CHAPTER 33

ERGONOMICS

4 AM, March 28, 1979

During the first minute of a loss of coolant accident at Three Mile Island, 500 or more lights go on and off; during the second minute, more than 800 lights are illuminated. Operators incorrectly diagnose the problem: for more than 2 hr, they do not recognize that they have too little cooling water; they think they have too much. Instead, the reactor was boiling dry. Investigations after the accident reveal many problems of questionable design in control rooms. For example, two digital controllers are side by side and look exactly alike. The left one concentrates borated water and the right one dilutes it. The operator has to remember that the decimal point is one digit before the end digit on the left controller and one digit after the last digit on the right controller. Another example is two auxiliary feedwater meters. One labeled A is on the left; one labeled B is on the right. There are two related switches, labeled A and B. However, switch A is on the right and B is on the left.[1]

May, 1979, to May, 1980

Four women working with visual display terminals (VDTs) at the *Toronto Star* all delivered fetuses with different birth defects. Four co-workers who did not work with VDTs gave birth to normal, healthy babies during the same period. This observation of a cluster of miscarriages raised the continuing question: are their dangers working at VDTs? The answers have not satisfied everyone. Whereas one of every six pregnancies ends in miscarriage, to date, there seems to be no direct relationship to VDTs, even though workers still discover miscarriage clusters. The use of computers in office and other work continues to grow tremendously. The question of miscarriages among office workers has focused a lot of attention on VDT workstation problems and has produced design and ergonomic solutions for office workstations.

June, 1988

OSHA proposed a $3.1 million penalty against a meat packing company that was charged with willfully ignoring a serious health hazard that had injured hundreds of employees. The health hazard covered cumulative trauma disorders, including carpal tunnel syndrome. Because OSHA had no particular standards on ergonomics, the agency later agreed on a smaller fine and required the company to conduct research into ergonomic aspects of their workplace.

Safety and Health for Engineers, Second Edition, by Roger L. Brauer

January, 2004

In an unusual action, the U.S. Congress passed a law rescinding the ergonomics standard established by OSHA. After completing extensive hearings and several attempts at an ergonomics standard, OSHA had approved a standard to deal with repeated motion and musculoskeletal disorders. Many companies believed that the standard imposed liability and excessive government intervention and lobbied Congress for action.

33-1 INTRODUCTION

Definition

Ergonomics has become a major element of safety. Approximately one third of all workers' compensation claims involve repetitive motion disorders or cumulative trauma disorders. Some estimate that such claims will climb to one half before long. Ergonomics is much broader than safety and health. It addresses job performance and the ability of people to perform tasks. It extends to preferences and choice, which are important in marketing.

Ergonomics comes from the Greek words *ergon*, meaning work, and *nomos*, meaning law. Ergonomics means the laws of work. It may be defined also as the relationships between people and a variety of things: equipment, environments, facilities, vehicles, printed materials, and other informational media. Ergonomics relates human capabilities and limitations to the design of products, systems, and environments. In the field of ergonomics, there are three major kinds of relationships, which are somewhat interrelated: performance, safety and health, and satisfaction. Performance attempts to extend the abilities of a person by improving output and reducing errors. The safety and health relationship attempts to minimize accidents and injuries resulting from human limitations. Satisfaction involves designing things that people judge as comfortable, desirable, convenient, and pleasing.

Ergonomics is applied through design. Consequently, designers must understand human behavior, physiology, kinesiology, biomechanics, and other fields that study the characteristics of humans. Designers apply human characteristics in creating workplaces, furniture, vehicles, buildings and equipment, and informational products for human use. Designs must reflect normal operation, foreseeable misuses, and maintenance and repair. Ergonomics data contribute to all of these.

Ergonomics, human factors engineering, and human engineering are virtually the same, although some people may argue over subtle differences. Ergonomics in building design sometimes is called architectural psychology or environmental design.

History

To a great extent, ergonomics developed out of aviation and other military matters in World War II. Critical tasks in flying an aircraft required effective presentation of information and error-free operation of controls. Today, ergonomics has become a fairly common term and its application continues to grow. Circa 1980, the application of ergonomics to the office environment paralleled the growth of microcomputers, and circa 1985, ergonomics started to gain more attention in occupational safety because claims for cumulative trauma disorders grew rapidly.

Applications in This Book

Many previous chapters discussed hazards, injuries, and controls that involve ergonomics. For example, Chapter 7 discussed warnings and other chapters contributed information about signs. Chapter 11 discussed design of floors, stairs, ladders, and handholds; Chapter 13 included a review of cumulative trauma disorders and design of tools and machines that incorporate ergonomic features; Chapter 15 covered manual materials handling and prevention of lifting injuries; Chapters 18 through 20 covered human aspects of thermal conditions, pressure, and lighting. Not only is health a concern in hot and cold environments, so is performance. Altitude and high pressure environments impact human performance and impose dangers. People cannot function if lighting is inadequate. Both quantity and quality of light affect performance, and reduced performance and errors may lead to accidents. Chapter 23 covered noise and vibration, both of which impact performance and safety, and Chapter 28 reviewed personal protective equipment, where ergonomics is an essential element in proper and comfortable fit.

This chapter discusses major areas of the field of ergonomics and considers safety and health applications of these areas, which include anthropometry, displays and controls, work physiology, and biomechanics. The bibliography at the end of the chapter provides additional ergonomics references and data that cannot be reproduced here.

Some General Principles

A few principles of ergonomics apply to a wide variety of applications. Some general principles are introduced here. Other, more specific ones follow in later sections.

People versus Machines People and machines have different capabilities; neither is best at all functions. Table 33-1 lists some functional differences between people and machines.

