care, etc.) . On a societal level, examples will include public policy decisions such as mandatory as voluntary government regulations. Other examples in the chapter will relate to planning and management on a personal as well on an organizational level.

Chapter II : Design As A Process

The process of designing an artifact or system for satisfying design criteria within constraints will be the focus of this chapter. The design process includes needs assessment, finding best solutions via optimization techniques, and testing models to make more informed decisions about design options. Specific case studies of the design of automobiles, computer keyboard, auto safety technologies , etc. will be to show the application of the engineering design process. Design will be presented as an iterative process. This chapter concludes with a section that discusses failure-based design paradigms.

Chapter III : Modeling Techniques

The ability to model the behavior of systems in a more precise and predictive manner is one of the hallmarks of modern science and engineering. Computer-based modeling tools are transforming the way design is done. Both functional models (working replicas or computer simulations) and descriptive models (scale drawings or math graph and equations) and their utility will be explored. The role of scientific and mathematical models in engineering design and management will also be discussed. Modeling activities is one of the best ways of demonstrating the relevance of science and mathematics concepts to engineering studies.

Chapter IV : Optimization Techniques

Optimization is the process of finding the best solution to satisfy criteria within constraints. The techniques can be used to help in making better decisions or creating more effective designs. Both quantitative and more subjective techniques will be discussed to illustrate the science and art of making trade-offs in the search for optimum solutions. Topics will include maxima/minima problems, cost/effectiveness analysis and linear programming,

Chapter V Systems Analysis

The study of how systems are or can be controlled and how the components interact is the essence of systems analysis. The role of feedback in systems determines its goal-seeking capabilities. Feedback is also the key concept that governs the design of automated systems. Systems analysis also helps to determine how systems are designed and how stable or unstable they are. An important technique is the input/output or "black box" approach to studying the behavior of systems.

Chapter VI : Engineering Ethics

Besides using technical specifications (criteria and constraints) to design and select technology for meeting a need, engineers must also include human and environmental impacts in their decision-making process. Specific cases will be presented to provide context for the ethical dilemmas that are faced by modern engineers. Including ethical considerations complicates both the design and management process but provides a reality check for nascent engineers.

Chapter VII : Technology Assessment

In order for technology to provide the greatest societal benefit, new systems must be assessed to insure human compatibility and that the benefits do outweigh the costs. Making sure that machines fit people is human factors engineering or *ergonomics*. In order to assess broader societal impacts, technological forecasting techniques, cost/benefit techniques and other methods for carrying out assessments need to studied. The ultimate goal of assessments to produce recommendations of using emerging technologies or to determine if technology can help fix a problem .

Chapter VIII The Information Society

As we move towards the information-based society of the 21st century, the ability to know how to access and use suitable electronic information will be required of all professionals, especially engineers. This chapter will focus on the science and engineering concepts that underlie the transition from an analog and print-based world to a digital and multi-media world.

# Chapter 1 Decision Making in the Technological World

" A good deal of work now involves *decision making* and knowledge, so information tools have become, and will continue increasingly to be, the focus of inventors"

From: The Road Ahead
Bill Gates, 1995

## [I] Types and Elements of Decision Making

You have just passed your driving test and are anxious to get behind the wheel of your family car. However, your parents before giving you permission to use the car want to make sure that you can make intelligent decisions about how to use and drive it. Is there a systematic way of making decisions about how to use technology more efficiently and safely? How can you make better decisions about gasoline economy and auto safety? These are examples of the many personal decisions that we have to make as users of technology. In this and the next section we will focus on a gasoline economy problem and an auto safety problem to begin our study of the elements of the engineering approach to decision making.

Besides having to make decisions about using technology well, we also need to make choices about what technology to buy to satisfy the many needs of our daily life. Think of the many purchases that you and your family make each year. Your list might include a car, hi-fi system, new electrical appliances, sports equipment or even a new computer system to provide access to the information tools that Bill Gates, the CEO(Chief Operating Officer) of Microsoft Inc. discussed above. Is there a generic process that will help you make consumer decisions? In section III, we will focus on a few consumer decision making problems to explore the common elements of a decision making process.

In the near future, you will be working as a professional and will have to make many technology-based decisions. One activity which is fundamental to the management and development of the technological world (indeed, fundamental to all human activity) is the making of decisions. For example, the professional engineer is basically a decision-maker. The electrical/industrial engineering team in designing and producing a television receiver, decides how best to achieve picture and sound quality standards, what size picture tube to use, how many sets to produce and the arrangement of the manufacturing facilities to produce the sets. The mechanical and automotive engineering design team for an electrical vehicle have to make decisions such as, what vehicle performance to achieve, what batteries to use, and how to recharge the batteries. In section IV, the decisions related to the design of a new HDTV (High Definition Television) will be explored.

Engineers and other technologists when designing or managing systems besides being concerned about technical decisions, also have to consider the impacts of the technology on people as individuals and as members of a community. For example, when designing a TV set, the vision capabilities and limitations as well as viewing habits of people will affect what will work and be accepted. Consumer acceptance is one of the keys to the ultimate success of a new product. In the concluding section of this chapter the renewed interest in the design and development of a viable electric vehicle will be discussed in the context of decisions that relate to consumer acceptance and public policy issues.

As individuals, we make decisions daily, from relatively simple ones with clear choices to more complex ones where the choices depend on uncertain factors. For some decisions problems, there are systematic ways (algorithms) of determining the best or optimum solution. Unfortunately for most decision problems, we have to make trade-offs or compromises to arrive at an acceptable solution.

To begin our study of the elements of decision making, we will start with the simple problem of how fast to drive a car to obtain the greatest gas mileage ( as measured in miles per gallon). Notice, an important aspect of the engineering approach to decision making is the use of a quantitative measure for determining the optimum solution. In this case the greatest miles per gallon is our objective or CRITERION. Since we also want to reach our destination quickly, a second criterion is to get somewhere in the shortest time as possible. So even in this simple example we have two criteria to satisfy. Maybe the answer is to drive at the speed limit. Or is it that simple?

One way to begin the search for the best answer (OPTIMIZATION) is to consider the most important criterion first. In order to try to get the best gas mileage we need more information about how much gasoline cars use at different speeds. Figure 1-1 shows how gas mileage depends on the speed for a particular car. Engineers think of this type of graph as a descriptive MODEL of one aspect of the performance of a car. Notice that as the speed increases the gas economy improves, until at about 45 miles per hour (mph), it reaches a maximum of about 22 miles per gallon. Beyond 45 mph the gas economy falls off mainly due friction in the engine, the wheel bearings, and in the air through which the car moves. So the obvious answer is to drive at 45 mph if we want the best gas mileage.

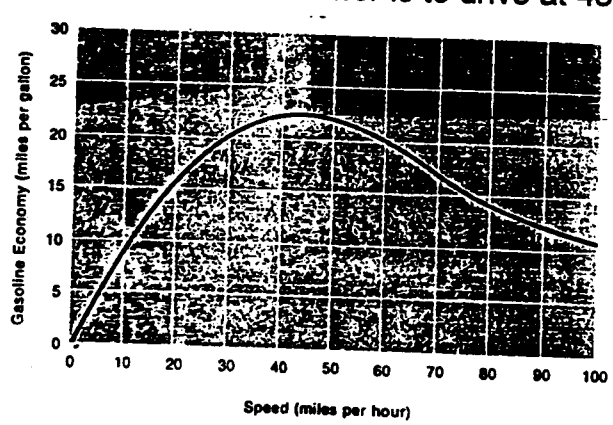



*Fig. 1-1 Gasoline economy as a function of automobile speed.*

When driving in the real world, the speed limits (CONSTRAINTS) in cities or highways limit our choice of speeds. Figure 1-2 shows a modification of Figure1-1 to model driving in a city that has a 25 mph speed limit. Now, if we wish to maintain maximum gas economy under this constraint, we have to drive at 25 mph. This is the highest point on the curve of the graph within the feasible region.

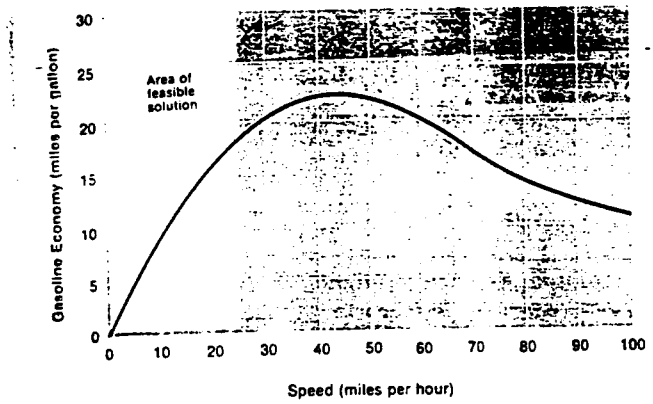



*Fig. 1-2. Speed limit added.*

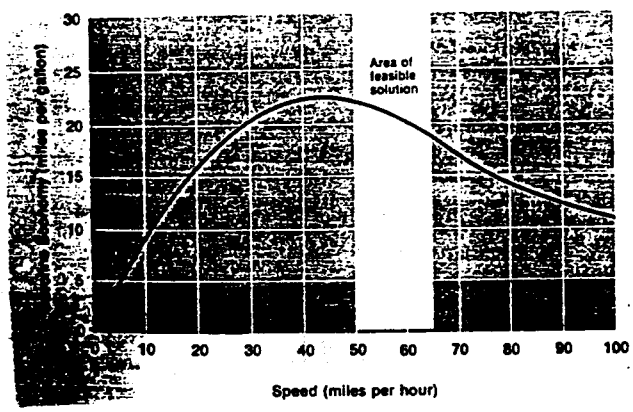



*Fig. 1-3. Case with minimum and maximum speeds.*

If, on the other hand, we drive along a limited-access road such as the New York State Thruway or Interstate 5 in California, a different set of constraints may be imposed as shown in Figure 1-3. Here, we are not permitted to travel faster than 65 mph, nor slower than 50 mph. Again, the answer is obvious, we should drive at 50 mph if our only objective is to save gas. Notice that if we only have one criterion and a good model for the decision problem , it is not difficult to find the optimum solution. However, in most decision situations, we have to make decisions on the basis of conflicting desires and criteria.

As indicated earlier, besides wanting to save gas, we may also want to reach a destination as soon as possible. We now have a more complex decision problem because we are trying to satisfy two criteria. We see from Figure 1-3 that we cannot simultaneously drive at maximum speed (within the speed limit, of course) and achieve maximum gas mileage. Such conflicts are typical of real decisions. We can drive at 50 mph to save the most gas or at 65 mph to save the most time. We can also compromise and drive at a speed between 50 mph and 65 mph. Our choice would depend on the relative importance of the conflicting criteria.

The above automobile driving decision problem contains all the elements of the decision making process. The four elements are :

| | |
|---|---|
| Criteria | Constraints |
| Models | Optimization Techniques |

The definitions for these terms are :

1. *Criteria* are the measurable objectives of the decision problem. In our example, the two criteria are to achieve the best gas mileage and to arrive at our destination in the shortest time. When there are criteria that are incompatible, we have to make trade-offs and reach a compromise solution. We have to decide on the relative importance of the conflicting criteria which is often a subjective process. Thus two people using the same criteria , constraints, and models might choose different optimum solutions.

2. *Constraints* are added factors that limit the choices in the decision problem. In our example, the speed limits represent constraints. Other constraints in our example could be unsafe road conditions or driver fatigue. The constraints specify the region within which we should look for a solution. Thus, we must find the best solution that satisfies the criteria within the constraints of the decision problem.

3. *Models* provide descriptive or functional representation of aspects of the system that relates to the decision problem. In the example, we used a descriptive model (graph) of how cars consume gasoline at different speeds. We could have used a computer simulation (functional model) to search for optimum solutions. Although there are many different types of models that can be used, they are all based on mathematical or quantitative relationships between variables that relate to the criteria and constraints of the decision problem.

4. *Optimization Techniques* are used after we decide what we really want (the criteria), what is permissible (the constraints), and find relevant quantitative models to determine the best solution. In our speed example, optimization is simple, because all we had to do was to examine the model in the context of the criteria and constraints. In more complex problems, special engineering or applied mathematics techniques have to be used. In many practical cases, a trial-and-error approach still has to be used.

Now that you have had an introduction to the four main elements of the decision making process, the remaining sections will use these concepts to analyze more complex technology-based decision problems. We will continue to study car related decision problems by studying the factors that affect the timing of traffic lights, especially the yellow light. This example will also begin your study of ERGONOMICS or the study of how human factors affect the design of technological systems. In other words, how can technological systems be designed to better fit the characteristics and limitations of human users.

## [II] Matching Technology to the Human User: The Traffic-Light Problem

Technology should serve people. Technology should fill a need; it should make life richer safer, and more productive. If these goals are to be reached, technology must be matched to the human user. In other words, we must design and manage the use of technology by considering both the physiological and psychological traits of people.

The need to match technology to the human user is illustrated by the traffic problem in this section. In this decision problem, we focus on the place where the technology meets the human user and many decision making questions are raised and analyzed. How do we identify and measure the human factors that affect the problem? How do we decide what technology to use and how it should work? Finally, given the criteria and constraints, what is the best possible or optimum technology?

### The Traffic-Light Decision Problem

The pictorial model for the problem is shown in Figure 1-4. A side road, we call it Residential Street, leads from a group of homes onto a main state highway, which we call Main Turnpike. The speed limit on Residential Street is 30 mph, although some people drive at 50 mph when going to and from work. The speed limit for Main Turnpike is 55 mph. There is heavy traffic during the day. In the late evening, drivers are sometimes observed driving at over 70 mph with apparent disregard for safety.

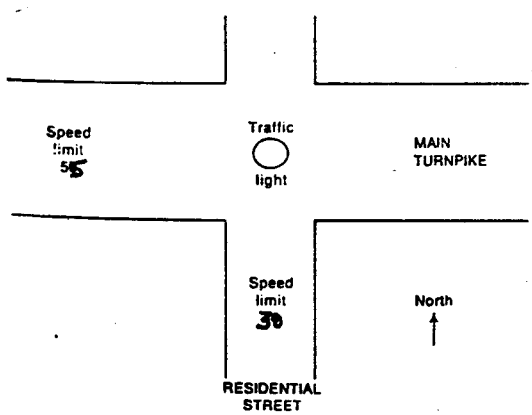



*Fig. 1-4*
*Intersection of two-lane Residential Street and four-lane Main Turnpike. A traffic light is installed at the intersection.*

A series of accidents at the intersection of Residential Street and Main Turnpike has finally convinced officials that a traffic light should be installed at the intersection. A red-yellow-green light is to be purchased. We must decide what kind of cycle the light system should have. Among the many possibilities that a transportation engineer (usually someone with a civil engineering degree) would consider are:

1. Should the light have a regular cycle? That is, should the light regularly change? If so the engineer would identify the following four periods of time:
   a) Green for Main Turnpike, Red for Residential Street
   b) Yellow for Main, Red for Residential
   c) Red for Main, Green for Residential
   d) Red for Main, Yellow for Residential

Instead of this regular cycle, the engineer might consider placing a car detector on Residential Street. The light on Main would stay green until a car drove passed the detector. Then the light would turn green on Residential Street for a short time.

2. If a regular cycle is chosen, should it be the same all day long or should periods a,b,c,d, be changed to better match the traffic at off-peak periods?
3. If a regular, unchanged cycle is chosen how long should periods a,b,c,d, be?

This is not an easy problem to solve mainly because of the human factors of drivers and how cars move. As with the previous gas mileage problem, we have conflicting criteria that also complicates the problem. In this case, we want to use the traffic light system to improve auto safety while moving the maximum number of cars through an intersection. Let's see what are some of the factors that will have to be considered to arrive at a compromise solution that be optimal.

More cars can be moved through the intersection if the lights do not change very often. Every time cars slow down to stop or accelerate to get up to speed time is being wasted. Since most of the traffic is on Main Turnpike, keeping the Green light on for three minutes might be good for moving traffic. Even though a very long Green light on Main might be a good way of satisfying one of the criteria, it won't work with human drivers. A visitor to the area who doesn't know about the very long Red light on Residential Street will think that it broken after waiting a minute or two. An accident is likely to occur as the driver attempts to drive on to Main Turnpike.

Thus, to improve safety, the duration of the Green light on Main cannot be so long that drivers will not accept it. On the other hand , the shorter the duration the fewer we can move through the intersection causing a traffic jam. To complicate matters, it is difficicult to pick an optimum duration of the yellow lights (parts b and d of the above cycle) in either direction.

Suppose that as a car drives up to the intersection on Residential Street, the light turns yellow. The driver has to make a decision immediately whether to stop or not. If he is close to the intersection, the safe thing to do is to keep going. Why? The duration of the yellow light should be long enough for the car to make it through the intersection before the cars waiting on Main are given a green light and surge forward. Unfortunately, if we make the yellow light too long fewer cars move through the intersection and traffic piles up. To make matters worse a long yellow light may be safer for some people but not for others, why? In order, to answer the two why? questions we need to take a more scientific and quantitative view of the yellow light problem. Understanding the science (in this case, the physics of motion) and math models that relate to the decision problem often helps at arriving at more optimum solutions.

The Yellow Light Problem

A driver on Residential Street sees the light ahead turn from green to yellow. If the driver is far enough from the intersection, he will apply the brakes and stop. As we will see below, the math models for the physical laws of motion shows that depending on the speed, human response time and quality of the brakes the car will travel from 100 to 300 feet before stopping. That is why if the car is close to the intersection the only safe decision is to keep going, otherwise the car will stop in the intersection and may cause an accident. Figure 1-5 shows the GO and STOP zones. If the driver is in the GO zone, s/he keeps going. If the car is in the STOP zone the decision should to stop.

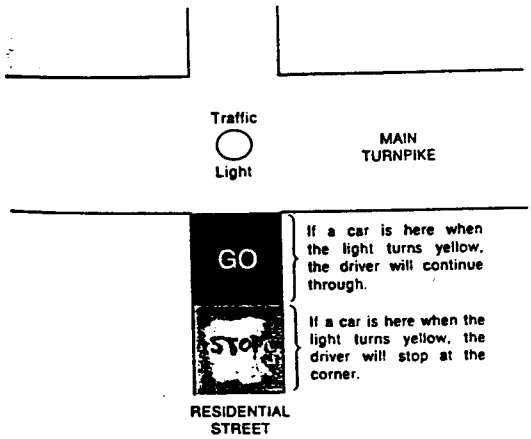



*Fig. 1-5*
*GO and STOP zones as driver comes north on Residential toward the intersection with Main Turnpike.*

Of course, there is no sharp separation between the GO and STOP zones. Different drivers will behave differently. even a single driver will vary depending on her or his mood, speed , alertness, and number and type of passengers, and so on. We certainly want to keep the light yellow long enough to allow most the drivers to make it through the intersection. Should this duration be 2,3,4 seconds or what? In other words, how large does the GO zone have to be.

In general, having a longer Yellow Light will be safer. However, we do not want to make the yellow light longer than necessary for two reasons:

1. A long yellow light means longer times when traffic is not moving through the intersection.

2. Most drivers on Residential Street drive here frequently. If they learn that the yellow light is long they will gradually extend their GO zones and some them might even treat the yellow light as a green light.

In order to better understanding this decision problem, we will need to collect data from an actual traffic intersection and use quantitative models and certain assumptions about the main factors that affect the size of the GO and STOP zones. This analytical process is an important aspect of the engineering approach to decision making.

A Quantitative Look at a Real Traffic Intersection

One of the best ways to study a technological system is to collect information about the system and to create a model to study how the system might behave under varying conditions. At an intersection near my university, I and a few of my students collected the following data for the traffic light system for a residential-type street :

Time of Yellow Light = 3.2 seconds
Speed Limit = 40 miles per hour
Width of Intersection = 50 feet

GO Zone

This data was collected so that we could determine the GO zone. When trying to determine system behavior, we first need to select a math model or equation that relates to the input parameters of what you are trying to determine ( in this case, the GO zone ). So how do the above three input parameters affect the GO zone. It is actually pretty straight forward, First, we have to figure out how far the car will travel during the time that the light is yellow. Thus:

Distance Traveled = Speed x Time of Yellow Light

However, before we can use the equation we have to make sure that all the parameters are expressed in the same units, in this case we have to change miles per hour to feet per second. Changing miles to feet and hour to seconds and dividing seconds into the number of feet will result in the conversion factor of 1.47 feet/sec for 1 mph.

So, Distance Traveled = 40 mph x 1.47 ft/sec/mph x 3.2 sec. = 188 feet

Since the GO zone is measured from the beginning of the intersection and the car has to get through the intersection the GO Zone = Distance Traveled - Width
Thus the Go Zone for this intersection is 188 feet - 50 feet or 138 feet

STOP Zone

The determination of the STOP zone is more complicated and understanding of information about human response time and the physics of vehicles that are changing speeds or accelerating are needed. We can simplify the problem by realizing that the STOP zone is made up of two parts. First, the car will travel a certain distance while the driver is deciding whether to STOP or to GO and will travel an additional distance when the driver foot is being moved from the accelerator to the brake. The time needed for making a decision and moving the foot is usually called the human response time and varies from 0.6 to 1.0 second. Thus, the car traveling at 40 mph (59 ft/sec) will travel from 35 ft. to 59 ft. depending how quickly the driver can respond. We will assume a response time of 1 second so that all drivers will be safe.

Once the brakes are engaged the car begins to slow down and travel a certain distance until it stops. How far the car will move while slowing down will depends on the rate of slowing down or negative acceleration (sometimes called deceleration). The range of deceleration rates vary from 10 ft/sec/sec (poor brakes) to 20 ft/sec/sec (excellent brakes). For our sample problem, we will use a deceleration rate of 10 ft/sec/sec because we want to be sure that the system will be safe for all cars. We will also use a speed of 60 ft/sec (instead of 59 ft/sec) to simply the calculation. When analyzing a system quantitatively it is often useful to keep initial data simple to facilitate understanding. Later, a spreadsheet or a calculator can be used to analyze actual data.

If we assume an initial speed of 60 ft/sec (about 40 mph) and a deceleration rate of 10 ft/sec/sec, then the car will come to a stop in 6 sec. Since the initial speed was 60 ft/sec and the final speed was 0 ft/sec, and the car slowed down at a uniform rate, the average speed while slowing down was 30 ft/sec. Since the distance traveled by a car is average speed x time, then the distance covered while braking is 30 ft/sec x 6 sec. or 180 ft. Notice that we determined the braking distance in two steps:

1. We first figured out it took 6 seconds for the car to slow down uniformly from 60 ft/sec to 0 ft/sec.
2. Next, we figured out the average velocity to be 30 ft/sec and multiplied it by the time (6 sec.) to obtain a braking distance of 180 feet.

For students who have studied Physics, you may remember an equation for determining the braking distance in one step by using :

Braking Distance = Speed ^2/2xdeceleration rate

Braking Distance = 60 ft/sec x60 ft/sec/2 x 10 ft/sec/sec

3600/20 = 180 ft.

Now we are ready to figure out the size of the STOP Zone. It is simply the sum of the distance traveled while the driver was responding and the braking distance. Thus :

STOP Zone = Responding Distance + Braking Distance

59 feet + 180 feet = 239 feet

This sample calculation was based on designing the safest possible system because :

1. We assumed a relatively long response time ( 1 second)
2. We assumed a low deceleration rate (10 ft/sec/sec) to account for cars with poor baking systems.

In Figure 1-6, the minimum stopping distances for cars traveling at different speeds are shown. Notice that the stopping distance for a car traveling at 40 mph is only 116 feet. Why is there such a great difference between our calculation of 239 feet and the chart's 116 feet? Try changing the above two assumptions to see how close you can come to the 116 feet stopping distance.

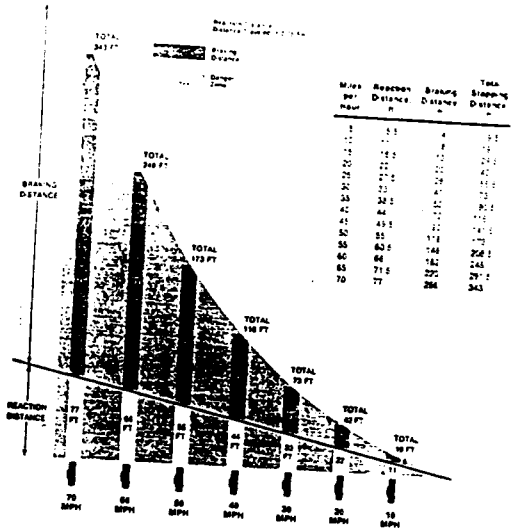


Fig. 1-6
*These minimum stopping distances are based on tests made by the Bureau of Public Roads. The chart shows how greatly braking distances and danger zones increase when you increase your speed. The distances are for a stop in minimum time (under emergency conditions). Reaction time is 0.75 second. (American Automobile Association)*

Upon analysis, we can see that the minimum stopping distances displayed in the above chart are based on testing cars that have excellent braking systems and assuming that people have pretty a good reaction time ( we use the term response time because besides reacting to the yellow light a driver also has to make a decision of whether to GO or STOP).

## Systems Analysis of the Yellow Light Problem

Now that we have an initial understanding and model for studying the Yellow Light Problem we are ready to analyze the problem in a more systemic manner. Many of the techniques of systems analysis will be discussed in greater detail in Chapter 5. Here we will only introduce the INPUT-OUTPUT approach to studying the behavior of systems. In our approach to figuring out the GO and STOP Zones we used five parameters or variables . They are:
Yellow Light Time Car-Speed Intersection Width Response Time Deceleration Rate
We will call these our input variables. They are used to determine the output variables, as shown in Figure 1- 7. Notice besides indicating the two output variables GO and STOP Zones, a third output is shown, namely a DILEMMA Zone. What is the significance of this zone and how is it determined ?

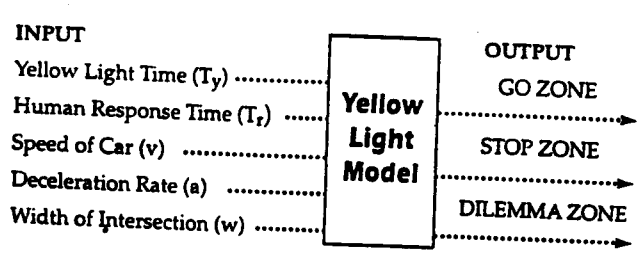
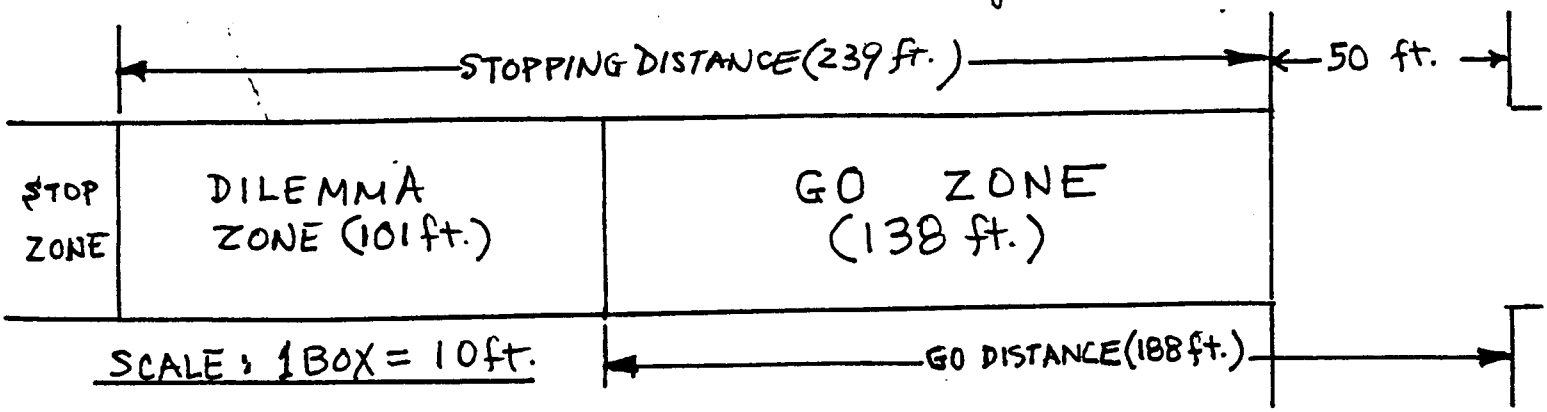



Fig. 1-7 Systems Analysis of Yellow Light Problem

In the sample problem, we determined that the GO Zone is 138 feet and the STOP Zone 239 feet. To help us visualize this situation we can use these output parameters to make a simple scale drawing (an important tool for quantitative thinking) as shown in Figure 1-8.

Fig 1-8 Scale Drawing




The above diagram or scale drawing clearly shows there is a region between the GO Zone and the STOP Zone that labeled the DILEMMA Zone. Why would a driver who is in this zone have a dilemma? Would all drivers have a dilemma? Remember that our analysis assumed that the car had a poor braking system and that the driver had a relatively long response time. So only some drivers and cars would experience a DILEMMA ZONE : a situation when the car is too far from the intersection to GO safely and too close to the intersection to STOP safely.. To insure maximum safety for all drivers instead of a DILEMMA Zone we should have an OVERLAP Zone where an unsure driver would be safe whether to GO or STOP. Unfortunately this usually requires a long yellow light duration or lower speeds, both of which decreases traffic flow. Alas, the need to compromise between conflicting criteria.

Improving the MODEL

As indicated in Figure 1-7, this model for studying the Yellow Light Problem is rather simple and only included five input variables. However, it did provide us with output parameters that are useful in deciding how long yellow lights should stay on. As with most engineering models, once the basic model is developed, it can then be improved to better represent the system that is being modeled.

In this example, two additional parameteres can easily be added to the model to make it more realistic. For instance, how can the length of a car be incorporated into the model? Remember, the GO zone took into account the width of the intersection. To be more accurate we should also subtract the length of a car in determining the GO zone. Thus the equation for the GO zone should be:

GO Zone = Speed x Time of Yellow LIght - Width of Interesection - Length of car

We can also improve the model by including the slope of hills .If a car is approaching a light when coming down a hill the brakes will also have to act against gravity.

If a car is coming down a hill. depending on the slope of the hill. an additional acceleration will have to be overcome by the brakes. So, for the same braking force, the deceleration variable will decrease. Thus, the car will travel a greater distance before stopping.

Another factor that can be included to refine our yellow light model is the condition of the road surface. In our initial model we assumed that the car was stopping on a dry road surface. Data is presented in Fig. 1-9 to show that, depending on the speed and type of vehicle, an additional 40 ft. to 140 ft. is added to the stopping distance when the road is wet.

The source of the information that is shown on the right [Fig 1-9] is provided by the U.S. Department of Transportation's National Highway Traffic Safety Administration, In their safety campaign literature. They say:

" Drivers who exceed the posted speed limit or drive too fast for road conditions increase the length of time and distance necessary to stop their vehicles. It is important for drivers to adjust their driving behavior to adapt to road and weather conditions."

At this point in our analysis of the yellow light problem, let us compare the stopping distance that we calculated earlier with the values shown in figures 1-6 and 1-9. Notice, that our stopping distance of 239 ft. [for 40 mph] is very similar to the 280 ft. [for 45 mph] that is shown in Fig. 1-9 for a truck. When comparing the information shown in Fig. 1-9 to the ones shown in Fig. 1-6 we notice a big difference. The stopping distances in Fig. 1-9 provides a greater margin of safety.

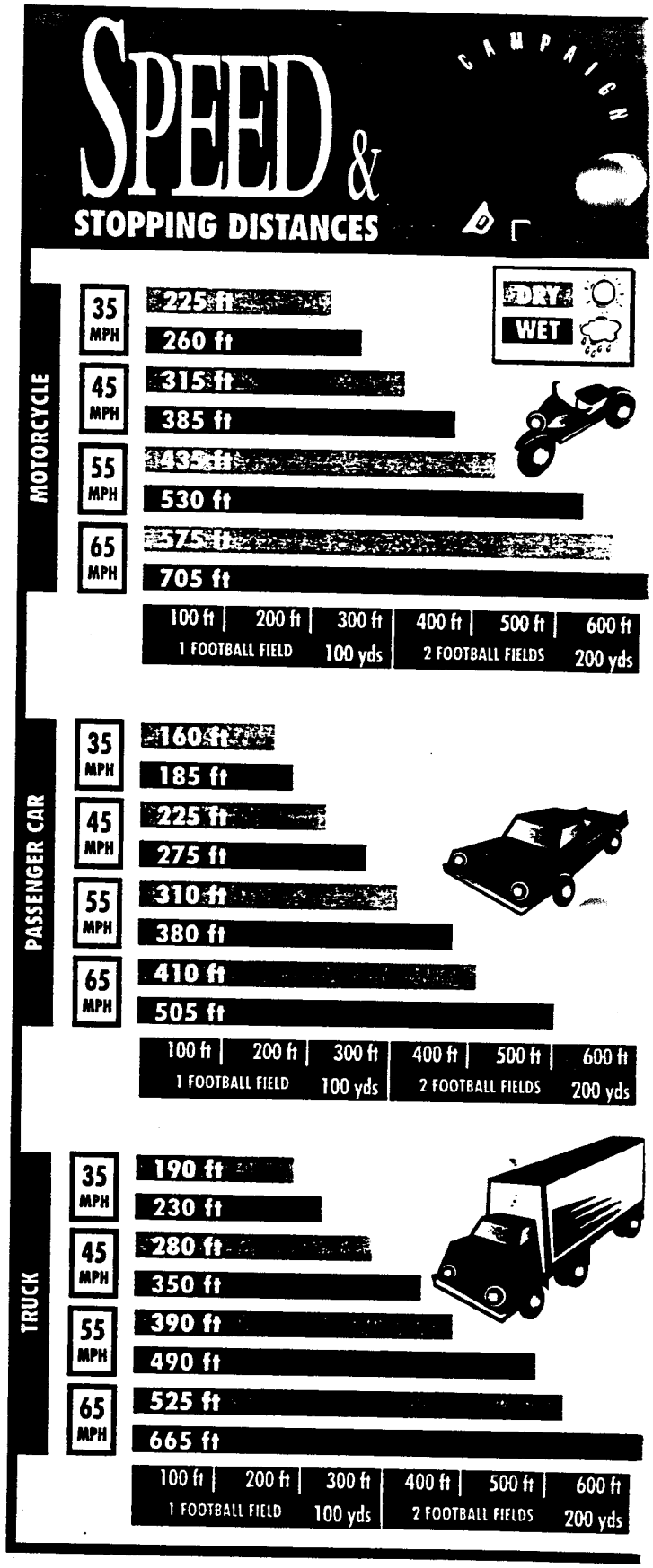



Fig. 1-9

Determining Human Response Time

In modern driver education programs. simulators are used by students to determine their response time under various driving conditions. The response times of 0.6 to 1.0 seconds that are measured involves two types of activities:

1. Noticing a change and deciding what to do [e.g. change from green to yellow]
2. Carrying out the decision [e.g. moving the foot to activate the brakes]

When responding to a traffic light system going to yellow, the time needed by most people in carrying out each of the above two activities is on the average about 0.4 seconds.

The first half of the response time activity involves decision making and is much harder to measure. However, the second half involves human reaction and can be measured with simple equipment. Depending on the reaction activity the times can also vary. We can gain some idea of human reaction times by doing a simple experiment.

Human Reaction Time Experiment: The person being tested [subject] sits with hand outstretched [Fig.1-10]. The thumb and forefinger are ready to close and grab a ruler. A 12-inch [30.5 cm] ruler is held by someone else [the tester], with the 12-inch mark at the top and 0 at the bottom. The tester drops the ruler at any instant. The subject should react to grab the ruler only after she observes that the ruler has started falling. The tester uses the ruler to measure how far it fall after being grabbed. If the ruler merely falls and is not thrown downward, the distance it falls can be used as a measure of time. The relationship between distance fallen and reaction time is shown in Fig. 1-11. A fall of 7.7 inches [20 cm.] corresponds to a time of 0.2 second. The time is the human reaction time for one trial of an experiment. It is the time need for the eye to observe the ruler falling, the message to go to the brain, and a message to go to the muscles controlling the thumb and forefinger. Fig. 1-11 is a graphical model for a freely falling object that can also be modeled by the equation :

*Fig. 1-10.*
*Testing human reaction time.*
*The tester drops the ruler at some unexpected moment. The subject closes his fingers to grab the falling ruler*

Distance Fallen = 1/2 g [acceleration due to gravity] x time squared

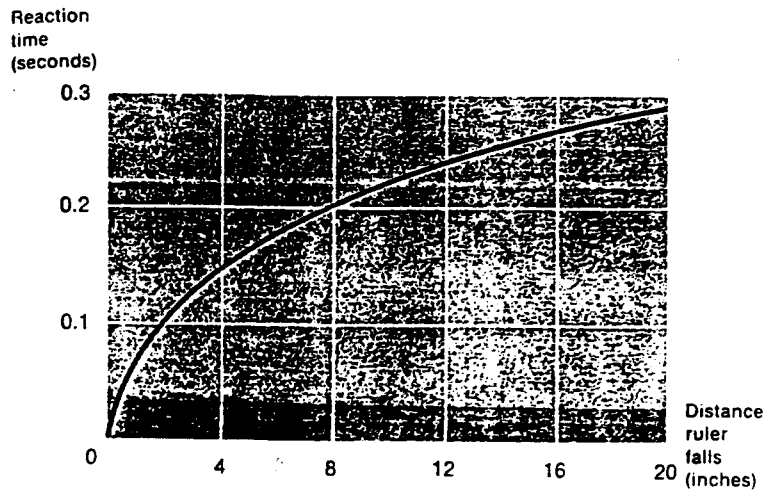



*Fig. 1-11.*
*Reaction time found from the distance the ruler falls.*

## [III] Consumer Decisions

All of us are consumers of technology. Some of us are or will be involved in designing, manufacturing, and marketing consumer products. Whether we like it or not we live in a society that consumes many products, some we really need and others where a need has been created. Daily we all make many decisions that relate to the purchase, use, management, and design of consumer products. In this section, we will focus on the purchase and use of technological products. In subsequent sections we will focus on management and design decisions.

### Energy Intensive Products

One way to categorize the hundreds of products that we buy and use yearly, is to separate those that consume energy and those that do not. We could further focus on those products that consume large amount of energy. In this section we will explore and apply the engineering approach to decision making to two types of energy intensive products: home appliances and automobiles..

### Cost-Effectiveness of Electrical Home Appliances

When making a decision about what electrical appliance to buy, we usually want to purchase one that meets our needs in an highly effective manner. We also try to spend as little money as possible for a quality product. We can quantify this type decision problem by using an optimization technique called cost-effectiveness analysis.

The first step to an analysis of cost-effectiveness is to decide how the cost and effectiveness of a technological product is to be measured. Usually, the cost of a product is measured in terms of funds needed to buy, operate, and maintain the technology. However, more forward looking consumers might also include other costs to society such as those associated with environmental impacts. In order to determine the economic impact, all direct and indirect costs would have to be translated in monetary units.

On the other hand, units of measurement of effectiveness will vary and will depend on how the performance of a technological system is being determined.For example, the effectiveness of an air conditioner can be measured by how well it cools a room or how much heat it removes [ BTUs /hour ] . In addition, its efficiency can be measured by comparing the electrical energy needed to remove a certain amount of heat energy [ BTUs /watt-hour ] . Notice that in this example we are using both Metric and English units of measurement. This is unfortunate, but reflects the fact that in the US we still use a combination of the two systems of units.

When purchasing home appliances such as air conditioners and refrigerators, we are often confronted with the decision of whether it is worthwhile to buy a more expensive model that is more effective. In the case of the selection of the best air

conditioner to buy we can compare the purchase price with the monetary benefits of buying a more effective model.

In this type of consumer decision problem we have two primary criteria:

1. To select the most effective system for cooling a room
2. To select the lowest cost option

The constraints of the consumer decision problem could include:

1. Size of the room to be cooled
2. Number of people using the room
3. Capability of electrical outlet [new wiring will add to the cost]
4. Size of window for mounting the air conditioner

Our analysis will start by making a few assumptions that will simplify the problem. Then we will add other factors to make the analysis more realistic. Let's assume that we have used the above criteria and constraints to narrow our selection to two brands of air conditioners that are designed to cool a 12 by 20 foot room [ 240 sq. ft. ].

Shown in Fig. 1-12 is a table that is reproduced from the June,1995 issue of the Consumer Reports magazine . It provides information about the cooling capacity needed by rooms of different sizes. Notice that for a room between 150 to 250 sq. ft. the recommended cooling capacity is 6000 BTUs /hr.

In the same issue of the magazine, a rating chart comparing different brands presented the following information for two of the brands with the same 6000 BTUs /hr. of cooling capacity :

Brand A : Price is $ 310
EER is 8.6 BTUs /watt-hour

Model B : Price is $ 360
EER is 10 BTUs / watt-hour

EER is short for Energy Efficiency Rating.

**HOW BIG?**

This table, developed by Carrier Corp., gives a rough idea of the cooling capacity you'll need.

| Room area | Capacity |
|---|---|
| 100 to 150 sq. ft. | 5,000 Btu/hr. |
| 150 to 250 | 6,000 |
| 250 to 300 | 7,000 |
| 300 to 350 | 8,000 |
| 350 to 400 | 9,000 |
| 400 to 450 | 10,000 |
| 450 to 550 | 12,000 |
| 550 to 700 | 14,000 |
| 700 to 1000 | 18,000 |

- **Reduce** the capacity by 10 percent if the room is heavily shaded.
- **Increase** the capacity by 10 percent if the room is very sunny.
- **Add** 600 Btu per hour for each additional person if more than two people normally occupy the room.
- **Increase** the capacity by 4000 Btu per hour if you're using the air-conditioner in a kitchen, to compensate for heat from cooking and appliances.

Notice that for the same input [1 watt-hour] of electrical energy, Brand B removes 10 BTUs of heat instead of the 8.6 BTUs of heat for Brand A. Thus, Brand B is using electrical energy more efficiently. Unfortunately, Brand B costs $ 50.00 more than Brand A. Assuming that all other features of the two models are about the same, how can we figure out if the more expensive model is worth it. In other words, will we save enough electrical energy and money to make up the difference in cost or better yet come out ahead in the long run.

A Quantitative Model for Determining Energy and Cost Savings

In many technology-based problems, a technique that is often used to search for optimum solutions is to work backwards. In this case, we can start with your electric bill. By examining the bill that your family receives from electric company, you will notice that you are being charged about 10 cents per kilowatt-hour of electrical energy. Actually the national average cost is 8.76 cents per kilowatt-hour. So, the rate on your bill may vary from 5 cents to 15 cents per kilowatt-hour. In this example, let's assume that the electric rate is 10 cents per kilowatt-hr. and we want to figure out the cost of running the two air conditioners for one cooling season.

First we have to figure out how many watts of electric power is need to operate each machine. To do this we need to use the EER value and cooling capacity [CP] of the air conditioners to calculated the wattage, as follows :

Brand A : Power[watts] = CAP / EER = 6000 BTUs /hr. / 8.6 BUS / watt-hr.= 700 watts

Brand B : Power[watts] = CAP / EER = 6000 BTUs /hr. / 10 BTUs / watt-hr. = 600 watts

So, we see that it takes 100 watts less power for Brand B to provide the same cooling capacity as Brand A. We next need to estimate how many hours will the machines be used in one cooling season. Assuming 100 days and 12 hours per day will result in 1200 hours in one season. Now we have all the information that we need to figure out the energy and cost savings per season.

Energy saved = Power[watts] x Time[hrs.] = 100 watts x 1200 hrs. = 120,000 watt-hrs.

Energy saved = 120,000 watt-hrs. / 1,000 watt-hrs./kilowatt-hrs. = 120 kilowatt-hrs.

Cost Savings = Energy Used x Cost/kilowatt-hrs = 120 kw-hrs. x 10 cents / kw-hrs.

Cost Savings = 1,200 cents or $ 12 per cooling season

So in four cooling seasons, we would almost make up for the extra $50 that we would have to pay for Brand B. This is sometimes called the payback period for spending extra for a more efficient machine. Actually, we will save less than $ 12 per year because if we left the extra $50 in the bank we would be earning interest. For example, for an annual interest rate of 5 % the $50 would earn $2.50. So, we only gain $ 9.50 per year and thus the payback period is over 5 years.

Life Cycle Cost

Another way of comparing the costs of buying and operating a technological system is determine the life cycle cost. For example, the life cycle cost for an automobile ranges from 25cents/mile to 35cents/mile. That is why when people use their personal car for a business trip they are given about 30 cents/mile for the trip. How is this life cycle cost determined? Assume the car the total cost of car including interest on a loan is $20,000. We assume the car will be driven 100,000 miles in an eight-year period. The car's gas mileage is 25 miles per gallon and over the eight-year period the cost of regular gas will average $ 1.50 per gallon and maintenance cost is $400/year.

Thus, one way of estimating the life cycle cost for a car will depend on sample data such as: Total Cost of Car-- $20,000 Total Mileage-- 100,000 miles
Average Cost of Gas-- $1.50/gallon Energy Efficiency-- 25 miles/gallon
Maintenance cost per year-- an average of $400/year for eight years

The first step in the calculation is to add up all the costs over the eight period :
Total Cost = cost of car + cost of gasoline + cost of maintenance
= $20,000 + 4,000 gallons x $1.50/gallon + $ 400 x 8 years
= $20,000 + $ 6,000 + $3200 = $29,200
Cost/mile = Total Cost / Total miles
= $29,200 / 100,000 miles = $ 0.292 / mile or 29.2 cents/mile

In this estimate of life cycle cost, we only included information that would used to compare alternative vehicles. We were assuming that other costs such as cost of insurance and highway tolls would be the same for all newly purchased vehicles.

Comparing gasoline powered vehicles with electric vehicles

Due to a need to address the air pollution problem in urban areas the electric vehicle [EV] is being considered again as an alternative to gasoline powered cars. However, incentives will be needed to get consumers to buy EVs because the performance of EVs are poor compared to gasoline cars. Unfortunately, the limitations of the EVs cannot be out-weighed by a lower life cycle cost. An EV that is the same size as a sub-compact gasoline car costs more to buy. Using off-peak electricity will result in lower energy costs. The maintenance on EVs is simpler but batteries have to replaced about every two years. So the total cost of maintenance will probably be about the same for the two types of vehicles. Thus, the life cycle cost for EVs and comparable gasoline vehicles will probably about the same.

Since EVs will not have an economic advantage in the market place, government incentives such as tax deductions may be needed to encourage usage. On the other hand, improvements in EV technology could make them attractive as an alternative. The key to getting urban drivers to switch to EVs will be consumer acceptance of the EV. In the next two sections, we will continue our study of decision making by focusing on how public policy and consumer acceptance issues relate to the desire of the government to get some people to make the decision to switch to EVs. Prior to the discussion of the future of EVs, we first focus the FCC's [Federal Communications Commission ] ten-year initiative to establish new HDTV standards.

[IV] Technology and Public Policy: Development of HDTV Standards

In the past ten years, many magazines and newspapers have reported on the FCC's attempts to adopt new standards for broadcast television as indicated by the following headlines :

* Setting a New Standard : HDTV [1988 ]
* US Surging in TV Technology Race [ 1990]
* Who Needs HDTV ? [1992 ]
* The Challenges of Digital HDTV [ 1994 ]

Why has it taken so long to make this decision on new HDTV standards. In order to explore this question we need to study how today's standards came about. The current NTSC [National Television Systems Committee] standards only took about two years [1939-1940] to be developed and approved. The original NTSC standards were for Black and White TV and provided the following specifications :

Number of Lines per Picture: 525
Number of Pictures per Second: 30
Number of Fields per Second: 60
Aspect Ratio: 4/3 [Horizontal to Vertical]

In the early 1950s when color TV technology was developed, the NTSC standards had to be modified to take advantage of the color capability. The first system adopted broadcasted color signals that could not used by black and white TV sets. In other words the new system was not compatible with the old one. After six months of broadcasting the new color signals, the system shut down due to the lack of viewers. About a year later a new color TV system was adopted that insured compatibility.

The engineering and public policy decisions that were made in the early 1940s and 1950s showed that much research and thought went into the development of the TV standards that have stood the test of time [over fifty years]. The FCC's advisory committees made sure that the capabilities and limitations of human vision were used to make sure that the NTSC standards matched the TV viewers. Since humans have a limited ability to see details at a distance showing only about 500 lines per picture was good enough. So why do we need more lines now [proposed HDTV systems will have more than 1000 lines per picture] ? The simple answer is that today's TV screens are much larger and the 500 lines will spread and become noticed if viewers sit too close to the TV set.

The two human factors that had the most effect on the NTSC standards were :

1. Persistentance of Vision or After Image: Perceived Images remain on the retina for a fraction of a second. Thus, images will appear to merge if over twenty of them are displayed in a second. Thus, the number of pictures per second was selected to be 30 to achieve the illusion of continuous motion. Motion picture projectors display only 24 pictures per second.

2. Flicker Fusion Frequency: Humans observing flashes of light will notice a flicker up to about 50 flashes per second. To avoid the flicker problem, engineers came up the technique of interlacing or showing half pictures in 1/60 of a second[60 fields/second].

The FCC advisory committee also made a good decision by choosing the aspect ratio to be 4 to 3 for the rectangular TV set. They chose this ratio to make it compatible with the movies that were going to shown on TV. Unfortunately, with today's wider screen movies we no longer have compatibility. Given this early awareness of the importance of compatibility, it is surprising the FCC initially selected an incompatible color TV system. The next phase of the evolution of TV broadcast systems is HDTV with design criteria that include :

1. Greater Definition [Picture quality similar to movies or at least double the definition]
2. Wider Picture [Change aspect ratio to match modern movies]
3. Eliminate Interlacing [Show 60 full pictures per second]

In order to achieve the above three criteria, about five times more information had to be broadcasted. In the mid 1980s, the constraints of existing technology meant that the frequency bandwidth that was be needed would have to be at least five times the six megahertz that was used for the NTSC system. In fact, the Japanese at that time had launched a satellite-based HDTV system that used a 36 megahertz bandwidth. This system has been a failure because it is not compatible with the regular TV system.

Given the failure of the Japanese HDTV system, some US Hi-Tech planners see the development HDTV as an opportunity for the US to recapture the TV industry. In the late 1980s, the FCC announced to all developers of HDTV that the chosen system must satisfy two primary constraints :

1. The new HDTV must be compatible with the existing NTSC color system.
2 . The HDTV broadcast system might use the existing bandwidth that is allocated for VHF and UHF broadcasts.

The early prototype HDTV systems used analog technology and the bandwidth requirements were the most difficult to achieve. In early 1990's, digital systems became an alternative with the development of digital compression techniques. By the mid-1990s, digital compassion and pulse code modulation techniques had improved so much that designers of digital HDTV systems proposed systems that only require a 6 megahertz bandwidth which is the current FCC allocation to TV station.

So the answer to the question that we raised at beginning of this section about the lack of new HDTV standards after ten plus years of debate by the FCC depends on a number of factors. At the time of this writing [Spring, 1996] the FCC still had not approved new HDTV standards. In 1995, the FCC recommended that a consortium of companies with competing designs to work together to come up with more optimum systems.

Some of the reasons for taking so long to decide on new standards may be that:

1. The design criteria and constraints were too difficult a set of specifications to satisfy with analog technology.

2. Consumers were satisfied with existing TVs. New digital TV sets that converted the NTSC analog signals into digital format provided better quality pictures for consumers who willing to pay for the improvements. Most consumers have not purchased the new TV sets demonstrating that wide consumer acceptance of HDTV may be a problem.

3. It took time for digital technology to mature. For example, improved techniques of digital compression have made it possible to pack more information into the same six megahertz bandwidth.

4. With the spread of cable TV and small dish satellite TV, it isn't clear that there is a great need for HDTV to be broadcasted via VHF and UHF channels.

5. The FCC may be barking up the wrong telecommunications tree. Leading information technology experts such as Nicholas Negroponte of MIT's Media Lab. and Bill Gates of Microsoft Inc. think that the issue is not better pictures but asynchronous TV delivered by future communications networks with built-in high quality pictures and sound. Video on Demand [VOD] may be the wave of the future.

So the debate over the future of HDTV may turn out to be much ado about nothing. Stay turned for the next episode of as the TV turns or evolves. This brief case study of the evolution of television is a good example of the complexity of public policy decisions. Since the standards that are set by government agencies such the FCC affect society for decades, much consultation and discussion are needed to avoid mistakes.

There is a continuing debate about the role of government in setting standards that promote technology. Some planners feel that it is better to let market forces determine what new technology should be developed. We will conclude this chapter on decision-making with another example of the attempt by the US government to promote a new technology. In this case, the development and usage of Electric and Hybrid Vehicles [EVs and EHVs]. EVs use only electrical energy that are stored in batteries while EHVs use a combination of electrical and another type of energy source [such as gasoline] to power the vehicle.

[V] Technology Assessment: Future of EVs and EHVs

In order for modern industrial societies to make more informed decisions about the future of technological development, assessments of the potential and impacts of nascent technologies need to carried out. Until 1995, the US Congress had an Office of Technology Assessment [OTA] to conduct Technology Assessment [TA] studies to provide additional background for new legislation. OTA studies were of two types:

* Technology Initiated Assessment [TIA]
* Problem Initiated Assessment [PIA]

If the purpose of the study was to assess the potential and impacts of a specific technology such as a new energy source [such as fusion power] or a new medical technology [such as artificial hearts], a TIA study was conducted. On the other hand, if the purpose was to explore the role of alternative technologies for dealing with socio-technological problems such as the need to find a substitute for the fossil fuels that currently power our cars, homes and electric power plants, a PIA study was carried out.

In this concluding section of the decision-making chapter, we will focus on the public policy decisions related to development of EVs [Electric Vehicles] and EHVs [Electric and Hybrid Vehicles] in the US. For over twenty years the US Congress [via OTA] and the Department of Energy have been conducting both TIAs and PIAs that resulted in decisions to encourage the development of EVs and EHVs even though some of the studies showed a lack of consumer acceptance for the new vehicles due to the limited performance of the EVs. EHVs, on the other hand, performed better but were much more expensive to make.

Comparison of 1970s and 1990s Public Policy

People who were born before 1965, will remember the 1973 oil boycott by OPEC which resulted in a severe gasoline shortage in the US. People had to wait on long lines to buy gas on odd and even days. The political pressure to decrease our dependence on foreign oil resulted in PIA studies that compared alternative ways of dealing with the problem. One of the alternatives that caught the eye government decision-makers was using the energy of electric power plants that mainly use coal as a fuel. The problem was that the performance of the electric vehicles in the 1970s were very limited and could not even compete with small subcompact gasoline powered cars. EVs were only being used in special applications areas such golf carts and fork lifts where the travel was at low speeds and for short distances.

EVs have been around ever since the beginning of the 20th century but never really caught on as a private vehicle due mainly to its limited performance. For example, experimental EVs in 1975 had the following typical performance capabilities:

Acceleration ----[ from 0 to 30 mph ] in 9 seconds
Top Speed [flat terrain] —— 70 mph
Top Speed [5 % grade] —— 40 mph
Range [flat terrain] ——— about 100 miles
Time recharge batteries— 6 hours

The limited performance of !970s EVs was due mainly to the low energy density of the lead-acid batteries. In order to achieve a range of 100 miles about 40 % of the weight of the EVs had to be allocated for the weight of the batteries. So a 3,000 lb. EV carried around a bank of batteries that weighed about 1,200 lbs. To make matters worse it took at least 6 hours to recharge the bank of batteries. Given these performance limitations, it is not surprising that consumers did not choose to use EVs.

To stimulate the use of EVs as a way of decreasing US dependence on foreign oil, the US Congress, in 1974, passed the Electric and Hybrid Vehicle Act. This legislation provided funding for R&D [Research and Development] projects that were designed to improve vehicle performance in the near-term [ 5 to 10 years ]. Among the many projects that were funded was the design of a better performing prototype EV, experimentation with EHVs, and the R&D of higher energy density batteries that could be recharged in a shorter time.

From 1975 to 1985, even with substantial funding from the government, EV technology was unable to be improve enough to compete with gasoline powered vehicles. TIA studies did indicate that the state-of-the-art of storage battery technology was a constraint that could not be loosened or changed in the near-term. In the 1980s the flow of foreign oil became plentiful again and stayed relatively cheap. Thus, the original reason and political pressure for making the decision to push EV technology, that was not ready for implementation, had disappeared.

So why are EVs being promoted again in the 1990s? This time around the governmental push for the technology is related to PIA studies for dealing with air pollution problems of urban areas, such as the Los Angeles, California. The new air pollution legislation calls for the phasing in of "zero emission" vehicles in high air pollution areas. So automobile companies are developing new EVs to try to satisfy a new government mandate that a certain percentage of the cars sold in the late 1990s and beyond will have to be vehicles that do not emit pollutants in high air pollution areas. Unfortunately, the new brand of EVs are still not as cost-effective as the gasoline cars that they are designed to replace.

Future of EVs

As reported in the May 1, 1996 issue of Newsday [ A Long Island Newspaper], the 1998 requirement to phase in electric vehicles has been pushed back. The specifics of this decision by 11 people in California are as follows :

" Under pressure from the auto industry, which claims that electric cars are yet perfected enough to satisfy most drivers' needs, the California Air Resources Board voted to push back its requirements that major car makers sell specific numbers of them in that state beginning in 1998. Until that vote California law had required that 2 percent of cars sold in 1998 be electrics, with the percentage rising gradually to 10-percent in 2003. Two percent would have been about 20,000 cars."

In 1996, it is still not clear how EVs will be phased into the marketplace. EHVs are much more complicated and expensive to make and thus is not a near-term option. In order to encourage individual consumers to purchase EVs, some type of incentive will be needed to get people to switch from gas to electric powered vehicles. Another option is to provide tax incentives to companies with fleets of delivery vehicles to switch to EVs. The daily travel profile of urban delivery vans, in many cases, is a good match with the limited performance of EVs. In the next chapter, on the engineering design process, the specifics of the design of more efficient cars will be discussed to further show that socio-technological decisions need to be based more on consideration of the technological constraints or reality rather than on what is politically popular.

Up to now technology assessments have shown us that, in the near-term [next ten years], electric vehicles will not be the answer to decreasing our dependence on foreign oil or air pollution in cities. In short, the technology is just not ready for general use. For example, current EVs will only go about 125 miles between rechargings, which take about 8 hours. By comparison, a subcompact gasoline car will go over 300 miles on at a tank of fuel. And, of course, the tank can refilled in minutes. Further, there is a safety issue because it takes about 18 seconds for an EV to go from zero to 60 miles per hour, an important consideration when entering busy highways. Most comparable cars can get up to this speed in only half the time.

Advocates of EV technology bank their hopes on "breakthroughs' in battery technology. But the fact is that even with over 20 years of R&D, we are still waiting for a battery that offers a combination of acceptably long driving range, acceptably short recharging time or battery replacement system, and reasonable cost. With these three design criteria, inventors of new battery systems have a very difficult technological challenge.

## Chapter 2 Design Process

"The realization that design is a social process, that alternative designs are possible, and that a design's quality is as much a question of culture and context as it is of a thing in itself or of the dictates of [engineering] science or market forces---"

Louis L. Bucciarelli
Designing Engineers
MIT Press, 1994

[I] Aspects of the Engineering Design Process

The above quote is a broad vision of the process of engineering design. In his book, Professor Bucciarelli of MIT reveals significant discrepancies between the ideal image of engineering design as a technical and scientific process and the reality of design as a social process that is full of uncertainty and ambiguity. There are many ways of carry out engineering design. So, it is a myth, to think that there is a specific method that is used by design engineers The best we can do is identify and describe the various aspects of the process. There are also many ways of defining engineering design. To begin our study of the process, it useful to start with a definition which can modified and refined as we learn more about its various components. For example, a gifted teacher of engineering design, Professor Eric F. Thacher of Clarkson University, provides the following definition:

"Engineering design is the choice-making process used to evolve a set of instructions for making an artifact or developing a system to meet a need. It begins with broad concepts and continues in the direction of ever-increasing detail. The process is iterative because some early decisions must be made with incomplete knowledge. "

Three phrases in the above definition are central to the understanding the various dimensions of the design process. They are:

* Choice-making process
* To meet a need
* The process is iterative

As discussed in chapter 1, engineers are decision-makers. Thus, it is not surprising that in the process of designing they have to make choices constantly. The elements of decision making [ Criteria, Constraints, Modeling, and Optimization] that were studied in chapter 1 can be adapted and used as part of a design process. Deciding on design criteria is related to the need(s) for the design and depends on the values of the people involved. The design process needs to be iterative not only because of incomplete knowledge but also because alternative designs need to be selected, tested and revised as needed.

The following concept map [see figure 2-1 ] shows how various components of the design process might interact in an iterative manner:

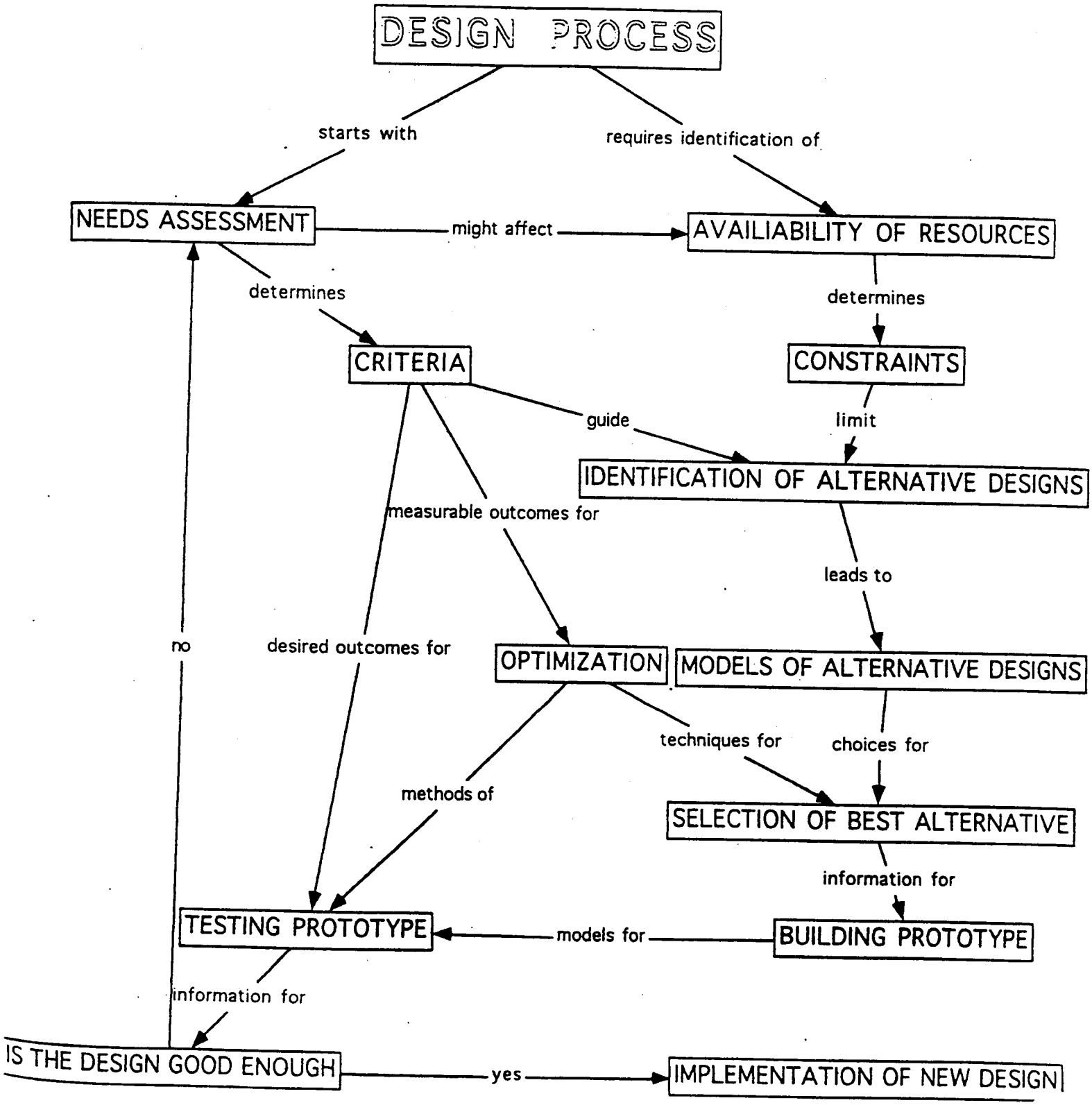





Fig 2-1

In one of the case studies that was used for studying the design process, Professor Bucciarelli said : "I have the feeling in tracking the discussion of redesign options with Sergio, that I am going up a down staircase in an Escher engraving, rather than neatly traversing an engineering textbook's block diagram of the design process". The block diagram or concept map that is presented on the previous page is not intended as an accurate description of what actually occurs in the real world but as a mind tool to help beginning engineering students to see how the various aspects of the design process might be connected. It is a first step towards understanding of a complex process with many interacting dimensions.

It is important to point out that depending on the charge given to the design team , the concept map can entered at different points. For example, if the design team was charged with improving an existing product they might start with a needs assessment that would involve exploration why the product needs to be improved. On the other hand, if the design team was asked to develop a product to compete with an existing product of another company, they might start by carrying out a reverse engineering study. In this case, they might start with the box that entitled "Testing Prototype". For example, the team could start by testing the product designed by the competition to figure out its strengths and weaknesses.

In order to study how various parts of the design process interact we must first study the meaning and activities of each of the boxes in the concept map. The arrows and linking phrases in the concept map provide a description of the dynamics of the process.

Needs Assessment: The design team must have a clear statement of the need(s) of a design project. Basically, they have to know why a device or a system needs to be designed? If the project involves a client, then the wishes of the customer needs to be clearly specified. As shown in the concept map, the needs assessment will affect the determination of the design criteria and might affect the availability of resources.

Availability of Resources: The phrase "design under constraints" is often used to characterize the uniqueness of engineering design. The availability of resources such as human expertise, money, time, materials, tools will limit what types of designs can be invented and implemented to address problems and needs.

Design Criteria: In order to develop designs that address the real needs of a situation, measurable objectives or criteria must be clearly specified. Clear statements of design criteria help guide the work of design teams and are needed to evaluate whether the proposed design are good enough to solve the problem and to address the needs of the project.

Design Constraints: Design options must work in the real.world and be acceptable to users of the system. The availability of resources will always limit what can be designed. Sometimes, constraints might have to loosened in order to make possible more innovative design options.

Models of Alternative Designs: Given clear statements of Design Criteria and Constraints, a design team can begin the exploration and analysis of alternative designs. Both descriptive and functional models can be to develop alternative designs that can be compared. The process of modeling is such a important analytical tool that a complete chapter will be devoted to it.

Optimization: The overall goal of a design project is the search for the optimum design that best satisfies the criteria within the constraints. For some design tasks optimization techniques can used in the search of best solutions. Other design tasks, require trade-offs among conflicting criteria in the context of the design constraints. As with Modeling, Optimization is also a generic tool and is essential to all areas of engineering. Thus, chapter 4 is devoted to the study of Optimization Techniques.

Iterative Process: The decision box with the question, Is the design good enough?, provides an opportunity for iteration if the answer is NO. An YES response initiates the implementation phase of a project. In the concept map only the primary iteration loop is shown. However, in a more detail concept map iteration in other sections of the process can also be shown. For example, in some cases, in searching for and deciding on alternative designs a team might have to reconsider the design criteria and constraints.

The introductory discussion of how the various aspects of the design process can be connected into a unified activity can best be understood in the context of a design project. In the past fifty years, the inability to replace old technological systems with new improved designs have come to be known as the "QWERTY" problem. The word "QWERTY" refers to the six letters on top row of the computer and earlier typewriter keyboard. The initial design of the layout of the keyboard and the many subsequent attempts to improve it provides an excellent case study to begin our study of how the various dimensions of the design process interact.

The inability of society to benefit from new inventions or ideas is often due the difficulty of breaking social tradition or human habit. The inability of the US to make a complete swift to the Metric System of measurement and units is another excellent example of the "QWERTY" problem . Can you think of other examples ?

## II Improving the "QWERTY" Keyboard

Have you ever wondered why the keyboard that you use with computers does not have the most frequently used letters on the home keys [ the row of letters on which the fingers rest ]? It doesn't make sense to have the most frequently letter [E] on a key where you have move a finger to reach it. The design project that is described in this section will give you an opportunity to design a more efficient layout for a keyboard.

This design task and related case study of the history of keyboard design will help you to develop an initial understanding of how the various components of the design process, that were described in the previous section, can interact.

Recognition of Need : As we approach the 21st century, we are still stuck with a keyboard layout that was designed in the 19th century. In the early 1870s Christopher Latham Sholes experimented with many types of layouts for the newly invented typewriter keyboard. In 1873 his work resulted in the "QWERTY" or standard keyboard. This layout for the keyboard was "anti-engineered" to force the human operator to slow down because Sholes' primary design criterion was to prevent the keys of the mechanical typewriter from jamming. Study the "QWERTY" layout and describe the techniques that the inventor used to slow people down.

By the beginning of the 20th century, the mechanisms used in typewriters had improved so much that there was no longer a need to slow down typing speed. In fact the new criterion was to design systems for speeding up typing. This was initially accomplished by the system of touch typing. Researchers such as August Dvorak also begin studying the problem and invented more efficient layouts for the keyboard. After you and your classmates have attempted to design your own improved keyboard layout you can compared your designs with those designed by other inventors.

Definition of the Design Problem : In order to achieve an optimum design, both the design criteria and constraints must clearly stated and understood by all members of the design team . This phase of the design process for products that will be designed for use by people must include consideration of human factors. In this design task, we are mainly interested in improving the design of the layout of the keyboard so finger strength and dexterity will an important consideration.

1. Design Criteria : To design a more efficient keyboard that :

[a] increases the number words typed per minute

[b] decreases the number of errors

Other criteria such as degree of finger fatigue can be considered. The design team should identify all relevant criteria and prioritize them. The decisions made in this phase of the design process will guide the evaluation of alternative designs and selection of the best design.

2. Design Constraints : Many things will limit what can be designed. For example, the design team will have to consider constraints such as :
[a] Maximum and Minimum Area of keyboard
[b] Number of rows on keyboard
[c] Time and other resources that allocated to the design task

Development and Evaluation of Alternative Designs : All alternative designs must satisfy both design criteria and constraints. One way to begin the search for alternative designs which can then be tested to arrive at an optimum design is to start with a set of research questions such as :
[1] Which letters of the English language are used the most often ?
[2] Which letters of the English language are often used together ?
Answers to the above and related questions will provide information about the nature the information that we want to input.
Another set of research questions can be used to address the ergonomics [human factors engineering] considerations include :
[3] Are the more frequently used letters placed on the keys that are easiest to reach ?
[4] Are the fingers with most strength and dexterity doing the most work ?
[5] How should the work be distributed between the right and left hands ?

Additional questions that can also be raised about the shape and spacing of the keys include :
[6] Do the keys have enough separation to limit the occurrence of striking two keys simultaneously or striking the wrong key ?
[7] What works best, flat or curved keyboards ?

Optimization Process : After alternative designs have been developed, some of the above questions can also be used to determine how well the designs achieved the design criteria within the design constraints. However, one of the best ways to determine which of the alternative designs is best is to test the performance of the system that was designed. In this keyboard design task, the determination of optimum can be achieved in two ways :
[1] Comparison of student designs with those of "expert designers" such as those of August Dvorak and Roy Hoke that shown on the next page [ See figures 2-2 and 2-3 ]. Notice that even these two designs are quite different,
showing for this design problem there are a number solutions that can achieve the criteria in an optimum manner.
[2] Students can also test their new designs by relabeling a standard keyboard and writing a computer program to reassign the keys to match the new layout. With this system students can learn how to type with the new layout and compare its efficiency in terms of words per minute and error rate with performance on a "QWERTY" keyboard.

August Dvorak is the best known person who designed a replacement for the "QWERTY" keyboard. A less known inventor was Dr. Roy Hoke. Both of their designs for new keyboard layouts are reproduced below. As indicated in the previous section, these two designs can be compared with each other and can be used as a basis for evaluating the designs produced by student design teams.

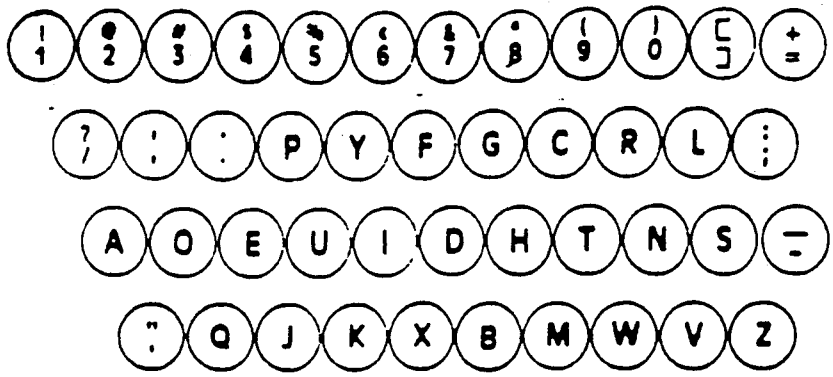



Fig 2-2 *Here's the keyboard of "that screwball typewriter," the culmination of Dvorak's 20 years of scientific study and experimentation.*

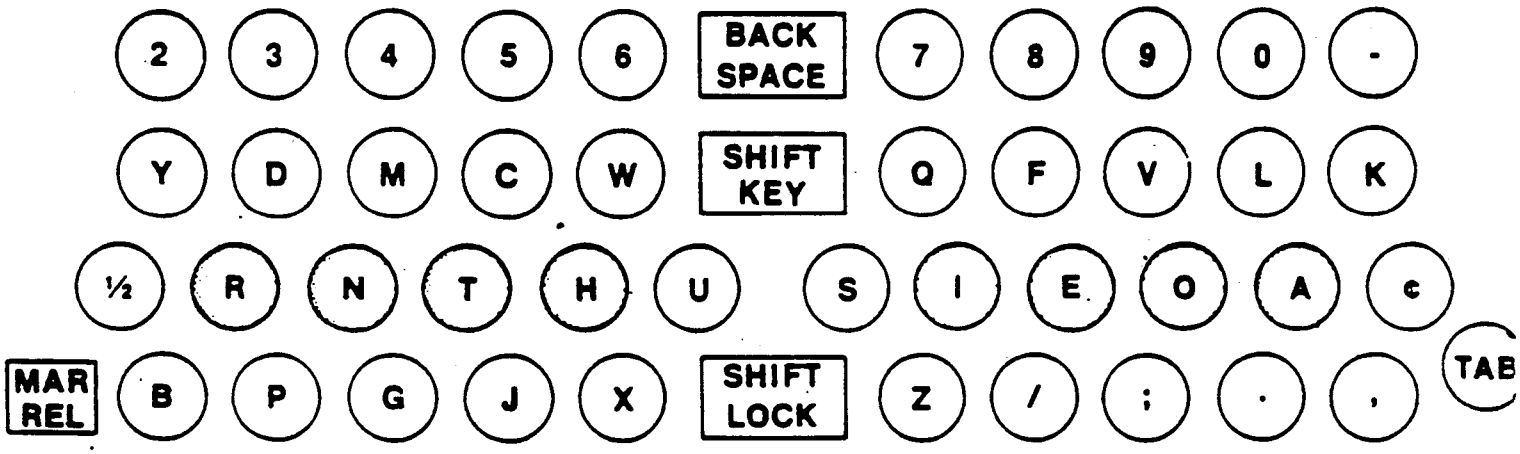



Fig. 2-3

DR. ROY HOKE'S KEYBOARD

Is the design good enough? is an question that can only be answered after field-testing of the prototype designs are conducted with typical consumers. For example, the Dvorak keyboard was the result of 20 years of study, development of alternative designs and field-testing of many keyboard layouts. Dvorak's simplified keyboard emerged in 1942 after analysis and testing produced the following results :

* At a speed of 100 words per minute, a typist's fingers travel a little over a mile in motions on the Dvorak keyboard during an eight-hour day compared with 12 to 20 miles on the "QWERTY" keyboard.
* The Dvorak keyboard can be mastered in half the time with a 75 % increase in productivity.
* The burden of typing is shifted to the stronger, longer fingers and to the right hand [56 % right hand, 44 % left hand]. On the "QWERTY" keyboard the exact opposite is the case.

The following truism about society's acceptance of new ideas and inventions has been attributed to the poet Ralph Waldo Emerson :

" If a man can write a better book, preach a better sermon, or make a better mousetrap than his neighbor, though he builds his house in the woods the world will make a beaten path to his door. "

Was Emerson wrong? In this case, the answer is yes. A vastly improved keyboard that was perfected in 1932 is still not being used. Despite a record of proven success for over sixty years, the Dvorak keyboard remains mostly unknown. Maybe in the 21st century this will no longer be an issue because voice input and scanning of printed text will the primary of methods of information input in computers.

An important engineering technique that is often used in the various aspects of the design process is quantitative analysis. For example, in order to evaluate alternative designs or test prototypes, the engineer must use applied science and mathematics techniques to analyze the proposed designs. In the next section, we will focus on a specific example of how designers of automobiles analyze how the power requirements and energy consumption are affected by vehicle characteristics. This type of analysis helps automotive engineers design vehicles that can use energy more efficiently.

## III Designing More Efficient Cars

In a special issue of the Scientific American magazine [September, 1995], a series of articles attempted to forecast the emerging "technologies for the 21st century". In the automobile article by Dieter Zetsche, he said :

"It takes little imagination to envision a market for advanced, ecologically friendly vehicles, distinguished by extreme fuel efficiency. These cars would be twice as fuel efficient as today's thrifty cars; a liter of gasoline would propel them about 25 kilometers in mixed driving conditions. "

Since one gallon is about the same as 4 liters and 25 kilometers is about 15 miles the gas mileage these more efficient cars would be about 60 miles per gallon. Dieter Zetsche goes on to discuss the technologies that are being developed to make cars more efficient. In this section of the chapter about the design process, we are focusing on how engineering analysis [using applied math and science techniques] can help the designers to search for more optimum design options. In attempting to design cars that will use energy more efficiently, engineers need to analyze how much energy is needed to move the vehicle and how much is wasted in the process of energy conversion. In his paper, Dieter Zetsche provides the following example :

" One essential technology for these ultra efficient cars will be advanced, electronic motor-transmission management systems, which will increase efficiency through heightened sensitivity and interaction between the engine and load on it "

The following analysis will provide us with a way of predicting how much energy will be needed to move the vehicle [load]. For example, if a subcompact car had a mass of 1,000 kilograms [2,200 pounds], how would we figure out how energy would needed to move it. The first thing to do is to recall that to move the car we have to do work which requires energy. The amount of work that the motor has to do depends on the forces that are required and the distance the car travels. The equation for calculating the amount of energy that is needed is : Work = Force* Distance .

### Energy and Power Needed for Acceleration

So, in order to calculate the energy needed to move a car, we first have figure out what forces have to be overcome by the motor. On a normal trip, cars have to provide energy to overcome four types of forces. The first thing that the motor has to do is get a car up to speed by providing a force to accelerate the vehicle. What does the size of the accelerating force depend on ? Newton's second law to the rescue! It tells that if we know the mass of the car and decide how quickly we want to speed up [accelerate], the force is simply the product of the mass and the acceleration.

In other words : Force = Mass * Acceleration.
For example, if we wanted to accelerate our 1,000 kilogram car for 0 to 50 kilometers/hour [about 30 mph] in 10 seconds , how energy would be needed ?
Since Force = mass * acceleration
Then Force = 1,000 Kg * 50 Km/hr/10sec.
In order to do the calculation we first have to change hour to seconds [1 hr=3,600 sec.] and kilometer to meters because the unit of force should be in newtons.
Now Force = 1,000 Kg * 50,000 meters / 3,600 sec. / 10sec.
Force = 1,000 Kg * 1.4 meters /sec./sec.
Force = 1,400 newtons

In order to compute the energy needed to accelerate the car we need to determine how far it traveled while accelerating. Since it started from rest and gained 1.4 meters/sec. in each second, after 10 seconds it is traveling at 14 meters/sec. So the average speed is 14/2 or 7 meters/sec. Thus, the car will travel 70 meters [7 meters/sec. * 10 sec.].

The energy needed to accelerate the car is then :
Energy = Force * Distance
Energy = 1,400 newtons * 70 meters
Energy = 98,000 joules

Since this energy has to be provided in 10 seconds, we can figure the power that is needed [ Power = Energy/Time ]. Thus :
Power = Energy/ Time = 98,000 joules / 10 seconds = 9,800 watts [about 13.1 HP]

The HP [Horse Power] is computed by using the relationship 1 HP=746 watts Notice that not much power is required because we assumed a light vehicle that has poor acceleration. If we chose to design a vehicle with twice the mass and double the acceleration we would need four times the power [about 52.4 HP]

Once the car gets up to speed, in order to keep it going at a constant speed, we need to use energy to overcome both the friction of the road and the air. The design challenge is to keep the energy loss as low as possible. In this case, automotive engineers would be trying to improve the design of tires and to make the car as streamlined as possible.

Force Needed to Overcome Rolling Friction

This force [FR] simply depends on the weight [W] of the car and coefficient of rolling friction of the tire [CT]. So FR=W*CT and for a CT of 0.012 the force is :
FR= W*CT=mg * CT=1,000Kg*9.8m/s/s* 0.012 = 117.6 newtons

Force Needed to Overcome Air Resistance

The equation that is needed to compute this force is more complicated because four parameters are involved. The force needed to overcome air resistance or drag[FD] is affected by the following four parameters :

* Density of Air
* Shape of the car [Drag Coefficient]
* Frontal Area of the car
* Speed of the car

The equation that results from combining these four factors is :

FD= 1/2(density)(drag coefficient)(frontal area)(Speed Squared)

The following sample calculation is for an experimental electric vehicle [ETV1] that is traveling on a flat highway going at a constant speed of 72 Km/hour. Thus, we only have to compute the energy used and power needed to overcome rolling friction and air drag.

**SAMPLE CALCULATION**

Mass of Car = 1,500 kg.

$C_t$ = 0.012 A = 1.84 $m^2$

$C_d$ = 0.31 v = 72 km/h

D (distance traveled) = 1 km

$\rho_{air}$ = 1.225 $kg/m^3$

$F_r = C_t \times Wt$ = 0.012 (1,500 kg) (9.8 $m/sec^2$) = 176 newtons (≈40 lbs.)

$F_d$ = (1/2)(1.225 $kg/m^3$)(0.31)(1.84 $m^2$)(72 km/h X 1,000 m/km X 1 hr/3600)$^2$sec

$F_d$ = 140 newtons (≈34 lbs.)

$F_t$ (total force needed) = $F_r + F_d$ = 176 newtons + 140 newtons

$F_t$ = 316 newtons

Energy = $F_t$ X Distance

E = 316 newtons (1000 m) = 316,000 joules

$$P = \text{(Energy/Time to travel 1 km)} = \frac{316{,}000 \text{ joules}}{(3{,}600 \times 1/72) \text{ sec}} = \frac{316{,}000 \text{ joules}}{50 \text{ seconds}}$$

P = 6,320 watts (≈8.8 HP)

Note about units of power : As indicated in section II, a significant QWERTY problem in the US, is the continued use of the English system of units as the country slowly shifts to usage of the Metric system. Thus, the HP [horsepower] unit is still used in indicating how powerful motors are. Basically, 1 HP is 550 ft-lbs/sec. and is equivalent to 746 watts or joules/sec.

Force to Overcome Gravity

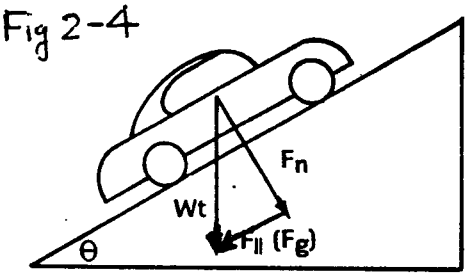
Up to now we have assumed that the car doesn't have go up a hill. In order to include this travel situation we need to figure out how much force [FG] is needed to overcome the gravitational force or weight of the car. Only a fraction of the weight of the car will make it roll down the hill. The size of FG will depend on the weight [W] of the car and the slope of the hill [see diagram on the right]

The greater the angle of the slope [θ], the greater will FG be. The equation needed to calculate FG is : FG=W*sin[θ]. For example if a 1000 Kg car was trying to go up a ramp that had a 30 degree angle then : FG= W*sin[θ]=mg* sin [θ]

FG= 1000 Kg*9.8m/s/s*sin 30

FG= 9,800*0.5=4,900 newtons

Fig 2-4




Total Energy Usage and Power Requirement

It is not surprising that we will use the most energy and require the most power while trying to accelerate up a hill. This analysis showed us that we need to overcome the following four forces:

* FA -- Force of acceleration
* FR -- Force to overcome rolling friction
* FD -- Force to overcome air drag
* FG -- Force to overcome gravitational pull

Thus, the total force [FT] is simply the sum of the forces :

FT=FA+FR+FD+FG

And the total energy[ET] used is :

ET= FT * Distance Traveled

And the total power [PT] required is :

PT= ET/Time

This analysis of the energy usage and power requirement of cars under different driving conditions can also be used to create a computer simulation for testing the energy consumption and power requirements of prototype car designs. It can also be used to identify the significant variables that relate to energy and power requirements of alternative vehicles. The most obvious observation is that the mass or weight of the car affects three out of the four forces that the car has to overcome. Thus, it is not surprising that electric vehicles with an extra 500 Kg [1,100 pounds] of battery mass has poor acceleration and does not climb hills well. Finally, the design of future high efficiency cars will be use strong ultra-light composite materials to minimize mass.

## IV Designing Automated Auto Safety Systems

There are many reasons and auto safety techniques for the problem of auto accidents. In this section we focus on the design of technological fixes for preventing accidents. Specifically, we will study the design of recently designed and developed systems that use sensors to provide feedback for automatic activation of auto safety systems.

The avoidance of auto accidents has always depended on two principal factors : the skill of the driver and the design of the vehicle. Most of the auto safety systems that were introduced into cars have been those that are designed to help the driver to do a better job of avoiding accidents. So improvements in the design of tires, lights, brakes, etc. were all designed to help people to drive safer. In recent years, with the development of better sensors and microprocessors, new automated systems are being introduced that only required limited human control of the technology.

ABS Technology : One of the most dangerous driving situations of all is uncontrollable skids. This is usually caused by a driver of a car with conventional brakes who steps hard on the brake pedal. This action may cause the wheels of the car to lock up and stop turning . Wheel lock up can cause dangerous skids especially on slick roads. Engineers have designed and developed an Antilock Braking System [ABS] that deals with this problem.

The heart of a typical ABS is a small computer, which is attached to the normal hydraulic braking system. During braking, a sensor on each wheel feeds a continuous stream of data about the wheel's movement to the computer. If the computer detects that a wheel is locking up it activates a small electrically powered valve to momentarily reduce the fluid pressure to the wheel to allow it to continue turning. These automatic adjustments are repeated in quick succession to prevent the wheels from locking up.