Design the Job to Fit the Person People are limited in what they can do. Failure to recognize capabilities and limitations may cause people to make errors or create hazards. Errors can be errors of commission, doing something that should not have been done, or

TABLE 33-1 A Comparison of Functional Capabilities of People and Machines[a]

People Are Better at	Machines Are Better at
Detecting signals in high noise environments	Responding with minimum lag time (machines have microsecond lags, whereas people have lags of 200 ms or more)
Recognizing objects over varied conditions of perception	Precise, repetitive operations
Handling unexpected occurrences	Storing and recalling large amounts of data
Ability to reason inductively	Monitoring kinds of functions
Ability to profit from experiences	Deductive reasoning ability
Originality	Sensitivity to stimuli (the range of human sensitivity is limited)
Flexibility of reprogramming	Exerting force and power
Ability to perform when overloaded and to adjust to compensate for the overload	

[a] From Meister, D., and Rabideau, G. F., *Human Factors Evaluation in System Development*, Wiley, New York, 1965.

errors of omission, failing to do something that should be done. Asking people to adjust to a job, equipment, or environment may be asking them to exceed their capabilities. In fact, the conditions may be harmful.

Work Smart, Not Hard Productivity is not increased by only speeding up the activities and methods in place. It is improved also by finding new ways to accomplish something. Errors and accidents are not reduced by only doing a better job. Changing the job by applying knowledge of accident and error causes will reduce them.

All People Are Not Alike There are variations among people. Some differences, like size, build, and weight, are easily observed. Other differences are discerned through physiological and behavioral measures. Reaction time, strength, coordination, responses to environmental conditions, beliefs, and other attributes of people require measures. The variability among people requires that designers provide adjustment. It may require that managers treat people differently. There is no one solution that works for everyone.

33-2 ANTHROPOMETRY

Description

Anthropometry is the science of measuring the human body. There are two classes of anthropometric data: static and functional or dynamic. Static measurements include standing height, sitting height, length, breadth, and depth of body segments and postures. Functional data describes such things as reach, range of motion, and forces generated by hands and feet in different directions. Tables in Appendix B include basic anthropometric data.

Anthropometric data are normally reported for fifth, fiftieth, and ninety-fifth percentiles in males and females. For a given dimension, 95% of the population is larger than the fifth percentile value, 95% of the population is smaller than the ninety-fifth percentile dimension, and 50% of the population is larger or smaller than the fiftieth percentile dimension.

People who are tall and are at the ninety-fifth percentile in height do not necessarily have arms or legs that are at the ninety-fifth percentile. There is a moderate correlation among dimensions of body members.

Many of the static data are measured on nude or lightly clothed persons. When applying this data to design, there is often a need to make some allowance for clothing. Some of the main data are now roughly a generation old and may not fully reflect today's population. The source for data in the bibliography is primarily from young adults in the United States. Diffrient et al.[2] provide data for a wide range of populations, but generally the data available for children, the elderly, and the disabled are limited. Data also may not reflect the true dimensions for populations in other countries.

There are special instruments for making anthropometric measurements: calipers and anthropometers are used to measure many static dimensions, and goniometers measure joint angles. There are standard landmarks of the body used in defining particular measurements and movements.

Application

The primary use of anthropometric data is for fit and reach, but there are other uses, too. People come in a variety of sizes and shapes. A few principles apply to the use of anthropometric data in design, although each principle may not work for every situation.

1. *Design so things are adjustable for different users*. One size does not fit all. Office furniture manufacturers now provide many adjustable features in chairs, work surface heights, and positioning of keyboards and monitors, and adjustments are starting to appear in seating and workstation equipment in factories and shops. Barber chairs have had adjustment in height, tilt, and rotation for years to make hair cutting easier. For pallet loading, there are now adjustable height pallet platforms that allow the user to adjust the pallet height as the pallet is filled or emptied. People may need to read or observe an object. One example of this is rear view mirrors on automobiles that are adjustable for different drivers and sitting postures. Displays on equipment may need to be adjustable so a process or machine operator can view them easily. Many computer monitors now come with adjustable bases.
2. *Design for the ninety-fifth percentile male to fit and the fifth percentile female to reach*. Not everything can be designed for adjustment. Designing a doorway, seating in airplanes, or headroom in an automobile allows only one possible solution. The goal is to allow most people to fit within the dimensions. If a very large person will fit, a small person will fit as well. If a person must reach a control or a part, the distance from the person to the object should not be longer than a short person's reach; a tall person can reach that far, as well. Note that in using this principle, at least 1 of every 20 people is not accommodated by data for those within the ninety-fifth percentile. As a result, some designs may need to extend the limits for the extreme population.
3. *Know the population you are designing for*. If data on a particular population are available, a design can be fitted to them. Anthropometric data from reference tables are useful when there is no other source of information for estimating dimensions and movements of people. However, reference tables may have been derived from a population significantly different than the population for which something is being designed.

33-3 INFORMATION AND DISPLAYS

The People–Machine Interface

Displays and controls are elements in an interface between people and machines. Figure 33-1 illustrates the interface and elements involved for people and for machines. Machines perform some functions and people control the operations of most machines. The operator must know what the machine is doing to know how to adjust the controls. *Displays* provide information about the machine to the operator, and the operator must sense the information provided by the display. The operator *processes* the information, *decides* what action to take, *acts* on some control, and affects the machine *operation*. If there is a failure in the person–machine loop, it may affect the performance of the system. Failures on the person side are usually called errors.

Sensory Reception of Information For a display to be useful, information must be in a form that can be sensed. If it is outside human sensory capabilities, the display is useless. For example, humans cannot see wavelengths in the infrared or ultraviolet region, and few can hear ferquencies near or higher than 20,000 Hz.

By far, vision is the richest sensory mode because it has a high rate of reception. People can discriminate among many shades, shapes, and textures. The second best sense is audition, but it is well below vision in capacity. The rate of information flow is quite

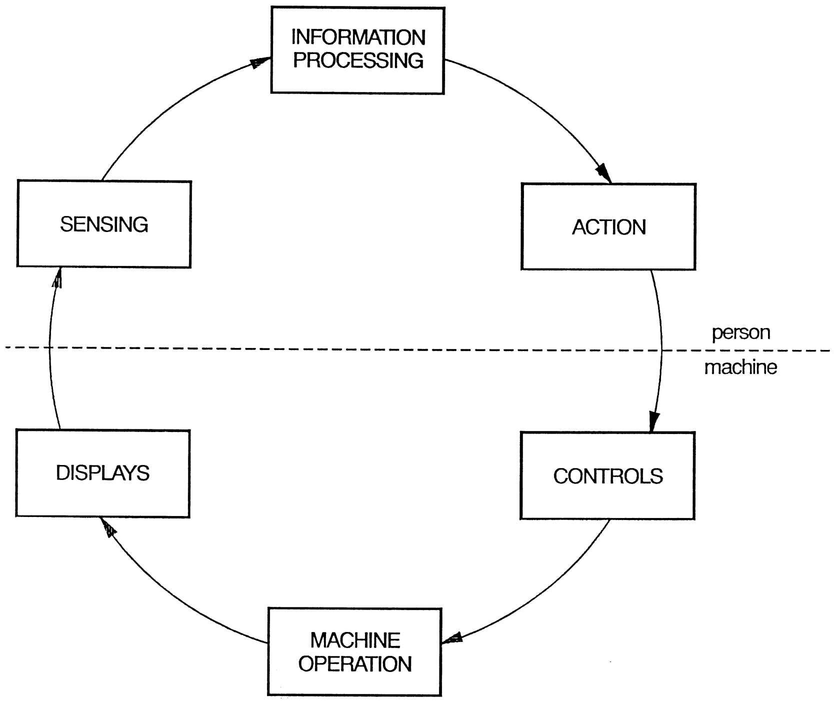


Figure 33-1. Example of a job safety analysis worksheet. Schematic of the interface between people and machines.

limited, but people can learn to discriminate among many different sounds. The tactile sense is less capable than audition. Humans can discriminate accurately among limited shapes and textures through touch.

Processing of Information Information received through the senses needs to be interpreted and processed: letters of the alphabet or symbols must be converted into some meaning; what the sound of an alarm means must be recalled. The processing of information in the brain involves understanding the meaning of the stimuli, long-term and short-term memory, problem solving, making judgments, and deciding. Not only would the sound of 500 alarms in a nuclear power plant control room create sensory overload, it would produce processing overload. When there are multiple elements of information coming in, one must prioritize them and select which is the most important.

There are many potential sources of error as people process information. One may have difficulty selecting and understanding competing information or one may have to integrate information from several sources to recognize a pattern for an event that is starting to occur. One must also remember what information means. An example is what to do in an emergency when there is an audio alarm. When the same alarm signals fire and tornado, the wrong action could be fatal. The correct action for fire is to get out, whereas the correct action for a tornado is to stay inside and take cover. Another processing error is difficulty solving a problem, such as diagnosing what is wrong with a machine. One may not have the experience (previous information) to make correct decisions or judgements that are safe.

Types of Displays

Displays are classified first by the sensory mode of their information. Visual displays are most common, followed by auditory displays, and occasionally, displays for other senses. No matter what sensory mode is selected for a display, the conditions must be suitable for information transfer. For visual displays, there must be sufficient quantity and quality of light for the displayed information to be seen. Auditory signals must be loud enough to be heard and, preferably, should not compete with other sounds.

Visual Displays

Visual displays are classified as quantitative and qualitative. Quantitative displays present numerical values; qualitative displays present conditions. There are also status displays, signals, lights, and representational displays. Several types of displays may be integrated into a complex display.

For quantitative displays, three common styles of indicators are direct reading or digital display, moving pointer–fixed scale, and fixed pointer–moving scale. Figure 33-2 gives examples of these displays and Table 33-2 summarizes the usefulness of each type of indicator.

Status indicators give qualitative information about the status of a system or component. The red-yellow-green traffic lights are a common status indicator that tells which lanes of traffic are moving and which are stopped.

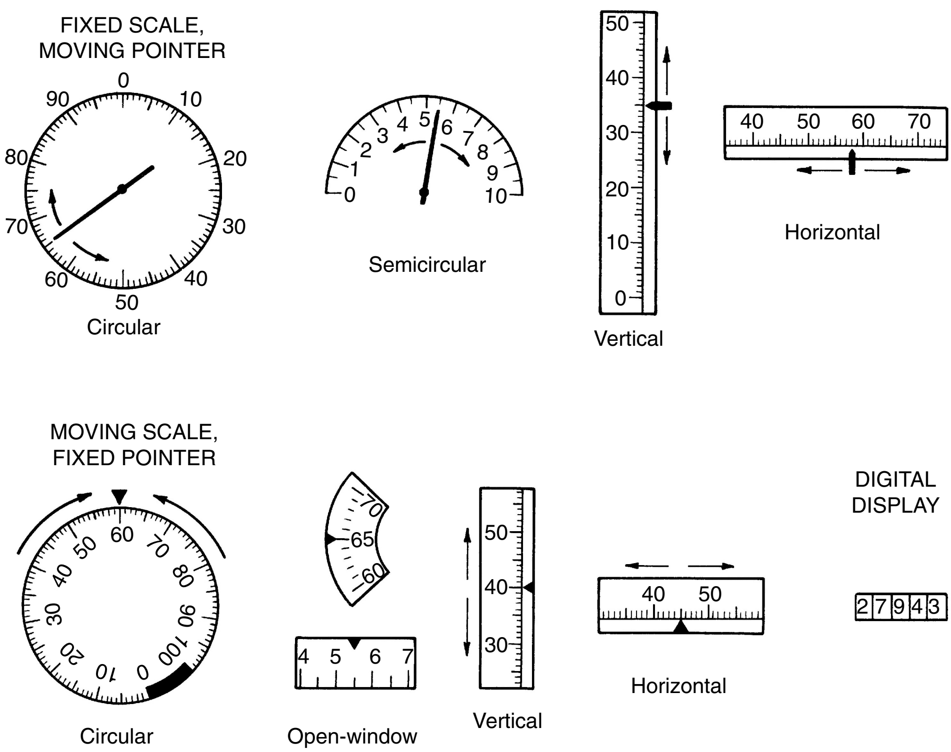


Figure 33-2. Examples of indicators for visual displays.