Some drivers who have developed the habit of pumping their brake pedals to avoid wheel lock have to break this habit if they drive a car with ABS. Basically the car is already automatically "pumping the brakes" so the driver should just step on the brake pedal. This a good example of how people sometimes have to adapt to changing technology. ABS was introduced in the late 1980s and offers such an obvious advantage that , even with a cost of about $800, by the mid 1990s about 50% of the new cars sold in the US were equipped with them. As more and more people drive cars with ABS, will the number of auto accidents decrease? This a difficult question to answer because other safety features are also being introduced at the same time and some drivers take more chances if they think they are driving a safer car.

Another type of automated auto technology that also provides better traction in bad weather is the all wheel drive transmission system. Again sensors located on each wheel detects the amount of traction and sends the information to a small computer which then controls the amount torque assigned to each wheel. Cars that are equipped with all wheel drive or four wheel drive in combination with the ABS feature are among the safest cars to drive during rain and snow storms.

These systems that have only become available in recent years to improve the control of cars is a good illustration of the fact that design engineers are also limited by the state-of -the-art of the technological systems that they have to work with. In this case, the limitations of the human driver to respond quickly was replaced by a computer-based feedback system. Currently, similar technologies are being used to design warning and automatic braking system such as ACAR [Automatic Collision Avoidance Radar].

RADAR-Based Collision Avoidance Systems

The design concept of using a RADAR [ RAdio Detection And Ranging] to determine the distance and position of potential obstacles has been considered since the 1960s. However, it wasn't until the 1980s that it become practical to design and test a prototype. Why was it impossible it to develop an ACAR type system earlier? The answer to this question is an excellent illustration of the need to have the available technology to overcome design constraints. In this case, the primary constraint was that the RADAR transmitting and receiving antenna had to fit across the front of the car. The question that engineers had to address was what does the size of the antenna depend on ?

Remember that RADAR systems use radio or electromagnetic [EM] waves to obtain echoes of targets. All EM waves travel at the speed of light [3 x 10^8 m/sec] but differ in frequency and wavelength. The higher the frequency, the shorter the wavelength. The formula speed = frequency x wavelength is used to relate these characteristics of EM waves. RADAR of the 1940s and 1950s used equipment that could only generate relative low frequency microwaves of about 1,000 million [10^9] hertz (cycles/sec). Using the above formula we can determine the wavelength :

Wavelength = Speed of Light / Frequency
= 3 x 10^ 8 m/sec / 10^9 cy/sec
= 0.3 m/cy [ about 1 foot ]

In order to focus the RADAR beam narrowly, the diameter of the dish antenna must be at least 50 times the wavelength. In this case, the antenna would have to be at 15 meters or about 50 feet, much too large to fit between the headlights of a car.

Given that one of the constraints of ACAR is the placement of the RADAR antenna between the headlights of a car, the wavelength must be small enough to satisfy this constraint. For example, let's assume the distance between a car's headlights is 1 meter which will then be the diameter of the antenna. That means that the wavelength of the RADAR will have to be at 1/50 of a meter. In this case, we can use the above formula to determine the frequency that would be needed :

Frequency = Speed of Light / Wavelength
= 3 x 10^8 m/sec / 1 / 50 m/cy
= 150 x 10^8 = 1.5 x 10^10 cy/sec [hertz]

Thus, ACAR type systems had to wait for the development of higher frequency microwave RADAR transmitters and receivers that could be linked to a microcomputer.

Currently, RADAR-Based auto safety systems are being designed and tested for a number accident avoidance situations. The most obvious application is a system to warn the driver of an unexpected obstacle. The system could actually be designed to brake the car automatically but most drivers may not want to lose control. With the exposure of more drivers to cruise control, more people may come to accept automatic braking. In fact, ACAR systems are being tested in combination with cruise control systems so that a car cruising on a highway would automatically brake when the vehicle encounters traffic.

Another experimental car RADAR system that is being tested is a side mounted system that is positioned to monitor the blind spot in the rear view mirror. When a driver wants to change lanes the RADAR system would provide a warning of an unseen vehicle in the next lane. The blind spot is commonly eliminated with a wide angle side mirror. The jury is still out on whether consumers will spend a few hundred dollars for the RADAR system instead of an wide angle mirror. For drivers who may forget to use the side mirror, the warning RADAR system could provide an additional margin of safety.

The above examples show that technologies can be designed to decrease the number of auto accidents. Unfortunately, poorly designed systems can be the cause of auto accidents when they fail to operate properly. However, auto designers can learn how to design more reliable and durable systems by studying the causes for the failures. In the next section, failure-based design paradigms or principles will be studied via a set of historical case studies of systems that failed.

## V Failure-Based Design Paradigms

Headline : 8.7 M Fords Recalled [ Newsday-April 26 , 1996 ]

" Ford Motor Co. said yesterday it is recalling 8.7 million cars and trucks with ignition switches that could short circuit and cause fire."

The above headline and lead sentence of a newspaper report is unique in a number of ways. Besides being a timely example of a poorly designed piece of technology, it is the largest recall involving one manufacture. Since the cost of fixing the problem is about $100 per car, it is estimated that the failure of the ignition switch will cost Ford about 870 million dollars. As will be discussed later, the design flaw that caused the problem, probably could have been avoided if failure-based design paradigms were used more extensively in the design process.

The above problem has been traced by the National Highway Traffic Safety Administration [NHTSA], to be a poorly designed and manufactured switch that permits two electrical contacts to come too close together. NHTSA and Ford have received about 1,100 reports from owners of overheating, smoke and fires in the switches, including allegations of 19 minor injuries and two serious ones. So even the design of something as sample as a switch might be carried with care to avoid failure that in case is costing the auto manufacture almost a billion dollars to correct. And one can only speculate above the lost in future sales of Ford automobiles.

The impact of this initial example of the a design error is mainly inconvenience of the auto owners and monetary loss to the auto company. Fortunately, no lives were lost due to the failure of the ignition switch. In the following discussion of failure-based design paradigms, historical examples of technological failure that will be used have had much more severe human consequences.

An eloquent spokesperson for the need of engineers to pay more attention to the study of failures in design is Henry Petroski of Duke University. His books : To Engineer is Human : The Role of Failure in Successful Design [1985] and Design Paradigms : Case Histories of Error and Judgment in Engineering [1994] are must reading for engineering students as well practicing engineers. The ideas and examples that are presented below are mainly based on the material in the Design Paradigms book.

In the concluding sentence to the introductory chapter Petroski says :

" A familiarity with the details of past mistakes gained through the kinds of case studies presented here may the surest way to break established patterns of failure and ensure more successful and reliable designs in the future"

Design Paradigm 1 : Error in Conceptual Design

In attempting to satisfy design criteria within specified constraints engineers can arrive at designs that can fail when it is implemented. Designs might not experience failure when prototypes and early manufactured models are tested. The history of auto safety is filled with examples of design flaws that surfaced after millions of cars were sold including :

* GM's Corvair [documented in Ralph Nader's book "Unsafe at Any Speed"]
* The Fuel Tank Problem of the Ford Pinto
* The Back door Latch Problem of Chrysler's MiniVan

Foreign cars also have experienced many design flaws as evidenced by the recall of 8.8 million Japanese-brand cars and trucks equipped with potentially defective seatbelts. Usually, auto designers do not pay enough attention to the use and potential for failure in the real-world. For example, in the case of the short-circuiting ignition switches, they fail most in cars that are used in very cold weather.

Petroski cites the Roman Point apartments collapse in Great British as an example of a new method for designing and constructing apartments that failed. The collapse of the 18 story building killed three people and injured eleven others. In his discussion of this case study he said :

" The concept of system construction had many advantages over the more traditional schemes, but it clearly had the disadvantage of very little redundancy, for when one wall was blown out there was nothing left to support the walls above. The fundamental error of the concept was not revealed in the logic of the design process but in the chance events that led to a gas explosion."

The key to avoiding failure that relates to a new design concept is to assess the potential for failure under various stress scenarios. Another aspect of the search for potential failure modes is to check how the failure of a sub-system will affect the reliability or durability of the total system. The ideas and techniques of systems analysis that will be discussed in chapter V will provide specific approaches for thinking about this type of failure analysis.

Design Paradigm 2 : Limits of Size in Design

Whether one is involved in structural architecture or computer architecture, the notion of appropriate size or scale is an important consideration. What will work in a scale model may not work in the full size. A bridge that is structurally sound if changed in scale may collapse. In discussing the scale effects in bridges, Petroski said:

"The history of suspension bridges provide an especially sad chronicle of how the mistakes of the past can be repeated in a state-of-the-art environment that appears to have more confidence in its analytical sophistication than fear of the effects of scale as bridge spans have increased in bold leaps rather than incremental steps. Such overconfidence led, of course, to the classic failure in 1940 of the Tacoma Narrows Bridge."

The collapse of the Tacoma Narrows Bridge is an excellent case study in that the designers didn't pay much attention to either Design Paradigms 1 or 2. Instead of designing to avoid failure from natural forces such as wind, the bridge designers of the 1930s based structural extrapolation on models of success. The result were flexible bridges with little damping for reducing the effects of wind. Thus wind induced failure modes that guided earlier bridge designers were forgotten or ignored.

The failure of the Tacoma Narrows Bridge also demonstrates that in the process extrapolating successful designs, new factors may appear that previously could be neglected because their effects were below some threshold level. The twisting oscillations of a bridge do not become important compared to its up-and-down oscillations until the span becomes very long and narrow. Designers of the unprecedentedly long span of the bridge did extrapolate the increased stiffness required to control up-and-down vibration, but neglected to consider the previously unimportant twist factor.

Another example of the need to pay attention to scaling problems is the large truss used in the Orlando Civic Center. Investigators think that the designers assumed that it would not crack because they tested the small scale model and it did not fail. According to John Fisher, a fatigue expert and failure analyst, the failure of the massive steel truss came about from a complete lack of knowledge about scale effects.

Design Paradigm 3 : Design Change for the Worse

Two of the most dramatic and highly publicized technological failures of the 1980s were the collapse of the suspended walkways of the Hyatt Regency Hotel in Kansas City and the Challenger explosion. Although there were many circumstances that contributed to these fatal accidents, the lack of consideration of the potential failure of design changes were central to both catastrophes.

A seemingly minor design change was the cause of the structural collapse that killed over 100 people in the Hyatt Regency in 1981. The original design of the support system for elevated-walkway consisted of long rods attached to the roof and passing through box beams under the fourth floor and continuing down through similar box beams under the second walkway. As originally designed the support system have a safety factor of two. In other words, the system had a reserve strength that was about equal to that required to hold it up [dead load]. Henry Petroski provides the following account of how a design change caused the system to collapse :

"However, a change in the walkway support was suggested and agreed to by the various parties involved. The change , which is illustrated on the left of Figure 2-5, consisted in replacing each single long rod with a pair of rods offset on the upper roadway's box beam. But, the new arrangement meant that the weight of not just the top but both walkways would now bear down on the washer and nut under the top box beam, thus effectively doubling the bearing strength required of the connection. And neither the box beam nor the washer and nut were resized in the changed design."

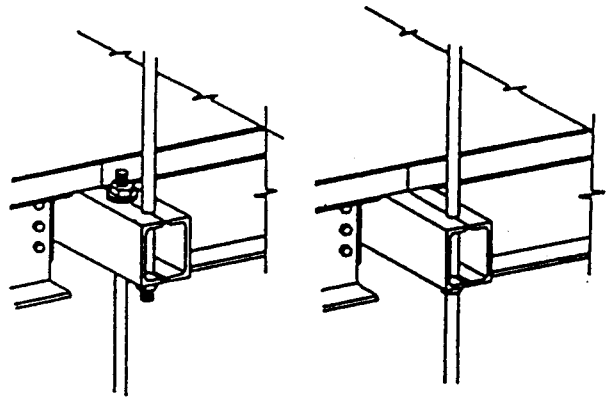


Fig. 2-5 Connection detail of upper suspended walkway in the Kansas City Hyatt Regency Hotel, which failed in 1981: *left*, as built; *right*, as originally designed

The reasons for the design change is unclear but a change of any kind must be assessed for potential problems. In this case, the effect of the design change on the forces acting on the washer and nut arrangement of the box beam should have been reexamined. No such reconsideration took place and the walkways were built with only a safety factor of about one against the rod being pulled through the box beam. The connections could barely support the weight of the walkways and the additional weight of people watching a dance below overloaded the marginal design.

In the case of the Challenger, the redesign of the space shuttle's booster rockets may have contributed to the decision to launch under ill-advised conditions. The solid-fuel booster rocket design was based on that of Titan III, a proven design. The Titan rocket successfully worked with a single O-ring and in adapting its design for Challenger's booster rocket a second O-ring was added to insure greater reliability and safety. This design logic was evidently agreed to by almost everyone and the belief that the double o-ring joint was so robust and dependable may have caused the decision-makers to take the chance and launch under near-freezing conditions.

The above discussion of three failure-based design paradigms clearly shows the importance of this aspect of the design process. It should also whet the reader's appetite to want to read Professor Petroski's book which discusses four additional design paradigms that are entitled :

* A Paradigm of Logical Error in Design
* A Paradigm of Success Masking Error
* A Paradigm of Tunnel Vision in Design
* A Paradigm of the Selective Use of History

PRINCIPLES OF ENGINEERING

# DESIGNING AUTOS FOR SAFETY

# Preface

Most high school juniors and seniors are either driving, preparing to drive, or looking forward to the time when they will drive. This case study introduces the students to potential auto safety problems through readings, suggested multi-media, computer simulation, and hands on investigative activities.

Auto safety problems are caused by at least one of the following: the driver, the vehicle, the road, the regulations, or a combination of them.

A study of the mathematics, science, and technology involved prepares the students for designing appropriate technologies for the solution of the various problems which occur as a result of driver action, or the design of roads, vehicles, and regulations.

These suggested appropriate technologies might include behavior modification, legislation, technological fixes, or a combination of them. For example, rear end accidents might be caused by tailgating, inattention, poor signaling, highway sign location, location of accelerator and brake pedals, dashboard display and lighting, etc. After examining the situation and determining the cause of a specific accident the students design appropriate devices, systems, laws, and/or educational materials to overcome the problem. They then look at the second generation effects of the implementation of the solution. A device or system which prevents the car from colliding with the one in front by notifying the driver or by taking immediate automatic mechanical action, must not increase the possibility of being hit by the car behind.

Each of the many situations in the case study are presented as challenges to the students to design solutions which will solve the immediate problem without causing subsequent problems more serious than the original.

Throughout the case the students will be introduced to the basic concepts: modeling, systems, feedback, optimization, technology-society interaction, design, and ethics.

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# Principles of Engineering

## DESIGNING AUTOS FOR SAFETY

By E.J.PIEL

### I. DESCRIPTION

Analysis of data regarding the causes of accidents and the injuries and fatalities which result from those accidents reveals that the major areas of responsibility are the driver, the vehicle, the road, and the regulations.

The approach to possible resolution of the auto safety problem is to examine various alternative solutions as they relate to the design of autos, roads, law enforcement technologies ie. police radar and asses their feasibility, and their potential effect on the overall safety of travel by automobile.

The analysis of the various auto safety situations will involve the application of physical laws, mathematical analysis using graphs and simple algebra as well as discussion of ethical values.

The approach to possible solutions will involve measurement of force, acceleration, velocity, human reaction time,and hand eye coordination. The design and construction of experimental apparatus will include the use of design skills as well as the use of hand and machine tools.

### II. DEFINITION OF THE PROBLEM

To study the causes of auto accidents and the fatalities and injuries resulting from them. As a result of the study to design means of preventing accidents as well as minimizing the injuries when accidents do happen.

### III. THE LEARNING STANDARDS FOR MATHEMATICS,SCIENCE, AND TECHNOLOGY RELATED TO THE PERFORMANCE OBJECTIVES

Standard 5: Students will apply technological knowledge and skills to design, construct, use, and evaluate products and systems to satisfy human and environmental needs.

Standard 7: Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.

1. Students will describe how drivers are responsible for auto accidents
2. Students will describe how vehicle problems are the cause of accidents.
3. Students will describe how road hazards cause accidents
4. Students will describe how conflicting regulations cause accidents

B. Students will learn how the design of technological devices can prevent accidents caused by drivers.

1.Students will describe the operation of police radar, breathalizers, and traffic light systems as technological systems outside the auto which are involved in the prevention of accidents

2. Students will describe the need for and operation of technological devices in the car such as collision avoidance radar, placement of stop lights, convex rear view mirrors, etc. which serve to prevent accidents.

C. Students will learn how to design devices and systems to prevent accidents caused by drivers.

1. Students will design the traffic light system for a given intersection to eliminate the "dilemma zone".
2. Students will design a system for reducing the number of people who drive while impared.
3. Students will design the system of controls and dashboard display to provide for minimum need of a drivers visual attention in order to operate while the car is in motion.

D. Students will describe how injury and death result from auto accidents.

1. Students will describe how auto design results in injury and death following an accident.
2. Students will describe how design of roads result in injury and death following an accident.

E. Students will examine the design of systems and devices which are developed to reduce the possibility of injury and death resulting from auto accidents.

1. Students will compare proposed systems and devices to the present systems and devices and judge their possibility for success in reducing injury and death.
2. Students will develop prototype systems and devices for preventing injury and death from auto accidents.

## IV. EXPLANATION OF SPECIFIC MATRIX

**The Driver.** The driver has certain characteristics which are involved in the auto accident situation. The matrix points out how the concepts can be learned through various activities involving the driver and his/her interaction with the entire auto safety situation from modeling through graphing of real data through various laboratory experiments to actual design of equipment and discussion of ethical behavior of drivers.

**The vehicle.** All of the concepts are stressed in a thorough application of study, discussion, experiment, and vehicle design involved in the prevention of accidents, as well as the prevention of injury in the event of accidents. While the basic activities listed cover all of the concepts, there are many more possible depending on the interest and resources available in the specific class.

**The Road.** Application of the concepts in the study, discussion, and design activities demonstrates how all encompassing the basic concepts are in the examination of the various ways in which road design is a factor in causing, preventing, and reducing fatalities involved in the interaction of the driver, vehicle, and the road.

**The regulations.** While regulations are usually developed for the purpose of protecting society from danger, there are times when poorly developed regulations actually contribute to accidents in the first place, and injury which follows the accident. Again, the regulation situation is studied in the light of each of the basic concepts underlying the course.

## V. Background Material

### 1. Introduction

A Twentieth Century epidemic

Analysis of data from newspapers and technical reports(graph from real data)

CONTENT OUTLINE

The History of auto safety (graph from text data)

How great a problem is auto safety?

Comparison of auto deaths with deaths from other causes. ( Graph from real data)

Study of the probability of death by auto for various age groups in U. S. and other countries. (Probabilistic Analysis)

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | CONCEPTS | DRIVER | VEHICLE | ROAD | REGULATIONS |
| 2 | MODELING | Graph driver | Using models of | Determine the | Model a real |
| 3 | | caused accidents | various designs | effect of various | intersection |
| 4 | | from real data | determine the | radii of curvature | traffic light , |
| 5 | | | stability at high | of turns on | speed limit, |
| 6 | | | speed in turns | stability | width & traffic |
| 7 | | | | | density. |
| 8 | | | | | |
| 9 | SYSTEMS, INPU | Determine human | Explain the use | Design a traffic | Explain the |
| 10 | OUTPUT | reaction time & | of feedback in | light system so | working of the |
| 11 | FEEDBACK | use it to devise | the design of | that the timing | police radar |
| 12 | | a driver rule to | automatic braking | of the yellow light | system and the |
| 13 | | prevent rear end | systems | does not result in | radar detectors |
| 14 | | collisions | | a dilemma zone | used by motorists |
| 15 | | | | | |
| 16 | OPTIMIZATION | Describe how the | Design a dashboard | Based on data | Draw up auto |
| 17 | | driver optimizes | and control system | provided to the | specifications |
| 18 | | between speed | for optimum | student, decide on | which optimize |
| 19 | | and safety | driver comfort | most cost effective | among the |
| 20 | | | and safety | road improvements | environment, |
| 21 | | | | | energy use, and |
| 22 | | | | | safety |
| 23 | | | | | |
| 24 | TECHNOLOGY | Discuss effect | Research: how | What is the social | What technologies |
| 25 | SOCIETY | of driver decisions | does vehicle size | Effect of highway | are involved in the |
| 26 | | on society as | affect society | Alignment? | RADAR WAR |
| 27 | | a whole | as a whole? | | between police |
| 28 | | | | | and the motorist |
| 29 | DESIGN | Design a system for | Design a system for | Design, build and test | Design, build and test |
| 30 | | measuring human | measuring the effect | various impact | improved wordless |
| 31 | | responce time to brak | water and temperatu | attenuatorsfor model | signs to control |
| 32 | | light position at | on brake reliability | cars hitting a barrier | traffic |
| 33 | | various levels above | | at high speed | |
| 34 | | the road | | | |
| 35 | ETHICS | Discuss the ethics | Discuss the ethical | Discuss the ethical | Discuss the ethical |
| 36 | | involved in the driver | responsibility of | responsibilities of | and moral |
| 37 | | decision todrive after | manufacturers in the | committees in decidin | responsibilities of |
| 38 | | drinking | design and advertisin | where to install | juries in drunk |
| 39 | | | of cars | traffic lights | driving cases |

## 2. PEOPLE CAUSING ACCIDENTS

Analysis of safety studies regarding the responsibility of drivers in causing auto accidents. (Use IIHS "FACTS")

Failure to comply with regulations

Speeding

Analysis of graphs of stopping distance required for vehicles traveling at various speeds.

S is distance traveled

V ave is average velocity

$V_i$ is the initial velocity

$V_f$ is the final velocity

( $S=V_{ave} \times t$) ( $a=V_i / t$) or ( $V_i=at$), ($V_{ave}=V_i+V_f/2$)

Therefore $S= at^2/2$ when initial velocity or final velocity is zero.

$S=V_{ave} \times t$, When final velocity is zero,

Substitute $V_i/2$ for V ave to get $S= (V_i/2) \times t$, Now

Substitute at for $V_i$ to get $S=(at/2)xt$, or $S=at^2/2$

Failure to yield right of way

Class discussion of the state regulations regarding right of way.

Driving under the influence

Analysis of state and national reports of percentage of accidents caused by people driving while under the influence of drugs and /or alcohol ( Graph using pie chart.)

Tailgating

Measure actual reaction time of individuals by simple means of dropping a ruler , measuring how far it falls before it is caught and applying the data to graphs or equations to measure reaction time. Then relate that reaction time to the distance which must be allowed between your car and the car in front.

Coordination problems

Design and construct a system for measuring hand eye coordination reaction time for use in various parts of the module.

## 3. VEHICLE PROBLEMS

The various vehicle problems which contribute to the actual crash and the subsequent injuries are studied through both readings and hands on experiments.

The items to be researched are described briefly under each of the categories listed.

Brakes: Complete failure/brake lock-up, unbalanced braking, brake fade on hills or upon long use in traffic, what happens when tractor trailers disconnect front brakes.

Accelerator: Sticks in open position, sticks in closed position.

Displays and controls: Driver confusion in emergencies, inattention due to complexity of the entertainment and climate controls.

Lights: Blinding oncoming cars, brake lights not easily visible, tail lights or brake lights not functioning.

Mirrors: Rear view mirrors do not give a n adequate view of cars just behind on the passenger side.

Steering and wheels:Complete failure of steering arms, oversteer or under steer,driving too fast for radius of the curve, uneven air pressure in tires, worn steering linkages, loose lug nuts.

Tires: Complete failure - blowout, smooth tires on wet road, uneven wear and/or uneven tire pressure causes unsteady steering.

Windshields: Loss of visibility due to anti shatter film clouding up or hitting dirt or frost.

## 4. HAZARDS OF THE ROAD

Through the use of photographs and/or diagrams students will have the opportunity to explain the science behind the problem, and the engineering involved in the solution of problems caused by various road hazards.
Signs and light posts: the problems involved because signs supported by two wooden legs fall on cars when they are hit. The problem of light poles too close to the road.
Sharp Curves:he relationship between radius of curvature of a curve in the road and the safe speed limit.
Traffic lights: The factors involved in the timing of traffic lights.

## 5. REGULATORY AGENCY DECISIONS

While the purpose of regulatory agencies is the development of rules and regulations which will improve the safety situation, some rules actually result in situations which are more dangerous than those which were being corrected. Sometimes groups of drivers feel forced to ignore rules for economic, or personal freedom reasons. Three such regulations are studied through reading and personal observation of actual situations.

The 55 mph decision: While the 55mph speed limit was instituted for economic and resource reasons, it was credited with saving lives. When it was thought to be unnecessary for energy saving many states rescinded it.This situation in which the rule is in force in some states and not in others provides opportunity to analyze its safety aspects.

Mandatory passive restraints: This regulation has both supporters and detractors. There are many reports on both sides of the issue. This provides an excellent opportunity for students to have discussions regarding the ethics of disconnecting mandatory restraints including air bags, or refusing to wear seat belts. The problem of recycling junked cars with air bag units still intact is also appropriate for study.

Right turn on red: Does this rule save time or, fuel, and does it cause accidents costing more that any fuel or time saved.?

## 6. WHEN CRASHES OCCUR

Protecting People in crashes: While the ideal situation in auto safety is never to have an accident, we must prepare for the less than ideal. Students will discuss the two major goals involved in protecting people in crashes. The first goal is to protect the people in the vehicle from injury during the crash, and the second goal which is sometimes in conflict with the first is to get the people out of the vehicle as soon as possible after the crash. The remainder of this section is devoted to attempting to meet both goals with a minimum of conflict.

The National Traffic Safety Act: through library research, class discussion, teacher or student presentation the history of the development of the various regulations found in the NATIONAL TRAFFIC AND MOTOR VEHICLE SAFETY ACT will be studied. The effects of the regulations on manufacturers and consumers will be discussed. Classroom experiments using student designed equipment will be carried out.

For example students will test the effect of brake light position on the ability of the driver of the following car to react. Other appropriate experiments will be carried out.

Preventing Injuries in a Crash: Students will design and construct models of systems for the prevention of injury because of coming in contact with at least one of the following:

THE DASHBOARD INSTRUMENT PANEL
DOOR HANDLES AND WINDOW CONTROLS
THE STEERING WHEEL
THE WINDSHIELD.

They will also consider the problem of being thrown from the car upon impact, the seat coming loose from the body of the car, and being trapped in the car after a crash, or when submerged, or when the car is on fire. The question of how rapidly the air bag should inflate. Should it be designed so that it takes into account the size and weight of the person being protected?

Areas of study which will be required in order to attack these problems are: Acceleration, "G" forces, reaction time, arm strength, and various mechanical, electrical, and computer systems.

How much money can we afford for safety?: Through class discussion involving economic consideration, ethical considerations, trade-offs, government vs individual responsibility, students will make recommendations as to how much we might expect to pay for various safety systems. Tables of cost vs lives saved for various safety systems are available for student study in this section.

7.EVALUATION

Student progress in meeting the expected outcomes as defined in the syllabus outline will be measured by the teacher using the systems suggested in the syllabus.

## SKILLS TO BE DEVELOPED

### 1. PROBLEM DEFINITION

Class activities involving mathematical analysis of accident data, application of physical principles in arriving at conclusions as to the actual cause of accidents and resultant injuries.

### 2. COMMUNICATION SKILLS

A. Person to person

Team activities in research activities as a part of the analysis of auto safety problems, as well as in the design of appropriate alternative solution

B. Person to group

Individual reports to team and to the entire class on results of laboratory investigations and library research.

Technical report to group regarding design of equipment for experiment and/or design of alternative solution.

C. Person to machine

Use of computer to measure human reaction time, velocity of moving vehicle,and stopping distance under various conditions.

D. Machine to Machine

Possible design of automated braking system.

## 3. TECHNICAL TOOLS, TECHNIQUES AND RESOURCES

Computer simulations

Computer analysis of experimental data

Machine and hand tools used in constructing devices and systems for both experimenting and developing safety systems.

Research using books, technical reports, internet sources,and journal articles.

## 4. SELECTION OF MATERIALS AND PROCESSES

Individuals and teams will research the properties of various materials for testing equipment and for design of safety systems.

## 5. MEASUREMENT

Measurement of time, distance, and force under various conditions in gathering data for analysis. Measurement of strength of various components of safety devices.

## ATTITUDES

As a result of the study of the case it is expected that each student will develop attitudes which show that he or she:

1. Accepts the fact that Science, Technology, and Society interact.

The interaction of the laws of science (F=ma) with the laws of society (Mandatory seat belts) requires technological innovation in order to satisfy both.

2. Accepts the concept that technology can be used to solve human problems.

The development of passive restraints to neutralize the human reluctance to buckle up. The introduction of collision avoidance systems and automatic braking systems to neutralize the variations in reaction time of drivers.

3. Accepts the concept that Technology is a part of a larger system. (Societal, Economic, and Political).

The conflict among the regulations involving safety, energy conservation, environmental pollution, and the manufacture of autos which consumer is willing to purchase.

4. Accepts the concept that humans should use technology to their best long term advantage.

The value of wearing seat belts, motorcycle helmets, etc.

5. Accepts the concept that engineers must hold paramount the health and welfare of people in the performance of their duties.

The need for keeping passenger safety in mind while designing autos, roads,highway lighting,etc.

## VI. Project Overview, Procedures

The study of auto safety design begins with a look at the causes of vehicle accidents. This is accomplished by research in local papers, the supplementary text material, insurance reports, classroom and on site research, and appropriate audio visuals including TV news broadcasts and data retrieved from the internet. Students will learn that accidents are caused by the driver, the vehicle, the road, and regulations. This is followed by research into the causes of injury and death following the accident.

The second phase of the course is to design devices and systems to prevent accidents, and to reduce injury following an accident. While the devices will often be scale models of actual devices, the systems might include rules and regulations as well as mechanical or electrical systems.

If classroom computers are available they will be used to simulate actual systems as well as to analyze model car crashes and to design devices and systems. Analysis of traffic light timing to provide safety for cars and pedestrians while maintaining smooth traffic flow will be done at actual traffic intersections as well as through computer simulation.

## VII. SUGGESTED EVALUATION METHODS.

Since a variety of classroom procedures will be used in the teaching of this case study, a variety of evaluation methods will be used.

Students will be evaluated on their contribution to small group success in design and manufacture of the various systems and devices, as well as in their contribution to small group and classroom discussions. Portfolios are particularly appropriate here.

Paper and pencil tests to measure the understanding of the various concepts will be administered from time to time as well as a final examination. These tests will include both multiple choice questions and essay questions. The final exam might be prepared though the cooperation of teachers from different schools.

## VIII. CASE STUDY TIME TABLE

While the actual time for study of this case study will depend on the interest and background of both the teacher and the students and the resources available, the following minimum time table is recommended.

**WEEK ONE:** Driver and vehicle causes of accidents and injuries

**WEEK TWO:** Road and regulations as causes of accidents and injuries

**WEEK THREE:** Design and development of devices and systems to prevent accidents caused by drivers and vehicles.

**WEEK FOUR:** Design and development of devices and systems to prevent accidents caused by roads and regulations

**WEEK FIVE:** Design and development of devices and systems to prevent injury following accidents.

**WEEK SIX:** Continue design and development of week five. Discuss the ethical ramifications of manufacturing unsafe cars, planning unsafe roads, and development of conflicting regulations which result in traffic accidents and injuries.

## IX. RESOURCES FOR STUDENTS AND TEACHERS

### A. Books

1. AUTO SAFETY, by E.J.PIEL, Published by Penn State University, University Park, PA, 16802. **Selected readings from this text are included in the section following the "teacher materials"and may be reproduced for student use.**
2. 55: A DECADE OF EXPERIENCE, Transportation Research Board, Special Report 204, National Research Council, 2101 Constitution Ave. N.W. Washington, D.C. 20418
3. THE HIGHWAY RISK PROBLEM, Robert F. Baker, WILEY-INTERSCIENCE a division of John Wiley & sons New York.
4. SUDDEN IMPACT: An Occupant Protection Fact Book, U.S.Department of Transportation. National Highway Traffic Safety Administration, 400 Seventh St SW, Washington DC 20590

**B. Periodicals**

1. The local daily newspaper for information on accidents and fatalities.
2. Popular Science and Popular Mechanics Magazines for new developments in auto safety.
3. Status Report, IIHS 1005 North Glebe Rd, Arlington, VA 22201. (703) 247-1500, Fax (703) 247- 1678
4. There are a vast number of WEB sites available. Search under "autos" "tires" etc.

**C. Computer software**

1. Program to analyze distance/time, speed/time, acceleration/time available from IBM.
2. Various auto driving games

**D. Video Tapes**

1. The following tapes are available on free loan from the Insurance Institute for Highway Safety (IIHS) 1005 North Glebe Road, Arlington, VA, 22201 (703)-247-1500

AIR BAGS NOW,
SHOPPING FOR SAFETY,
HELMET LAWS:Whose Freedom?,
BUMPERS:A Retrospective,
SAFETY BELTS &AIR BAGS:Two decades of Progress,
ANTI LOCK BRAKES MAKE SENSE,
CHILDREN IN CRASHES,
CRASHING CARS:Testing For Safety,
MAKING THE LAW WORK:Safety Belt Use ir Elmira, NY,
WHEN TEENAGERS DRIVE,
FACES IN CRASHES.

**E. Free Materials**

1. **FACTS,** published by **The Insurance Institute for Highway Safety** for statistical data on the various factors involved in highway accidents such as: alcohol,bicycles, children, elderly, motorcycles, passenger vehicles, pedestrians, roadside hazards, teenagers,tractor-trailers, vehicle size, and state by state data. The same publication lists recent laws such as child restraint laws, DUI/DWI laws, helmet use laws, safety belt laws, and young driver laws.

**FACTS** is available at no cost from **The Insurance Institute for Highway Safety,(IIHS) 1005 North Glebe Road, Arlington, VA, 22201.**

2. **STATUS REPORT** is a weekly newsletter from IIHS at the same address. It contains up to date reports on such topics as "5mph bumpers", "truck brake systems" "short term changes in crash deaths" New videos available on sale or loan for school use.

**F. List of Supplies**

1/4" plywood for making ramp for car crash research
Scrap wood, cardboard etc. for making test cars
Brake Pads, new and used
SPRING BALANCES for brake pad experiments
Large paper for design of dashboard, and other design projects

## X. EQUIPMENT AND MATERIALS NEEDED

A. Hand tools
B. MAC or IBM PC
c. Overhead projector

# DESIGNING AUTOS FOR SAFETY

# Student Activities

# AUTO SAFETY MODULE

E.J. PIEL
Student activities related to the Module
Student activities involving analysis of data.

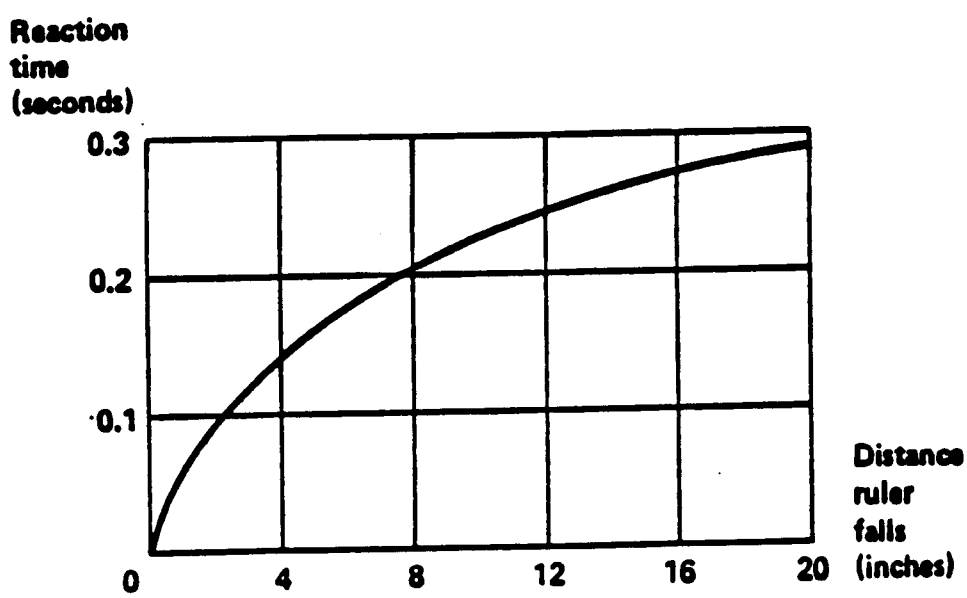
From the AUTO SAFETY READINGS

**THERE ARE 16 STUDENT ACTIVITIES SUGGESTED IN THE AUTO SAFETY READINGS. THE STUDENT ACTIVITIES LISTED BELOW ARE IN ADDITION TO THOSE IN THE READINGS.**

SUGGESTION:
Fig.8 In the readings can be used as a means of converting miles per hour to feet per second by locating the point at which the 1.0 second line crosses the miles per hour line. For example, 60 mile per hour crosses the 1.0 second line at the distance 88 feet. Therefore 60mph equals 88ft/sec.

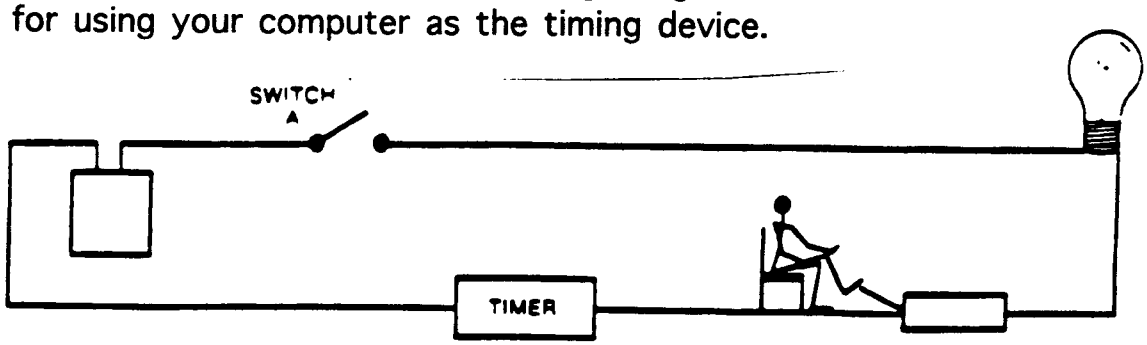
## STUDENT ACTIVITIES

Activity: REACTION TIME vs DISTANCE TRAVELED AT DIFFERENT SPEEDS
The individual reaction time can be obtained quickly by having a student attempt to catch a falling ruler.
Use the graph below to find the reaction time.



If you wish, you can have your students construct the graph by solving the equation $S=gt^2/2$ in which S is the distance the ruler falls, g is the acceleration due to gravity (384 inches /sec/sec) and t is the time in seconds. Solving $S=gt^2/2$ for $t^2$ we get $t^2=2S/g$. Using a calculator we can get the square root of $t^2$. If we assign different distances for S from 2inches to 20 inches to different students we get the graph.

A more realistic measurement of reaction time uses the apparatus shown in the following diagram. Kits are available for using your computer as the timing device.



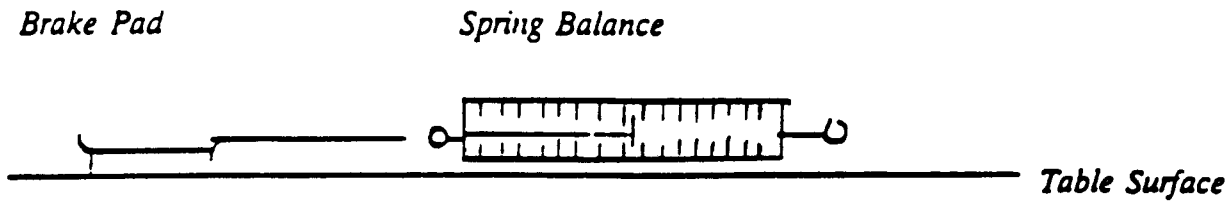

Brakes:

Unbalanced braking and brake fade result from changes in the coefficient of friction between the brake pads or shoes and the rotor or drum.

An experiment to determine the coefficient of friction between the brake pads and the table top or a sheet of metal can be done with both new and used brake pads. A set of brake pads can be purchased from an auto parts store for about $10.00. Local garages are happy to give you used pads.

Students can do the experiment to find the coefficient of friction between the pad and the surface by following these directions.

The coefficient of friction between any two surfaces is determined by dragging one of the surfaces over the other at a constant speed. The coefficient of friction is calculated by dividing the force necessary to overcome friction (the force of friction) by the weight of the object being dragged (force pushing the two surfaces together). The set-up is as in the diagram on the next page.




Procedure:
Weigh the brake pad. (W)
Drag the pad accross the surface at a constant speed and record the force necessary to do this.(force of friction) (Ff)
Make five trials and get the average values for weight and force of friction.

$$Fc = Ff/W$$

Divide the force of friction by the weight of the brake pad (Ff/W) to get the coefficient of friction(Fc).

**Pile additional weights on top of the brake pad and repeat, calculating the coefficient of friction for each set up.**
Students will find that the coefficient of friction does not change regardless of the amount of weight added to the pad.
**Soak the pad in water and repeat the procedure.**
Students will find that the coefficient of friction does change.
If facilities are available heat the brake pad and the surface and repeat the experiment.
**Repeat all of the above with worn brake pads from the local garage.**
Discuss the results of the experiment in terms of possible braking problems in rainstorms and when going down hill.

## Accelerator

Discuss the possible consequences of the accelerator sticking in either the open position or the closed position. Develop procedures for overcoming the problems while traveling on a highway at 55mph and when driving in the city at 25mph.

## Displays and controls

There are many conditions in which improper location of displays and controls results in accidents. For example the handle for the hood release is often close to the brake release handle. The question of idiot lights vs dials or digital readout, location of radio and tape controls, etc.

Students should be assigned the task of identifying and prioritizing the various dashboard displays and operating controls.
Following a class discussion there should be some level of agreement of the priority of each of the controls and displays.
A small group project (4 students per group) contest should be held with each group given one week to come up with the best design of both the controls and the display. The class (or the driver ed teacher or some outside judge) will then judge which of the designs best meets the criteria agreed upon by the class.

Lights

Have students bring in ads or actual photos of the rear light arrangement for different cars. Note and discuss the merits of each. Using the apparatus designed for the reaction time study measure the reaction time related to brake lights at different levels from the lowest shown in the pictures brought in by students (be sure to have pre-1986 mid sized GM station wagons in the group).

Mirrors:

Using a convex mirror borrowed from the science department or one from the passenger side of a car, note the difference in the field of vision provided by the convex mirror as compared with a plane mirror. Also note the difference in virtual image distance of the same object distance from the two mirrors.
Discuss the advantages and disadvantages of these two types of rear view mirrors.
Discuss the advantages and disadvantages of periscope type mirrors mounted on the top of the car.

Tires:

Oil deposited on the road during a long dry spell is lifted to the surface by the water which is more dense.]
In order to demonstrate the effect of the combination of a light rain following a dry spell, repeat the coefficient of friction experiment with any hard object (a hockey puck is fine) on a dry table followed by the same object on a wet table, followed by the same object on a table with a mixture of oil and water on the surface.

Windshields:

Have students try to read a sign the distance of the length of the room through a sheet of glass or plexiglass which is first clean and then slightly dirty with water droplets on it.

Sharp curves

Have students take pictures of curves which are banked. Banking allows the force of the tire on the road to be exerted in a direction which is closer to the vertical to the road rather than across the surface of the road. If the students are familiar with vectors it might be appropriate to discuss this situation in term of vectors.

Traffic Lights

The main problem with traffic lights is that drivers often assume that they can get through the intersection while the light is yellow.

The Auto Safety text page 55 through 62 details the yellow light situation.

Actual measurements of your local intersections can make this situation even more realistic.

## ANALYSIS OF LOCAL TRAFFIC INTERSECTION

A Traffic intersection involving left turns and right turn on red can be effectively analyzed by a group of 12 - 16 traffic analysists.

At each corner there should be three to four people assigned as follows:

**A. COUNT THE NUMBER OF CARS THAT GO STRAIGHT THROUGH THE INTERSECTION WHEN THE LIGHT IS GREEN.**

**B. COUNT THE NUMBER OF CARS THAT TURN RIGHT ON GREEN.**
**ALSO COUNT THE NUMBER OF CARS THAT TURN RIGHT ON RED.**

**C. COUNT THE NUMBER OF CARS THAT TURN LEFT WHEN THE LIGHT IS GREEN.**
**ALSO COUNT THE NUMBER OF CARS THAT ARE STILL WAITING TO TURN LEFT WHEN THE LIGHT TURNS RED.**

**D. TIME THE LENGTH OF TIME THAT THE LIGHT IS GREEN, IS YELLOW, AND IS RED.**

Upon returning to the classroom draw a large diagram of the intersection and indicate on the chart the data gathered by the group.

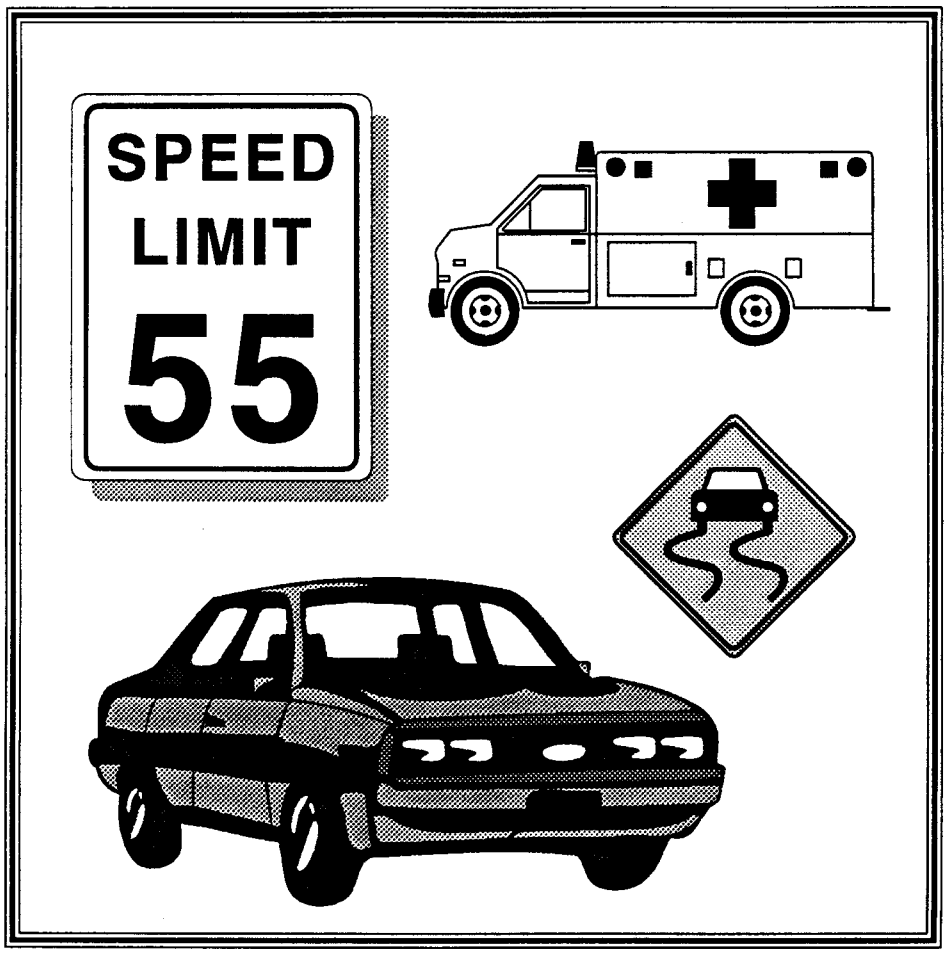
The data should include time of day, day of the week, weather, time of year, condition of each of the roads involved in addition to the numbers of vehicles counted.
Discuss the flow of traffic and any problems noticed by individules. These problems might be in the nature of: Cars which did not make it on one change of light; Large gaps in traffic in one direction accompanied by heavy traffic density in another direction; Number of cars thaT RAN THE RED LIGHT.
Have the group make recommendations toward the reduction of the traffic problems observed.

## Protecting people in crashes

The following section "**Bill and Ted's Eggselent Adventure**" details a comlete laboratory activity regarding seat belts. There are a number of modifications to the lab . Using accurate timing systems suggested in the reaction time lab can make seat belt activity more realistic.

Principles of Engineering

# *"Bill and Ted's Eggsellent Adventure"*




## Auto Safety Case Study

Developed by: Barry E. Borakove, Syosset High School

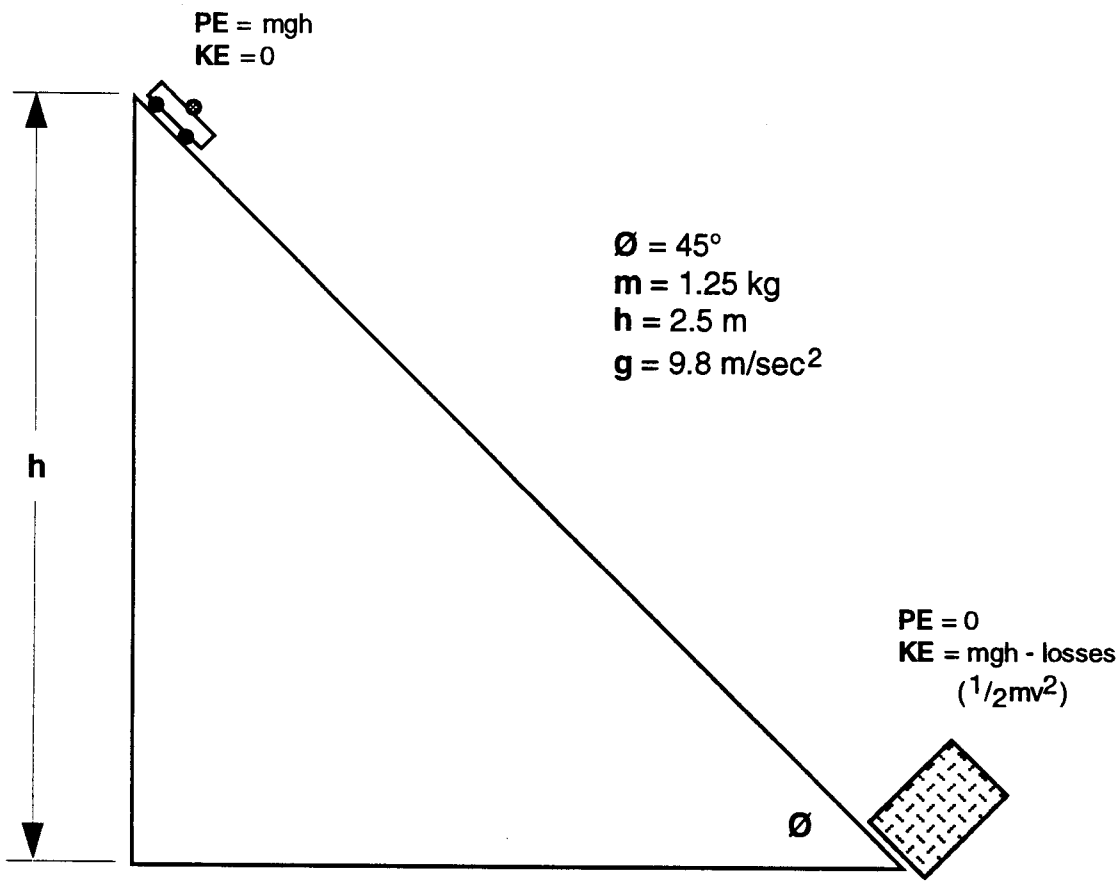
Auto Safety Case Study

# *"Bill and Ted's Eggsellent Adventure"*

Design Team Activity

## • *Introduction to the Design Activity*

In this problem solving and design activity you will use elements of physics, mathematics and technology to design safety systems that will protect the *occupants* of a vehicle. The vehicle will be a standard dynamics cart (purchased from Frey Scientific). The occupants will be two eggs (Bill and Ted). The vehicles will be tested by sending them down a ramp and allowing them to slam into a concrete block at the bottom (see illustration below).




Each team of students will design the following systems: a restraint system, a crumple zone system, an ergonomics system and a car body system. The design solutions will be modeled and

tested. This activity will utilize the ***energy model*** to determine whether or not the safety systems designed (restraint and crumple zone) will allow the occupants to survive a crash test.

When each vehicle is placed on the top of the ramp, it will have a certain amount of stored, or **potential** energy (*PE*) that is a function of the mass of the vehicle (*m*), the height of the ramp (*h*) and the acceleration due to gravity (*g*). This can be expressed as:

$$\mathbf{PE = mgh}$$

***PE*** is the potential energy in joules;
***m*** is the mass in kilograms;
***h*** is the height in meters;
***g*** is the acceleration due to gravity (a constant 9.8 meters/second$^2$).

**Energy** is defined as the ability to due work, or the ability to put an object into motion. **Work** is defined as the amount of force exerted on an object to move it a specified distance. Work and energy are both measured in foot-pounds in US units, and in newton-meters in SI (International) units. The *joule* is an SI unit that is equivalent to one newton-meter. ***Joules*** will be used in all calculations of work and energy in this activity.

The PE of the vehicle can also be referred to as its GPE, or gravitational potential energy. The vehicle will have a certain number of joules of PE at the top of the ramp. The energy in motion, or **kinetic** energy (KE) at the top of the ramp will be zero, until the vehicle is released. The car will accelerate as it travels down the ramp. The increase in the velocity of the car will relate to an increased KE, and a decreased PE. At the bottom of the ramp, the velocity of the vehicle will be maximum, as will its kinetic energy. The potential energy at the bottom will be zero, indicating that all of the PE has been converted into KE.

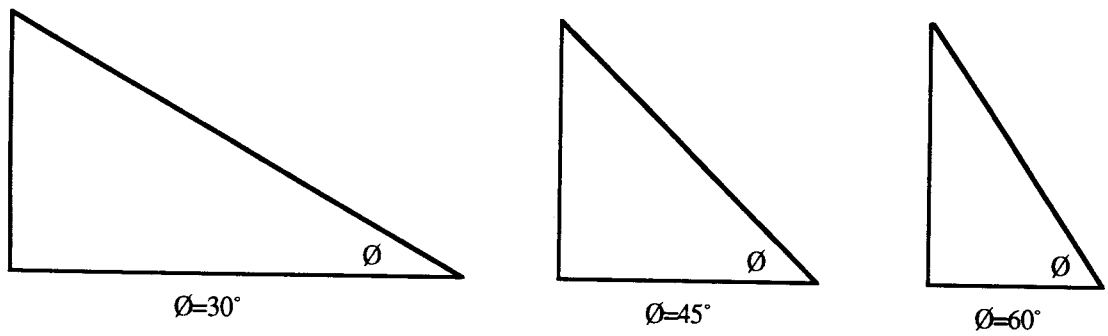
The kinetic energy can be expressed as:

$$\mathbf{KE = 1/2\ mv^2}$$

***KE*** is the kinetic energy in joules;
***m*** is the mass in kilograms;
***v*** is the velocity on meters per second.

This is of course theoretical; all of the potential energy will be not converted into kinetic energy of the vehicle (1/2 mv$^2$) at the bottom of the ramp . Energy will be lost due to friction (between the road surface and the wheels, and between the axles and wheels). Rotational losses will also be a factor (the energy used to turn the wheels) in the final velocity at the bottom of the ramp. These frictional and rotational losses can be significant, and must therefore be considered.

Another important consideration is the angle of the ramp. Although the acceleration due to gravity is a constant (9.8 $m/s^2$), the angle of the ramp will control the actual acceleration of the vehicle. The vehicle acceleration will be higher as the ramp is made steeper. We can relate this to the "thrill" of accelerating down a steep section on a roller coaster. The illustration below shows three ramps at different angles; the height is held constant for each ramp. The ramp at 30° will accelerate the vehicle the least, and the 60° ramp will accelerate the vehicle the most.




If the same vehicle was placed at the top of all three ramps, it would have the same amount of potential energy (***mgh***) which would be converted into kinetic energy as it travels down the ramp (including losses). The actual distance traveled along the ramp will differ for each angle; as the ramp steepens, the distance the vehicle travels becomes less. Using the relationships for ***work*** and ***force***, it can be shown that when the vehicle travels a shorter distance (on the 60° ramp), the force of the vehicle upon impact will be higher than it would be on the 30° or 45° ramp. This is evidenced by the greater magnitude of impacts that occur at steeper angles. The acceleration of the vehicle varies proportionally as the angle of the ramp is changed.

The actual acceleration of the vehicle is proportional to the **sine** of the angle of the ramp. The acceleration of the vehicle down the ramp equals the product of the acceleration due to gravity and the sine of the angle:

$$\mathbf{a = g \sin Ø}$$

The **g sinØ** values for each of the three angles above is:

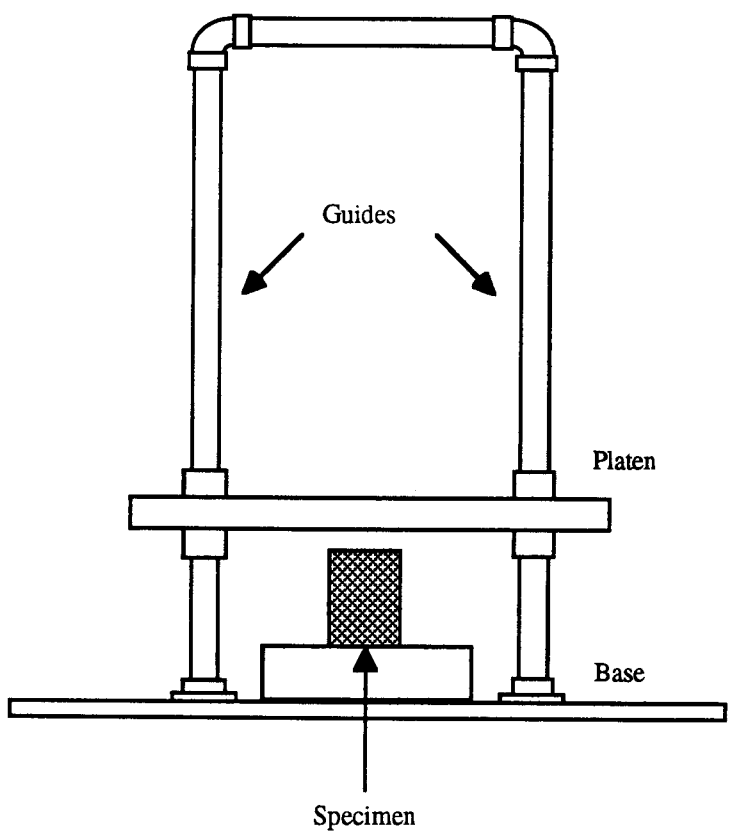
***30° ramp***: 9.8 (.500) = **4.90** $m/s^2$
***45° ramp***: 9.8 (.707) = **6.93** $m/s^2$
***60° ramp***: 9.8 (.866) = **8.49** $m/s^2$

The above example illustrates the significant differences in acceleration that occur as the angle of the ramp is varied. These differences in acceleration will translate into proportionally different forces at impact.

## • *Inquiry, Analysis and Design*

Since the energy model is used in this case study, an analysis of the forces exerted on either the vehicle or the occupants is unnecessary. Resolving the forces (using vectors) requires a much more involved analysis. Since the acceleration due to gravity is a constant (9.8 $m/s^2$) tests will be performed by determining the amount of PE (mgh) each safety system can absorb.

A suggested apparatus to test the restraint and crumple zone safety systems is described below. The apparatus consists of guides fabricated from 1" PVC pipe, sleeves fabricated from 1 1/4" PVC pipe, a wooden base (5/4x6) and platen (2x6), and a variety of pipe flanges, elbows and couplings. The PVC guides are 1 meter long, and spaced approximately 0.5 meters apart. The specimen is tested by allowing the platen to drop a specified distance. With the weight of the platen known, the distance that the platen falls (including the compressed portion of the specimen) can be used to calculate the potential energy (mgh) absorbed by the specimen. Weights can be added to the platen to increase the mgh without increasing the height of the apparatus. Tests on each of the safety systems can be analyzed, and the results used to optimize the design solution.



Auto Safety Case Study

# *Engineering Team Responsibilities*

"Bill and Ted's Eggsellent Adventure"

All members of each design team are expected to actively participate in all of the facets of this design and problem solving activity. Although all responsibilities will be shared, each team member will be placed in charge of a specific subsystem. The ***Chief Engineer*** for each subsystem will be held accountable for the operation and final success of that subsystem.

## *Subsystem Chief Engineers:*

- **Restraint Subsystem Chief Engineer**: Responsible for "occupants" being held in a safe/secure position during and after the collision.
- **Crumple Zone Chief Engineer**: Responsible for the modeling of the subsystem to insure that the design is adequate for the predictable forces and energy transfers at impact.
- **Car Body Design Chief Engineer:** Responsible for the design and construction of a realistic looking car body.
- **Ergonomics Chief Engineer**: Responsible for the ***human factors*** considerations which include: entry/exit, visibility, and space considerations.

Design teams will determine the forces and energy transfers for their vehicle; they will then determine the resulting energy that will be absorbed by their safety systems.

## *Assessment of Work by Design Teams*

- Portfolio documenting and describing the design:
  Research, investigations, report, drawings.
- Optimization of design solutions.
- ***Eggonomics*** of the design.
- Realistic component of the car body design.
- Presentation/justification of design to class.
- Survival of the occupants *(Bill and Ted)*.
- Student Journal/Log Book
- Class participation.

Auto Safety Case Study

# *Design Team Portfolio*

"Bill and Ted's Eggsellent Adventure"

*Each Design Team must submit a portfolio which documents their work on this case study. The portfolio must contain each of the following materials:*

### ✯ *Restraint Subsystem*

- Sketches of all preliminary designs.
- Materials chosen and rejected (analysis).
- Test results (mgh) for each trial.
- Reasons for failure: observations, causes/effects.
- Methods of optimization and results.
- Final optimized solution: drawings/description.

### ✯ *Crumple Zone Subsystem*

- Sketches of all preliminary designs.
- Materials chosen and rejected (analysis).
- Test results (mgh, mg$\Delta$h) for each trial as a function of height and/or angle.
- Reasons for failure: observations, causes/effects.
- Methods of optimization and results.
- Final optimized solution: drawings/description.

### ✯ *Car Body Design Subsystem*

- Sketches of all preliminary designs.
- Materials chosen and rejected (analysis).
- Design goals stated: appearance, aerodynamics, ergonomics, weight, crash worthiness.

### ✯ *Ergonomics Subsystem*

- Measurements and investigations on human factors engineering.
- Methods used to apply ergonomics to final design.
- Evidence of ergonomics in car body design.

Auto Safety Case Study

# *Final Results of Activity*

"Bill and Ted's Eggsellent Adventure"

| Team Number | Vehicle Mass (kg) | PE (mgh) | Driver | Distance in 1/30 sec. | Final V m/s mph | KE ($1/2mv^2$) | E losses (PE-KE) |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |

Auto Safety Case Study

# *Log Book Assessment*

"Bill and Ted's Eggsellent Adventure"

**Student:** _____

## *Assessment Scale:*

**4: Mastery:** Your work demonstrates excellence in this portion of the activity.

**3: Accomplished:** Your work fulfills all of the objectives of this portion of the activity.

**2: Acceptable:** Your work is acceptable, but needs minor revisions.

**1: Unacceptable:** Your work is either incomplete, or requires major revisions.

1. Entries are made on a daily basis to document student's work. _____
2. Entries are thorough and complete containing all relevant material. _____
3. Entries contain data, observations and an analysis of the investigations. _____
4. Entries indicate use of problem solving and design techniques. _____
5. Illustrations are included where appropriate, and they enhance the clarity of the log book entries. _____
6. Entries demonstrate student's contribution to the group effort in this activity. _____

**Total:** _____

Auto Safety Case Study

# *Assessment of Activity*

"Bill and Ted's Eggsellent Adventure"

***Design Team # ____ Subsystem Chief Engineers:***

Restraint Subsystem: _____ Crumple Zone Subsystem: _____

Car Body Subsystem: _____ Ergonomic Subsystem: _____

## *Assessment Scale:*

**4: Mastery:** Your work demonstrates excellence in this portion of the activity.

**3: Accomplished:** Your work fulfills all of the objectives of this portion of the activity.

**2: Acceptable:** Your work is acceptable, but needs minor revisions.

**1: Unacceptable:** Your work is either incomplete, or requires major revisions.

### *A. Restraint Subsystem*

a) Preliminary designs are clearly identified with sketches. _____

b) All data collected for preliminary designs, calculations (analysis of data), and observations are clearly documented for each trial. _____

c) Design shows evidence of optimization. _____

d) Final solution is provided with suitable drawings. _____

e) A concise, written description documents your work. _____

### *B. Crumple Zone Subsystem*

a) Preliminary designs are clearly identified with sketches. _____

b) All data collected for preliminary designs, calculations (analysis of data), and observations are clearly documented for each trial. _____

c) Design shows evidence of optimization. _____

d) Final solution is provided with suitable drawings. _____

e) A concise, written description documents your work. _____

## C. *Car Body Design Subsystem and Ergonomics Subsystem*

a) Preliminary designs are clearly identified with sketches. _____

b) Safety systems are incorporated into a realistic car body design. _____

c) Car body illustrates quality workmanship, and good utilization of both materials and equipment. _____

d) Effective use of ergonomics in restraint system design. _____

e) Visible indications that human factors engineering is incorporated into the vehicle design. _____

## D . *Survival of the Occupants* (Bill & Ted)

| | | |
|---|---|---|
| Bill and Ted survive the crash unharmed (no cracks): | (4) | |
| Either Bill or Ted is injured (shell cracked) in the crash: | (3) | |
| Bill and Ted are both injured in the crash: | (2) | |
| Either Bill or Ted *eggspires* (cracks with leakage) in the crash: | (1) | _____ |

## E. *Presentation of Design to Class.*

a) Presentation was organized and well planned. _____

b) Presentation was thorough and included all relevant content material. _____

c) Responses to questions were clear and appropriate. _____

d) Design was justified to class in presentation. _____

e) All design team members actively participated in presentation. _____

f) Presenters handled themselves in a professional manner. _____

g) Presentation included a variety of audio-visual media and visual aids. _____

## F. *Classwork/Groupwork*

a) Student shows consistent effort. _____

b) Work started in a businesslike manner at bell. _____

c) Willingness to help other students. _____

d) Suitable class conduct displayed. _____

e) Student actively contributes to the group effort. _____

f) Student actively participates in the peer review process. _____

g) Student completes work in a timely fashion (at specified deadlines). _____

h) Student worked responsibly as a subsystem Chief Engineer, and was supportive to the other members of the design team. _____

**Student's Name:** _____

# Auto Safety Lab Displays and Controls

GROUP NAME_____

MEMBERS

NAME_____RESPONSIBILITY_____

NAME_____RESPONSIBILITY_____

NAME_____RESPONSIBILITY_____

NAME_____RESPONSIBILITY_____

Ergonomics is the study of the relation between humans and machines. Deciding on the location and shape of the displays and controls in the automobile is part of the design function.

BEFORE YOU START THE ACTUAL DESIGN OF THE DASHBOARD AND CONTROLS

1. As a group, decide on the

**Criteria for the design of displays and controls of a passenger automobile:**

2. List the factors which might make it difficult to meet all of the criteria; they are called

**Constraints:**

**ONCE YOU HAVE LISTED THE CRITERIA AND CONSTRAINTS YOU MAY BEGIN THE ACTUAL DESIGN OF THE DISPLAY AND CONTROLS.**

Use the newsprint to draw your design.

3. Trade offs which need to be made in order to **Optimize** among the criteria and the constraints. These might not be known at the start, but should be listed as they are made.

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**NetFind Tip**

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**AOL NetFind** found **63975** documents about **tires**.
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67% The Goodyear Tire & Rubber Company [More Like This]
***URL:*** http://www.goodyear.com/
***Summary:*** Get some tips on finding your way around our site, then take a look behi blimp for late-breaking news, our 1996 Annual Report and insurance verification. Ou Government Sales site offers federal, state and local agencies instant access to price li updates and more.

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***URL:*** http://www.islandnet.com/~cameron/procure/
***Summary:*** Helps maintain constant air pressure. Helps avoid costly and inconvenie time.

66% Dunlop Tire Corporation Motorcycle Tires [More Like This]
***URL:*** http://www.dunloptire.com/cycle/index.html
***Summary:*** . The information contained in this site is developed in the United States

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***Summary:*** Bridgestone Tyres are a member of Welcome to the Bridgestone Info C FIRST RADIAL MOTORCYCLE TYRES WITH TWIN COMPOUNDS FOR GRIP MILEAGE.

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**61%** Porsche in Geneva [More Like This]
***URL:*** http://www.team.net/www/ktud/911.html
***Summary:*** Electrical system : Battery,36Ah,generator 115A/ 1,610W. Brake systen four-piston,fixed-saddle brakes front and rear with ventilated and cross-bored brake diameter in front, 322mm diameter in back,four-channel ABS.

**61%** General Maintenance - Tires [More Like This]
***URL:*** http://www.bridgestone-firestone.com/news/tips/general/tires/tires.htm
***Summary:*** One of the most popular types of tires sold today, all-season radials, are handle dry and wet surfaces, and some amounts of snow. Even the rubber is speciall to stay pliable in the cold and give you better traction on icy roads.

**61%** bmx May '96: PSI & Primo tires. [More Like This]
***URL:*** http://cycling.org/lists/bmx/bmx-archive-hyper/bmx.9605/0641.html
***Summary:*** Messages sorted by: [ date ][ thread ][ subject ][ author ]. Next message: "Re: too much mail! . Reply: Bobby Kimani Carter: "Re: PSI & Primo tires."

**61%** Tires, Tyres & more Tires - Internet Ser... [More Like This]
***URL:*** http://www.rubber.com/tires/web/index.html
***Summary:*** * Web Pages * HTML Link Services * Graphic Advertising *. Tires, T Tires has developed a range of services to assist recyclers in taking advantage of the c strengths of the Internet. Through effective use of the Internet's resources, Tires, Tires can offer dynamic tools to assist in developing market presence, expand glob and improve network.

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Did you know AOL NetFind's Find a Person can help you locate the phone number of that long-lost pal from high school?

61% Karting Mailing List: tires/rims [More Like This]
*URL:* http://www.cynical.net/hypermail/karting.jan15-feb20/0286.html
*Summary:* Messages sorted by: [ date ][ thread ][ subject ][ author ]. Next message: "Re: Suggestion - Tip for locating axle bearings." Next message: Pete Muller: "Re: S Tip for locating axle bearings."

61% Classic Car Source -- Historical Automob... [More Like This]
*URL:* http://www.classicar.com/clubs/haco/haco.htm
*Summary:* Classic Car Source -- Historical Automobile Club of Oregon -- Club. Th Automobile Club of Oregon and the Ladies Auxiliary would love to welcome anyone who has a genuine interest in historical automobiles.

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Principles of Engineering Case Study

# AUTO SAFETY

## Teacher Materials

**Contents:**

Background information on appropriate physics and mathematics.
Sample test and answers
Traffic Intersection data, questions, and analysis
Transparency masters for possible use in introducing the Case Study

# PHYSICS, MATH, AND AUTO SAFETY

## MECHANICS

How can we calculate the force on a car that hits a stone wall, or with which a person's head hits the windshield?

**Two physics concepts necessary in order to understand auto safety technology are:**

1.the relationships among force, mass, and acceleration

2. The relationships among velocity, acceleration, time, and distance traveled.

**The following equations are mathematical models of the relationships.**

1.The force applied to a given mass results in an acceleration

The mathematical model is $(F=ma)$ Where" F" is the force applied, "m" is the mass of the object, and "a"is the acceleration.

2. The distance traveled is equal to the average velocity times the time during which the body was traveling at that average velocity.

The mathematical model is (S=vt) Where S is the distance traveled "v" is the average velocity and "t" is the time.

When a body accelerates uniformly(changes velocity) the average velocity is the original velocity plus the final velocity divided by two.

The mathematical model is "$v$" = $(v_1 + v_2)/2$

The final velocity is equal to the initial velocity plus the product of the acceleration times the time.

The mathematical model is $v_2 = v_1 + at$

If the body starts at rest $v_1$ is zero; if the body ends up at rest(a car coming to a stop) then $v_2$ is zero.

**The mathematical model when the body starts at rest is $v_2 = 0 + at$ or $v = at$**

The mathematical model when the body comes to a stop is $0 = v_1 + at$ or $v = -at$. The MINUS indicates that the acceleration is in the opposite direction from the initial velocity.

All of the explanation above can be expressed in the following **mathematical models:**

**$S=vt$, $v=S/t$, $t=S/v$** in which v is understood to be the average velocity.

**$v=at$, $a=v/t$, $t=v/a$** in which v is understood to be either the initial velocity or the final velocity depending on whether the acceleration was positive or negative.

In the problems involving auto safety in this case study we can assume that the final velocity is zero, and therefore the average velocity is the initial velocity divided by two.

I f **$S=vt$ and $v=at$,** and the average velocity equals the initial velocity divided by two, then **$S=at/2 \times t$ or $S=at^2/2$.** Since we designate "g" as the acceleration due to gravity , the mathematical model for falling bodies is **$S=gt^2/2$.**

To summarize, the mathematical models which are useful as we examine the physics of auto safety are:

**$S=vt$, $v=S/t$, $t=S/v$ where v is the average velocity**

**$v=at$, $a=v/t$, $t=v/a$ where v is either the initial or the final velocity.**

**$S=at^2/2$, $a=2S/t^2$, $t^2=2S/a$**

**$S=gt^2/2$, $g=2S/t^2$, $t^2=2S/g$**

**g=an acceleration of 32ft/second/second or 9.8m/sec/sec**

**60mph=88ft/sec. 60mph is approximately 100km/hr.**
**100km/hr= 27.8m/sec**

The downward "g" force on a body at rest at the surface of the earth is the weight of the body. An acceleration of 3gs on a person in a car crash would provide a force of three times the weight of the person.

If we know the initial speed of the car, and the distance it travels after it hits an object, or the distance the victim travels before coming to a stop we can calculate the "g" forces on the car or person by combining two of the previous equations.

(1)$t=v/a$ where " t" is the time it takes to stop a body moving at a velocity "v" if the average acceleration is "a". If we keep in mind that the acceleration due to gravity is 32ft/sec/sec we can substitute "g" for "a".
(2) $t=2s/v$ where "t" is the time it takes to go a distance "s" while the original velocity "v" is changing to zero as the body comes to a stop.
Since we are looking at the same "t" in each case we can say that $v/a=2s/v$, or $v^2 = 2as$ which is equivalent to $s=v^2/2a$ or(3) $a= v^2/2s$. Substituting g for a we get $g=v^2/2s$. We now can show that the g forces on a car hitting a stone wall at 60mph are four times that of a car hitting the same wall at 30mph.

Going back to F=ma, and substituting the mass of the person's head for m, we can calculate the force on that head having solved equation (3) for "a".

## How do we design highways to reduce the forces on cars and people in crashes?

We now know that as we increase time ( in F=ma which is the same as F=Mv/t) We can now devise systems for increasing the time it takes for a vehicle or passenger to come to a stop in an accident.

### How does the impact attenuator do that?

### How does the padded dashboard do that?

### How does the air bag do that?

There is now a concern about Air Bags injuring and even killing children due to the force on the child as the bag inflates. Some suggested solutions are: reduce the speed at which the air bag inflates, allow people to disconnect the air bag when children are riding in the front seat, pass a law requiring that persons below a specific height and weight sit in the back seat. Discuss the advantages and disadvantages of each of these alternatives.

Do the coefficient of friction labs using auto brake pads both dry and wet. Discuss the need for and the principles behind Automated Braking Systems (ABS) being advertised. Bring in ads for ABS equipped cars.

Discuss forces and accelerations on bodies traveling in a circle and relate that to highway curve radius and speed limits on country roads.

OTHER AREAS OF PHYSICS

Electromagnetic waves

Radar: Discuss incidents which students **DO RESEARCH** in order to relate to the area of police radar. Trees speeding, false accusations by police, etc. Have students bring in ads for radar detectors.
Discuss ECHOES, doppler effect, pulse radar and doppler radar.

**OTHER AREAS FOR RESEARCH**
How does a radio or radar receiver tune to a specific frequency?
What is superhetrodyne? What does it have to do with enforcing of police radar laws? What are the various measures and countermeasures which police and the developers of radar detectors have resorted to in the "RADAR WAR"

How does collision avoidance radar work in preventing auto accidents?

What does the principle of light intensity being inversely proportional to the square of the distance from the light source have to do with the location of light poles on the highway? How is the light reflector designed to overcome the effects of this principle?

**Reflection and refraction**

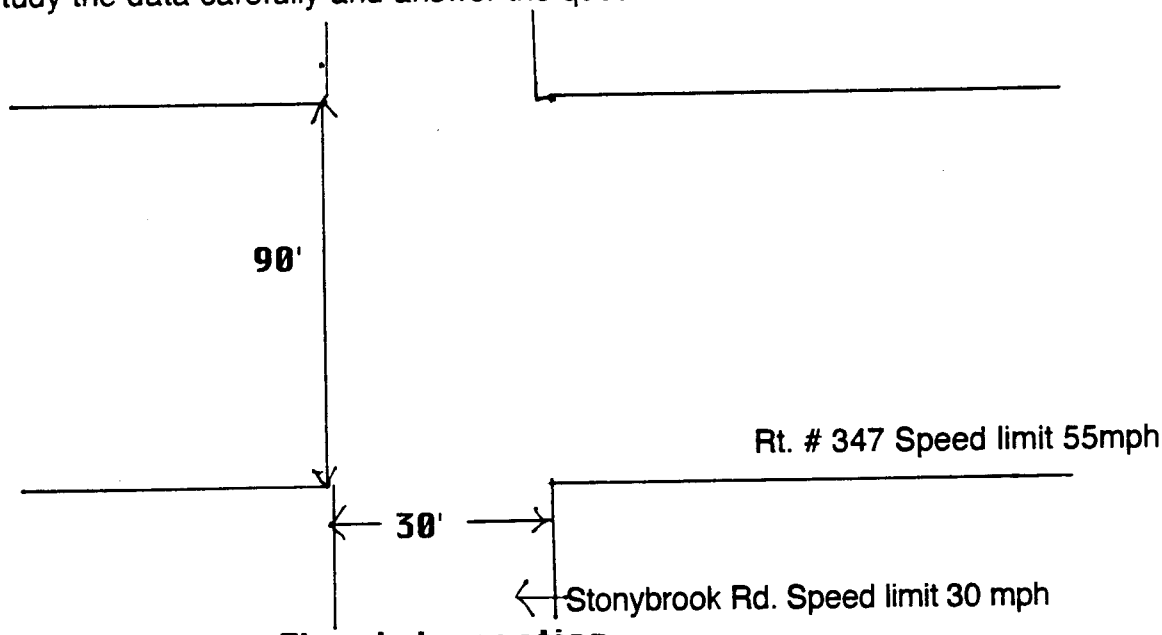
Why is the mirror on the passenger side a convex mirror? What does the warning on the mirror say? What is the physics behind this? **There is a lab suggested in the Student activity section which looks at this problem.**

Discuss the situation in which the stop light lens of the car in front of you seems to light up when your headlights shine on it.
What does refraction have to do with this phenomenon?

Discuss the advantages and disadvantages of periscope type mirrors mounted on the top of the car.

# Traffic Intersection Analysis Problem

The following data was collected at an intersection on Long Island.
Study the data carefully and answer the questions.




**The Intersection**

## The Data

Light facing Stonybrook Rd. where the speed limit is 30mph.

Became green at 8:15:54
Became yellow at 8:16:37
Became red at 8:16:40
Became green again at 8:18:18

Light facing Rt#347 where the speed limit is 55mph

Became green at 8:16:41
Became yellow at 8:18:13
Became red at 8:18:17

Questions:

1. How many cars can get across Rt #347 during the green light?
2. How many cars can get across Stonybrook Rd. during the green light?
3. Is the yellow light on long enough to eliminate a dilema zone for the cars on Stonybrook Rd.? If not, how large is ti?
4. Is the yellow light on long enough to eliminate a dilemma zone for the cars on Rt #347? If not, how large is it?
5. How is the timing set to give the drivers an added factor of safety?(hint: check all starting and ending times carefully) Does it work for both roads?

**HINT:** Use the graphs of speed vs distance and stopping distance vs speed to help in your analysis.

## Solution to the Traffic Intersection Analysis Problem

The Traffic Intersection Analysis problem can be given as an individual homework problem or as group problem in the classroom. It is presented to remind the students that even simple looking problems can require a number of steps in their solution. If possible students should gather their own data, if not, use the information presented. It is from real data gathered by a group of students.

**There are a number of assumptions which must be made in order to answer the questions. You may want to state them immediately, or wait for students to ask for more information.**

### Assumptions:

(1) There are five cars waiting when the light turns green.
(2) It takes an average of 3 seconds for each of the five cars to cross Stonybrook Road
(3) It takes 5 seconds for each of the five cars to cross Rt. #347.
(4) All of the cars following the originally stopped cars are moving at the speed limit.
(5) Allow 2 seconds between cars travelling at the speed limit.
(6) A car in the intersectionwhen the light turns red is assumed to get across safely.
(7). All reaction times are 1second.

The following is a system for analyzing the situation. You might want to use it as aguide for giving hints to students who get stuck on various parts of the problem.

**1.** For the light facing Stony Brook Road.

The light is green for 43 seconds. (8:16:37 - 8:15:54 or 8:15:97 - 8:15:54 =0:0:43)

The first five cars use up 25 seconds (5 cars @ 5 seconds per car) remaining time 18sec.

A car going 30mph travels 45feet in one second. It takes 2 seconds to cross plus 2 seconds for safe spacing between cars, or 4seconds per car. Four cars will take 16 of the 18 seconds leaving 2 seconds for the last car to get through.

The total number of cars going through on the green light is 5+4+1=10.

**2.** For the light facing Rt. #347

The light is green for 92 seconds( 8:18:13 - 8:16:42 = 92 sec.)

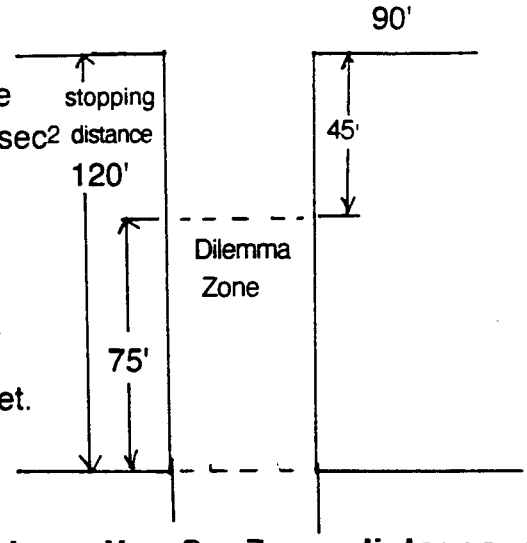
The first five cars use up 15 seconds (5 cars @ 3 seconds per car) remaining time is 77 seconds.

A car going 55mph travels 81 feet in one second takes 60/81or 0.74 seconds. Add 2 seconds for safe distance. Total time is 2.74 seconds per car.

An additional 28 additional cars can get through in 76.72 seconds for a total of 33 cars. If the 34th car is following at the 2 second interval it could not get through legally in the remaining 0.28 seconds.

3. Stopping distance is reaction distance (45 ft/sec x 1sec=45ft) Plus stopping distance at negative acceleration of 1.3 ft/sec$^2$ (Graph Fig.16) at 30mph is 120ft.

Yellow Light is 3 sec. Speed is 45ft/sec. Go Zone is distance car goes during the time the light is yellow minus the width of the intersection which is 90 feet. 45ft/sec x 3 sec = 135 ft. minus 90 ft = 45feet.




**Dilemma Zone is 120ft minus the Go Zone distance 45ft which equals 75 feet.**

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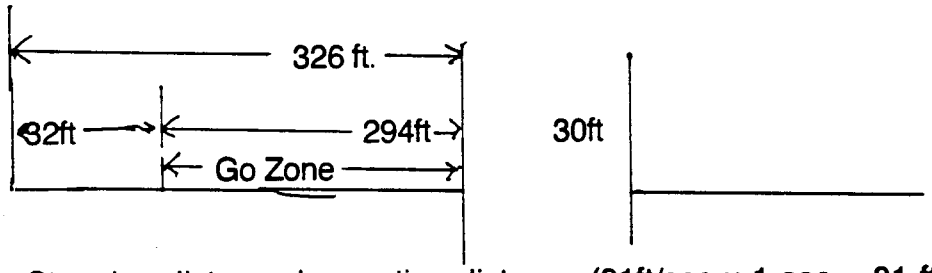
4. Yellow light 4 sec. Speed 81ft/sec. Go Zone is distance car goes during the time the light is yellow minus the width of the intersection. 81ft/sec x 4 sec =324 ft minus 30 ft = 294 ft.




Stopping distance is reaction distance (81ft/sec x 1 sec = 81 ft) Plus braking distance at negative acceleration of 13 ft/sec$^2$ (Graph fig 16) at 55mph is 245 ft plus 81 ft reaction distance = 326 ft. This distance compared with the go zone of 294 ft gives a **dilemma zone of 32 ft.**

5. There is an extra second from the end of the yellow until the beginning of the green for the other direction. This makes the effective go zone for the Stony Brook Road cars 90 feet. That still leaves a **30 foot dilemma zone.**It makes the effective go zone for the Rt # 347 cars 375 feet which is a **50 foot overlap.**

**Optional Problem.**

Use the data from this problem as input to the Yellow Light Simulation to try to eliminate the dilemma zone for the Stony Brook cars and the overlap zone for the Rt. #347 cars.

## SAMPLE QUIZ QUESTIONS

1. Highway "Booby Traps" are responsible for approximately one third of traffic fatalities. Describe five such "Booby Traps" and explain in detail how two of them have been eliminated through improved engineering.

2. Discuss the difference between an "active" passenger restraint system and a " passive" passenger restraint system for automobiles and give an example of each in terms of optimization.

3. The collision between the victim and the interior of the automobile accounts for approximately one third of all traffic fatalities. List five safety features which are available in cars to reduce the number of such fatalities. Describe in detail including the science and engineering involved how two of these features work in preventing injury and/or death.

4. (a). Assume that you are driving on highway at 50 miles per hour, your reaction time is 0.8 seconds. Use the attached graphs as models of the systems involved to find the shortest distance you would travel from the time you saw an accident ahead until you were able to bring your car to a complete stop.

(b) What would be the shortest distance if you were travelling at 70 miles per hour?

(c) While 70mph is 40% more than 50mph, the stopping distance at 70mph is_____% more than at 50mph. How do you account for this?

5. Name two ways in which RADAR systems are used in the prevention of vehicle accidents. Describe in detail how one of the systems works to prevent an accident.

## Suggested Answers to Auto Safety quiz

1. Any of the following would be considered as Highway "Booby Traps":
   A. Railroad or highway overpasses.
   B. Highway signs close to the road on wooden posts
   C. Light poles too close to the road
   D. Sharp turns
   E. Railroad crossings
   F. Intersections with timing of the yellow light which does not match the speed limit, width of the intersection or human reaction time.
   G. Lack of stop signs at narrow intersections.