TABLE 33-2 A Comparison of Different Indicator Styles[a]

Used for	Counter or Digital Display	Moving Pointer–Fixed Scale	Fixed Pointer–Moving Scale
Quantitative	GOOD. Requires minimum reading time with minimum reading error	FAIR	
Qualitative	POOR. Position changes not easily detected	GOOD. Location of pointer and change in position easily detected	POOR. Difficult to judge direction and magnitude of pointer deviation
Setting	GOOD. Most accurate method of monitoring numerical settings, but relation between pointer motion and motion of setting knob is less direct	GOOD. Has simple and direct relation between pointer motion and motion of setting knob, and pointer-position change aids monitoring	FAIR. Has somewhat ambiguous relation between pointer motion and motion of setting knob
Tracking	POOR. Not readily monitored, and has ambiguous relationship to manual-control motion	GOOD. Pointer position is readily monitored and controlled, provides simple relationship to manual-control motion, and provides some information about rate	FAIR. Not readily monitored and has somewhat ambiguous relationship to manual-control motion
Orientation	POOR	GOOD. Generally moving pointer should represent vehicle or moving component of system	GOOD. Generally moving scale should represent outside world or other stable frame of reference
General	FAIR. Most economical in use of space and illuminated area; scale length limited only by number of counter drums; difficult to illuminate properly	GOOD. But requires greatest exposed and illuminated area on panel; scale length is limited	FAIR. Offers savings in panel space because only small sections of scale need be exposed and illuminate; long scale is possible

[a] From Van Cott, H. P., and Kinkade, R. G., eds., *Human Engineering Guide to Equipment Design*, rev. ed., Superintendent of Documents, U.S. Government Printing Office, Washington, DC, 1972.

There are many applications for steady or flashing signal lights. They give location, attract attention, indicate status, or give instructions. Size, duration of signal, brightness, flash rate, setting among other lights, and color all affect their performance in the person–machine interface.

Representational displays are pictorial or symbolic displays. Examples are video images, graphs, and maps. These displays may be static or dynamic. Size of display, size of elements displayed, realism, resolution, color, and rate of change affect performance. Symbols were also discussed in Chapter 32.

Display Characters and Elements

Many visual displays have numerical and alphabetical characters. The readability of the characters is important, particularly when there are emergency and adverse conditions. Also important are dial pointers and scale markings. Many factors affect the ability to read displays. Size of characters, aspect ratio, font, stroke width, color of character, background color, and coding all contribute to reading speed and error rate.

The standard viewing distance for displays is assumed to be 28 in from the display to the eye, and recommended dimensions for characters and display elements are based on that distance. For other distances, characters and elements should be adjusted in size. One formula for sizing the height of letters, H, is

$$H = 0.0022D + K_1 + K_2, \tag{33-1}$$

where

H is in inches,
D is viewing distance in inches,
K_1 is a correction factor for illumination and viewing conditions, and
K_2 is a correction factor for importance.

Values for K_1 are as follows:

	Illumination Level	
Reading Conditions	>1.0 fc	<1.0 fc
Favorable	0.06	0.16
Unfavorable	0.16	0.26

K_2 is 0.075 for important items such as emergency labels and 0.0 for all other conditions.

Another estimate of letter height is

$$H = 0.0046D. \tag{33-2}$$

Equation 33-2 does not consider adverse conditions, importance of labels, or vision problems of readers. In some cases, it would be better to adjust sizes upward than to limit them to the values from these empirical equations. This is especially true if one anticipates poor lighting, information critical to safety, and the population of readers that may have vision problems. If characters have long ascenders and descenders, the size of the main body of the characters is the important dimension. Adjustments in overall height are needed to keep readability high.

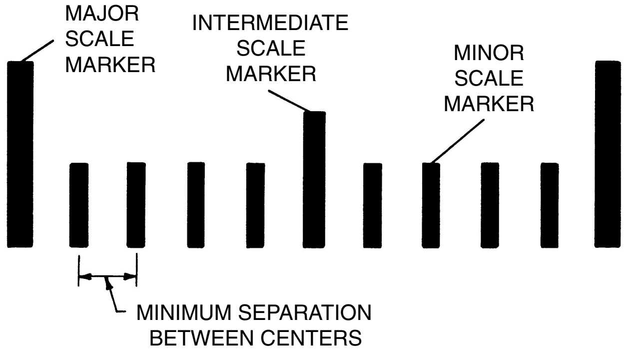
Sizing and spacing of scale markings are important for accurate reading. Figure 33-3 illustrates recommended dimensions for scale markings and spacing for a 28-in reading distance. The dimensions should be adjusted for other reading distances.

Coding

Codes are representations that have meaning. For example, the inverted triangle shape for traffic signs infers caution and the hexagonal shape is reserved for stop signs. One can use numbers, letters, shapes, colors, and configurations to code visual information. Compound codes use two or more codes at the same time. Codes often are applied for convenience or some practical reason, but they should be used with care. Codes may slow processing, particularly when they are not used regularly, because a person must recall the meaning of the code. In some cases, however, codes may speed up a task.

Auditory Displays

Auditory displays are commonly used for warnings and alarms. They are generally preferred over visual displays for many of the situations listed in Table 33-3. Table 33-4 summarizes characteristics of various audio alarms.



ATTRIBUTE	LOW ILLUMINATION, 0.03 TO 1.0 ft-L	NORMAL VIEWING CONDITIONS, above 1.0 ft-L
Major scale marker height	0.22	0.22
Major scale marker width	0.035	0.0125
Intermediate scale marker height	0.16	0.16
Intermediate scale marker width	0.030	0.0125
Minor scale marker height	0.10	0.09
Minor scale marker width	0.025	0.0125
Minimum separation between scale marker centers *	0.07	0.035
Minimum distance between major scale marker centers	0.5	0.5

Figure 33-3. Recommended minimum scale marking dimensions (inches). The data assume a 28-in reading distance and high contrast between graduation marks and a dial. In the table, the superscript asterisk denotes that the distance should never be less than one stroke width for black marks on a white dial face.

TABLE 33-3 When to Use Auditory and Visual Displays[a]

Use Auditory Presentation if	Use Visual Presentation if
The message is simple	The message is complex
The message is short	The message is long
The message will not be referred to later	The message will be referred to later
The message deals with events in time	The message deals with location in space
The message calls for immediate action	The message does not call for immediate action
The visual system of the person is overburdened	The auditory system of the person is overburdened
The receiving location is too bright or dark-adaptation integrity is necessary	The receiving location is too noisy
The person's job requires moving about continuously	The person's job allows remaining in one position

[a] Van Cott, H. P., and Kinkade, R. G., eds., *Human Engineering Guide to Equipment Design*, rev. ed., Superintendent of Documents, U.S. Government Printing Office, Washington, DC, 1972.

TABLE 33-4 Characteristics and Features of Selected Audio Alarms[a]

Alarm	Intensity	Frequency	Attention-Getting Ability	Noise Penetration Ability
Foghorn	Very high	Very low	Good	Poor in low-frequency noise
Horn	High	Low to high	Good	Good
Whistle	High	Low to high	Good if intermittent	Good if frequency is properly chosen
Siren	High	Low to high	Very good if pitch rises and falls	Very good with rising and falling Frequency
Bell	Medium	Medium to high	Good	Good in low-frequency noise
Buzzer	Low to medium	Low to medium	Good	Fair if spectrum is suited to background noise
Chimes and gong	Low to medium	Low to medium	Fair	Fair if spectrum is suited to background noise
Oscillator	Low to high	Medium to high	Good if intermittent	Good if frequency is properly chosen

[a] Van Cott, H. P., and Kinkade, R. G., eds., *Human Engineering Guide to Equipment Design*, rev. ed., Superintendent of Documents, U.S. Government Printing Office, Washington, DC, 1972.

33-4 CONTROLS AND MOTOR ACTIVITY

Description

After processing information in the person–machine loop, an operator activates some control that modifies what the machine is doing. Most controls require some force to activate them. Controls must be accessed easily, must function within human limits of force, skill, and duration, must operate consistently with expected response of the system, and must have dimensions that fit people. If these and other characteristics are not met, people will make errors in using controls or be unable to operate them.

Compatibility

Compatibility deals with the stimuli and responses that are consistent with human expectations. Spatial, movement, or conceptual relationships with stimuli and responses are all types of compatibility. For example, if a system component moves up and down, a control for that movement should move up and down (movement). If, as in the introductory paragraph on Three Mile Island, there are pairs of controls and displays that go together, they should have the same spatial orientation. Pair A should be on the left and pair B on the right (spatial). If water flows through five pumps in sequence, the controls for the pumps should be in the same sequence as the flow through the pumps (spatial and conceptual). Red means stop or danger; green means go or safe (conceptual).

Many compatibility relationships are learned and some are specific to particular cultures. Compatibility relationships involving control movement are called population stereotypes. For example, turning a steering wheel clockwise infers that the vehicle will turn right.

Compatibility relationships are tendencies, not universal behaviors. There are always some people who will not follow the relationship. Some compatibility relationships are strong and most people will follow them, whereas others are not as strong. In some design situations, more than one compatibility relationship may be involved and a solution may require violating one of the relationships. Use of labels will help those who may not follow the majority in applying a compatibility relationship when operating a control. Table 33-5 lists several compatibility relationships.

Example 33-1 Two workers were setting up a machine. Because vibrations would cause defective parts, it was essential to determine if parts moved together and apart smoothly. Feeling the vibrations was the only way to accomplish the fine adjustment needed. Consequently, the hands of one of the workers were placed in contact with parts of the machine. In this instance, the worker's hands were on a fixed part that was contacted by a moving part called a table.

Because the hands of the first worker were occupied in feeling for the vibration, the second worker was obliged to operate the controls. The control panel was located to the right of the machine parts, and the control for the up and down table movement was a rotary knob. The label for the control indicated that clockwise rotation would lower the table and counterclockwise rotation would raise it. When the first worker said "Drop the table," the second worker turned the control knob counterclockwise and the table moved up, crushing both of the first worker's thumbs.

This accident was probably caused by the lack of compatibility between the motion of the control knob and the movement of the machine part. With the knob on the right of the machine, most people would turn the knob counterclockwise to cause the table to move down.

Another identical machine had controls on the left and for it, the knob required a clockwise rotation to lower the table, just as the label indicated. In this case, the rotation of the control knob was more compatible with the expected up-and-down movement of the table.

Had the control in both cases been an up-and-down toggle switch that defaulted to a neutral position, there would have been an even stronger compatibility relationship between the control and the expected motion of the machine. In addition, the placement to the left or right of the table would have had no significance compared with the rotary knob.

Tracking Controls

Tracking tasks require continuous control. The right amount of movement at the right time is critical. Many kinds of tracking tasks require the operator to keep a system on course. An example is driving a car on a winding road. In other tracking tasks, the operator sees a target on a display and must keep it on course. The display may show vehicle deviation, and it is the operator's task to keep it in the center of the display or within certain bounds.

Two kinds of tracking displays are pursuit and compensatory displays. In pursuit tracking, both the target and a controlled element move. The operator tries to keep the controlled element on the target. The deviation between them is the error. In compensatory displays, either the controlled element or the target is fixed, and the remaining element moves in response to a control. Again, the operator tries to keep the two superimposed. The display may present the deviation between targets as a planar representation or a spatial one. The cursor appearing on a monitor for a computer mouse is an example of a compensatory display.