The engineering solutions to these problems are as follows:

A. Impact Attenuators (plastic barrels filled with sand) which are designed to increase the time it takes the vehicle to stop after impact, thereby reducing the force on the vehicle.(F=MV/T)

**B.** Guard rails with front end sunk in the ground to act as an inclined plane.As the car rides up the inclined plane friction between the car and the guard rail brings the car to a gentle stop away from the sign. Or three legged signs with hinged legs that swing out of the way when a car hits any one of them, thereby increasing the time necessary for the car to come to a stop.(F=MV/T) As the time is increased, the force on the car is decreased. Since the sign has three legs, displacing one leg still leaves two legs to support the sign and it does not fall on the car.

**C.** Tall light poles with brighter lights place back from the road. This design solves two problems, it provides more illumination of the road, and is further from the side of the road.

**D.** Warning signs which alert the driver that there is a sharp turn ahead and suggesting a safe speed for the vehicle to travel depending on the radius of the turn. Increase the radius of the turn when possible.

**E.** Appropriate gates, bells and lights depending on the visibility which the driver has as the vehicle approaches the tracks, or an overpass depending on the contours of the land and the expense involved.

**F.** Change timing of the light or change the speed limit in order to decrease the dilemma zone in which the vehicle is too close to the intersection to stop in the time allowed by the yellow light, and too far away to get through the intersection safely in that time at that speed limit. (S=VT) and, ($S=V^2/2a$)

**G.** Install stop signs., possibly in all four directions if necessary.

2. A passive restraint is one in which the occupant does not need to activate.The decision to require passive restraints was an optimization among the constraints of human negligence in fastening his or her own passenger restraint and the increased cost of designing and manufacturing pa 'e restraints as well as the infringement of personal freedom of people to make their own decisions regarding their own safety versus the responsiblity of motorists to the general public. the Examples are automatic seat belts and/or air bags.

An active restraint is one which the occupant must *Activate.* An example is the seat belt or shoulder belt which the occupant must fasten.

3. Safety features which protect the occupant inside the car are:

A. Padded dash board B. Air bags
C. Shoulder Harness D. Collapsible Steering column
E. Recessed door handles F. Reinforced Doors
G. Safety Glass in windshield and windows
H. Head rest
I. Doors which do not spring open on the impact of the crash.

The following minimum information should be included in the detailed description.

A. The framing of the dashboard is designed to collapse easily rather than be crush resistant. This design along with the padding on the dashboard increases the time between original contact and the actual stopping of the movement of the part of the body that hits e dashboard. Since F=MV/T if the time is increased, the force is decreased.

B. The air bag is inflated by nitrogen gas which is generated when an electric spark ignites sodium azide. The electric spark is triggered by a small weight which continues to move forward when the car stops suddenly. The weight is restrained from moving by a spring which is designed to allow contact if the sudden stop occurs if speed difference between the car and the object it hits is 15mph or greater. The air bag increases the time necessary for the passenger to come to a stop thereby decreasing the force.(F=MV/T)

C. The shoulder harness holds the occupant back so that her/his body slows down at the same rate as the car and therefore does not come in contact with the interior of the car.

D. Collapsible steering column telescopes its various sections into each other, this increases the time between the impact and the time the driver comes to a stop. F=MV/T

E. Recessed door handles prevent to occupant from hitting the handle a n becoming impaled on it.

F. Reinforced doors have horizontal girders inside the door shell, these prevent the other car or the tree or pole from coming through into the occupant compartment.

G. Safety Glass does not splinter because it is actually a sandwich of two pieces of glass with a strong plastic material in between. W h e r the glass is stressed to the breaking point the plastic is still intact. Since they are glued to each other the shattered glass pieces still adhere to the plastic.

H. The head rest (when properly adjusted) prevents the head from snapping back when the car is hit from the rear.

I. All doors have a double latch system. If the door begins to open on impact the second latch catches and prevents the opening.

**4.**(a) At 50 mph the car goes 60 feet during the time it takes you(0.8 sec) to put your foot on the brake.

After you put your foot on the brake the car travels another 200 feet. The total distance traveled is 260 feet.

(b) At 70mph the car goes 83 feet before you put your foot on the brake. After you put your foot on the brake the car travels an additional 410 feet before it stops. The total distance traveled is 493 feet.

(c) 493 feet is 90% more than 260 feet This seemingly excessive distance is due to the fact that stopping distance varies with the square of the velocity for any constant acceleration.( $S=V^2/2a$)

**5.** Radar is used to prevent accidents by alerting the highway police that a car is speeding. If a large number of 'RADAR TRAPS' are known to be set up on a highway fewer drivers will speed thereby reducing auto injuries and death.

Radar is also used to prevent tailgating accidents by alerting the driver that he or she is approaching the car in front at a dangerous rate.

Both systems use Doppler RADAR. Doppler radar works on the principle that if the "target" at which the radar is aimed is moving with respect to the transmitter that is sending the radar signal the returning signal will be at a different frequency than that which was transmitted. Knowing the original frequency and the speed at which the radar signal travel and applying the difference in frequencies the difference in speed of the two vehicles can be calculated by the built in computer.

In the case of the police radar another computer in the police vehicle calculates the speed of the target by adding or subtracting the speeds of the target vehicle and the police car.In the case of the collision avoidance radar, a light flashes to indicate that the car is approaching at an unsafe rate. If there is no response by the driver a tone sounds ; if there is still no response the cars brakes are engaged automatically.

# AUTO SAFETY

## TEACHER MATERIALS

### SPECIAL SECTION.

The following pages T13-T17 can be used for special class discussion and/or home Assignments.

### MATRIX FOR CATEGORIZING AUTO SAFETY TECHNIQUES

T-13 is a matrix for categorizing auto safety techniques. Students may use the matrix to develop their own form for taking notes during discussions of the topics. They might use the boxes formed under Technological fixes as inspiration for designing their own Technological fixes. You might use the matrix as a guide for planning class and laboratory lessons.

### AUTO SAFETY BIBLIOGRAPHY

T14&T15 Contain lists of articles and books which told the auto safety story in the 1980's. Students can be assigned to look for these articles listed in the bibliography and through search of the internet and current articles for discussions of the same topics. Then should be able to develop an historical perspective on how the topic of Auto Safety has developed in the time elapsed. For example in the Air Bag section there is an article in Ward's Auto World , September 1986 about Nader saying that dealers do not brag about air bags. How does that compare with the present situation? If there has been a change, what brought it about?

### TRANSPARENCIES

T-16 & T-17 Are masters from which you may make transparencies for use in class discussions. Students might relate reasons for accidents which they have used or which they know their friends have used.

The "Is it a Problem?" transparency demonstrates how the reading public becomes immune to shock when a "shocking" situation becomes an everyday situation. It also demonstrates the concern about a single catastrophe that claims many lives compared with many smaller catastrophes each claiming one or two lives. Also, check the statistics to compare 1989 with today.

MATRIX FOR CATEGORIZING AUTO SAFETY TECHNIQUES

| | Methods/Causes | Technological Fixes | Laws and Regulations | Education Programs | Purpose |
|---|---|---|---|---|---|
| PRE COLLISION | Drunken Drivers | | | | PREVENT ACCIDENTS |
| | Poor Drivers | | | | |
| | Unsafe Cars and Components | | | | |
| | Poorly Designed Road Systems | | | | |
| POST COLLISION | Primary Crash | | | | REDUCE SEVERITY |
| | Secondary Crash | | | | |
| | Emergency Medical System Capability | | | | |

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# "IT HAPPENED THIS WAY"

The Following are actual statements made by drivers following accidents.

The guy was all over the road, I had to swerve a number of times before I hit him.

I pulled away from the side of the road, glanced at my mother-in-law and headed over the enbankment.

To avoid hitting the bumper of the car in front, I struck the pedestrian.

Coming home, I drove into the wrong house and collided with a tree I don't have.

I told the police that I was not injured but on removing my hat, I found that I had a fractured skull.

The pedestrian had no idea which direction to go, so I ran over him.

An invisible car came out of nowhere, struck my vehicle, and vanished

## AUTO SAFETY:

### Is it a problem?

112 People Killed in Plane Crash 7/19/89

122 People killed in Auto Accidents 7/19/89

122 People killed in Auto Accidents 7/18/89

122 People Killed in Auto Accidents 7/17/89

122 People Killed in Auto Accidents 7/16/89

" " " " " "

ETC., ETC.,ETC., =44530 killed by auto in 1989

Why is there more coverage for one plane crash one day than for a greater number of people killed every day by Auto Crashes?

=

WHAT IS THE DISEASE WHICH WAS

ESSENTIALLY NON-EXISTANT IN 1900 BUT NOW

KILLS OVER 40,000 PEOPLE IN THE U. S. EVERY

YEAR?

# PHYSICS CONCEPTS

$F=ma$

$a=v/t$

$F=mv/t$

---

$M_1V_1=M_2V_2$

---

$$S=\frac{GT^2}{2}$$

---

# AUTO SAFETY

E. J. Piel
Suny, Stonybrook

# CHAPTER 1

## AUTO SAFETY - INTRODUCTION

This is part of an STS course from which you should (1) learn about the importance of science and technology to you as a person and to you as a citizen - a member of society - and (2) learn about the links between science, technology and society: how each affects the others. There is no doubt that this is important to you: whether you are a driver, a passenger or a pedestrian, auto safety will concern you throughout your life. The more you know about it, the better your chances of living a long life rather than a short, crippled one.

Auto safety has many aspects, all of which involve more or less science, more or less technology, and all of which have social dimensions. It is not just a question of fastening your seat belt and driving carefully.

First, there is you the driver (or the passenger or the pedestrian)

Then there is you and the auto.

Then there is you and the auto and the road system.

And then there is you and the auto and the road system and all the regulations and laws that control road transportation.

We are not going to investigate every aspect of this huge and complicated technology; that would take too long. But we are going to explore some aspects of each of these headings.

At the end of this part of the course you should

(1) improve your chances of living longer with all your limbs and organs in good working order,

(2) improve the chances of your passengers, pedestrians, and other drivers, living longer with all their limbs and organs in good working order,

(3) understand something of the scientific principles and the technology of autos and of road transport, and

(4) be able to take an informed part in debates on matters affecting auto safety at local and national levels.

Let's start by considering what could be called a twentieth century epidemic.

A TWENTIETH CENTURY EPIDEMIC

What if we were faced with a disease that

(1) was unheard of 100 years ago,

(2) killed almost 50,000 people a year,

(3) killed two and a half times as many males as females between the ages of 15 and 28 (Figure 1),

(4) had well-known symptoms, and

(5) could be reduced in severity if individuals, governments, and corporations took action?

We would be alarmed. We would expect magazines and newspapers to run articles about its causes and possible cures. We would expect schools to warn their students about it and tell them how to avoid it. We would expect citizens' groups to lobby the Congress for action.

But we seldom think of auto safety as a problem. If we think of it at all, we see it as someone else's problem. Unless we or someone we know well has just been in an accident, we think we are immune to the "disease."

A typical school assembly hall holds about 1,000 people. How will auto accidents affect them? Of that group about five are almost certain to die in auto accidents in the next ten years

and about 200 will be seriously injured, many of them maimed for life. We seldom think of auto safety in those terms; auto accidents are things that happen to other people, not to ourselves or to our friends. Visualize the frequency of such accidents in another way: every week in the U.S., the number of people killed would fill two 747 Jumbo Jets; the number of seriously injured would fill 80 Jumbo Jets.

About 20 million people are between the ages of 15 and 19 in the United States. Ten thousand people in that age bracket are killed in motor vehicle accidents each year. The chance of anyone in that age range being killed this year is one in 2,000. If a driver or passenger - in any age range - does not wear a seatbelt he or she doubles the risk of being killed. If he or she also drinks before driving, or rides with someone who does, the risk is doubled again. It is estimated that every person in the U.S. can expect to be in an accident once every 10 years.

Look at FIGURE 1 and ask the following questions:

(1) What are three possible explanations for the very high death rates in the youngest age ranges falling off steeply as ages increase?

(2) Why does the rate begin to rise again in the 60-70 year old range?

(3) Why are the death rates so much higher for males than females in the youngest age ranges?

(4) How does the answer to (3) affect your answer to (1)?

Remember that one in every six fatalities is a pedestrian (one in three in urban areas!), but do not assume that they are all innocent victims; pedestrians may cause or contribute to accidents in some way (such as drunkeness or carelessness).

FIGURE 1
MALE VS. FEMALE FATALITIES
CRASHES PER 100 MILLION MILES
BY AGE AND SEX

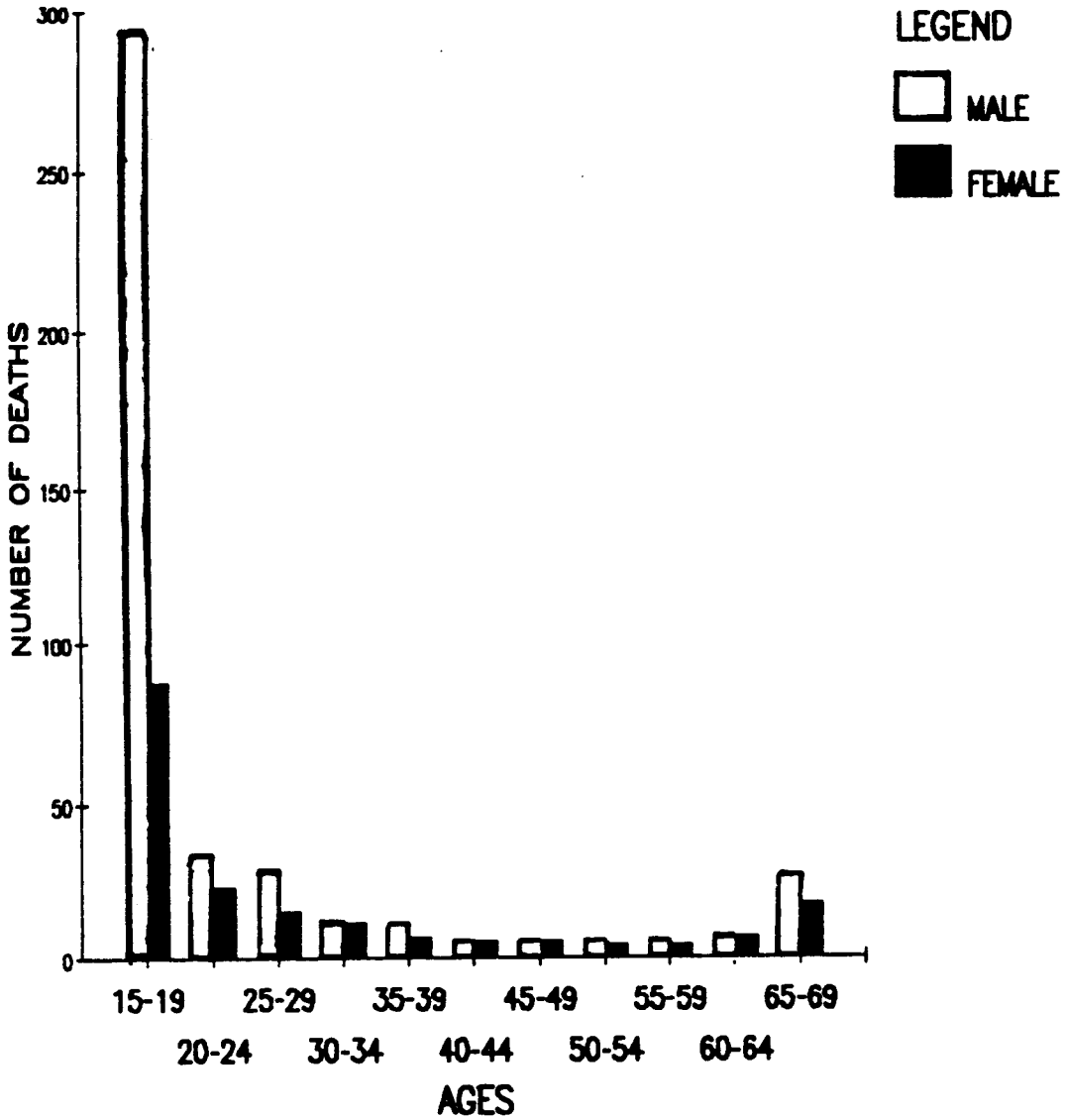


FIGURE 1: This diagram shows the relative rates at which male and female drivers were involved in fatal accidents in passenger vehicles. It is constructed from data found in Accident Facts (1987 Edition) published by the National Safety Council. Notice the very high rates, particularly for male drivers, in the 15–19 age range. Notice also that these rates, and the differences between the sexes, drop off very sharply and continue to fall steadily, rising slightly at the highest ranges.

## ACCIDENTS IN YOUR COMMUNITY

Have you ever been in an accident? Do you know anyone who has? Probably we all have some experience with auto accidents and near accidents, as drivers, passengers, bike riders, pedestrians, or onlookers.

**********

Activity 1. Describe an Accident

Write a description of the accident or accidents you have been in or know about. What happened? How many cars were involved? Was anyone injured? What caused the accident? Write down as many causes as you can think of.

**********

But even though the accident you experienced was frightening, it probably did not make the headlines. Newspaper headlines are usually devoted to government scandals, airplane crashes, earthquakes, international crises, and other unusual events. Accidents happen every day. We accept auto accidents as a normal part of American life. Unless traffic is tied up for hours or the accident kills many people, it is not big news.

**********

Activity 2. Where Accidents Are Reported in Your Local Newspaper

To see for yourselves, scan your local newspaper carefully to find out how many traffic accidents are reported in one week. You probably will not see any on page one, and some may be covered only under "Accident Reports" or "Police Reports."

Set up a page in your note book like the one below to organize your findings for each day:

■ AUTO ACCIDENTS IN THE NEWSPAPER ■

Date_____ Newspaper_____

1. Accident with fatalities Page No

Headline

2. Accidents with no fatalities Page No

Headline

3. Accidents (auto and other)

Headlines on the Front Page

**********

Here is an account of an accident issued by the National Transportation Safety Board Highway (NTAB/HAR-86/03):

> About 7:51 PM on June 21, 1985 a privately owned, 70,000 pound tractor and semi-trailer lost control while descending a steep, 3,439 foot long grade on southbound State Route 59 in downtown Van Buren, Arkansas. The truck collided with the rear of and overrode a station wagon which was stopped at the bottom of the hill. The truck and the station wagon continued 84 feet forward, across an intersection, up a curb, and through a guard rail. They then traveled another 22 feet and struck two commercial buildings. A fire ensued and engulfed both vehicles and three buildings. Both occupants of the truck and the seven occupants of the station wagon were fatally injured.
>
> The National Transportation Safety Board determined that the probable cause of this accident was
>
> (1) The failure of the truck driver to comply with regulatory signs on the very steep grade,
>
> (2) The failure of the truck driver to properly use limited service brakes and transmission for speed control,
>
> (3) The improper adjustment of the vehicle service line,
>
> (4) Inadequate vehicle maintenance,
>
> (5) The truck driver's lack of experience, and
>
> (6) The absence of an adequate surveillance and enforcement program for the trucking system.

In summary, the accident was caused by the driver, the vehicle , the road, and the regulatory system. Because this accident was so spectacular, killed so many people, and caused a big fire, it probably made the headlines.

## THE HISTORY OF AUTO SAFETY

The very first U. S. motor fatality on record occurred in September 1890 in New York City. While assisting a woman to alight from a trolley, H. H. Bliss was struck by a passing car and died the following day. Since 1890, the number of motor vehicles has increased and so have accidents. In 1900, only 8,000 cars were registered in the whole United States. Automobiles were considered unreliable (compared to horses); manufacturing facilities were limited; and consumers were dubious about the utility of this radical form of transport. Until 1910-12, the automotive industry was concerned mainly with developing a product that at least would operate.

As cars improved, so did the roads. The driver of a 1908 Packard jolting down a dirt road at 20 miles per hour traveled only 23 feet between the time he saw the cows grazing in the road and his foot hit the brake 0.8 second later. The accidents that took place were usually at a slow speed and resulted in few fatalities. Improved cars and improved roads permitted greater speed. Fatalities from auto accidents increased, and only gradually did road design standards, vehicle design, and regulations catch up with the need for them.

The average number of traffic deaths per year between 1913 and 1917 was 6,800. That amounted to 6.8 per 100,000 people, 23.8

per 10,000 motor vehicles registered, and we do not know how many deaths per million vehicle miles. We have no records of how many miles people drove per year for that period. In 1930, the total deaths had risen to 31,200: 26.7 per 100,000 population, 12.4 per 10,000 motor vehicles and 16.0 per 100 million vehicle miles.

By 1950, traffic fatalities had grown to 34,763 for the year: 23.0 per 100,000 population, 7.2 per 10,000 cars registered and 7.6 per 100 million vehicle miles driven during that year.

In 1986, fatalities reached 47,900 for the year, which translated to about 19.9 per 100,000 people in the country, 2.63 per 10,000 registered automobiles, and 2.57 per 100 million miles driven.

**********
Activity 3. <u>The Accident Rate That Might Have Been!</u>

Notice that the fatalities per 100,000 people, per 10,000 registered automobiles, and per 100 million miles driven all went down from 1930 on. What are the possible explanations for this improvement? What would the number of deaths have been in 1986 if there had been no improvement since 1930?
**********

Although, as we have seen the situation might have been worse, nonetheless 47,900 deaths is a lot for only one year. For the whole period 1900 to 1985, 2,425,358 people were killed in motor vehicle accidents. In all the wars between 1775 and 1985, less than half that number of Americans were killed: 1,177,936.

FIGURE 2
WAR DEATHS VS. AUTO DEATHS

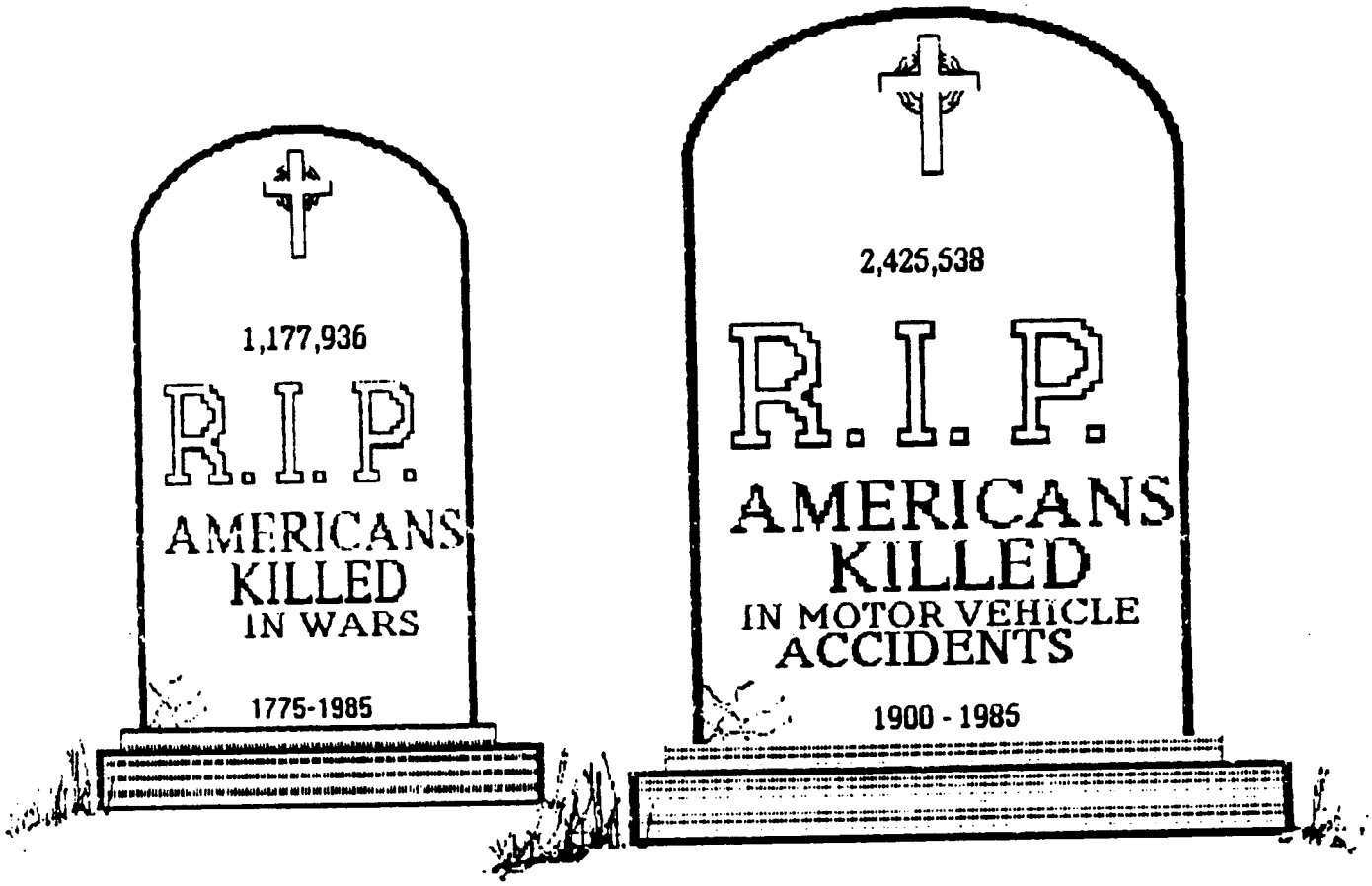


FIGURE 2: In all the wars in which the U.S. was involved from 1775 until 1985, the total American deaths were less than half the deaths in motor vehicle accidents of all kinds between 1900 and 1985. The average deaths per year by motor accident are five times greater than by war.

## HOW GREAT A PROBLEM IS AUTO SAFETY?

To understand the magnitude of the problem, we must look at the statistics carefully. For each year since 1913, Table 1 (National Safety Council statistics) shows the total deaths, deaths per 100,000 population, the deaths per 10,000 motor vehicles, and the deaths per 100,000 vehicles miles.

TABLE 1: MOTOR-VEHICLE DEATHS AND RATES, 1913 - 1986

| Year | No. of Deaths | No. of vehicles (millions) | Vehicle Miles (billions) | No. of Drivers (millions) | Death Rates | | |
|---|---|---|---|---|---|---|---|
| | | | | | Per 10,000 Motor Vehicles | Per 100,000,000 Vehicle Miles | Per 100,000 Population |
| 1913 | 4,200 | 1.3 | (a) | 2.0 | 33.38 | (a) | 4.4 |
| 1918 | 10,700 | 6.2 | (a) | 9.0 | 17.37 | (a) | 10.3 |
| 1923 | 18,400 | 15.1 | 85 | 22.0 | 12.18 | 21.65 | 16.5 |
| 1928 | 28,000 | 24.7 | 173 | 37.0 | 11.34 | 16.18 | 23.4 |
| 1933 | 31,363 | 24.2 | 201 | 35.0 | 12.96 | 15.60 | 25.0 |
| 1938 | 32,582 | 29.8 | 271 | 44.0 | 10.93 | 12.02 | 25.1 |
| 1943 | 23,823 | 30.9 | 208 | 46.0 | 7.71 | 11.44 | 17.8 |
| 1948 | 32,259 | 41.1 | 398 | 55.0 | 7.85 | 8.11 | 22.1 |
| 1953 | 37,956 | 56.3 | 544 | 69.9 | 6.74 | 6.97 | 24.0 |
| 1958 | 36,981 | 68.8 | 665 | 81.5 | 5.37 | 5.56 | 21.3 |
| 1963 | 43,564 | 83.5 | 805 | 93.7 | 5.22 | 5.41 | 23.1 |
| 1968 | 54,862 | 103.1 | 1,016 | 105.4 | 5.32 | 5.40 | 27.5 |
| 1973 | 55,511 | 122.3 | 1,268 | 118.4 | 4.60 | 4.43 | 26.9 |
| 1978 | 52,411 | 153.6 | 1,548 | 140.8 | 3.41 | 3.39 | 23.6 |
| 1983 | 44,452 | 169.4 | 1,657 | 154.2 | 2.62 | 2.68 | 19.0 |
| 1984 | 46,263 | 171.8 | 1,718 | 155.4 | 2.69 | 2.69 | 19.6 |
| 1985 | 45,600 | 177.1 | 1,775 | 156.9 | 2.57 | 2.57 | 19.1 |
| 1986 | 47,900 | 181.9 | 1,861 | 158.6 | 2.63 | 2.57 | 19.9 |
| 1976-86 | +2% | +27% | +32 % | +18% | -20% | -23% | -8% |
| 1985-86 | +5% | +3% | +5 % | +1% | +2% | 0% | +4% |

Source, Deaths from National Center for Health Statistics except 1985 (revised) and 1986 (preliminary), which are National Safety Council estimates based on data from state traffic authorities.
a Mileage data inadequate prior to 1923.

If we look only at the increase in fatalities due to auto accidents per year, we see a constant and alarming growth in the number of deaths, an "epidemic." However, as the population increases it is likely that the number of deaths from any single cause will increase. In the end, everyone dies of something. Only deaths due to diseases to which we have found a cure, like polio or tuberculosis, will decline or vanish. The question is: has the death rate in relation to auto and road usage increased or decreased?

To be scientific, we must consider auto fatalities in light of some relevant factor: all other causes of death, the total population, the total number of motor vehicles on the road, or the total number of miles traveled by the whole population.

**FIGURE 3**
**NUMBER OF AUTO FATALITIES PER YEAR**
**1913 - 1986**

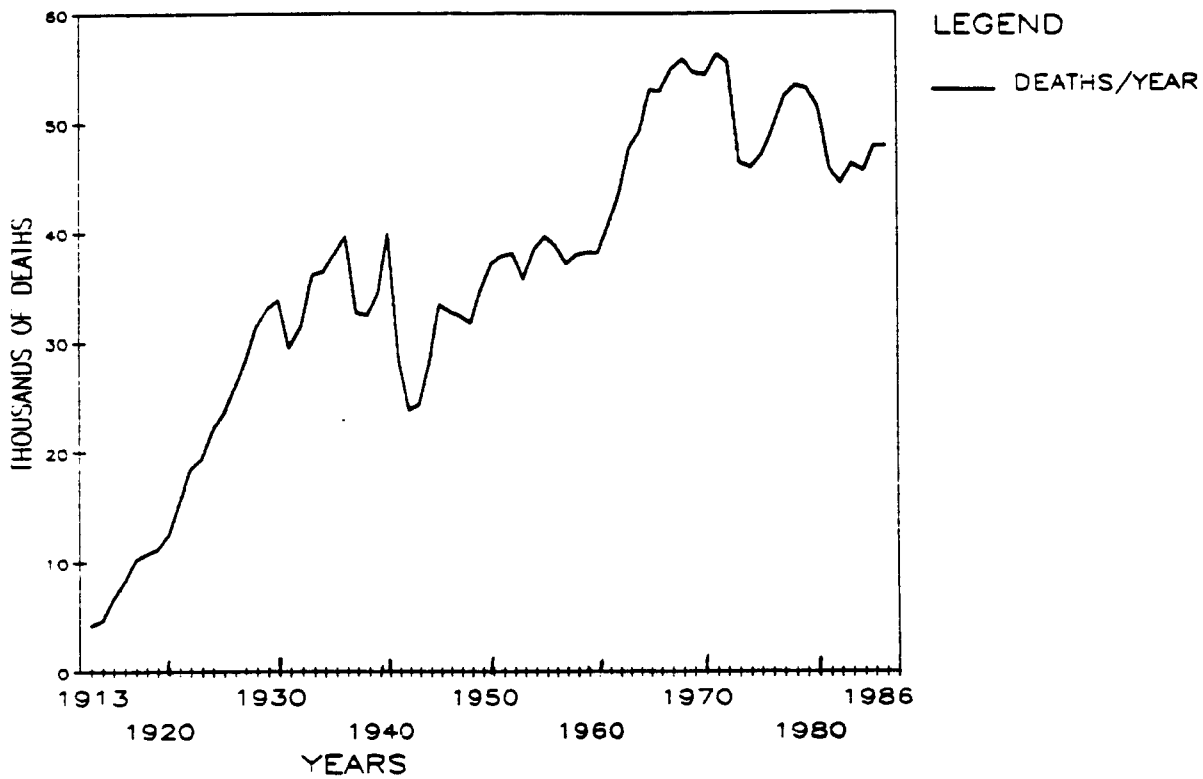


FIGURE 3: This graph shows the number of deaths in motor-vehicle accidents in the U.S. from 1913 to 1986. The general tendency has been for the death rate to increase as the number of vehicles has increased, the number and variety of drivers has increased and the number of vehicle miles has increased, but there are very marked variations from that tendency.

FIGURE 4
AUTO FATALITIES PER 100,000 PEOPLE
1913 - 1986

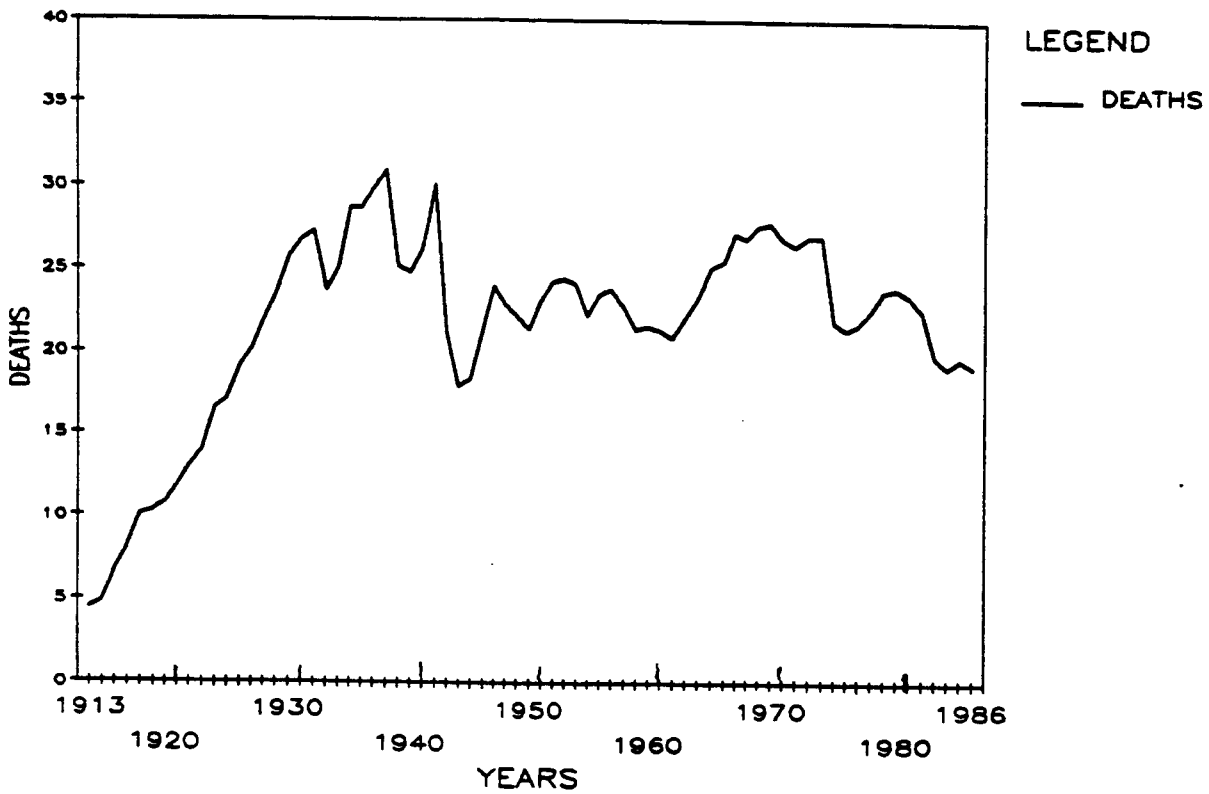


FIGURE 4: This graph shows how the upward tendency is arrested about 1939-1940, when the increase in population is taken into account, and is followed by a slow decline.

FIGURE 5
AUTO FATALITIES PER 10,000 REGISTERED CARS
1913 - 1986

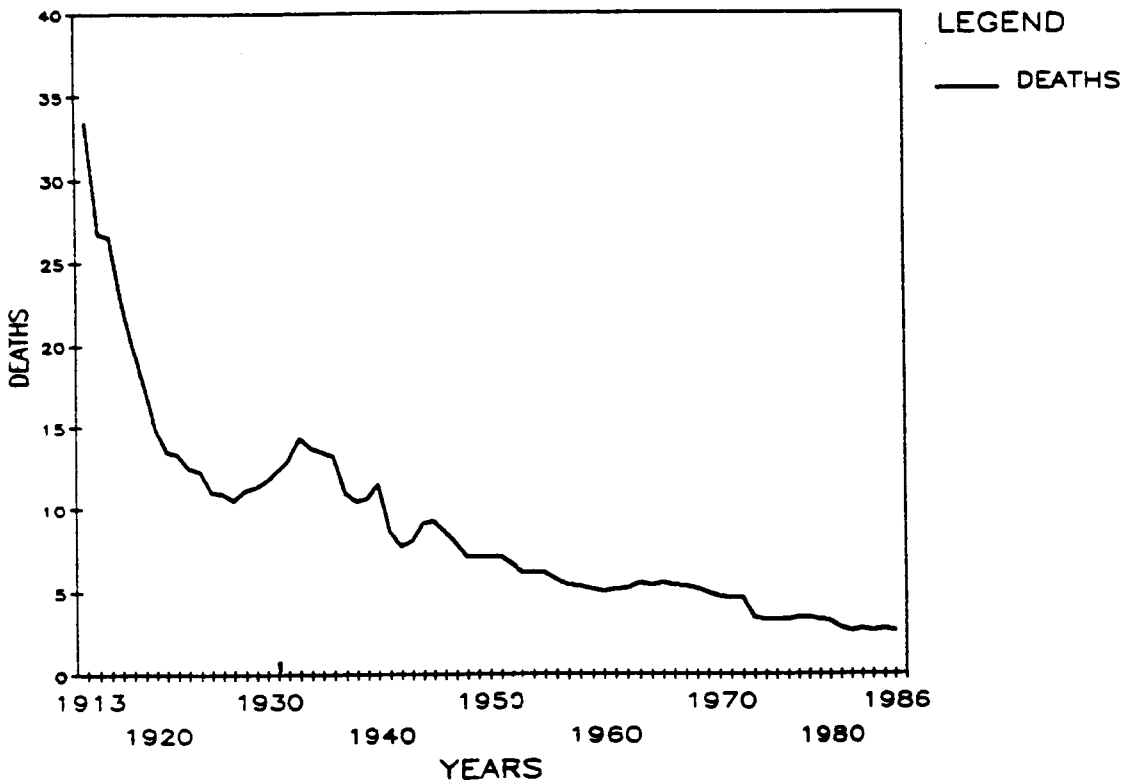


FIGURE 5: Here we have taken into account the number of motor vehicles on the roads and how the death-rate shows a marked improvement to 1926, some ups and downs in the late 20s and 30s, followed by a slow, steady improvement to the present.

FIGURE 6
AUTO FATALITIES PER 100 MILLION MILES TRAVELED
1913 - 1986

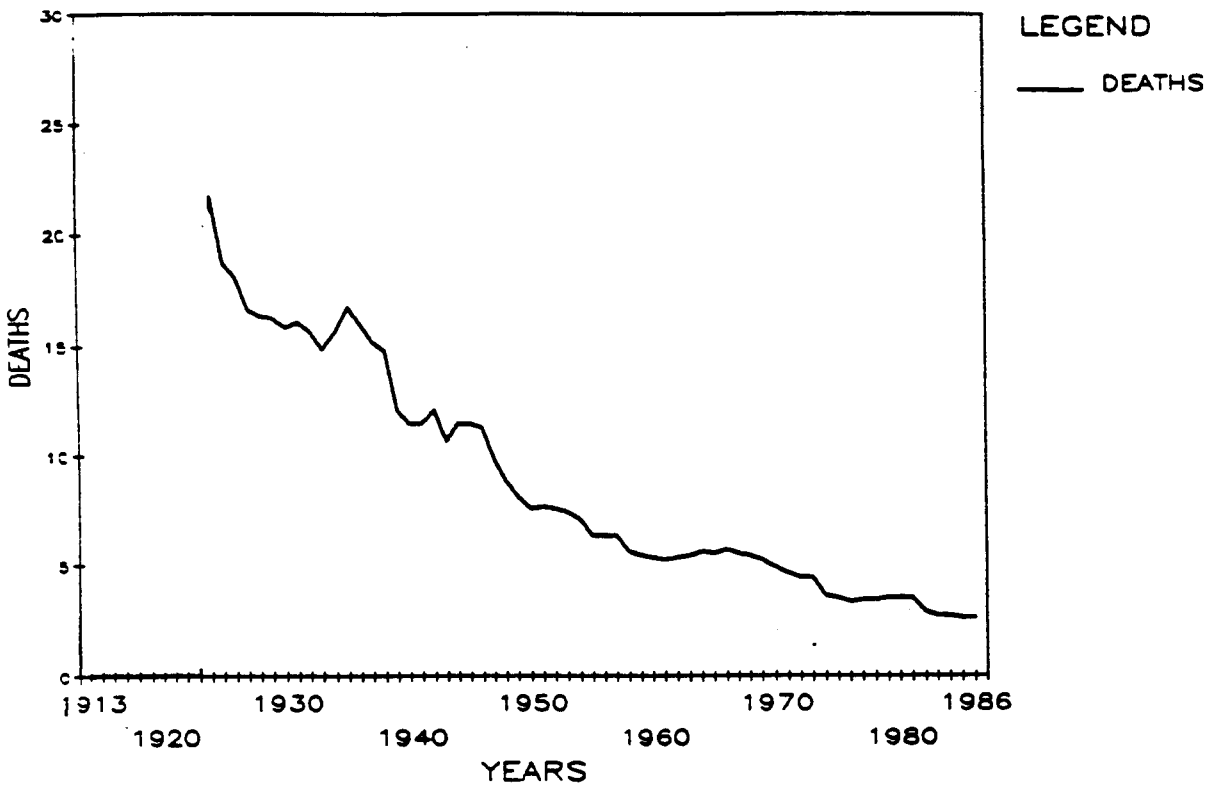


FIGURE 6: This shows a nearly steady improvement in death rates since these figures were first collected in 1923, taking into account the increase in motor-vehicle use. Many factors have contributed to this changed death rate, some positively and some negatively: many more milses of paved roads, improved vehicle design, improved highway engineering, freeways, increased vehicle speeds, speed limits, alcohol and drug usage, the introduction of driving tests ... and more.

What could be the reasons for the changes in the graphs? In particular what could be the causes of the dips and peaks?

Looking at the graphs we can see that although the total number of deaths has risen every year, they have declined dramatically in respect to the number of motor vehicles and in respect to the number of vehicle miles driven per year.

These declines indicate that we have found some "cures" to the "disease" that work, though we are far from eliminating motor vehicle accidents altogether as a cause of death.

Do you think that would be possible? What measures help to avoid motor vehicle accidents? What further measures would be effective? What can we change about drivers, automobiles, roads, and regulations to prevent accidents and to protect people in accidents?

SUMMARY

**In this chapter you have learned:**

(1) that auto accidents are a major cause of premature death and of serious injury in the U.S., particularly among the very young and more particularly among very young males.

(2) that during this century the number of accidents has risen but the rate of accidents per 100 million miles driven has decreased very significantly.

(3) that despite improvement in accident rate, the problem is still very complex and large, a jig-saw puzzle of cause and effect.

**In the next chapter** you are going to start looking at one of the pieces in the jig-saw: the person, in particular the driver.

## CHAPTER TWO

## PEOPLE CAUSING ACCIDENTS

The accident report in Chapter 1 blamed the vehicle (the brakes), the road (a steep hill leading directly to an intersection in a town), a guard rail (which did not hold), the driver (failure to comply with signs, failure to use brakes properly, lack of experience), and the regulatory system (absence of an adequate surveillance and enforcement program for the trucking system).

The three criticisms of the truck driver are typical of comments on accident reports about driver behavior. Some of the most common driver faults follow:

* Failure to comply with regulations
    - Speeding
    - Failure to yield the right-of-way
    - Driving under the influence of drugs or alcohol
    - Tailgating
* Lack of Experience
    - Running the red light
    - Tailgating
    - Making improper turns
    - Drifting from lane to lane
    - Inattention - tuning the radio, talking, dozing-off
    - Unfamiliarity with the laws of motion

FIGURE 7
ACCIDENTS INVOLVING IMPROPER DRIVING
1986 DATA FOR ALL ACCIDENTS

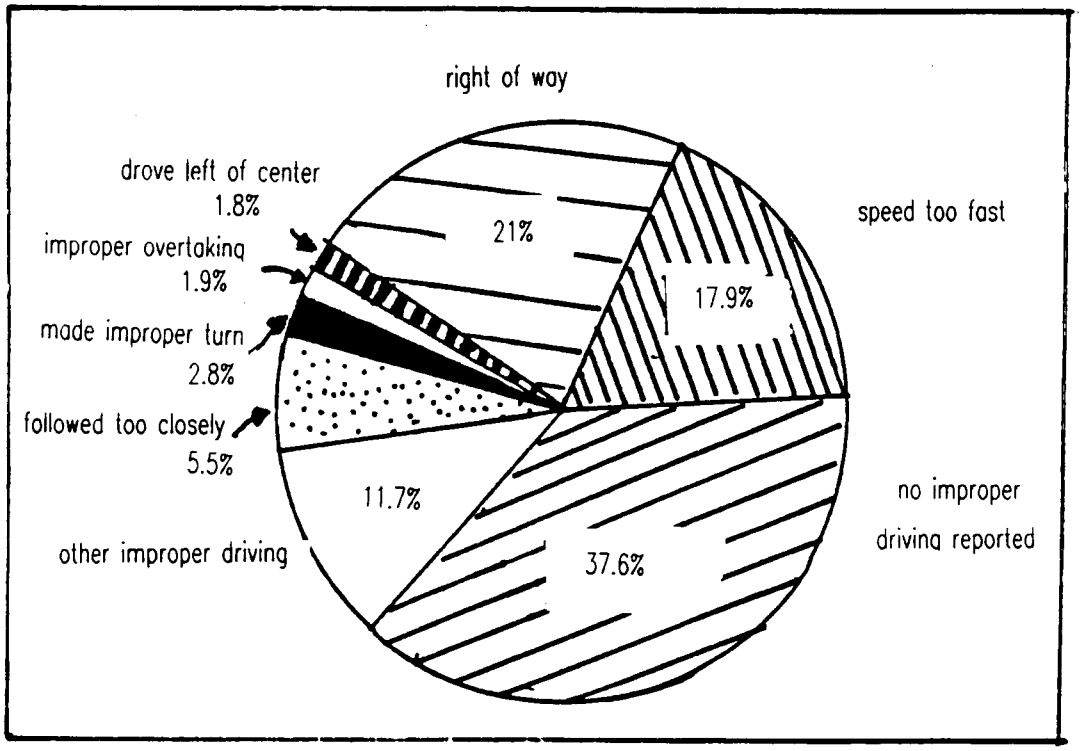


FIGURE 7: Accidents involving improper driving (shaded area shows percentage of accidents in which improper driving was reported in 1986).

## FAILURE TO COMPLY WITH REGULATIONS

### SPEEDING

Eighteen percent of the accidents in which improper driving was reported involved speeding (Figure 7). More than 95 percent of all drivers over 25 admit to speeding at least once in their lives. Speeding can be going 35 mph in a 25 mph zone as well as going 75 mph in a 55 mph zone. One reason drivers give for speeding is to save time. Another reason they do not often give is for the thrill.

FIGURE 8
DISTANCE TRAVELED IN DIFFERENT TIMES FOR SPEEDS UP TO 90 MPH

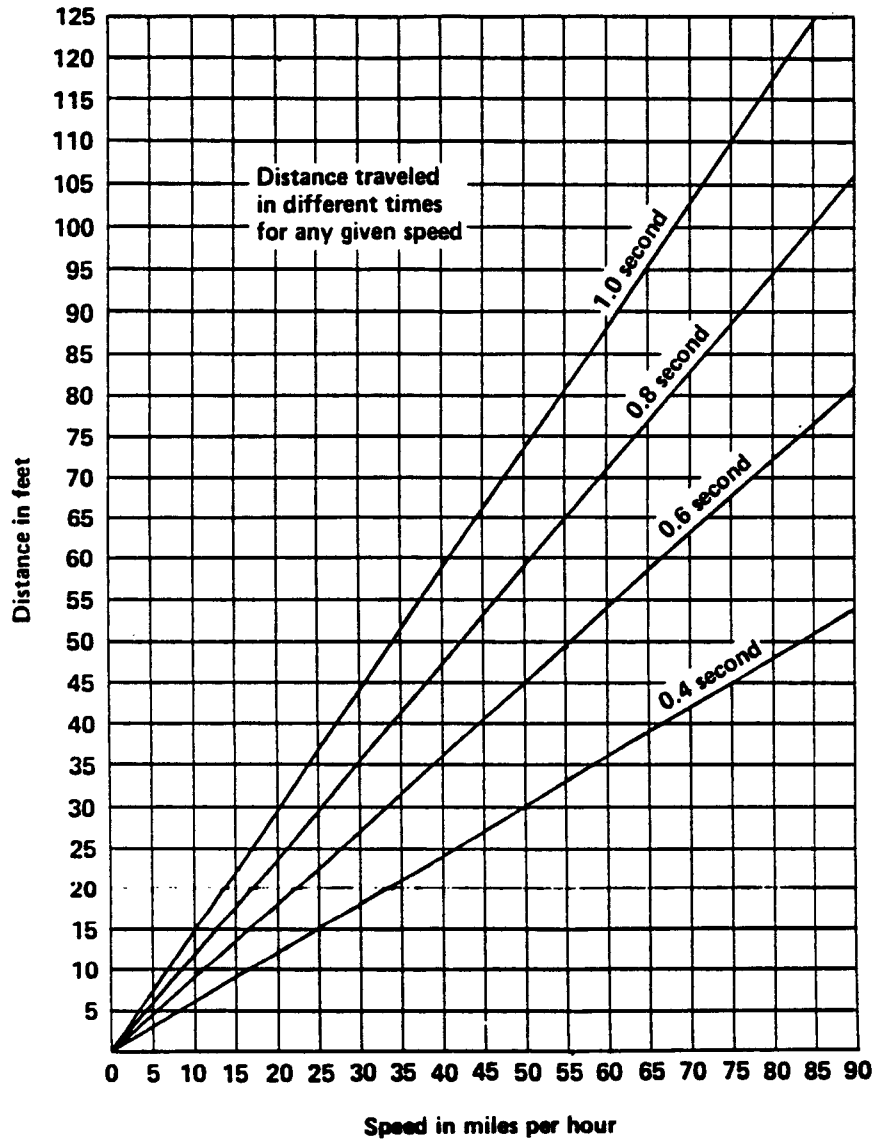


FIGURE 8: Distance travelled in different times for speeds up to 90 mph.

**FIGURE 9**
**STOPPING DISTANCE VS. SPEED FOR DECELERATION OF 13 FT./SEC$^2$**

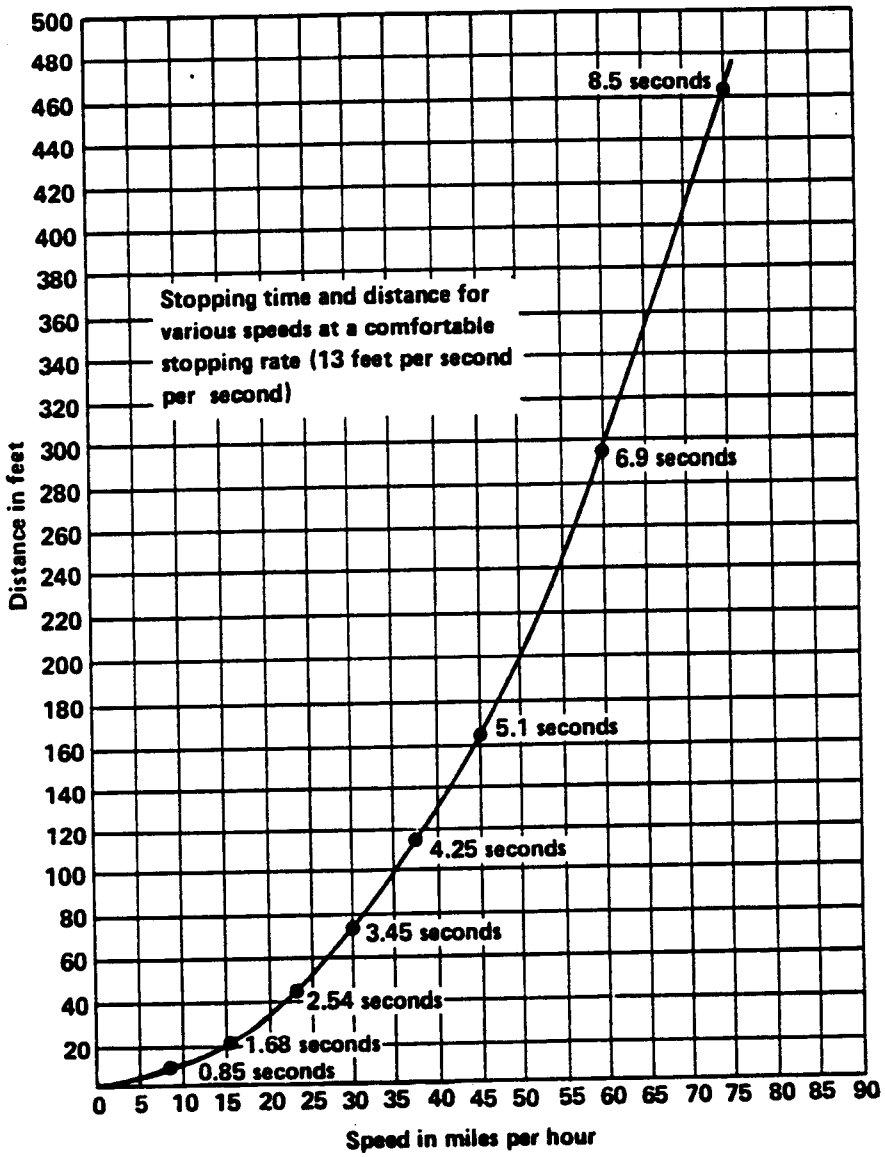


FIGURE 9: Stopping distance versus speed for a deceleration of 13 feet/sec$^2$

Figures 8 and 9 show how far cars traveling at different speeds go after the driver sees an emergency: both the distance before the brakes are used and distance after. It is easy to see why speeding causes accidents. A car going 55 mph will travel about 65 feet in the 0.8 seconds it takes for the driver to take his or her foot off the accelerator and slam it down on the brake pedal. The car will travel another 152 feet at a deceleration rate of 21 ft./sec./sec. before stopping, for a total of 207 feet.

At 65 mph the car will travel 71 feet during the driver's reaction time and 215 feet during braking for a total of 287 feet (almost the length of a football field). At 75 mph the reaction distance is 88 feet and the braking distance is 288 feet for a total of 376 feet.

Notice that for an additional 10 mph from 55 mph to 65 mph the reaction distance increases by 11 feet and from 65 mph to 75 mph, the reaction distance increases the same amount again (11 feet). This is known as a linear growth pattern. For every 10 mph, if the reaction time is the same 0.8 seconds, the car goes 11 feet. A graph of speed vs. distance shows straight lines (linear increases). The distance covered during the reaction time is directly proportional to the speed.

The stopping distance after the brakes are applied is <u>not</u> linear. From 55 mph to 65 mph the braking distance increases by 60 feet. From 65 mph to 75 mph the braking distance increases by 70 feet. This is because the braking distance is not proportional to speed but to the square of the speed.

The deceleration "d" used to produce the graph in Figure 9, is 13 ft./sec$^2$. This is a comfortable stopping rate for cars as they approach a traffic light. In an emergency, however, the stopping rate "d" might be closer to 20 ft./sec.$^2$ Using the equation for distance "S" traveled while slowing down at a constant rate $\mathbf{s = v^2/2d}$ we can calculate stopping distances for various speeds.

$$\mathbf{s = v^2/2d \quad if\ d = 20\ ft./sec^2}$$

| V = Velocity | S = Stopping Distance after brakes applied |
|---|---|
| 15 mph (22 ft./sec) | 12.1 ft. |
| 30 mph (44 ft./sec) | 48.4 ft. |
| 45 mph (66 ft./sec) | 109.0 ft. |
| 60 mph (88 ft./sec) | 194.0 ft. |
| 75 mph (110 ft./sec) | 303.0 ft. |

for 15 mph (or 22 ft./sec) we would calculate as follows:

$$S = V^2/2d = (22 * 22)/(2 * 20) = 12.1 \text{ ft.}$$

**********

Activity 4. <u>How Braking Distance Depends on Velocity</u>

On graph paper plot the distance traveled "S" on the vertical axis against the velocity "V" on the horizontal axis. Connect the points you have plotted. Note the shape of the curve. Once you understand that braking distance varies directly with the square of the velocity, you can understand why 65 or 75 mph is so much more dangerous than 55 mph and why many safety experts opposed increasing the speed limit in some states from 55 to 65 mph.

**********

**FAILURE TO YIELD RIGHT-OF-WAY**

Almost as many accidents occur because drivers fail to yield the right of way as occur because of speeding. Right-of-way accidents occur at stop streets, at intersections with no stop signs, and when drivers make left turns. The solution to right

of way problems is not technological or legislative. The rules concerning right of way are described in driver manuals and knowledge of them is tested in driver examinations. The solution is educational and depends on modifying drivers. Attentiveness and courtesy will insure that you yield the right of way when it it in question. Better to yield the right of way than to have your tombstone read:

**HE WAS RIGHT, DEAD**
**RIGHT AS HE SPED**
**ALONG, BUT HE IS**
**JUST AS DEAD AS**
**IF HE'D BEEN WRONG**

**R RIGHT**
**I IS**
**P PRECARIOUS**

**DRIVING UNDER THE INFLUENCE - DRIVING WHILE IMPAIRED**

Because of our advanced highway design, guard rails, and highway signs, we have one of the safest highway systems in the world. BUT the proportion of our accidents that are alcohol related is the highest in the world.

* 250,000 people have died in alcohol-related vehicle accidents in the past 10 years.
* 25,000 people are killed each year in alcohol-related vehicle accidents

  480 people per week,

  68 people each day,

  2 people during a class period,

  1 person every 21 minutes.
* One million drunk driving collisions occur each year.
* More than half of all fatal highway crashes involving two or more cars are alcohol-related.

* Two out of every three fatal highway crashes are alcohol-related.

* Alcohol-related crashes are the leading cause of death for Americans between the ages of 16 and 24.

* While people between the ages of 16 and 24 account for 22 percent of all drivers, they also account for 44 percent of all night-time fatal alcohol-related crashes.

* 36 percent of all adult pedestrian accidents involve an intoxicated pedestrian.

* Laboratory testing of 317 volunteer on-duty truck drivers showed that 29 percent had used marijuana, cocaine, alcohol, or prescription or non-prescription stimulants. Of the 355 drivers originally asked to participate in the test, 38 refused. If they had also been using one of the substances listed (a reasonable assumption), the users would have amounted to 36 percent of the total.

* In response to a 1984 seven-state survey of 50,000 high school students, nearly half of the male drivers and one-third of the female drivers said they had driven after drinking.

* In a California study of the causes of crashes of 440 male drivers between the ages of 15 and 34 who were killed, investigators found that:

  19 percent were between 15 and 19
  38 percent were between 20 and 24
  26 percent were between 25 and 29
  17 percent were between 30 and 34

  In 43 percent, two or more drugs were detected.
  In 70 percent, alcohol was detected.
  In 37 percent, marijuana was detected.
  In 11 percent, cocaine was detected.

* Approximately 10 percent of U.S. drivers have drinking problems.

* The Department of Transportation sets permissible levels of blood alcohol concentration for various categories of drivers. The BAC allowed for automobile drivers (0.05) is higher than the level permitted for any crew member of an aircraft or for railroad crew members (0.04). A similar regulation is being considered for drivers of trucks and buses.

Drinking and driving is a serious problem at all ages and among all kinds of drivers: of trucks, buses, autos, and motorcycles. Drinking is even a problem for pedestrians.

**ATTACKING THE PROBLEM**

In order to control drunk driving, we must decide what constitutes a drunk driver, devise methods of measuring degrees of drunkenness, and develop systems for preventing or discouraging people who are drunk from driving.

In a series of controlled experiments, drivers drank measured amounts of liquor, beer, or wine and then drove in a test area under controlled conditions. Their reactions to various driving hazards were observed, and they were given blood, balance and coordination tests. The testing group agreed that when blood alcohol concentration (BAC) was greater than 0.05 percent (0.05 percent of a sample of blood was alcohol) the drivers' skills were reduced. When the BAC was 0.10 percent, they considered drivers too drunk to drive.

Alcohol concentration in the blood depends on two factors - how much blood and how much alcohol.

Because large people have more blood in their systems than smaller people, it requires more alcohol to produce a 0.05 percent BAC in a 200 lb. person than in a 100 lb. person. A person with a full stomach (average meal) will take longer to absorb alcohol into the blood stream. Once a given number of ounces of alcohol are in the blood stream, it takes a heavier person less time to get rid of it than a light person. A lighter person must drink less and wait longer before driving. The New

Jersey Department of Transportation furnishes New Jersey motorists cards with their driver's licenses that show that a 100 lb. person must wait six hours before driving after having three drinks while the 200 lb. person must wait only one and a half. Those times bring the BAC to 0.05 percent, a level that is usually not enough to make a person uncoordinated but is enough to give many people a false sense of their extraordinary ability to think and respond quickly. Such a driver can be quite dangerous even though not legally drunk.

**FIGURE 10**
DRUNK DRIVING CHART

NEW JERSEY DIVISION OF MOTOR VEHICLES
Bureau of Alcohol Countermeasures

**POINT·ZERO·FIVE**

**Drinking/Driving Chart**

| BODY WEIGHT | Number of Drinks* Consumed: 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| | Hours to wait after start of drinking and before driving | | | | | |
| 100 lb. | 0 | 3 | 6 | 9½ | 12½ | 15½ |
| 120 lb. | 0 | 2 | 4½ | 7½ | 9½ | 12 |
| 140 lb. | 0 | 1½ | 3½ | 5½ | 8 | 10 |
| 160 lb. | 0 | ½ | 2½ | 4½ | 6½ | 8½ |
| 180 lb. | 0 | 0 | 2 | 3½ | 5½ | 7 |
| 200 lb. | 0 | 0 | 1½ | 3 | 4½ | 6 |
| 220 lb. | 0 | 0 | 1 | 2½ | 3½ | 5½ |

*1 Drink = 86 proof-1½ oz. of whiskey, gin, vodka, etc. 1 bottle beer (12 oz.) 3 oz. wine (20%) or 5 oz. wine (12%).

FIGURE 10: The message of this chart is clear: The only way to reduce the risk of a crash, is by not drinking – or driving – "over point zero five." This wallet card shows the time it takes, depending on your weight, to get rid of the alcohol in your body.

Very few passengers would want to ride in an airplane or train knowing that the pilot or engineer's confidence was inflated by drink. Pilots during World War II said, "There are old pilots and there are bold pilots, but there are no old bold pilots." By bold they meant overconfident.

The U.S. Department of Transportation considers an airline or railroad crew member with a 0.04 percent BAC under the influence of alcohol and therefore unfit for work. Regulations for crews of planes and trains are easier to enforce than they are for the general public.

**PREVENTING OR DISCOURAGING DRUNKEN DRIVING**

Fining people caught driving under the influence or increasing their insurance premiums may not dissuade them from getting behind the wheel drunk in the first place. Regulation against drunk driving are not obeyed very consistently if drivers do not believe that they will be caught or that once caught they will be punished. For years, states have had laws against driving under the influence of alcohol but have not usually enforced them unless a driver was in an accident.

**********

Activity 5. Reducing Drunk Driving

Find out what the penalties are in your area for driving under the influence of alcohol. Find out how other states handle the offense. Does your state have severe penalties? Do you think these penalties are effective or would you recommend other methods?

Contact the local SADD or MADD groups (Students Against Drunk Driving and Mothers Against Drunk Driving) to find out about their local educational programs. Do they also attempt to influence politicians? What measures do they advocate?

Go back to the newspaper reports in 1984 concerning the Uniform Minimum Drinking Age Act, which Congress passed in that year. Was the Congress responding to public pressure? How did the federal government obtain the cooperation of the states? Changing the minimum drinking age has decreased the number of fatal accidents involving teen-agers by 13 percent. Do you think it is reasonable to single out this age group?

Divide the class into teams to research and debate questions about laws designed to prevent drunken driving:

> Is it a violation of 18-year olds' basic rights as citizens to prevent them from buying alcohol?
>
> Is it reasonable to make those who serve alcoholic beverages (bartenders and private individuals) responsible for their customer's or friends' conduct as drivers?
>
> Is it legitimate to prevent beverage companies from advertising alcoholic beverages on radio or television?

**********

TAILGATING

Comedian George Carlin describes two types of drivers:

- The driver who drives too close in front of ya is an "idiot."
- The driver who drives too close behind ya is a "maniac."

For a long time drivers were advised to allow one car length for every 10 mph of speed. Judging car lengths can be difficult. A much simpler way depends on time. The normal reaction time needed to take your foot off the accelerator and put it on the brake is approximately one second.

Your reaction time may be 0.75 seconds if you are concentrating on the car in front of you. If you happen to glance at something along the road, you may not see the brake

lights on the car ahead immediately, and you may take longer than one second to hit the brakes. By using a safety factor of two, you can be reasonably safe. You should plan to stay two seconds behind the car in front of you. If traffic is going 30 mph, you travel 44 feet/sec so you stay 88 feet behind the car in front of you. You judge the distance by counting seconds. As the car in front of you passes some point of reference (a mark on the road, a pole, a sign, or hydrant) start counting "one thousand one, one thousand two ..." If you reach the point of reference before you say "two," you are too close to the car ahead. The distance you should allow between cars varies with the speed: at 45 mph it is 2 sec. * 66 feet/sec. = 132 feet; at 55mph that distance is 2 sec. * 81 ft./sec. = 162 feet. At night and in snowy or rainy weather, you should increase the safety factor to three or four; the number of seconds you count from when the car ahead passes the reference point and when you do should be three or four instead of two. If you follow this rule, you will always be a safe distance behind the car in front. One problem is that the car behind will pass you - and then you will need to calculate your two second interval again. As traffic on the highway slows down, cars normally come closer together, but they should still stay two seconds apart. As traffic speeds up again many drivers wrongly maintain the same distance they did at the slower speed.

SUMMARY:

**In this chapter you have learned:**

(1) that there are many ways in which a driver may cause or help to cause an accident;

(2) that speeding is one of them and the graph of stopping distance against speed should tell you why;

(3) that it is better to be careful than dead: do not tailgate; obey the right-of-way rules, and assume that the other guy won't;

(4) that drink and driving don't mix.

**In the next chapter** you are going to bring the motor vehicle into the discussion, focussing principally on brakes and braking.

# CHAPTER 3

## VEHICLE PROBLEMS: BRAKES

### THE VEHICLE AND THE CRASH

What factors in the design, manufacture, and wear of automobiles, trucks, and buses contribute to accidents? What factors contribute to injury and death in crashes? Table 2 lists some systems in vehicles that can contribute to crashes: the accelerator, the brakes, the controls, the lights, the mirrors, the steering, the tires, the windshields.

Table 2 lists eight different vehicle factors that can cause crashes. Understanding how each of these factors contributes to crashes, knowing the science involved, and understanding how the technology works can help us to make better decisions as we drive, in buying cars, and in deciding on legislative or technological measures that promise to reduce accidents.

TABLE TWO - VEHICLE SYSTEMS THAT CONTRIBUTE TO CRASHES

| VEHICLE SYSTEMS | CAUSES OF CRASH |
|---|---|
| Accelerator | Sticks in open position (runaway)<br>Sticks in closed position (can not speed up) |
| Brakes | Complete failure/brake lock-up<br>Unbalanced braking<br>Brakes fade on hills or upon long use in traffic<br>Tractor trailers sometimes disconnect front brakes |
| Displays and Controls | Driver confusion in emergencies<br>Inattention due to complexity of the entertainment and climate controls |
| Lights | Blinding oncoming cars<br>Brake lights not easily visible<br>Tail lights or brake lights not functioning<br>Need for running lights |
| Mirrors | Rear view mirrors do not give a good view of cars just behind on the passenger side |
| Steering and Wheels | Complete failure (disconnect)<br>Oversteer or understeer<br>Driving too fast for curve<br>Uneven air pressure in tires<br>Worn steering linkages<br>Loosened lug nuts |
| Tires | Complete failure - blowout<br>Smooth tires on wet road<br>Uneven wear causes unsteady steer |
| Windshields | Loss of visibility due to antishatter film clouding up or sun hitting dirt or frost |

We will concentrate on brakes as a vehicle problem. We could equally well have chosen steering, accelerator problems, lights, tires, and human design problems.

BRAKES

Total brake failure, unbalanced brake application, and brake fade all contribute to crashes (Table 2).

What are the brakes supposed to do? How do they do it? Why do they fail? These are the questions we need to answer.

The first question is easy. The brakes are supposed to slow or stop the moving car at a comfortable and safe rate while providing steering control. The other two questions are tougher.

How do brakes work? Brakes work by exerting frictional force on the moving wheels in such a way that they cause equalized friction between all the tires and the road. Ideally, even if some tires have tread and some are bald, the brake system should be able to sense the differences so that the car does not go out of control when the driver steps on the brakes.

What is friction? Why does it vary with different tires and road conditions? Why does the friction between the brake shoe or pad and the wheel change even as the brakes are being applied?

Friction is defined as "the resistance to relative motion (sliding or rolling) of surface bodies in contact." In simpler language this means that if two objects (your hand and the desk top for example) are moved in opposite directions (move your hand across the desk) there will be a resistance to the motion (your hand will feel warm, make noise, or just feel the resistance of the table).

Any time two surfaces move with respect to each other (your hand moves but the desk remains unmoving) and they are in contact with each other, there is friction. The amount of friction (resistance to the motion) depends on the kind of materials that are in contact (ice is more slippery than sandpaper), the total area of contact (your whole hand creates more friction than a single finger), and the force applied to keep the surfaces in contact for a given area (the harder you press your hand down the more friction you will feel).

The amount of friction can be calculated by multiplying the force applied perpendicular to the surface by the coefficient of friction for the two surfaces in contact (friction = force * cf). The coefficient of friction is a number given to the friction between two objects that scientists have determined correct to help predict the friction between the two. In many cases, these coefficients were obtained through experimentation. The coefficient of sliding friction between rubber (tires) and dry concrete is 0.7, while the coefficient of friction of rubber on ice is only 0.07, only a tenth as much. No wonder cars are harder to stop on ice. They are ten times more likely to slide on ice than on dry road.

In a car, the coefficient of friction between the brake pad material and the steel rotor disc or the drum is very high. When the brake pedal is depressed (when you use the brakes), the pads are forced against the drum or rotor of the wheel. This force is increased by the design of the brake system using hydraulics and perhaps a computer controlled system. The harder you press down

on the brake, the harder the brake pads will press against the rotor or drum to stop the car.

The energy the moving car expends against the brakes is changed to thermal energy (heat) and in a short time the brake pad and the rotor or drum get very hot. When the brake pad is hot, its coefficient of friction with the hot metal is much lower than when it is cool, and the brakes fade. Unfortunately, as they fade you tend to push harder on the brake pedal, especially if you are going down a steep hill. Pushing harder makes the brakes hotter (in some cars, the temperature goes as high as 500 degrees Fahrenheit), and the brake pad gets slipperier. As the brakes get hotter, the hydraulic fluid will boil (between 300 and 440 degrees Fahrenheit depending on its type). The end result is a reduction in friction and, therefore, less effective brakes.

Sometimes oil or dirt gets between a brake pad and its rotor or drum and reduces the friction between them; the stopping ability of that brake is then lower than the other three. When the brakes are applied, the friction between the four tires and the road is not equal, and the car swerves.

Road salt can corrode the brake lines (small steel pipes that carry hydraulic fluid under pressure from the master cylinder to the wheels), or a stone may fly up and knock a hole in them. When the brake lines leak, brake fluid is lost, and pressure on the brake pedal has no effect on the brakes. When brakes fail completely, drivers say that the car tends to speed up.

## WHAT CAN BE DONE TO AVOID BRAKE PROBLEMS

Brake fade can usually be avoided. On a steep hill or when you see a problem ahead and you need to stop, pump the brakes instead of applying constant pressure. This does two things: First, it prevents the wheels from stopping completely; contrary to popular belief, friction between the tires and road - the grip - is greater when the wheels are rolling than when they are stopped and skidding. Pumping gives better braking effect and allows the driver to control the direction of the car. Secondly, pumping the brakes reduces the build up of heat and thus reduces the probability of the brakes fading. The technological solution to some brake problems is to fit an antiskid system, found on many cars manufactured after 1980. An antiskid system permits normal application of the brakes as long as the wheels are rotating. If the brakes are applied so forcefully that one wheel or all wheels stop turning, the system overrides the human-applied force and partially releases the brakes so that the wheels continue to rotate just fast enough to prevent their skidding, and that provides maximum control and braking. The original antiskid systems were mechanically controlled; the modern ones are computer controlled. Sensor devices sense the speed of rotation of each wheel and send messages to the control module, which then controls the hydraulic pressure to each wheel to prevent any wheel from stopping completely. When the car is traveling at very slow speeds and, stopping, for example, at a traffic light, the system does permit the wheels to stop.

Although there is no legislation requiring the installation of antiskid systems on all cars, more and more automobile manufacturers are installing such systems, especially on the more expensive models.

BRAKE PROBLEMS WITH BIG TRUCKS

The brake problems automobiles have are magnified in trucks. The larger the truck, the greater the problems. The more sections to the truck, the greater the problems. Tractor-trailers have greater problems than single-unit trucks. Tandem trailer trucks have even greater problems than single trailer trucks. Heavier vehicles require more force (braking capacity) to stop in the same distance from the same speed than do lighter vehicles. The physics law that states this is Newton's Second Law of motion.

Newton's Second Law simply states that "the net force acting on a body is proportional to the mass and the acceleration producing the force." If you push something, you apply a force. A truck's engine pushes it so that it will go. The brakes create a force in the opposite direction that makes it slow down. The heavier the object, the more force is required to give it the same acceleration or the same deceleration.

To stop an object, such as a truck, that is moving you need to apply a force in the opposite direction to its travel. This force comes from the friction between the tires and the road surface. Simply stated, it is harder to stop a larger, heavier vehicle because you will need more powerful brakes.

We can express this law with the following equation:

$$F = ma$$

where F = the force, m = the mass and a = the acceleration (or deceleration in the case of braking)

This explains why large trucks are more difficult to stop than cars. Many trucks have 40 times more mass than a car. This means that they require 40 times the force to stop in the same distance. The heavier the vehicle the more force is required to stop that vehicle.

Unfortunately truck brakes are not 40 times better than car brakes. In most cases trucks take almost twice as long to stop because of their large size. If a truck is following close behind a car that suddenly slams on its brakes, the truck has no way of stopping before it hits the car. Truck brake technology is not 40 times better than car brake technology.

In an emergency, properly applied brakes on most cars provide a deceleration of approximately 21 feet/sec./sec. This will bring the car to a halt from 60 mph in about 185 feet, well within the legal distance. A loaded tractor-trailer under similar conditions takes 250 to 300 feet to stop. Making the danger even more serious is a difference in reaction time between the automobile hydraulic brake system and the truck air brake system. When the brake pedal on a hydraulic brake system is pushed down, the brake pads move against the rotor or drum immediately with no delay. Air brake systems on tractor-trailers have a delay of from 0.3 seconds to 2.5 seconds, depending on how

well the tractor brake system matches the trailer system. This delay increases the stopping distance of a truck going 60 mph by at least 44 feet and by as much as 200 feet.

In 1987, the National Highway Traffic Safety Agency (NHTSA) stated that "efforts to improve truck brake systems shall receive the highest priority." Research should focus on improving braking compatibility between the tractor braking system and the trailer brakes and assuring that brakes stay "reasonably well adjusted" with reliable replacement parts available to replace original equipment.

In 1985, the NHTSA issued a notice of a proposed rule that would modify track air brake standards for straight trucks, buses, and tractor-trailers. The proposed rule would require manufacturers to use smaller diameter tubing in air brake systems. Air brakes do not work on compressed air, they work because normal atmospheric air pressure is applied on one side of a diaphram or piston and a partial vacuum created by the engine is on the other side. Since even a perfect vacuum on one side would only result in a 14.7 lb./sq.in. difference in pressure, the diameter of the pipes involved is a critical factor; the greater the diameter of the pipes, the quicker the vacuum can be created.

While antilocking brake systems have been available for automobiles since before 1980, systems for trucks were still under study in 1987, and the NHTSA was then embarking on a two-year study of antilock systems for trucks.

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Activity 6. Antilock Systems for Trucks

Locate magazine and newspaper articles reporting the results of the studies. Summarize what you find.
**********

Often the findings of such studies result in changes in regulations regarding future manufacture but still leave older vehicles operating with dangerous systems. For example, in 1985, the federal government required all new trucks to be equipped with front wheel brakes but still allowed them to be removed from three axle tractors. In 1987, this ruling was changed to require that all vehicles (trucks and tractors) be required to have front brakes. Because parts for trucks manufactured prior to 1980 would be difficult or impossible to find, pre-1980 tractors were exempted from the regulation. This means that older, less reliable tractors (which are more apt to have other problems that could lead to an accident) are allowed on the highways without front wheel brakes.

## SOLVING BRAKE PROBLEMS WITH TRUCKS

A truck's brakes fading on a downhill grade often causes a runaway situation that is far more serious than with a car. Remember that a truck can weigh as much as 40 times the weight of a car. Regardless of the braking system or the regulations, when truck brakes fade the driver can do little to stop and there are no truck mechanisms that help. Some highways with long hills provide additions to the road shoulder that can be used as emergency stopping systems. These gravel arrester beds are wide sections on the shoulders of highways consisting of gravel of various sizes and of varying depths. These arrester beds have

been very effective at stopping runaway trucks on hills and preventing accidents caused by brakes fading.

However, gravel arrester beds cannot be used to solve the problem of failed or inoperative brakes on cars, buses, trucks, and motorcycles in other settings.

The best solutions we have are to improve materials, design, construction, and inspection. In some states, brake inspection consists of actually driving a car over a device, applying the brakes, and measuring the brake force applied to each wheel and, therefore, the balance. Other states require visual inspection of the brake lines and the lining, pads, rotors, and drums. Any testing program must involve a trade-off between thoroughness and the time and cost needed to do it.

SUMMARY:

**In this Chapter you have learned:**

(1) about frictional forces and about coefficients of friction;

(2) that it takes time to stop - reaction time plus deceleration time;

(3) that it takes more time - much more time - the faster you are going;

(4) that the greater the speed, the greater the stopping distance;

(5) that the greater the weight, the greater the stopping distance; and

(6) that the greater the reaction time (air brakes), the greater the stopping distance.

All of which means that you should

(1) think about your stopping distance when driving, especially if you are driving a truck or a Rolls Royce;

(2) avoid tailgating;

(3) prevent truck drivers from tailgating behind you; and

(4) think twice about stepping out in front of a truck, especially on a rainy day.

Remember that a loaded truck-trailer can take up to 500 feet to stop on a dry road; on a wet road the braking distance will be increased, because the physical laws as they apply to braking operate in the same way for everyone - and that includes you.

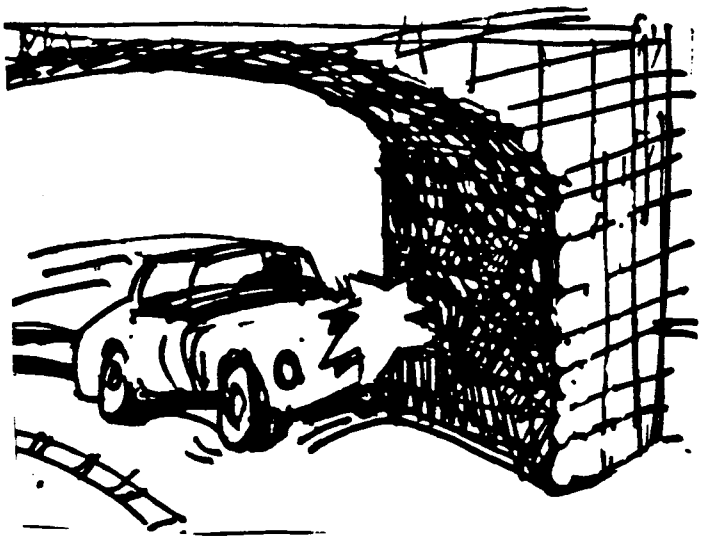
**In the next chapter** you will consider how the road and road equipment can be designed to improve safety.

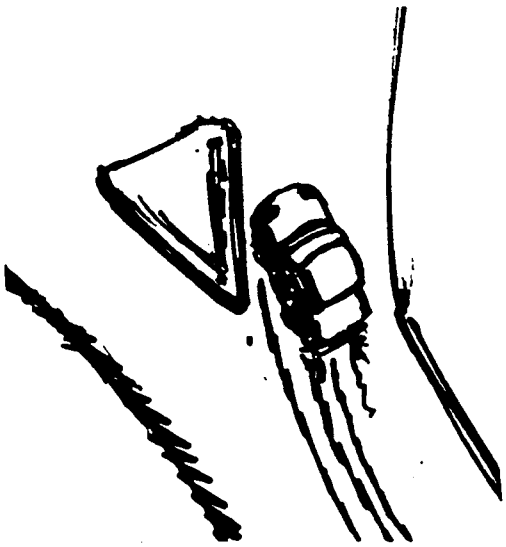
## CHAPTER 4

## HAZARDS ON THE ROAD: DESIGN, SIGNING, AND LIGHTING

Among the road hazards that have been responsible for crashes resulting in injury and death are fence type guard rails, bridge abutments, sharp curves, barriers where roads divide, incorrectly timed traffic lights, and poles or signs close to the road.

FIGURE 11a
ROAD HAZARDS: BRIDGE ABUTMENTS AND ROAD DIVIDERS





To reduce the number of crossroads and therefore the number of intersections requiring traffic lights, highways are often depressed below the surrounding ground level so that local roads can pass over the highway on bridges. These bridges are usually supported by stone or concrete supports or abutments. These abutments and other roadside objects: signs, road dividers, light poles, trees, and so forth, may cause out-of-control cars to stop abruptly. The force which acts on a car causing it to stop is described by Newton's Second Law of Motion:

$$F = md$$

where F = force, m = the mass, and d = deceleration.

If we use the equation of motion found in the box in this chapter, we see that deceleration is equal to the change of velocity divided by the time taken for the velocity to change:

$$d = (V_i - V_f)/t$$

If the car hits an immobile object like the side of a bridge, the car must stop ($V_f = 0$) and this equation becomes

$$a = V_i/t.$$

Substituting this into Newton's Second Law gives us

$$F = m V_i/t.$$

We can now restate Newton's Second Law as "the net force acting on a body is equal to the mass times the change in velocity divided by the time it takes to stop the body's motion."

We can now see that to stop a car of a given mass, going at a set speed, the only way to change the force on the car is by changing the time it takes to stop. If we have more time (t is large), then the force required will be less, and it will

be easier to stop. It the time is short (t is small), then the force required will be greater, and it will be harder to stop.

**********
Activity 7. Cushioning Forces

Show how time relates to force by plotting various forces for a car of mass = 2000 lbs. and velocity = 50 ft/sec for t = .001,
**********

These are the forces on the car. The longer the stopping time, the less the force acting on the car, and therefore the less the car will be damaged.

In the same way, a longer stopping time will cause smaller forces to act on a driver or passenger in the car and therefore lessen the injury to that person.

So for example, a passenger of 200 lbs. mass, traveling at 50 ft/sec, brought to a stop in a collision in 0.1 seconds will experience a force of 100,000 ft lbs/sec$^2$.

To get a feeling for how large that force is we usually compare it with the force of gravity on that person (i.e. his or her weight). The acceleration of anything falling freely under gravity is 32 feet/sec$^2$. So using Newton's Second Law again, the force of gravity (i.e. weight) = mass * acceleration due to gravity, and for a 200 lb. person,

WEIGHT = 200 * 32 = 6,400 ft. lbs./sec.$^2$.

We usually simplify this sort of calculation by calling the gravitational force on a person (his or her weight) 1 G. So the force acting on him or her if stopped from 35 mph in 1/10 second is 100,000/6,400 = 15.6 Gs.

15.6 G's is a pretty hefty force and would cause a lot of injury, internal and external (remember that your internal organs, your heart, lungs, liver, kidneys, stomach, bladder, etc., are also stopped by collisions within the body).

But if the speed had been 70 mph, the collision would have caused a force on the body of 31 Gs.

And if the stopping time from 35 mph had been 1/50 sec, the force would have been about 80 Gs.

And these forces would certainly cause serious injuries, probably fatal.

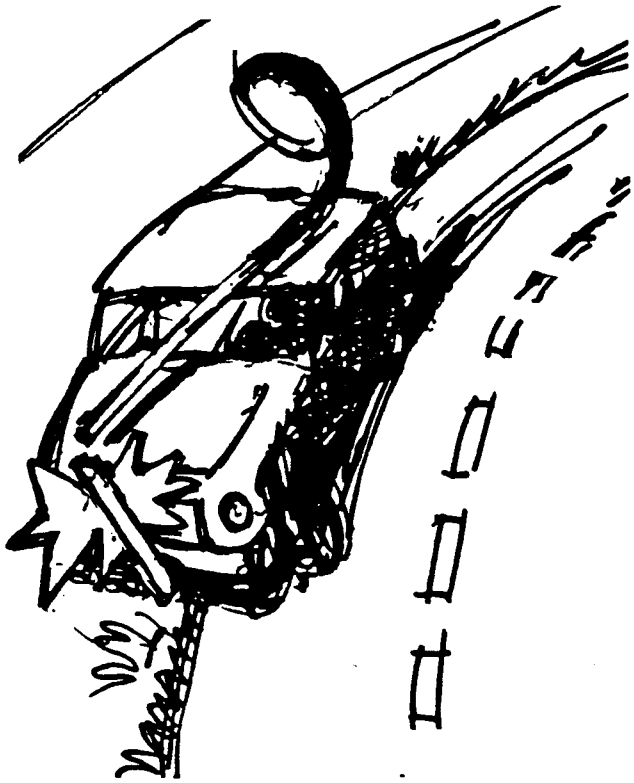
You already have an intuitive feeling for these things. You know from experience that if you catch a fast ball, there is less of a jarring impact (less stopping force) if your hands give (move back) with the ball. If you hold your arms and hands rigid, the ball strikes with more force because it stops in less time. If you use a well-padded glove, the padding also slows down the ball - gives it a longer time to stop and softens the impact.

On many highways, large plastic barrels filled with sand can be seen blocking dangerous obstacles (for example, between off-ramps and the highway). The barrels act like a giant catcher's mitt, increasing the amount of time the car has to stop. This lessens the destructive force on the car and on the people inside it.