TABLE 33-5 Compatibility Relationships

Control or Control Movement	Expected System Response
Spatial	
Cooking stove: control-burner units	
Which control on front operates which burner on surface	Left/right controls operate left/right burners Front/rear relationships confusing
Aircraft engines	
Four controls, one for each engine should be spatially consistent with engine locations	
Operating engine control on far right	Engine at far right affected
Operating engine control on far left	Engine at far left affected
Location of separate controls for forward movement and backward movement, assuming operator is facing forward	
Operating movement control farthest forward of operator	Affects forward movement
Operating movement control nearest to operator	Affects rearward movement
Movement	
Turning a horizontal steering wheel clockwise	Vehicle turns right
Turning a horizontal steering wheel counterclockwise	Vehicle turns left
Turning a vertical steering wheel clockwise	Vehicle turns right
Turning a vertical steering wheel counterclockwise	Vehicle turns left
Moving a horizontally mounted control lever up	Controlled object moves up
For fixed-scale display and rotary control	
Clockwise rotation of control	Pointer moves clockwise Value represented increases
Counterclockwise rotation of control	Pointer moves counterclockwise Value represented decreases
Rotary controls and linear controls in the same plane	
Control on left, vertical scale on right	
Clockwise rotation of control knob	Pointer moves down and value decreases
Counterclockwise rotation of control knob	Pointer moves up and value increases
Control on right, vertical scale on left	
Clockwise rotation of control knob	Pointer moves up and value increases
Counterclockwise rotation of control knob	Pointer moves down and value decreases
Rotary controls and display movement in different planes (these may be associated with the similar action of screws and bolts)	
Clockwise rotation of the control	Movement away from control
Counterclockwise rotation of the control	Movement toward the control
Conceptual	
Red, yellow, and green traffic or signal lights or signal lights	Red means stop or dangerous Yellow means caution Green means go or safe

Control order in tracking tasks is important. Order applies to the way the device or system responds to a movement of the control. Table 33-6 characterizes the terminology and functions of control order.

The movement of a control can be continuous, discrete (step changes), or proportional (ramp change), and the response varies with system or device. Higher-order track-

TABLE 33-6 Control Order for Tracking Tasks

Order	Control Type	Movement of Device Resulting from Movement of Control	Example
Zero	Position control	Movement of device is directly proportional to control movement	Pointing a spotlight at a moving performer
First	Rate control	Rate of change in a device is related to movement of control	Depressing the gas pedal of a car changes the speed (rate of change in position)
Second	Acceleration control	Movement of the control causes a change in the rate of movement of the device	A steering wheel in a car causes the car to change direction proportional to to the angle of the front wheels
Third or greater	Higher-order control	Movement of the control causes a change in the rate of change in the device or higher-order movement	Some ship steering systems approximate a third-order control

ing is very difficult for people to master because a control movement may have too great an effect on the target. Predictor displays and aiding and quickening features in controls help operators manage higher-order control tasks.

Types of Controls

Control devices may be classified as discrete or continuous and linear or rotary. Discrete controls have predetermined positions and transmit discrete information, thereby disallowing a control to be between positions. Conversely, a continuous control can take any position within its range and can transmit values throughout its range of movement. Linear controls essentially move in a line, whereas rotary controls move in a circle or arc. Figure 33-4 illustrates controls for each pair of classifications.

There are many factors that affect the selection and design of controls. Included are control/display (C/D) ratio, direction-of-movement relationships, control resistance, grip, control coding, control function, the control or tracking task, information needs of the operator, space availability, and consequences of inadvertent activation. Some of these factors are reviewed briefly. For further details on control design, refer to more complete discussions in works cited in the bibliography.

Control/Display Ratio

C/D ratio or control/response (C/R) applies to continuous controls and refers to the distance a control moves relative to the movement of the display or system or the response of a system. C/D ratio is important in the ability of an operator to track movement and the time required to move the control and gain the desired response of the system. The significant aspects of C/D ratio vary somewhat with control order. An example of C/D ratio is the difference in steering ratio for a race car compared with a luxury car. The race driver moves the steering wheel a small amount to cause the vehicle to turn sharply. The driver of a luxury car moves the steering wheel much farther to achieve the same degree of turning. The race driver would have difficulty negotiating curves without the proper C/D ratio.

For many continuous controls, the operator moves the display quickly to the approximate desired location (slewing movement) and then uses small movements to adjust the

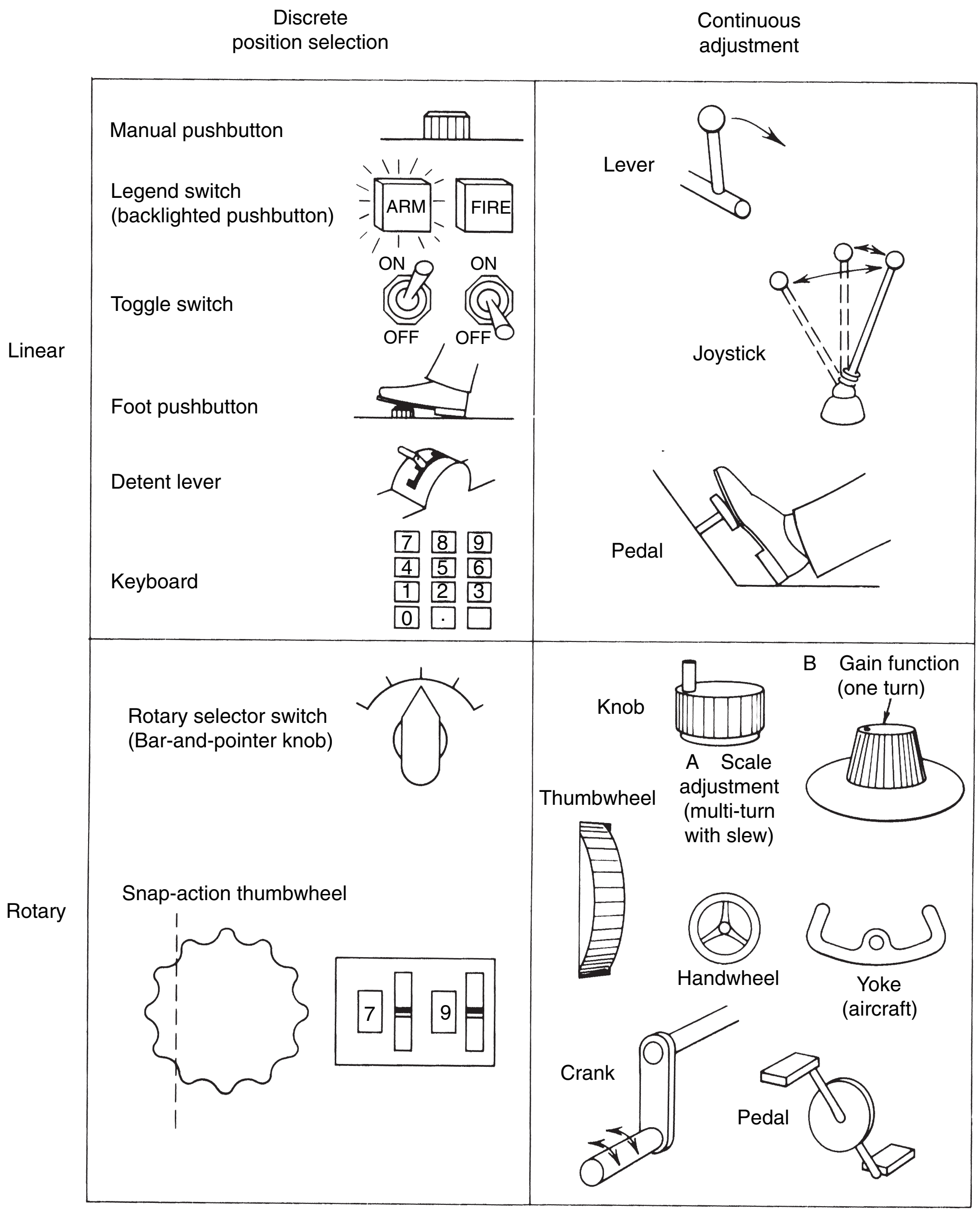


Figure 33-4. Examples of controls. (Reprinted with permission from Huchingson, R. D., *New Horizons for Human Factors in Design*, McGraw-Hill Book Company, New York, 1981.)

display precisely. This minimizes the time required to move the display on target. C/D ratio affects these two movements: a high C/D ratio increases the time required to move the display on target, whereas a low C/D ratio may cause the operator to overshoot the target and have control problems.

Control Movement

Other factors besides C/D ratio affect response time and errors. If the hand must move a large distance to reach a control, the response time is increased compared with a short movement distance. For movements less than 3 in, vertical movement of the hand is fastest. For larger movements, horizontal movements are faster than vertical. Fore and aft movements are preferred over lateral.

The amount of movement also can impact error rates. If controls have too little movement, operators may actuate them inadvertently. However, compatibility of movement, standardization, and other factors also are important in movement so as to minimize movement time and errors.

Control Resistance

The force required to move a control affects the response time, errors, accidental activation, and operator fatigue. There are different methods for introducing reactive force into a control. Springs, friction, viscous damping, and inertia may be used. Forces that are too low cannot be sensed and increase errors; forces that are too high reduce response rates and may increase fatigue in muscles involved in the control activity and eventually may lead to fatigue errors.

Forces and the variation of force with movement can affect performance. Spring or elastic resistance increases with the distance moved. Near the neutral point of a continuous control movement, the control may have a “sloppy” feel for the operator, and near the center the movements have little resistance. To reduce this feel, a combination of elastic and inertial forces may be desirable. Some rotary controls have a detent for on–off. A high detent force to turn the control on may cause an initial movement that is too large after the control is turned on.

Control Coding

Controls are coded to help an operator identify them. The common types of coding are location, labels, color, shape, and size. Several kinds of coding may apply to a particular control. For example, emergency shutoff push-button controls often are located away from other controls, are larger than other controls, are red, and are labeled in large letters for easy identification and use. In selecting coding, it is important to apply existing standards and to evaluate compatibility with users and other principles.

Preventing Accidental Activation

Some controls that are activated accidentally may have serious consequences. Methods for protecting controls from accidental activation include recessing, location, orientation, covering, locking, operational sequences, and resistance. A combination of methods may be desirable. The application and potential consequences of accidental activation will affect which methods are useful and suitable. If accidental activation leaves a system in a safe condition, rigorous methods are probably not necessary, but if accidental activation may produce serious injury, methods that greatly reduce the likelihood of activation must be applied. Maintenance is also an important consideration. A failure in a protective device may increase the likelihood of accidental activation until the protective device is repaired or replaced. Protective methods should not violate other design principles directed at minimizing errors. Figure 33-5 illustrates several of these methods.

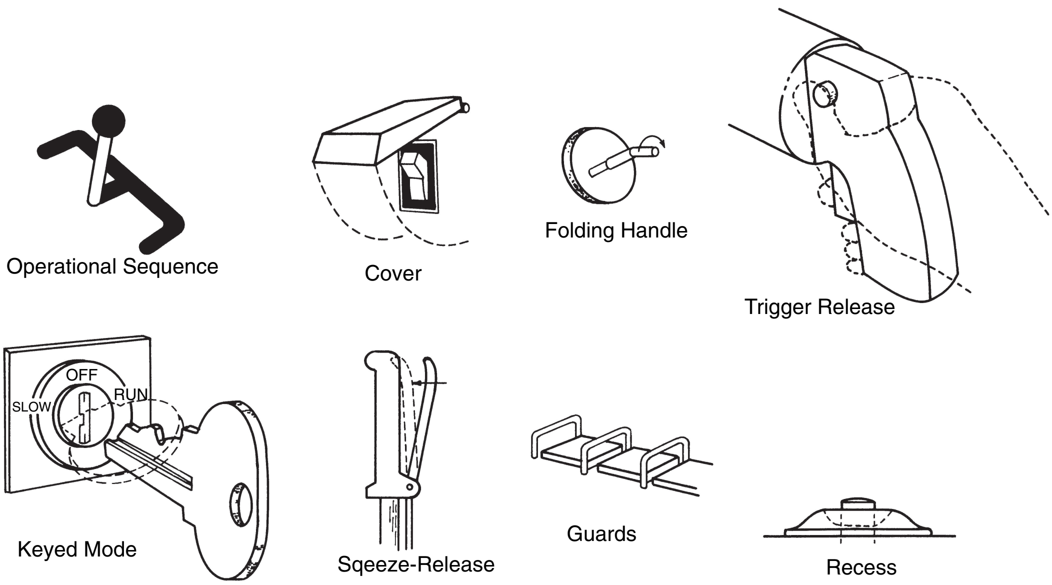


Figure 33-5. Examples of methods for preventing accidental activation of controls.