SIGNS AND LIGHT POSTS

Signs along the side of the road are often supported by two large wooden vertical posts. If a car runs off the road and hits one of these posts, it can break it off at bumper level. Then the stump of the post may come up through the floor of the car and the sign may fall down on top of it.

FIGURE 11b
ROAD HAZARDS: SIGNS AND LIGHT POSTS



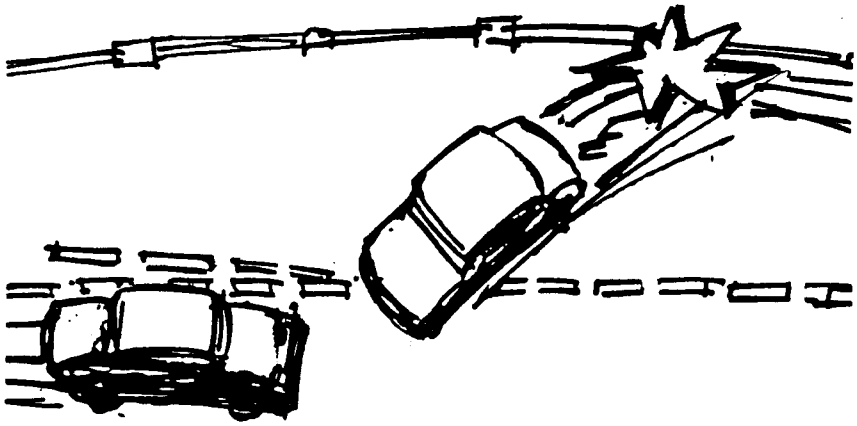
Damage to cars hitting sign posts can be prevented by supporting the sign with three specially designed metal posts. Instead of being sunk into the ground, these posts are bolted to a concrete pier, the top of which is flush with the ground. The posts are attached to the back of the sign, and each post is hinged near the bottom of the sign. When a car hits one of the three posts, the bolts fastening it to the concrete pier at the back are sheared off, the post's base slides out from under the bolts in the front, and the post swings on its hinge away from the car. The sign is still supported by the other two posts. There is essentially no damage to the sign and very little to the car (depending on its original speed).

However, the best solution is to support the sign on an overpass or on a large frame work that stretches completely across the highway and is supported by large metal posts set back a considerable distance from the driving lanes. This eliminates roadside posts altogether. Also, drivers can read signs hung overhead without looking away from the road.

## PREVENTING HEAD-ON CRASHES

Metal guard rails are used to protect signs or to prevent cars from leaving the road where the land drops off suddenly just beyond the road. Such rails will bend on impact, and sometimes even break if they are hit at close to a right angle. Because they can break, such guard rails are not adequate as a protection between two lanes of traffic traveling in opposite directions.

FIGURE 11c
ROAD HAZARDS: GUARD RAILS



Opposing traffic on high speed highways is usually separated by a kind of concrete barrier that was first introduced on New Jersey highways. The New Jersey barrier (Figure 11d) is designed to steer cars back into their own lanes and away from the oncoming traffic. If a car strays out of the driving lane and hits the bottom vertical section of the barrier at a small angle, it will be diverted back into the lane with no damage other than a bruise to the tire. If the angle of impact is a little larger, the tire will roll up the barrier and again be turned to steer the car back into its original lane. Cars following this car or next to it may collide with it. Even so, accidents involving cars traveling in the same direction are usually less serious than head on collisions, and drivers following at a safe distance should be able to avoid such collisions.

FIGURE 11d
THE NEW JERSEY BARRIER

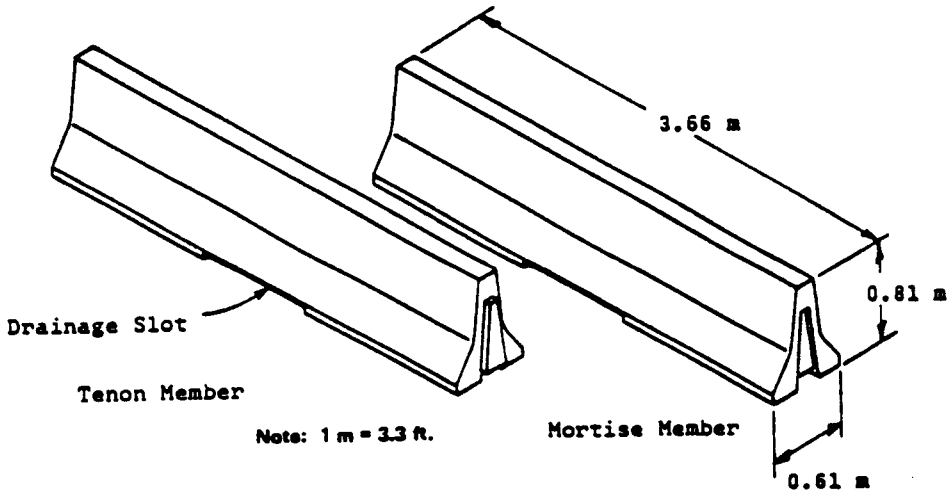
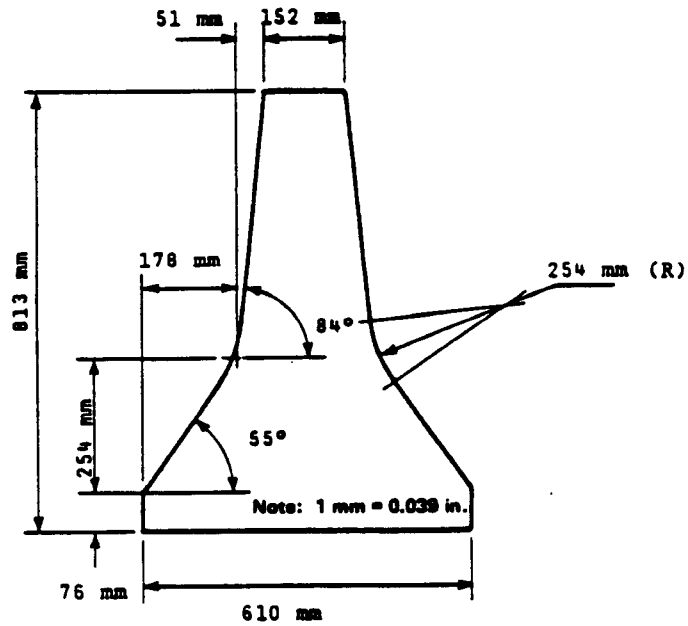



FIGURE 11d: The illustrations above show sections of the New Jersey Barrier and how they fit together. The diagram below shows the cross-section. Each section weighs about 2200 kg. (2 1/4 tons).



SHARP CURVES

Many U.S. roads in use today were originally built in the 18th and 19th centuries for horse-and-buggy traffic. These roads curve sharply to eliminate steep climbs, to avoid large rocks, or to follow a property line. For horse and buggy traffic, the curves avoided obstacles and created no hazard since the horse and buggy did not go very fast. As cars came into use, those old dirt roads were paved and widened. The sharp curves remained. Our discussions of Newton's Second Law dealt with straight line motion only, and deceleration "d" was considered a straight-line rate of change in speed. Deceleration is defined as the rate of change of velocity. However, velocity has two components: quantity, e.g. 45 mph (66 ft./sec.) and direction, (e.g. north).

FIGURE 11e
ROAD HAZARDS: SHARP TURNS

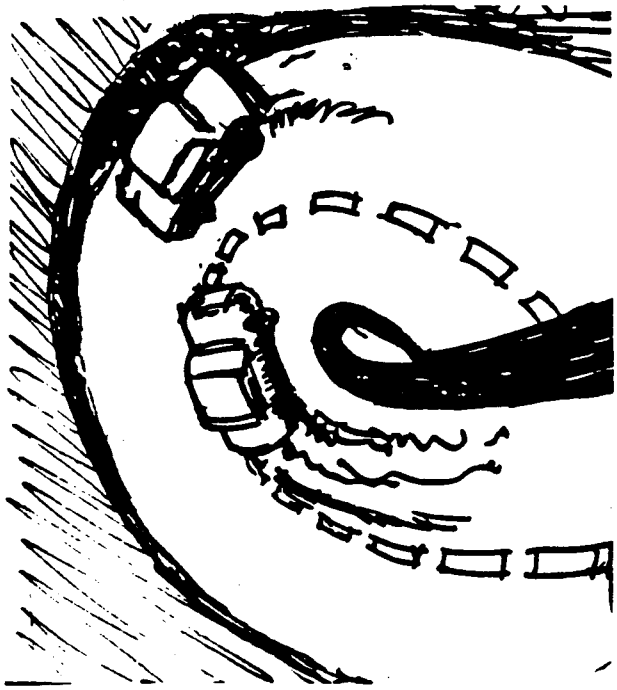


FIGURE 11e: Autos making sharp turns at speed are in danger of slipping sideways and either leaving the road, or colliding with barriers or with oncoming traffic.

Uniform motion is motion at a constant velocity in a straight line. A car in motion will want to continue at the same speed in a straight line until a force is applied to it. In the

case of a car, there is always a slight force from the friction between the tires and the road that slows down the car and can in some instances turn the car. To slow or stop a car, we apply the brakes, which creates a force opposite to the direction the car is moving. To turn a car, we apply a force by turning the tires away from the direction of travel. This causes the friction between the tires and the road to turn the car. The car will turn safely as long as the tires maintain this friction. If they cannot maintain enough friction, if they are on ice for example, the car will not turn quickly enough.

The sharper the turn, the more friction the tires need to turn the car. Also the faster the car is going, the more friction the tires need to turn the car - as it will tend to continue in the original direction. This is why cars must slow down to go around sharp turns. On many highways the curves have been banked. Banking makes turning easier because it reduces the frictional forces which tend to make the tires slip.

On a gradual curve we need to apply less force to change direction than on a sharp curve. We have more time in which to change direction. For example, if the radius of a right angle curve is 75 feet, to change direction from north to east (90 degrees), the car must travel 118 feet (one quarter of the circumference of a circle with a radius of 75 feet). (Figure 12)

FIGURE 12

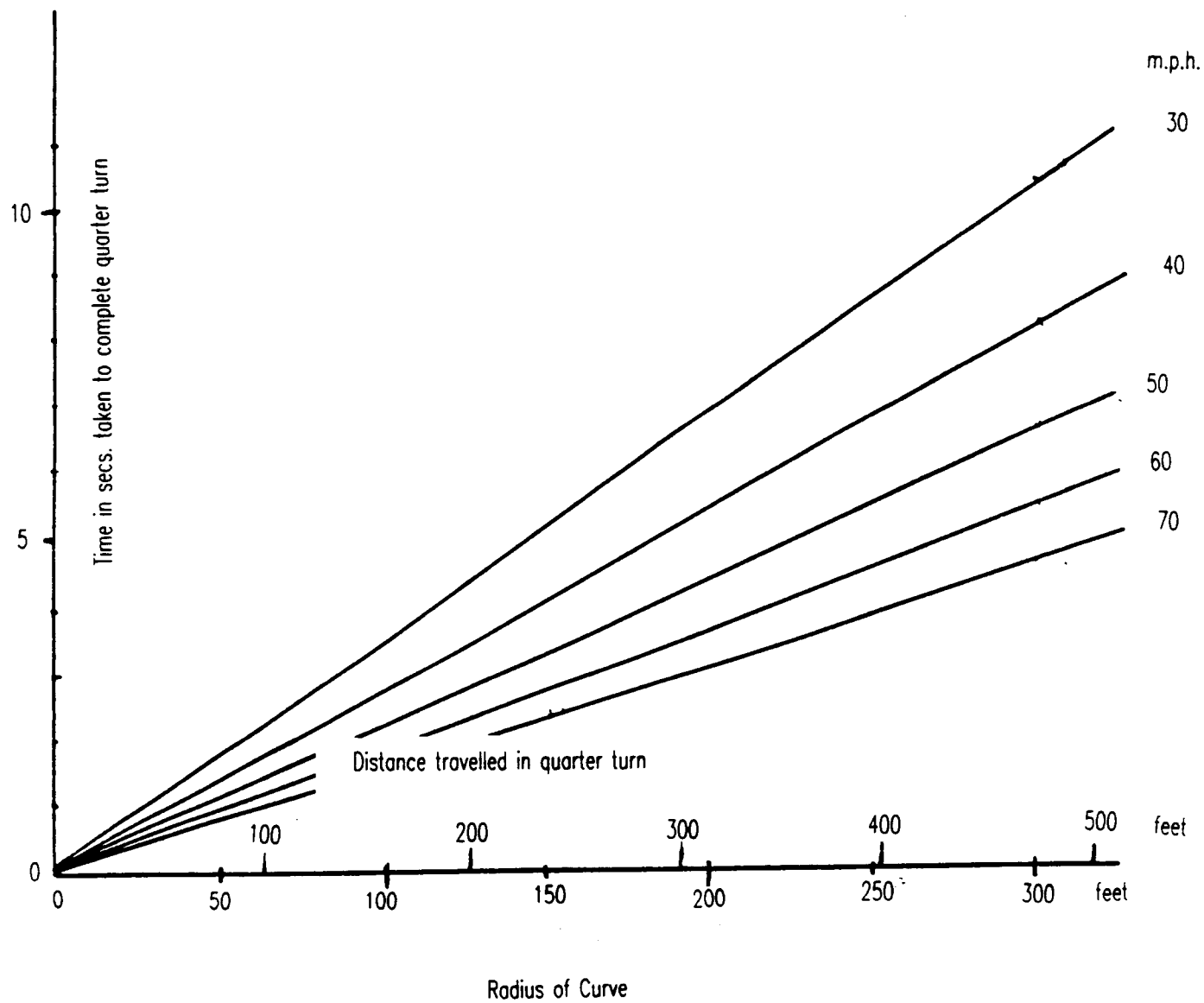



FIGURE 12: Time to make a right-angle turn at different speeds and different radii.

If the car is going 66 ft./sec. (45 mph), it will take 118 feet/66 ft./sec. = 1.78 seconds to go around the curve.

But if the radius of the curve is 200 feet, the distance the car travels in changing from north to east is 314 feet. At 66 ft./sec., this takes 4.72 seconds (2.65 times as long), which means it takes only 1/2.65 as much force of friction between the tires and the road to go around the curve (it takes more time to go 314 feet than to go 118 feet). The more gradual turn is therefore a much safer turn.

An alternative way to make the original curve just as safe would be to drive around the curve at only 1/2.65 the normal speed - 17 miles per hour. But drivers traveling on country roads at 45 mph are not likely to slow down to 17 mph for a sharp curve.

The cost of rebuilding the road from a curve with a 75-foot radius to one with a 200-foot radius can be enormous. It is much cheaper to put up a sign that says "sharp curve, speed limit 20 mph." The sign may have very little effect on driver behavior: we have traded off safety for money. Look for other examples of this kind of trade-off on the roads as you travel.

**********

Activity 8. Road Hazards In Your Community

Locate hazards in your community. Photograph or sketch what you find and describe the problem. Sketch or describe a solution.

**********

TRAFFIC LIGHTS

When a traffic light is green, drivers know exactly what to do: keep going. When it is red, drivers know that they must stop. But when it turns yellow, drivers must make a split-second decision. The yellow light is supposed to warn drivers that the light is about to change from green to red.

A group of college students was asked "What does the yellow light mean to you?" More than half of them said, "speed up!" When asked how many had ever gone through an intersection just as the light turned red, all but one raised their hands. That one confessed that he did not drive. If the yellow light is supposed to warn drivers that the light is about to turn red, why do they go through the intersection? Is the time the light is yellow too short? Is the speed limit too high? Is the intersection too wide? Do drivers enjoy breaking the law? In order to answer these questions, we need to examine a typical situation. Students at one school recorded the situation at one intersection (Figure 13).

FIGURE 13
NEW HIGHWAY AND SUBURBAN ROAD INTERSECTION

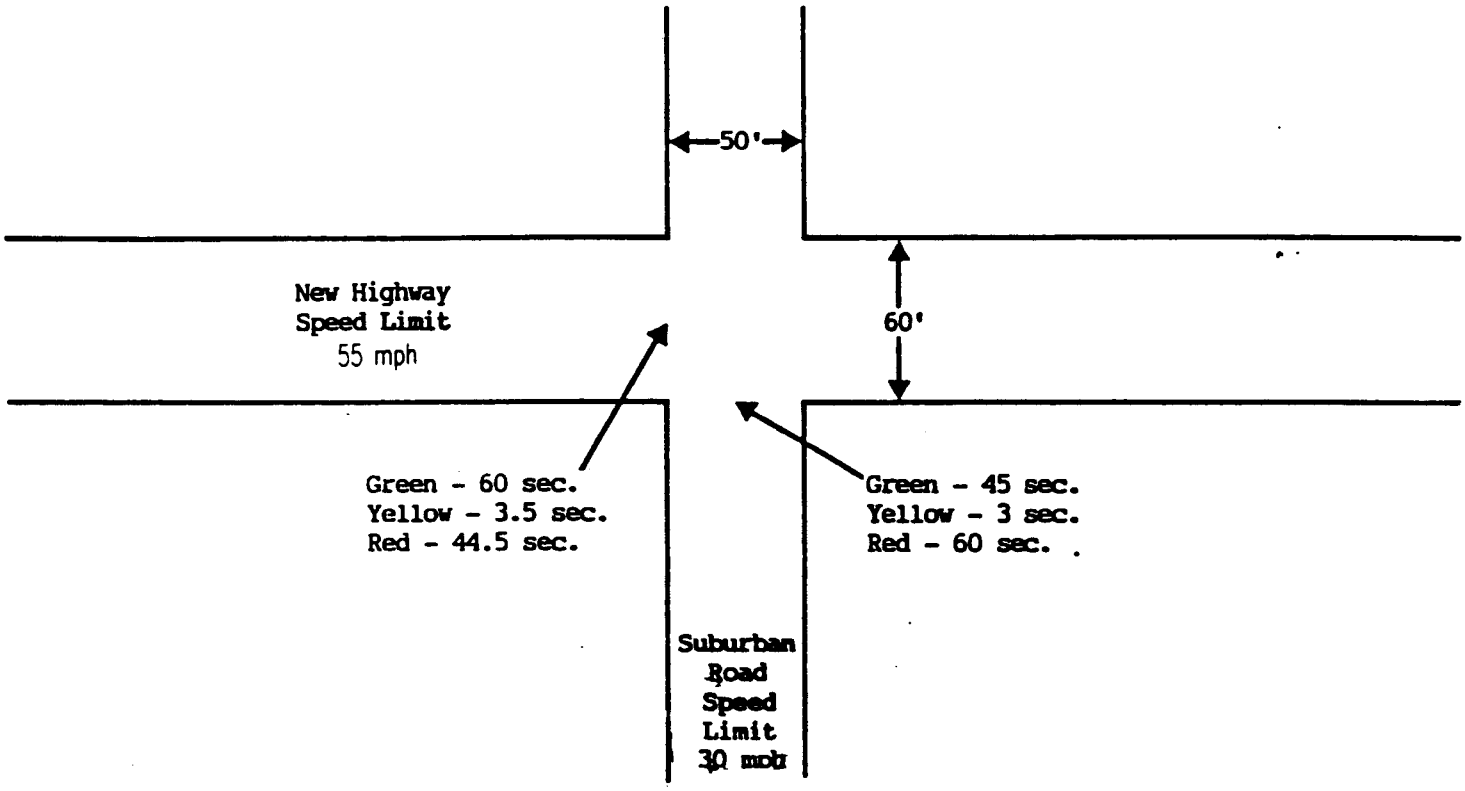



FIGURE 13: The intersection of New Highway and Suburban Road with the factors noted that affect drivers behavior at the intersection.

The students also checked with the county highway department to find out the assumed stopping rate. They were told it was 13 ft./sec./sec. (for the average car on dry pavement).

Discussing the study in class, the students agreed that different people have different reaction times. They measured their reaction times. Here is how they did it:

One student held a yard stick vertically by one end while another held thumb and forefinger at the bottom ready to catch it. When the first student let go, the second tried to grab it quickly. By measuring the number of inches it fell before the student caught it, they figured out his or his reaction time. They used the equation $s = gt^2/2$, in which S is the distance the ruler falls, g is the acceleration due to gravity, and t is the time the ruler was falling (reaction time).

FIGURE 14
GRAPH OF TIME VS. FALL DISTANCE

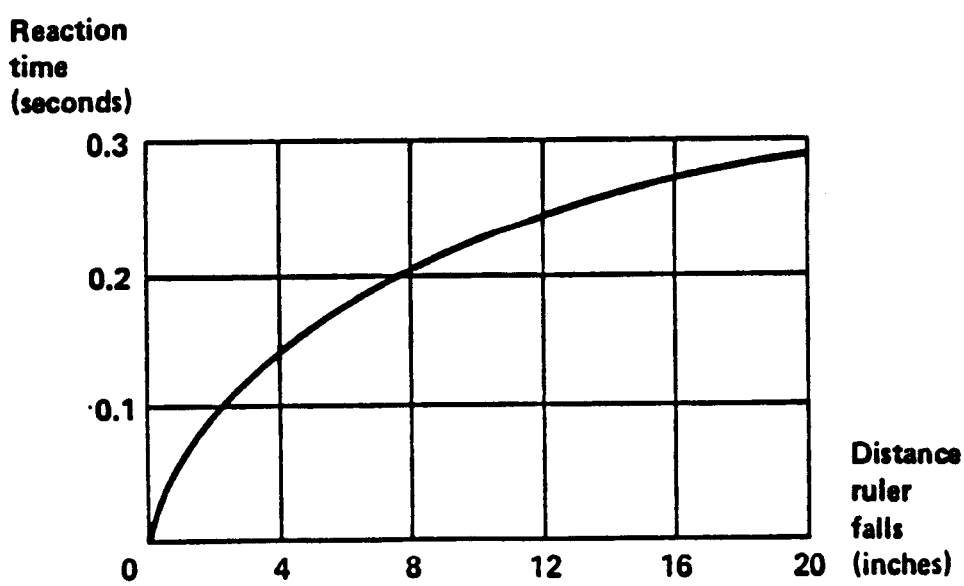



FIGURE 14: Reaction time versus the distance a yardstick falls before it is caught.

The results of this equation have been graphed so that you can convert inches to reaction time easily.

What is the average reaction time of your class? What reaction time would be needed to see the light change, lift your foot from the accelerator pedal and put it on the brake? If the class average reaction time was .22 seconds you should probably figure on about 0.8 seconds to brake a car, allowing for a lower degree of concentration and the greater movement needed.

**BOX 1: THE PHYSICS OF MOTION**

Simple motion can be described using equations dealing with velocity (V), acceleration (a), distance (S), and time (t).

We will look here only at what happens when a body moves in a straight line.

Velocity (sometimes called speed) is defined as how far a body (an object like a car) can travel over a given time. Cars usually measure velocity in miles per hour (mph). Symbolically velocity has the following equation:

$$V = S/t. \qquad (1)$$

Using algebra, we can also write this equation as

$$S = Vt. \qquad (2)$$

Acceleration is the rate of change of velocity. If the object increases in velocity, it accelerates. If it decreases in velocity, it decelerates. The equation for acceleration shows that acceleration (a) is the change of velocity from an initial velocity ($V_i$) to a final velocity ($V_f$) over time.

$$a = (V_f - V_i)/t. \qquad (3)$$

Likewise deceleration, slowing down, is

$$d = (V_i - V_f)/t; \qquad (4)$$

and if we decelerate to a stop, $V_f = 0$ so

$$d = V_i/t; \qquad (5)$$

and during deceleration the velocity changes steadily from $V_i$ to zero, so the average velocity is $V_i/2$.

So the stopping time t from an initial speed $V_i$ for a given braking power (deceleration) d is

$$t = V_i/d; \qquad (6)$$

the stopping distance S in time t at average speed $V_i/2$ from (2) is

$$S = (V_i/2)t = (1/2)V_i t; \qquad (7)$$

and if we put in the stopping time from (6), we find that the stopping distance is

$$S = (1/2)\ V_i(V_i/d) = (1/2)V_i^2/d; \qquad (8)$$

which tells us that the stopping distance does <u>not</u> increase in proportion to the speed but is proportional to the square of the speed. If we travel at 70 mph it takes <u>four</u> <u>times</u> the distance to stop as it does from 35 mph.

**********

Activity 9. Intersection Light Hazards

Calculate the time and distance required for cars to stop on the two different streets shown in FIGURE 13.

Using the graphs in FIGURES 15 and 16 and the equation of motion (2), $S = Vt$, for a car traveling at 55 mph (80 ft./sec.) on the New Highway (FIGURE 13) with a yellow light of 3.5 seconds, calculate how far the car would travel in 3.5 seconds if it did not try to stop. Given that the intersection is 50 feet wide, how far away could the car be as the light turned yellow and still clear the intersection? This zone can be called the "Go Zone."

If the car decelerated at 13 ft./sec.$^2$ when the light turned yellow, how much time and space would it need?

If we assume that the driver needs 0.8 seconds to react, how far would the car travel before the driver applied the brakes?

Does this leave an area (the dilemma zone) where the car can neither make it through the intersection nor stop before entering it?

If an intersection does have a dilemma zone, what would be the most efficient way to eliminate it? Would you:

- Change the width of the intersection,
- Change the speed limit, or
- Change the length of time the light is yellow?

Consider these and other possibilities in light of the following questions:

- Is this change economical?
- How will it affect traffic on the neighboring road system?
- How will the change be received by motorists?

To answer these questions, you need to consider the following questions:

- How much does it cost to change the width of an intersection? What problems are caused by making an intersection two lanes wide if the road feeding into it is three lanes wide?

- If the speed limit on the road is normally 55 mph, what happens to traffic if it is changed to 45 mph on the approach to each traffic light?

- What effect does making the yellow light last longer have on drivers who pass that particular light every day?

The emergency braking rate for cars on a dry road with brakes and tires in perfect condition is approximately 21 ft./sec./sec. Why was 13 ft./sec./sec. chosen for the example given for this problem? What happens if you are driving 55 mph on a highway and the car in front of you brakes at the rate of 21 ft./sec./sec.? Is this an appropriate rate for stopping at a traffic light? Should the expected rate be based on perfect brakes and tires on dry pavement? Even if the expected rate is based on the average rate for all cars under all conditions, approximately how many of the cars would fall below that rate? When you did the reaction time experiment, how many people had a slower reaction time than the class average? What reaction time would it be safest to assume for the intersection? Is this a practical assumption?
**********

FIGURE 15
DISTANCE TRAVELED IN DIFFERENT TIMES FOR SPEEDS UP TO 90 MPH
(Figure 8)

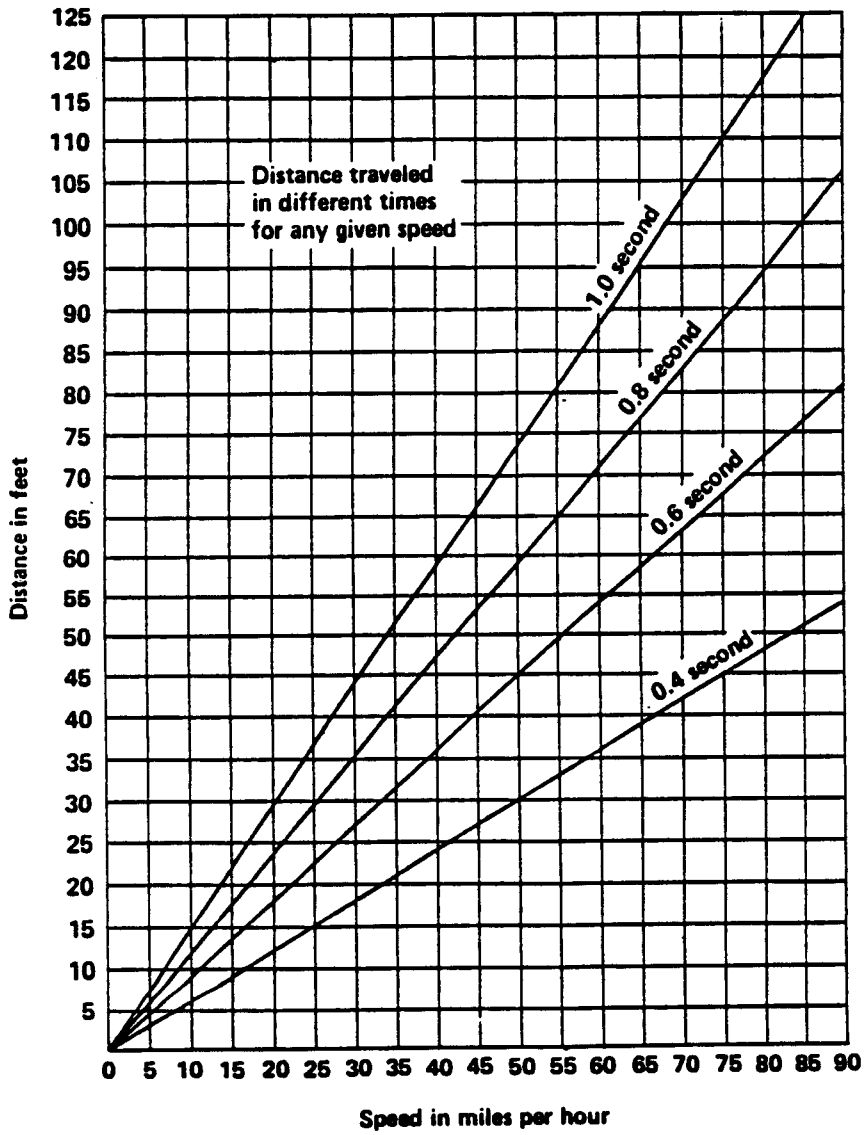



FIGURE 15: Distance travelled in different times for speeds up to 90 mph.

FIGURE 16
STOPPING DISTANCE VS. SPEED FOR DECELERATION OF 13 FT./SEC$^2$.

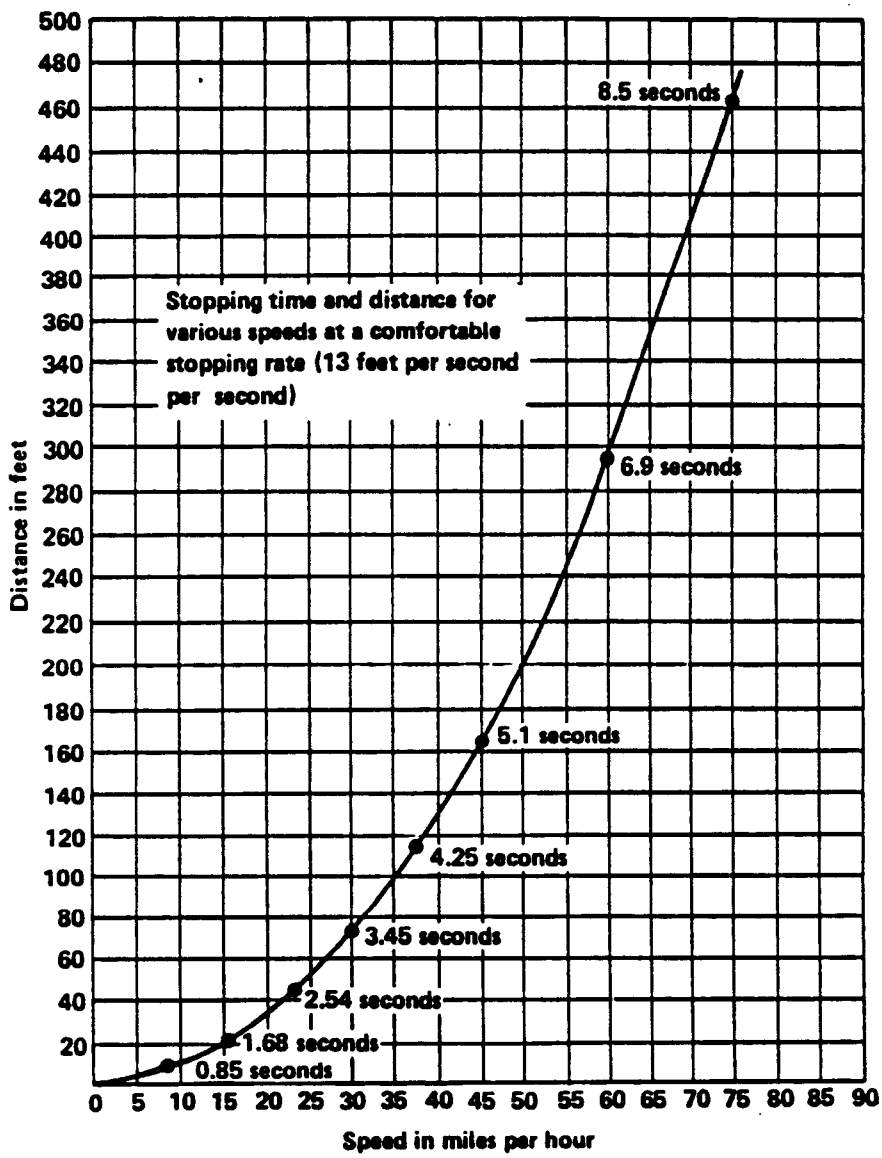



FIGURE 16: Stopping distance versus speed for a deceleration rate of 13 feet/sec$^2$.

SUMMARY

**In this chapter you have learned:**

(1) that to reduce injuries to drivers and passengers in collisions, the duration of the collision must be made as great as possible; the more abrupt the collision, the greater the injuries,

(2) that sign posts, light posts and guard-rails can be designed so as to reduce injury when collisions occur,

(3) that sharp curves mean slow down,

(4) that a driver has a real problem when the lights turn yellow and that a spur-of-the-moment decision is not the right way to deal with it.

**In the next chapter** you will look at some attempts made by government and state legislation to make our roads safer, some of which have been good, some bad.

CHAPTER 5

# REGULATORY AGENCY DECISIONS

To make driving, riding, and walking safer, the federal government and state governments make regulations governing speed, traffic lights, vehicle inspections, road use by oversize vehicles, licensing drivers, and so forth. These regulations usually improve safety, but sometimes they have the opposite effect.

## THE 55-MPH SPEED LIMIT

Of the various regulations that concern highway safety, one of the most effective was passed for an entirely different reason. In 1973, the Arab oil embargo caught the United States in an energy crisis for which we were not prepared. A number of attacks on the energy crisis were proposed and instituted. Among the more successful regulations was the 55 mph speed limit (FIGURE 17). While States have the right to pass their own speed limits, Congress encouraged them to pass a 55 mph maximum for any road. The encouragement consisted of refusing federal funds for highway construction to any state that did not adopt the 55 mph limit. Since federal funds usually pay 90 percent of the cost of highway construction, all states passed the 55 mph limit.

FIGURE 17
GASOLINE ECONOMY VS. SPEED OF TYPICAL MID-SIZE CAR

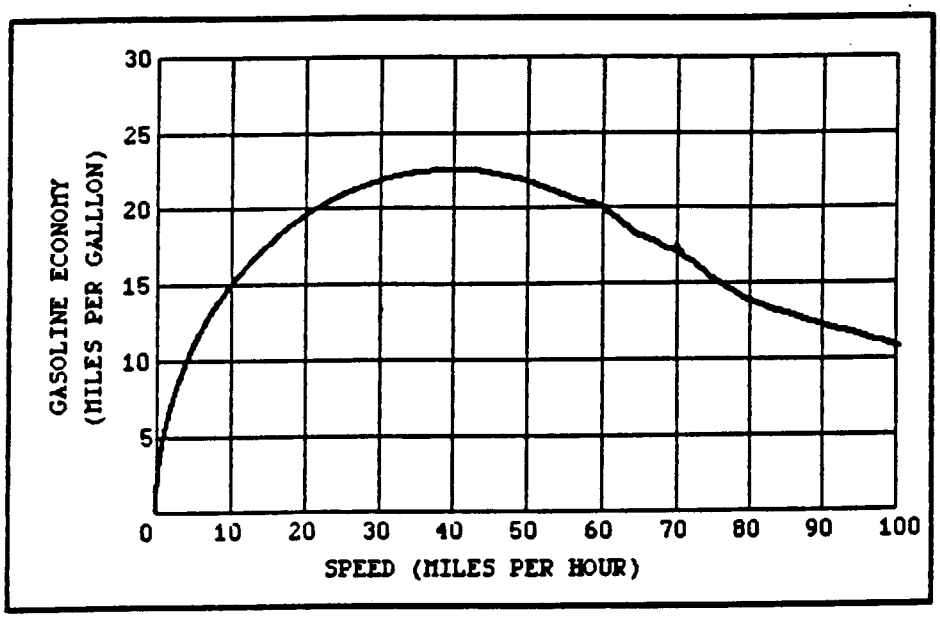



FIGURE 17: An examination of this figure shows that maximum economy (miles per gallon) occurs at approximately 45 mph. The maximum miles per gallon shown on the graph is about 22 mpg; however, it is different for different cars ranging from less than 15 mpg to over 50 mpg.

During the years the 55 mph limit has been in effect, motoring magazines and the trucking industry have campaigned to have it removed. In 1982, an organization called Citizens Coalition for Rational Traffic Laws, Inc. was formed. It argued

that the 55 mph law benefited various well-organized groups: the police, the insurance industry, the legal industry, and certain regulatory bureaucracies. In addition, it said most motorists do not obey the law, most interstate highways were designed for 70 mph, the energy crisis that brought about the law was no longer a factor, and the 55 mph limit wastes time.

The argument that the 55 mph limit wastes time was interesting:

> "the average American driver wastes about seven hours each year in extra travel time. Multiply that seven hours by 157 million licensed drivers and you arrive at a total of 1,099,000,000 hours or 1,670 lifetimes per year. Given the possibility that the 55 mph limit may save some fatalities, it's clear that we're wasting life to save life." [Sherman 1986]

Are you convinced by this argument? How would you argue against it? People also argued that foreign countries have higher speed limits and fewer accidents.

When the speed limit in Denmark was reduced in 1973, the fatalities dropped from 1,100 to 750 per year. When the speed limit was raised in 1974, fatalities climbed to about 820 and stayed there until the speed limit was again reduced in 1978. By 1980, the fatalities per year dropped to about 650.

The arguments against the 55 mph speed limit were rebutted by the police, the insurance industry, and the regulatory agencies, the groups most interested in highway safety. The basic responsibility of highway police is to enforce laws in order to improve safety. Insurance companies try to save money by not paying accident and death benefits. Insurance companies lose money when their clients have more accidents; the more serious they are, the more it costs the company!

Data on the 55 mph speed limit were published in 55: A Decade of Experience (Transportation Research Board Special Report 204). A few comments from that report follow:

* High speed increases the likelihood of a crash (less time to react)

* Crash forces increase with the square of the impact speed. Your chance of being killed in an accident at 55 mph is one in 30; at 70 mph, it is one in two (FIGURE 23)

* The fatality rate per 100 million vehicle miles on interstates went steadily down from 2.29 in 1973 to 1.21 in 1984, a 47 percent decrease, while the fatality rate on local roads not affected by the 55 mph regulation fluctuated, going from 3.66 in 1973 to 3.14 in 1984, a decrease of only 14 percent.

* There has been an overall reduction in deaths from 1973-1986 of about 4,000 per year attributed to the 55 mph limit.

FIGURE 18
COMPARATIVE LIKELIHOOD OF CRASH DEATH

**Comparative Likelihood of Crash Death**

| Velocity Change (Impact Speed) | Likelihood of Death Compared to Velocity Change of 20 mph |
|---|---|
| 20 mph | — |
| 30 mph | 4 |
| 40 mph | 10 |
| 50 mph | 20 |

FIGURE 18: This chart shows how the risk of a crash causing a death increases with the speed of the vehicle. The risk is 4 times greater at 30 mph than at 20 mph.

FIGURE 19
MOTOR VEHICLE CRASH FATALITIES IN DENMARK, 1970-1982

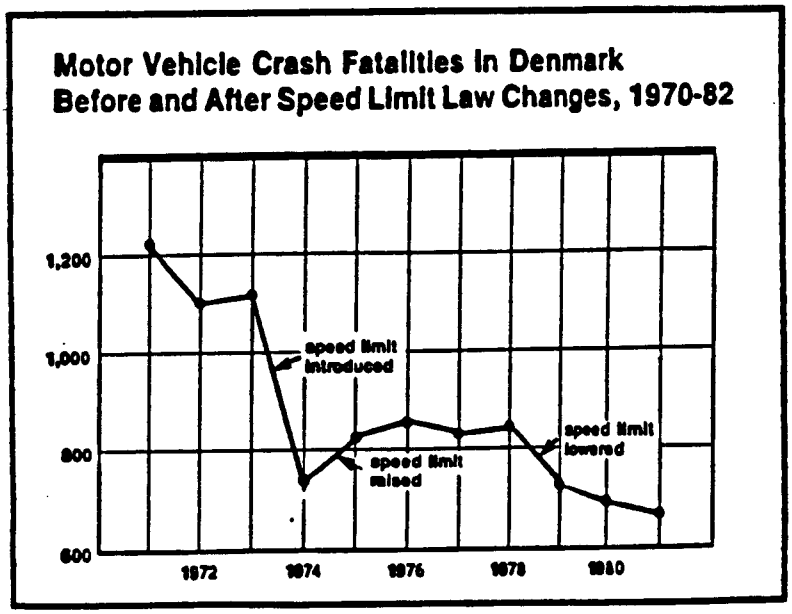



FIGURE 19: This graph shows clearly how the death rate increases if the speed limit is raised, and decreases when it is lowered.

While it is difficult to prove that the reduction in the speed limit saved 4,000 lives per year in the U.S., it is interesting to see the correlation between the changes in the speed limit and changes in the number of highway fatalities in Denmark where the speed limit has been reduced, then raised, and then reduced again (Figure 19).

A major claim of the group lobbying to dump the 55mph speed limit has been that although the speed limit in Germany is unlimited, their death rate is lower. The group says that German motorists whip along at blinding speeds on the autobahns yet have a lower death rate than Americans traveling on U.S. interstates with speed limits of 55 mph. The facts are that for every year except 1984, deaths per mile traveled on the autobahns were higher than on the U.S. interstate system. Trucks have a speed limit in Germany of 56 mph on the whole system, and they are banned from autobahns from noon Saturday to midnight Sunday. Whenever the weather causes poor conditions on the roads, a speed limit of 62 mph is imposed. Seat belt use is rigidly enforced, and belt use is 90 percent. It is forbidden to pass on the right on the autobahns. The minimum age for drivers in Germany is 18, but German teen-agers do not have as much chance to drive as Americans. German laws regarding drinking and driving are much more strict than those in the U.S. Look back to FIGURE 1 in Chapter 1 and to the discussion on drinking and driving in Chapter 2 and estimate what effect these differences will have on the deaths per mile.

With high seat belt use, no passing on the right, no trucks on weekends, reduced speeding in wet weather, fewer teen-age drivers, and tougher drunk driving laws, the autobahns should be safer than U.S. interstates, but they are not.

Groups lobbying against the 55 mph limit also argued that since most motorists break the 55 mph limit anyway, it should be raised to 65. A survey of New Mexico drivers was conducted three weeks after the speed limit was raised to 65 mph. Thirty-seven

percent of the passenger cars surveyed were going faster than the new speed limit. Eight weeks later, 49 percent were exceeding 65 mph, and 12 percent were exceeding 70 mph. This is exactly what the opponents of raising the speed limit predicted.

RIGHT TURN ON RED

For years California and a few other states allowed a right turn on red traffic lights. Between 1974 and 1980, all the other states adopted laws permitting drivers to make right turns on red as a means of saving gasoline. The theory was that cars waiting for a light to turn green use up valuable fuel, and that allowing right turns on red would not increase accidents at such intersections. Only New York City refused to go along. Motorists entering New York City were greeted by a sign that said, "right turn on red only when specifically allowed." Other communities put up signs saying "no turn on red" at intersections they considered dangerous. A 1984 study reported that at 80 percent of the intersections where right turn on red was permitted, the right-turning crashes increased by 23 percent, pedestrian impacts increased by 60 percent, and bicycle crashes with cars doubled.

A group of students at the State University of New York at Stony Brook found that on the average the right turn on red did not save gas. The students attached a graduated cylinder with a tube to the carburetor to measure the small quantities of gasoline used. They then made a large number of trial runs at intersections near the university where right turns on red were permitted. They measured the gasoline consumed by the car as it

waited for the light to turn from red to green and then turned the corner and accelerated up to the speed limit. They then made a number of right turns on red and accelerated to the speed limit. They found no appreciable difference in the amount of gasoline consumed, although they used slightly more turning on red. They attributed this to the fact that they had to accelerate faster to join the traffic already on the road when they made the right turn on red, whereas they did not accelerate as rapidly when they turned on the green light. This more rapid acceleration used up approximately the same amount of fuel as idling at the red light.

Changing this regulation did not save fuel, and it had far greater costs in damage, injuries, and fatalities.

INSPECTIONS, ETC.

To save time or because of bureaucratic overlap, two agencies sometimes publish different requirements. As recently as 1986, the National Highway Traffic Safety Administration (NHTSA) and the Bureau of Motor Carrier Safety (BMCS) had opposite regulations regarding disconnecting front brakes on trucks. The NHTSA required that front brakes be installed on all trucks while BMCS allowed trucks to disconnect the front brakes. Both agencies are under the control of the U.S. Department of Transportation (DOT). When this conflict was brought to the attention of the secretary of transportation, Elizabeth Dole, she said that the BMCS ruling would be changed.

Many states allow truck owners to perform their own inspections because ordinary state inspection stations cannot

handle large trucks. The state then sets up roadside inspection stations and randomly stops trucks for inspection. These roadside inspections turn up defects serious enough to require putting as many as 25 percent of the trucks out of service until they are repaired.

States and the federal government often differ in their approach to safety regulations. When the U.S. Department of Transportation agreed to allow tandem trailers (two trailers pulled by one tractor) on all interstate highways, many states refused to allow them, especially in high volume areas.

**********
Activity 10. Tandem Trailers

Why do you think the U.S. Department of Transportation decided to permit tandem trailers? Find out who wanted tandem trailers? Why? What groups opposed permitting them on the highways? Are they allowed in your area?
**********

Since motor vehicles first became popular early in the 1900s, we have made great strides in lowering the accident rate. We have used education, legislation, and technology together in an attempt to minimize crashes of autos, trucks, buses, motorcycles, bikes, and pedestrians. We have not eliminated all crashes: even when all systems are working at their best, accidents still happen.

SUMMARY

**In this chapter you have learned**

(1) that governments aren't all bad; they sometimes get it right;

(2) that they got it right with the 55 mph speed limit;

(3) that they got it wrong with the "right turn on red"; and

(4) that we need a better way to ensure that fewer vehicles are on the road in a dangerous condition.

**In the next Chapter** you are going to look at ways in which auto/driver/passengers can reduce the damaging effects of crashes: fewer fatalities, less serious injuries.

## CHAPTER 6

## WHEN CRASHES OCCUR

"I'll never buy another car without an air bag," is the headline of a news story about a woman whose 2,780 pound Mercedes-Benz 190E drifted over the center line into the path of a 3,500 pound Ford F100 pick-up truck. The vehicles were each traveling between 30 and 35 mph - no speeding, no reckless driving, no driving while drunk, just a momentary lack of attention on the part of the car driver. The Mercedes went from 30 mph to 0 mph in a split second. The car was demolished: the front was pushed back 31 inches. The driver sustained seven fractured ribs and some internal injuries but no head or pelvis damage. Without the air bag, she would almost certainly have been killed.

In another head-on crash, two people in a 1984 Oldsmobile survived when they collided with a 1979 Ford Sedan that had crossed the center line. The driver of the Ford was killed as a result of massive head injuries. The occupants of the Oldsmobile were protected by air bags that had been installed as part of a test.

In another head-on crash between two identical small cars, both traveling at 40 mph, the front end of each vehicle was a total wreck. The driver of one car, who had been wearing a seat-belt, climbed out of the wreckage unaided, slightly bruised around the legs and body, and went to the aid of the other driver. She had not thought it worth while to put her seat-belt

on: driving on local roads, at modest speeds on a short journey - "what the heck." She was trapped in the wreckage, had broken legs, ribs, and pelvis, and serious face lacerations and spent five months in hospital.

In spite of education, legislation, and technological advances, drivers drink, brakes fail, people cross dividing lines, roads get slippery, signs are erected too close to the road, tires blow out, and, therefore, crashes occur. The question then changes from "How do we prevent crashes?" to "How do we protect people in crashes?" and "How do we prevent further injury after a crash?"

## PROTECTING PEOPLE IN CRASHES

When cars crash, they stop suddenly (head on crashes), change direction suddenly (side crashes), accelerate suddenly (rear end crashes), roll over, burn, or end up underwater. The problem to be solved is how to protect the passengers.

If you are in a crash, you want to be kept from bouncing around inside the car during the crash, and you want to get out quickly when the car finally stops moving. These two goals are sometimes in conflict. To provide a balance between them, a number of regulations govern the design of the interior of the car and the operation of doors or other means of exit.

## THE NATIONAL TRAFFIC AND MOTOR VEHICLE SAFETY ACT

In 1966, Congress passed the National Traffic and Motor Vehicle Safety Act. That year, 53,041 people were killed in motor vehicle accidents. This was 5.72 deaths for every 100 million vehicle miles traveled. By 1986, those numbers had

changed to 47,900 deaths or 2.57 deaths for every 1,000 million vehicle miles.

FIGURE 20
AUTO DEATHS VS VARIOUS PARAMETERS

**Improper Driving Reported in Accidents, 1985**

| Kind of Improper Driving | Fatal Accidents | | | Injury Accidents | | | All Accidents[a] | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | Urban | Rural | Total | Urban | Rural | Total | Urban | Rural |
| **Total** | **100.0%** | **100.0%** | **100.0%** | **100.0%** | **100.0%** | **100.0%** | **100.0%** | **100.0%** | **100.0%** |
| **Improper driving** | **55.2** | **53.8** | **55.6** | **61.5** | **64.3** | **57.5** | **56.4** | **57.3** | **54.9** |
| Speed too fast[b] | 23.1 | 22.3 | 23.5 | 19.3 | 18.0 | 21.3 | 15.5 | 13.5 | 19.6 |
| Right of way | 12.2 | 15.9 | 10.3 | 23.9 | 26.0 | 21.0 | 22.2 | 25.3 | 15.5 |
| *Failed to yield* | 8.3 | 9.8 | 7.5 | 17.3 | 18.4 | 15.7 | 16.9 | 18.9 | 12.7 |
| *Passed stop sign* | 2.2 | 2.5 | 2.0 | 2.9 | 3.2 | 2.5 | 2.2 | 2.5 | 1.5 |
| *Disregarded signal* | 1.7 | 3.6 | 0.8 | 3.7 | 4.4 | 2.8 | 3.1 | 3.9 | 1.3 |
| Drove left of center | 9.9 | 5.5 | 12.1 | 3.3 | 2.0 | 5.0 | 2.8 | 1.9 | 4.8 |
| Improper overtaking | 1.9 | 1.3 | 2.1 | 1.9 | 1.9 | 1.9 | 1.8 | 1.8 | 2.1 |
| Made improper turn | 1.4 | 2.9 | 0.7 | 2.3 | 2.3 | 2.3 | 3.5 | 3.9 | 2.8 |
| Followed too closely | 0.6 | 0.5 | 0.5 | 5.3 | 6.4 | 3.6 | 5.7 | 6.7 | 3.8 |
| Other improper driving | 6.1 | 5.4 | 6.4 | 5.5 | 7.7 | 2.4 | 4.9 | 4.2 | 6.3 |
| **No improper driving stated** | **44.8** | **46.2** | **44.4** | **38.5** | **35.7** | **42.5** | **43.6** | **42.7** | **45.1** |

Source: Based on urban and rural reports from 9 state traffic authorities.
[a]Principally property damage accidents, but also includes fatal and injury accidents.
[b]Includes "speed too fast for conditions."

FIGURE 20: In most accidents, factors are present relating to the driver, the vehicle, and the road, and it is the interactionof these factors which often sets up the series of events which culminates in the mishap. This relates just to the driver and shows the principal kinds of improper driving which were factors in accidents. Correcting these improper practices could have an important effect on accident occurrences. This does not mean that road and vehicle conditions can be disregarded.

In the 20 years between 1966 and 1986, during which the number of vehicles increased, and the number of drivers, passengers and pedestrians also increased, not only did the deaths per million vehicle miles decrease but also the actual number of deaths decreased (FIGURE 20).

In fact, since 1923 when vehicle miles driven per year were first estimated, the fatality rate per 100 million vehicle miles

has dropped from 33.38 to 2.57. The graph of fatalities per 100 million vehicle miles driven shows some hills and valleys; these may have been caused by major historical events, major safety regulations, or other factors that changed motor vehicle safety.

**********
Activity 11. Changes in Fatality Rates

What events do you know of that might have changed the trend? Look back to the answers you gave to the questions at the end of Chapter 1.
**********

Those who are against regulation by the government might use only the total increase in number of deaths to "prove" that even after the 1966 regulations deaths increased. On the other hand, supporters of the regulation would use deaths per vehicle miles traveled to "prove" that the regulations prevent deaths.

In 1966, when regulations were passed requiring new cars to have interior padding or head restraints, millions of cars were on the road without those features. Until most existing cars are replaced with cars meeting new regulations, the regulation affect only a small part of the cars on the roads.

**********
Activity 12. Eye-Level Brake Lights

In 1986, regulations were passed requiring eye-level brake lights. The next time you are riding in a car or walking in a parking lot, make a survey. Count how many cars out of 20 or so have eye-level brake lights and how many do not. Figure out the ratio. How many years have passed since 1986? When do you think 80 percent of the cars will have eye-level lights?
**********

TABLE THREE: VEHICLE SAFETY STANDARDS PASSED SINCE 1966

## FEDERAL MOTOR VEHICLE SAFETY STANDARDS (FMVSS)

| FMVSS Number | | Car | MPV | Truck | Bus | Equip |
|---|---|---|---|---|---|---|
| 100 | SERIES Accident Prevention | | | | | |
| 101 | Controls, Location & Identification | • | • | • | • | |
| 102 | Transmission Shift Lever Sequence | • | • | • | • | |
| 103 | Windshield Defrosting & Defogging | • | • | • | • | |
| 104 | Windshield Wiping & Washing System | • | • | • | • | |
| 105 | Hydraulic Brake System | • | • | • | • | |
| 106 | Brake Hoses | • | • | • | • | • |
| 107 | Reflecting Surfaces | • | • | • | • | |
| 108 | Lights and Reflectors | • | • | • | • | • |
| 109 | New Tires for Passenger Cars (1) | | | | | • |
| 110 | Tire Selection & Wheels for Passenger Cars | • | | | | |
| 111 | Rearview Mirrors | • | • | • | • | |
| 112 | Headlamp Concealment Devices | • | • | • | • | |
| 113 | Hood Latch System | • | • | • | • | |
| 114 | Theft Protection | • | • | • | | |
| 115 | Vehicle Identification Number | • | • | • | • | |
| 116 | Hydraulic Brake Fluids | • | • | • | • | • |
| 117 | Retreaded Tires | | | | | • |
| 118 | Power Operated Window Systems | • | • | | | |
| 119 | New Tires for Trucks, Buses, etc | | | | | • |
| 120 | Tire Selection & Wheels for Trucks, Buses, etc | | • | • | • | • |
| 121 | Air Brake Systems | | | • | • | |
| 122 | Motorcycle Brake Systems | | | | | |
| 123 | Motorcycle Controls Displays | | | | | |
| 124 | Accelerator Control Systems | • | • | • | • | |
| 125 | Warning Devices | | | | | • |
| 126 | Truck—Camper Loading | | | | | • |
| 200 | SERIES Injury Protection | | | | | |
| 201 | Occupant Protection in Interior Impacts | • | • | • | • | |
| 202 | Head Restraints | • | | | | |
| 203 | Steering Wheel Impact Protection | • | • | • | • | |
| 204 | Steering System Rearward Movement | • | • | • | • | |
| 205 | Glazing Materials | • | • | • | • | • |
| 206 | Door Locks & Hinges | • | • | • | | |
| 207 | Anchorage of Seats | • | • | • | • | |
| 208 | Occupant Restraints | • | • | • | • | • |
| 209 | Seat Belt Assemblies | • | • | • | • | |
| 210 | Seat Belt Anchorages | | | | | • |
| 211 | Wheel Nuts, Wheel Discs & Hub Caps | • | • | | | • |
| 212 | Windshield Mounting | • | • | • | • | |
| 213 | Child Restraint System | | | | | • |
| 214 | Side Door Strength | • | | | | |
| 215 | Exterior Protection | • | | | | |
| 216 | Roof Crush Resistance | • | | | | |
| 217 | Bus Window Strength & Emergency Release | | | | • | |
| 218 | Motorcycle Helmets | | | | | • |
| 219 | Windshield Zone Intrusion | • | • | • | • | |
| 220 | School Bus Rollover Protection | | | | • | |
| 221 | School Bus Body Joint Strength | | | | • | |
| 222 | School Bus Seats | | | | • | |
| 300 | SERIES Post Accident Protection | | | | | |
| 301 | Fuel System Integrity | • | • | • | • | |
| 302 | Flammability of Interior Materials | • | • | • | • | |

PASSENGER CAR: Motor vehicle with motive power except a multipurpose passenger vehicle, motor cycle or trailer designed for carrying 10 persons or less.

TRUCKS: Motor vehicle with motive power, except a trailer designed primarily for the transportation of property or special purpose equipment.

BUS: Motor vehicle with motive power, except a trailer designed for carrying more than 10 persons.

MULTIPURPOSE PASSENGER VEHICLE: Motor vehicle with motive power, except a on a truck trailer designed to carry 10 persons or less which is constructed chassis or with special features for occasional off-road operation.

EQUIPMENT: Individual vehicle components or systems whether installed on a new vehicle or provided as a replacement.

SOURCE: Compiled by Motor Vehicle Manufacturers Association of the U.S., Inc

The list of Federal Motor Vehicle Safety Standards (FMVSS), includes various categories of standards passed since 1966 (Table 3). Those numbered in the 100s are intended to prevent accidents. The 200 series standards are designed to prevent injuries during a crash, and the 300 series are designed to protect passengers from injury after the crash. Each standard is based on a knowledge of science and technology. Understanding the reasoning behind a standard is important in accepting the regulation or technology it requires. We cannot examine all the standards in detail here, but we will look at a few of them, study the science behind them, and discuss their value in terms of cost per life saved.

## PREVENTING INJURIES DURING A CRASH

### THE VEHICLE

In a crash, the driver and passengers, particularly if they are not wearing seat belts, may be injured by various features of the car:

* The Dashboard Instrument Panel - a person's head may hit knobs, a hard surface, or an instrument; knees may hit something under the panel.

* The Doors - may spring open allowing someone to be thrown out of the car, or they may be crushed into the occupants.

* Door Handles and Window Controls - various parts of the body may hit extending handles.

* The Seats - may come loose in a head-on crash and crush people against the dash.

* The Steering Wheel - the driver may hit his or her face on the wheel itself, or the steering column may puncture the chest.

* The Windshield - may break and the glass may cut the faces and arms of the car's occupants.

None of these surfaces and structures would be a serious problem if everyone always wore shoulder seat belts so that they could not move more than a few inches from the normal sitting position. In a survey of crashes at speeds up to 60 mph, nobody wearing lap and shoulder belts was killed - but there is no guarantee that everyone will wear seat belts.

**THE DASHBOARD**

The dashboard should be padded and the knobs should be recessed rather than protruding.

As for most safety features, the basis for padding is Newton's Law ($F = ma$). Because acceleration ($a$) is defined as velocity change ($v$) over time ($t$), $F = ma$ is the same as $F = mv/t$ or $Ft=mv$. $\underline{F}$ is the force on your head when it hits the dashboard; $\underline{t}$ is the time it takes your head to stop moving forward after it first hits the dashboard, $\underline{m}$ is the mass of your head, and $\underline{v}$ is the velocity with which your head first hits the dashboard. The only thing that can be changed to reduce $\underline{F}$ is the time it takes for your head to stop. If the dashboard were made of thick steel your head might stop in 3/1,000 of a second after hitting the dash. Padding takes time to crush. If the padding takes 3/100 of a second to crush, the force on your head would be only one tenth of what it would be against an unpadded solid steel dash. If the dash were made of a thin sheet steel or aluminum and were padded, the dash would crumple as your head hit it, taking a total of 3/10 of a second to stop your head and reducing the force by a factor of 100 from the solid steel plate.

**THE DOORS**

Even if those riding in a car are restrained by seat and shoulder belts, they can be seriously injured or killed in a side crash if the door is crushed into the car. The construction of the door should provide two seemingly opposite qualities. Doors must be strong enough to resist being pushed into the occupants and flexible enough to absorb some of the shock of impact. Actually, the entire body of the car should be able to absorb the shock of impact so that the force of the impact is not transferred to the occupants whether they are held in place by restraints or not.

**DOOR AND WINDOW HANDLES**

If door and window handles are recessed within the padded interior of the door, then if you are thrown against the door, you body will not hit the handles until after it has crushed the padding.

**THE SEATS**

The seats must be securely fastened to the body of the car to prevent them from shooting forward when the car comes to a sudden stop.

**STEERING WHEEL AND COLUMN**

When the driver's face or chest hits the steering wheel, the wheel absorbs some of the force before it breaks. If the velocity is great enough, the driver will break the steering wheel and become impaled on the steering column. This is prevented by designing steering columns to remain intact under

normal forces of driving but to collapse forward like a telescope when the force down on it is greater than normal. Once again the time it takes to stop the driver's body has been increased, and the force on the body has been decreased. Newton to the rescue!

**THE WINDSHIELD**

In the United States, windshields are laminated. They are made like a sandwich with two sheets of glass surrounding a central sheet of plastic material. When your head hits such a windshield, it does not shatter. The glass on both sides of the plastic breaks but remains glued to the plastic, and the whole assembly gives in the way a fireman's net gives. This allows the windshield to "catch" your head rather than letting it go through, and it also prevents severe cuts.

Today's dashboard, door and window handles, steering wheel, seats and windshield are great improvements over those in early cars. A number of restraints have been added to cars recently to prevent or reduce injury in the event of a crash.

## PASSENGER RESTRAINTS: SEAT BELTS AND HEAD RESTRAINTS

**HEAD RESTRAINTS**

Just as your body continues forward when the car comes to a sudden stop, when you are hit from behind, your head, which is not attached to the car, continues to move forward at whatever speed it was originally moving, while the car accelerates forward rapidly. Your head in effect snaps back relative to your body, and you receive neck and spine injuries called whiplash. The

head restraint, which is adjustable in some cars, should hit your head high enough to prevent it from being forced back rapidly, bending your neck and spine backwards. The tests with dummies, which have been instrumented to measure acceleration of the head and neck bones, indicate that when properly adjusted a head restraint can prevent serious injury even if the car is hit from behind at a difference in speed of 45 mph. If the head restraint is too low, it will allow the head to move back and cause additional force to be applied to the back of the neck. Whiplash can be great enough to cut the spinal cord resulting in death or paralysis of the entire body below the neck.

Except for the head restraint, and the seat anchoring, the improvements would not be so vital if the occupants were prevented from being thrown about in the event of a crash.

**SEAT BELTS**

What reasons have you heard people give for not wearing seat belts?

* "I don't need a seat belt because I am a really good driver and I have excellent reactions."
* "I don't need it. In case of an accident, I can brace myself with my hands."
* "I don't want to be trapped in the car by a seat belt; it's better to be thrown free in an accident."
* "If I wear a seat belt, I might be trapped in a burning or submerged car."
* "Most people will be offended if I ask them to put on a seat belt in my car."
* "I just don't believe it will happen to me."

* "I only need to wear a seat belt when I am on a long trip at high speed."
* "Even when I have my shoulder harness on I can still touch the dashboard with my head - why wear it?

You can do experiments to find out if such statements are valid or not.

Remember how to find your reaction time:

Have another person hold a yardstick in a vertical position. Put your fingers and thumb on either side of it at the bottom and get ready to grab it. When the other person drops it, you try to catch it. Use the graph in FIGURE 21 (that shows reaction time vs. the distance the yardstick falls) to determine your reaction time. To be safe, double the time. You do not drive or ride as a passenger with the same concentration you had in trying to catch the ruler; that gives you the time it takes you to close you hand. Double this time as a measure of how long it would take you to get your hands up in front of your face if you were a passenger in a car that crashed. If you caught the yardstick at the six-inch mark, your reaction time was about 0.2 seconds for the experiment. Doubling this to allow a safety factor of two makes it 0.4 seconds.

FIGURE 21
GRAPH OF TIME VS. FALL DISTANCE

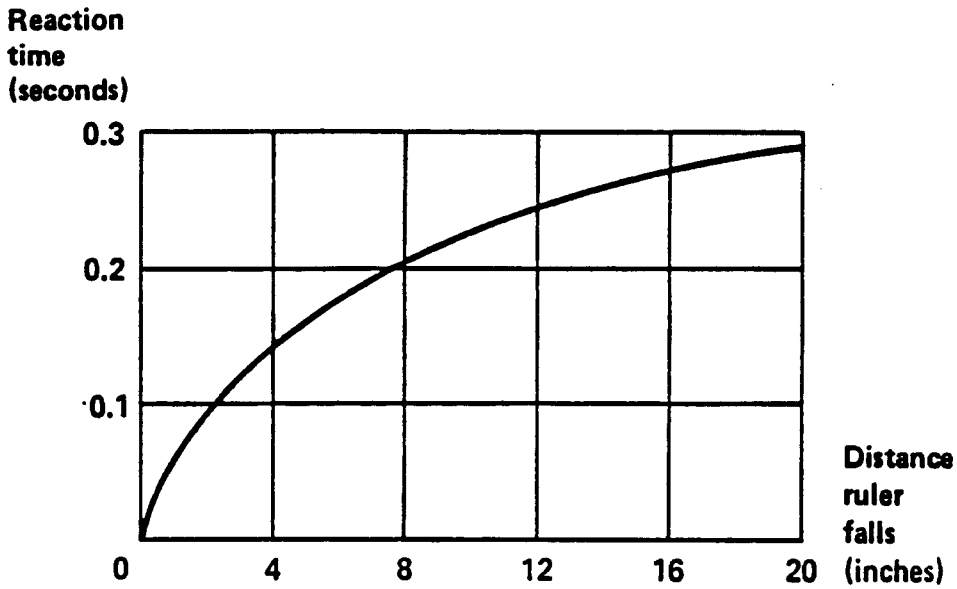



FIGURE 21: Reaction time versus the distance a yardstick falls before it is caught.

How far does a car going 40 mph travel in 0.4 seconds? (40 mph is 59 ft./sec.)

Multiply 59 ft./sec. by 0.4 seconds to get 24 feet.

If the car hits a tree or pole or another car head on, the impact times the force is the same as that shown in Figure 13.

FIGURE 22
DECELERATION FORCE OF A CAR

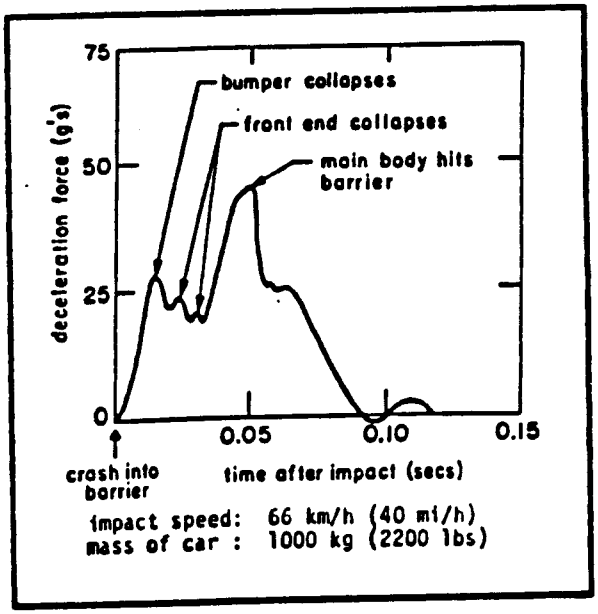



FIGURE 22: Notice that the main body of the car hits the barrier (pole or other car) 0.05 seconds after the original contact. The collapse of the bumper and the front end buys a little time (and does absorb some of the energy of the crash) but this time plus the time between the impact on the main body of the auto and the driver striking the dash (see Fig. 23) are very short.

The main body of a car traveling 40 mph hits the barrier 0.05 seconds after the original contact; during that 0.05 seconds, both the bumper and the front end of the car have collapsed. Figure 23 shows the deceleration force on an unrestrained person. To find out what happens to an unrestrained person in a crash, scientists perform experiments using dummies.

FIGURE 23
DECELERATION FORCE ON UNRESTRAINED DUMMY

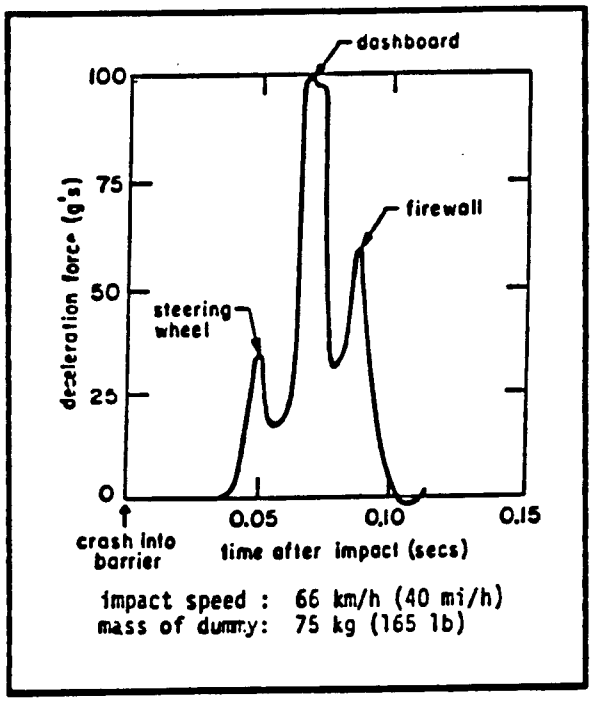



FIGURE 23: Even at this quite modest speed the dummy hits the steering wheel in 0.05 secs. and the dash in 0.07 secs. after the impact on the main body of the car (see Fig. 22) insufficient time for driver to take any protective or avoiding action.

The dummy hits the dashboard 0.07 seconds after the car hits the barrier. This is the same time it takes the ruler to fall half an inch. Were you able to catch the ruler as it fell only half an inch? Your reaction time in catching the yardstick indicates your <u>best possible</u> time in starting to react; it does not include the time it takes to raise your hands to your face or to the dashboard, nor does it allow any safety factor. Can you brace yourself with your hands?

Now suppose that you already have your hands braced on the dash at the moment of impact. Let's find out how many G's you can exert with your arms.

**********
Activity 13. How Many Gs?

Have someone hold an ordinary bathroom scale against the wall. Push as hard as you can on the scale and record the number of pounds of force you can exert with your arms. One G is your own body weight; two Gs is twice your body weight, and so forth. Divide the number of pounds by your body weight to find the G's. How many Gs were you able to exert with your arms? FIGURE 23 shows that the force of an unrestrained dummy against the steering wheel is about 35 Gs and against the dash is 100 Gs; how does this compare with the number of Gs you could exert on the scale? In a crash, could you brace yourself with your hands?
**********

**Is it better to be thrown free of the car in an accident?**

(1) You might be thrown through the windshield. If you missed the dash and hit the windshield instead, you would strike it with a force of 50 to 100 Gs. If you weigh 150 pounds this would be a force of 7,500 to 15,000 pounds weight. In addition to a severe headache (concussion or fractured skull), you would undoubtedly suffer cuts and broken bones. After passing through the windshield you would hurtle along until you hit some solid object, a pole, tree, car, or building perhaps.

(2) You might be thrown out of the door. If you were, you might land on the pavement, which is more rigid than a padded dash. Or you could scrape along the ground into and under the oncoming traffic.

Research with dummies in controlled accidents indicates that being thrown free is about 25 times more dangerous than staying in the car.

**Will people be offended if you ask them to fasten their seat belts?**

Polls show that most people are in favor of seat belts. many do not wear them because they do not think about it. A reminder may be enough to get them started wearing seat belts. For those who find that seat belts rub against their necks, soft covers are available for the shoulder harness to eliminate this problem.

**What are your chances of being in a serious accident?**

Remember what was said in Chapter 1:

About 20 million people are between the ages of 15 and 19. Ten thousand people in that age bracket are killed in motor vehicle accidents each year. Your chance of being killed in an auto accident is one in 2,000. Wearing a seat belt and shoulder harness reduces this chance by 50 percent, improving your odds to one in 4,000. Not drinking and driving yourself and not riding with someone who drives after drinking improves your odds to one in 8,000. It is estimated that every person in the U.S. can expect to be in an accident once every ten years.

**Do you need a seat belt to drive locally, usually under 40 mph?**

Statistics on all accidents involving fatalities or serious injury show that 80 percent of such accidents occur at speeds under 40 mph. Seventy-five percent of deaths or injuries occur within 25 miles of home. Look back to the description of the head-on crash between two small cars at the start of this chapter.

**If the seat belt lets you lean forward to adjust the radio or get something from the glove compartment, won't it do the same thing in a crash?**

The seat belt is designed to allow you free movement in all ordinary conditions and to lock during a crash. Figure 24 shows the operation of the seat belt lock found in most cars. The pendulum swings forward when the car stops suddenly.

FIGURE 24
THE SAFETY BELT AND HOW IT WORKS

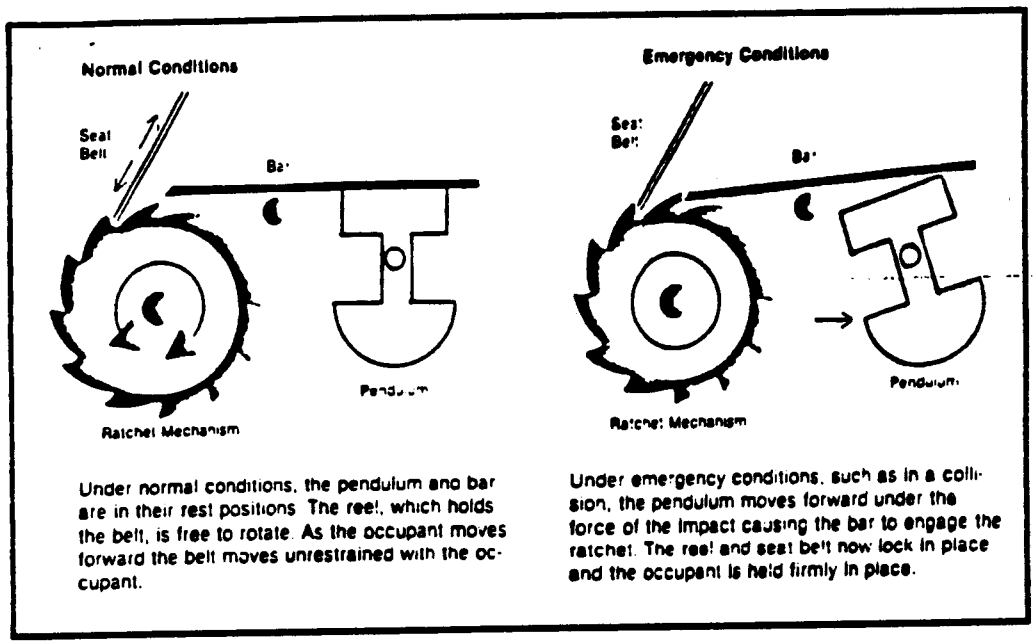



FIGURE 24: Shows the operation of the seat belt lock found on most cars. Notice that the pendulum swings forward as the car stops.

Safety belts are effective if they are used. how can we get people in the United States to use them?

This problem involves both technology and society. It has been attacked through education, legislation, and technology.

If you do not have a safety belt in the car, you cannot use it. The first major push to get people to use belts was to require their installation in all cars.

## HISTORY OF RESTRAINT SYSTEMS IN THE U.S.

The following is a short history of restraint systems in the United States.

1964 Major auto corporations in the U.S. make the lap belt standard on all cars.

MVSS #208 (page XX) required occupant protection according to the following sequence

1966 Lap belts

1968 Lap and torso belts in front

1972 Three-point lap belt with non-detachable torso belt

1973 Belt locking system integrated with starter system so that car would not start if person sitting in the driver's seat did not connect the belt.

1974 Restraint system could be active (occupant puts belt on) or passive (belt is automatically across body when door is closed)

1977 Passive restraint options clarified - belt or air bag.

1978 Passive restraints scheduled for eventual installation as follows:

1978 All large cars
1983 All medium-sized cars
1984 All cars including sub-compacts

**What took so long?**

Seat and torso belts were standard equipment for pilots in all World War II aircraft. Even so, people questioned whether

the average person could withstand the force of the belt on the body in a car crash. Colonel Stapp of the U.S. Air Force undertook a research project to find out how much force a belted person could withstand. He and his research team developed a rocket powered sled that could be sent down a track and then stopped as abruptly as a car would be in a head-on crash. Stapp actually rode the sled at 600 mph coming to a stop in 1.4 seconds.

Using the equation to find acceleration (a) or deceleration (d):

$$a = (V_f - V_i)/t$$

$$V_f = 0$$

$$V_i = 600 \text{ mph or } 880 \text{ feet/sec.}$$

$$t = 1.4 \text{ sec.}$$

So: $a = (0 - 880)/1.4 = -629$ ft./sec./sec.

One G is an acceleration or deceleration of 32.2 ft./sec./sec., the acceleration due to gravity.

So a deceleration of 629 ft./sec./sec. is 19.56 or 20 Gs.

Stapp experienced an average force on his body 20 times greater than gravity, as if his weight had increased 20 times. When the sled first began to stop the actual force was 40 Gs. Stapp was wearing a very wide double shoulder harness and seat belt. Except for bruises, he was not injured. He proved that the human body properly supported could withstand tremendous deceleration in a crash.

A car crashing at 40 mph into a barrier and stopping in 0.125 seconds exerts an average deceleration of 15 Gs on the body. If the person is attached to the car by a harness, that

15 Gs is spread over the entire 0.125 seconds. If the person is free to bounce around, he or she decelerates with a momentary force of 35 Gs while hitting the steering wheel and 100 Gs on the head as it hits the windshield.

A look at the history of Federal Motor Vehicle Safety Standards shows how the Congress and the Department of Transportation have wavered between strict application of technology and little or no application of technology and between strict enforcement of requirements on drivers and no enforcement.

In February 1966, President Johnson said that highway deaths were second only to the Vietnam War as the "gravest problem before this nation." Actually, the annual highway death rate was greater than that of the Vietnam War.

Acting with unusual speed, Congress formed the National Traffic Safety Bureau on September 9, 1966 and passed a number of Federal Motor Vehicle Safety Standards (FMVSS).

One of these, FMVSS 208 concerned occupant restraints and required that all cars manufactured after 1966 be equipped with lap belts for the driver and all passengers, front and back.

The next regulation under FMVSS 208 required that all front seats be equipped with both lap and shoulder harness by 1968. Connecting the shoulder harness with the lap belt at the buckle was difficult and inconvenient; even so the General Accounting Office concluded that the initial FMVSS requirements saved over 28,000 lives between 1966 and 1974.

The next requirement under FMVSS 208 was to begin with the 1973 model cars: all passenger restraints had to be connected to an interlock system that would not allow the engine to start if

the driver's seat belt was not fastened. Congress received so many complaints about possible mechanical problems and individual freedom that the requirement was repealed.

Controversy continued in 1975 and 1976 regarding passive restraints with the National Association of Insurance Commissioners, two physicians' associations, and various public interest groups on one side and the major auto manufacturers on the other; the National Highway Traffic Safety Administration (NHTSA) was caught in the middle.

**PASSIVE RESTRAINTS**

Passive restraints do not require the occupant to buckle, push a switch or anything else to be protected. Manufacturers wanted to delay mandatory installation while they did more research on air bags and on harnesses attached to the door that restrained the front seat passengers when the door was closed. In May 1976, the secretary of transportation promised a final decision by August. Politicians were betting that his decision would wait until after the presidential election in November. In August, Secretary William Coleman said that he was still getting comments and suggestions on the issue but he proposed five alternatives. He promised a decision before the end of 1976. After a delay, the Department of Transportation made additions to FMVSS #208 that required manufacturers to install passive restraint systems in all cars beginning with the 1982 models. In 1981, DOT revoked those provisions. In June 1983, the U.S. Supreme Court ordered DOT to reconsider the ruling, saying that the revocation was "arbitrary and capricious".

In 1984, New York and New Jersey became the first states to pass seat-belt laws: drivers of cars in which driver and front seat passengers were not belted could be fined. In New York a car could be stopped for the specific purpose of checking on seat belt use, and the driver could be fined up to $50.00. In New Jersey, the driver had to be suspected of a moving violation before he or she could be stopped, and then the driver could be fined $20.00 for failure to use seat belts.

In July 1984, U.S. Secretary of Transportation Elizabeth Dole promised a mandatory passive restraint law that would require auto manufacturers to provide passive restraints in 10 percent of the cars made for sale in the U.S. after September 1, 1986. The restraints were to protect occupants of front seats in crashes up to 30 mph. After September 1, 1987, 25 percent of cars must be so equipped; 40 percent after September 1, 1988, and 100 percent after September 1, 1989.

This law is to be withdrawn if States having populations adding up to two-thirds of the total U.S. population enact mandatory seat belt use laws that meet federal criteria by April 1, 1989. The New Jersey law was purposely designed not to meet the federal criteria so that its population could not be counted to withdraw the law.

By December 1984, Secretary Dole and a group of insurers were in court fighting the revocation provision. The insurers contended that despite a 14-year delay in implementation of the

FMVSS 208 rule, the court should not decide the case for several more years. If the court then rules against DOT, it would be several more years before a new rule was attempted.

The U.S. Government seems to be set against making a firm rule regarding safety. Why? Partly because the Government itself is complex and partly because analyzing data from competing sources on the safety of different systems is complex.

**How does a Passive Restraint System work?**

Passive systems are of two basic types: air bags and automatic seat belts and shoulder harnesses.

Air bags work by combining a Newtonian Law of Motion and a chemical reaction. The same principle that makes an unrestrained passenger hit the windshield - momentum - is used to move the trigger that inflates the air bag. A small mass is held in place by a magnet or a spring. When the car stops suddenly (hitting a barrier at 25 mph) the mass in the air bag sensor continues to move forward. It has only about one inch to travel before it makes electrical contact and a spark occurs inside a container containing 1.0 to 1.5 lb. of sodium azide. The sodium azide breaks down into nitrogen gas and a harmless salt. Within 0.02 seconds, the nitrogen gas fills a bag located in the hub of the steering wheel or in the glove compartment section of the dash in front of the front seat passenger. During this time, the occupant has moved forward in the car at the rate of 44 ft./sec. or about 10 inches. The air bag has moved toward the occupant a distance of about one foot if it is in the steering wheel, or two feet if it is in the dash. The occupant is slowed down by the

cushioning effect of the inflated bag. The bag is made of a porous material that deflates quickly so that it does not bounce the person back as a rubber balloon would. Since it takes about 0.5 seconds for the passenger's head to stop moving forward, the acceleration is a = v/t or a = 44 ft./sec. /0.5 sec. = 88 ft./sec.$^2$ = 2.75 Gs. The force is about 2.75 times the weight of the head and shoulders or approximately 150 lb. total spread over the entire head and shoulders. Without restraint the force would be 100 Gs just on the head.

This system sounds so straightforward you may wonder why it has been delayed so long. The description explains what happens in a head-on or partial (up to 45 degree from head-on) head-on collision. The air bag alone does not offer protection against rear-end collision, side collisions, a panic stop which is not great enough to set off the air bag, roll over, or broadside into a tree or pole.

**********
Activity 14. For and Against Restraints

Find out what arguments the pro-air bag faction offer in campaigning for its installation in all cars and what arguments those against it use. What groups are for air bags and what groups are against them? For what reasons do people oppose the mandatory use of seat belts? Do you agree with those who believe it is an infringement of personal freedom if the laws force them to buy air bags, to use seat belts, or to wear crash helmets if they drive motorcylces?
**********

## HOW MUCH CAN WE AFFORD FOR SAFETY?

TABLE 4 ranks safety measures by cost for a 10-year period. For example, it is estimated that it would cost $45,000,000 to enforce a mandatory seat belt use law over a period of 10 years.

It is also estimated that such enforcement would save 89,000 lives during that 10 years at a cost of $506 per life saved. This is undoubtedly a bargain. Item number 37 shows that it would cost $4,530,000,000 to realign and grade enough roads to save approximately 590 lives in 10 years. This would cost about $7,680,000 per life saved. All the programs in items 1-37 would cost $41,587,900,000 over a period of 10 years, or $4.16 billion per year. This would add a considerable amount to the Department of Transportation Budget, and would undoubtedly be vetoed by both Congress and the President.

TABLE FOUR

RANKING OF COUNTERMEASURES BY DECREASING COST EFFECTIVENESS IN PRESENT VALUE DOLLARS PER TOTAL FATALITIES FORESTALLED — 10-YEAR TOTAL

| | Fatalities Forestalled (A) | Cost ($ millions) (B) | Dollars Per Fatality Forestalled (C) |
|---|---|---|---|
| 1. Mandatory Safety Belt Usage | 89,000 | 45.0 | 506 |
| 2. Highway Construction and Maintenance Practices | 459 | 9.2 | 20,000 |
| 3. Upgrade Bicycle and Pedestrian Safety Curriculum Offerings | 649 | 13.2 | 20,400 |
| 4. Nationwide 55 mph Speed Limit | 31,900 | 676.0 | 21,200 |
| 5. Driver Improvement Schools | 2,470 | 53.0 | 21,400 |
| 6. Regulatory and Warning Signs | 3,670 | 125.0 | 34,000 |
| 7. Guardrail | 3,160 | 108.0 | 34,100 |
| 8. Pedestrian Safety Information and Education | 490 | 18.0 | 36,800 |
| 9. Skid Resistance | 3,740 | 158.0 | 42,200 |
| 10. Bridge Rails and Parapets | 1,520 | 69.8 | 46,000 |
| 11. Wrong-Way Entry Avoidance Techniques | 779 | 38.5 | 49,400 |
| 12. Driver-Improvement Schools for Young Offenders | 692 | 36.3 | 52,500 |
| 13. Motorcycle Rider Safety Helmets | 1,150 | 61.2 | 53,300 |
| 14. Motorcycle Lights-On Practice | 65 | 5.2 | 80,600 |
| 15. Impact Absorbing Roadside Safety Devices | 6,780 | 735.0 | 108,000 |
| 16. Breakaway Sign and Lighting Supports | 3,250 | 379.0 | 116,000 |
| 17. Selective Traffic Enforcement | 7,560 | 1,010.0 | 133,000 |
| 18. Combined Alcohol Safety Action Countermeasures | 13,000 | 2,130.0 | 164,000 |
| 19. Citizen Assistance of Crash Victims | 3,750 | 784.0 | 209,000 |
| 20. Median Barriers | 529 | 121.0 | 228,000 |
| 21. Pedestrian and Bicycle Visibility Enhancement | 1,440 | 332.0 | 230,000 |
| 22. Tire and Braking System Safety Critical Inspection — Selective | 4,591 | 1,150.0 | 251,000 |
| 23. Warning Letters to Problem Drivers | 192 | 50.5 | 263,000 |
| 24. Clear Roadside Recovery Area | 533 | 151.0 | 284,000 |
| 25. Upgrade Education and Training for Beginning Drivers | 3,050 | 1,170.0 | 385,000 |
| 26. Intersection Sight Distance | 468 | 196.0 | 420,000 |
| 27. Combined Emergency Medical Countermeasures | 8,000 | 4,300.0 | 538,000 |
| 28. Upgrade Traffic Signals and Systems | 3,400 | 2,080.0 | 610,000 |
| 29. Roadway Lighting | 759 | 710.0 | 936,000 |
| 30. Traffic Channelization | 645 | 1,080.0 | 1,680,000 |
| 31. Periodic Motor Vehicle Inspection — Current Practice | 1,840 | 3,890.0 | 2,120,000 |
| 32. Pavement Markings and Delineators | 237 | 639.0 | 2,700,000 |
| 33. Selective Access Control for Safety | 1,300 | 3,780.0 | 2,910,000 |
| 34. Bridge Widening | 1,330 | 4,600.0 | 3,460,000 |
| 35. Railroad-Highway Grade Crossing Protection (Automatic gates excluded) | 276 | 974.0 | 3,530,000 |
| 36. Paved or Stabilized Shoulders | 928 | 5,380.0 | 5,800,000 |
| 37. Roadway Alignment and Gradient | 590 | 4,530.0 | 7,680,000 |

The table shows the cost per fatality of various countermeasures against highway deaths. If we estimate that each fatality costs society $140,000, Countermeasures 1 through 17 are cost-beneficial.

All countermeasures shown have the same goal: saving lives. Mandatory belt use would accomplish this goal at the least cost. This means it is the most *cost-effective* of the countermeasures.

**********
Activity 15. The Cost of Safety

Suppose that a compromise figure of $2 billion per year for the next 10 years were to be made available. What programs would you recommend for full support and why? What partial funding would you recommend for the remaining programs?

Of the programs you recommend for full support, describe how you would spend the money for five of them. For example, if you choose number 2, what specific highway construction and maintenance practices would you recommend and why?
**********

SUMMARY

**In this chapter you have learned**

(1) that there will always be auto accidents as long as there are autos and roads

(2) that we can reduce the damage caused by improving the design of many parts of the auto

(3) that the excuses people give for not wearing seat belts don't bear examination; **always** wear your seat belt -- you'll live longer -- in one piece!

(4) that other restraints can reduce crash injuries

(5) that all safety measures cost money and that we may have to choose those which give the best return per dollar -- or, more realistically, per million dollars.

**That's it folks.** That about wraps it up -- well not quite. We're going to a concluding chapter in which we think about the whole subject of road safety and suggest some things you might like to do.

# CHAPTER 7

## CONCLUSIONS

If you have studied this course carefully, and thought about it, you should have a good understanding of the seriousness, the extent and the complexity of the problem of auto safety. You should know about Newton's Second Law and the equations of motion. Understanding the science behind the technological problems gives you confidence in handling them: you know what you are talking about. Ask your teacher about Newton's First and Third laws and talk to him or her about how the three laws together form a consistent and coherent system.

You will have realized that there are several aspects of auto safety that we have not discussed; for example, preventative maintenance, radar surveillance, random blood alcohol testing, stiffer penalties for moving traffic violations (particularly drunken driving), motorcycles, and automatic seat-belts, and we have only touched on the subject of the the relative costs and effectiveness of various safety measures. These could be subjects for class discussions. The one you can deal with yourself most effectively is preventative maintenance -- regular and simple checking to ensure that your auto is in safe condition. Ask the driving instructor in your school to talk to the class about maintenance and to show you how to do it. Read your State's driver's manual of rules and regulations -- you have to know its contents in order to pass your driving test. And observe the rules of the road.

You have learned that auto safety is not just a matter of driver behavior. Vehicle design, road design, and road regulations are all involved. Cost must be considered. Perfect safety can never be ensured: politicians, car designers, transport engineers, and pedestrians all make mistakes as well as drivers. We can reduce the frequency of those mistakes and the damage and the injury they cause. But only at a cost. As there is never unlimited money available we have to assess the cost and effectiveness of any measure and of the alternatives.

But the person, the individual, is where it all begins and that is why we have emphasized the role and responsibility of the driver in this concluding chapter. So, over to you, and good luck.

NO, NO, NO! That's the wrong thing to say! The person who relies on luck ends up in those accident statistics. Don't depend on luck, <u>use your head</u>.

**********

Activity 16. <u>Using Your Head</u>

Now, here are a few things you and your fellow students might do:

**(1). Locate a local danger spot:**

- A place that has a high rate of accidents.
- Ask the experts: police, borough manager, local paper, town maintenance group, area state DOT.
- Find newspaper article concerning this spot: locate articles about, accidents at this spot over the past year.
- Map out the area on paper:
  > make a drawing to scale
  > what is the speed limit?
  > are there special warning signs?
  > if there is a traffic light, how long do the various lights take?

- Answer the following questions:
  > Why is it a dangerous spot?
  > What are the factors involved?
  > What precautions were taken to solve this problem?
  > What from this module can be applied to this problem?
  > How does this relate to the equations of motion?
  > To Newton's Second Law?
  > What are the major reasons that this is a problem?
  > Can any of these factors be changed?
  > What are the costs of the alternatives?

- Create a cost and benefit list.
  > Which alternative do you think is best? Why?

- Report your findings to the class.

**(2) Explore a relevant safety issue:**

- Choose an issue like the 65 mph speed limit, airbags, the third breaklight, use of tandem trailers, or stricter drunk driving laws.

- Locate information on the issue.
  > What is the technology involved?
  > What is the science involved?
  > What are the social concerns?
  > What are the various groups involved and what are their positions? List them.

- If this issue has been voted on in Congress, contact your local Congresspersons to find out how they voted and why?

- Answer the following questions:
  > How does this issue affect you, your town, your State?
  > What are the various options?
  > Who supports each option?
  > What are the costs and benefits of each? (list in table) Compare the various options' strengths and weaknesses.
  > Make a decision and defend it. Why is this the best alternative?
  > If the issue has already been decided, what was the decision? Compare with your decision.

- If this issue has not come up before Congress, write a letter to your Congresspersons explaining and defending your position.
  > Report your findings to the class.

**(3) Contact community action groups**

- Find out what various groups exist in your community that are concerned with auto safety issues, for example, SADD, MADD, a coalition for a traffic light, or a PTA Committee.

- Contact the various groups.
  > Are they affiliated with government agencies?

- Locate literature on these groups if any exists.
  > What are the groups concerned about?
  > What technology is involved?
  > Why were the groups formed?
  > What do they do? Do they perform community services? Do they educate groups? Do they lobby for laws and regulations?

- Answer the following questions:
  > Have they been successful? Why?
  > What were their successes? Their failures?
  > What solutions or actions do they propose?
  > What are the costs and benefits of each?

- Report to the class on the various groups.

**********

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PRINCIPLES OF ENGINEERING

# STRUCTURES: A Case Study

# Preface

When people think of engineering they usually think of structures of one kind or another, usually bridges or skyscrapers. This case study is developed around the concerns that engineers have in planning, designing, and building structures. When disasters occur(earthquakes, floods, volcanoes) it becomes necessary to build emergency structures to house temporarily those people who's homes have been destroyed. One such method is to build **tower** structures for the four corners of the building and then fill in the spaces between the towers and install a flat roof. The first activity in this section is to build such a tower.**Appendix A.** Next, the students and teachers have the opportunity of planning, designing, and building a **model bridge** as part of a contest, and/or a **structure** which must be delivered to, and provide shelter for a small group of people in a region of severe cold. Since the shelter must be delivered by plane, it must be able to withstand being dropped, and must be assembled by a group of people who may have no experience in building, and who do not necessarily read English..
This requires that the students be able to calculate heat loss, strength, portability, and ease of construction using a variety of possible materials. They must also develop a communications system for providing the information on how to construct the structure, provide for its transportation from the spot where it lands to a suitable spot for erection.

In meeting the constraints in all three of these projects, the students must use knowledge of physics, chemistry, biology, and weather, and mathematical analysis, and communication skills. All of these skills are exemplified by the well rounded engineer.

# PRINCIPLES OF ENGINEERING

## STRUCTURES: A case Study

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TECHNOLOGY EDUCATION
*PRINCIPLES OF ENGINEERING*
*STRUCTURES CASE STUDY*

## I Case Study Description:

Human kind has been engaged in the building and designing of structures since the beginning of recorded history. The conquest of the environment and the ability to exist anywhere on the planet earth has allowed humans to create the technological wonders we now see as common place. The design and construction of structures is a knowledge built on thousands of years of practical trial and error study and application, and more recently, analysis and simulation of forces acting on structures. The understanding of structures and the forces that act upon them will be explored in this case study. A teacher led discussion on a structural collapse (walkway failure - Hyatt Regency Hotel, 1981) as well as various demonstrations of structural principles should be covered as an introduction to the case study problem. The main focus of this study is building a model structure. The actual type of structure is up to the instructor as two diversely different studies may be generated here (See *Definition of Problem* below). Regardless of the actual structure chosen, the instructor will have the ability to diverge into structural forces, torques and moments of structural members, heat loss and gain, packaging, ergonomics, instructional documentation, mass production and materials processing.

This understanding will be accomplished though a combination fo classroom theory, library research, rough sketch and final designs utilizing CAD and/or Technical Drawing, as well as hands-on experiences in building a model structure.

## II Definition of Problem:

This case study may be divided into two design problem sub-studies: (1) designing for the structural forces acting on a given structure (including static and dynamic loading) and (2) designing for ergonomic considerations (including the comfort levels within a structure, heat loss and gain). Both of these would require the student to research, design and create some structure. In addition to research on structures gathered throughout the case study, students will be expected to support design decisions through mathematical models, computer simulations and simple physics. Depending upon the direction the instructor(s) wishes to direct his/her students, the availability of materials and resources, and time constraints, either sub-study (or both) may be considered.

**Bridge Structure Sub-Study:** Since the study of forces is paramount to understanding why a structure stands up, a study focussed on how forces are distributed and countered may be best demonstrated by having students participate in a bridge building contest. The contest may involve static or dynamic loading of a bridge of pre-determined size and specified materials, spanning a fixed distance. A copy of one such contest is provided at the end of this case study.

**Emergency Shelter Sub-Study:** The original structures study involving a portable survival shelter is still an excellent choice for designing a structure for comfort while concentrating on heat flow considerations.

## III. PERFORMANCE OBJECTIVES AND SUPPORTING COMPETENCIES

1 Using a formalized design brief problem-solving method, the student research design and implement the optimal solution to a given structural problem through laboratory based activities. The problem will involve structural engineering as applied to the proposed design problem and the solution will meet the stated problem criteria and limitations.

In order to do this, the student must be able to:

a. List the steps in the problem-solving process.
b. Employ laboratory-based activities such as:
   - use of construction of models and prototypes
   - use of working drawings, sketches, charts, diagrams, mathematical equations, computer aided drafting, etc.
c. Collect, organize and evaluate data.
d. Use materials, tools, instruments, equipment and procedures safely in a laboratory.

2.1 **BRIDGE STRUCTURE:** Given a structural engineering problem that identifies certain environmental obstacles to be overcome, combined with structural and strength to weight ratio considerations and physical constraints that must be adhered to, the student will prepare final working presentation of the solution.

In order to do this the student must be able to:

a. Understand structures and the forces that act upon them.
b. Understand why structures are designed in the way they are and the relationship between integral members that ma up that structure.
c. Write a final report documenting the case study and its solution
d. Use materials, tools, instruments, equipment and procedures to process design information that will maximize design considerations.

2.2 **EMERGENCY SHELTER STRUCTURE:** Given a structural engineering problem that identifies certain environmental hazards to be overcome, combined with packaging structural and assembly information specifications that must be satisfied, the student will prepare final graphic presentation of the proposed solution.

In order to do this the student must be able to:

a. Understand structures and the forces that act upon them.
b. Understand the limits of human physiology in cold weather situations.
c. Develop a set of structure construction documentation that can be easily followed and implemented.
d. Write a final report documenting the case study and its solution
e. Use materials, tools, instruments, equipment and procedures to process information and communicate a message through drawings, photographs, charts, graphs, and written text.

## V. EXPLANATION OF SPECIFIC MATRIX

### A. EXPLANATION OF HORIZONTAL DESCRIPTIONS

1) **STRUCTURAL FORCES**
In addition to gravity, buildings are subject to winds, snow, earthquakes and internal weight which create both static and dynamic loading. Wind gusts may apply a dynamic load which can cause structures to oscillate.

2) **STRUCTURAL DESIGN**
What structural design can be used to overcome structural forces. A technical understanding of tension, compression, beams, columns, cables, trusses, frames, arches, domes, and membranes should be transmitted to students prior to design work.

3) **ERGONOMICS**
How do people fit into structures that are designed to protect them. What are the various ranges of human sizes that the designer must consider before making an average structure. What are the design considerations for people who must stand, sit, and lie down in shelters.

4) **MATERIALS**
What materials are available to the engineer before the design phase begins. Should the engineer use only materials that currently exist or help create new products to develop the project.

5) **DOCUMENTATION**
What is the importance of documentation in building and construction of structures. How do people communicate ideas and instructions to each other when dealing with complex designs.

6) **PACKAGING**
How are items packaged so that they are protected from damage before being utilized. How is the structure package able to withstand forces that will be placed upon it during delivery.

7) **CONTRACT SPECIFICATIONS**
What are the written requirements of the structure and are they being met by the designer.

# INTRODUCTION TO ENGINEERING
# CURRICULUM DESIGN MATRIX STRUCTURE

| Factors/ Concepts | Structural Forces | Structural Design | Ergonomics | Materials | Documentation | Packaging | Contract Specifications |
|---|---|---|---|---|---|---|---|
| Modeling | Build testing devices to load model | Build model of shelter | Use figures to determine human size requirements of shelter | Test samples of materials | Draw and incorporate documentation into model | Fold and package model to show delivery capability | Determine if model meets requirments |
| Systems | Weather systems forecasting system | Building systems: modular, pre-fab, custom | Explain how much space needed for inhabitants | | Is documentation included into structure as a unit? | Is package part of structure system? | |
| Optimization | Decision to build for maximum force | Structural integrity vis-a-vis portability and assembly | Determine minimum space per individual needed for extended stay | Materials vis-a-vis structural forces | Can instructions be made clear to all survivors? | Is package small enough for storage? | |
| Design | | Sketch, draw, plot final design | Interior space vis-a-vis structural integrity | | Are instructions part of overall design? | Is package designed to be found and opened by survivors? | Does design satisfy specifications? |
| Ethics | Should shelter survive maximum environmental conditions? | Can designer plan on all possibilities and conditions? | Should people be denied entry to shelter in shortages? | Should different materials be substituted? | Should all people be able to construct shelter? | | |
| Technology/ Societal Impacts | | Historical survival shelters and structures | | Materials that have been used in other structures | | | Who gives specifications to other shelter structures? |

## V. BACKGROUND MATERIAL

This case study will expose students to the following engineering applications with a hands-on problem solving, research oriented approach.

**Structural Forces:** To learn about weight and gravity, live loads and dead loads, pressure, wind, static and dynamic loads and their effect on structures of all types and sizes.

**Structural Design:** To comprehend the application of structural design in resisting structural fores. (For example, integrating beams, trusses, cables, membranes, columns, frames, arches, domes and geometric shapes into structures.)

**Environmental Hazards:** To comprehend the physical forces applied to structures such as wind, snow, rain, earthquakes and temperature.

**Human Engineering (ergonomics):** To comprehend the various sizes and shapes of human beings in various physical positions so that structures can be developed for maximum comfort and protection in difficult situations.

**Construction Materials:** To test paper based materials for use in load bearing, thermal resistance and structural capabilities as well as adhesives, fasteners and other structural elements deemed practical for the specified requirements of the emergency shelter.

**Human Physiology:** To research the limits of human capabilities in cold weather and the requirements for extended survival in such climates. Students can obtain much of this data and information in the school library and school science department.

**Design Specifications:** To design and provide accurate plans and dimensions through technical drawing skills that will accurately convey the solution to the problem.

**Product Documentation:** To learn to communicate building instructions to people who would be unskilled and perhaps unable to read instructions in the English language. Simple pictogram instructions could be developed to be printed on the structure or included with the package.

**Packaging:** To design a suitable container and protection that will protect the structure during an air drop situation and provide protection when being stored for use.

Model Building: To construct an exact scale model of the design of, with the ability to support, an exterior load such as Ice or snow (emergency shelter or model bridge). Simple models using paper products (emergency shelter) 3/32" basswood or balsa (model bridge)) and other fasteners (emergency shelter) for this project.

## VI. Project overview, Procedures

A. Application of the design process

**Model Bridge Contest**

The model bridge contest offers a rigorous exercise in developing an analytical solution to a structures problem. In addition to the actual building process the students should be encouraged to research various bridge designs (since many are one - of - a - kind type structures) and determine which would be best to meet the **criteria and constraints** of the specific bridge contest rules. Once the design has been chosen, a method of analysis (nodal or other - see Instruction Sheet #6) should be used to determine member usage. Students should then determine the proper design methods and trade off to create tension and compression members based on the member's function as well as the connections between members. All design ideas, glue tests, joiner sketches and analysis work should be maintained in a team journal.

**Criteria and Constraints:**

Loading: The instructor or class may decide to load the bridge structure statically by placing increasing force on a predetermined spot on the bridge until failure occurs. A dynamic loading can be accomplished by using a small vehicle ( Tonka Truck) that is loaded with successively increased mass and either dragged or pushed across the bridge until failure. In each case a maximum mass might be specified rather than increasing until failure.

Winner: The contest winner is determined using an efficiency formula:

$$\text{Efficiency} = \frac{\text{Mass supported} \times 100}{\text{Mass of bridge}}$$

**Emergency Shelter**

The emergency shelter project is outwardly a fairly simple structure when first looked at by students. The requirements, while fairly straightforward for construction , assembly, delivery, and structural integrity tend to work against each other. Questions such as how can a prefabricated structure unfolded from a package resist extreme snow and wind loading will strain optimization factors to the limits. Other trade - off will come from the students' analysis of package delivery and assembly requirements by freezing-cold survivors. Students will be required to research environmental, ergonomic, and human physiology data in order to provide the best problem solving design brief.

B. Design log/journal and Notebook

Students must keep a design notebook ( one with removable pages) that documents their ideas and progress. The design submitted is to include the final report, the design notebook and files containing any computer related material used in the project. Students must submit the design sketches they develop in the geometry related parts of the design. They must also submit final design drawings to document the geometry related aspects of their design.

A final written report documenting their case study is required. It should include :

1. A table of contents
2. A summary ( a short description of the purpose and results of the studies for the busy reader).
3. An introduction
4. A description of the design solution (The case)
5. A summary of research findings.

6. An appendix documenting your case study design solution with appropriate:

   a. Graphics
   b. Tables
   c. Design sketches and final drawings

7. A complete mathematical analysis for static loading on the bridge design structure including the maximum mass held. The analysis could include information on why and where the structure failed.

C. Rules and Specifications for Structures Engineering Case Study

Project - Model Bridge

Decide on span of the bridge
Decide on physical constraints of the bridge
Decide on physical makeup of the bridge
Decide on static or dynamic loading

Design, construct and test a model bridge to be built to the specifications decided in class within six weeks of delivery of RFP (Request for Proposal)

1. Gap Span: length (300mm - 500mm) See Instruction Sheet #7)
2. Bridge Size: length, width and height
3. Allowable Designs: substructure, superstructure or both, required roadbed
4. Allowable Materials: 3/32 basswood, balsa, glue types, wire, string, etc.

Project-Emergency Shelter

Request for Proposal
Agency - Federal Administration of Aviation
Open Bidding
Project - POE - 1992
Shelter, Portable, Emergency Rescue, Cold Weather Type

Design, construct and test an emergency rescue shelter to be built to the following specifications within six weeks of delivery of RFP (Request for Proposal).

1. Shelter Capacity - Protect five adults for three days.

2. Construction Materials - Standard corrugated cardboard in multiple layers as needed, additional composite materials, hardware as required for fastening, anchoring, packaging, etc.

3. Interior temperature to be maintained at 50°F when exterior temperature is -20°F.

4. Capable of air drop to landing site.

5. Construction time 30 minutes maximum.

6. Instructions for construction to be printed on packaging or structure using pictograms and numerals only.

7. Cold weather survival instructions to be displayed on inside of structure using pictograms and numerals only.

8. Structural capacity must withstand two foot snowfall and 50 MPH wind loading.

9. Shelter package must be capable of being transported 1/4 mile by one survivor.

VII. Suggested Evaluation Methods

D. Project Requirements - Model Bridge Contest

1. Research report - 10% of project grade
2. Sketches and final drawing(s) - 15% of project grade
3. Analysis of model - 25% of project grade
4. Construction of model - 20% of project grade
5. Bridge efficiency - 30% of project grade

Project Requirements - Emergency Shelter

1. Research Report - 20% of project grade.

2. Preliminary Sketch - 10% of project grade.

3. Analysis of student reasoning for the particular design approach utilized - 10% of project grade.

4. Orthographic projection of shelter parts and details drawn to scale of 1" = 1'-30% of project grade.

5. Construction of model shelter from corrugated paper - 20% of project grade.

6. Demonstration of shelter air drop and assembly capabilities 10% of project grade.

E. Requirements of Research Report, Due 3rd Week
Model Bridge

1. 1-page report on bridge types
2. Glue/wood-joint testing for tension and compression
3. Roadbed designs
4. Log/Journal check #1

Requirements of Research Report, Due 3rd Week
Emergency Shelter

1. 1-page report on effects of hypothermia.

2. Static load capabilities of corrugated cardboard, etc.

3. Average wind force above 1,000 ft. altitudes.

4. Average 24-hour snowfall above 1,000 ft. altitude in North America.

5. Breathing air needed for 5 people per hour.

6. Human ergonomics for sleeping sitting and standing.

F. Preliminary Sketch - Due in 4th week

Paper and pencil drawings to include:
1. Isometric sketch/or 3-D
2. Orthographic projection

G. Analysis, Design and Construction - Due 6th Week
Model Bridge

1. Two-page report on design choice including preliminary model analysis
2. Completed sketches and final scale drawings
3. Completed Roadbed designs
4. Log/Journal check #2
5. Class presentation
6. Bridge Contest
7. Bridge Efficiency and final analysis

Emergency Shelter

1. Two page report on why various decisions were made to satisfy design parameters and construction requirements, including heat loss characteristics of design.

2. Orthographic projection of shelter, Scale 1" = 1', CAD or TRAD (Drafting Board).

3. Construction of model shelter from corrugated cardboard stock or foamboard. Scale of 1" = 1' to be utilized.

4. Report to class on design and demonstrations of air drop and assembly capabilities.

## VIII. Case Study Timetable

**Week 1 - *Structures***

| Suggested Periods | |
|---|---|
| 1 | A. Explanation of the design problem in structures. |
| 1 | B. Discuss the following items:<br>Rules and specifications<br>Research needed<br>Evaluation of project<br>Materials and resources available |
| 2 | C. Lesson - Structures<br>"Architecture and Engineering" teachers manual<br>forces<br>equilibrium<br>tension<br>compression |
| 1 | D. Lesson - Heat loss equations and formulas for Delta T analysis. |
| 2-3 | - Nodal analysis for structures and trusses. Homework/classwork on moments, tension, compression and equilibrium (See Instruction Sheet #6) |

WEEK 2 - *Structures*

Suggested
Periods

2 A. Lesson - Structures
"Architecture and Engineering" teacher manual
Beams and columns
Cables
Trusses
Arches and domes

2 B. Lesson - Orthographic projection

1 C. Structural collapse analysis (e.g., Hyatt Regency, Galloping Gertie, etc.)

WEEK 3 - *Structures*

Suggested
Periods

.5 A. Divide class into design groups of size, explain job assignments.

.5 B. Review project requirements and optimization of solution.

1 C. Review research reports and have teams share data with groups.

2 D. Brainstorming ideas by groups to determine optimal solutions to engineering of structure.

1 E. Preliminary sketch and orthographic projection work session in class. (continue for homework)

WEEK 4 - *Structures*

Suggested
Periods

2 A. Brainstorming final team concepts for structure.

1 B. Team assignments and concepts are reviewed by instructor

2 C. Work sessions

WEEK 5 - *Structures*

Suggested
Periods

5 A. Team work sessions
Individual team members are engaged in project final construction and testing.

WEEK 6 - *Structures*

Suggested
Periods

2 A. Team work session

2 B. Report to class on final design,

1 C. Review of case study on structures.

1 D. Bridge Contest and final analysis of design.

1 E. Hand in Log/Journal for final evaluation.

IX. Resources for Students and Teachers

A. Instruction Sheets

1. Wind Pressure
2. Heat Loss Formulas
3. Heat Loss BASIC Program
4. Heat Loss PASCAL Program
5. Engineering Careers
6. Understanding Static Forces on a Bridge/Truss Structure
7. Sample Bridge Contest

B. Books

1. Required Teachers Manual
2. Suggested Books on Structures
3. Hyatt Regency Investigation Report
4. Bibliography

C. Videotapes

1. Why Buildings Stand Up Series
2. To Engineer Is Human
3. The Brunel Experience

D. Equipment and Materials

*Instruction Sheet #1*

Wind Pressure

The equation for the pressure p due to a wind velocity V: p (kg/m2)=0.00488 V2 (KPH squared); p(PSF)=0.00256 V2 (mph squared).

Wind Pressure Table

| Wind Velocity mph | Wind Pressure psf |
|---|---|
| 0 | 0 |
| 10 | .256 |
| 20 | 1.024 |
| 30 | 2.304 |
| 40 | 4.096 |
| 50 | 6.400 |
| 60 | 9.216 |
| 70 | 12.544 |
| 80 | 16.384 |
| 90 | 20.736 |
| 100 | 25.600 |

Example: V=60 mph (0.00256 x V2) = PSF
0.00256 x 60 2 = 9.216PSF

*Instruction Sheet #2*

Heat Loss Formulas

Reference: Architecture Drafting and Design
Donald E. Hepler, Sixth Edition,
Glencoe-McGraw-Hill, 1991 - ISBN-0-07- 028322-2, pgs. 508-514

Shelter Heat

1 Watt = 3.413 BTU/HR
1 Person = 108 Watts
1 Person = 369 BTU/HR
5 People = 1843 BTU/HR

## Shelter ΔT (Delta T) Temperature Difference

| | | |
|---|---|---|
| Outside Temperature | = | -20 F |
| Inside Temperature | = | 50 F |
| Δ Temperature | = | 70 F |

## Shelter Surface Area

Surface area is written as A in square feet
A = ? (depends on design)

## Shelter Wall Material R Values

| | |
|---|---|
| Corrugated Cardboard | R= .184 |
| Exterior Air Film | R= .5 avg. |
| Interior Air Film | R= .5 avg. |
| Interior Reflective Film (Foil) | R = 1.32 |

## Total of R Values

RT = R1 + R2 + R3 + R4

| | |
|---|---|
| Exterior Air Film | .5 |
| Interior Air Film | .5 |
| 15 Layers Cardboard | 2.76 |
| Interior Film | 1.32 |
| Total R = | 5.08 |

## Combined Thermal Conductivity

This is called the U Factor. U is the reciprocal of R and is obtained by the formula U = 1/R

If R = 5.08 then U = .196

## Heat Loss Formula

Area x U Factor x ΔT = Heat Loss in BTUs
HL = A x U x ΔT

Example

Total shelter area = 180 square feet
HL = 180 x .196 x 70 = 2469 BTU/HR
5 Person BTU output = 1843 BTU/HR
Problem: Heat loss through walls greater than heat generated by people inside.

Possible Solution

1. Reduce Area?
2. Increase R Value
3. Reduce Acceptable Inside Temperature?
4. Use Other Materials?
5. Etc.

***Instruction Sheet #3***

BASIC program to calculate "R" value of shelter given various variables.

Students can quickly test their structure theory to determine if the BTU output of the human inhabitants will be sufficient to heat the structure.

This program is designed to compliment the heat loss formulas contained in the case study instruction sheet #2.

*Basic Program*
*for*
*INSTRUCTION SHEET #3*

```
20 COLOR 5,9,3:CLS
30 PRINT:PRINT:PRINT"                                   Principles of Engineering"
40 PRINT"                                   Structure Case Study"
50 PRINT"                                   Myron B. Rock"
60 PRINT"                                   Engineering Software Project"
70 PRINT:PRINT:PRINT" Calculation of 'R' Value  :"
80 PRINT:PRINT:INPUT" Please enter the inside temperature(degrees F) ...";TI
85 PRINT:INPUT" Please enter the outside temperature(degrees F) ...";TO
90 PRINT:INPUT" Please enter the number of occupants in the shelter ... ";N
95 PRINT:INPUT" Please enter the area of the shelter ... ";AREA
96 PRINT:INPUT" How many layers of cardboard are needed ... ";THICK
100 R=.184
101 TR=(THICK*R)+2.5
102 TW=THICK*.125
103 REM ** R Value plus outside and inside airfilm plus vapor seal = 2.5 **
110 TD=TI-TO
120 HEATLOSS=AREA*(1/TR)*TD
 30 PRINT:PRINT:PRINT" The heat loss of this system is ";:PRINT HEATLOSS;:PRINT"
 BTU'S"
135 PRINT:PRINT" Heat output of occupants is ";:PRINT N*368:PRINT" BTU's"
140 PRINT:PRINT" The total Rval is ";:PRINT TR
150 PRINT:PRINT" The thickness of the wall is ";:PRINT TW;:PRINT" inches."
```

```
(*********************************************************************
*            Instruction Sheet #4  - Structures Case Study            *
*   PASCAL program for determining 'R' value - Principles of Engineering
*   Original BASIC program by Myron B. Rock.  Rewrite by Glen P. Botto
*            Written in TURBO PASCAL Version 6.0   -   1995          *
*********************************************************************)
Program R_Value(Input, Output);

Uses
     Crt;     { For ClrScr GotoXY routines }
Const
     R = 0.184;  { R Value + outside and inside airfilm + vapor seal = 2.5 }
     ESC = #27;

Procedure Calculator(I_Temp, O_Temp, Area : Real; Num_Occ, Layers : Integer);
{ PRE : I_Temp = Inside Temperature, O_Temp = Outside Temperature, Area =
        Area of Shelter, Num_Occ = Number of Occupants, Layers = Number of
        Cardboard Layers.
  POST: Calculates and Displays heatloss information on the shelter.      }
Var
   HeatLoss, R_Value,  Wall_Thickness : Real;
   X, Y : Byte;
Begin { Calculator }
      R_Value :=  (Layers * R) + 2.5;
      Wall_Thickness := Layers * 0.125;
      HeatLoss := Area*(I_Temp-O_Temp)/R_Value;

      TextColor(LIGHTCYAN);
      X := 14;
      Y := 18;
      GotoXY(X,Y);
      Write('The Heat Loss of this system is: ',HeatLoss:6:2,' BTU''s');
      GotoXY(X,Y+1);
      Write('The Heat Output of the Occupants is: ',Num_Occ * 368,' BTU''s');
      GotoXY(X,Y+2);
      Write('The Total R-Value of this system is: ',R_Value:6:2);
      GotoXY(X,Y+3);
      Write('The Thickness of the wall is: ',Wall_Thickness:6:2,' inches.');
End; { Calculator }

Procedure GetInput(Var I_Temp, O_Temp, Area : Real;
                   Var Num_Occ, Layers:Integer);
{ PRE : Same as Calculator above.
  POST: All information fields are filled.                              }
Var
   X, Y : Byte;
Begin { GetInput }
        X := 14;
        Y := 10;
        TextColor(YELLOW);
        GotoXY(X,Y);
        Write('Enter the Inside Temperature in degrees F: ');
        Readln(I_Temp);
        GotoXY(X,Y+1);
        Write('Enter the Outside Temperature in degrees F: ');
        Readln(O_Temp);
        GotoXY(X,Y+2);
        Write('Enter the Number of Occupants in the shelter: ');
        Readln(Num_Occ);
```

```
      GotoXY(X,Y+3);
      Write('Enter the Area of the Shelter in Square Feet: ');
      Readln(Area);
      GotoXY(X,Y+4);
      Write('Enter the Number of Pieces of Cardboard Required: ');
      Readln(Layers);
      GotoXY(X,Y+5);
End;  { GetInput }

Procedure OpeningScreen;
{ PRE : NONE
  POST: Main Opening Screen.        }
Var
   X, Y : Byte;
Begin  { OpeningScreen }
       X := 28;
       Y := 3;
       TextBackGround(BLUE);
       TextColor(CYAN);
       ClrScr;
       GotoXY(X,Y);
       Write('PRINCIPLES OF ENGINEERING');
       GotoXY(X+2,Y+1);
       Write('STRUCTURE CASE STUDY');
       GotoXY(X-1,Y+2);
       Write('ENGINEERING SOFTWARE PROJECT');
       GotoXY(X+2,Y+4);
       TextColor(WHITE);
       Write('CALCULATION OF ''R''VALUE');
       Writeln;
End;   { OpeningScreen }

Procedure MainEvent;
{ PRE : NONE
  POST: Calls all routines and opening screen .          }

Var
   IT, OT, Ar : Real;
   NOcc, Lrs  : Integer;
   Ch : Char;
Begin { MainEvent }
     Repeat
            OpeningScreen;
            GetInput(IT, OT, Ar, NOcc, Lrs);
            Calculator(IT, OT, Ar, NOcc, Lrs);
            TextColor(LIGHTRED+BLINK);
            GotoXY(13,23);
            Write(#7,'Press ESCape to Quit or any other key to do another');
            Ch := Readkey;
     Until Ch = ESC;
End;  { MainEvent }

Begin  { MAIN }
       MainEvent;
       ClrScr;
End. { MAIN }
```

*Instruction Sheet #* 5

## A. CAREERS - ENGINEERING CAREERS IMPLICATIONS

### *Civil and Construction Engineering*

Civil engineers plan, design, and supervise the construction of facilities essential to modern life in both the public and private sectors--facilities that vary widely in nature, size and scope, space satellites and launching facilities, offshore structures, bridges, buildings, tunnels, highways, transit systems, dams, airport, irrigation projects, treatment and distribution facilities for water, and collection and treatment for wastewater.

Construction engineering is concerned primarily with the design and supervision of construction of buildings, bridges, tunnels, and dams. The construction industry is one of America's largest industries. Geotechnic investigations, such as in soil mechanics and foundation investigations, are essential not only in populated areas but also for successful conquest of new lands such as Antartica , below the sea, and extraterrestrial surfaces. Transportation systems include the planning, design, and construction of necessary roads, streets, thoroughfares, and superhighways. Engineering studies in water resources are concerned with the improvement of water availability, harbor and river development, flood control, irrigation, and drainage. Pollution is an ever-increasing problem, particularly in urban areas. The environmental engineer is concerned with the design and construction of water supply systems, sewerage systems, and systems for the reclamation and disposal of wastes. City planning and municipal engineers are concerned primarily with the planning of urban centers for the orderly, comfortable, and health growth and development of business and residential areas. Surveying and mapping are concerned with the measurements of distances over a surface (such as the earth or the moon) and the location of structures, rights-of-way, and property boundaries.

Civil engineers engage in technical, administrative, or commercial work with manufacturing companies, construction companies, transportation companies, and power companies. Other opportunities for employment exist in consulting engineering offices, in city and state engineering departments, and in the various bureaus of the federal government.

*INSTRUCTION SHEET #6*

A. UNDERSTANDING STATIC FORCES ON A BRIDGE/TRUSS STRUCTURE

The simple reason why structures such as buildings and bridges stand up is in part due to Newton's third law of motion. Roughly stated, "For every Action Force, there is an equal and opposite Reaction Force". Structures are able to counter any acting force (called an **ACTION FORCE**) such as weight and wind with a combined resistive force called the **REACTION FORCE**. The structure's engineered materials and their interconnections (called nodes) must be carefully calculated so that all Action forces may be countered. If the Reaction force equals the Action Force, the structure remains at rest or **EQUILIBRIUM**. Otherwise, motion results (Newton's second law) which could lead to the failure of that structure. It is important to note that some motion is necessary to achieve a new equilibrium.

These concepts are mathematically expressed in the following manner:

$$\Sigma F_Y = 0 \qquad \Sigma F_X = 0 \qquad \Sigma M_a = 0$$

(the Greek symbol Σ (sigma) means the sum of)

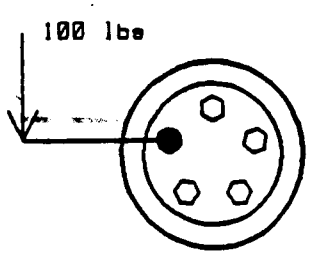
where:

$\Sigma F_Y = 0$ which means the sum of all of the forces acting in the "Y" or vertical direction cancel - or for every force acting downward, something in the structure must react upward to cancel it;

$\Sigma F_X = 0$ which means the sum of all of the forces acting in the "X" or horizontal direction cancel - or for every force acting to the left, something in the structure must react to the right to cancel it;

$\Sigma M_a = 0$ which means sum of all of the **MOMENTS** about a structural member connection "a" (also known as a **NODE**) cancel - or the sum of **TORQUES** about node "a" is zero. A Torque or a Moment takes place when a force acts some distance away from the Node in question. Moment calculations involve multiplying a Force and a Distance (displacement) that are perpendicular to each other.

A classic example involves a lug wrench/socket and a car's tire. The **MOMENT** about the lug is the product of the force you apply and the distance away from the lug the force is applied. If you are using a 20" breaker bar and the bar is pointing to the left when you apply 100 lbs of force on its end, in a downward direction, you apply a **TORQUE** or **MOMENT** about the lug. The calculation is simple since the force is perpendicular to the distance:



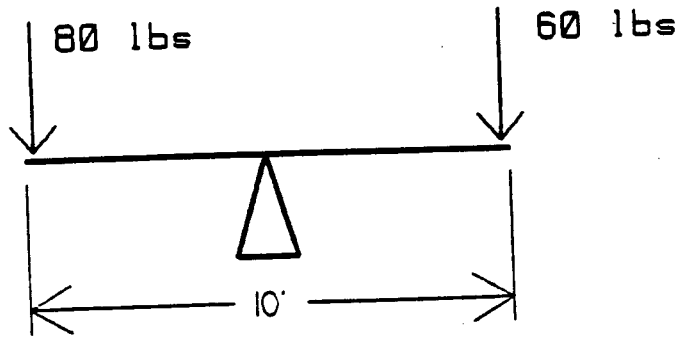

$M_{LUG}$ = Distance x Force
$M_{LUG}$ = 20" x 100 lbs
$M_{LUG}$ = 2000 in·lb.

Increasing the length of the breaker bar will gain some "mechanical advantage" which increases the **MOMENT** or **TORQUE** value.

Several simple examples follow to help in the analysis of a structure.

:xamples:

a.) Consider a teeter-totter that has a length of 10 feet and a placed underneath, in the center of the teeter-totter, is a supporting fulcrum. An 80-lb student sits on one end at the same time a 60-lb student sits on the other. What happens?



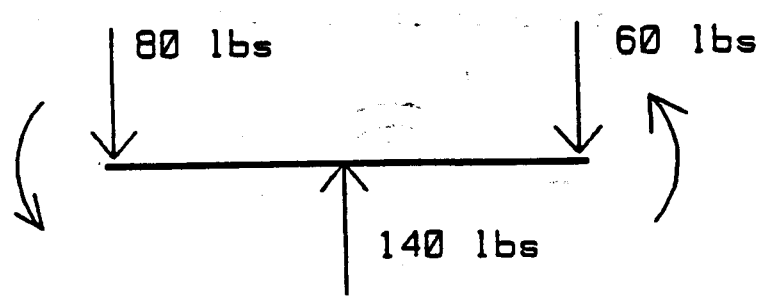

<u>Solution</u>: Intuitively we can see that the student on the left is going cause the teeter-totter to swing counter-clockwise about the fulcrum. This motion means that all equilibrium statements have not been met. Since there are no horizontal forces, $\Sigma F_X = 0$ must be true. If we assume that the teeter-totter does not sink into the earth, we will check the "Y" forces or $\Sigma F_Y = 0$. If two students are "pushing" down with their weight what "pushes" up to counter this?

Let's assume that any downward force is negative and an upward force is positive so that the sum of all of the up forces must equal the sum of all of the down forces. Listing the downward forces is:

-80 lbs - 60 lbs = -140 lbs total downward.

What is countering the downward force? The only part of this structure that can counter a downward force is the fulcrum. And, since the teeter-totter is not moving up or down, the fulcrum must support all of the weight as shown below:

$$\Sigma F_Y = -80 \text{ lbs} - 60 \text{ lbs} + \text{fulcrum} = 0$$
$$\text{fulcrum} = 140 \text{ lbs upward.}$$



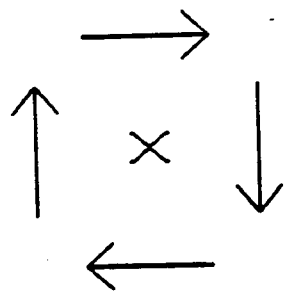
Our final test deals with the **MOMENTS** about any point shown on this teeter-totter. As a matter of convenience, we will choose the fulcrum as our center point of the moment: $\Sigma M_{fulcrum} = 0$. To sum these moments, you need to multiply all of the Action and Reaction forces acting **AROUND** the center of the moment and the **DISTANCES** from that center, making sure that the force is always perpendicular to the distance. As before, we will need to choose a direction to determine if the moment is positive or negative.

Since the moment will cause a "rotation" effect, we will assume that the direction clockwise is positive. Look at the diagram below to understand this better (X represents the center of the moment, stated as "a moment about X"):

**CLOCKWISE ANALYSIS:**

a force above X acting to the right is positive

a force to the left of X acting up is positive



a force to the right of X acting down is positive

a force below X acting to the left is positive

From our example, there are two moments about the fulcrum:

Moment 1 = Distance x Force { 80 lb person }
Moment 1 = 5 ft x ( -80 lbs)
Moment 1 = - 400 ft•lbs

NOTE: The force is -80 lbs because the force appears to the left of the moment's center and is downward. This is a negative force when assuming clockwise direction is positive.

Moment 2 = Distance x Force { 60 lb person }
Moment 2 = 5 ft x 60 lbs
Moment 2 = +300 ft•lbs

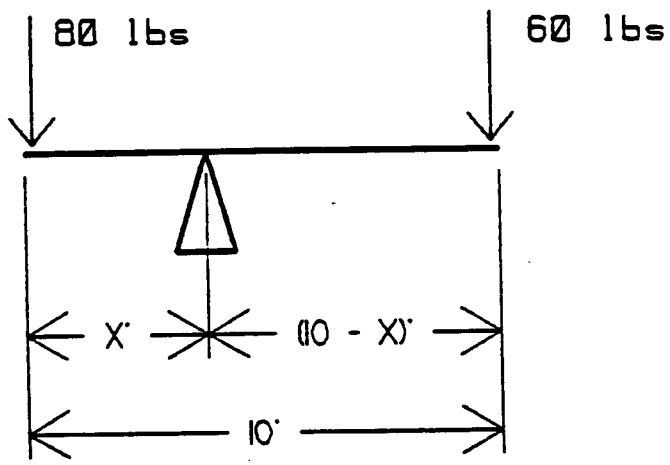
NOTE: The force is +60 lbs because the force appears to the right of the moment's center and is upward. This is a positive force when assuming clockwise direction is positive.

$\Sigma M_{fulcrum}$ = Moment 1 + Moment 2
= -400 ft•lbs + 300 ft•lbs
= -100 ft•lbs

Since this value is not zero, the teeter-totter is in motion and not at equilibrium. In addition, since we decided that clockwise motion was positive and our answer was a negative value, the direction of motion is counter-clockwise about the fulcrum.

b.) Consider the same 10-foot teeter-totter and pair of students that we had in the prior example. Where should the fulcrum be placed so that the mechanism is in equilibrium?

<u>Solution</u>: Let the distance from the student on the left to the fulcum's proper place be X feet. Then, the distance from the fulcrum to the student on the right is (10 - X) Feet as shown.




As before: $\Sigma F_x = 0$ and $\Sigma F_y = 0$ and $\Sigma M_{fulcrum} = 0$

If we let clockwise direction be positive for the moment's calculation we get the following:

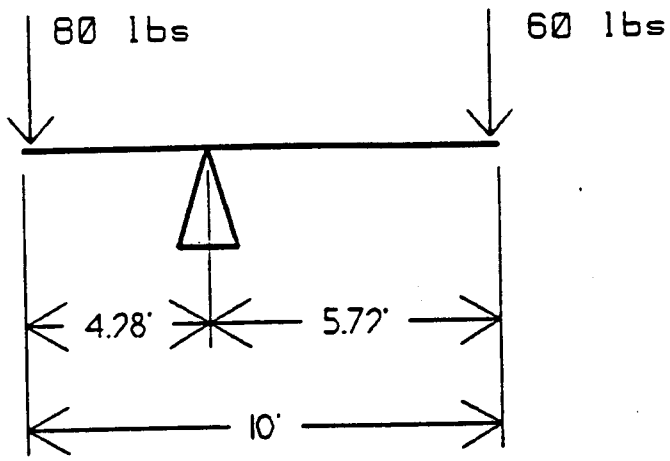
Moment 1 = Distance x Force [ 80 lb person ]
Moment 1 = X ft x ( -80 lbs)
Moment 1 = - 80•X ft•lbs

Moment 2 = Distance x Force [ 60 lb person ]
Moment 2 = (10 - X) ft x 60 lbs
Moment 2 = (10 - X)•60 ft•lbs
Moment 2 = (600 - 60X) ft•lbs

Since equilibrium demands that these two moments add up to be zero,

$$\Sigma M_{fulcrum} = \text{Moment 1} + \text{Moment 2} = 0$$
$$-80 \cdot X \text{ ft}\cdot\text{lbs} + (600 - 60X) \text{ ft}\cdot\text{lbs} = 0$$
$$600 \text{ ft}\cdot\text{lbs} - 140X \text{ ft}\cdot\text{lbs} = 0$$
$$600 \text{ ft}\cdot\text{lbs} = 140X \text{ ft}\cdot\text{lbs}$$
$$\frac{600}{140} = X$$

or approximately 4.28 feet from the end.



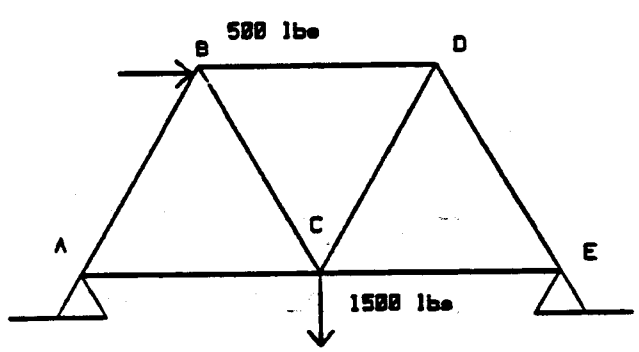

You could check the solution using a different center for the moment. For example, take the moment about the 80 lb student on the left.

Moment 1 = Distance x Force { fulcrum }
Moment 1 = 4.28 ft x 140 lbs
Moment 1 = 600 ft•lbs

Moment 2 = Distance x Force { 60 lb person }
Moment 2 = 10 ft x -60 lbs
Moment 2 = - 600 ft•lbs

$\Sigma M_{left}$ = Moment 1 + Moment 2 = 0
600 ft•lbs + (-600) ft•lbs = 0
0 = 0

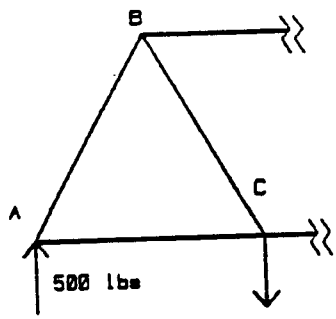
c.) Consider a simple bridge truss, weighted as shown. Determine the forces acting on member AB and determine if the member is in tension or compression. All member lengths are 15 feet in length and their internal angles are all 60°. The structure is anchored at nodes A and E.



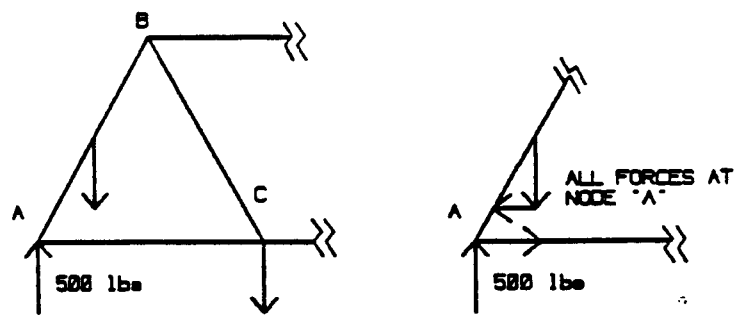

<u>Solution</u>: $\Sigma M_E = 0$ (Assume clockwise is positive, $F_A$ is up)

$\Sigma M_E = -F_C \cdot 15 \text{ ft} + F_A \cdot 30 \text{ ft} = 0$
$-1000 \text{ lbs} \cdot 15 \text{ ft} + F_A \cdot 30 \text{ ft} = 0$
$-15000 \text{ lbs} \cdot \text{ft} + F_A \cdot 30 \text{ ft} = 0$
$15000 \text{ lbs} \cdot \text{ft} = F_A \cdot 30 \text{ ft}$
$500 \text{ lbs} = F_A$ (Upward - ground pushes up at A to support bridge weight)

Looking at Node "A" we have the following force:




Since there is an upward force at "A" of 500 lbs, it must be countered (Newton's third law) by 500 lbs in a downward direction. Since member AC is horizontal, it cannot counter a vertical force. Member AB is a diagonal member which enables it to counter both vertical and horizontal forces. The amount of vertical force that AB must counter is a downward 500 lbs for this example as shown below:




**Because the force is causing AB to be "pushed toward" node "A", this member is in COMPRESSSION. The amount of compression may be determined using trigonometry:**

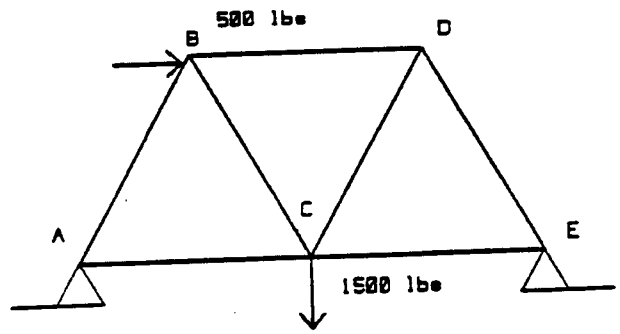
**The member represents the hypotenuse of a right triangle with vertical (opposite) side = 500 lbs and internal angles of 60°.**

$$\text{Since:} \quad \frac{\text{Opposite}}{\text{Hypotenuse}} = \text{Sin}(60°)$$

$$\frac{\text{Opposite}}{\text{Sin}(60°)} = \text{Hypotenuse}$$

$$\frac{500 \text{ lbs}}{0.866} = \text{Member AB} = 577 \text{ lbs}$$

d.) At some time later, the bridge truss from problem "c" is loaded as shown. The new force at node "B" represents a wind force on this structure. Determine the forces acting on members AB, BC and BD. Then determine if the members are in tension or compression. All member lengths are 15 feet in length and their internal angles are all 60°. The structure is anchored at nodes A and E.




<u>Solution</u>: $\Sigma M_E = 0$ (Assume clockwise is positive and the "Y" force at "A" ($F_A$) is up. Since the force at "B" is horizontal, we will need a vertical distance to satisfy the moment equation. The height above "E" to "B" is found using trigonometry again.

Since: $\frac{\text{Opposite}}{\text{Hypotenuse}} = \text{Sin}(60°)$

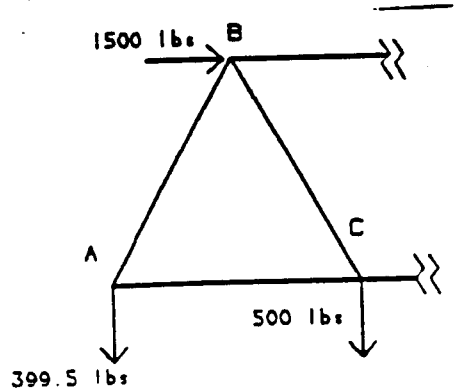
$$\text{Opposite} = \text{Hypotenuse} \cdot \text{Sin}(60°)$$

$$\text{Opposite} = 15 \cdot \text{ft} \cdot \text{Sin}(60°)$$
$$\text{Opposite} = 15 \cdot \text{ft} \cdot 0.866 = 12.99 \text{ ft}$$

$$\Sigma M_E = -F_C \cdot 15 \text{ ft} + F_B \cdot 12.99 \text{ ft} + F_A \cdot 30 \text{ ft} = 0$$
$$-500 \text{ lbs} \cdot 15 \text{ ft} + 1500 \text{ lbs} \cdot 12.99 \text{ ft} + F_A \cdot 30 \text{ ft} = 0$$
$$-7500 \text{ lbs} \cdot \text{ft} + 19485 \text{ lbs} \cdot \text{ft} + F_A \cdot 30 \text{ ft} = 0$$
$$-11985 \text{ lbs} \cdot \text{ft} = F_A \cdot 30 \text{ ft}$$
$$-399.5 \text{ lbs} = F_A$$

The answer is negative which means the force at "A" is not upward but rather Downward! The ground actually "anchors" "A" to keep the bridge from lifting!

Looking at Node "A" we now have the following known force:



Unlike before, there is a downward force at "A" of 399.5 lbs that must be countered (Newton's third law) by an upward direction. Since member AC is horizontal, it cannot counter a vertical force. Memb AB is a diagonal member which enables it to counter both vertical and horizontal forces. The amount of vertical force that AB must counter is an upward 399.5 lbs (for this example) as shown below in Figure A:

Figure A

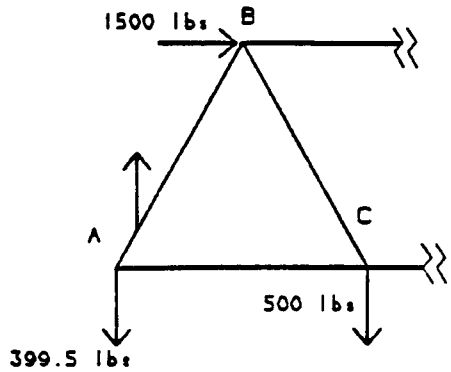
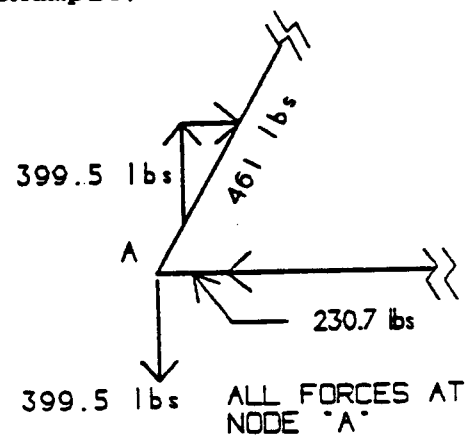


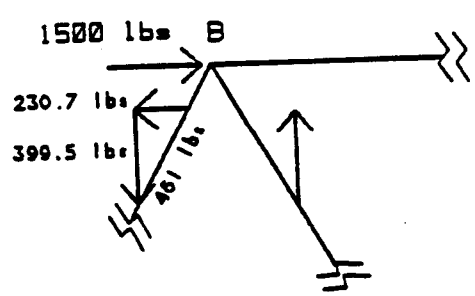

Figure B




Because the force is causing AB to be "pulled away" from node "A", this member is in TENSION. The amount of tension is found in the same manner as before.

$$\frac{399.5 \text{ lbs}}{0.866} = \text{Member AB} = 461 \text{ lbs} \quad \{ \text{ Figure B above } \}$$

Looking at Node "B" we have the following forces:




$\Sigma F_Y = 0$. There is a downward force of 399.5 lbs at "B" from member AB and a leftward force at "B" of 1500 lbs. The only member at "B" that can counter a vertical force from member AB is member BC. Therefore, member BC must have the same vertical force that member AB has. Assume that up is positive and member $BC_Y$ is upward.

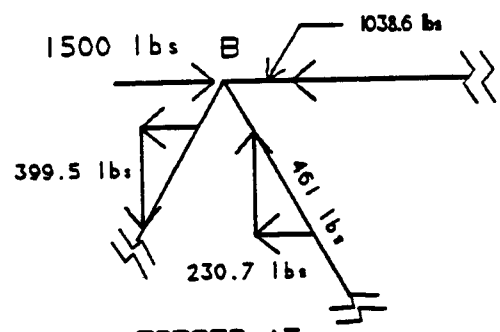
$$\Sigma F_Y = 0 \qquad - \text{member } AB_Y + \text{member } BC_Y = 0$$
$$- 399.5 \text{ lbs} + \text{member } BC_Y = 0$$
$$399.5 \text{ lbs} = \text{member } BC_Y$$

Since we assumed that up is positive, and the answer is positive member $BC_Y$ is in the upward direction.

In like manner, the horizontal forces must also sum to be zero. We have determined that member AB is in tension. The total force on AB is 461 lbs and its components Y and X are: 399.5 lbs and 230.7 lbs respectively. (The X force may be found using Pythagorean's theorem or trigonometry)

The total force on BC is also 461 lbs and its components Y and X are: 399.5 lbs and 230.7 lbs respectively, but BC is "pushing toward" node "B". This "pushing toward" action is once again, compression.

Notice from the diagram below that even though the "Y" forces on these two members are equal and opposite, the "X" forces are pointing in the same direction, to the left. If these two forces cancel the 1500 Action force at "B" then all other horizontal members do nothing. Otherwise we need at least one horizontal member to cancel the difference (member BD for example).




ALL FORCES AT NODE "B"

We will assume that a force to the right is positive. Then, member $BD_x$ is assumed to "push" to the left and so is designated as a negative value.

$$\Sigma F_x = 0 \quad -\text{member } AB_x - \text{member } BC_x + 1500 \text{ lbs} - \text{member } BD_x = 0$$
$$-230.7 \text{ lbs} - 230.7 \text{ lbs} + 1500 \text{ lbs} - \text{member } BD_x = 0$$
$$1038.6 \text{ lbs} = \text{member } BD_x$$

The value is positive so our assumption is correct. Member BD is "pushing toward" "B", this member is in compression.

**NOTE:** This type of analysis is referred to as a nodal analysis which is similar to the nodal method used by electrical engineers to solve complex electronic circuits. For these engineers, moments are replaced by Ohm's law components of resistance, current and voltage.

*Structural Engineering*

Structural engineers are planners and designers of buildings of all types; bridges, dams, power plants; supports for equipment; special structures for offshore projects, space programs, transmissions towers, telescopes, and many other kinds of projects. Structural engineers analyze the forces that a structure must resist (its own weight, wind forces, temperature forces, earthquake forces, etc.), and develop the combination of appropriate materials (steel, concrete, plastic, timber, etc.) Wherever concrete, steel, aluminum or other metals and materials are required to carry a load, structural engineers do the planning and design and they visit the construction site to make sure the work is done properly. Structural engineers usually work with a team that included architects, mechanical and electrical engineers, contractors, owners of the project, bankers, lawyers and officials of local government.

## B. BOOKS

1. Highly Suggested Books for Structure Lessons
Mario sawlvadori and Michael Tempel, ARCHITECTURE AND ENGINEERING, ($10.00). The architectural and engineering principles on why buildings stand up. An excellent companion book to the video series. (Discounts available for quantity orders). ARCHITECTURE AND ENGINEERING available from address below.

2. Additional Books
Mario Salvadori, THE ART OF CONSTRUCTION, ($6.00). A worthwhile te for K-12 grades with description of numerous, easily performed experiments. (Available for quantity orders).

Mario Salvadori, WHY BUILDINGS STAND UP, ($10.00). A perfect primer for the beginner and a treasure trove of insights for the professional, this book explains the theory and techniques of architectural engineering.

Phylis Shulman and Lorraine Sesti, INTEGRATION OF SALVADORI CURRICULUM AND THE CURRICULUM OF THE CENTRAL BOARD OF EDUCATION OF NEW YORK CITY, ($2.00). This pamphlet provides detailed examples of how to integrate the Salvadori Program with math, science, social studies and english curricula at the junior high school level.

Irving J. Levinson, INTRODUCTION TO MECHANICS 2nd Edition ($34.00). An excellent source of structural analysis problems and solutions as they apply to real-world applications. Prentice-Hall Pub. 1968 Lib of Congress No.: 68-20859. Also available - Transparencies series on Mechanics -Part I - Statics, Part II - Dynamics.

J.L. Meriam, L.G. Kraige ENGINEERING MECHANICS Volume I - STATICS 3rd Edition ($49.00). Another excellent source of structural analysis problems and solutions as they apply to real-world applications. Wiley Pub. Pub. 1992 ISBN 0-471-90294-2

Kits: A package of all the materials and instruments needed for the demonstrations and "hands-on" experience in the Salvadori curriculum. ($100.00).

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INVESTIGATION OF THE KANSAS CITY HYATT REGENCY WALKWAYS COLLAPSE. U.S. Department of Commerce, National Bureau of Standards, Washington, DC 20234. Report #NBSIR 82-2465 from: National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161. Telephone: (703) 487-4650; Order # PB82242363; Cost $42.00.

3. ***Bibliography***


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6. James, Albert. STRUCTURES AND FORCES, STAGES 1 AND 2. Macdonald Educational, London, 1972.

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9. Reier, Sharon, THE BRIDGES OF NEW YORK, Quadrant Press, New York, 1977. Organized according to the area of the city in which the bridges are located. Excellent history, including photos of bridges under construction and drawings of rejected proposals and unrealized plans.

10. Salvadori, Mario, STRUCTURE IN ARCHITECTURE: THE BUILDING OF BUILDINGS. Prentice-Hall, Englewood Cliffs, New Jersey, 1975. This comprehensive but nontechnical work provides a solid background in structures, and can serve as a continuing reference for teaching this course case study.

11. Salvadori, Mario (illustrations by S. Hooker and C. Ragus). BUILDING: THE FIGHT AGAINST GRAVITY. Atheneum Publishers, New York, 1979. Could serve as textbook for this course. The topics and activities in the book are covered by the course. Although a book for children, it is also a good first course of information for the teachers using this manual.

12. Young, Edward M. (drawings by Lile Rithi). THE GREAT BRIDGE: THE VERRANZANO NARROWS BRIDGE. Ariel/Farrar, Straus Giroux, New York, 1965. A well illustrated story of the construction of one of the world's longest suspension bridges.

## C. VIDEOTAPES

WHY BUILDINGS STAND UP is a series of videotapes in which Dr. Mario Salvadori explains the fundamental principles of architectural structures through classroom demonstrations. Using commonly available materials, this master teacher and a class of 6th grades explore basic structural principles and illustrate their applications to architecture in the design of buildings and skyscrapers, bridges and domes. WHY BUILDINGS STAND UP is presented by the American Institute of Architects and the New York City Board of Education Community School District #10.

Mario Salvadori, Professor of Civil Engineering and Professor of Architecture (Emeritus) at Columbia University in New York, is the author of fourteen books on structures and mathematics. His methodology for the teaching of structures to young people has been featured in The New York Times and on radio and television, and has been adopted by schools all over the United States and abroad. He is a member of the National Academy of Sciences and an honorary member of both the American Institute of Architects and the American Society of Civil
Engineers.

### WHY BUILDINGS STAND UP TAPES

Program 1 LOADS ON BUILDINGS
Demonstrations of static and dynamic loads, and the effects of winds and earthquakes on buildings. (28.50 min.)

Program 2 EQUILIBRIUM AND MATERIALS
Activities on tension, compression, and bending; beams, columns, cables and arches. (28.07 min.)

Program 3 BRIDGES
An exploration of frame structures, arches, truss and suspension bridges. (26.30 min.)

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Using paper to create folded plates, beams, arches, and domes. (21.56 min.)

Program 5 CHILDREN AND MATH
A panel discussion on teaching math. (27 min.)

VIDEOTAPES continued

Program 6 HISTORY OF ARCHITECTURE AND ENGINEERING
A survey of architectural and engineering monuments from 8,000 B.C. to the present time. (27.30 min.)

Program 7 BRIDGES
A tape on bridges with emphasis on swing bridges. (25 min.)

Program 8 SKYSCRAPERS
A tape illustrating high-rise buildings in New York. (25 min.)

Program 9 CHILDREN AND STRUCTURES
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| | | |
|---|---|---|
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Additional Videotapes

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5547 N. Ravenswood Avenue
Chicago, IL 60640-1199
800-323-4222

## TO ENGINEER IS HUMAN (BBC, 1990), 50 min. 1/2" VHS $149.00

In Kansas City in 1981, a local television station was filming a tea dance in the spectacular atrium of a new hotel, where spectators stood on skywalks to look down on the dancers below. Suddenly, two of the skywalks collapsed, and the film recorded one of the worst engineering disasters in American History....

How could such disasters have happened? TO ENGINEER IS HUMAN shows how engineering science is subject to human limitations. Henry Petroski, professor of engineering at Duke University, demonstrates how structures can fail. Using graphic footage of some of the world's major civil failures, he illustrates some of the greatest disasters in history. There is a complex learning process involved, and Professor Petroski explains why with every new development, engineers may enter new territory, but may also develop some new modes of failure.

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Specifically created for courses in design and technology, this remarkable five-part series is an invaluable exercise in finding working solutions to engineering problems. Each program, divided into two sections, contains a case study of one major practical problem. The first section presents the problem and identifies the key stages in the problem-solving process. The second section explains the basic principles underlying the process (BBC 1988)

**The Brunel Experience program titles:**

1. The Great Divide
2. A Watery Grave
3. A Hefty Problem
4. Easy Does It
5. Down and Under

20 min. each, 1/2" $79 each
Series Price: $395.
Shipping Rate: $3.00 per tape

D. EQUIPMENT AND MATERIALS NEEDED

| KEY | MATERIAL/EQUIPMENT |
|---|---|
| (S) | 1. Foamcore board 20" x 30" sheets FC-2030 25 sheet pkg $60.00 |
| (E) | 2. Safetyedge - Cutting Straightedge 12" SE-12 $15.00 each |
| (E) | 3. Alvin Snap Blade Knife KN-8 $1.50 each |
| (B) | 4. 3/32" basswood (bundled for bridge-building) with instructions & glue KIT8650S $ 67.60 or 3/32" balsawood (bundled for bridge-building) with instructions & glue KIT8660S $ 72.40 |

Above items available through:

Modern School Supplies, Inc.
P.O. Box 958
Hartford, CT. 06143
PH: 1-800-243-2329

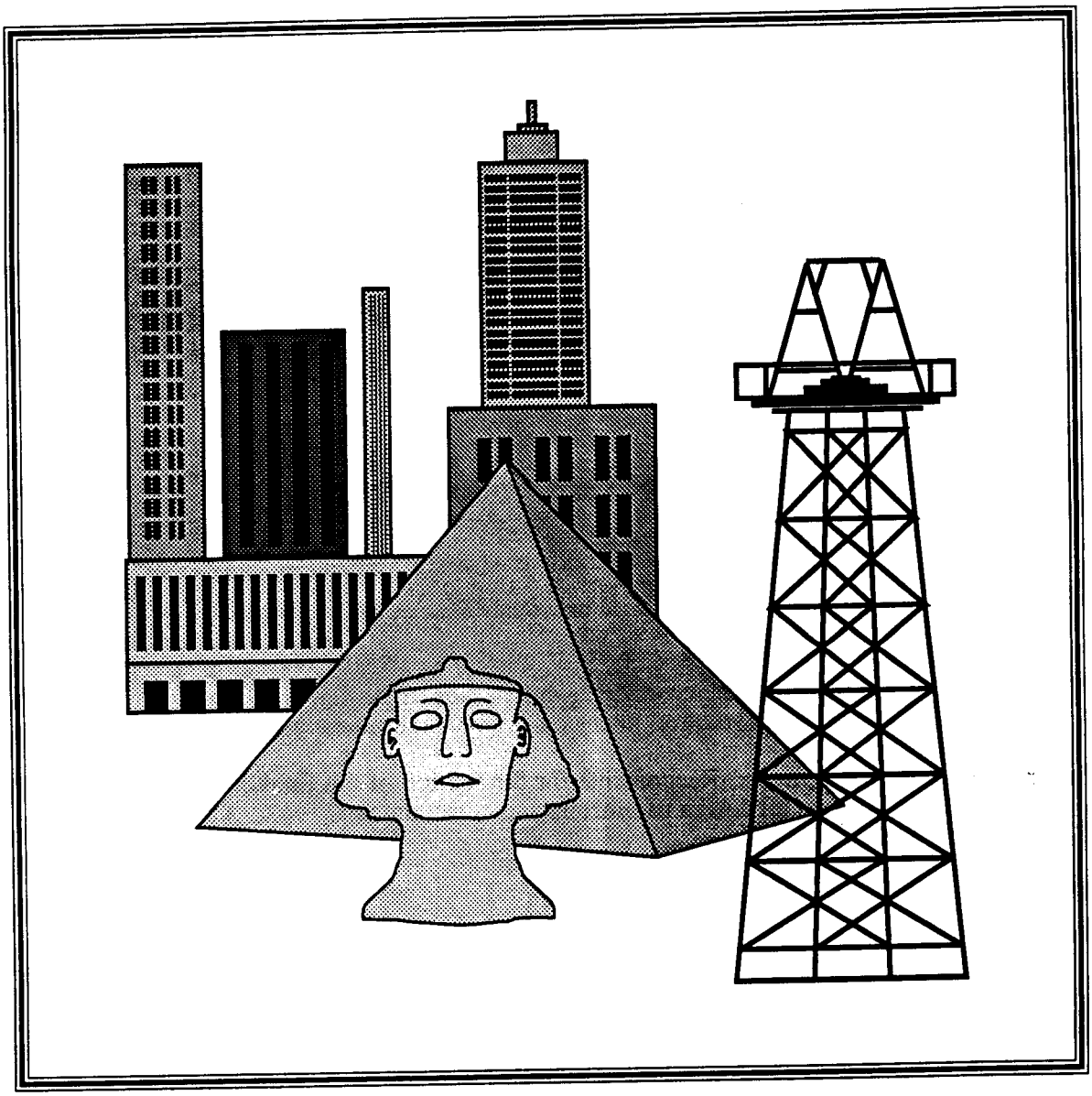
| | |
|---|---|
| (B) | 5. Miniature "C"-clamps, clothespins |
| (E) | 6. Rope, string, cable materials |
| (S) | 7. Letter stencils |
| (E) | 8. 24" metal straight edges |
| (E) | 9. Adhesives - White, Yellow Glues, Hot Glue |
| (S) | 10. Fasteners - Velcro, Hinges, Nuts, Bolts |
| (S) | 11. Corrugated Cardboard |
| (E) | 12. Drafting Equipment |
| (B) | 13. Razor Saws |
| (B) | 14. X-Acto Mitre Box |

**KEY Legend**:

(B) - Denotes required for bridge-building structure
(S) - Denotes required for emergency shelter
(E) - Denotes required for either project

# *Structural Design Problem*

*Engineering Design and Problem Solving Activity*



# Structural Design Problem

### *The Problem*

You will design and construct a tower structure that will support a 100 pound load. The structure will be loaded for 30 seconds, and then the load will be removed. The efficiency of the structure will then be calculated by dividing the load (100 pounds) by the mass of the structure. Since the structure will not be tested to failure, we are not concerned with the structure's maximum load capacity. It is for this reason that the structure should be designed to use as little material as possible; this will keep weight to a minimum.

### *Design Parameters and Constraints*

- Structure will be loaded with 100 pounds for 30 seconds.
- Only the supplied materials (3/32 x 3/32 bass wood and glue) can be used in the structure.
- Structure must be at least 7.5 inches high, and at least 2 inches in both width and depth.
- Structure must be hollow to allow a 1 inch dowel to pass vertically through its center.

### *The Design Solution*

Each design team will consist of two students who will assume the role of Chief Engineer for each part of the design solution. Teams will prepare a portfolio of materials documenting the design process. All design solutions must show evidence of optimization. The final design solution will include an analysis of the forces calculated for each structural member.

**Structural Chief Engineer:** Responsible for the theoretical design solution.
Computes all action and reaction forces on structural members.

**Construction Chief Engineer:** Responsible for fabrication of the final design solution.
Structure must meet all design parameters and constraints.

# Structural Design Problem
# *Design Team Portfolios*

*Each Design Team must submit a portfolio which documents their work on this design problem. Your portfolio must contain each of the following materials:*

- **Full size graph paper drawing of your *initial* design solution**

- **Analysis of load on each structural member.**
  - Label each structural member and indicate load.
  - Include all necessary calculations and vector diagrams.

- **Full size graph paper drawing of *optimized* design solution**

- **Analysis of load on each structural member**
  - Label each structural member and indicate load.
  - Include all necessary calculations and vector diagrams.

- **Report Documenting Design Solution**
  - Analysis of mode of failure for initial design solution.
  - Comparison of the ultimate strength of the structure (as tested) and it's safety margin (as designed).
  - Methods used to optimize solution.
  - Remedies for mode(s) of failure.
  - Improvements in efficiency in ***final*** design solution.
  - Report should be 2 to 3 typed pages (not including any diagrams or data).

## Structural Design Problem
# *Structural Terms and Definitions*

***Stress:*** Amount of force applied to an object per unit area.

***Strain:*** Amount of deformation (change in length) of a material caused by the application of a force.

***Elastic limit:*** Greatest force that can be applied to an object and it will return to its original length when the force is removed.

***Plastic region:*** Object will not return to its original length when the applied force is removed; the object is permanently deformed.

***Breaking point:*** Maximum elongation of a material before failure occurs.

***Ultimate strength:*** Maximum force applied to an object without breaking.

***Proportional limit:*** Provides a good approximation of the stress to strain ratio for common materials.

***Elastic modulus/Young's modulus:*** Ratio to stress to strain of a material. The amount of predicted elongation of a material for a specified applied force.

***Young's Modulus*** **($N/m^2$)** for various materials:

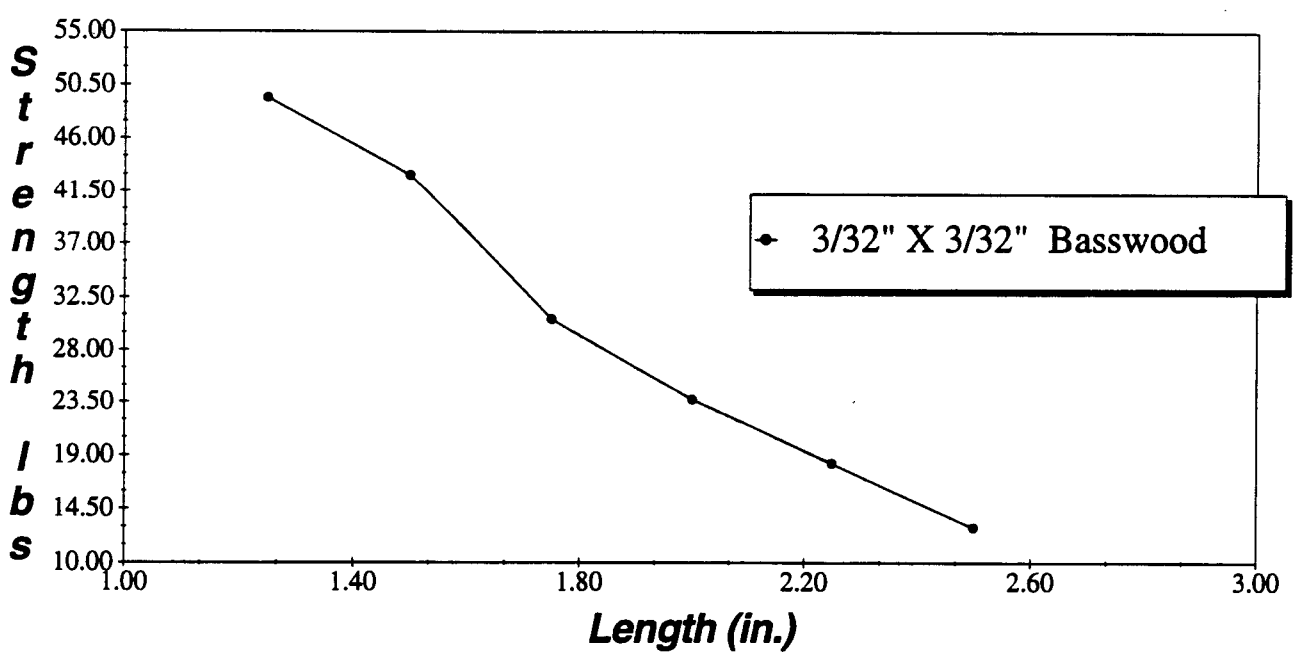
| | |
|---|---|
| Cast iron | $100 \times 10^9$ |
| Steel | $200 \times 10^9$ |
| Brass | $100 \times 10^9$ |
| Aluminum | $70 \times 10^9$ |
| Concrete | $20 \times 10^9$ |
| Marble | $50 \times 10^9$ |
| Brick | $14 \times 10^9$ |
| Wood (// to grain) | $10 \times 10^9$ |
| Nylon | $5 \times 10^9$ |
| Rubber | $4 \times 10^6$ |

***Euler's Equation:*** Used to compute the relative deflection of a vertical column under load. This can be used to predict failure of material.

# Structural Design Problem

| Length (in.) | Strength (lbs.) | | | |
|---|---|---|---|---|
| 1.25 | 49.40 | 48.43 | Equation | Y(X) = -30.08000 * X + 86.03333 |
| 1.50 | 42.90 | 40.91 | Corr Coeff (r) | 0.99 |
| 1.75 | 30.60 | 33.39 | (r^2) | 0.98 |
| 2.00 | 23.70 | 25.87 | Max Error | 2.79 |
| 2.25 | 18.30 | 18.35 | Avg Error | 1.67 |
| 2.50 | 12.90 | 10.83 | RMS Error | 1.90 |
| | | | Chi Square | 0.41 |
| | | | Standard Error | 2.33 |

## *Ultimate Strength*



APPENDIX B.

# EMERGENCY SHELTER

Case Study- Structures
Mr. S. Wilansky

## I Case study description

Human kind has been engaged in the design and building of structures since the beginning of recorded history. The conquest of the environment and the ability to exist anywhere on the planet, has allowed humans to create the technological wonders we now see as common place. The design and construction of structures is a knowledge built upon thousands of years of practical trial and error study and application. The understanding of structures and the forces that act upon them will be explored in this case study. The main focus of this study is on survival and how structures must protect human inhabitants in the most difficult of situations. You must have the ability to diverge into structural forces, thermodynamics, heat loss and gain, packaging, ergonomics, instructional documentation, mass production considerations, ethics in engineering and materials processing.

This understanding will be accomplished through a combination of classroom theory, library research, and model construction. We will further this understanding by drawing rough sketches freehand and final designs utilizing CAD or Technical Drafting techniques.

## II Definition of Problem

The Federal Aviation Administration has requested proposals from engineering firms for the design and construction of an emergency shelter. There will be open bidding and a competition from those firms submitting bids. The project will be given the designation: Project - ITE-5, Shelter, Portable, Emergency Rescue, Cold Weather Type. All correspondence is to be sent to Mr. Paul Davis at::

Federal Aviation Administration
Emergency Disaster Team A-3
Department 43-3692
2394 Spencer Street
Washington, D.C. 23112

## III Rules and specifications for Engineering Case Study Project-Emergency Shelter.

1. Shelter capacity - Protect three adults for five days.
2. Construction materials - 3/16 foam core, or whatever the design team feels is appropriate, hardware as required for fastening, anchoring, packaging, etc.
3. Interior temperature to be maintained at 50 degrees F, with no combustible heat source.
4. Capable of air drop to landing site.
5. Construction time not to exceed thirty minutes.
6. Instructions for construction to be printed on packaging or structure using pictographs and or numerals only.
7. Cold weather survival instructions to be displayed on inside of structure using pictographs and or numerals only.
8. Structural capacity must withstand 2 foot snowfall and 50 MPH wind loading.
9. Shelter must be capable of being transported 1/4 mile by a single survivor.

## IV Model Building

Each design team will construct, with craftsmanship, an exact scale model of the design with the ability to support an exterior load such as ice or snow. Simple models using foam core or paper products may be used. The model will be submitted with the final report after the presentation.

## V Report Requirements

Each team must keep a design notebook to document your ideas, progress and proposals. The final report must be either typewritten or computer generated on a word processor. The final report will include a table of contents, introduction, design solution, research findings on hypothermia, static load capabilities of corrugated cardboard or other building materials, average wind force above 1,000 feet, average 24 hour snowfall above 1,000 feet in North America, amount of breathing air needed for three people per hour, heat loss characteristics of corrugated cardboard or foam core (R value), human ergonomics for sleeping, sitting, standing, appendix with graphics, tables, sketches, and CAD generated or Mechanical Drawings of the shelter.
Each team will also give an oral presentation to the FAA (our class) extolling the virtues of their particular design.

## VI Time Line

| | |
|---|---|
| Week one | Preliminary sketch<br>Paper and pencil drawings to include:<br>1. isometric sketch/ or 3-D<br>2. orthographic projection |
| Week two | Research on thermodynamics |
| Week three | Research on structures |
| Week four | Continue research, drawing |
| Week five | Begin model construction |
| Week six | Analysis and drawing<br>1. Two page report on why various decisions were made to satisfy design parameters and construction requirements.<br>2. Orthographic projection of shelter, scale of 1"=1', CAD or drafting board. |
| Week seven | Continue model construction |
| Week eight | Continue construction, begin to compile research for reports |
| Week nine | Complete research and model construction, prepare final presentation |
| Week ten | All models to be completed. Scale of 1"=1'<br>Report to class on design and demonstrations of air drop and assembly capabilities. |

# Emergency Shelter
# Grading Criteria

Team members _____

_____

_____

_____

| | | |
|---|---|---|
| _____ | (15 pts.) | Final report with table of contents, introduction, design solution, research findings, appendix with graphics, tables, and sketches. |
| _____ | (10 pts.) | Research paper on hypothermia, wind, snowfall, breathing air, heat loss and gain, and other investigations. |
| _____ | (10 pts.) | Calculations of wall thickness, surface area and volume of shelter. |
| _____ | (5 pts.) | Human ergonomics for sleeping, sitting, standing, and metabolism. |
| _____ | (10 pts.) | Analysis of reasoning (brainstorming and optimization factors in modeling). |
| _____ | (5 pts.) | Daily log |
| _____ | (5 pts.) | Pictograms, instructions |
| _____ | (25 pts.) | Model construction |
| _____ | (5 pts.) | Packaging (to withstand air drop). |
| _____ | (10 pts.) | Individual participation. |

_____ (100 pts.)
Total Score

## HEAT LOSS FORMULA

AREA X U FACTOR X DELTA T = HEAT LOSS
HEAT LOSS IN BTU'S = A X U X DELTA T

## EXAMPLE

**TOTAL SHELTER AREA INCLUDING FLOOR WALLS AND CEILING = 180 SQ. FT.**

**HEAT LOSS = 180 X .196 X 70 = 2469 BTU**

**5 PERSON HEAT OUTPUT AT REST IS EQUAL TO 1843 BTU**

## PROBLEM

**SHELTER IS LOSING HEAT AT A RATE OF 626 BTU'S PER HOUR**

# TOTAL OF R VALUES

R TOTAL FOR MULTIPLE LAYERS = RT
RT= R1 + R2 + R3 + R4

| | |
|---|---|
| EXTERIOR AIRFILM | .5 |
| INTERIOR AIRFILM | .5 |
| 15 LAYERS CARDBOARD | 2.76 |
| INTERIOR FOIL FILM | 1.32 |
| TOTAL R VALUE = | 5.08 |

## COMBINED THERMAL CONDUCTIVITY IS CALLED THE U -FACTOR

U = 1 DIVIDED BY R
1 DIVIDED BY 5.08 = .196
U = .196

## SHELTER HEAT

1 WATT = 3.413 BTU/HOUR
1 PERSON = 108 WATTS
1 PERSON = 369 BTU/HR
5 PEOPLE = 1843 BTU/HR

## SHELTER DELTA T

OUTSIDE TEMPERATURE IN DEGREES = -20 F
INSIDE TEMPERATURE IN DEGREES = 50 F
DELTA T = 70

## SHELTER INSIDE WALL AND FLOOR AREA = A

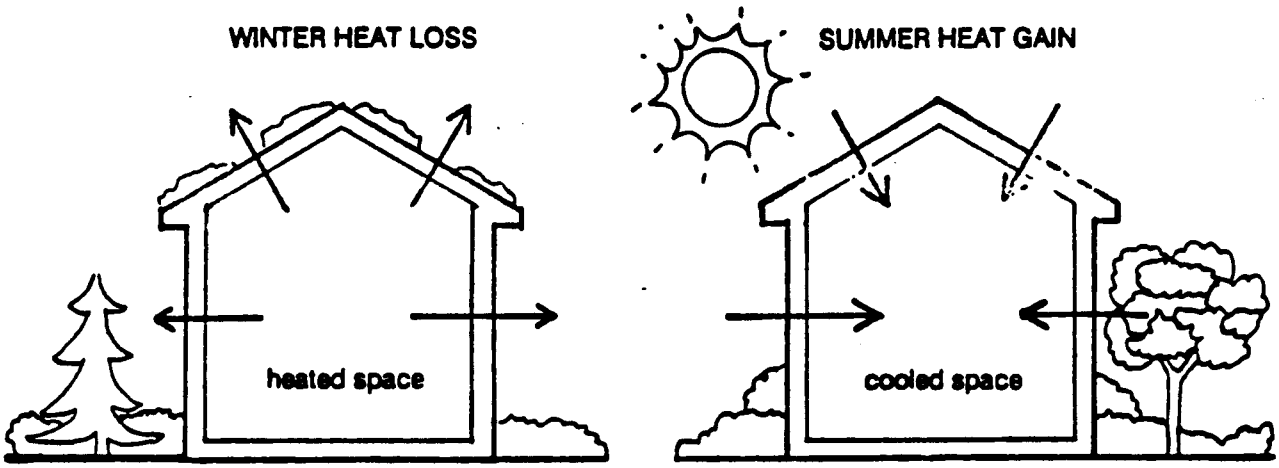
SHELTER MATERIAL R VALUE = R
CORREGATED CARDBOARD R = .184
EXTERIOR AIRFILM R = .5 AVG.
INTERIOR AIRFILM R = .5 AVG.
INTERIOR REFLECTIVE FILM R=1.32

Appendix D

# Definitions

## ENERGY

Energy is the capacity to do work. Heat is one form of energy. When heat flows out of a building in winter, energy must be consumed to produce heat to offset this loss. In summer, heat flows into a building and often energy must be used to replace this warm air with cool air.




## BTU

A BTU (British Thermal Unit) is a measure of heat energy much like a kilowatt is a measure of electrical power. A BTU is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. Regardless of the type of heating fuel, the more BTU's needed to heat a dwelling, the higher the energy use.

## COMFORT HEATING

Comfort heating is the use of heating equipment that provides warmth for human comfort as opposed to heat for process or manufacture.

## ELECTRIC COMFORT HEATING

Electric comfort heating is the provision of comfort heating by any equipment that utilizes electricity as the primary means to produce heat, other than a heat pump which meets the requirements of the Energy Code.

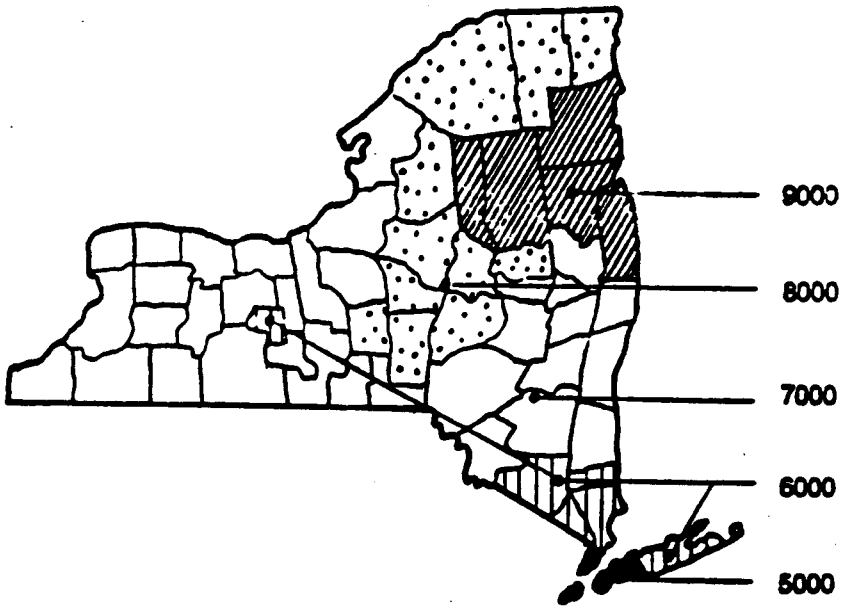
# Definitions

**HEATING DEGREE DAYS**

**A Heating Degree Day is a unit relating to temperature and time. Heating Degree Days for an area provide an indication of comparative amounts of fuel required for heating. The number of Heating Degree Days for any day is equal to the difference between the average temperature of the day and 65°. For instance, if the average temperature of the day was 35°, for that day there would be 65° (base) - 35° (average) = 30 Heating Degree Days.**

Colder areas of the State have more Heating Degree Days than warmer areas. Yearly totals range from 5000 to 9000 Heating Degree Days throughout the State. The total Heating Degree Days for the year provides a base from which to estimate fuel use.

HEATING DEGREE DAYS IN NEW YORK STATE



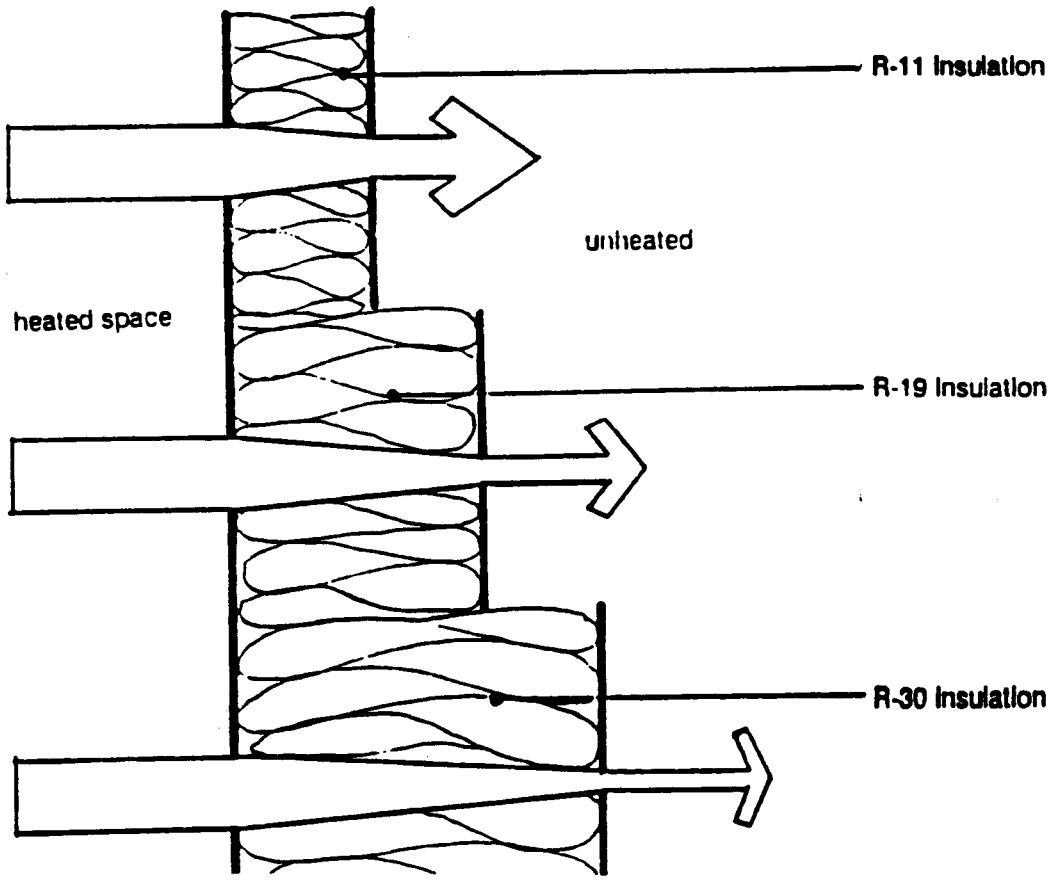
# Definitions

**CONDUCTOR**
A conductor is any solid material that offers little resistance to the flow of heat through it. For example, metal is a conductor.

**INSULATOR**
An insulator is a material that resists the flow of heat through it. For example, cork is an insulator. Insulators often restrict heat flow due to air spaces within the material. Fiberglass has many small air spaces, and these air spaces "short-circuit" the flow of heat.

**R-VALUE**
An R-value is a measure of a material's resistance to the flow of heat. All materials have some resistance to heat flow, but conductors have less resistance (lower R-value) than insulators (higher R-value). Materials with high R-values are used as insulators. A Table listing R-values for some common building materials can be found in Appendix C.

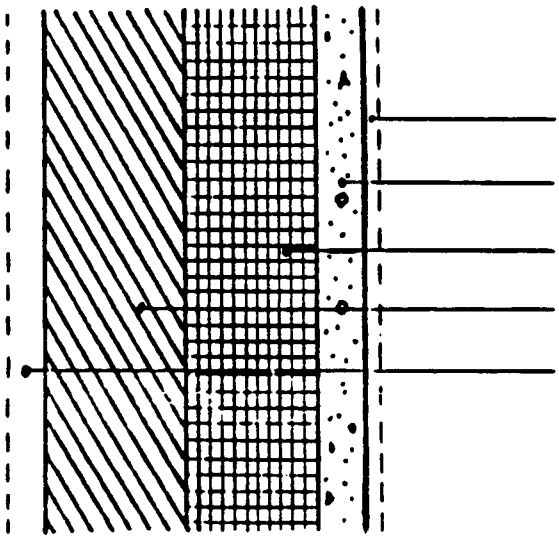
COMPARATIVE HEAT FLOW THROUGH VARIOUS R-VALUES



## U-VALUE

The U-value is a measure of heat flow through a combination of several different materials. Most wall and floor sections, for example, are constructed of a combination of materials and air spaces, each having its own R-value. In addition, the air films at the inner and outer surfaces of a building also offer some resistance to heat flow and are given R-values. The U-value combines these R-values to provide a measure of the heat flow through the entire combination of different materials, air spaces, and air films. Lower U-values indicate less heat flow. A conversion table of R- to U-values can be found in Appendix A.

COMBINATION OF MATERIALS WITH ONE U-VALUE



| Construction Components | R value |
|---|---|
| Outside air film | R-1 |
| Material 1 | R-2 |
| Material 2 | R-3 |
| Material 3 | R-4 |
| Inside air film | R-5 |
| | R-total |

$$\text{This wall has a U-value} = \frac{1}{\text{R-total}}$$

Typical U-values for an entire assembly might be: .04, .05, .08, .15, .18

**Lower** U-value numbers indicate that less heat will flow through the assembly.

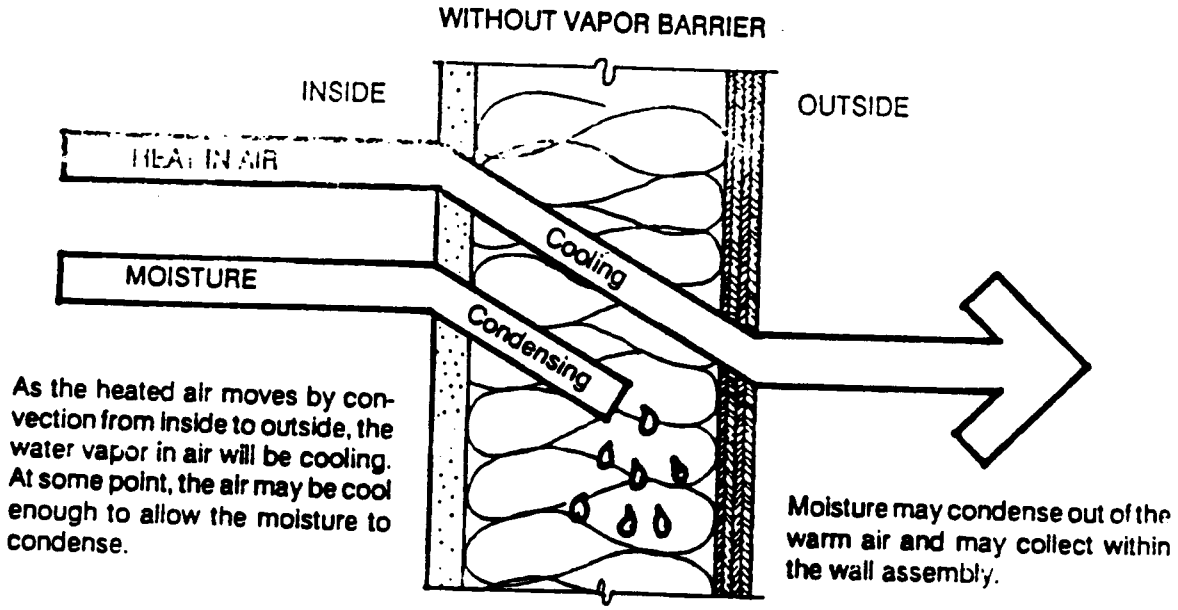
Typical R-values for various materials might be: 3, 11, 19, 22, 25, 33

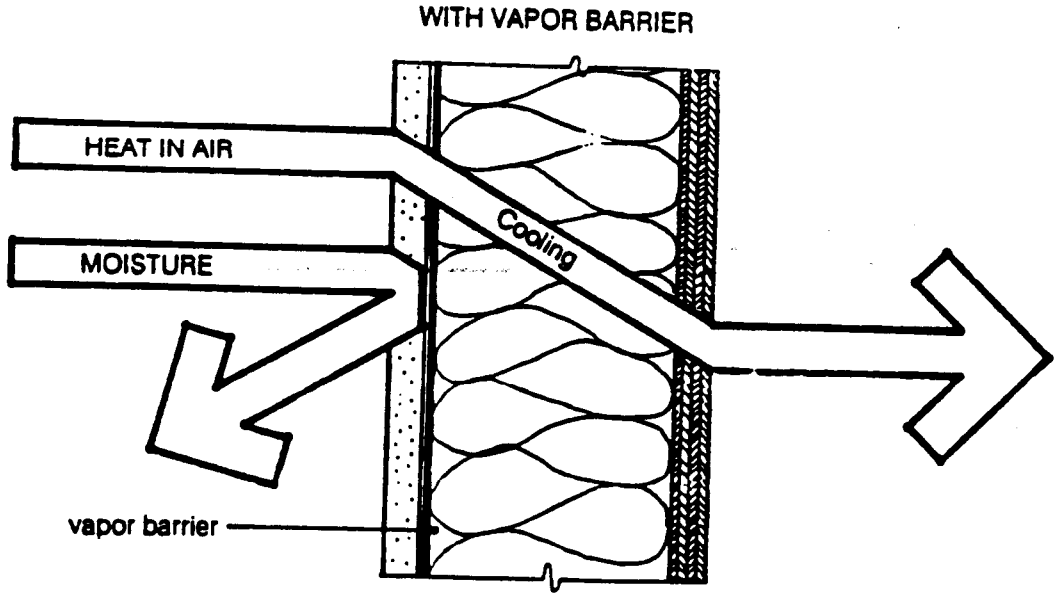
**Higher** R-value numbers indicate greater resistance to heat flow.

# Definitions

## VAPOR BARRIER

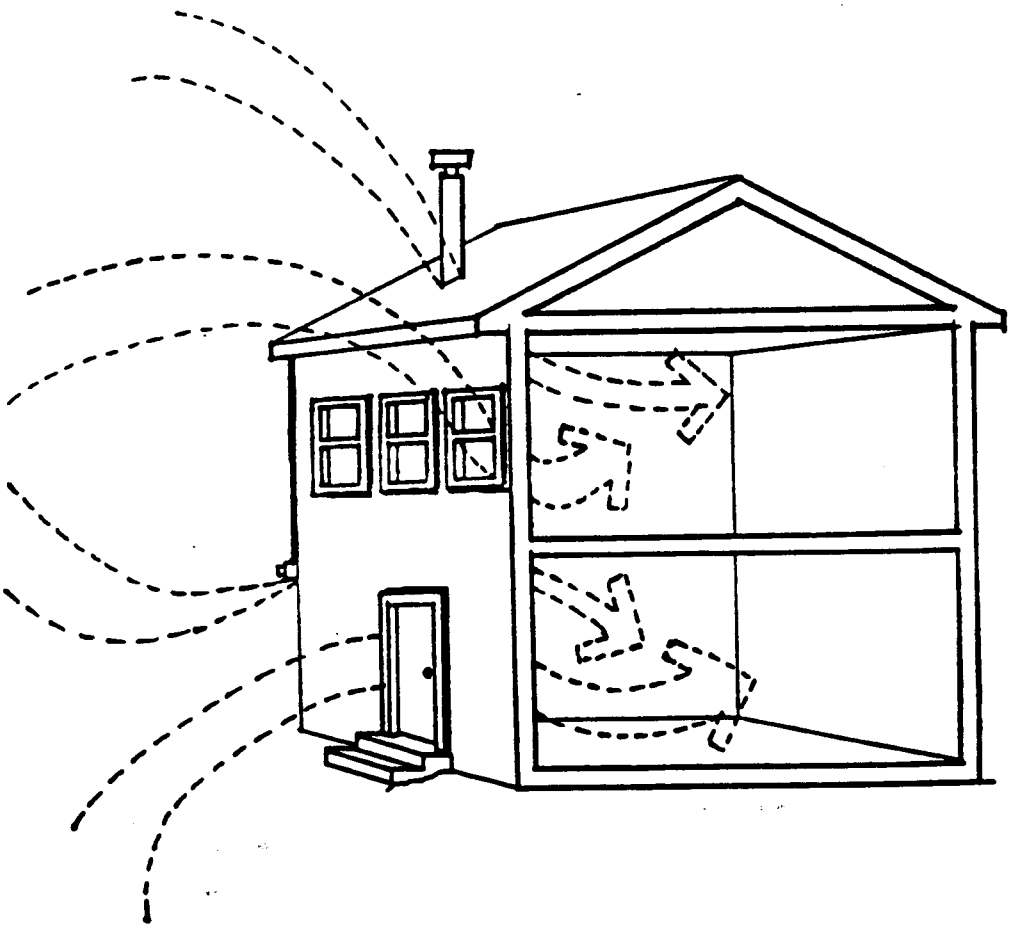
A vapor barrier is a sheet or film that limits the amount of water vapor passing through a construction assembly. Warm interior air can hold more water in the form of water vapor than cool air. As warm air passes through an exterior wall, it cools and the water vapor in this air may condense inside the wall. A vapor barrier placed on the warm side of the construction assembly will limit the ability of the water vapor to move into the construction assembly.



**INFILTRATION**

Infiltration is caused by air movement into a building. When the wind is blowing, outside air will be forced into the house through cracks between windows and walls, under doors, and through any "holes" or leaks in the exterior of the building. If the air which leaks into the building is colder than the air inside, this infiltration will increase the heating load on the building.



# R to U CONVERSION TABLE

| R | U | R | U |
|---|---|---|---|
| 0.4 | 2.500 | 27.0 | 0.037 |
| 0.6 | 1.670 | 28.0 | 0.036 |
| 0.8 | 1.250 | 29.0 | 0.034 |
| 1.0 | 1.000 | 30.0 | 0.033 |
| 1.2 | 0.833 | 31.0 | 0.032 |
| 1.4 | 0.714 | 32.0 | 0.031 |
| 1.6 | 0.625 | 33.0 | 0.030 |
| 1.8 | 0.555 | 34.0 | 0.029 |
| 2.0 | 0.500 | 35.0 | 0.029 |
| 2.5 | 0.400 | 36.0 | 0.028 |
| 3.0 | 0.333 | 37.0 | 0.027 |
| 4.0 | 0.250 | 38.0 | 0.026 |
| 5.0 | 0.200 | 39.0 | 0.026 |
| 6.0 | 0.166 | 40.0 | 0.025 |
| 7.0 | 0.143 | 41.0 | 0.024 |
| 8.0 | 0.125 | 42.0 | 0.024 |
| 9.0 | 0.111 | 43.0 | 0.023 |
| 10.0 | 0.100 | 44.0 | 0.023 |
| 11.0 | 0.091 | 45.0 | 0.022 |
| 12.0 | 0.083 | 46.0 | 0.022 |
| 13.0 | 0.077 | 47.0 | 0.022 |
| 14.0 | 0.071 | 48.0 | 0.022 |
| 15.0 | 0.067 | 49.0 | 0.020 |
| 16.0 | 0.063 | 50.0 | 0.020 |
| 17.0 | 0.059 | 51.0 | 0.020 |
| 18.0 | 0.055 | 52.0 | 0.019 |
| 19.0 | 0.053 | 53.0 | 0.019 |
| 20.0 | 0.050 | 54.0 | 0.019 |
| 21.0 | 0.048 | 55.0 | 0.018 |
| 22.0 | 0.046 | 56.0 | 0.018 |
| 23.0 | 0.043 | 57.0 | 0.018 |
| 24.0 | 0.042 | 58.0 | 0.017 |
| 25.0 | 0.040 | 59.0 | 0.017 |
| 26.0 | 0.039 | 60.0 | 0.017 |

$$U = \frac{1}{R} \qquad R = \frac{1}{U}$$

# PRINCIPLES OF ENGINEERING

## MACHINE AUTOMATION AND CONTROL

### A Case Study

## Preface

The world has not yet caught up with science fiction, but it has made great strides in bypassing men on the assembly line.

This case study concentrates on how humans can use their ingenuity to control machines so that the machines can perform operations which involve feedback and decision making.

Students will design systems and devices to do specific operations automatically.

Among the dictionary definitions for automation the one which best fits this case is: *The theory, art, and technique of converting a mechanical process to maximum automatic operation especially by the use of electronic control mechanisims.*

In the study of this case the students will gain an understanding of feedback as they design a machine to take information which it "sees" and use that information to make a decision.

As the students marvel at what they are able to combine a bunch of wires, some small componemts, and program a computer to automate a machine.

This leads to thoughts of how machines can be devised to do the "thinking" jobs that only humans could do just a few years ago.

Questions of the ethics of making machines that put people out of work are discussed along with what kind of education do I need to have to prevent it from happening to me.

The trade offs of devising machines to handle toxic waste, perform boring accident prone jobs, reduce the cost of manufacturing against unemployment are discussed informaly in the groups as they work on thier design of the automated designs.

# PRINCIPLES OF ENGINEERING

## MACHINE AUTOMATION: A Case Study

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APPENDIX

1. POSSIBLE PROGRAM SOLUTIONS
2. ADDITIONAL ADVANCED PROBLEM SETS
3. AUTOMATED TOLL BOOTH AND ACCOUNT MANAGER
4. SMART AUTOMOTIVE DASHBOARD
5. SMART PARKING GARAGE
6. SURGICAL ROBOTICS MECHANISM
7. MACHINE AUTOMATION PORTFOLIO

# INTRODUCTION TO ENGINEERING

## MACHINE AUTOMATION AND CONTROL

By Kenneth Ford

## I. CASE STUDY DESCRIPTION

The objectives of this case study are to encourage students to become familiar with, and understand some of the principles involved in machine automation, to understand the importance of automation and control processes on our society, and to participate in an exercise in creativity. The design problem will require a student to design, draw, build, and test a machine automation project. After the project has been completed, students will have a new awareness of machine automation and control; and the importance it has in shaping our civilization and economy. Students will be introduced to the disciplines of mechanics, control engineering, structural design, pneumatics and hydraulics, and robotics. Schools, for this vital reason, should be providing students with an introduction to the fundamentals of these evolving technologies in an intensely practical way, through hands-on experience and problem-solving applications.

How these technologies work and how they can be applied are the thrusts of this case study on machine automation. The emphasis is on gaining an understanding, in a totally practical way, of the physical sciences behind the technologies. Math and physics come alive to students when what has been abstractions are applied in real-life problem-solving situations.

The main focus of this case study is on conversion of energy and transmission and control of power. It is not intended to produce "technicians" or "automation specialists". Instead, the students are being exposed to fundamentals on which such new jobs skills depend. This will be accomplished by a combination of classroom theory and practical hands-on experience with the actual mechanisms that convert energy and transmit and control power. In doing this, we will equip students with the conceptual tools and the pragmatic skills needed to function in a world of high technology.

## II. DEFINITION OF PROBLEM

To research, design, and construct a miniature automated material handling system that would automatically separate a group of clear and colored marbles. All components of this miniature system will be controlled by a microcomputer and interface acting as a programmable controller.

## III. PERFORMANCE OBJECTIVES

A. Students will learn the principles of control systems and how they are applied to a production system to achieve automation.

1. Students will understand the basic concepts of control system technology.

2. Students shall be familiar with the methods of describing control systems using block diagrams.

3. Students will identify the major subsystems which make up an automated control system.

4. Students will identify the differences between open- and closed-loop control systems.

B. Students will learn the principles of connecting a computer interface to sensors and actuators. They will study the set up and operation of simple (discrete, binary) and complex (analog) sensors control. To accomplish this, the student will be able to:

1. Connect the interface ribbon cable and power unit to the computer with instructor's assistance.

2. Connect sensors and actuators to the interface using the ribbon cable and wiring diagram.

3. Write simple basic programs needed to sense and control external equipment.

4. Explain how the computer and interface can be used as a flexible programmable controller.

C. Students will have an opportunity to work with mechanical devices and systems. They will study the principles, concepts, and applications of various mechanisms encountered in industrial applications of engineering technology.

1. Describe machines and mechanisms in terms of the types of motion they produce.

2. Explain the relationship between mechanical advantage and velocity ratio.

3. Define the different types of levers and linkages used in the transmission of force and energy.

4. Demonstrate the transmitting of motion and energy between two shafts by the use of pulleys and sprockets.

5. Explain the different types of gearing mechanisms and how they are used in the transmitting of energy and motion.

6. Describe the function of cams, eccentrics, and ratchets and how they are used to convert one form of motion and energy into another.

7. Explain how crank/slider and screw mechanisms convert motion and transmit energy.

8. Describe how couplings and shafts are connected to transmit energy and motion.

## IV. EXPLANATION OF SPECIFIC MATRIX

**Computer control** is an essential part of machine automation. Computers are used everywhere in industry these days. Many industries are converting to flexible programmable equipment. The computer control section of the machine automation curriculum matrix is designed to expose students to real world monitoring and control functions using a computer as a programmable controller. Students will interface sensing devices to the computer, write simple control programs to process this information, and then output signals to control external devices. In doing this, the students will use the computer as a tool in controlling technological systems.

The **monitoring function** is an important part of computer automation. The computer "looks at" the process or devices being controlled to see what is happening. For example, the computer can monitor switches, contacts, temperature, the presence or absence of light, liquid level, pressure, and many other parameters. Transducers that monitor these physical characteristics convert them into electrical signals that the computer can understand and respond to. Once the computer has processed this information, it can control external devices. For example, the computer can actuate relays and solenoids or turn lights and motors off and on. It is actually being employed as a sophisticated timer or sequencer. Many devices can be controlled at the same time by a simple computer. Microcomputers are widely used in this type of application.

In **control applications**, the computer actually determines when external devices are turned on or off. Computers can also change the control function in response to one or more of the input conditions that it is monitoring. For example, the computer can sense the level of liquid in a tank. If the liquid exceeds a given level, the computer can automatically turn off the pump that is filling the tank. If the liquid goes below a predetermined level, the computer detects this automatically and starts the pump. The key to this is that the computer makes its own decisions based on the input data it receives. The result is a fully-automated system.

**Levers and linkages, pulleys and sprockets, gear mechanisms, cams, eccentrics, and ratchets** are all mechanical devices which do work by converting or transmitting energy. Students must understand the principles, concepts, and applications of mechanisms and how they relate to machine automation and control. All machines are made up of mechanisms. Even very large and complex machines are made of basically simple mechanisms or working parts. The lever, pulley, gear, cam, screw, and rachet are all basic mechanisms. They transform an input motion and force into a desired output motion and force.

In using these mechanisms, the student will design and build a mechanical device to solve real world engineering problems. In doing this, they will gain a knowledge and understanding of mechanical components and how they are used in industrial applications.

Introduction to Engineering Curriculum Design Matrix
Machine Automation (Mechanisms)

| FACTOR / CONCEPT | COMPUTER CONTROL | MONITORING FUNCTIONS | LEVERS & LINKAGES | PULLEYS & SPROCKETS | GEAR MECHANISMS | CAMS ECCENTRICS & RATCHETS |
|---|---|---|---|---|---|---|
| MODELING | DESIGN, BUILD AND WIRE A DIAGNOSTIC TEST BOARD | DESIGN AND BUILD A TRAFFIC LIGHT WITH A SWITCH MONITORING SYSTEM | DESIGN AND BUILD A MECHANICAL LIFT SYSTEM | CONSTRUCT A MODEL OF A CONTINUOUS POSITION INDICATOR | BUILD A MECHANICAL SORTING SYSTEM | BUILD A VALVE SYSTEM SIMILAR TO A CAR ENGINE |
| SYSTEMS | EXPLAIN & DEMONSTRATE THE COMPUTER USED AS A PROGRAMMABLE CONTROLLER | EXPLAIN THE CONCEPT OF OPEN AND CLOSE LOOP CONTROL | MECHANISM AS A BLACK BOX WITH INPUT/OUTPUT | | EXPLAIN THE CONCEPT OF GEAR RATIO & COMPOUND GEAR TRANSMISSION. | EXPLAIN THE CAM SYSTEM USED IN AN AUTOMOBILE |
| OPTIMIZATION | EXPLAIN THE ADVANTAGES OF A COMPUTER OVER HARD AUTOMATION | EXPLAIN HOW LIGHT INTENSITY IS USED IN CONTROL CIRCUITS | MECHANICAL ADVANTAGE VS. VELOCITY RATIO | PERFORM SIMPLE CALCUALTIONS ON PULLEY & SPROCKET SYSTEMS | EXPLAIN THE RELATIONSHIP BETWEEN COST, SPEED AND STRENGTH | REVIEW THE DIFFERENT CAM SHAPES VS FOLLOWERS |
| T/S IMPACT | DISCUSS THE EFFECTS OF COMPUTERS ON SOCIETY | DISCUSS THE IMPACT OF REMOTE CONTROL DEVICES ON SOCIETY | HISTORICAL IMPACT | | THE EFFECT OF AUTOMATIC TRANSMISSION | REVIEW THE EFFECT OF THE AUTOMOBILE ON SOCIETY |
| ECONOMICS | DISCUSS THE IMPACT OF COMPUTERS ON OUR ECOMONY | REVIEW THE ECONOMICS OF LIGHT SENSING STREET LAMPS | | EXPLAIN THE ECONOMICS BETWEEN THE TWO SYSTEMS | | PREVIEW THE EFFECTS OF THE INTERNAL COMBUSTION ENGINE ON ECONOMICS |
| DESIGN | DESIGN & BUILD A COMPUTER CONTROLLED AUTOMATED SYSTEM | DESIGN & BUILD A LIGHT CONTROLLED MECHANICAL SYSTEM | DESIGN AND BUILD A SIMPLE WEIGHING MACHINE | DESIGN AND BUILD A SIMPLE SPROCKET SYSTEM | DESIGN & BUILD AN AUTOMATED MACHINE TOOL TO SIMULATE AN INDUSTRIAL PROCESS | DESIGN AND BUILD A SIMPLE WINCH |
| ETHICS | | | | | | DISCUSS THE EFFECTS OF AIR POLLUTION |

## V. BACKGROUND MATERIAL

### A. Computer Interfacing Techniques

1. Installing interface module.
2. Making program backups and loading software.
3. Assembling cables.
4. Assembling diagnostic board from wire diagram.
5. Review diagnostic program.

**Reading Material:**

1. Electronic Applications for the Fischertechnik Computing Kit by Karen Jolicoeur ed. (Appendix A&B)
2. Fischertechnik Interface Booklet For Your Computer (12 pages of reading).
3. Fischertechnik Programming/Kit Building Instructions (use as reference for projects).

### B. Simple Basic Programing

1. What is a computer?
2. Why learn to program?
3. Using variables.
4. Making decisions.
5. Computer arithmetic and numbering systems.

**Reading Material:**

1. A Guide to Programming the IBM Personal Computers by Bruce Presley
2. A Guide to Programming in Applesoft by Bruce Presley
3. A Beginner's Guide to the Commodore 64 by Bruce Presley and Ted Deckel

### C. Monitoring and Control Functions

1. Sensing Devices
    a. analog and digital
        1. motion
        2. force
        3. temperature
        4. light

2. Control Devices
    a. actuators
        1. electrical
        2. mechanical
        3. electro-mechanical
        4. pneumatic
        5. hydraulic

**Reading Material:**

1. Modular Courses in Technology, Electronics by Oliver and Boyd
2. Radio Shack's Getting Started in Electronics by Forrest M. Mims, III
3. Electricity and Electronics by Gerrich/Dugger (good section on D.C. motors and relays)

D. Mechanical Devices

1. Levers and Linkages
2. Pulleys and Sprockets
3. Gear Mechanisms
4. Cams, Eccentrics, and Ratchets

**Reading Material:**

1. Modular Courses in Technology, Mechanisms by Oliver and Boyd

E. Final Report

1. Title (a few words describing the experiment).

2. Abstract (single paragraph describing what the experiment was about, how it was performed, and what the results were).

3. Introduction (single paragraph giving background on the experiment, why it was important, references to past experiences of others).

4. Experimental (written summary on the construction of the project, procedure used to conduct the experiment, materials used, how it was assembled and tested, and how the efficiency of the system was tested.

5. Results and Discussion (summary of observations taken during the construction of the project).

6. Conclusions (a short paragraph discussing what was learned from the experiment, highlighting the essential points made in the "Results and Discussion" section).

## VI. PROJECT OVERVIEW, PROCEDURES

**Explanation of the Design Problem in Machine Automation**

The instructor will explain how the design problem will be run and what the students should expect, such as time and size constraints, materials to be used in the construction of the project, and any resource materials that will aid students in project development. The instructor will also explain any relevant historical developments pertaining to the given design problem and the effects of this machine automation on society as a whole.

**Brainstorming**

This is the creative part of a design problem in machine automation. Each team member will develop ideas or possible solutions to the design problem. They will then break them down into individual subsets with thumbnail sketches representing each solution. Students should not discard seemingly inappropriate ideas, since some part of them may be used to build portions of the design problem at a later date.

**Choose a Design**

All students on the team should agree on the final design solution. Students may choose to combine ideas from several possible solutions. For instance, they may use a structure from one design, the drive system from another, and the sensing techniques from a third. These solutions should be sketched out in a 3-view drawing on graph paper and later transferred using formal drafting techniques into a working drawing.

**Building the Design Problem**

This is where collaboration and team work among students is essential. For example, one student may choose to build the super structure, while another develops the drive system, and a third wires the interface and writes the control program. While the students are working on aspects of the project individually, they must communicate and work together to come up with the final design solution.

**Testing and Redesign**

During the testing process, the students will evaluate their design concepts and make modifications where necessary. While testing their final design, the students may deem it necessary to make modifications in structure, drive system, or sensing control techniques. The students must work together, much like a team of engineers would in industry.

**Presentation**

Each team will give a presentation which will explain and demonstrate their design problem solution, why this design was chosen, and how the design problem actually performs. The team will submit working drawings for reference and evaluation by the instructor. They will also submit a written report which includes the title of the project, an abstract, an introduction or background section, a procedure section, and conclusion.

## VII. SUGGESTED EVALUATION METHODS

The main reasons for evaluating students are to provide feedback on their progress and to discriminate between individual performance.

There are several ways of assessing student performance.

1. Teachers may use **contract assessment.** This is a method of assessment where the student and instructor form a written contract or agreement. This contract spells out the expectations of both parties and is completed before project work is started. The contract can only be altered if both parties agree.

2. **Subjective assessment** is another form of evaluating students. This form of assessment has very little set criteria. It is usually subject to the instructor's biases and is based on a wide range of interpretations.

3. **Ranking assessment** is a comparative method of evaluation. It is based on reports submitted and different forms of testing and may also include teacher assessment.

4. **Objective-based assessment** is a form of evaluating students using clearly specified and defined objectives. After developing these objectives, the instructor must decide the weighting of each objective for marking purposes. Once this has been completed, the instructor should convey these objectives to the students. The students must then carry out the performance objectives, each using supporting competencies. Upon completing each objective, the instructor will sign off the objective and allocate a grade based on the weight of each objective.

5. **Performance assessment** is based on a number of specific areas of assessment. Some of these areas include:

   - *composition* (accuracy, clarity, presentation, use of material)
   - *research* (developing resources, evidence of reading and understanding information courses)
   - *originality* (examples of information presented and projects constructed, standardized results, original design of or use of equipment)
   - *scope* (difficulty of topic covered, relevance of material relationship with previous knowledge)

   An alternative list could be based on behavioral characteristics , such as:

   Personal qualities
   Resourcefulness
   Creative thinking
   Perseverance
   Initiative
   Ability to work on a team.

## VIII. CASE STUDY TIME TABLE

**WEEK 1: INTRODUCTION TO MACHINE AUTOMATION CASE STUDY AND COMPUTER INTERFACING**

MONDAY: Explanation of the design problem in machine automation. Divide class into design groups of equal size.

Discuss the following items:
- Project constraints
- Resource materials
- Marking procedure

TUESDAY: Installation and instruction on interface modules.

WEDNESDAY: Formatting student data disks, loading the basic language and Fischertechnik programs.

THURSDAY: Begin building diagnostic board projects and review wiring diagram for computer interface.

FRIDAY: Finish wiring diagnostic board project and run the diagnostic program provided with interface. Instructor should explain the diagnostic program and its uses.

**WEEK 2: PROGRAMMING TECHNIQUES FOR MONITORING AND CONTROL FUNCTIONS**

MONDAY: Using the diagnostic board project, have students load the driver program from their data disks and enter simple motor control commands. Explain how the computer is being used as a programmable controller.

TUESDAY: Review simple programming techniques and explain the following concepts:

- What is a program?
- Why learn to program?
- How to enter a program.
- How to edit a program.
- How to load and save a program.

WEDNESDAY: Introduce students to control system technology by citing examples around home and school. Explain the following concepts:

Components of a control system
Block diagram representation of a control system
External inputs
External outputs
Controller
Signal conditioning
Sensors
Actuators

THURSDAY: Explain the concept of open- and close-loop control and how this is accomplished using a **small control project.** (Give small programs as examples.)

FRIDAY: Explain the use of analog and digital sensors for monitoring automated systems. Review the following sensor types.

Motion
Force
Temperature
Light
Electrical

**WEEK 3: MECHANICAL DESIGN AND CONTROL ALGORITHMS**

MONDAY: Discuss design problem with students and divide the problem into individual subsets with each student producing thumbnail sketches of possible solutions. Discuss the sequence of events that need to happen in order to solve the design problem.

TUESDAY: Introduce students to simple control programs needed to solve the design problem. (This is best accomplished through the building and programming of small one- or two-day projects.

WEDNESDAY: Have student teams choose possible solutions for each individual subset of the problem and begin 3-view drawings on graph paper. Instructor should discuss at the beginning of class the following concepts of mechanical design:

Mechanical advantage versus velocity ratio
Levers and linkages

THURSDAY: Discuss the use of the procedure sheet in solving a design problem. Review the following concepts:

3-view drawing generation
Formal drafting techniques
The need for team work

FRIDAY: Have student teams build a **small control project** that will familiarize them with the control techniques needed to solve a portion of their design problem. The instructor should provide the control program and analyze it with the students.

**WEEK 4: MECHANICAL DESIGN & CONSTRUCTION OF PROJECTS**

MONDAY: Have students begin formal drafting of 3-view working drawings needed for the construction of the project.

TUESDAY: Continue formal drafting of 3-view drawings while entering information on design procedure sheets. Instructor should discuss at the beginning of class the principles behind pulleys and sprockets and how they may relate to their design problem.

WEDNESDAY: Continue formal drafting of 3-view drawings while entering information on design procedure sheets. Instructor should discuss at the beginning of the class the principles behind gear mechanisms and how they may relate to their design problem.

THURSDAY: Student teams will continue formal drafting and begin construction on design problem. Instructor will explain to students the need for good construction techniques and team work.

FRIDAY: Have student teams build a **small control project** that will familiarize them with the control techniques needed to solve a portion of their design problem. The instructor should provide the control program and analyze it with the students.

**WEEK 5: TESTING AND REDESIGN**

MONDAY: Students will continue to work on constructing design project. They will construct each subsystem individually, continuously evaluating their design concepts and making modifications where necessary. The instructor, at the beginning of class, should discuss the use of cams, eccentrics, and ratchets.

TUESDAY: Students will continue to work on design problem construction. At the beginning of class, the teams will meet and discuss construction progress and any suggested modifications. The instructor will discuss proper procedures for running a job meeting and delegating team member duties.

WEDNESDAY: Project construction: Certain members of the design team should be writing the control program while others are wiring the interface and construction subsystems.

THURSDAY: Project construction: During the construction process, the students should periodically test and evaluate control programs and subsystem models while also working on design procedure sheets.

FRIDAY: Have student teams build a **small control project** that will familiarize them with the control techniques needed to solve a portion of their design problem. The instructor should provide the control program and analyze it with the students.

**WEEK 6: EVALUATION AND PRESENTATION**

MONDAY: Discuss team reports and presentations. The instructor will explain the format to be used for writing the reports and presentations.

TUESDAY: Finishing construction and evaluation projects: Students will meet as a team and evaluate the project design. They will analyze the results and delegate duties for project write-up and presentation.

WEDNESDAY: Final report writing and developing presentation: The written report will include a title page abstract, an introduction or background section, a procedure section, and conclusion.

THURSDAY: Final reports and presentations: Teams will hand in their final reports and give their presentations.

FRIDAY: Final reports and presentations: Teams will hand in their final reports and give their presentations.

## IX. RESOURCES FOR STUDENTS AND TEACHERS

**Videotapes**

"Flexible Manufacturing Systems" (45 min) Society of Manufacturing Engineers

"For Years to Come" (20 min) Chrysler Corporation

"The New Industrial Revolution" (13 min) Society of Manufacturing Engineers

**Movies**

"The Robot Revolution" (18 min) Society of Manufacturing Engineers

"Ballet Robitique" (10 min) General Motors

**Filmstrips**

"Robot Nomenclature," "Robot in the Workplace," "Robot Classification," and "Basics of the Teachmover Robot." Available from: Bergwall, P.O. Box 238, Garden City, New York 11530-0238

"Robotics: Science Fiction Come True" (F8507), "Introduction to Robots" (F8507A), and "Robots in Everyday Life" (F8507B). Available from: Eye Gate Media, 3333 Elston Avenue, Chicago, Illinois 60618

**Catalogs**

Modern School Supplies
P.O. Box 958
Hartford, Connecticut 06143

Radio Shack
Fort Worth, Texas 76102
(hardware/software catalog)

Heath Kit Electronic Center
3476 Sheridan Road
Amherst, New York 14226
(component catalog)

**Suggested Equipment**

Modeling systems which include the following modules:

- computer control (interface)
- pneumatics
- motor and gears
- electricity/electronics
- structures
- fasteners
- building blocks and base plate

A tabletop robot (with interfacing capabilities)

Apple or IBM Microcomputer

Optional Equipment:

- AC and DC experiment (trainers)
- digital logic (trainers)
- servo motor (trainers)
- stepper motor (trainers)
- motor control (trainers)

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# MACHINE AUTOMATION AND CONTROL

I. Definition: *A system of manufacture designed to extend the capacity of machines to perform tasks formerly done by humans.* For years, machines were designed to be controlled by an operator whose job it was to change machine speeds, gear ratios, direction, pressure and cutting depth. Recently, advances in microprocessor controls and software programs have eliminated many of the menial, tedious and even dangerous tasks of the operator. There are many automated systems that are sophisticated enough to aid an operator in the design and creation of a part without that operator ever physically touching the object until its completion. This process is the marriage of CAD and CAM.

Other fields that have benefited from Machine Automation and Control (M.A.C.) include communications, medicine, aviation and exploration. Each of these, and others too numerous to list, incorporate M.A.C. to handle millions of instructions and operations safely, efficiently and quickly. For example, consider the speed and cost effectiveness of sending a FAX when compared to mailing a letter or the ability to scan thin layers of human tissue using an MRI compared to exploratory surgery.

II. Reasons for Teaching this Case Study: More than ever before in the educational history of this nation, students today need to understand basic control applications using a computer and how computer-automated systems operate. Through the development of key concepts including open and closed loop systems, feedback and control, and how these relate to both hardware and software, a greater appreciation and growth in understanding will take place. In addition, the social and ethical impacts of this growing field will be explored:

a.) Machines replacing their human counterparts can cause massive unemployment for unskilled workers and the economic distress of small towns and cities where these workers live.

b.) Machine Automation and Control offers newer, cleaner work environments, opening up a a wealth of new job opportunities that were unheard of only a few years ago.

c.) Machine Automation and Control can replace tedious tasks which may lead to employee boredom, carelessness and possible safety hazards.

d.) Workers, exposed to toxic chemicals and waste in their normal employ, can benefit by having M.A.C. oversee and handle materials in those areas of a plant that are too dangerous for humans.

III. Methods of Automating: Machine automation may be viewed in two domains. The first may be referred to as Self Contained and the second, Computer Controlled. There are pros and cons to both systems as outlined briefly below:

a.) Self Contained: Has no external processor or computer connection. There may be a microprocessor contained within the device that has been "pre-programmed" to do a set number of tasks. A garage door opener or a home heating system (See Microsoft Encarta reprint on the following page) are examples.

PROS: small, inexpensive, efficient for task, no operator required due to set programming task
CONS: not expandable, usually cannot be "reprogrammed"

b.) Computer Controlled: Has an external processor or computer connection. No set tasks designed into the device allowing it to be more versatile than a Self-Contained device. A robotic arm used in the automobile industry is an example.

PROS: versatile, multiple task orientation, expandable, requires an operator
CONS: must be programmed, requires an operator, expensive, larger

IV. Machine Automation Systems for the Classroom: There are two major kit manufacturers for machine automation simulation, *Fischertechnik Computing* and *Dacta Control Lab*. Both systems are made with a high degree of precision which eliminates wasted laboratory time machining tedious parts (gear boxes, sensors, etc.). The high degree of precision is not without drawback: Kits purchased from these companies are expensive to outfit a classroom properly but the cost is justifiable when one considers the tradeoffs in locating equally flexible materials or making kit parts from scratch.

The *Fischertechnik* computing system may be purchased by piece or in a variety of kit forms ranging from generic parts to specific tasks. The computer interfaces for these kits may be purchased for any Apple or IBM computer supporting interpreter BASIC. *Lego Dacta Control Lab* is similar in scheme but requires a faster processor machine as found on later IBM's and Macintosh computers. (See appendix for vendor listing)

V. Methods of Programming: Automated machines are only as useful as the information sent to them. In general, they are controlled by an exclusive set of instructions called a "program". The instructions are received by the machine through some coded form of a "programming language". Programming languages, in themselves, are a combination of trade offs between readability, "user friendliness", portability (moving from one machine to another), execution speed, reliability and purpose.

There are many different types of computer languages ranging from the more commonly known types such as BASIC, C, and Pascal to the obscure such as ADA, Modula2 and RPGIII. All of these have their strengths and weaknesses but in general, they all do the same task, that is to precisely tell a computer what to do.

Programmers that write instructions for a specific machine control system must be "literate" in the language of that machine. The language is optimized to work best with that machine's task and still be efficiently coded by the programmer. Since the focus of this case study is not the programming language, nor the methods employed in efficient programming instructions (algorithms), programming methodologies will not be covered here.

VI. Problem Definition: This study may be divided into two sections consisting of Background Information and Problem Approach. The former is outlined in a sample portfolio included at the end of this case study. The second is used to offer some suggestions to the instructor in planning an automation problem.

Background Information - Since machine automation requires the disciplines of computer science, electricity/electronics and mechanical design, all students in the "team" will need to understand how all of these areas interact in their solution. This will include structural parts and their connections, electronic sensors and drivers and how the program instructions link all of the mechanisms together. The first three pages of the sample portfolio are dedicated to providing an overview of control problems for the student. (Possible solutions are found in the appendix).

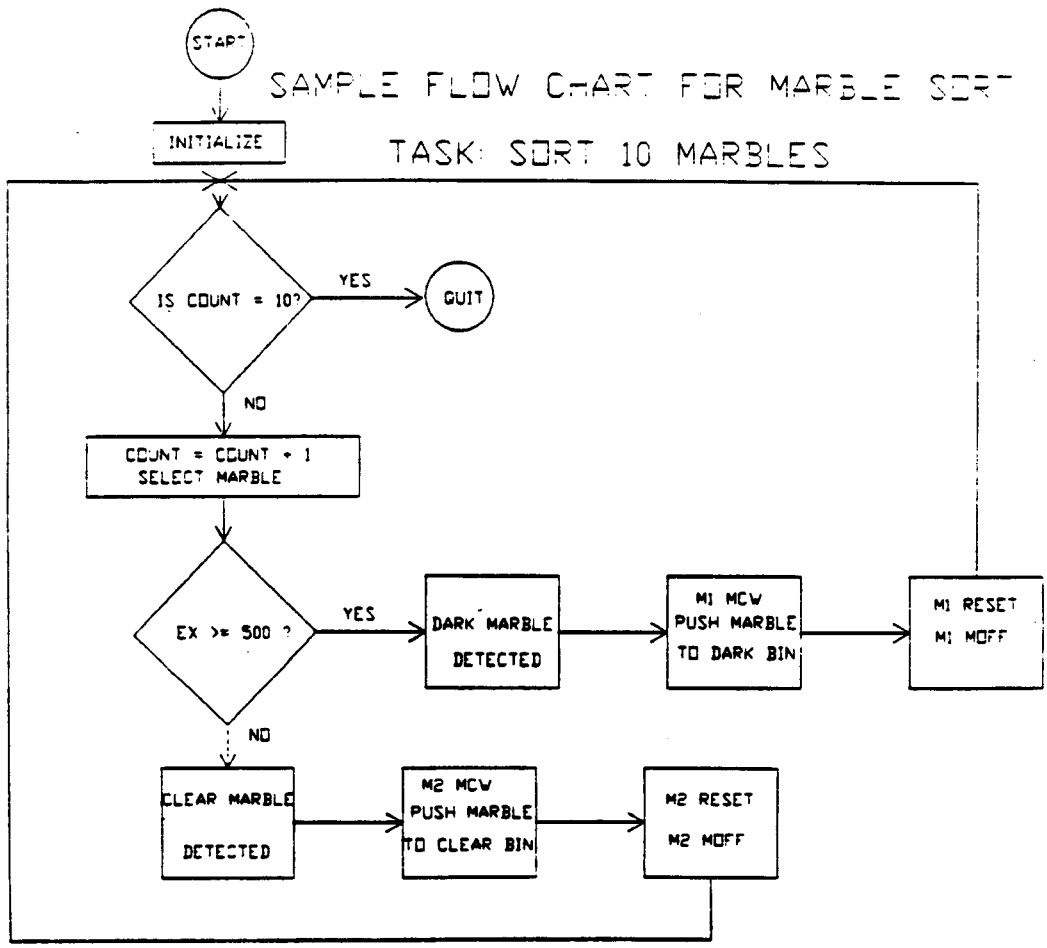
Problem Approach - With some basic knowledge of machine control understood, students will be ready to apply that information to a more complex task set. Ideally, the problem that the instructor chooses should be one that challenges the more talented students without swamping the rest of the class. A few basic problem suggestions are: Research, Design and Construct a device that will:

- sort clear glass marbles from opaque glass marbles
- sort different sized marbles
- sort glass marbles from steel balls of the same size
- transport a small ball down a ramp, change direction, and return to the start after a predetermined time period

Additional advanced problem suggestions are available in the appendix of this case study. All components should be computer controlled and no human intervention should take place once the system is activated. NOTE: Repetition is important in this case study and so a large number of sortable items (marbles, cubes) should be available to properly test the system.

VII. Project Overview, Procedures: The instructor will choose a problem and design his/her particular constraints around it. Using a real-world problem approach (sorting glass marbles could simulate sorting recyclable glass at a recycling plant) can be used to draw some of the social and ethical impacts resulting from machine automation.

Due to the complexity of the problems in this study, it is suggested that short term deadlines are given throughout the development of the student's solution. Students should begin by developing a series of diagrams (or flow charts) depicting the possible control system solutions. Then, with their own team, students should discuss "bugs" in their solutions and ways to overcome them using trade offs and optimization techniques discussed earlier. Below is a possible flow control chart for sorting glass (clear and opaque) marbles.



Explain the Resources
Students will need to examine the seven resources as they apply to this case study.

*TIME*: How much time will it take to research, develop, test and perfect a solution to this problem. How can the team work efficiently to make the best use of the time given?

*Tools and Equipment*: What tools are needed to create your solution? Which are not provided by the "kits"? How are these additional tools incorporated into the process?

*Capital*: Students should be aware of the cost of the "kits" and associated components provided for them in this case study. Make an inventory of their solution and compare relative costs to another team's solution. Discuss the cost relationship between the solution (model) and a full scale solution.

*Materials*: What materials are required to solve the problem? How will integrating additional "non-kit" parts affect the performance and time constraints of the solution?

*Power Source*: Discuss the types of power used in machine automation including electrical and mechanical. Discuss how these are interrelated and interdependent to accomplish the task.

*People*: Have the student team divide the task amongst themselves into three major disciplines: Electrical Engineering, Mechanical/Structural Engineering and Programmer. How are these disciplines related to the success of the task? Discuss the importance of good communication between and among the disciplines.

*Information*: Each engineering discipline should develop a means to research what is required for task success. How is communication between team members critical in this case study? How is information from machine (mechanical) to machine (computer) handled with and without human interaction?

**Generate Alternate Solutions** Now that the students have recorded a number of possible solutions and have identified the resources required to accomplish the task, the teams may wish to interact to share their solutions outside of their group. Each alternate solution should be completely investigated to determine its viability using some of the engineering concepts discussed earlier (ethics, society and technology, design, modeling).

**Choose the Best Solution:** After the team has thoroughly examined all of their best possible solutions, they will need to synthesize their ideas to form an optimal solution for the task at hand. Class presentations work well for this as each team is given the opportunity to explain their approach to the problem and reasons for selecting their particular final solution. Flow charts and other graphic presentations should be incorporated into the activity.

Building and Testing the Prototype: With the team's ideas finalized and the entire problem evaluated, the team may now begin to build, wire and test a simple prototype. The testing phases should be as close to the actual problem set as possible to determine the actual solution's viability. The teams should critique the performance of their solution and make corrections to the device and their journal.

**Evaluating the Design and the Team Effort:**

*I. Was the design completed in a timely manner*

4 All aspects completed on time
3 Nearly all aspects completed on time - some troubleshooting to do
2 Still major troubleshooting to complete - machine doesn't function properly
1 Not done at all

*II. See if the prototype works as intended*

4 Works equal to or better than expected
3 Design works but not up to recommended standard
2 Device works intermittently - not stable
1 The device does not work

*III. Was the time used effectively by the team*

4 All members of the team participated equally on all aspects of the device
3 All members of the team participated nearly equally but some overlap occurred
2 Some team interaction but the solution was developed primarily by one individual
1 No design analysis evident, team interaction was minimal

*IV. Problem design solution correct and creative*

4 The solution was clever, effective and captured the essence of the problem
3 The solution was a success but without totally unique ideas
2 The solution is intermittent due to problems not overcome in the testing phases of this project
1 The solution does not work. Evidence of trial and error methods and poor planning

*V. Portfolio/Journal Evaluation*

4 Journal written neatly, chronologically and in complete sentence Evidence of research, sketches, final drawings, final flow chart and the six major engineering concepts.

3 Well written and developed journal but with limited outside research. Drawings lacked total clarity and the flow chart(s) was(were) incomplete.

2 Journal was kept up to date as the project progressed but no final analysis found. Sketches were found, but no final drawing(s) nor flow chart(s)

1 Poor quality of writing, incomplete or missing sketches, final drawings and/or flow chart(s)

*VI. Self Assessment*

As part of the *Portfolio/Journal Evaluation* the students should reflect upon the case study, their individual roles and personal involvement in the development of their team's solution, and the successes and failures of the team in this endeavor. This may be accomplished with a series of prompts or in a *Conclusion* section at the end of the portfolio/journal.

## I. Possible Program Solutions - *PRELIMINARY INVESTIGATION*

### Problem #1 Solution

```
600 REM M1 to turn CW and M2 to turn CCW until a count of 500 is reached
610 Count = 0
620 WHILE Count <> 500
630    Count = Count + 1
640    Call (M1, MCW)
650    Call (M2, MCCW)
660 WEND
670 Call (M1, MOFF)
680 Call (M2, MOFF)
690 END
```

### Problem #2 Solution

```
600 REM Two lights, wired in to outputs M3 and M4, turn on before M1
610 REM M2 as in previous problem.  A delay of 400 shows that the lights
620 REM are on before the motors M1 and M2
630 Count = 0
640 WHILE Count <> 400
650    Count = Count + 1
660    Call (M3, MCW)
670    Call (M4, MCW)
680 WEND
690 Count = 0
700 WHILE Count <> 500
710    Count = Count + 1
720    Call (M1, MCW)
730    Call (M2, MCCW)
740 WEND
750 Call (M1, MOFF)
760 Call (M2, MOFF)
770 Call (M3, MOFF)
780 Call (M4, MOFF)
790 END
```

**Problem #3 Solution - Same code as above for problem #2.**

### Problem #4 Solution

```
600 REM A light and motor connected to M1 and M2 respectively
610 REM Both turn on at the same time and remain on for a count of 1000
620 Count = 0
630 WHILE Count <> 1000
640    Count = Count + 1
650    Call (M1, MCW)
660    Call (M2, MCW)
670 WEND
680 Call (M1, MOFF)
690 Call (M2, MOFF)
700 END
```

**Problem #5 Solution - Same code as above for problem #4.**

Problem #6 Solution

```
600 REM  A light and motor connected to M1 and M2 respectively
610 REM  Lines 650 - 680 test against the system clock above :50
620 REM  FIRST$ gets the initial seconds reading from the system clock
630 REM  SECOND$ continues to read the system clock until 10 seconds
640 REM  has past
650 FIRST$ = MID$(TIME$,7,2)
660 WHILE (VAL(FIRST$) > 51)
670        FIRST$ = MID$(TIME$,7,2)
680 WEND
690 SECOND$ = MID$(TIME$,7,2)
700 WHILE ((VAL(SECOND$) - VAL(FIRST$))< 10)
710    Call (M1, MCW)
720    Call (M2, MCW)
730    SECOND$ = MID$(TIME$,7,2)
740    LOCATE 12,12:PRINT "Time Elapsed: ", SECOND$
750 WEND
760 Call (M1, MOFF)
770 Call (M2, MOFF)
780 END
```

Problem #7 Solution

NOTE: Moving a rack four inches is estimated in the following routine. By changing the Count value, the students can approximate the length required.

```
600 REM  A motor connected to M1 with a rack system set up.
610 Count = 0
620 WHILE (Count < 5000)
630    Call (M1, MCW)
640 WEND
650 Count = 0
660 WHILE (Count < 5000)
670    Call (M1, MCCW)
680 WEND
690 Call (M1, MOFF)
700 END
```

Problem #8 Solution

```
600 REM  A motor connected to M1 with a rack system set up. Two switches
610 REM  E1 and E2 are connected such that 0 = OFF, 1 = ON.  Count
620 REM  allows the entire action to repeat itself twice.
630 FOR Count = 1 to 2
640    WHILE (USR(E1) = 0)
650       Call (M1, MCW)
660    WEND
670    WHILE (USR(E2) = 0)
680       Call (M1, MCCW)
690    WEND
700    Call (M1, MOFF)
710 NEXT Count
720 END
```

Problem #9 Solution

```
600 REM  A motor connected to M1 with a rack system set up. Switches
610 REM  E1, E2 and E3 are connected such that 0 = OFF, 1 = ON.  Count
620 REM  allows the entire action to repeat itself twice.
630 REM  E3 is now the start switch, initially in the OFF position.
640 WHILE (USR(E3) = 0)
650 WEND
660 FOR Count = 1 to 2
670    WHILE (USR(E1) = 0)
680       Call (M1, MCW)
690    WEND
700    WHILE (USR(E2) = 0)
710       Call (M1, MCCW)
720    WEND
730    Call (M1, MOFF)
740 NEXT Count
750 END
```

Problem #10 Solution

```
600 REM  A motor connected to M1 with a rack system set up. Two switches
610 REM  E1, and E2 are connected such that 0 = OFF, 1 = ON.  Count
620 REM  allows the entire action to repeat itself twice.
630 REM  EX is now the start switch, initially DARK, in the OFF position.
640 REM  Striking the photocell with light will activate the program.
650 WHILE (USR(EX) >= 500)
660 WEND
670 FOR Count = 1 to 2
680    WHILE (USR(E1) = 0)
690       Call (M1, MCW)
700    WEND
710    WHILE (USR(E2) = 0)
720       Call (M1, MCCW)
730    WEND
740    Call (M1, MOFF)
750 NEXT Count
760 END
```

## II. Additional Advanced Problem Sets

The following machine automation problems have been used in classes over a period of four or more years and may be used to offer a greater degree of programming and electrical challenges. Working student solutions, journals and program source code are available for each of these problems (See Vendor Listing - Modern Programming Language Support)

(1) ELEVATOR: To make a three (3) floor working model elevator with the following features:

a.) single car with two (2) opposing doors.
b.) doors to open according to floor otherwise lockout.
c.) programmed for random floor access.
d.) programmed for specific user access.

(2) MACHINE LATHE: to make a machine lathe and indexing head with the following features:

a.) rotating tool post with three (3) cutting tools.
b.) indexing head with four (4) lock-in positions (maximum).
c.) create three (3) duplicate "machined" parts based upon programmed part (styrofoam) which would include all tools and indexing head (drilling) operations.

(3) ROBOTIC ARM: to make a robotic arm for the sole purpose of the following:

a.) identifying three (3) basic shapes.
b.) sorting the shapes and placing them into separate bins.
c.) created automatic feeding system (belt, etc) to load shapes into the "sensing-section" of the robotic arm.
d.) shapes may include: sphere, box, pyramid, cone, cylinder.

(4)

PROBLEM BACKGROUND: In many industries, shipping parts and whole units is an expensive but necessary part of the business. To minimize shipping expenses ar maximize resources, cargo space is filled as efficiently as possible before the shipping process from a central agency can actually take place. In order to dc this, one must be able to determine what volume is available (cargo space), wha weight limitations exist (union restrictions, trucking/shipping laws, etc.) anc the cargo volume(s). (NOTE: Bear in mind that the latter consideration may have as many variables as there are container shapes to work with.)

Therefore, we will design a robotics device that could be used in any facility that ships items in containers (containers will be represented with different size wood cubes - sizes to be determined later). The robot's gen specifications are as follows:

I. General Information - Mechanical & Electrical

a.) must be able to determine box volume
b.) must be able to sort by box volume
c.) must be able to fill two different sized volumes representing cargo spaces or two different sized trucking vehicles
d.) must be able to maximize the cargo space (see "b")
e.) must be able to determine when cargo space is maximized
f.) must be able to determine when cargo to be shipped has been exhausted (no more to ship that day)

II. General Information - Computer Program

a.) must have a user friendly interface - computer program that will save the facility money in learning costs for the "new" system
b.) the program must be able to track where the cargo goes
c.) the program must be able to track the type of cargo enroute
d.) must be able to warn operator that cargo space is filled and shipment is ready to leave facility

- MACHINE AUTOMATION CASE STUDY -
AUTOMATED TOLL BOOTH AND ACCOUNT MANAGER

(5)
PROJECT DESCRIPTION (General):

To create an automated toll booth[1] and account manager that could be used on a toll road such as the NYS Thruway or the NJ Garden State Parkway. The device must be able to:

* accept[2] U.S. coins (nickels, dimes and quarters)
* determine[3] the coin's face value[4]
* update the collection amount for the booth (deposit)
* sort[5] all coins deposited according to the coin's face value
* alert the "driver" that the wrong coinage amount has been deposited
* alert the "driver" that non-U.S. coinage has been deposited

SPECIAL NOTES:

booth[1] : A pre-determined toll amount will be decided by the class

accept[2] : Each sorter will require a means to "load" the coins into the sorting device. No contact may be made after the coins have been "loaded" into the device.

determine[3] : Each sorter will require having a system of sensors to determine the face value of the coin.

value[4] : The face value of any coin is its legal tender value - nickels = 5¢, dimes = 10¢ and quarters = 25¢

sort[5] : All coins must be sorted according to their face value so that nickels are only with nickels, etc.

(6)
**Problem** *"SMART" AUTOMOTIVE DASHBOARD*: Design a COMPUTER-CONTROLLED automobile dashboard that is "sensitive" to the driver's needs based upon comfort, road and weather conditions, and ergonomic requirements. The dashboard must contain ALL of the following details **PLUS** two additional features that your team develops to make this a viable product for an automotive company to include in their automobile line.

- A "dashboard" displaying the manual and automated controls
- An audible means to warn the driver when the legal speed limit has been exceeded
- A pair of external driven mechanisms to represent the headlights and windshield wipers
- A means to sense and automate the headlights when lighting is dim
- A means to sense and automate the windshield wipers when it begins to rain
- A means to sense and activate the air conditioning when it becomes too warm in the automobile
- A complete design log/journal with all engineering aspects included (electrical, mechanical and computer programming design)

(7)
**Problem** *"SMART" PARKING GARAGE*. Design a COMPUTER-CONTROLLED parking garage consisting of two or three tiers (or floor levels) accessed by a single "freight" elevator located in one corner capable of reaching all level beginning at "street" level*. The garage's computer should be able to "remember" where all of the cars are parked in each of the tiers and be able to help the unskilled employees locate the vehicle as outlined below. The garage must contain ALL of the following details **PLUS** two additional features that your team develops to make this a viable choice to leave your second most expensive investment.

- A "parking garage" with two or three tiers, working "freight" elevator and parking spaces for nine "automobiles" on each level
- An audible means to alert one of the employees that another vehicle has arrived and needs to be "parked"
- A means to indicate an open space for the vehicle both in the computer and on the tier/level selected (LED matrix)
- A means to show that the automated elevator is loaded and ready to move to the selected tier
- A means to sense that "time" has passed and an accounting of the amount that the vehicle's owner owes the garage
- A means to sense and determine an efficient method of using the elevator during times of heavy flow in and out of the garage
- A complete design log/journal with all engineering aspects included (electrical, mechanical and computer programming design)

*NOTE*: level* - If you choose the two tier system, the elevator must be able to load below the two levels used for parking.

(8)
**Problem** *"SURGICAL ROBOTICS MECHANISM*: Design a COMPUTER-CONTROLLED surgical tool that requires the use of a computer screen to best determine the "location" and "action" of the tool when activated by a remote "joystick" device. The joystick must be student designed and built, work in a single two-dimensional plane, and be computer analog sensed. The tool must contain ALL of the following details **PLUS** one additional feature that your team develops to make this a viable choice for surgeons doing a very small and delicate procedure.

- A "joystick" working in a fixed two-dimensional plane
- A means to sense where the location of the joystick's position is using a computer screen
- A means to limit the boundaries for the joystick's travel so that surgical errors can be minimized - this "boundary" can be loaded at the start of each "surgical" procedure
- A means to show that an "incision" has been completed after activating an external mechanism located on the joystick pad
- A means to show that "material" has been separated and can be removed from the organism
- A complete design log/journal with all engineering aspects included (electrical, mechanical and computer programming design)

III. Vendors

Lego Dacta
555 Taylor Road
Enfield, CT 06083-1600
PH : 800 527-8339
FAX: 203 763-2466

Model Technologies (representing Fischertechnik)
2420 Van Layden Way
Modesto, CA 95356
PH : 209 575-3445
FAX: 209 575-2750

Modern School Supplies
P.O. Box 958
Hartford, CT 06143
PH : 800 243-2329
FAX: 800 943-7206

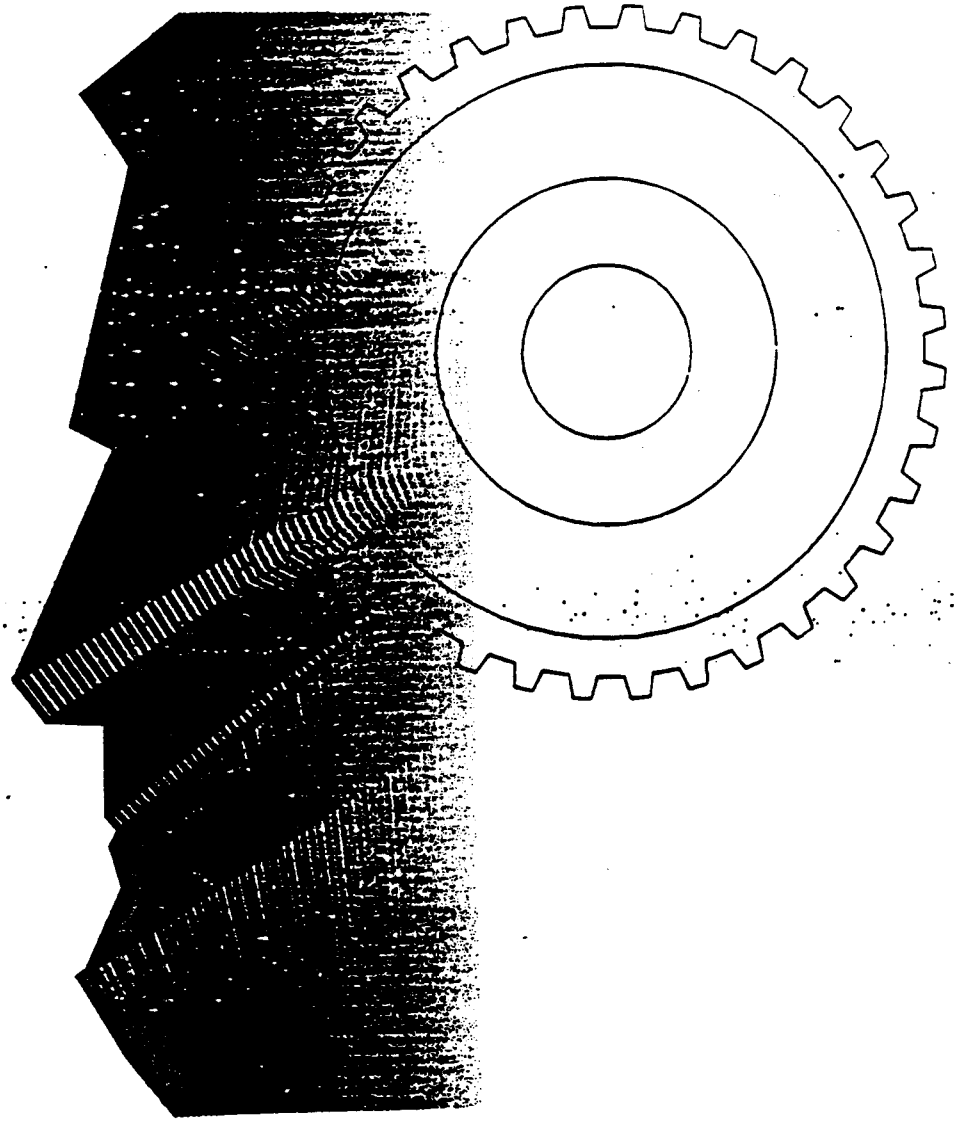
**Modern Programming Language Support**

Pascal, C and C++ language drivers for IBM PC/AT & Fischertechnik are available if you do not wish to use BASIC, BASICA or GWBASIC with the Fischertechnik devices. These drivers allow students to use more modern languages to program their devices. Two new diagnostic interfaces are included along with several program examples. All proceeds go to the students who developed these drivers.
Cost: $15.00 per diskette/manual Not copy protected.

Also available - Problem solutions for Additional Advanced Problem Se

For addition information: Arlington High School Computer Club
Fischertechnik Drivers
Arlington High School North
263 Route 55
Lagrangeville, NY 12540
PH : 914 486-4860 Ext:128
FAX: 914 486-4879

# MACHINE AUTOMATION PORTFOLIO



## Group Members

_____

_____

_____

# PRELIMINARY INVESTIGATION

Programming a circuit to turn on a motor clockwise and another counterclockwise.

(Draw a sketch of the circuit and the wire hook-up?)

(List the program you used)

Add two lights to the circuit and have it come on prior to the motors.

(What happens when you activate the program?)

(List the program you used)

Now remove one light and replace it with an electromagnet

(What happens now?)

Construct a device that will run a turntable or large gear while keeping on a light.

(List the program)

(Draw the circuit and its elements)

Now add some sort of timing device to the program

(List the program)

Now keep the turntable running for 10 seconds

(List the program)

Design a system that will move a rack on a pinion gear back and forth 4 inches with Programming
(list the program)

Now add one or two switches to the system and have it accomplish the same task.
(List the program)

Next add a switch which will activate the system.
(List the program)

Change the switch with a photocell and a light.
(List the Program)
(Draw a sketch of the problem)

# Define the Problem

**Describe the problem.**

**What Goals must be met to solve the problem?**

**Brainstorm Ideas**

# Identify the Resources

**Time**

**Tools & Equipment**

**Capital**

**Power Source**

**Materials - Building blocks and Components**

**People - Job descriptions**

**Information - Previous Investigation**

# Generate Alternative Solutions

**List Ideas**

# Choose the Best Solution

**Describe it**

**List the program**

# Build a Prototype

# Test the Prototype

**What tests will you use?**

**How will you know if this is the optimum solution?**

**What changes were necessary after the prototype was constructed?**

# Evaluate your Design

**Does the prototype work?**

**Given more time what could you have done to make it work better?**

**What is the best feature of your design?**

**What is the worst feature of your design**

# Self -Assessment

**What was learned in this project?**

**What did you not understand about your project?**

**Did the finished prototype meet your design expectations?**

**If so why - If not why not.**

**What part of the design problem was the most difficult to solve?**

**What was the easiest part to solve?**

**Rate yourself from a 1 to 5, (5 being the higest score) on this project and explain why**

**Procedure Sheet for Design Problem**

1. What is your definition of the design problem?

2. List the major subsystems within the design problem?

3. On a separate sheet of paper, list each subsystem of the design problem and provide a sequential list of events that must occur within that subsystem.

4. List the types(s) of sensing devices used in the design problem and explain how they are used.

5. List the types(s) actuators used in the design problem and explain how they are used.

6. Explain the relationship of each sensing device to the actuator(s) it controls.

7. Draw the block diagram of the control system used for each subsystem within the design problem.

8. Draw the wiring diagram for each actuator and sensing device used in the design problem.

9. Explain the mechanics behind each motion generated by an actuator.

10. List each step of the program used to control the design problem and give a brief explanation of each major section of code.

## Marking Procedure for Design Problem

1. **Thumbnail sketches on graph paper** (1/2 point for each sketch) ____

2. **3-View sketches on graph paper** (10 points maximum) ____

3. **Formal drafting** (20 points maximum) ____

4. **Design** (10 points maximum) ____

5. **Procedure sheet** (20 points maximum) ____

6. **Materials planning** (10 points maximum) ____
   Number of modeling pieces predicted ____
   (determined by use of drawings)

   Number of modeling pieces used ____
   (determined by counting actual parts)

   Formula for materials planning (# of pieces predicted /# pieces used)
   1.00 - 0.9 = 10 pts.
   .899 - .80 = 7 pts.
   .799 - .70 = 4 pts.
   .699 - .60 = 2 pts.
   .599 - .50 = 1 pt. ____

7. **Efficiency** = Number of marbles/time in sec. ____
   1st place team = 5 pts.
   2nd place team = 4 pts.
   3rd place team = 3 pts.
   all remaining teams = 1 pt. ____

8. **Written report** (20 points maximum) ____

Total Points ____

**Class of Certificate**

**90-100 points** *Automation Designer 1st Class (CEO)*
**80-89 points** *Automation Designer 2nd Class (Engineer)*
**70-79 points** *Automation Designer 3rd Class (Technician)*
**60-69 points** *Automation Designer 4th Class (Worker)*

The following is a list of suggested equipment for the Machine Automation Case Study. The instructor may adjust this list depending upon class size, nature of design problem and funding constraints. The list is adequate for a class of 20 students using the problem stated in the case study.

***Fischertechnik Equipment***
***1992 Price List***

*Recommended for Principles of Engineering*

| ITEM # | DESCRIPTION | QUANTITY NEEDED | UNIT PRICE | EXTENDED |
|---|---|---|---|---|
| RBT 105 | Computing Kit/Interface | 5 | $299.00 | $1495.00 |
| RBT 206 | Starter Kit | 5 | 99.95 | 499.75 |
| RBT 210 | Start Static | 5 | 59.95 | 299.75 |
| RBT 265 | Start Motor & Gears | 5 | 59.95 | 299.75 |
| RBT 230 | Mini-Motor & Gears | 5 | 65.95 | 329.75 |
| RBT 256 | Gray Building Blocks | 5 | 19.95 | 99.75 |
| RBT 259 | Chain Elements | 5 | 19.95 | 99.75 |
| | | | **Total:** | **$3123.50** |

# TECHNOLOGY EDUCATION
# PRINCIPLES OF ENGINEERING

## ENERGY CASE STUDIES

NewYorkPower Authority

Developed with
funding from the
New York Power Authority

The University of the State of New York
The State Education Department
Bureau of Home Economics
and Technology Education Programs
Division of Occupational Education
Albany, New York 12234

# Preface

Following an introduction which presents the problems of energy supply and electrical energy production, this case is presented in three parts: 1. The use of electrical energy in lighting and household appliances. 2. Building a model low energy use home. 3. Building a model solar-electric car.

In some classes the emphasis will be on only one of the sections, and in other classes the teacher and students will want to study all three. In all cases the class should study the introduction and participate in the electrical generation activity in order to get the feel for the need for energy conservation.

While the study of any one of the sections might take three or four weeks, a study of all three might take as long as eight to twelve weeks depending on the depth of study.

In some classes the students might concentrate on one solar house for the whole class, in others there might be competition among groups in which each group builds its own structure.The same might be true in the solar-electric car section.

Principles of Engineering

# ENERGY CASE STUDIES

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# INTRODUCTION TO ENGINEERING

## ENERGY CASE STUDY

### Case Study Description:

Energy is at the heart of all that we do. Our own personal energy enables us to move, speak, and breathe. Entire bookshelves of written materials and whole courses and even careers are devoted to the study of energy.

This six to eight week case study will of necessity deal with a very small segment (three aspects) of the energy situation. Following a brief study of energy sources and transformations students will examine the use of electrical energy in lighting and household appliances( **Section A.)** They then have the have the option to concentrate on one or both of the other two aspects of energy covered in the case study. Designing and building an energy efficient house( **Section B.)** or designing and building an energy efficient car( **Section C.)**. In either case, the concepts of the syllabus: MODELING, SYSTEMS, OPTIMIZATION, TECHNOLOGY SOCIETY INTERACTIONS, DESIGN, and ETHICS will form the basis of the activity.

### Energy: A Brief Background.

Energy is generally taken for granted, most of us think that it will always be available on demand. Its availability is actually dependent on many factors. The future availability of all off our natural resources, including energy, is dependent on the wise selection of the best energy mix for any specific purpose. The basis of the determination of the "best mix" will depend on an appropriate combination of EDUCATION (behavior modification), LEGISLATION (rules and regulations), and TECHNOLOGY (Research and development of viable systems).

Most household energy today is generated by conversion of oil, coal, and natural gas. These are fossil resources and are non-renewable. Conversion processes vary among resources. Each process of converting from source to energy has positive and negative consequences.

**This is true for fossil fuels, wind, solar, nuclear, water, geothermal, and bio-mass. The most efficient and the least polluting energy option is conservation.**

Energy choices should reflect the most efficient and effective conversion, using education, legislation, and technology in addressing economic, political and environmental issues.

So what is the best energy mix? Who will make future decisions on energy policy? How can selections be made to provide energy to maintain current levels of use, keep costs reasonable/ and not harm the environment?

There is no such thing as a **"FREE LUNCH".** There is no energy system that is FREE of problems. Another way of saying the same thing is to recall the concept of optimization and say that in all energy systems we must consider the **TRADE-OFFS.**

* The use of nuclear energy poses no problems in regard to smog, acid rain, or global warming, but there are problems involved in the disposal of used fuel rods from nuclear power plants. Because fissioning of uranium fuel in these rods produces highly radioactive products, the rods must be disposed of at specially isolated sites so their radioactivity will not contaminate the environment.
* Falling water provides the mechanical energy to turn electric generators, and when the water supply is adequate, the electricity generation capacity is equal to the original design criteria for the system.. If we wish to insure an water supply for ` the generators, we build dams. These dams are often accused of affecting the ecology of the region.
* Heat from below the surface of the earth (geo-thermal) can provide the energy to heat buildings or boil water to provide steam for turbine to generate electricity. There is often environmentally damaging material associated with the steam which comes out of the earth in the process.
* The process of manufacturing photovoltaic solar cells results in the production of toxic waste which is difficult to dispose of, or recycle.
* Wind generators are useful only in regions where there is a strong enough wind for a reasonable time each day to turn the turbines which turn the generators to produce electrical energy.
*Many of the present generating plants are designed to usefossil fuels. Any change from fossil fuels requires expensive replacement.

The job of the energy producers and the energy consumers is to agree on the optimum mix of energy systems.

**Definition of the Problem:**
Students will research various ways in which energy is transformed from one form to another. They will then choose to design and construct either an "energy efficient house" or a "solar-electric car" that will demonstrate the conversion and efficient use of energy.

## ENERGY CASE A

**Explanation of Specific Matrix**
The matrix matches the six concepts, MODELING, SYSTEMS, OPTIMIZATION, SCIENCE TECHNOLOGY, DESIGN, and ETHICS against the two major topics of the introduction, ENERGY BACKGROUND, and GENERATOR ACTIVITIES.
In each of the twelve boxes of the matrix there is a suggested student action. Some require library research, some a class discussion, and some the construction of a graphical or flow chart model of a situation, as well as actual laboratory experience with converting mechanical energy to electrical energy.

**Statistical data**
Statistical data is available from a variety of sources. "The World Almanac", published by Newspaper Enterprises Association, is usually found in school libraries. "State of the World", published by The Worldwatch Institute, or "the Universal Almanac", published by Andrews and McMeel. the following table is an example of data found in "The Universal Almanac 1992". It can be used to develop the model for any one year as suggested under Background in the matrix. It can also be used to show graphically the change over thirty nine years.
U.S. NET GENERATION OF ELECTRICITY BY UTILITIES BY ENERGY SOURCE, 1950-89 (Billion Kilowatt hours)

| YEAR | COAL | NATURAL GAS | PETRO-LEUM | NUCLEAR POWER | HYDRO-ELECTRIC | GEOTHERMAL &OTHER | TOTAL |
|---|---|---|---|---|---|---|---|
| 1950 | 155 | 45 | 34 | 0 | 96 | <0.5 | 329 |
| 1960 | 403 | 158 | 48 | 1 | 113 | <0.5 | 756 |
| 1970 | 704 | 373 | 184 | 22 | 248 | 1 | 1,532 |
| 1980 | 1,162 | 346 | 246 | 251 | 276 | 6 | 2,286 |
| 1989 | 1,551 | 264 | 158 | 529 | 264 | 11 | 2,779 |

This is a good time to emphasize that power is expressed in kilowatts and horsepower while energy is expressed in kilowatt hours and BTUs.

Introductory Matrix for Energy Case Studies

| CONCEPTS | BACKGROUND | ACTIVITY |
|---|---|---|
| **MODELING** | From information in the library and the various publications listed in the references, construct a pie chart of the percent use of various sources of energy to produce electricity. | Graph the power vs. voltage in the second activity. Graph the current vs. voltage in the second activity. |
| **SYSTEMS** | Diagram the systems involved in the generation of electricity from a renewable and a non-renewable. | Construct a flow chart to describe the apparatus set-up for each activity. Specify input, output, feedback. |
| **OPTIMIZATION** | Explain the trade-offs involved in the generation of electricity from coal as compared to the generation of electricity from any other source. | As a result of experience in generating electricity to light four bulbs, explain the concept of peak power loads and make recommendations for maintaining low levels of peak power. |
| **TECHNOLOGY-SOCIETY INTERACTION** | Role-play ways in which engineers and legislators might work together to reduce the potential negative effects of electrical generation and distribution. | Discuss some of the educational and technological alternatives which electrical generation companies might institute to reduce the peak load at any specific time of day. |
| **DESIGN** | Use the design process to develop a procedure for examining the effects of various energy transforming systems on the environment. | Design a system which would compare the power in vs. the power out in an electrical generation system. |
| **ETHICS** | Discuss regulations as they relate to ethical problems involved in energy conversion. | In terms of peak power, discuss the ethics involved when citizens demand that industry reduce its push for more generating plants while continuing to use all of their electrical appliances at the same time each day. |

**Introductory Activity:**

This can be done as a demonstration or as a class activity depending on the amount of equipment available.

The purpose of the activity is to demonstrate physically that there is no such thing as a free lunch. We will use mechanical energy as the input to produce an output of electrical energy.

Use a hand operated electrical generator connected to a voltmeter and a single light bulb as in the diagram.

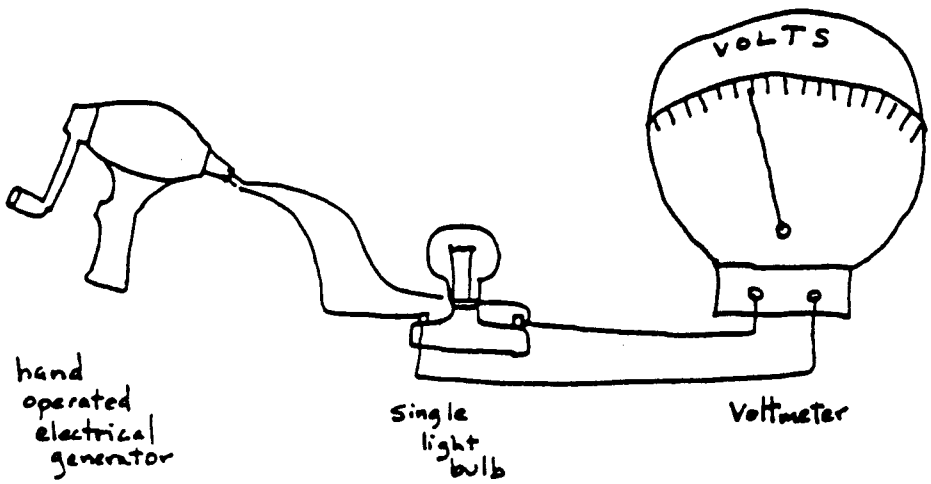


**Figure 1. Measuring volts with change in speed.**

Note the voltage as you turn the handle at different speeds. The faster you turn the handle the greater the voltage. For a given resistance (a light bulb) the greater the voltage, the greater the current going through the filament of the bulb, and the brighter the light.

Next, connect more light bulbs in parallel with the original bulb and note the difference in energy required to maintain the same voltage as more bulbs are added to the circuit. This is analagous to the need for more energy to turn the generators as more air conditioners are turned on during heat spells in the summertime. If the electrical drain is great enough the voltage supplied by the generators drops and there is a "brown out". As more factories and houses are added to the grid more generating energy is needed. When we require that a given percentage of cars in the state must be powered by electricity we need more electrical generating capacity. **THERE IS NO FREE LUNCH**

This is demonstrated in the following activity in which we measure not only the voltage but also the current drawn as we add more bulbs. Multiplying the voltage times the current gives the power. P= E x I in which P is the power Watts, E is Volts, and I is the current measured in amperes.

Repeat the experiment with a voltmeter and ammeter connected to the circuit as in Figure 2. Record both the voltage and current readings as the person turning the generator keeps the lights glowing at a steady brightness. This is best done by having one person call "mark" and one person reads the voltage while another person reads the current. One horsepower is 746 watts. How much horsepower is required to keep the four bulbs lit? Check your air conditioner at home for its rating in horsepower. If you know the voltage (usually 120 volts) you can calculate the amperage. How does this compare with the capacity of the fuse or circuit breaker which protects the circuit on which the airconditioner is operated.

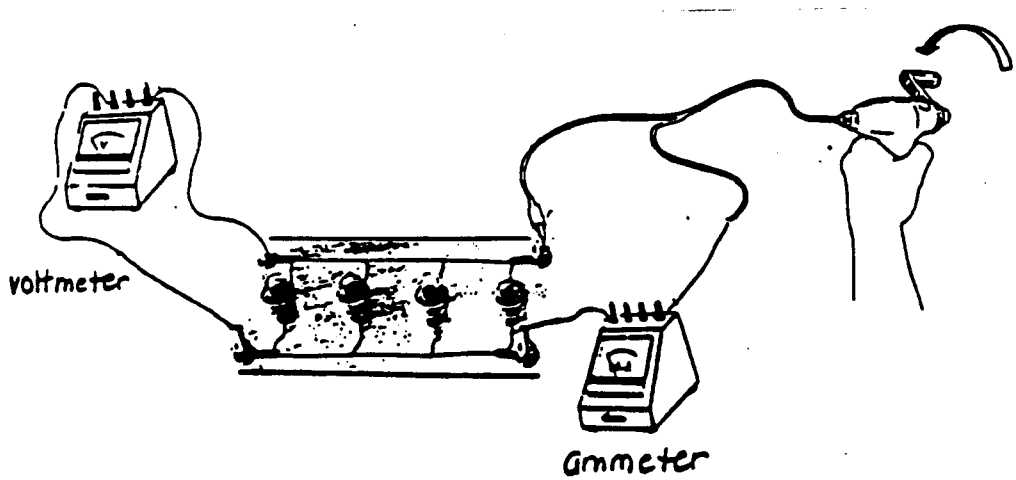


**Figure 2. Measuring Power Requirements For Various Loads**

It is important that each student have the opportunity to experience the mechanical power drain on the system as more electrical power is required. This experience should be referred to as the students work through and design their various projects. It should bring home the concept of "peak power".

.

Activities A-2 through A-5 Involve students in a home energy survey, and studies of lighting efficiency.

# Activity A-2

## HOME ELECTRIC ENERGY SURVEY

**Background**

On the first day of study of the Introduction, each student will survey his/her own family's use of electric energy for a week. The survey should begin the day the unit starts so that it can be discussed at the end of the one-week Introduction. The purpose of this survey is for students to become aware of how much electric energy is used in the home and how it is used. This can serve as a benchmark against which the energy use of the planned house can be compared.

In the Home Electric Energy Survey, two appliances will be in use all the time: electric clocks and refrigerators. Because the refrigeration equipment is not always operating, though, less energy will actually be used than if the refrigerator is considered to be operating all the time. The fraction of time that the refrigerator does operate can be determined by listening and measuring the time intervals of operation and the time intervals of non-operation. For a 2.5 watt clock, energy use for a week is

$$2.5\ \text{W} \times \frac{1\ \text{kW}}{1000\ \text{W}} \times \frac{24\ \text{hrs}}{\text{day}} \times \frac{7\ \text{days}}{\text{wk}} = 0.42\ \frac{\text{kWh}}{\text{wk}}\ .$$

In assessing how their present appliances can be replaced by more energy efficient ones, students will want to examine the yellow energy efficiency tags on appliances at appliance and department stores.

Controlling the time of operation of appliances to minimize their energy use can be done manually by a conscientious consumer or by automated control in a "Smart House." The controls in a "Smart House," while adding their own cost to the price tag, also offer the following advantages: (1) improved security and (2) additional financial savings by programming certain appliances, like dishwashers, to run when electricity costs are lowest.

**Student Activity**

In order to plan your house to use electric energy efficiently, you need to know how much electric energy you are using now. You can survey your present electric energy use by filling out a table like on the next page. Start by inventorying your electric appliances and listing the number of each in column 1 of the table — i.e., how many electric clocks you have. Next fill in column 2 by reading the power requirements (in watts) on each of your appliances. (If the number of amperes is given instead, multiply this by 115 volts to determine the number of watts.) If you cannot find this information, use the wattage given in column 2. Divide the wattage in column 2 by 1000 to get the kilowattage in column 3. In columns 4-10 list the number of hours the appliance is used each day for a week. In column 11 add the total number of hours. Multiply the number of hours in column 11 by the number of kilowatts in column 3 to get the number of kilowatt-hours (kWh) in column 12.

(Note: This exercise has been adapted from "Electrical Energy Use in the Home," National Coordinating Center for Curriculum Development, SUNY, Stony Brook, NY 11794.)

After you have assessed your present use of electric energy, you need to investigate how you can achieve the same results with less energy. There are two ways to do this:

1) Use appliances which require less power (smaller number of watts).
2) Avoid needless use of appliances.

Both approaches are addressed specifically in terms of light bulbs in the Instruction Sheets, "Lighting Specifications" and "Special Lighting Features to Promote Energy Efficiency." These approaches to using less electric energy in the home to achieve the same results are being pursued to the fullest in the "Smart House" developed by the National Association of Home Builders with the cooperation of the Electric Power Research Institute. You will want to read about "Smart House" developments in magazine articles to investigate what features are available and decide which you wish to incorporate into your own "smart house."

HOME ELECTRIC ENERGY SURVEY

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Appliance | Number | Wattage | Kilowattage | Hrs. Dy.#1 | Hrs. Dy.#2 | Hrs. Dy.#3 | Hrs. Dy.#4 | Hrs. Dy.#5 | Hrs. Dy.#6 | Hrs. Dy.#7 | Total Hrs. | Energy (kWh) |
| Air cond (sm) | | 700 | | | | | | | | | | |
| Air cond (med) | | 900 | | | | | | | | | | |
| Air cond. (lg) | | 1200 | | | | | | | | | | |
| Blender | | 390 | | | | | | | | | | |
| Broiler | | 1500 | | | | | | | | | | |
| Clock | | 2 | | | | | | | | | | |
| Coffee maker | | 890 | | | | | | | | | | |
| Dishwasher | | 1200 | | | | | | | | | | |
| Dryer (elec) | | 4000 | | | | | | | | | | |
| Elec skillet | | 1200 | | | | | | | | | | |
| Hair dryer | | 1200 | | | | | | | | | | |
| Iron | | 1000 | | | | | | | | | | |
| Light bulb | | 60 | | | | | | | | | | |
| Light bulb | | 75 | | | | | | | | | | |
| Light bulb | | 100 | | | | | | | | | | |
| Microwave oven | | 1500 | | | | | | | | | | |
| Radio | | 50 | | | | | | | | | | |
| Range (elec) | | 8800 | | | | | | | | | | |
| Refrigerator | | 330 | | | | | | | | | | |
| Sewing machine | | 75 | | | | | | | | | | |
| Stereo | | 100 | | | | | | | | | | |
| TV (b/w) | | 150 | | | | | | | | | | |
| TV (color) | | 300 | | | | | | | | | | |
| Toaster | | 1000 | | | | | | | | | | |
| Vacuum cleaner | | 650 | | | | | | | | | | |
| Washing machine | | 500 | | | | | | | | | | |
| Water htr (elec) | | 2500 | | | | | | | | | | |
| Window fan | | 200 | | | | | | | | | | |
| Other | | | | | | | | | | | | |
| TOTAL | | | | | | | | | | | | |

## Activity A-3

### LIGHTING SPECIFICATIONS

**Background**

The amount we pay our electric utility is determined by the amount of energy (measured in kilowatt-hours (kWh)) we use. The amount of light provided by a light bulb depends not only on the amount of energy provided the light bulb but also on how efficiently the light bulb converts the utility's electric energy into light. This efficiency (or more precisely "efficacy") is measured by the ratio of "lumens per watt" — the number of watts represents the amount of electric energy provided the bulb every second and the number of lumens represents the amount of illumination provided by the bulb, adjusted for the sensitivity of the human eye to various parts of the visible light spectrum. Thus a light bulb with a large number of lumens per watt produces a large amount of illumination for a unit of electric energy and is thus an efficient converter of electric energy into light.

Another concern in choosing lighting for a home is economic. Many of the new lighting products on the market use less electric energy and/or last longer. However, they are usually more expensive. To determine the most economical light bulb requires calculating the cost of both buying and lighting it over its lifetime. The cost of lighting the light bulb is found by multiplying the number of kilowatt-hours of energy it uses by the cost of a kilowatt-hour of electric energy. The number of kilowatt-hours is found by dividing the wattage by 1000 (to find the kilowattage) and multiplying by the average lifetime (in hours) of the bulb. Comparing these costs of different light bulbs requires standardizing them to, say, one hour. Taking into account the varying number of lumens provided by light bulbs of even the same wattage additionally requires standardizing the cost to providing one lumen for an hour.

Local utilities usually publish information about energy efficient products for the home. In fact, many even provide them for their customers — it costs less money to use less electric energy than to build a new power plant. In addition to obtaining information about energy efficient light bulbs, students will need to visit local hardware stores and other vendors of light bulbs to collect specific information about light bulbs available in their area: cost, number of lumens, wattage, and average lifetime (in hours). A recommended way to catalog the data gathered and to analyze them for energy efficiency and least economic cost is to set up a spreadsheet like the one on the next page. Note that in calculating the cost of one lumen for an hour, the only products less expensive than the standard incandescent light bulb are the COMPAX and biaxial fluorescent bulb. However, if the lower number of lumens from the MISER and Energy Choice bulbs is ignored, both are slightly less expensive.

The attached spreadsheet considers only fluorescent bulbs that have been manufactured for use in appliances designed for incandescent bulbs. Additional cost and energy savings can come from designing fluorescent lighting directly into a home in place of incandescent lighting.

LIGHT BULB ENERGY EFFICIENCY DATA *

| Category | Bulb Type | Cost/bulb | Lumens/bulb | Bulb wattage | Hours lifetime | Cost/kWh | Cost/lumen-hr | Cost/hour | Lumens/watt |
|---|---|---|---|---|---|---|---|---|---|
| 100W | standard | $0.72 | 1750 | 100 | 750 | $0.10 | 6.26E-06 | 0.01096 | 17.50 |
| | soft white | $0.82 | 1710 | 100 | 750 | $0.10 | 6.49E-06 | 0.01109 | 17.10 |
| | s.w.extra life | $1.49 | 1600 | 100 | 1125 | $0.10 | 7.08E-06 | 0.01132 | 16.00 |
| | MISER | $1.00 | 1620 | 95 | 825 | $0.10 | 6.61E-06 | 0.01071 | 17.05 |
| | Energy Choice | $0.82 | 1540 | 90 | 750 | $0.10 | 6.55E-06 | 0.01009 | 17.11 |
| 60W | standard | $0.75 | 870 | 60 | 1000 | $0.10 | 7.76E-06 | 0.00675 | 14.50 |
| | soft white | $0.82 | 855 | 60 | 1000 | $0.10 | 7.98E-06 | 0.00682 | 14.25 |
| | s.w.extra life | $1.49 | 820 | 60 | 1500 | $0.10 | 8.53E-06 | 0.00699 | 13.67 |
| | MISER | $0.98 | 810 | 55 | 1100 | $0.10 | 7.89E-06 | 0.00639 | 14.73 |
| | Energy Choice | $0.82 | 780 | 52 | 1000 | $0.10 | 7.72E-06 | 0.00602 | 15.00 |
| | COMPAX | $19.99 | 700 | 15 | 9000 | $0.10 | 5.32E-06 | 0.00372 | 46.67 |
| | biaxial fluor. | $21.60 | 800 | 13 | 10000 | $0.10 | 4.33E-06 | 0.00346 | 61.54 |
| 75W | standard | $0.75 | 1190 | 75 | 750 | $0.10 | 7.14E-06 | 0.00850 | 15.87 |
| | soft white | $0.82 | 1170 | 75 | 750 | $0.10 | 7.34E-06 | 0.00859 | 15.60 |
| | s.w.extra life | $1.49 | 1125 | 75 | 1125 | $0.10 | 7.84E-06 | 0.00882 | 15.00 |
| | MISER | $1.00 | 1140 | 70 | 825 | $0.10 | 7.20E-06 | 0.00821 | 16.29 |
| | Energy Choice | $0.82 | 1080 | 67 | 750 | $0.10 | 7.22E-06 | 0.00779 | 16.12 |
| | MISER Circlite | $12.55 | 1200 | 27 | | $0.10 | | | |

* Because efficiencies are technically dimensionless ratios of two energies or powers, the lumen/watt ratio is more precisely called "efficacy."

## CHOOSING EFFICIENT LIGHTING FOR YOUR HOUSE

**Student Activity**

When you choose the lighting for your house, you will be interested in two types of optimization:

1) maximizing the amount of light (number of lumens) for the amount of electric energy used ("maximum energy efficiency") and

2) minimizing the cost on your electric bill ("minimum cost").

In many cases both types of optimization can be achieved with fluorescent lighting — i.e., a 30 watt fluorescent bulb will provide more light than a 100 watt incandescent bulb. However, many light fixtures are made for incandescent bulbs, and a comparison between standard incandescent bulbs and more recently available alternatives is in order. Some of these alternatives are incandescent bulbs designed to use less energy and/or to last a longer number of hours. Others are fluorescent bulbs with adapters that allow them to be used in fixtures designed for incandescent bulbs.

Your concern is the number of lumens provided by the bulb and the cost of buying it and lighting it. The number of lumens and the cost of the bulb can be read from the package or shelf label in the store. The cost of lighting it is

(# kilowatt-hours used) x (cost per kilowatt-hour).

In turn the number of kilowatt-hours used is

(wattage/1000 = kilowattage) x (hours of lifetime).

Thus, the cost of lighting the bulb is

(kilowattage) x (hours) x (cost per kilowatt-hour).

Because different bulbs provide different numbers of lumens and last different numbers of hours, it is most useful to calculate the cost of providing one lumen for one hour.

To design the lighting for your house, you will find the following information helpful:

1) publications from your local utility on energy efficient products for the home.

2) costs of and information about specific light bulbs from local hardware stores and other vendors.

A recommended way to compare the costs of alternative light bulbs is to set up a spreadsheet, which can be programmed to do the required calculations for you.

# Activity A-5

## SPECIAL LIGHTING FEATURES TO PROMOTE ENERGY EFFICIENCY

### Background

In addition to choosing light bulbs that will produce the same number of lumens for less cost and energy, we can also save energy and money by using light bulbs only when we really need them. For example, many people feel their home is more secure if lights are left lit when they are away. To avoid the cost — in both energy and dollars — of doing this during the day, we can use a timer or a photocell that is sensitive to the amount of light present. Or, to save more energy and money, we can obtain motion sensor light control, which activates light only when motion is sensed by infrared radiation emitted by the moving object. By causing a light controlled in this way to turn on, an intruder is likely to be frightened away. The same control system would allow a property owner to activate outdoor lighting upon arriving home, just when it is needed. The same type of control could also be employed to insure that indoor lights are turned on only when people enter a room and are turned out after they leave. (The time to shutoff after motion ceases to be detected can be selected to be any time between 1 minute and 20 minutes.)

These special lighting features require special lighting fixtures that are more expensive than conventional fixtures. Students will need to calculate the energy savings from using such fixtures if they choose to install them. Of special consideration is the *payback time*, the time required until the savings from the fixture equal its cost. Some students will be more willing to spend money on fixtures with a longer payback time than others.

**Student Activity**

In addition to choosing light bulbs that will produce the same number of lumens for less cost and energy, you can also save energy and money by using your light bulbs only when you really need them. For example, you might feel that your home is more secure if lights are left lit when you are away. To avoid the cost — in both energy and dollars — of doing this during the day, you can use a timer or a photocell that is sensitive to the amount of light present. Or, to save more energy and money, you can obtain motion sensor light control, which activates light only when motion is sensed by infrared radiation emitted by the moving object. By causing a light controlled in this way to turn on, an intruder is likely to be frightened away. The same control system would allow a property owner to activate outdoor lighting upon arriving home, just when it is needed. The same type of control could also be employed to insure that indoor lights are turned on only when people enter a room and are turned out after they leave. (The time to shutoff after motion ceases to be detected can be selected to be any time between 1 minute and 20 minutes.)

These special lighting features require special lighting fixtures that are more expensive than conventional fixtures. If you choose to install them, you will need to justify their cost. This is usually done by calculating the *payback time*, the time required until the savings from the fixture equal its cost. The cost saved is the cost of not lighting the bulb in the fixture:

(kilowattage of bulb) x (hours bulb is not lit) x (cost per kilowatt-hour).

Given the kilowattage of the bulb (wattage divided by 1000) and your utility's cost of a kilowatt-hour of electricity, you need to find how many hours you need to *not* light the light bulb in order to justify its cost. Adding to this the time the light bulb will be lit tells you how long it will take to save enough money to pay for the special lighting fixture. How long a payback time can you accept?

## VII. RESOURCES FOR STUDENTS AND TEACHERS


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## Appendix A

## REGULATION

The level of regulation in the energy industry varies widely. The electric power industry, for example, is highly regulated. Because granting franchises to electric utilities as sole or primary providers of electric power in specific areas limits competition, regulations assure that a reliable supply of energy is provided at a reasonable price.

To engineers, regulations often become, in effect, an additional specification for the design, construction, operation, analysis, or modification of their systems. The type of regulation and the limitations that result can affect the engineer's work profoundly.

Regulation of energy can be categorized from several viewpoints. One way is to look at the functional aspects of the energy system covered by the requirements. Major categories are:

Environmental: Regulations address and limit how energy production, delivery, and use can affect the environment. Federal regulations, such as clean air and clean water acts, as well as state and local rules, affect all facets of the energy industry.

Economic: Regulation of how electric and gas utilities do business assures that the cost of energy supplied to consumers is reasonable. Rather than dealing with market forces, economic pressures in this part of the energy industry result largely from regulations. New regulations require competitive bidding and more consideration of different alternatives than in the past.

Reliability: Because of the critical importance of electricity in our society, electric utilities are required to design and operate the facilities that produce and supply electricity with enough backup capabilities to minimize the chance and length of interruptions of electrical power.

Safety: In addition to standard industrial safety, as applies to all industries, the electric industry and, in particular, the nuclear power industry have extensive safety regulations. The Nuclear Regulatory Commission and other agencies closely regulate how radioactive materials are handled and how nuclear power plants are operated. The very nature of energy and energy sources involves the potential for fires and other hazards, making extensive regulations necessary.

# ENERGY CASE B.
# BUILDING A MODEL LOW ENERGY REQUIREMENT HOUSE

## I CASE STUDY DESCRIPTION

This case study follows the introduction. In the introduction (Section A), the various problems associated with providing and conserving electrical energy are presented. The suggestion is made that people look for the appropriate mix of energy sources and uses to choose the optimum plan for a specific situation. In this case study the students are encouraged to look at house construction to reduce the need for energy for heating in the winter and for cooling in the summer.

## II. DEFINITION OF THE PROBLEM

Present need for household energy is growing. This presents a problem for planners involved in energy production and distribution. Improvement in new house construction can eliminate energy waste. Accomplishing this will reduce the depletion of energy resources now and in the future. It will also reduce the environmental problems associated with changing energy from one form to another.

## III. PERFORMANCE OBJECTIVES

A Students will measure heat transfer through various materials.

B. Students will design an energy efficient house for a family of four with minimum energy use.

C. Students will build a model of the energy efficient house

1. The house will maintain an optimum indoor temperature under a variety of outside conditions.
2. The house will provide specifications for adequate lighting at a reduction in the amount of electrical energy used.

## IV. EXPLANATION OF THE SPECIFIC MATRIX

The matrix describes the various ways in which the study of the case study meets the learning of the basic concepts of the Principles of Engineering Syllabus: MODELING, SYSTEMS, OPTIMIZATION, TECHNOLOGY SOCIETY INTERACTION, DESIGN, and ETHICS.

| CONCEPT | HEATING &COOLING |
|---|---|
| MODELING | Model the heat energy involved in an energy efficient home |
| SYSTEMS | Examine heating, cooling,and cooking as systems affecting the energy efficiency of the house. |
| OPTIMIZATION | Minimize energy use within economic and space requirements |
| TECH/SOCIETY IMPACT | Are people willing to spend the additional money in the short term to conserve energy for the future? |
| DESIGN | Design effective use of shape and materials to produce an energy efficient house |
| ETHICS | Examine the impact of wasteful energy consumption on future generations. |

## V. BACKGROUND MATERIAL

Background material is presented along with the instructions for each of the activities involved in the preliminary study of energy use and the design and building of the Energy Efficient House.

## VI. PROJECT OVERVIEW

There is a need to conserve energy from the standpoint of resources. There is also the need to reduce environmental problems involved in the transfer of energy from the basic resources to useful energy in the home. There will be class discussion, laboratory and library research regarding these needs. Students will then design and build a model of an energy efficient home

## VII. SUGGESTED EVALUATION METHODS

A. Paper and pencil tests of information involved in energy waste and energy efficiency.

B. Observation of use of appropriate laboratory procedures during investigations.

C. Observation of appropriate use of tools in designing and building the energy efficient house.

D. Observation of ability and willingness to work in team activities.

E. Rating of actual design and final product.

## VIII. CASE STUDY TIME TABLE

### Day 1.

Explain the residential structure energy usage concept that energy required and energy used are always equal.( simplified: heat in=heat out)

Calculate the degree days for the next week. Explain by example how energy moves from a higher energy level to a lower energy level. Compare energy used per month in heating degree day months and cooling degree day months to other months to determine life cycle energy. (Consult degree day chart for the past year)

### Day 2

Do **Activity B1. Insulating Your House**

**Day 3.**

1. Provide a sample model of a low energy requirement home with the roof, living area, and mass storage separate but interconnectable
2.Calculate heat loss of the structure
3. Determine the desired solar percentage of the structure.
4. Calculate the percentage of the south wall that should be glazed

Explain mass storage. Diurnal swing (excess daytime energy, nighttime supplemental energy)

Explain energy absorption, latent heat, specific heat, release and change of state.

**Day 4.**

Invite the owner of a passive solar home to describe the features of the house. In the absence of the appropriate person show a video of a passive solar home or have students do library research on such a home.

**Day 5.**

Discuss the advantages and disadvantages of active, passive, and hybrid solar homes. **Activity B.2 Comparison of Solar Home Types**

**Day 6.**

Have students assemble in groups related to the arena of engineering that they find interesting and consistent with the composite systems in a passive/hybrid house. **Activity B.3 Designing a Passive/Hybrid House**

**Day 7.**

Assemble student groups with each type of engineering represented on day six and have students brainstorm and sketch passive hybrid solar designs.

Identify the most positive aspects of student designs and have the group select the most appropriate ideas for siting, aesthetics, economics, livability and efficient use of energy.

For the purpose of building the model, have students resketch their structures, selecting scale and adding dimensions appropriate for the model.

**Day 8-18**

Students will work in their groups to construct a model home, keeping appropriate written records of their work.

Students should read, research, and when possible find "consultants" (teachers, parents, engineers, contractors, suppliers) to obtain the information necessary to carry out their engineering roles.

The groups will then construct the actual model structure with appropriate members working on computers; researching systems for monitoring, and gathering and processing data. The model should incorporate students' findings concerning living space, glazings, insulations, monitoring and data gathering equipment and controls, and mass storage.

The whole class should meet periodically to insure that all students understand the entire design, construction, and evaluation process.

**Day 19-20**

Students gather data on energy gain, energy loss, time factors,temperatures, insulation information, etc. of their model structure. Students should then analyze the data, optimize the design, and repeat the analysis. Use Activity B-4 Analysis of Model House.

**Day 21-22**

Each group will make a presentation to the class on how it used the six engineering concepts to arrive at its final design solution.

**Day 23**

Each student will describe in writing his/her understanding of how the utilization of the engineering concepts contributed to the successful performance of the low energy requirement passive hybrid solar home.

## IX RESOURCES FOR STUDENTS AND TEACHERS

### APPENDICES

A REFERENCES,

B. SUPPLIES AND EQUIPMENT

C. DEGREE DAYS

D. INSULATION TESTING

E.A PASSIVE SOLAR HOUSE

# ACTIVITY B-1 INSULATING YOUR HOUSE

**Background**

In order to maintain their house at a constant temperature, students need to replace every unit of thermal energy which escapes from it. The three methods by which thermal energy is transferred are **conduction, convection,** and **radiation.** Loss of thermal energy due to radiation is determined by the relationship of the temperature of the house to that of its surroundings. Loss of thermal energy due to convection can be avoided by eliminating leaks — e.g., by caulking windows and doors, eliminating leaks around electrical outlets, switch plates on outside walls, celing lights, and wherever two pieces of material are joined together.

Minimizing heat losses due to conduction requires lowering the thermal conductance of the walls, ceilings, and floors. This is done by installing insulation. The formula for heat losses due to conduction is given on page 87 of the field test edition of the Principles of Engineering syllabus:

Heat Loss (in Btu's per hour) = A (area in sq. ft.) x U (thermal conductance) x $\Delta T$ (temperature difference between inside and outside, in °F),
where U is the reciprocal of the thermal resistance, R, otherwise known as the R-factor.

According to a booklet published by the Owens-Corning Fiberglass Corporation, the U.S. Department of Energy recommends that homes in New York State be insulated with R-38 in ceilings below ventilated attics, R-11 or 13 in 2" x 4" exterior walls (R-19 in 2" x 6" exterior walls), and R-19 in crawlspace walls or floors over unheated crawlspaces or basements. R-19 insulation means that it takes 19 hours for a Btu of thermal energy to escape through an area of 1 square foot if the difference between internal and external temperature is 1°F.

The R-factor for a given material depends on both the material itself and its thickness. It can be calculated by dividing the thickness in inches by the thermal conductivity.

**Note:** The Laboratory Investigation under Student Activity focuses on the relationship between insulation and the thickness of the insulator. An activity which focuses on the insulation provided by the same thickness of different materials is "Insulation Testing," which can be found in Appendix D.

**Student Activity**

In order to maintain your house at a constant temperature, you need to replace every unit of thermal energy which escapes from it. The three methods by which thermal energy is transferred are **conduction, convection,** and **radiation.** Loss of thermal energy due to radiation is determined by the relationship of the temperature of the house to that of its surroundings. Loss of thermal energy due to convection can be avoided by eliminating leaks — e.g., by caulking windows and doors, eliminating leaks around electrical outlets, switch plates on outside walls, ceiling lights, and wherever two pieces of material are joined together.

Minimizing heat losses due to conduction requires lowering the thermal conductance of the walls, ceilings, and floors. This is done by installing insulation. The formula for heat losses due to conduction is:

Heat Loss (in Btu's per hour) = A (area in sq. ft.) x U (thermal conductance) x$\Delta$T (temperature difference between inside and outside, in °F),
where U is the reciprocal of the thermal resistance, R, otherwise known as the R-factor.

According to a booklet published by the Owens-Corning Fiberglass Corporation, the U.S. Department of Energy recommends that homes in New York State be insulated with R-38 in ceilings below ventilated attics, R-11 or 13 in 2" x 4" exterior walls (R-19 in 2" x 6" exterior walls), and R-19 in crawlspace walls or floors over unheated crawlspaces or basements. R-19 insulation means that it takes 19 hours for a Btu of thermal energy to escape through an area of 1 square foot if the difference between internal and external temperature is 1°F.

The R-factor for a given material depends on both the material itself and its thickness. It can be calculated by dividing the thickness in inches by the thermal conductivity. The thermal conductivities of several materials (in Btu/hr x ft$^2$ x °F) are as follows:

| material | thermal conductivity |
|---|---|
| air | 0.165 |
| polystyrene | 0.2 |
| rock wool | 0.26 |
| glass wool | 0.29 |
| asbestos | 0.55 |
| wood | 0.7 |
| cinder block | 2.5 |
| brick | 5 |
| glass | 6 |
| concrete | 7 |
| aluminum | 1450 |

To calculate the heat losses from your house (in Btu/hour) due to conduction, you will need to determine the area of wall, ceiling, and floor space made of different materials (e.g., wood, glass concrete) and the difference between internal and external temperature. In the case of layered materials, the R-factor for the composite of layers is the sum of the R-factors of the individual layers.

Calculate and total your heat losses due to conduction by entering these values and doing calculations in a table like the following:

| Material | # of square feet x temperature diff. / R-factor |
|---|---|
| | |

**Laboratory Investigation**

The conductive heat loss formula and the insulating properties of materials can be investigated by filling different containers of the same surface area with equal amounts of ice water (from which all ice has been removed) and measuring the temperature of the water in each container every minute until it increases by one degree. Particularly appropriate are nested sets of one, two, and three paper or polystyrene cups, respectively. In each case the cup must be covered with as good a thermal insulator as its walls — e.g., overturned polystyrene cups to serve as lids for other polystyrene cups. Holes in the lids for thermometers must be carefully inserted so that the thermometer fits into the lid as snugly as possible. How does the time it takes for the temperature of the water in a nest of two cups to increase by one degree compare with the time for the temperature of the water in one cup to do the same?

If mercury thermometers are used, great care must be taken not to break them and release toxic mercury vapor into the environment. Because polystyrene cups tip over easily, they should be supported by a ring stand. Another way to support a cup is to nest it in a glass beaker. This has the effect of providing further insulation by creating an air space between the cup and beaker. How does this affect the time for the temperature of the water in the cup to increase by one degree?

# ACTIVITY B-2 COMPARISON OF SOLAR TYPE HOMES

| | Advantages | Disadvantages |
|---|---|---|
| **Active** | • none known with the possible exception of integral solar hot water | • collectors on roof<br>• weight<br>• mounting systems<br>• damage from elements<br>• air leaks<br>• fluid leaks<br>• freezing<br>• control and pump maintenance<br>• storage system leaks<br>• cost<br>• safety |
| **Passive** | • direct solar gain through south glass<br>• low maintenance<br>• less expensive than active | • siting requirements<br>• diurnal temperature swings<br>• uneven temperatures within structure<br>• direct gain mass required<br>• no solar heated hot water<br>• active residents required |
| **Passive/Hybrid** | • direct solar gain through south glass<br>• direct and indirect mass storage<br>• low maintenance<br>• less expensive than active<br>• very even temperatures throughout structure | • siting requirements<br>• no solar heated water<br>• some energy needed to store and retrieve energy<br>• remote mass increases cost |

See Appendix E, "A Passive Solar House," for related activities.

Some activities for groups:

**Architectural/mechanical**

- Design the solar structure's exterior, considering:
  - square footage
  - solar percentage
  - scale
  - construction materials and methods
  - overhangs
  - insulation package
  - percent and type of glazing
  - size
  - materials
  - construction
  - location of mass

**Civil**

- Develop site selection factors, analysis, and recommended modifications

**Chemical**

- Investigate the advantages and disadvantages of phase change mass versus static mass.

**Electrical/Computer**

- Develop monitoring and data gathering methods for energy use and movement throughout the structure.

# ACTIVITY B-4 ANALYSIS OF A MODEL HOUSE

- Measure temperature gain within the structure with solar south orientation.
- Measure temperature within the structure with orientations of 15, 30, 45, and 90 degrees from solar south.
- Measure and compare temperature gain within the structure with no south glazing, with 30%, 40%, and 60% glazing. Plot a graph with temperature gain vs. time.
- Measure and compare temperature gain within the mass with the various glazing percentages with no fan and with fan.
- Measure and compare ambient air temperatures in the structures vs. temperatures in the mass during gain (day) periods.
- Measure and compare ambient air temperatures in the structure vs. temperatures in the mass during loss (night) periods.

## APPENDICES

A. References

B. Supplies and Equipment

C. Degree Days

D. Insulation Testing

E. A passive solar house

## A. **References**


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## B. Supplies and Equipment

Note: Substitutions are possible depending upon fiscal conditions.

**Solar House (scale 1" = 1')**

| Supplies | Equipment |
|---|---|
| foamboard 1/4" x 24" x 36" | safety glasses |
| acrylic sheet (plexiglass) | layout tools |
| polyisocyanurate (Hi-R, Max-R) | utility knives |
| aluminum tape 2" x 60 yds. | glue guns |
| glue sticks | jig saw |

**Mass Storage**

| Supplies | Equipment |
|---|---|
| plywood 1/4" x 4' x 8' | TA saw |
| copper tubing 3/4 x 5' | hammers |
| copper tee fittings 3/4" x 3/4" x 1/2" (6) | tubing cutter |
| copper caps 3/4 (2) | propane torch |
| copper tubing 1/2" x 8' | |
| copper 90 L fittings (6) | |
| solder | |
| flux | |
| 4d nails (1 lb) | |
| sand (quantity ?) | |

**Testing and Data Gathering**

| Supplies | Equipment |
|---|---|
| IBM personal science lab | IBM computer |
| temperature probes | thermometers |
| computer paper | |

## C. **Degree Days**

HEATING DEGREE DAYS Base 65 deg. F SYRACUSE, NEW YORK

| SEASON | JULY | AUG | SEP | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUNE | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1961-62 | 14 | 13 | 50 | 292 | 724 | 1107 | 1262 | 1211 | 937 | 552 | 172 | 25 | 6379 |
| 1962-63 | 6 | 16 | 185 | 422 | 875 | 1250 | 1364 | 1300 | 948 | 575 | 319 | 70 | 7330 |
| 1963-64 | 14 | 23 | 240 | 276 | 597 | 1365 | 1205 | 1190 | 922 | 546 | 160 | 89 | 6647 |
| 1964-65 | 2 | 30 | 154 | 475 | 636 | 1057 | 1370 | 1125 | 1069 | 676 | 275 | 132 | 6971 |
| 1965-66 | 27 | 50 | 144 | 521 | 782 | 1011 | 1422 | 1168 | 945 | 665 | 429 | 80 | 7244 |
| 1966-67 | 6 | 7 | 186 | 473 | 652 | 1104 | 1059 | 1275 | 1030 | 595 | 453 | 13 | 6853 |
| 1967-68 | 24 | 35 | 154 | 407 | 812 | 995 | 1438 | 1266 | 979 | 501 | 345 | 83 | 7039 |
| 1968-69 | 27 | 41 | 54 | 391 | 745 | 1163 | 1256 | 1152 | 1063 | 536 | 306 | 103 | 6837 |
| 1969-70 | 22 | 20 | 134 | 425 | 730 | 1269 | 1508 | 1139 | 1027 | 536 | 244 | 115 | 7169 |
| 1970-71 | 7 | 27 | 150 | 388 | 692 | 1222 | 1437 | 1069 | 1040 | 658 | 295 | 50 | 7035 |
| 1971-72 | 13 | 51 | 96 | 256 | 840 | 980 | 1189 | 1216 | 1098 | 731 | 204 | 84 | 6759 |
| 1972-73 | 9 | 23 | 98 | 567 | 833 | 1053 | 1128 | 1217 | 687 | 547 | 325 | 31 | 6518 |
| 1973-74 | 2 | 12 | 164 | 344 | 723 | 1094 | 1200 | 1206 | 1004 | 493 | 339 | 52 | 6633 |
| 1974-75 | 16 | 3 | 202 | 565 | 726 | 1069 | 1100 | 1026 | 1026 | 749 | 138 | 46 | 6666 |
| 1975-76 | 3 | 32 | 230 | 357 | 545 | 1154 | 1449 | 936 | 872 | 509 | 329 | 47 | 6463 |
| 1976-77 | 24 | 45 | 179 | 556 | 869 | 1303 | 1520 | 1086 | 767 | 511 | 209 | 111 | 7180 |
| 1977-78 | 14 | 60 | 121 | 444 | 624 | 1162 | 1348 | 1322 | 1097 | 677 | 252 | 92 | 7213 |
| 1978-79 | 10 | 1 | 184 | 470 | 735 | 1062 | 1315 | 1457 | 796 | 591 | 242 | 74 | 6937 |
| 1979-80 | 19 | 39 | 146 | 454 | 607 | 971 | 1215 | 1302 | 1007 | 511 | 194 | 115 | 6580 |
| 1980-81 | 3 | 0 | 120 | 496 | 814 | 1307 | 1544 | 869 | 882 | 446 | 221 | 27 | 6729 |
| 1981-82 | 2 | 4 | 145 | 523 | 775 | 1110 | 1552 | 1114 | 978 | 626 | 183 | 79 | 7091 |
| 1982-83 | 13 | 57 | 152 | 449 | 628 | 951 | 1280 | 1073 | 902 | 615 | 351 | 67 | 6538 |
| 1983-84 | 11 | 25 | 140 | 457 | 769 | 1312 | 1432 | 949 | 1246 | 563 | 386 | 68 | 7358 |
| 1984-85 | 16 | 33 | 227 | 390 | 797 | 971 | 1329 | 1048 | 882 | 514 | 193 | 109 | 6509 |
| 1985-86 | 10 | 18 | 121 | 415 | 702 | 1200 | 1266 | 1156 | 856 | 471 | 172 | 76 | 6463 |
| 1986-87 | 12 | 50 | 155 | 468 | 838 | 1027 | 1270 | 1208 | 831 | 395 | 211 | 35 | 6500 |
| 1987-88 | 7 | 27 | 138 | 529 | 717 | 1007 | 1290 | 1167 | 942 | 571 | 187 | 131 | 6713 |
| 1988-89 | 9 | 33 | 150 | 574 | 653 | 1148 | 1120 | 1175 | 989 | 639 | 242 | 38 | 6770 |
| 1989-90 | 3 | 36 | 151 | 406 | 779 | 1554 | 976 | 1001 | 849 | 496 | 319 | 43 | 6613 |
| 1990-91 | 2 | 2 | 160 | 386 | 675 | 967 | | | | | | | |

COOLING DEGREE DAYS Base 65 deg. F SYRACUSE, NEW YORK

| YEAR | JAN | FEB | MAR | APR | MAY | JUNE | JULY | AUG | SEP | OCT | NOV | DEC | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1969 | 00 | 00 | 00 | 0 | 22 | 94 | 183 | 222 | 102 | 1 | 00 | 00 | 624 |
| 1970 | | | | 8 | 22 | 74 | 160 | 127 | 51 | 3 | | | 445 |
| 1971 | | | | | 17 | 145 | 145 | 124 | 111 | 4 | | | 552 |
| 1972 | 00000 | 00000 | 00000 | 0 | 9 | 78 | 262 | 160 | 61 | 0 | 00 | 00 | 570 |
| 1973 | | | | 0 | 0 | 177 | 249 | 281 | 79 | 2 | | | 795 |
| 1974 | | | | 7 | 6 | 77 | 148 | 128 | 31 | 1 | 00 | 00 | 405 |
| 1975 | | | | 14 | 80 | 114 | 221 | 138 | 1 | 1 | | | 555 |
| 1976 | | | | 0 | 2 | 141 | 84 | 83 | 31 | 0 | 00 | 00 | 357 |
| 1977 | | | | 16 | 71 | 47 | 202 | 138 | 49 | 0 | | | 520 |
| 1978 | | | | 12 | 49 | 92 | 231 | 215 | 36 | 0 | | | 623 |
| 1979 | | | | 0 | 50 | 109 | 232 | 134 | 46 | 2 | | | 595 |
| 1980 | | | | 2 | 41 | 62 | 243 | 279 | 80 | 1 | | | 706 |
| 1981 | | | | 0 | 47 | 125 | 264 | 180 | 49 | 0 | 00 | 00 | 671 |
| 1982 | | | | 4 | 18 | 25 | 186 | 72 | 25 | 0 | | | 329 |
| 1983 | | | | 0 | 2 | 125 | 236 | 155 | 70 | 7 | | | 595 |
| 1984 | | | | 0 | 4 | 88 | 119 | 154 | 14 | 1 | | | 380 |
| 1985 | | | | 0 | 7 | 30 | 165 | 144 | 87 | 0 | | | 459 |
| 1986 | | | | 5 | 1 | 52 | 201 | 112 | 28 | 0 | | | 481 |
| 1987 | | | | 0 | 7 | 73 | 142 | 280 | 143 | 29 | | | 674 |
| 1988 | | | | 0 | 33 | 112 | 296 | 251 | 32 | 9 | | | 733 |
| 1989 | | | | 0 | 37 | 112 | 198 | 144 | 59 | 0 | | | 550 |
| 1990 | | | | 33 | 2 | 118 | 222 | 177 | 51 | 16 | | | 624 |

## INTRODUCTION

Why is it that some houses have small heating needs while others of the same size use so much fuel? Insulation often makes all the difference.

In this activity you will compare the insulating ability of several different materials.

## OBJECTIVES

At the completion of this activity you should be able to:

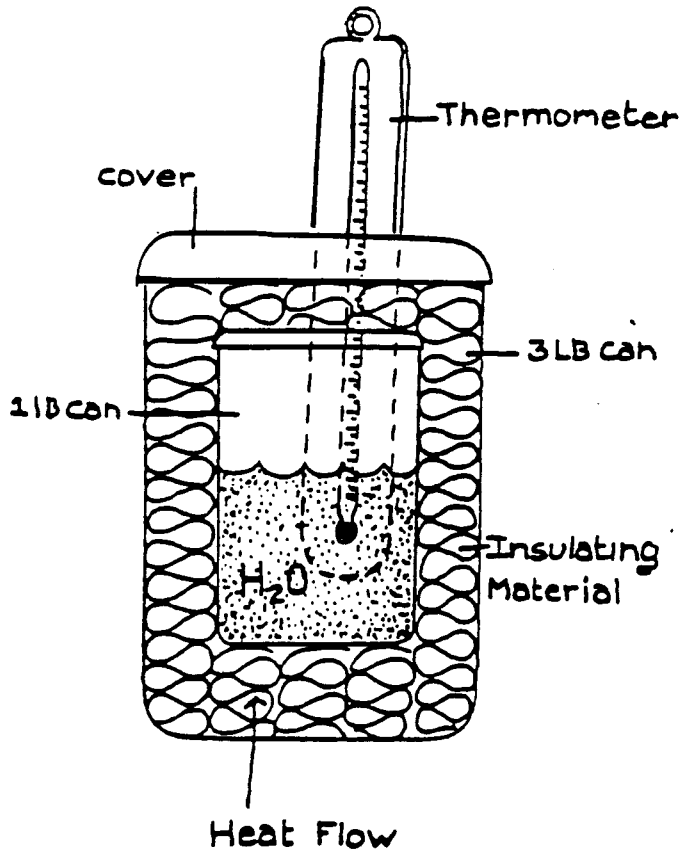
- o construct a device to be used in measuring the effectiveness of insulation materials.
- o compare the insulating abilities of various materials.

## SKILLS AND KNOWLEDGE YOU NEED

- How to read a thermometer and a clock or timer.
- How to measure liquids using a graduated cylinder.
- How to construct and interpret graphs.

## MATERIALS

- A standard laboratory calorimeter or a 3 lb. coffee can and a one lb. coffee can, both with plastic lids.
- One thermometer.
- One ring stand.
- One bunsen burner.
- A clock or timer.
- Insulating materials, such as vermiculite, styrofoam, urethane foam, fiberglass, cellulose, sand, paper, etc.
- Safety goggles and gloves.




## METHOD

1. Assemble your insulation tester:

   a. Using a punch, place a hole in the plastic lids of the two coffee cans.

   b. Place a layer of one kind of insulation around the inside and on the bottom of the 3 lb. can in such a way that the one lb. can fits inside comfortably. (See diagram.) Other students will use different insulation materials.

   c. Place the one lb. can inside the 3 lb. can.

   d. Place 300 ml. of water at room temperature in the one lb. can.

   e. Place the plastic lids on the cans.

   f. Carefully insert the thermometer through the holes in the two lids.

2. Place the insulation tester on a ring stand.

3. Record the temperature of the water.

- What might be some of the sources of experimental error in the measurements of heat flow you made with this apparatus? How could these be reduced?

- Find out what type of insulation you have in your home. How does it compare with others tested in this activity?

DATA TABLE A

| TIME (min) | MATERIAL A | MATERIAL B | MATERIAL C |
|---|---|---|---|
| | temp. $^{o}C$ | temp. $^{o}C$ | temp. $^{o}C$ |
| 0 | | | |
| .5 | | | |
| 1 | | | |
| 1.5 | | | |
| 2 | | | |
| 2.5 | | | |
| 3 | | | |
| 3.5 | | | |
| 4 | | | |
| 4.5 | | | |
| 5 | | | |
| 5.5 | | | |
| 6 | | | |
| 6.5 | | | |
| 7 | | | |
| 7.5 | | | |
| 8 | | | |
| 8.5 | | | |
| 9 | | | |
| 9.5 | | | |
| 10 | | | |

Teacher Information Sheet

# INSULATION TESTING

## Suggested Grade Level and Discipline

7-12 Science
Physics

## Background Information

There are a number of factors which determine the effectiveness of insulators. The type of material is a major consideration. The density of the insulation and its water vapor content are two other important variables. The number of small enclosed "dead" air spaces is still another. R-value is the measurement used to communicate insulating capacity.

The most common types of insulation are fiberglass, mineral wool, and cellulose that has been treated with chemicals to retard flammability. Various foams sold in sheets or processed on site are gaining in popularity. Homes built before the last decade often have 1½ inches of insulation in the ceilings and none in the walls. Properly insulated ceilings have the potential for reducing heat losses by 20%.

## Hints on Gathering Materials

- Most physics labs have commercial calorimeters which are suitable for this investigation. The metal containers are good thermal conductors and are less apt to contribute to errors than glass containers, which themselves are insulators.

- Insulating materials can be gathered from a variety of sources. Science equipment is often packed in styrofoam or vermiculite.

## Suggested Time Allotments

- One 20-minute period to go over instructions, assemble equipment, set up lab notebooks, break up into groups and assign timer, recorder, etc.

- One 40-minute period to conduct the activity, copy and exchange results, etc.

## Suggested Approach

- Break students up into groups of 4-5 students.
- Have each group investigate a different type of insulation.
- Students should be encouraged to do two trials and average results.
- Have students follow the method from step 1 to step 5 for different materials or different trials with the same materials. The graphing can be assigned as out of class work.
- Students not familiar with graphing can be directed to skip steps 6 and 8.

## Typical Results

- Using a set of 10-minute trial runs, the following heat flow values were obtained:

| | |
|---|---|
| fiberglass | - 1.44 degrees per minute |
| air | - 2.80 degrees per minute |
| paper | - 2.0 degrees per minute |

## Precautions

- *Use a medium to small flame on bunsen burner. Keep flame temperature as consistent as possible on all trials.*
- *Make sure students wear safety goggles.*
- *Be careful not to melt plastic lids.*
- *Keep thermometer from touching sides and bottom of can.*
- *Insulation should be packed loosely in the coffee cans. Use gloves.*
- *Pretest the process using your heat source and a moderate flame, as the insulation may char under high heat.*
- *CAUTION: foamed plastic board insulation is highly flammable, as is styrofoam unless it has been treated with a flame retardant.*

## References

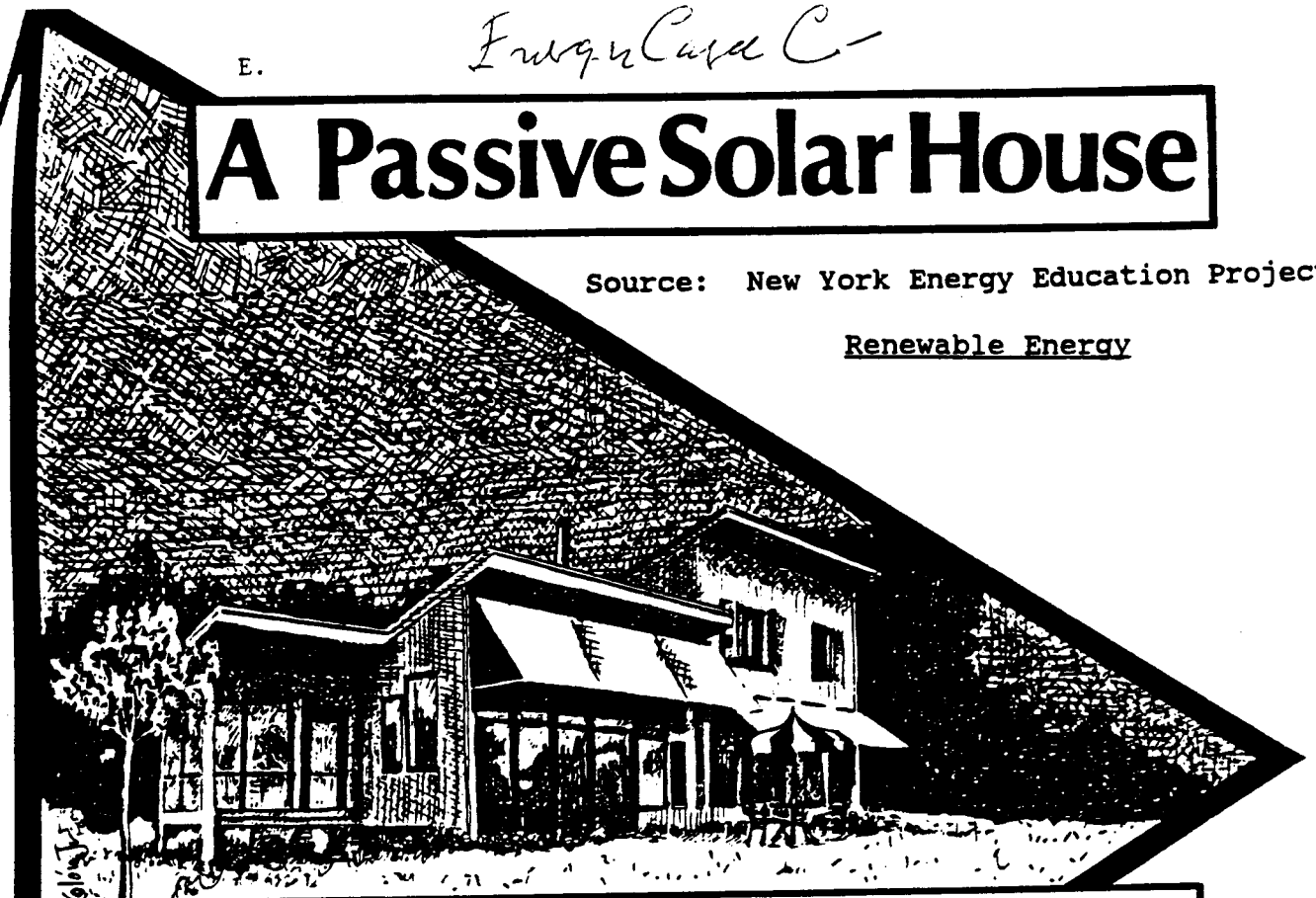
*Solar Energy Experiments for High School and College Students,* Thomas Norton, Rodale Press, Emmaus, Pennsylvania, 1977.

*Science Activities in Energy Conservation,* Oak Ridge Associated University, USDE EDM-1049

E. Energy Cycle C-

# A Passive Solar House

Source: New York Energy Education Project, Renewable Energy



Every house collects solar energy. Sunlight falls on the house, passing through windows and skylights and being absorbed by roof and walls. The sun helps to heat the house in cold weather, but it can overheat the house in warm weather.

Some houses are specially designed with the sun in mind. The designer plans the house so that it collects as much sunshine as possible in winter, and as little as possible in summer. Such houses are called passive solar houses, and they can save their owners a lot of expense in heating and air-conditioning.

Based on what you know about the sun and wind, you are going to assemble, locate, and landscape a model passive solar house. To help you get started, think about these questions.

What is the sun's path in the winter? In the summer?

Where does most wind come from in the winter? In the summer?

Where should most of my windows be?

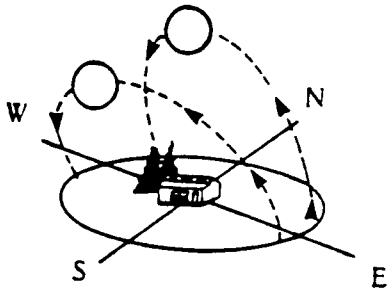
What kinds of trees and shrubs should I have around my house, and where should I place them?

## objectives

At the completion of this activity, you should be able to

- recognize the basic features of a passive solar house,
- use your knowledge of trees and shrubs to landscape your model house for energy conservation, and
- use your knowledge of the angle of the sun during different seasons to determine how effective your model is as a passive solar house.

## skills and knowledge you need




The skills of basic cutting, taping, and diagramming

The knowledge that the sun's rays strike the earth's surface at a lower angle in winter than in summer

The knowledge of the direction of the winter winds and summer breezes in your area

## materials

scissors

tape

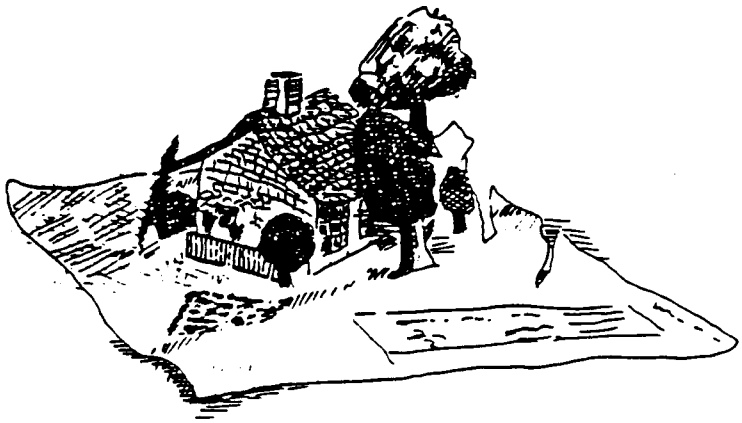
toothpicks

straight edge

Worksheets A, B, and C

a light source (flashlight, lamp)

crayons or markers (optional)



## procedure

1. Select one model from the two model house drawings on Worksheet A. Cut out, fold, and assemble (without taping) the model you chose.

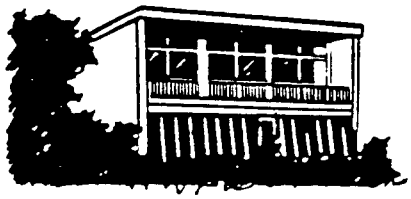
2. Place the folded model house on the plot plan (Worksheet B) and decide on the setting of the dwelling. In which direction will it face? Decide how many windows and doors your house should have and choose their locations based on the setting of the house. Then unfold the model and draw in the windows and doors neatly with a pencil and straight edge. Color the house if you wish.

3. Refold and tape the model together. Then tape the roof in place. Place the completed house on the plot plan.

4. Find out the directions of the winter winds and summer breezes in your area. Draw arrows in the proper corners of your plot plan to indicate these directions. Label each arrow.

5. Draw in fencing (if any), driveway, and sidewalks. Can you place these features to provide protection from winter winds?

6. Cut out the model trees and shrubs (Worksheet C) and use them to trace out as many additional trees and shrubs as you want to use in landscaping. Cut these out and fold their bases. For added strength, tape toothpicks to the backs of the trees. Keep in mind that deciduous trees lose their leaves in fall and that winter winds and summer breezes come mostly from one direction. Plan how you will landscape the plot, then tape the summer deciduous models in place. Tape the models of the winter deciduous trees directly behind the summer models. Tape all other models in place.



7. Find out the noontime angle of the sun in your area for winter and for summer. Set the light source at the noontime angle for the summer sun. Check your house and landscaping for the effectiveness of summer shading. How many windows receive direct summer sunlight? Do your deciduous trees shade the house to help keep it cool? Does your roof overhang provide shading from the summer sun? Does your landscaping channel cooling summer breezes toward your house?

8. Now fold down your summer tree models so that the winter models are visible. Set the light source at the noontime angle for the winter sun. Again check your house and landscaping, this time for the effectiveness of winter solar heating. How many windows receive direct winter sunlight? Do any trees block the sun's rays, preventing them from warming the house? Does the roof overhang allow the winter sunlight to pass through your windows? Do your evergreen trees break and slow those cold winter winds?

## questions

1. How does your model house compare to those of other students in placement of windows, size of doors, and roof arrangement?

2. Which model house in Worksheet A is best designed for winter heating and summer cooling? Why?

completed the activity, how could you improve your model house and landscaping to increase their effectiveness in winter heating and summer cooling?

4. A passive solar house such as you have constructed is considered one way to conserve energy. Why?

5. How should homes be landscaped to conserve energy?

6. In which direction should the roof overhang so that winter sunlight passes through windows and summer sunlight is blocked out?

7. Define the following terms: deciduous tree, evergreen tree, roof overhang, passive solar house.

# looking back

You have now planned the design and landscaping of a passive solar house. In doing this you may have discovered that there are many simple things you can do to use the sun's heat in cold weather and still avoid overheating in summer.

Did you consider which way the house should face? How many windows and doors did you plan, and where did you put them? Did you use roof overhangs for summer shade? What about evergreen windbreaks and deciduous shade trees? A passive solar house uses all these features to save energy by natural heating and cooling.

# going further

Make the improvements to the model house that you suggested in your response to Question 3.

Add a sunspace or solar greenhouse to your model house. Indicate an earth berm on the proper side(s).

Obtain additional copies of Worksheets A, B, and C. Redesign and landscape the same house for an active solar energy heating or hot water system. Draw flat plate solar collectors on the south-facing roof. Determine the best roof pitch for the collectors and redraw the sidewalls to obtain this pitch.

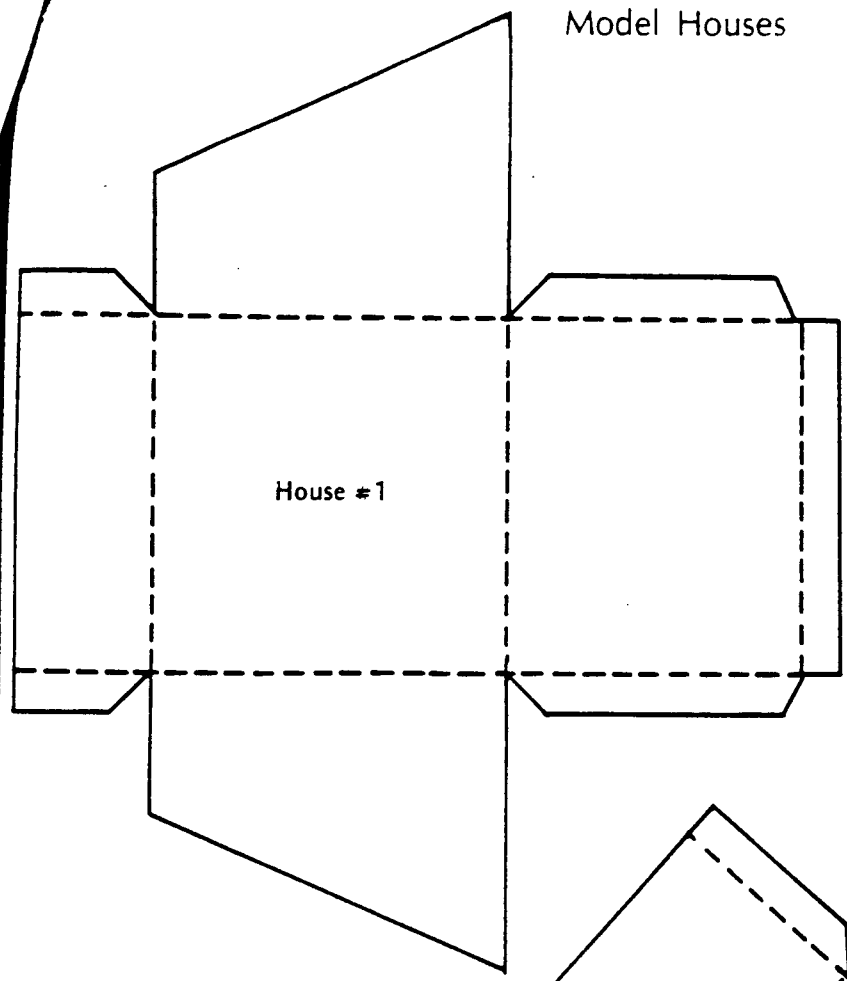
Obtain additional copies of Worksheets A, B, and C. Redesign the same house to include a cooling system, such as an evaporative cooling system. What factors will have to be considered for such a system?

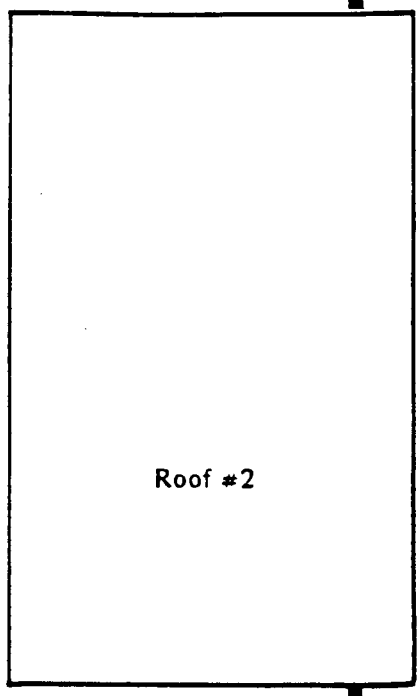
Construct a passive solar model home of your own design from other materials, such as wood or plaster of paris.

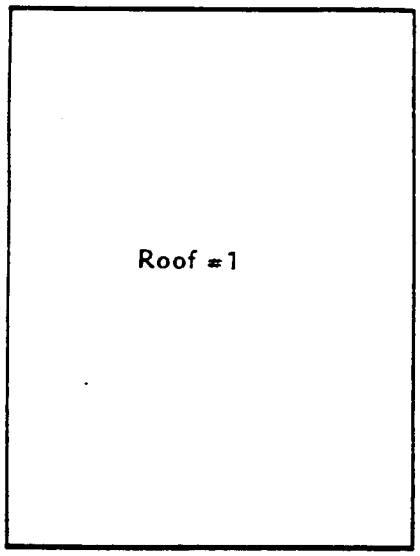
Windows permit passive solar heating due to the greenhouse effect. Explore this principle further by completing Activity 2 in the Earth Science Activities book.

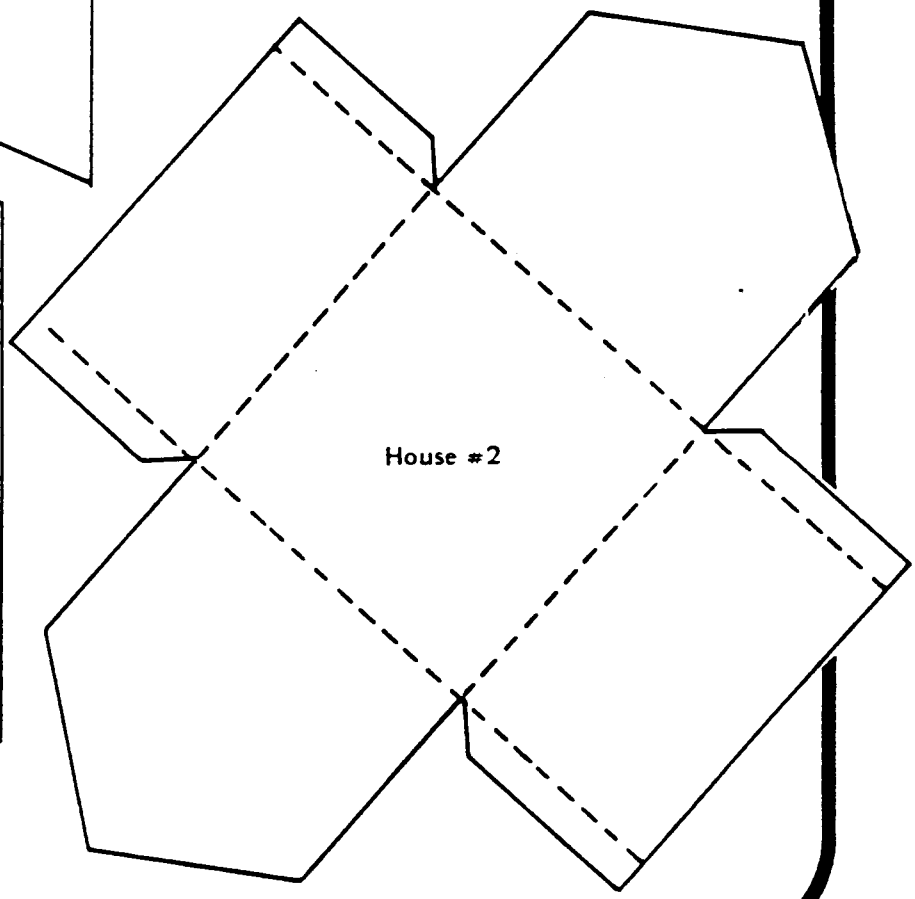
Worksheet A

Model Houses

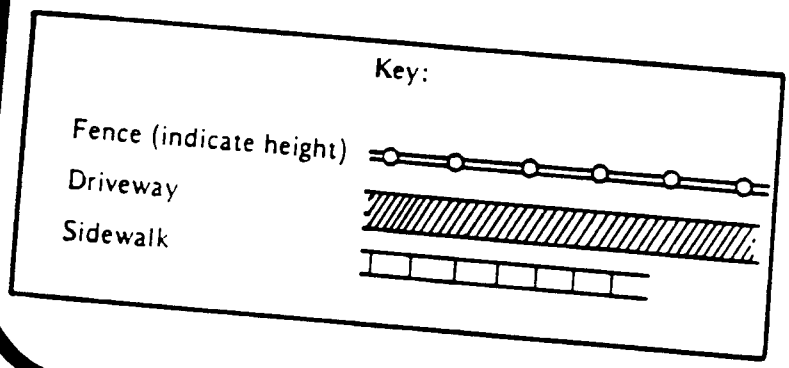


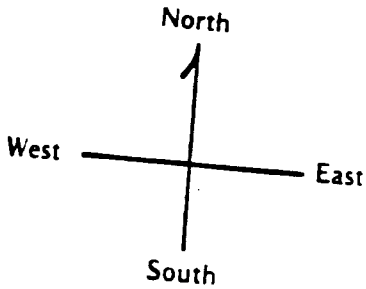



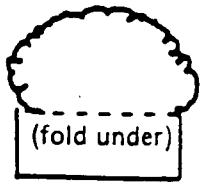



Worksheet B
Plot Plan

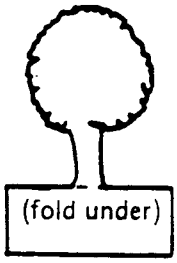


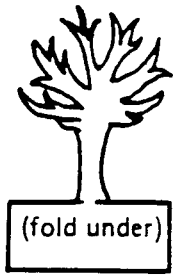
# Worksheet C
## Model Trees and Shrubs



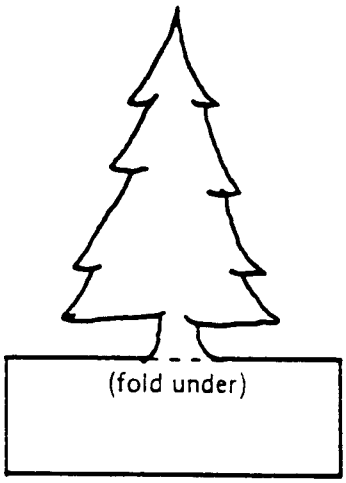

Shrub



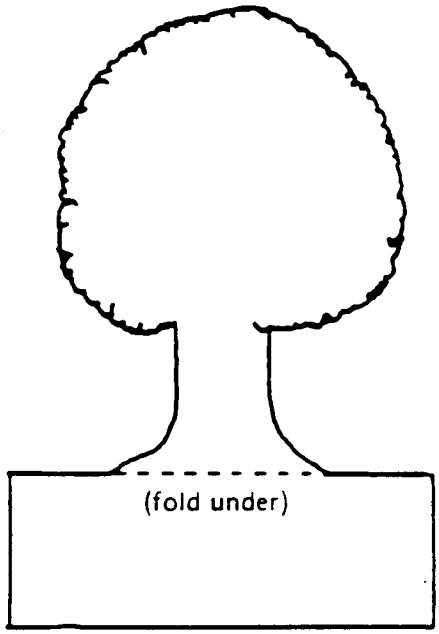

Small Deciduous Tree, Summer



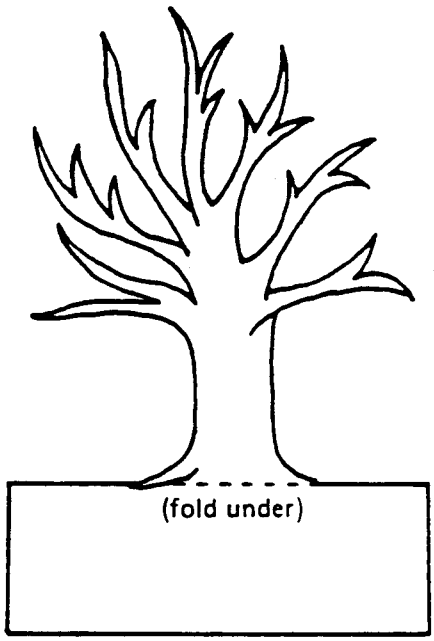

Small Deciduous Tree, Winter




Evergreen




Large Deciduous Tree, Summer




Large Deciduous Tree, Winter

Teacher Information

# A Passive Solar House

## Suggested Grade Level and Discipline

Science, grades 7-9
Home Economics
Consumer Education
Art

## Skill Objectives

Applying principles of passive solar construction to the structural design and landscaping of buildings

## Major Understandings

Buildings may be designed and landscaped, through proper placement of windows, doors, and vegetation, to maximize the greenhouse effect.

A roof overhang should block the more intense solar rays of summer, but should allow winter sunlight to enter windows.

Deciduous trees will provide a building with shading from the intense solar rays of summer but allow those rays to strike the building during fall and winter.

Coniferous trees serve as excellent windbreaks and can be located to reduce infiltration heat losses from a building during winter. Vegetation can also be located to channel summer breezes toward the building.

## Background

Homes can be heated by the sun in winter and protected from the sun's heat in summer. If this is done without mechanical equipment, then the house has a passive solar system. But if heat is transferred by pumps and fans, which require an outside source of energy, then the house has an active system. In a passive solar system, heat flows by natural means such as convection, conduction, and radiation.

Passive solar design is really very simple, and can be incorporated easily into a new or existing home. Basically, a passive solar home collects heat in winter through south-facing glass (glazing) and stores the excess in a thermal mass, from which it is distributed slowly when indoor temperatures drop at night or on cloudy days. A passive house will have more windows on the south side and fewer (or none) on the north side. Windows can be double-glazed on the south side and even triple-glazed on the other sides. In winter, all windows should be covered at night with insulating interior treatments to keep heat loss at a minimum. The house should be well insulated and weather-stripped to avoid infiltration and conduction heat losses as much as possible. To provide protection from the heat of the summer sun, a passive solar home should have overhangs to shade windows on the south and west sides. Exterior window treatments should be used to prevent sunlight or heat from entering. Vents and windows should be placed to increase natural ventilation or to exhaust excess heat from the house.

In addition, a passive solar house must be sited properly on its lot. The position of the sun at different seasons of the year can be charted to determine which portion of the site receives the most sun between 9:00 A.M. and 3:00 P.M. Hills, large trees, and other buildings should not obstruct the sun during the heating season.

Proper landscaping of the home contributes to energy conservation. Deciduous trees should be planted on the south and west sides of the house. Their leaves will shade the house in summer; but in autumn, when the leaves fall, the sun's rays will strike the house. Coniferous trees should be planted on the windward side of the building. They provide a windbreak for the prevailing winds. Wind reduction will cut infiltration heat losses. Other vegetation should be planted to channel cooling summer breezes toward the building.

[illegible] the direction of the prevailing winds for your area.

Find the sun angles for winter and summer for your latitude. Solar books, solar contractors and dealers, and your local weather station are all sources.

Worksheets A, B, and C can be reproduced by various copying machines on heavy weight paper.

## Suggested Time Allotment

Two class periods for model construction

One class period for class discussion

## Suggested Approach

Have the students work individually or in pairs. They should compare results after completing their designs.

Leaving some of the work on display will encourage further discussion and investigation.

An alternative would be to assign the activity for homework and to follow up with a full period of display and discussion directed by the teacher.

You might follow up this activity with a field trip to a local passive solar home.

## Points for Discussion

What factors would you consider in designing and building a passive solar home?

How might you modify an existing home in order to increase its passive solar heating or cooling effects?

What facts could you present to a homeowner in order to convince him that proper landscaping can promote energy conservation?

## Typical Results

Well-designed model homes should have most windows on the south side, a roof overhang on the south, a coniferous windbreak in the direction of the winter winds, and deciduous trees to the south.

Construction of the dwellings and var[illegible] landscapes will vary a great deal in quali[illegible] This should not receive much emphasis as [illegible] is not directly related to the objectives.

Inspect each passive home design and discuss its features with its designer.

Ask students to evaluate a model house and site drawing in terms of passive solar design.

## Modifications

Model house drawings can be traced onto tagboard, then cut out. This will provide sturdier models. You might want to provide larger scale cut-outs for students to trace, as they might find it easier to work with larger models.

Modify the activity for higher ability students by encouraging precise measurement of sun angle, roof pitch, and overhang length.

Students can research thermal storage units and then build them into their model homes. Suggestions include thermal storage walls, roof ponds, storage tanks, and Trombe walls.

## References


Solar Energy Education Reader
Part III: "PS Energy House," p. 162.
"Virginia is for Louvers," p. 172.
"How to Site a House," p. 181.
Part IV: "Solar Homes: The Shape of Things to Come?", p. 395.
(Solar Energy Education Project, NYS Education Department, Albany, NY 12234, 1981, contact the project for price.)

Landscape Design That Saves Energy, Anne Simon Moffat and Marc Schiler.
(William Morrow and Co., Inc., Wilmor Warehouse, 6 Henderson Dr., West Caldwell, NJ 07006, 1981, $17.95.)

Natural Solar Architecture: A Passive Approach, David Wright.
(Van Nostrand Reinhold Co.. Lepi Order Processing. 7625 Empire Dr., Florence, KY 41042, 1978, $8.95/paper.)

1979 NYSERDA Passive Solar Design Awards. NYS Energy Research and Development Authority.
(Technology Transfer. Rockefeller Plaza, Albany, NY 12223, 1980, $7.00/paper.)

The Passive Solar Energy Book, Edward Mazria.
(Rodale Press, Inc., 33 E. Minor St., Emmaus, PA 18049, 1979, $12.95/paper.)

Solar Site Planning: A Guide to Residential Landscaping for Energy Efficiency, David Marlatt et al.
(Southern Solar Energy Center, 61 Perimeter Park, Atlanta, GA 30341, contact SSEC for price.)

Southern Solar Homes: A Planbook of Energy Efficient Designs for the Southern U.S.
(Southern Solar Energy Center, 61 Perimeter Park, Atlanta, GA 30341, 1980, contact SSEC for price.)

"Passive Solar Heating," Solar Factsheet 121.
(Conservation and Renewable Energy Inquiry and Referral Service (CAREIRS), P.O. Box 8900, Silver Spring, MD 20907, 1980, single copies free.)

# ENERGY CASE C. BUILDING A MODEL SOLAR-ELECTRIC CAR

## I. CASE STUDY DESCRIPTION

The petroleum-based fuel burned by private automobiles and light trucks and vans is a major source of greenhouse gases and smog. In addition, the lifetime of known supplies of petroleum and natural gas is usually estimated to be about 50 years, sometimes less. Hence there is a need for vehicles that produce radically reduced exhaust emissions and that do not use petroleum-based fuel or natural gas. Currently, some delivery vans operate on electricity as their primary energy source, with solar energy used as a supplement. The scope of this case study is the design, construction, and test of a small, working model of such a vehicle: a solar-electric car.

The case study is shaped by the design process, which is fundamentally a decision-making process. An understanding of background material covering the mechanical and electrical theory underlying the operation of solar-electric cars must be gained to insure that the students have the information necessary to make these decisions. This understanding will be attained through a combination of classroom study and library research. The need to make good decisions and interest in the vehicle motivate this work. Teachers should consider arranging the case study as a competition between teams. This strategy supplies additional motivation and provides more resources for each car.

Each designer (or design team) should keep a notebook in which sketches, calculations, photographs, speculations, questions, measurements, etc. are placed. The teacher should review the notebooks periodically.

The first step is to define the characteristics that the model car must have and those that are desirable. These characteristics are few compared to a full-scale car. They arise from the methods chosen to evaluate the completed vehicle. However, this step provides an opportunity to study briefly the missions that full-scale, solar-electric cars could carry out and their advantages and disadvantages compared to other alternate-powered vehicles. The teacher can set up the study so that the students, or teams, (1) design and build a solar power system for an existing toy electric car to produce specified performance, (2) design and build a model from the ground up, or (3) have the flexibility to take whatever approach their ingenuity dictates.

The second step is to generate at least two alternate conceptual designs. A conceptual design describes the main features of the car, such as its weight, overall dimensions, range at design speed, and shape. Each concept should have all of the required characteristics and as many of the desired characteristics as possible. Predicting the performance of these conceptual designs will require the application of Newton's

second law and some other simple relationships, using graphs, simple algebra, and simple computer programs (see Section IX.D) to describe the interaction of the car with the sun (or other radiation source), the atmosphere, and the road.

The third step is to select one of the alternate designs, work out the details of its application, and build the model. Before beginning to build, the design should be drawn using a computer-aided design (CAD) system or manual drafting equipment, and, together with the calculations and reasoning supporting the design (here is where the notebooks will come in handy), presented to the teacher. After initial construction, and prior to demonstration, the students can test their cars using the methods described in Section IX.

The final step is to demonstrate the car. The most effective way to do this, because it generates the most interest and enthusiasm, is to stage a race over a straight outdoor (or indoor, if the weather is uncooperative) course.

## II. DEFINITION OF THE PROBLEM

The students' task is to design, construct, and test a model solar-electric vehicle based on general specifications supplied by this case study. Other constraints tailoring the specifications to fit the situation at a particular school may be added by the teacher. Students will be expected to support their design decisions with facts developed from their study.

## III. PERFORMANCE OBJECTIVES

A. Students will examine energy conversion as used in modern transportation.

   1. Students will describe how heat energy is converted to rotary motion in a modern internal combustion engine.

   2. Students will examine advantages and disadvantages of present methods and alternate methods of energy conversion for modern transportation.

B. Students will learn how light energy may be converted for use as an alternate energy source.

   1. Students will describe how light energy is converted to electrical energy using solar cells.

   2. Students will describe how electrical energy is converted into the rotary motion of an electric motor.

   3. Students will describe how energy is used in the electric motor to provide motion to the vehicle.

4. Students will describe how energy is lost in the electric motor in the form of friction and heat.

C. Students will learn how losses affect performance in a solar powered vehicle.

1. Students will describe the effects of drag, frictional forces, and mass on a solar powered vehicle.

2. Students will calculate the effect scale has on losses and how models may not mirror the true nature and quantity of losses found in a full-scale design.

3. Students will examine the trade-offs in designing a solar powered vehicle to reduce losses (e.g., use a smaller electric motor to reduce overall mass at the expense of lower performance).

D. Students will learn how to design a model solar powered vehicle.

1. Students will develop criteria for solar powered vehicles (e.g., basic transportation, racer, family vehicle).

2. Students will compare design trade-offs for creating solar powered vehicles.

E. Students will examine the design considerations in developing a solar powered racer.

1. Students will develop criteria for a solar powered racer including: maximizing speed; minimizing drag, mass, and friction; and maximizing solar collection capability.

2. Students will examine backup systems used to offset irregular solar collection during a race.

3. Students will develop a means of measuring the performance of their solar racer design.

4. Students will develop a means optimizing their design for the use intended based upon performance measurements.

## IV. EXPLANATION OF SPECIFIC MATRIX

The major focus of this study relates to the conversion of solar energy to some form of linear motion found in a solar racing vehicle. The systems employed by any transportation device using solar energy will be explored and investigated to determine which systems (if any) may be employed in the scale racer.

**Solar-Electric Car Matrix**

| CONCEPTS | ACTIVITIES |
|---|---|
| **MODELING** | Graph light intensity versus current output of solar cell. |
| **SYSTEMS** | Determine the necessary controls required on board for the solar racer to store electrical energy when no external light is available.<br>Determine control systems for speed and direction. |
| **OPTIMIZATION** | Determine the necessary trade-offs to maximize speed and efficiency. |
| **TECHNOLOGY—SOCIETY INTERACTION** | Examine and discuss the effects of using solar-electric vehicles on society as a whole. Discuss effects of additional need for electrical generation and peak power concept. |
| **DESIGN** | Design a scale solar racer and compare its performance to the design values. |
| **ETHICS** | Discuss the ethics of advertising the efficiency of an energy conversion.<br>Discuss the ethical responsibility of the automotive industry for air pollution. |

## V. BACKGROUND MATERIALS

### A. Computer Programs

A computer program has been written to cover all the calculations in the instruction sheets. It contains the following: Physical Motion Calculators, Solar Cell Calculator, Angle of Incidence Calculator, Solar Energy and Time Calculator, and Battery Calculator. See Section IX.D for further information.

### B. Interactions With Environment

The interactions of the vehicle with its environment (the road, the atmosphere, and the sun) must be understood physically and modeled mathematically in order to understand how to select the characteristics of the vehicle (its shape and weight, for example) to produce a certain speed and range under the design conditions. Instruction Sheets 2, 3, 4, and 5 are notes for study in this area. They are specific and contain both theory and example calculations. Program D.1, Physical Motion Calculators, contains the mathematical models and are intended to speed up the design calculations (see Section IX).

These materials may be reinforced by the Solar Energy Classroom Materials (Reference B.8), "Racing with the Sun" (Videotape C.1), and "Disk I, Construction Set" (C.2), and "Disk II, Solar Tutorial and Driving Simulation" (C.3). These latter two programs are not suitable for actual design; they are more like computer games. But they do illustrate some of the design trade-offs. The Insolation Data Manual (B.7) will be helpful in learning how the solar energy resource is distributed across the United States.

### C. Energy Conversion

Whereas air drag, gravity, and rolling resistance produce the energy demand, or load, that must be met to travel at a given speed, the conversion of the sun's radiant energy into mechanical energy and its delivery to the driving wheel, or wheels, is the supply that meets this demand. Instruction Sheets 6, 7, and 8 explain the workings of the solar cells that convert the solar energy into electrical energy, the battery that stores this energy, the electric motor that converts the electrical energy into mechanical energy, and the electric circuit that connects them, work.

There is no book on solar-electric vehicles. Section IX contains two references (B.3 and B.4) on solar cells and batteries as used in stationary systems and a manual on solar energy experiments (B.5). The

first two are written for persons without extensive technical background, and thus are useful to beginners. The manual, while written for college students, is adaptable to high school. The "Solar Cell Calculator" (Program D.2) should be helpful in making calculations for single solar cells and arrays of solar cells.

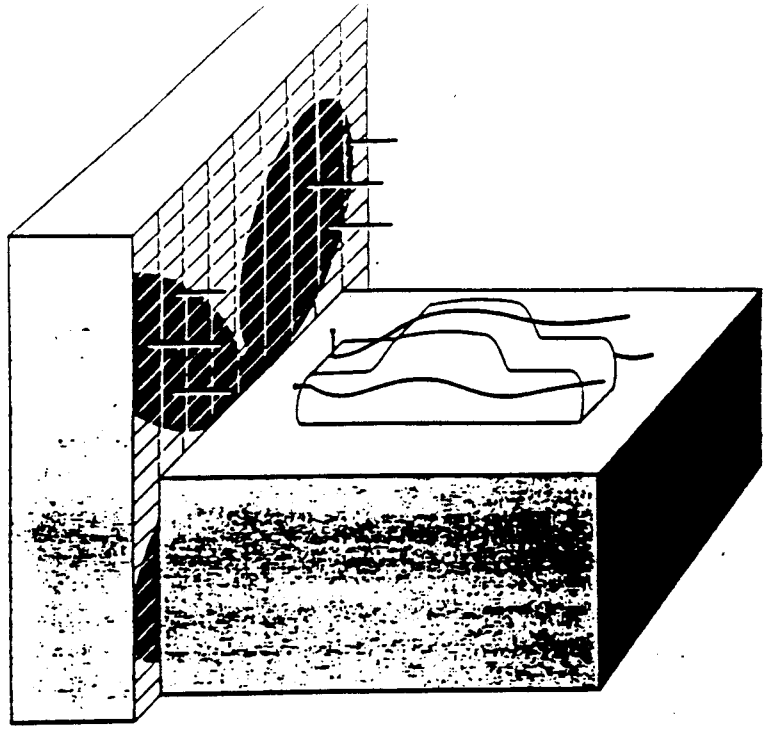
D. Aerodynamics

1. Aerodynamics - The study of air flow and its effect on moving objects. Other considerations being equal, the lower the air resistance, the faster a vehicle can go. Increased drag increases the amount of work required to move a vehicle. Air offers a resistance to any moving object. Air resistance is influenced by the shape of an object. Air resistance is referred to as aerodynamic drag. If a moving object is streamlined, the air will flow around it smoothly and cause less drag, so less energy will be needed to move the vehicle. Such a design is called aerodynamically efficient. When an object produces turbulent air flow, more energy is required to push it forward. Increased drag makes it more difficult for a low-power engine to propel a car.

2. Means of reducing rolling resistance - A low-power vehicle requires low weight because the greater its weight, the more drag from the wheels.

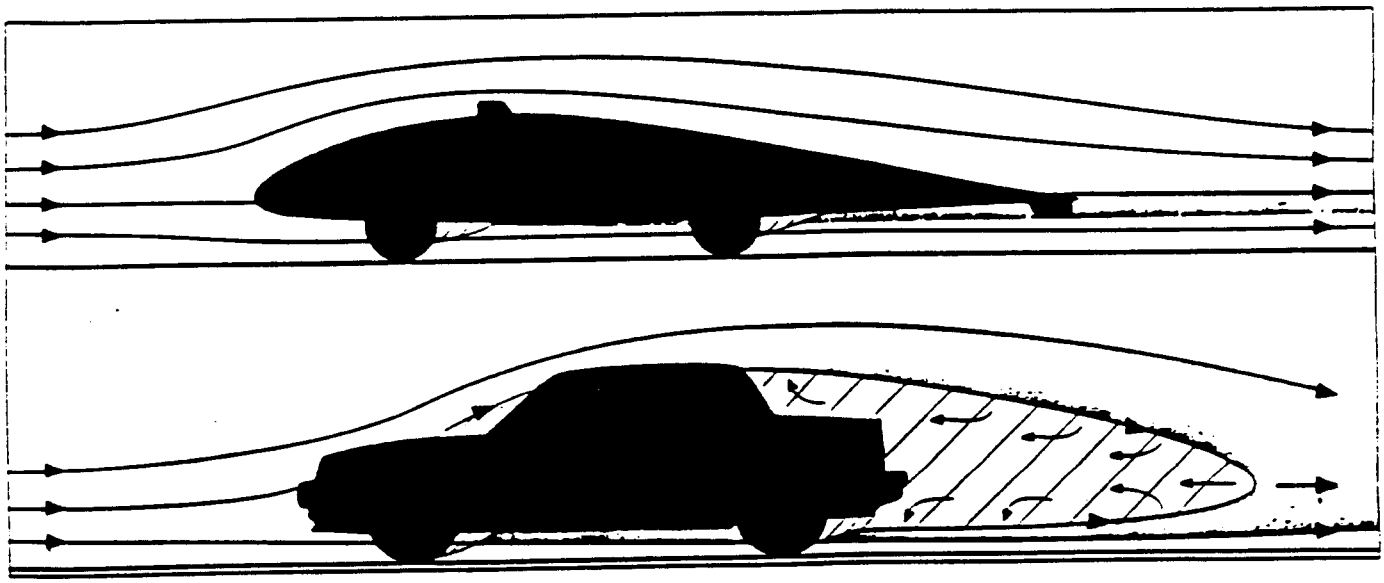
3. Weight - For the effects of aerodynamic drag to be observable, model cars should weigh no less than 50 grams and no more than 200 grams.

4. Methods of reducing drag - Streamlining reduces turbulent air flow, downstream and upstream. Air flowing upstream which is highly turbulent is known as separated flow. This is reduced by designing a vehicle with a rounded front end, a small, smooth profile, and small cross-sectional area.



Testing Device for Zero-Drag Racing Activity

In an efficient design, the strings will float along the surface of the car. In a less effective design, they will flap.



Airflow Over the GM SUNRAYCER and Over a Modern Conventional Automobile

Shaded areas indicate turbulent air that has been slowed but is still flowing downstream. Diagonal lines indicate highly turbulent air flowing upstream, known as **separated flow**. The SUNRAYCER had only small areas of this behind the wheels.

## VI. PROJECT OVERVIEW AND PROCEDURES IN BRIEF

### A. PROBLEM DEFINITION

1. Classroom activities involving discussions on our dependence on fossil fuels.

2. Data graphing and mathematical analysis of oil reserves and future availability of fossil fuels for transportation purposes.

3. Alternate energy approaches discussed and researched to provide a means to design and explore.

### B. STUDENT ACTIVITIES

1. SOLAR CELLS MEASUREMENT (Week 1, Day 3)
   Obtain a solar cell (Radio Shack #276-113 or equivalent - see Section IX.E). Have the students graph its output in relation to intensity of light input.

   The input may be measured using a light meter or a controlled lighting source. The output of the solar cell may be measured using a volt-ohm-millimeter set to any small current range.

   Plot a few points and extrapolate a linear curve to determine the approximate number of cells to power the car's motor.

2. ELECTRIC MOTOR MEASUREMENT (Week 1, Day 4)

   Obtain a small electric motor (Radio Shack #273-223 or equivalent - see Section IX.E). Have the students graph its output speed in relation to its current input.

   The speed may be measured using the Fischertechnik light sensor arrangement (used to determine the presence of a ping pong ball — see Machine Automation Case Study in Principles of Engineering) and a small propeller (cardboard or wood) connected to the motor's shaft. By using an oscilloscope (or computer program) to count the number of pulses of the light beam being cut by the propeller, the speed of the motor may be determined.

   The speed (revolutions per second) is determined using EVERY OTHER pulse as every pulse represents a half revolution. For additional circuit information, see Section IX, A.8.

3. ANALYSIS OF ROLLING-RESISTANCE TEST (Week 2, Day 8)

Obtain a spring scale (Physics Department) and connect one end to the body of the racer. To the other end of the spring scale connect a light string. Either pull the string (at a constant rate) or wind the string using a drill with a wide bobbin (again, at a constant rate), pulling slowly and smoothly, and record the rolling resistance of the car.

4. ANALYSIS OF DESIGN (Week 4, Days 18 and 19)

Use the Physical Motion Calculators to simulate the effects of drag and friction on the racer's performance.

Redesign and simulate the new design changes as above.

Show how frontal area affects drag.

5. ANALYSIS OF EFFICIENCY/ENDURANCE TESTING (Week 5, Day 25)

Develop a "treadmill" for testing the performance of the solar racer. The treadmill should be partially enclosed in a box to eliminate outside lighting interference. A fixed lighting source inside the box should provide the ONLY lighting for the solar racer.

Measure the number of turns per second of the treadmill with the box light on and with the box light off.

6. ANALYSIS OF COMPETITION TESTING (Week 6, Day 29)

Develop a straight line course (gymnasium floor or hallway) to allow for team competition racing.

Measure the speed of the car over a given distance in light and (if possible) in partial darkness, such as a poorly lit hallway.

C. COMMUNICATION SKILLS

1. Person To Person

a. Joint research and development of a solar racer design.
b. Joint analysis of design data and application of the analysis on design improvements.

2. Person To Group

   a. Persons within each team devise methods of improving original design through research and development.
   b. Each team member reports to the team as a whole.

3. Person To Machine

   a. Use of computer program to determine effects of drag and friction on solar racer.
   b. Additional program software to determine improvements on energy conversion, motor output, and energy storage capability.

D. TECHNICAL TOOLS, TECHNIQUES, AND RESOURCES

1. Computer programs for data analysis.
2. CAD program for design of solar racer.
3. Machine and hand tools used in the construction of model solar racers and testing devices.
4. Research materials on solar power conversion, electrical storage devices, electrical controls, friction, and drag losses.

E. SELECTION OF MATERIALS AND PROCESSES

Team members within each group or team research various materials and processes to be used in the construction of the solar racer, paying particular attention to mass and ease of machining.

F. MEASUREMENT

1. Measurement of forces acting on the racer - friction, drag, and vehicle weight.
2. Measurement of actual available current - light conversion into electric current.
3. Measurement of speed and distance with available lighting.
4. Measurement of speed and distance without light - storage battery life.

## VII. SUGGESTED EVALUATION METHODS

### A. UNDERSTANDING AND APPLICATION OF THEORY TO THE PROTOTYPE

1. Preliminary problems regarding free-body diagrams. (10%)
2. Sketches and drawings (CAD) of prototype. (20%)
3. Justification and evidence of research for chosen design type. (15%)
4. Evidence of prototype testing and application of theory using measured values. (20%)
5. Construction of working prototype and final racer. (35%)

### B. FINAL ANALYSIS AND DESIGN CRITERIA

1. Report of design trade-offs and reasons for deciding on final design outcome.
2. Re-testing and modification of prototype to create final design.
3. Final working drawings using CAD.
4. Formal presentation to entire class by team members.
5. Completed log/journal showing entire evolution of solar racer design.

## VIII. CASE STUDY TIME TABLE

WEEK 1 - INTRODUCTION TO SOLAR RACER CASE STUDY AND CIRCUIT BASICS

Day 1: Explanation of design problem, focus, and goals. Divide class into design teams of three or four (maximum).

Day 2: Review circuit basics - Ohm's and Watt's laws.

Day 3: Solar to electricity conversion. Focus on need to measure output of solar cells.

Day 4: Electrical control concepts and electrical drive motor systems. Focus on measuring motor energy usage and measurements involving speed.

Day 5: Students develop a means to set up preliminary cell, motor, and control circuitry. Preliminary measurements taken and curves drawn up to optimize initial design ideas.

WEEK 2 - MEASUREMENT AND ITS USE IN OPTIMIZING THE SOLAR RACER

Day 6: Use examples from student-made measurements to help focus design direction: size of car, weight, area of solar panel.

Day 7: Begin development of mechanical measurements of the racer. Free-body diagrams:
1. steady state - weight and normal forces
2. center of gravity - explain purpose

Day 8: Development of steady speed vehicle free-body diagram including:
1. drag
2. rolling resistance
3. tractive force
4. lift

Discussion should include purpose of analysis and a means to minimize destructive forces and maximize performance.

Day 9: Finalize study of component forces. Identify and define forces developed on Day 8. Additional information may include coefficients of friction - static ($\mu S$) and kinetic ($\mu K$).

Day 10: Sample problems based upon free-body diagram analysis.

WEEK 3 - PRELIMINARY IDEAS AND DEVELOPMENT OF INITIAL PROTOTYPE

Days 11 & 12: Begin preliminary design ideas using sketches and rough CAD work. Brainstorming of possible electrical systems to be incorporated into racer design.

Days 13 -15: Develop ideas from sketches and CAD to actual working wooden or plastic prototypes.

WEEK 4 - TESTING OF PROTOTYPE

Days 16 & 17: Testing processes - rolling resistance, drive system, and control circuitry. Compare and contrast with original paper design concepts.

Days 18 & 19: Coast-down test of cars to further determine drag and effects of surface and air forces acting on racer. See Reference B.8.

Day 20: General discussion of this week's collected data - a review of free-body diagram algebra for racer and direct application of student data to the free-body diagrams discussed.

WEEK 5 - MODIFICATION TO SOLAR RACER PROTOTYPE AND DEVELOPMENT OF FINAL RACER FOR COMPETITION

Days 21 & 22: Team brainstorming on optimizing racer design - minimizing mass, increasing speed, minimizing opposing forces.

Days 23 & 24: Modifications to CAD drawings and reworking of prototype models. Retesting to determine outcomes of redesign.

Day 25: Efficiency testing of cars using enclosed treadmill device box.

WEEK 6 - FINAL TESTING AND COMPETITION AND CASE STUDY WRAP UP

Days 26 & 27: Formal presentation by each team to the class. Include handouts of testing data with prediction of performance outcomes.

Day 28: Students' final work session to "fine-tune" racer.

Day 29: Racing competition in light/dark transitional environment. Use a gymnasium floor or hallway. Course set to be straight line using fishing line and small eyelets.

Day 30: Review of solar racer case study.

## IX. RESOURCES FOR STUDENTS AND TEACHERS

A. Instruction Sheets

1. Basic Circuit for Recharging NICAD Batteries
2. Electric Motors
3. Speed and Power
4. Energy and Range
5. Solar Energy
6. Solar Cells
7. Speed Sensing
8. Batteries
9. Solar-Electric Power System

B. Books

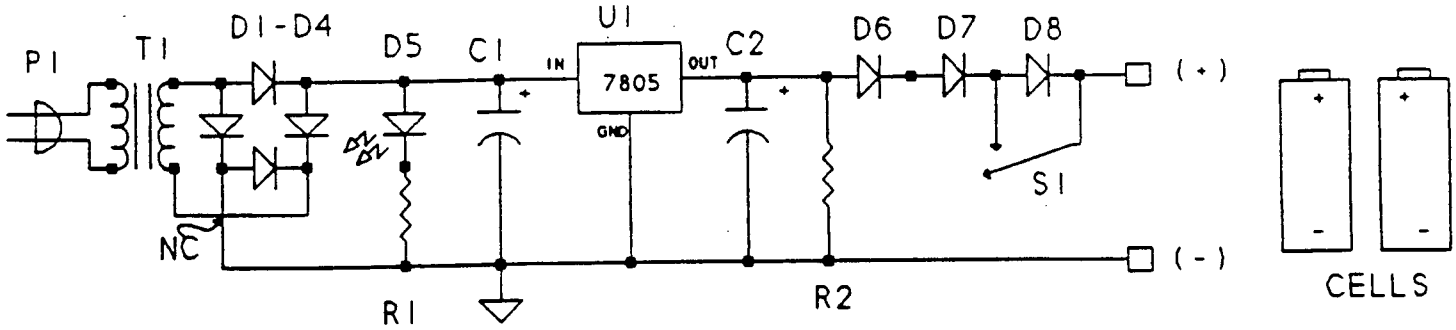
C. Videotapes and Software

D. Computer Program (Calculators)

E. Equipment and Materials

## Instruction Sheet 1

## Basic Circuit for Recharging NICAD Batteries




**Basic Recharging Circuit**

a) Parts Listing and Purpose

P1.....Standard 125 V plug and 18 AWG lamp cord for connection to T1 and wall outlet.

T1.....6.3 VAC/3 A step-down transformer which lowers the incoming line voltage from 125 V to 6.3 V.

D1-D4....50 PIV / 3 A diodes. These form a full-wave bridge that changes the 6.3 VAC output of T1 to rectified DC voltage (approximately 9 Vdc with the addition of C1)

D5.....General Purpose Light Emitting Diode (LED). This device lights up when current passes through it. It is used here merely as an "ON" indicator.

R1.....470 Ω ½ Watt resistor (YE, VI, BR, GO). his device limits the current through the LED (D5) to about 15 mA (milliamperes).

C1.....47 μF 35 Vdc electrolytic capacitor. This device will "smooth" out the rectified waveform received from the four diodes.

U1.....μA7805 5 V / 1 A voltage regulator integrated circuit (IC). As long as the input (wire from the top of C1) is between 5 V and 35 V, the output (top of C2) will remain fixed at 5 V. This is used to maintain a constant output voltage independent of loading.

C2.....4.7 μF 35 Vdc electrolytic capacitor. This helps to stabilize the output in the event of any output fluctuations.

R2.....1000 Ω ½ Watt resistor (BR, BK, RD, GO). This "bleeder" resistor allows the energy stored in C2 to dissipate when the circuit is disconnected.

D6-D8....50 PIV / 3 A diodes. These three diodes are used to lower the output to about 2.9 - 2.0 Vdc when connected to a "AA-size" or "AAA-size" NICAD cell.

S1.....SPST (Single Pole Single Throw) switch. The switch is used to "LOAD" switch and is optional. With the switch in the "OFF" position (shown), the three diodes D6-D8 are connected. Turning this switch "OFF" shorts out diode D8 which increases the output voltage slightly.

b) Circuit Parts Listing with Cost: Prices are from Radio Shack Catalog - #459, 1991.

| Reference | Part Number | Page | Cost Each | Total |
|---|---|---|---|---|
| P1..... | 61-2702 | 141 | 2/$ 1.39 | $ 1.39 |
| T1.....* | 273-1511 | 133 | $ 8.99 | $ 8.99 |
| D1-D8..... | 276-1141 | 124 | 2/$ .99 | $ 3.96 |
| D5..... | 276-041 | 123 | 2/$ .69 | $ .69 |
| R1..... | 271-019 | 128 | 2/$ .25 | $ .25 |
| R2..... | 271-023 | 128 | 2/$ .25 | $ .25 |
| C1..... | 272-1015 | 129 | $ .69 | $ .69 |
| C2..... | 272-1012 | 129 | $ .49 | $ .49 |
| U1..... | 276-1770 | 124 | $ 1.19 | $ 1.19 |
| S1..... | 275-401 | 132 | 2/$ 1.19 | $ 1.19 |
| | | | **Grand Total:** | **$19.09** |

*NOTE: T1 is actually a 12.6 VAC transformer with a center tap (CT) rated for 3 amperes. By using only the center tap and one outside lead on the secondary, the output is reduced to 6.3 VAC.

c) Possible Substitutions:

1. T1 could be an actual 6.3 VAC transformer available through other sources such as Mouser Electronics, MCM Electronics, etc. If you already have a 12.6 VAC transformer and it does NOT have a center tap, be sure to increase the value of R1 to 1000, Ω ½ watt. Otherwise, the LED will burn out.

2. D1-D4 could be replaced with a single Full-Wave Bridge Rectifier IC such as Radio Shack # 276-1146 ($1.39).

3. D5 can be eliminated completely if you have no need for a circuit "ON" indicator.

d) Additional Circuit Information:

1. The connections between P1 and T1 must be made very securely and completely wrapped with electrical tape to avoid any possibility of electrical shock. You may wish to solder all connections and seal them using heat-shrink tubing.

2. The entire circuit can be built and mounted on a single solderless IC breadboard [Radio Shack # 276-175 ($7.49)] with the exceptions of the transformer, plug, and NICAD cells.

3. The capacitors used in this circuit are electrolytic. They possess a polarity that must be observed. In the schematic given, the top connection is the positive side of the capacitor (usually indicated with a (+) symbol or a dent in the capacitor's casing). Connecting these incorrectly may cause injury or damage to the part.

4. The μA7805 IC will get hot if taxed a great deal. You may decide to add a heat sink [Radio Shack # 276-1363 ($ .79)] to help it dissipate the heat while operating.

5. Depending upon the cell energy source chosen for the solar racer, you will have to choose a means of connecting the cell(s) to the circuit. Radio Shack has a wide assortment of cell holders to choose from (Page 139) ranging in price from $ .79 to $ 1.59.

6. A final note: It is assumed that the instructor knows enough about electronic circuits to build this charger from the schematic given and can "fill in the gaps" where instructions on its completion are missing.

## Instruction Sheet 2

## Electric Motors

An electric motor is a device that converts electric energy into mechanical energy. The interaction that causes this conversion to take place is as follows: When an electric current is flowing in a wire which is also in a magnetic field, the wire experiences a force. The mechanism of the motor is arranged in such a way that this force causes rotation of the shaft of the motor. This rotating shaft can then be used to perform mechanical work, such as driving a model solar-electric car.

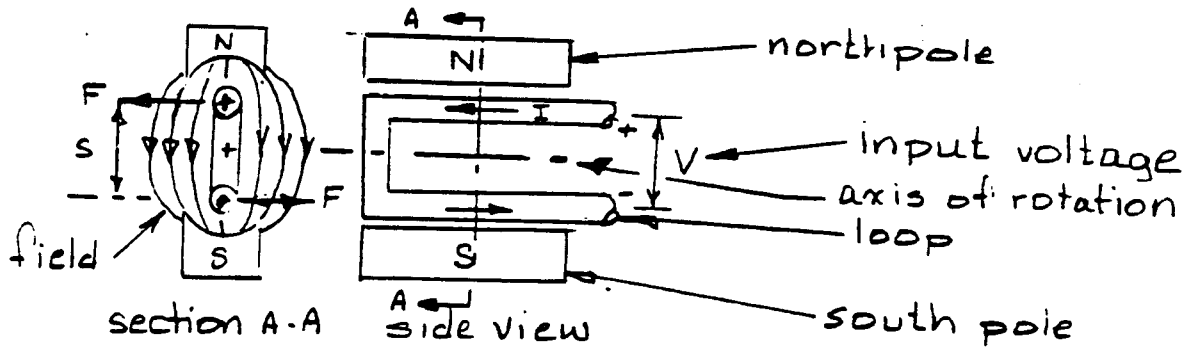



Figure 1

Figure 1 shows an elecric motor. A loop of wire connected to a source of DC current (a battery in this case) is held inside the field set up by the north and south poles of a magnet (only the magnet's poles are shown). The force on the wire is exerted sideways -- left or right, depending on the direction of the current relative to the direction of the field. The torque is the total moment (force times distance) of the two forces, "F," on the top and bottom parts of the wire,

$$\tau = F\ s \quad \text{(N-m)} \qquad (2\text{-}1)$$

where $\tau$ is the torque and s is the spacing between the center lines of the sides of the wire loop. The size of F, and therefore of $\tau$, depends on the strength of the magnetic field and the magnitude of the electric current. For a given magnet, the torque is directly proportional to the current.

$$\tau = k\ I \quad \text{(N-m)} \qquad (2\text{-}2)$$

where k is a proportionality constant and I is the current (A).

If the motor is rotating at N rev/sec, each force will travel in a circle a distance $c = \pi s$ ($\pi$ is 3.1416, approximately) every revolution. Thus each force will do work (force moving through a distance) of

$$W = \bar{F}\ C \quad \text{(N-m)}. \qquad (2\text{-}3)$$

where $\bar{F}$ is the average force during one revolution. For the one-magnet motor, the force is largest for the position of the loop shown, and nearly zero when the loop has rotated 90° from that position.

At the 90° position, a mechanical arrangement called a "commutator" switches the positive voltage to the lower side and the negative voltage to the upper side so the direction of current flow will be the same as shown in Figure 1 whichever side is lower, or upper. This prevents the forces from reversing direction and stopping the rotation.

The rate at which the work is done is called the "power." The power produced by the motor would be the sum of the rate at which each force does its work. This rate is the work per revolution times the number of revolutions per second.

$$P_M = 2\ W\ N = 2\ \bar{F}\ C\ N = 2\pi N\ \bar{\tau}\ (W), \qquad (2\text{-}4)$$

where $P_M$ is the power of the motor and $\bar{\tau}$ is the average torque per revolution. (In motors that have several pairs of poles, the torque would be more uniform during a revolution than for the two-pole motor shown.)

Figure 2 shows the electric circuit of the motor. The loop of wire, which is called the "armature," has some electrical resistance, $R_A$. The battery, or array, supplies the voltage, V, which drives the current, I, through the armature and makes it rotate. The little battery labeled "$V_C$" represents the "counter electromotive force" (counter emf).

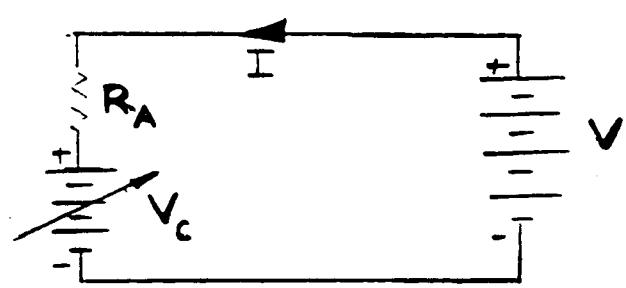



Figure 2

Because the wire rotates in the magnetic field, the field creates, or "induces," a voltage in the wire that tries to cause current to flow in the wire <u>opposite</u> to the current, making the wire rotate. For a given magnet, the counter emf is proportional to the rotational speed. Thus the faster the motor rotates, the higher $V_C$ is, and the higher the battery, or solar cell array, voltage must be to make it go.

$$V = I\ R_A + V_C. \qquad (2\text{-}5)$$

The electrical power supplied to the motor is

$$P_E = I\ V\ (W) = I^2 R_A + I\ V_C. \qquad (2\text{-}6)$$

The efficiency of the motor is the output power divided by the input power,

$$\eta_M = 100 P_M / P_E\ (\%), \qquad (2\text{-}7)$$

where $\eta_M$ is the motor's efficiency. This is a number less than 100% because of the losses in the armature resistance, the mechanical friction in the bearings of the motor, and the air friction opposing the rotation of the armature. Good motors have efficiencies around 90%.

The efficiency is higher at high N because I is lower and losses in $R_A$ are smaller, but the torque, which is proportional to I, is also smaller, if V is the same. Increasing V to increase the torque means increasing the size of the armature conductors so they will have smaller resistance and the efficiency will not decrease. This increases the size and weight of the motor. Hence lightweight motors tend to operate at high rotational speed, but have low torque. Motor designers look for magnet materials that have stronger fields. These materials would allow higher torque at higher speeds without increasing the current.

## Instruction Sheet 3

## Speed and Power

The calculations that follow use the Physical Motion Calculators on the program disk.

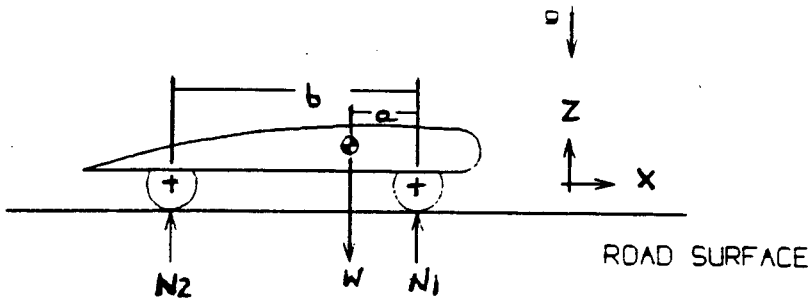



Figure 1. Free-Body Stationary Vehicle

Stationary Vehicle. Figure 1 shows a solar-electric car at rest on a horizontal road in still air. The wheel base is b meters long and the center of gravity is a meters from the axis of rotation of the front wheels. The weight, W, acts down from the center of gravity. $N_1$ and $N_2$ are the total reactions of the road on the front and rear wheels, respectively.

The wheel reactions can be found from mechanical equilibrium:

$$N_1 = \left( 1 - \frac{a}{b} \right) W \qquad (3\text{-}1)$$

$$N_2 = \frac{a}{b} W \qquad (3\text{-}2)$$

---

Example 1

A solar-electric racing car has a wheelbase of 3.5m and its center of gravity is 1.5m behind the axis of rotation of the front wheels. If the mass of the car is 260 kg, what are the front and rear wheel reactions?

$$W = Mg = (260 \text{ kg})(9.8 \frac{\text{m}}{\text{s}^2}) = 2548 \text{ N}$$

$$N_1 = \left( 1 - \frac{1.5}{3.5} \right)(2548 \text{ N}) = 1456 \text{ N}$$

$$N_2 = \left( \frac{1.5}{3.5} \right)(2548 \text{ N}) = 1092 \text{ N}$$

---

---

Example 2

A solar-electric car was weighed using scales under the wheels. The results were $N_1$ = 1200 N and $N_2$ = 1000 N. What is the location of the center of gravity on the longitudinal axis of the car if the wheelbase is 4.0 m long?

$$\frac{a}{b} = \frac{N_2}{W} = \frac{1000}{2200} = 0.4545$$

$$a = (4\ m)(0.4545) = 1.82\ m$$

Remark

The location of the center of gravity affects the crosswind stability and steering characteristics of the car.

---

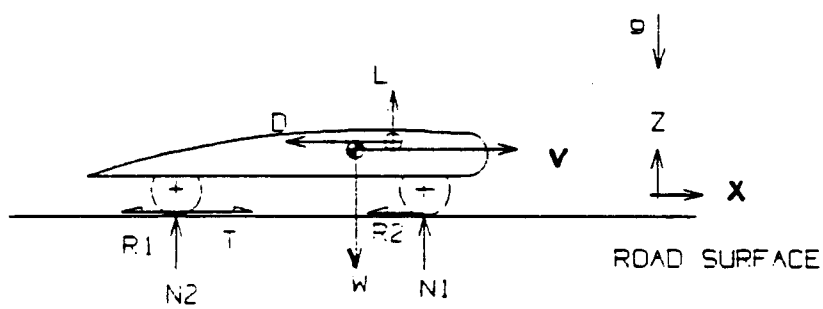



Figure 2. Steady Speed in Still Air

Figure 2 shows the car traveling at a steady speed v on a horizontal road in still air. Four more forces now are acting on the car: the drag, D, the rolling resistance, R(=R1+R2), the tractive force, T, and the lift force, L.

Drag. The drag force is the force of the air on the car that opposes its motion. It is the sum of the viscous frictional force on the surface of the car and the component of the non-uniform pressure distribution over the surface area of the car that opposes the motion.

The air at the surface of the car is at zero speed relative to the car, while the air far from the car is still. The result is a viscous shear force distributed over the car's surface.

The airflow may be thought of as flowing along "stream surfaces" which, near the car, conform to the shape of the car. The flow is said to be "attached" to the car. However, if the slope of the car's surface becomes too steep, the flow cannot conform to it. The stream surfaces break away and the flow is said to "separate" from the surface.

Downstream from the line of separation, pressure drops and backflow occurs. Large eddies form and trail behind the car, becoming a wake.

Upstream from the line of separation the pressure generally decreases as the front of the car is approached*, reaches a minimum at the point of maximum velocity (top of car), and then reaches a maximum at the point where the flow velocity is zero relative to the car. This is called the "stagnation point."

Figure 3 shows a two-dimensional picture of the flow relative to the car.

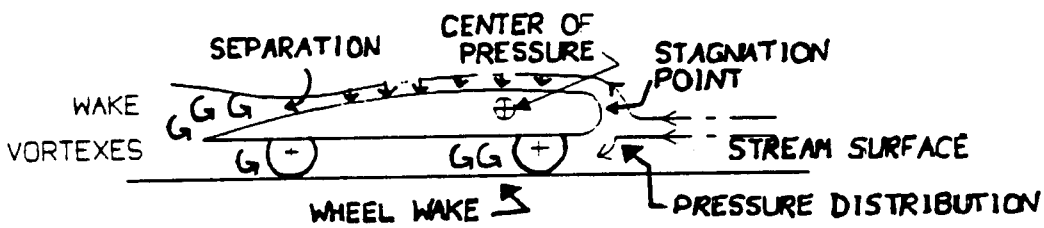



Figure 3. Separated Flow

Separation causes a drag force because there is a net pressure force that opposes the car's motion. Streamlined car shapes, such as that shown in Figure 3, delay separation and thus improve pressure recovery and reduce drag.

The pressure distribution may also cause a distributed lift force. The center of pressure shown in Figure 3 is the point at which the distributed lift and drag forces appear to act. That is, if an isolated lift force, L, and an isolated drag force, D, were to replace the actual distributed forces, they would have to act at this point to have the same moment about the center of gravity (or some other point) as the actual distributed forces do.

The drag force is customarily expressed as

$$D = C_D A_D \rho \frac{(v_R)^2}{2} \qquad (3\text{-}3)$$

* The details of the distribution are shape-dependent.

where $C_D$ is the drag coefficient, $A_D$ is the profile area ($m^2$) (although other reference areas are sometimes used), $\rho$ is the ambient air density ($kg/m^3$), and $v_R$ is the speed of the ambient air relative to the car (m/s). Thus if there is no wind velocity component in the direction of motion, $v_R = v$.

$C_D$ tends to be independent of $v_R$ at speeds for which drag is important because drag is dominated by separation. Hence $C_D$ will be taken as a constant for purposes of design and simulation.

The lift force, which should be small compared to the weight, will be neglected.

Rolling Resistance. Rolling resistance is the sum of the static frictional forces (that is, the tires are assumed not to slip) between the tires and the road, and a force applied at each of these points that has the same torque about the wheel axis as the frictional torques in the bearings when the gears are in neutral. A successful model for the rolling resistance is

$$R = \mu_1 N + \mu_2 vW \qquad (3\text{-}4)$$

where $\mu_1$ is a dimensionless static friction coefficient (characteristic of the road surface, the tire surface, the tire diameter, and the tire pressure), N is the component of the weight normal to the road, $\mu_2$ is a kinetic friction coefficient (sec/meter), and W is the weight. The two coefficients may be measured for a given car and road by a coast-down test. Table 1 gives typical values (from Reference B.12).

| | | |
|---|---|---|
| $\mu_2$ $\frac{h}{km}$ | $3.11\ (10^{-5}) - 1.09\ (10^{-3})$ | |
| $\mu_1$ | smooth pavement | unpaved |
| | $7.5\ (10^{-3})$ | 0.3 |

Table 1. Rolling Resistance Coefficients

Tractive Force. This is the force (T) which, viewed as applied at the tire's contact area, has the same torque about the wheel's axis as the driving torque from the motor. If r is a wheel's radius (flattening of the tire neglected)

$$\tau_w = Tr \qquad (3\text{-}5)$$

At steady speed, T is equal to the sum of all opposing forces,

$$T = R + D \qquad (3\text{-}6)$$

Tractive Power. This is the rate at which the tractive force does work on the car. It is

$$P_w = Tv, \qquad (3\text{-}7)$$

where $P_w$ is the power <u>delivered</u> to the driven wheel, or wheels (W), not the power generated by the motor. Note that the drag power increases with $v^3$ and the rolling resistance power, (Rv) with $v^2$.

<u>Hills</u>. Figure 4 shows a solar-electric car climbing a hill at steady speed. The hill makes an angle of $\alpha$ with the horizontal.

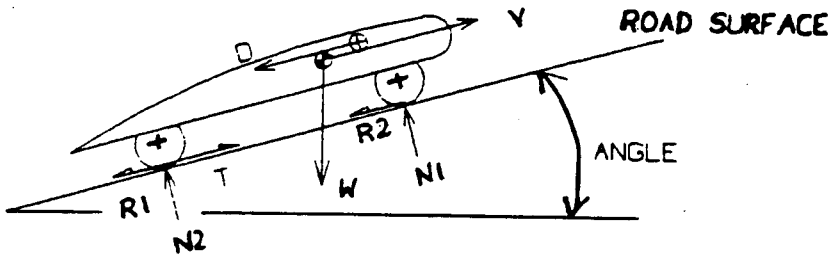



Figure 4. Solar Car Climbing a Hill

Equation (3-6) now becomes

$$T = R + D + W \sin\alpha \qquad (3\text{-}8)$$

<u>Wind</u>. If there is a component of the wind blowing in the direction of motion, then

$$V_R = v - w \qquad (3\text{-}9)$$

where w is the wind component, taken positive if it is in the same direction as v.

<u>Speed</u>. Using equations (3-3), (3-4) and (3-9) in equation (3-8), and then solving for v gives the result shown graphically in Figure 5. Figure 5 is a plot of

$$P_w^* = \frac{P_w}{Wv_D} \text{ and } T^* \text{ vs. } v$$

The variables in Figure 5 have been non-dimensionalized to make the figure more general. The "drag speed" is the speed the car would attain in stable, nose-first, free fall through still air of uniform density $\rho$.

It is

$$V_D = \sqrt{\frac{2W}{C_D A_D \rho}} \qquad (3\text{-}10)$$

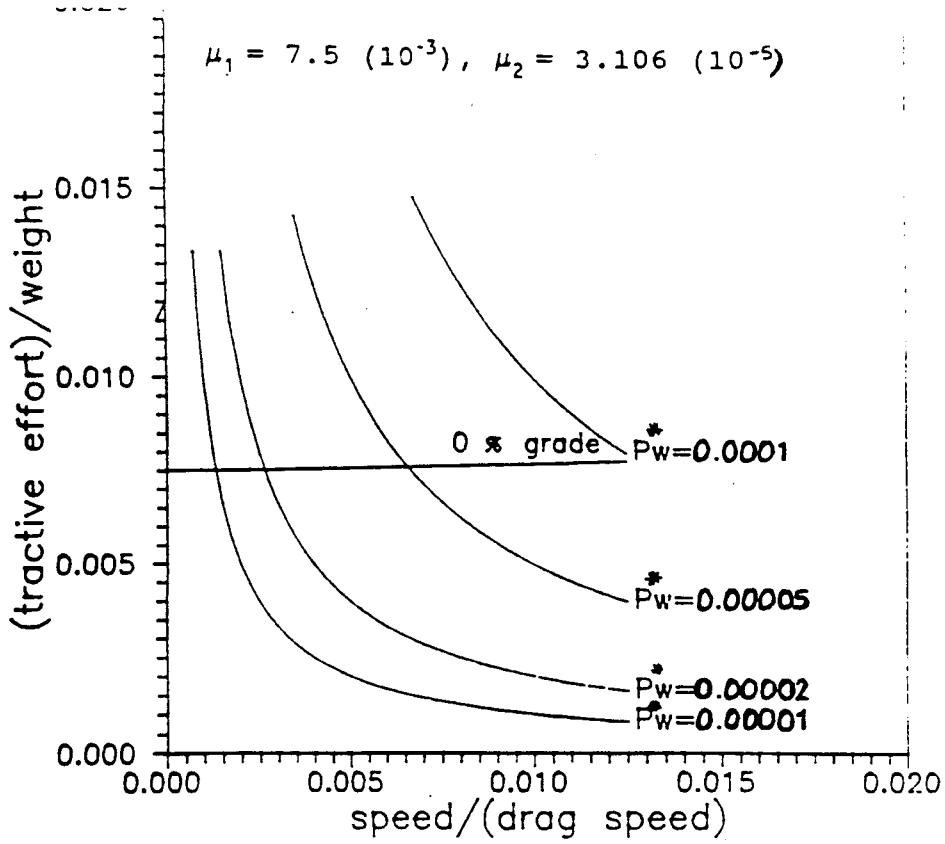



Figure 5. Tractive Force/Weight vs. Speed/Drag Speed

---

<u>Example 3</u>

A solar-electric car has a mass of 200g (0.2 kg) and a design speed of 1.0m/s under the conditions of

$$\mu_1 = 7.5\ (10^{-3}),\ \mu_2 = 3.106\ (10^{-5})\ \frac{k}{km} = 1.1$$

$$(10^{-4})\ (s/m)\rho = 1.0\ \frac{kg}{m^3}\quad w=0,\ \text{and}\ \alpha = 0.$$

(1) If $v_D$ = 200 m/s, what tractive force and $P_w$ are required?

$W = (0.2\ kg)\ (9.8\ m/s^2) = 1.96\ N$

$$V^* = \frac{1.0\ m/s}{200\ m/s} = 0.005$$

$T^* = 0.0076$ (Fig.5)

$T \approx (0.0076) = 0.015$

$P_w^* = 0.00004$ (Fig.5)

$P_w \approx (0.00004)\ (200\ \frac{m}{S})\ (1.96N) = .0157W = 15.7mW$

(2) If $C_D = 0.1$, what is $A_D$?

$$C_D A_D = \frac{2W}{\rho v_D^2} = \frac{(2)(1.96\ N)}{(1.0\ kg/m^3)(200\ m/s)^2} = 0.000098\ m^2 = 0.98\ cm^2$$

$$A_D = \frac{0.98 cm^2}{0.1} = 9.8\ cm^2$$

(3) Suppose the efficiency of power transmission is $\eta_D = 0.95$. What motor output power is required?

$$P_{MO} = P_W / \eta_D = \frac{15.7mW}{0.95} = 16.5\ mW$$

(4) Suppose the motor efficiency (including controller) is $\eta_M = 0.9$, the efficiency of the solar array in converting sunlight to electrical power is $\eta_s = 0.5$, and the irradiance is 300 $(W/m^2)$ (perhaps we are indoors). What size array is required?

$$P_{Mi} = \frac{16.5mW}{0.9} = 18.3\ mW$$

$$A_s = \frac{P_{Mi}}{\eta_s G_s} = \frac{0.0183W}{(0.5)(300\ W/m^2)} = 0.00122\ m^2 = 12.2\ cm^2$$

The Physical Motion Calculators can be used to solve these problems for any combination of parameters.

---

<u>Linear Acceleration</u>. If the car is accelerating in a straight line while on a grade

$$T = M_e v + R + D + W \sin \qquad (3\text{-}11)$$

and

$$P_W = Mv\dot{v} + (R + D + W \sin\alpha)v. \qquad (3\text{-}12)$$

where $\dot{v}$ is the rate of acceleration in $m/s^2$ and $M_e$ is the effective mass. $M_e$ is greater than the vehicle mass, M, by an amount needed to account for the rotational inertia of the wheels.

Equations (3-11) and (3-12) express the tractive effort and wheel power increases required to accelerate. Note also that these increases are proportional to the vehicle's effective mass.

## Instruction Sheet 4

## Energy and Range

Range is the distance a car can go without refueling. For a solar-electric car, "refueling" means stopping to recharge its batteries. This may be done from the sun or from the electric utility grid.

The range depends upon the energy available from the sun and the energy required to go a given distance. To compare these properly, they must be found for the same point in the car's energy conversion system. This point could be, say, at the motor input terminals. But it is convenient to refer the energy available and the energy required to the input of the driven wheel, in order to make use of the discussion in the previous information sheet. So, "wheel energy" will mean the energy required at the driven wheel to go a specified distance, just as "wheel power" meant the power required at the driven wheel to go a certain speed.

If an average tractive force, T, must be applied to the car for it to go a distance S at a speed v, then the work done at the driven wheel is

$$W_W = T\ S. \qquad (4\text{-}1)$$

Energy is expended when work is done. So the energy expended to go the distance S is equal to the work done.

$$\Delta E_W = W_W, \qquad (4\text{-}2)$$

where the $\Delta$ means a change in energy. For example, in a gasoline car, the energy stored (as fuel) in the tank would be reduced by this amount. So, if $\Delta E_W$ of energy is <u>available</u> at the driven wheel, the range will be

$$S = \Delta E_W/T.$$

Power is the rate of doing work, so it is also the rate at which energy is expended. This means that Figure 5 of the Power and Speed instruction sheet can be used to find the energy needed to go a distance S. In order to use this figure, we will have to assume that the speed is constant over S. For design purposes, this is acceptable. Example 1 shows how to do this.

---

<u>Example 1</u>

Suppose we use the model car and conditions that were assumed for Example 3 of the Power and Speed instruction sheet. How much energy must be delivered to the driving wheel to travel 100 m at 1.0 m/s?

The tractive force obtained from Figure 5 for this speed was 0.015 N. The energy is therefore

$$\Delta E_W = T\ S = (0.015N)\ (100m) = 1.5\ N\text{-}m = 1.5\ J.$$

From Example 3 of the previous sheet we know that this energy was delivered at a rate of $P_W$ = 0.015 W, or 0.015 J/s. The time, $\Delta$ t, required to travel 100 m at 1.0 m/s is 100 s. So we are not surprised to learn that the energy expended is also equal to $P_W\ \Delta t$.

---

We would still like to know if there is enough energy available to supply $\Delta E_W$ to the driven wheel. The electric power system of the car is discussed briefly in Instruction Sheet 9. The system first converts radiant energy into electrical energy in the solar array, then the electrical energy is converted into mechanical energy in the motor, and finally the mechanical energy is transmitted to the driven wheel. In each of these three stages there is a loss, and the largest loss is in the solar array. To estimate the solar energy available at the driven wheel, we must guess at the fraction of it that remains after each stage of conversion. This fraction is the efficiency of each stage.

---

<u>Example 2</u>

Suppose, as before, the solar array has an efficiency of 0.05, the motor an efficiency of 0.90, and the speed reduction an efficiency of 0.95. Using the conditions of Example 3 of the previous instruction sheet, estimate the solar energy available at the driven wheel for an S of 100 m.

The gym lights give 300 W/m$^2$ and the array area is 12.2 cm$^2$. The overall efficiency to the wheel is $\eta$ = (0.05)(0.90)(0.95) = 0.043. The energy is

$$E_{WS} = G_S\ A_S\ \Delta t\ \eta_C$$

$$= (300\ W/m^2)\ (12.2 \times 10^{-4}\ m^2)(100\ s)\ (0.043) = 1.57\ J.$$

Enough energy is available.

---

For a model solar-electric car racing over a fixed distance indoors with a constant light source, the range problem doesn't really exist. It is simply a matter of making the car go as fast as possible. However, for a solar-electric commuter car, say, the objective might be to design the car so that a round-trip commute could be carried out without recharging from the electric utility grid. The design conditions would account for the charging availability of sunlight with time, both daily and seasonally. Charging from the electric utility grid would be required when the available solar energy dropped below the design value.

## Instruction Sheet 5

## Solar Energy

This instruction sheet outlines the calculation of the rate at which solar energy falls upon a surface (such as a solar cell array) of some orientation, on some day of the year, at some time of that day, and at the same location on Earth. **The instruction sheet uses the two program calculators: Solar Energy and Time Calculator and Angle of Incidence Calculator.**

The energy released by the nuclear fusion reactions within the sun is broadcast in the form of electromagnetic radiation distributed over wavelengths ranging from the ultraviolet to the infrared. Earth's atmosphere truncates this radiation below about 0.3 micron (1 micrometer, or "micron," is $1/10^{-6}$ m) and above about 3.0 micron and reduces its intensity between these wavelengths. The chemicals mainly responsible for these effects are ozone ($O_3$) in the ultraviolet and carbon dioxide ($CO_2$) and water vapor ($H_2O$) at longer wavelengths. More detail about the distribution of this radiation over wavelength (the "spectral distribution" of solar energy) in space and at the Earth's surface may be found in textbooks on solar energy, such as Reference B.9.

The energy ($Q_s$) is emitted at a rate of about $3 \cdot 83 \cdot 10^{26}$ W. The intensity ($W/m^2$) of solar radiation at the average radius of Earth's orbit ($1 \cdot 5 \cdot 10^8$ km) is called the "solar constant" ($G_{sc}$).

---

<u>Example 1</u>

Estimate the solar constant.

The area of a sphere of radius $1.5 \times 10^8$ km is

$$A = 4\pi R^2 = (4)(3.1416)(1.5 \cdot 10^{11}\text{m})^2 = 2 \cdot 83 \cdot 10^{23}\ \text{m}^2.$$

The radiation intensity is

$$G_{sc} = Q_s/A = 3.83 \cdot 10^{26} \cdot 2.83 \cdot 10^{23} = 1353\ \text{W/m}^2.$$

---

The actual intensity, $G_s$, may differ from the solar constant during the year mainly because Earth's orbit is slightly elliptical, with the sun at one focus. Reference B.9 gives an equation for calculating $G_s$ for any day of the year. It is

$$G_s = G_{sc}\ [\ 1 + 0.033\cos(\ 360n/365\ )\ ], \qquad (5\text{-}1)$$

where the argument of cos is in degrees and n is the serial day of the year. This equation shows that $G_s$ is a maximum at midnight on December 31 (n = 0), when it is 1399 $W/m^2$, and a minimum during June 29 (n = 182), when it is 1308 $W/m^2$.

We neglect the atmosphere for now and assume that the sun is point source of radiation, so that its rays are parallel. Suppose that on a certain day (n) a flat plate (of area A) is located at some latitude (L) on Earth (latitude is positive when north of the equator), is tilted at an angle (t) above the local horizontal plane, and is pointing (a) degrees west of due south (a, the surface azimuth angle, is positive when west of south). A line drawn perpendicular to the plate's surface would make an "angle of incidence" (i) with the incoming solar rays. The area of the plate intercepting solar radiation would be

$$A_p = A \cos(i). \qquad (5\text{-}2)$$

So the rate at which solar energy strikes the plate would be

$$Q = G_s A_p = G_s A \cos(i). \qquad (5\text{-}3)$$

---

Example 2

Suppose a solar cell purchased from Radio Shack is lying on flat ground at Potsdam, New York (longitude 75° W and about latitude 45°N) at noon Eastern Standard Time on June 15. The cell is 4 cm long and 2 cm wide. At what rate does the cell intercept solar energy?

From the Solar Energy and Time Calculator the solar time is approximately noon.

$$A = (.02\ \text{m})(.04\ \text{m}) = 8 \cdot 10^{-4}\ \text{m}^2.$$

Using the Angle of Incidence Calculator we find i = 21.6° and therefore

$$A_p = (8\text{x}10^{-4}\text{m}^2) \cos(21.6°) = 7.438 \cdot 10^{-4}\ \text{m}^2.$$

From equation (5-1) $G_s = 1310\ \text{W/m}^2$. The rate of energy intercept is

$$Q = G_s A_p = (1310\ \text{W/m}^2)(7.438\text{x}10^{-4}\ \text{m}^2) = 0.97\ \text{W}.$$

---

The sun's rays diverge from parallelism by only 16 minutes of arc, so for most purposes (including ours) they may be assumed parallel. Neglecting the atmosphere introduces a far greater error, so we will now consider the affect of the atmosphere on the calculation of the incident radiation.

Absorption of solar radiation by the atmosphere has already been mentioned. The remaining radiation is either transmitted directly ("beam" radiation) or transmitted after scattering by the gases and dust particles in the atmosphere ("diffuse" radiation). So the solar cell in Example 2 actually receives its solar energy from both of these transmission mechanisms.

The actual amount of each is impossible to predict at any moment because of weather conditions. One hour may be clear with mostly beam radiation and then the next hour may be overcast with only diffuse radiation, or some intermediate case may occur. Furthermore, the diffuse radiation may be distributed non-uniformly over the sky, as on clear days when it tends to peak near the sun.

Because we cannot know the actual solar energy conditions our design will experience, we must use average radiation values found from measurements carried out over periods long enough to establish reliable trends. The datum usually tabulated is the total (beam plus diffuse) radiant energy intensity summed for a month on a horizontal surface, divided by the number of days in the month. We will call this value ($\overline{H}$, kJ/($m^2$ - day)) the "average daily horizontal radiation." The average daily horizontal radiation for each month at many locations in the United States and Canada is reported in Reference B.7 and may also be found in solar energy engineering texts, such as B.9.

---

Example 3

What is the average rate of energy reception by the solar cell in Example 2, including the effect of the atmosphere, for the average day of June?

Potsdam is not one of the locations tabulated in Reference B.7 or B.9. Massena, which is about 30 miles north of Potsdam, is the nearest tabulated location. Assuming Massena's data apply to Potsdam, we find $\overline{H}$ = 20,190 kJ/($m^2$ - day).

The total energy received is

$$Q = \overline{H}\, A_p = (20{,}190 \text{ kJ/(m}^2 \text{ - day))}(7.422 \cdot 10^{-4} \text{ m}^2)$$
$$= 15.0 \text{ kJ}.$$

From the Solar Energy and Time Calculator we find the day length (N) for June 29 to be 15.37 h, or 55,332 sec. So the average rate of intercept is

$$Q = Q/N = 15.0 \text{ kJ}/55332 \text{ sec} = 2.70 \cdot 10^{-4} \text{ kW}$$
$$= 0.27 \text{ W}.$$

---

Equation (5-3) (and common sense) shows that the collected energy can be increased by tilting the solar cell toward the south, because this will make the angle of incidence smaller. (If the cell is moved so that i = 0 always, i.e., so that it "tracks" the sun, then the collected energy will be maximized.) If the cell is tilted, the collected energy calculation must account for the fact that it cannot now view the entire sky, so some of the diffuse radiation from the sky will not be collected, that it will also see radiation reflected from the ground in front of it, and that the

tabulated values we want to use were derived from measurements on horizontal surfaces.

We can express the ideas in the previous paragraph by writing the radiation on a tilted surface as the sum of three terms: a beam radiation contribution, a sky-diffuse contribution, and a ground-diffuse contribution.

$$\bar{H}_T = \bar{R}_B\bar{H}_B + \bar{R}_D\bar{H}_D + \bar{R}_G\bar{H} \qquad (5\text{-}4)$$

The first term is the beam radiation contribution. $\bar{R}_B$ is the monthly average beam tilt-correction factor and $\bar{H}_B$ is the beam radiation portion of $\bar{H}$. The second term is the sky-diffuse radiation contribution. $\bar{R}_D$ is the monthly average sky-diffuse tilt-correction factor and $\bar{H}_D$ is the diffuse portion of $\bar{H}$. The third term is the ground-diffuse radiation contribution. $\bar{R}_G$ is the monthly average ground-diffuse tilt correction factor; it is multiplied by $\bar{H}$ because the ground intercepts all of $\bar{H}$.

In order to arrive at estimates for $\bar{R}_B$, $\bar{R}_D$, and $\bar{R}_G$, we must model the physical situation. For this model we take a practical view. We assume that the diffuse radiation from the sky is uniform in all directions, that the ground reflects the total horizontal radiation uniformly in all directions, and that we can ignore the atmosphere when calculating $\bar{R}_B$. This model of course introduces error, as do all models. But it is satisfactory for design purposes.

In order to use equation (5-4) we must know how much of $\bar{H}$ is diffuse. The fractional amount of diffuse radiation can be related to the ratio of $\bar{H}$ to the monthly average daily total radiation computed at the same latitude and longitude and for the same month, but just outside the Earth's atmosphere. This ratio, the "monthly average clearness index" ($\bar{K}_T$), is tabulated each month with $\bar{H}$ in Reference B.7 and in texts such as B.9. Finally, it is often of interest to estimate the total, beam, and diffuse components of radiation for each hour of the average day of the month. A method of doing this was initially developed by B. Y. H. Liu and R.C. Jordan (B.10) and further developed by M. Collares-Pereira and A. Rabl (B.11). The method developed by these workers is also presented in B.9.

The forgoing information has been incorporated in the Solar Energy and Time Calculator.

---

<u>Example 4</u>

Suppose that the solar cell of Example 3 has been tilted 5° above the local horizontal and turned so that it points due south. The other conditions remain the same. Calculate the average rate of solar energy interception by the cell during the hour centered on noon, Eastern Standard Time. Assume the ground reflectivity is 0.2.

From Reference B.7 or B.9 we find $K_T = 0.481$, L = 44° 56′ N, and Lo = 74° 51′ W for Massena. ($H_B$, $H_D$, H have been replaced by $I_B$, $I_D$, and I to distinguish hourly from monthly average values.) Enter the Solar Energy and Time Calculator and find:

$I_B = 1437$ kJ/$m_2$; $I_D = 844$ kJ/$m^2$; $I = 2281$ kJ/$m^2$.

$R_B = 1.051$; $R_D = 1.0$ (approx.); $R_G = 0$ (approx).

So that the energy intercepted is

$I_T = (10.51)(1437) + (1.0)(844) + (0.0)(2281) = 2353$ kJ/$m^2$.

The average rate of intercept is therefore

$Q = (2.353 \cdot 106\ J)(7.437 \cdot 10^{-4}\ m^2)/(3600\ sec) = 0.32\ W$

Compare this value with the results of Examples 2 and 3.

---

Consider a solar-electric car traveling north on a horizontal road in the vicinity of Massena, New York, on the average June day. The car's array is shaped like an inverted, rectangular "U." The east and west sides are vertical with respect to the car and are 4 m long by 1 m high. The center portion is horizontal with respect to the car and is 4 m long by 2 m wide. The array is made of several hundred of the 4 cm x 2 cm Radio Shack solar cells connect in one of the ways to be discussed in Instruction Sheet 6.

To estimate the energy intercepted by the array during each hour of the day, sunrise to sunset, the procedure for Example 4 would be carried out for each segment of the array at the midpoint of each hour, using the programs provided. The results for the three segments would then be summed to give the total for the car for each hour. To test their comprehension of this instruction sheet's material, the students are invited to carry out this calculation without further assistance.

## Instruction Sheet 6

## Solar Cells

Solar cells are thin, translucent wafers of special materials which, when exposed to sunlight and connected to a load such as a light bulb, produce a one-directional electric current (DC, or "direct current"). This is called the "photovoltaic effect" (or the "photoelectric effect"). The material most commonly used to make solar cells is silicon, which is found in beach sand.

Solar radiation may be thought of as traveling in small bits called "photons." Photons move at light speed and their energy is directly proportional to the radiation's frequency; they could be thought of as "light bullets." When a bullet strikes something, say an apple on its tree, it may have enough energy to do the work necessary to break the stem of the apple and remove it from the tree.

Suppose we think of the electrons in a silicon atom as the "apples." They are bound to the "tree," or nucleus, by a "stem" made of the electrostatic attraction between the positive nucleus and the negative electrons. If a photon with sufficient energy (high enough frequency) strikes an electron, the electron will be freed from the atom. The vacant electron orbit is called a "hole." The silicon atom then has a net positive charge equal to the magnitude of the electronic charge and is called an "ion." The positive charge may be thought of as belonging to the hole.

The free electron will wander until it finds a hole and falls in, or "recombines," becoming bound to another atom. Thus holes and free electrons appear and drift through the material, though in opposite directions. This is similar to jumping a piece in checkers, and then replacing that piece by your own piece from a location nearer to you; the vacancy, or "hole," on the board moves toward you.

What is needed is a way of separating the charges so that the electrons may be collected and forced to flow through an external circuit and do work before they return to the cell and recombine with the holes.

Charge separation is produced by placing "p-type" silicon, in which the majority of charge carriers are positively charged holes, on one side of a very thin junction region and "n-type" silicon, in which the majority of charge carriers are negatively charged free electrons, on the other. These two kinds of silicon are produced by putting specially selected impurities into the pure silicon by a process called "doping."

Holes diffuse across the junction into the n-type material because there are more holes on the p-type side than on the n- type side. For the opposite reason electrons diffuse across into the p-type material. The diffusion continues until a local net

positive charge builds up on the n-type side and a local net negative charge builds up on the p-type side. This creates an electrical potential barrier, or voltage, which opposes the diffusion of both species and eventually stops it.

Suppose the n-type material is on the illuminated side, the top. Thin metal strips called "electrodes" are bonded to the top (they have to be sparse because this is the illuminated side) and the back of the cell is completely "metallized," or covered by its electrode. Figure 1 illustrates this.

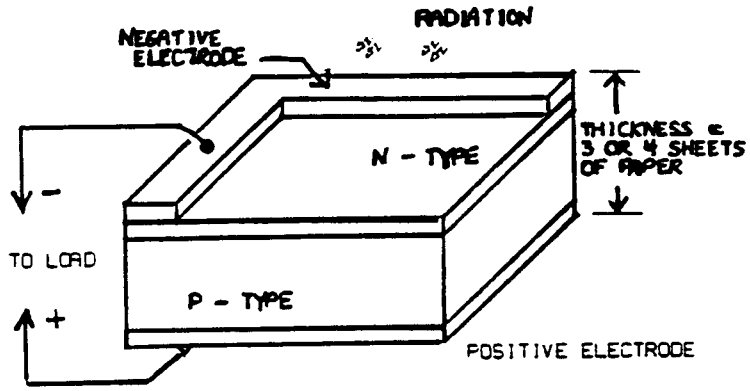



Figure 1

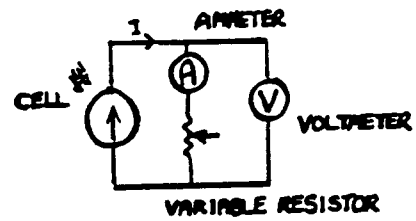
When the cell is illuminated, the free electrons in the p-type material are swept into the n-type material by the barrier potential and join the free electrons already on that side to flow to the top electrodes, which become negatively charged. Because the holes have positive charges, they are swept in the opposite direction by the barrier potential to the bottom electrode, which becomes positively charged. Just as in the case of the junction barrier potential, this migration continues until enough charge has been collected on the electrodes to prevent further migration (a very rapid process). Further ionizations are balanced by recombinations.

The voltage produced across the electrodes is called the "open circuit voltage" ($V_{oc}$) because no electrical load is connected to the cell. $V_{oc}$ is the largest voltage that the cell can produce. This is the voltage that would be measured by a voltmeter connected to the terminals of a cell. $V_{oc}$ is nearly independent of irradiation, but decreases slowly as the cell's temperature increases. At 25°C, $V_{oc}$ is about 0.6 VDC for silicon.

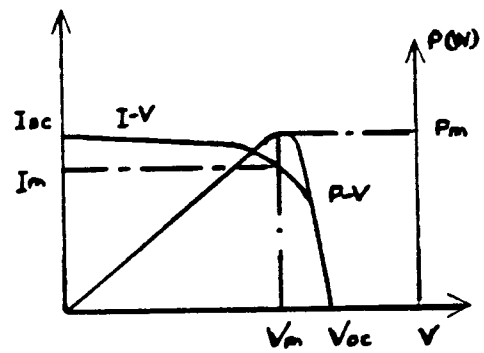
If the positive and negative terminals of the cell are connected together, the short circuit current ($I_{sc}$), the largest current that the cell can produce, will flow. This current can be measured by connecting an ammeter across the terminals of the cell. $I_{sc}$ is directly proportional to the intensity of the irradiation, or for a given irradiation it is directly proportional to the area of the cell. The proportionality constant for a unit area of a cell is called the "sensitivity" ($S_{sc}$, A/W).

If you purchase a cell from Radio Shack, the $V_{oc}$ and $I_{sc}$ for a cell temperature of 25°C and an irradiance (normal to the cell) of 1000 $W/m^2$ are printed on the package containing the cell.

Suppose that we connect a variable resistor, a voltmeter, and an ammeter as a cell, shown in the sketch below.




Keeping the irradiance constant, we increase the resistance from a low value to a very high value, reading the ammeter and voltmeter after each change. We then plot the measurements with the current on the vertical axis and the voltage on the horizontal axis. The resulting curve, called an I-V characteristic, is shown below.




The power (P) delivered to the resistor is equal to the product of the voltage (V) and current (I); this is the rate of delivery of electrical energy to the resistor. If we plot the power as a function of voltage we get a curve similar to the power curve shown in the sketch above. It is zero at both the short circuit and open circuit points and has a maximum at the knee of the I-V characteristic at about 0.5 VDC.

When possible, the cell should be operated near the maximum power point, where the rate of conversion of the incident solar energy into electric energy is a maximum. The fraction [ energy delivered over an interval ]/[ energy collected over the interval ] is called the cell efficiency. The efficiency is a maximum at the maximum power point.

**The examples which follow can be resolved using the Solar Cell Calculator.**

---

Example 1

Our model solar car design calls for a flat array. We plan to test the car in our school's gym and so we measure the horizontal radiation near the gym floor when all the lights are on as 300 $W/m^2$. The solar cells available to us have $I_{sc}$ = 0.06 A at 1000 $W/m^2$ and $V_{oc}$ = 0.6 VDC at 25°C. What will $I_{sc}$ be under the gym's lighting conditions?

$I_{sc}$ is directly proportional to the radiation level. The gym lighting's spectral distribution is not the same as that of solar radiation, but we assume that the difference is not significant. So $I_{sc}$ = (300/1000)(0.06) = 0.018 A is our estimate.

---

Suppose we measure the $V_{oc}$ of two identical cells under the same conditions using the previously outlined method. Then we connect the positive terminal of one cell to the negative terminal of the other cell; this is called a "series" connection. Then if we connect a voltmeter between the positive terminal of the second cell and the negative terminal of the first cell we read twice the $V_{oc}$ of a single cell. But if an ammeter is connected to measure $I_{sc}$, we find it to be the same as for a single cell. The voltages of cells in series add, but the current through each cell is the same.

Now we measure the $I_{sc}$ of each cell. Then we connect the positive terminals of the cells together and the negative terminals of the cells together; this is called a "parallel" connection. Now we measure $I_{sc}$ by connecting an ammeter between the joined positive terminals and the joined negative terminals. The meter reads twice the current of a single cell. But if $V_{oc}$ is measured with the voltmeter it is the same as for a single cell. The currents of cells in parallel add, but the voltage across each cell is the same.

---

Example 2

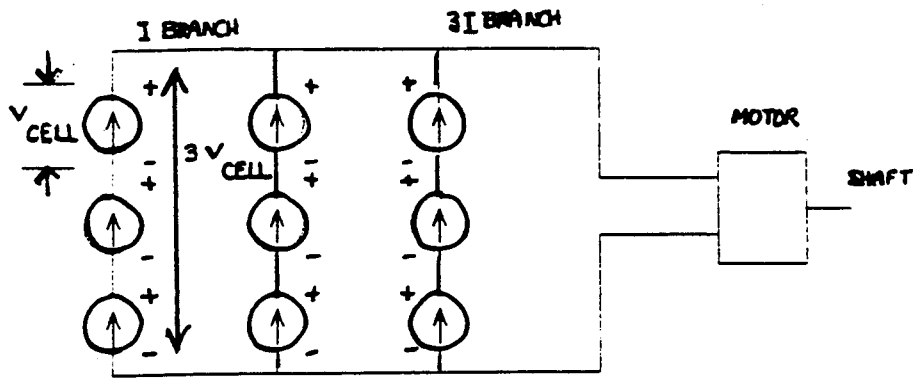
Assume that it has been estimated, using Instruction Sheet 3 and the Speed and Power Calculator, that the small DC electric motor with which we will power our model car requires 1.5 VDC at 0.05 A (0.075W) to move the car at 1.0 m/s across the gym floor. How many of the solar cells of Example 1 will it take to power the motor?

Our approach will be first to estimate the number of cells using $I_{sc}$ and $V_{oc}$, and then to show a more precise way of checking the result.

Our cells can produce 0.6 VDC, maximum. So we must string some cells in series to get 1.5 VDC. The number in series will be greater than 1.5/0.6, or 2.5. Round this up to 3, because only whole cells are possible.

This string of three cells in series can produce 0.018A, maximum, under the gym's lighting conditions. It will be necessary to connect some three-cell strings as parallel branches to get the current we need. The number of branches will be greater than 0.05/0.018 = 2.77. Round this up to 3. There are three branches with three cells per branch, so nine cells are required.

The drawing below shows how the cells are connected; the arrangement is called an "array."




The array may be regarded as one big cell with $I_{sc}$ = 0.054 A and $V_{oc}$ = 1.8 VDC. As we did earlier for the single cell, we can measure and plot the I-V characteristic of the array, but in the gym lighting.

Ohm's Law for a DC circuit states that the voltage is directly proportional to the current; the constant of proportionality is called the "resistance." The equivalent resistance of the motor ($R_{motor}$) at the design point is (1.5 VDC/(0.05 A) = 30 Ohms. We can represent the motor by its "load line," a straight line drawn on the I-V plot. For more detail, see Instruction Sheet 9.

The intersection of the load line and the I-V characteristic establishes the operating point (voltage and current) of the solar cells and the motor.

The I-V characteristic, the load line, and the operating point are illustrated in Figure 2 below. If the actual curves are similar to those illustrated, then the operating point will be close to 1.5 VDC and 0.05 A, and near the maximum power point--a bonus.

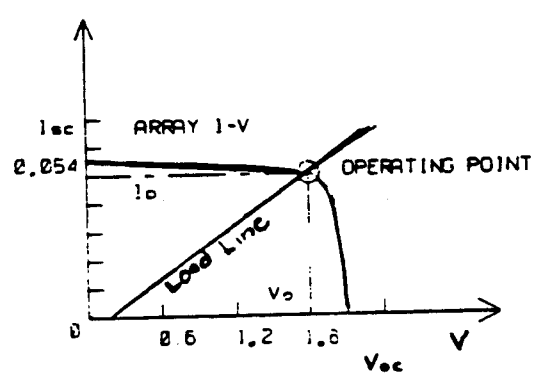
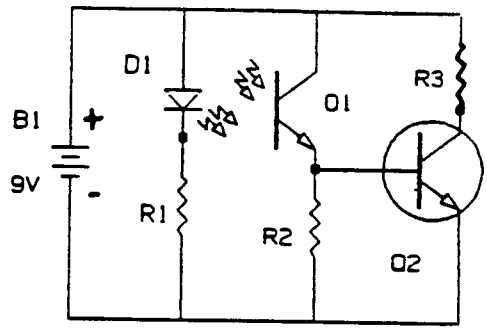



Figure 2

**Instruction Sheet 7**

**Speed Sensing**

SPEED SENSING CIRCUIT




The parts below are available from Radio Shack - R.S. # given.

| | | |
|---|---|---|
| D1, Q1 | - | (R.S.# 276-142 $ 1.99) IR (InfraRed) set |
| Q2 | - | (R.S.# 276-2009 $ 0.59) 2N-2222 or equivalent NPN |
| R1 | - | (R.S.# 271-1317 $ 0.39/5 pack) 470 Ohm, 1/4 Watt |
| R2 | - | (R.S.# 271-1335 $ 0.39/5 pack) 10 k-Ohm 1/4 Watt |
| R3 | - | (R.S.# 271-1321 $ 0.39/5 pack) 1 k-Ohm 1/4 Watt |
| B1 | - | 9 V transistor radio battery (with connector) |

(Suggestion: Mount all pieces on a small solderless breadboard such as Radio Shack #276-175 ($ 7.49) or equivalent)

NOTES:

1. Solder two extra lengths (about 2") of #22 solid copper wire to the leads of D1 and Q1. Be careful not to overheat these parts.

2. Mount D1 and Q1 inside a small, blackened tube such as a drinking straw. Epoxy them inset from the edge of the tube so that the IR light beam from D1 will focus on the base of Q1 more readily. Separate the tubes about three to four times the propeller thickness that will pass between them.

3. Test the circuit by connecting an oscilloscope to the circuit as follows: (+) probe between R3 and collector of Q2, (-) or ground lead to (-) terminal of battery B1. Set the oscilloscope vertical input to 5 volts/cm and the sweep to 2 mS/cm. Pass a pencil between the tube openings so that the IR light beam is broken. This will cause the transistor Q1 to turn off and, in turn, Q2 to turn off and on again. The result will be evident on the oscilloscope display as a rapid rise and decay.

4. With the motor running (and propeller spinning, cutting the light beam) the oscilloscope should display a square wave pulse. You may have to adjust the oscilloscope's vertical and horizontal controls to get the best display.

5. A full revolution is counted on every other rise or decay of the waveform. Count the number of divisions (cm) horizontally from the first rise to the third rise. Multiply this distance by the sweep time (in mS/cm). This gives the time it takes to complete a full circle or revolution. Inverting this value gives the speed of the motor in revolutions per second (NO LOAD SPEED).

---

Example

Distance between Rise 1 and Rise 3 is 6.2 cm. The time base (sweep) is set on 2 mS/cm.

The time is: (6.2 cm) ( 2 mS/cm) = 12.4 mS per revolution

The speed is: 1/(0.0124 seconds per revolution) = 80.65

revolutions per second (RPS) or (80.65 RPS) (60 seconds per minute)

= 4,839 RPM

## Instruction Sheet 8

### Batteries

Electric batteries are devices that store electric energy for later use. All gasoline-powered cars employ batteries to provide power for starting the engine, and for running auxiliary systems, such as the radio, when the engine is turned off.

Only in solar-electric and electric vehicles is the battery used for propulsion. If the power the motor needs to move the solar-electric car is less than the power available to the motor from the solar array, then the excess power is stored in the battery. If the power available from the solar array is less than that required by the motor, then the battery discharges to make up the difference.

A battery is made of a positive electrode, a negative electrode, and an electrolyte. External connections are made to the electrodes. The electrodes are immerse in the electrolyte, which may be liquid or solid. If solid, the battery in Figure 1 is called a "dry cell;" if liquid it is called a "wet cell." The sketch in Figure 1 shows how a battery would be connected to a DC motor.

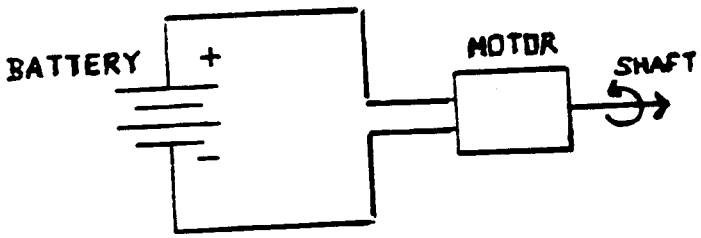



Figure 1

A battery stores electric energy by storing charge chemically at a certain electric potential, or voltage, between the electrodes. The voltage is characteristic of the electrodes and the electrolyte, or "couple." When charging, the chemical reactions between each electrode and the electrolyte proceed in a direction that requires electrons from an external source. When discharging, the reactions release electrons to the external load.

The calculations that follow can be resolved using the Battery Calculator.

---

<u>Example 1</u>

Suppose a battery is charged at an average current of 5 A for 10 hours at average cell voltage of 2 V. How much energy has been stored?

Rate of storage (from Watt's Law) = (5 A)(2 V) = 10 W.
Amount stored = (10 W)(10 h) = 100 W-h.
Or because 1 W = 1 J/s,
Amount stored = (10 J/s)(10 h)(3600 s/h)(1 kJ/1000 J)
= 360 kJ.

The W-h ("Watt-hour"), or kW-h ("kilowatt-hour"), is a commonly used unit of energy. Your home's electric bill is calculated according to how many kW-h you use.

---

When a battery is discharged only a portion of the stored energy can be recovered because of internal losses. These are manifest as a lower cell voltage when discharging. The ratio of the rate of energy discharge to the rate of energy charge at the same current and over the same interval is the battery's average efficiency.

---

Example 2

The battery of Example 1 is discharged for 10 h at an average rate of 5 A and an average cell voltage of 1.6 V. What is the battery's average efficiency and how much energy was recovered?

Efficiency = [ (1.6 V)(5 A) ]/[ (2 V)(5 A) ] = 0.8 or 80%.

Energy recovered = (1.6 V)(5 A)(10 h) = 80 W-h.

---

The depth of discharge (DOD) of some types of cells is limited to prevent damage to the cell when it is near total discharge. A typical limit for common lead-acid batteries is DOD = 0.8, or 80 %. So if this limit were to apply to the cell of Example 2, the net result would be that only about (0.8)(0.8) = 0.64 or 64% of the originally charged energy could be recovered.

A characteristic of batteries that is very important in solar car design is the energy stored per unit battery mass ($e_B$, W-h/kg). A battery type that has a high $e_B$ can store more energy for a given mass, or weight. Thus the solar-electric vehicle using this battery will have a longer range. The table below gives the energy densities of some battery couples and also of gasoline, for comparison.

| Storage | $e_B$ (W-h/Kg) |
|---|---|
| gasoline | 400 |
| zinc-air | 160 |
| sodium-sulfur | 100 |
| nickel-hydrogen | 50 |
| lead-acid | 25 |

These figures show the large gap remaining to be closed between batteries and gasoline.

Because of the energy efficiency problem, battery capacity is often given on an electric charge basis, rather than on an energy basis. This measure of capacity is the same for charge and discharge. For example, fully charging some battery at an average rate of 5 A for 10 h will store 50 A-h of electric charge (180,000 Coulomb) in the battery.

A battery's capacity decreases with the number of charge-discharge cycles it has experienced, referred to as the battery's "age." The capacity is also lower at high discharge rates than at low discharge rates. So capacities are usually quoted at some standard rate of discharge. Rather than mentioning the actual rate, the time required to completely discharge the battery will be given instead, for example "the capacity is 25 A-h at the 10 h rate." This rate would be 2.5 A.

Like solar cells, storage batteries can be connected in series to get more voltage and in parallel to get more current. The method of connection is the same as that described in Instruction Sheet 7.

---

Example 3

Small, AA-size rechargeable nickel-cadmium cells may be purchased locally. The cells are rated at 1.25 VDC and 0.045 A. At this rate the cell can discharge for 14 h, and no DOD limit applies. What is the capacity in A-h?

The capacity would be (0.045 A)(14 h) = 0.63 A-h ("0.63 A-h at the 14 h rate").

How many of these would be necessary to power the motor of Instruction Sheet 6, Example 2, if the 14 h rate is to be used? (This implies that we want the car to run for 14 h without recharging.)

The number in parallel would be 0.05/0.045 = 1.11. This would mean two branches. But if we are willing to discharge at 0.05 A, the battery would last for 12.5 h and one branch could be used. This would save weight, a very important thing to do when designing solar-electric cars.

The series "string" would consist of one battery, and so the total number is one. Otherwise, with two in series and the array in parallel with the battery (see Instruction Sheet 6, Figure 10)), the array would be held at open circuit. In this case, the batteries are not a good match to the motor, because it will have to work at a lower voltage.

## Instruction Sheet 9

## Solar-Electric Power System

The electric system of the car is composed of the solar array, the battery, and the motor. The purpose of this instruction sheet is to explain how these devices operate together to propel the car.

Figure 1 shows the electric circuit that interconnects the power system. (The solar cell array is represented by one cell for simplicity.) The battery and the array are wired in parallel with the motor so that either one can serve as a source of motor current, and so that the battery can be charged by the array.

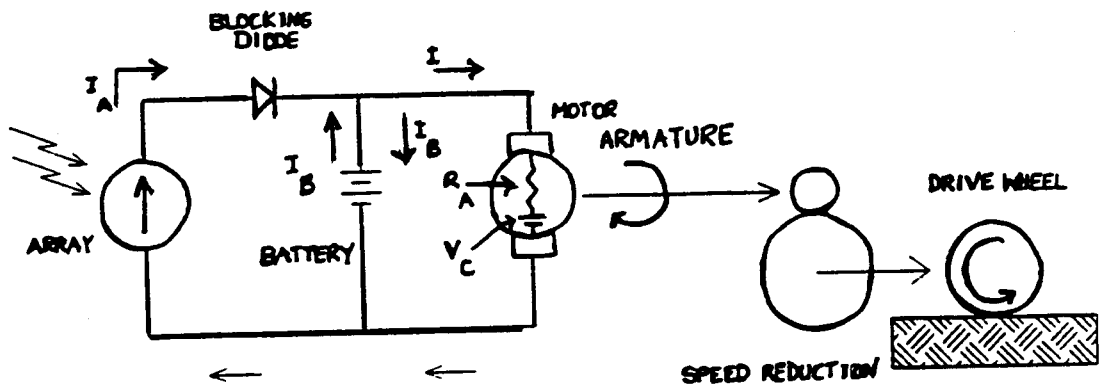



Figure 1

Two unfamiliar components have been drawn: a blocking diode and a speed reduction mechanism.

The blocking diode is a small electric device that allows current to flow only in the direction shown on its symbol by an arrow. Placed as shown, the diode prevents current from flowing backwards through the array (instead of to the motor) when the battery discharges.

The two gears between the motor armature and the wheel reduce the rotational speed of the drive shaft from that of the motor to that required by the wheel. The speed of the car is directly proportional to the rotational speed of the drive wheel. If the motor's rotational speed is 4000 rpm and the diameter of the larger gear is four times that of the smaller one, the rotational speed of the wheel will be 1000 rpm. The speed reduction also increases the torque delivered to the driving wheel by the same ratio (assuming no frictional losses in the reduction).

---

<u>Example 1</u>

A model solar-electric car is to be designed to travel 1.0 m/s and 1.0 W must be delivered to the drive wheel to do this. The car will use 5-cm diameter wheels ($D_W$). A small motor from Radio

which delivers 1.1 W at its maximum rotational speed of 4000 rpm (a torque of 2.63 ($10^{-3}$) N-m). This is also the motor's most efficient rotational speed; at lower speeds the torque is higher, but the efficiency is lower. Should this motor be used? And if it is used, what should the speed reduction be?

The motor should be used at its most efficient speed; this will keep the power it requires from the array or the batteries at a minimum. The motor power is 10% greater at 4000 rpm than that required by the car, so if the losses in the speed reduction are no greater than 0.1 W, this motor will serve. That is, the efficiency (output over input) of the reduction must be at least (100 x 1)/1.1 or 90.9%. Suppose that this is possible. The rotational speed of the wheel at 1.0 m/s is

$$N_W = v/(2\pi D_W) = 1.0 \text{ m/s} \quad /(2 \times 3.1416 \times 0.05 \text{ m})$$
$$= 3.18 \text{ rps}$$

The total reduction ratio must be

$$\text{reduction} = (4000 \text{ rpm})/(3.18 \text{ rps} \times 60 \text{ sec/min}) = 20.96$$

The torque delivered to the wheel will be

$$\tau = (20.96)(2.39 \times 10^{-3}) = 0.05 \text{ N-m}$$

at least, if the efficiency of the reduction is at least 90.9%. At a wheel diameter of 0.05 m and a speed of 1.0 m/s, this is the torque required to deliver 1.0 W to the driven wheel.

---

The current, I, required to produce a certain torque at a particular rotational speed, N, may be found from equation (2-5) of the Instruction Sheet 2 as follows:

$$I = ( V - V_C )/R_A. \qquad (9\text{-}1)$$

$V_C$ is fixed at a particular N for a given permanent-magnet motor, and $R_A$ is also fixed for a particular motor. For this case equation (9-1) describes a straight line -- the I-V characteristic or "load line" of the motor at N rpm, with a slope of $1/R_A$. This load line has been drawn on the I-V characteristic of the solar cell array shown on Figure 2 below for three different rotational speeds, $N_1$, $N_2$, and $N_3$.

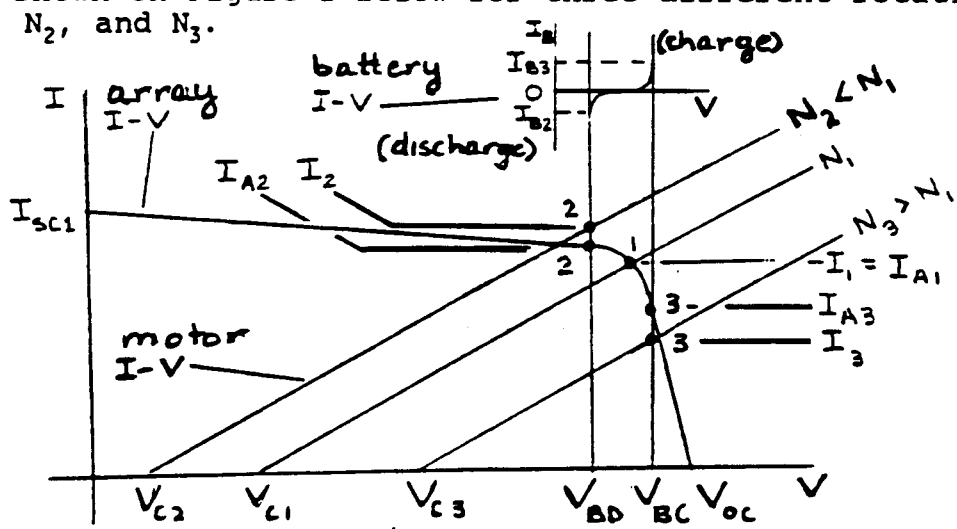


Figure 2

Also drawn is the battery's terminal voltage when it is discharging, $V_{BD}$, and when it is charging, $V_{BC}$. A small battery I-V curve appears above these limiting battery voltages. Recall that the same voltage is impressed on the array, the battery, and the motor, because they are connected in parallel and recall that torque is proportional to armature current.

The wires interconnecting the three components are usually called the "bus." Suppose that the intersection of load line 1 with the array's I-V curve represents the operating point for a steady speed $V_1$ on a horizontal surface under constant lighting conditions. The power demanded is $I_1V_1$. The battery is "floating on the bus," neither charging nor discharging.

Now suppose the car begins to climb a hill; more power is required to maintain $v_1$. But the speed drops because the solar power input is constant. If more torque (current) is required than can be supplied by the array, the bus voltage will drop until it reaches $V_{BD}$ and the battery begins to dischrge. The motor current is now supplied by both the array and the battery, each operating at its respective point 2. The power delivered to the motor equals the demand, $I_2V_{BD}$.

$$I_2 = I_{A2} + I_{B2}. \qquad (9\text{-}2)$$

Now suppose the car passes the top of the hill and starts down the other side. Initially, less power and torque are required than is available from the sun. So the car speeds up, gradually increasing the power demand, the bus voltage rises and may reach $V_{BC}$, then the battery is charged by the array at operating point 3 and the extra solar energy is stored for later use. The motor current now is

$$I_3 = I_{A3} - I_{B3}, \qquad (9\text{-}3)$$

and the power is $I_3V_{BC}$.

Figure 3 illustrates what happens when the solar input is increased. The car is presumed to be operating on a horizontal surface at steady speed, originally. The original radiation level gives a short circuit current $I_{SC1}$, as shown. The increased sunlight produces a situation similar to going down a hill: the power available initially exceeds the power required. The speed increases, shifting the load line to the right until the increasing power demand balances the available power. As shown, this new operating point may allow battery charging.

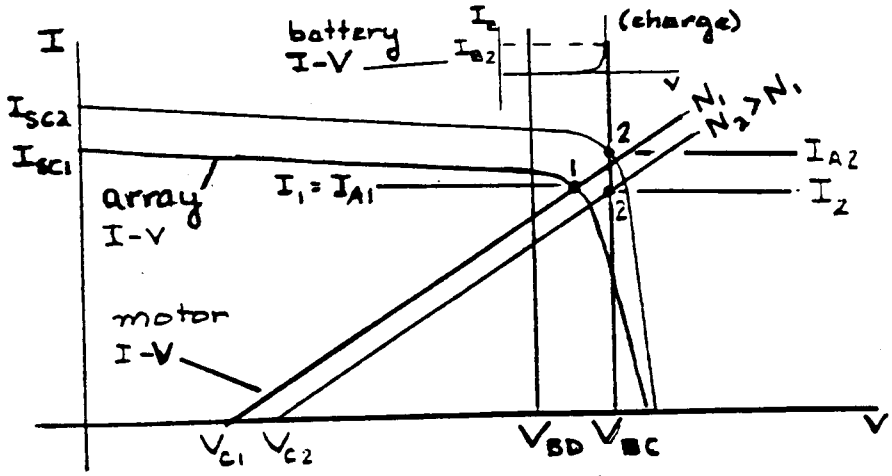



Figure 3

A reduction in the sunlight has an effect similar to going up a hill. Students can work this out for themselves using the forgoing explanation as a guide.

B. Books

1. Jr. Solar Sprint, A National Solar-Powered Model Car Competition for Science Students Grades 7 and 8.
Contact:

Marti Hahn
Argonne National Laboratory
Building 362-2B
9700 South Cass Avenue
Argonne, IL 60439
(708) 972-6489

The free information from this source will be helpful in planning competitions.

2. Celebrating the Sun! Building and Racing Solar Model Boats and Cars, by William S. Glazier, Ph.D ($2.00)
Contact:

William S. Grazier
Green Pastures Power Company
MANNA Corporation
1728 Rt. 198
Woodstock, CT 06281
(203) 974-3910

Dr. Glazier also stages solar-powered model boat, car, and airplane races.

3. Photovoltaics: A Manual for Design and Installation of Stand-Alone Photovoltaic Systems, by Steve McCarney, Ken Olson, and Jonny Weiss ($35.00)

Contact the authors at:

Colorado Mountain College
3000 County Road 114
Glenwood Springs, CO 81601

Also for sale at:
Sunnyside Solar
RD4 Box 808
Green River Road
Brattleboro, VT 05301
(800) 346-3240

A sensible, hands-on manual which gives the basics of solar cells with a minimum of solid-state physics.

4. Stand-Alone Photovoltaic Systems, A Handbook of Recommended Design Practices, SAND87-7023, Photovoltaic Design Assistance Center, Sandia National Laboratories, Albuquerque, NM.

   Contact:

   National Technical Information Service
   U.S. Department of Commerce
   5285 Port Royal Road
   Springfield, VA 22161

   Similar to 3., but contains short case studies.

5. Solar Energy Experiments, by Prof. Willis H. Thompson
   Contact:

   American Solar Energy Society
   2400 Central Avenue, Suite B-1
   Boulder, CO 80301
   (303) 443-3130

   Contains experiments on solar collector optics and solar cells.

6. Solar Hydrogen, Moving Beyond Fossil Fuels, by Joan M. Ogden and Robert H. Williams ($10.00)
   Contact:

   World Resources Institute
   1709 New York Avenue, NW
   Washington, DC 20006

   A comprehensive summary of the case for converting the energy base to solar-generated hydrogen, including transportation.

7. Insolation Data Manual, by Connie L. Knapp, Thomas L. Stoffel, and Stephen D. Whitaker, SERI/SP-755-789, October 1980.
   Contact:

   Superintendent of Documents
   U.S. Government Printing Service
   Washington, DC 20402

   Gives long-term, monthly averages of solar radiation (and other information) for 248 National Weather Service stations.

8. Solar Energy Classroom Materials (lesson plans, handouts, experiments, etc.) ($8)

   Contact: SoftSwap (see C.1., below for address and telephone number)

9. Hsieh, J. S., Solar Energy Engineering, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1986 ($71)

A college-level textbook on solar energy suitable for a teacher's reference book or as a text for advanced study.

10. Liu, B.Y.H., and Jordan, R.C., "Availability of Solar Energy for Flat-Plate Solar Heat Collectors," in Applications of Solar Energy for Heating and Cooling of Buildings, R.C. Jordan and B.Y.Y. Liu (eds.), American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia, 1977.

A book written for professionals in the field and useful as a teacher's reference or for advanced study.

11. Collarea-Pereira, M., and Rabl, A., "The Average Distribution of Solar Radiation--Correlations between Diffuse and Hemispherical and between Daily and Hourly Insolation Values," Solar Energy, 22, p. 155, 1979.

An article in a technical journal useful as a teacher's reference or for advanced study.

12. Steeds. W. The Dynamics of Road Vehicles. London: Iliffe & Sons, Ltd. 1960.

C. Videotapes and Software

1. "Racing with the Sun," GM SunRaycer's design, construction, test, and 1987 Word Solar Challenge performance ($24)
Contact:

SoftSwap
P.O. Box 271704
Concord, CA 94527-1704
(415) 685-7289

2. "Disk I: Construction Set," interactive design of solar-powered vehicle. (5 1/4-in, single-sided disk for 64K Apple) ($10)
Contact: SoftSwap

3. "Disk II: Solar Tutorial and Driving Simulation." (5 1/4-in, double-sided disk for 64K Apple) ($10)
Contact: SoftSwap

D. Computer Program

1. Physical Motion Calculators (drag, speed, tractive force, range, and energy)

2. Solar Cell Calculator

3. Solar Energy and Time Calculator

4. Angle of Incidence Calculator

5. Battery Calculator

## E. Equipment and Materials

1. SOLAR CELLS

   a. Radio Shack #276-113 ($5.95) includes battery circuit information.

   b. Radio Shack #276-124 ($3.95), a 2 x 4 cm cell delivering about 0.3 A at 0.55 VDC in full sun.

   c. Radio Shack #277-1201 ($10.95), a kit including one cell wired to a small DC motor, and an idea booklet.

   d. Edmund Scientific has several types and configurations of cells for sale, phone orders (609) 573-6250

   e. DIGIKEY has a wide selection of Panasonic Sunceram II series cells in a wide range of voltages and amperages starting at ($2.49). Bulk pricing is available.

      Contact:

      DIGIKEY
      701 Brooks Ave. South
      P.O. Box 677
      Thief River Falls, MN 56701-0677
      (800) 344-4539

2. SMALL ELECTRIC MOTORS

   a. Radio Shack #273-223 ($0.99) 8300 max. rpm, low voltage (1.1 vdc.)

   b. Radio Shack #273-255 ($2.99) 15,200 max. rpm, 12 VDC

   c. Edmund Scientific has many types of small DC motors for sale

3. ADDITIONAL MATERIALS

a. Volt-Ohm-Millimeter

b. Light meter

c. Fischertechnik equipment with computer interface or speed sensing circuit

d. Oscilloscope (for speed sensing circuit)

e. Computer

f. Computer calculator programs for this study

g. Spring scale

h. Model solar vehicle competitions

i. Variable power supply 0-10 V, 2 amp

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