Coding Coding methods are directed at identification errors. Coding will have little effect on accidentally bumping a control or on population stereotypes when they are inconsistent with them. For example, people often operate a control consistent with expectations, rather than consistent with labeling.

Recessing To prevent activation of a push-button or toggle control, the button should be recessed below the surface of the control panel. The depressed area for the button must be large enough for fingers or activating tools to access the control. Whether an operator wears gloves should be a design consideration, also.

Guards Another technique is to provide raised barriers or guards between push buttons or around them. These are called perimeter guards, and when buttons are adjacent to each other, they prevent activation of two buttons with the same finger. If there is a guard around a push button, the guard will be bumped instead of the button, unless the force is applied inside the guard. Guards require additional spacing between controls.

Another type of control guard is a cover. Covers may be full or partial. A full cover totally encloses the control, and the cover or a portion of it must be moved to gain access to the control. Full or partial covers are common for foot controls where there is a danger of some object falling on the control and activating it. For frequently used controls, covers may introduce inconvenience and may lead to their removal.

Location and Space Locate controls away from other controls and away from movement of people or equipment to prevent inadvertent contact. There should be sufficient space between controls for hand, finger, or tools to operate controls without affecting others. The clearances needed vary with the type of control.

Resistance Another means to prevent inadvertent operation of a control is to introduce a resistance force for fixed positions. Detent wheels and detent on–off rotary switches are examples of resistant forces. Some levers require a breakout force to move them from the neutral position.

Orientation Controls can be positioned so that normal movement around them will not activate them. If hand movements are lateral, vertical control movement for toggle switches reduce accidental activation. If one can walk by and snag clothing on a control, vertical orientation may provide some protection. If falling objects also can activate a control, both horizontal and vertical orientation may be ineffective protection.

Locking There are several ways to lock controls into position. One form of lock is a position slot where the control requires two directions of movement to change positions. Another form of lock is a squeeze release on a lever, which requires the operator to squeeze the handle and unlock the position for the lever before it can be moved. A third form of lock is a button on a finger control that must be depressed to release the movement of the finger control. A fourth kind of locking control is a keyed control where a key is inserted into the control to allow the control to be moved to the desired position, after which the key may be removed.

Operational Sequence Operational sequence involves requiring multiple steps to activate the control. Some of the locking devices have operational sequence. The squeeze release lever and the push button that releases a finger control are both examples. Operational sequences may have interlocks to the next or later steps. Opening a combination padlock is a type of operational sequence. A lock pin through a hole in a hitch pin for a trailer requires an operational sequence to release the pin.

33-5 WORK PHYSIOLOGY

Description

Another area of ergonomics is the ability of people to perform physical work and human physiological factors that limit physical work and related activities. People are limited in the amount and rate of physical work produced, and there are many physiological factors that contribute to such limits. The limits may be local or general. An example of a local limit is a finger or hand that becomes fatigued from operating a hand tool or push button, which results in a declining rate of activity and force generated. The fatigue may involve limitations in muscle activity, circulation or nerve conduction, disease of joints or other tissue, or other limiting factors. Limitations may affect the general ability to perform physical work.

The body must deliver oxygen and food to tissues or the tissues cannot function. The digestive system of the body converts food into useable forms and the excess food is stored as body fat. The circulatory system moves the food to tissues and cells, and the respiratory system transfers oxygen from the air into the blood for transport to the cells.

All these systems in the body have limits. There are limits to the food supply and the rate the body can convert it to the right form, and there are limits to the capabilities of the respiratory system and the circulatory system. Disease, behavior, and environment may limit the normal capacity further. Earlier discussions noted the effect carbon monoxide has on oxygen transport. Another notable example is reduced nerve conduction when potassium levels in the body decline. Reduced nerve conduction affects muscle strength and contraction.

This section does not address all of the factors that affect human physical performance. Discussion is limited to energy expenditure and metabolism. Readers should refer to Astrand and Rodahl[3] or a similar reference for a more complete review of work physiology.

Metabolism and Energy Expenditure

The energy output from muscle activity is related to oxygen consumption during the activity. The body burns fuel through two mechanisms. The first is oxidation of fuels: glucose (carbohydrates), proteins, or lipids (fats). The second involves breaking down glucose and glycogen molecules into two or more fragments, which are then oxidized by other fragments. The first mechanism is aerobic oxidation; the second is anaerobic.

The rate of oxygen uptake in the body increases with exercise and decreases with rest. Figure 33-6 illustrates the oxygen uptake after a change in activity level. It takes the body a few minutes to adjust respiration and heart rate to handle the new activity level. During this period, there is an "oxygen debt," which represents a temporary shift from aerobic to anaerobic oxidation or a supplementation of aerobic activity by anaerobic activity. After several minutes, the body adjusts oxygen uptake for the new activity level, and steady-state conditions denote that the oxygen uptake equals the oxygen requirements of the tissue. Cessation of the activity is followed by a recovery period and a return to a resting level. The oxygen debt is repaid during the recovery period, when the body replaces materials lost in anaerobic oxidation and completes removal of waste.

Humans have energy production limits. Because anaerobic capacity is very limited and of short duration, most activity involves aerobic oxidation. Maximum aerobic power is a function of maximum oxygen uptake. The maximum aerobic capacity, which is determined from physiological tests on treadmills or bicycle ergometers, varies with physical conditioning of an individual. For an individual, activities can be expressed as a percent of maximum aerobic capacity.

The energy produced during an activity is related to the oxygen uptake. Table 33-7 lists the energy cost for various activities for a person weighing 167 lb. Larger people have higher energy expenditures for the same activity because there is more body mass in motion, and smaller people have lower energy costs. Table 33-8 lists a classification of work by severity.

Humans are inefficient at converting oxygen and fuel to useful energy. Efficiencies as high as 30% can be sustained for only 1 or 2 min. For most activities, the energy cost is converted to waste heat.

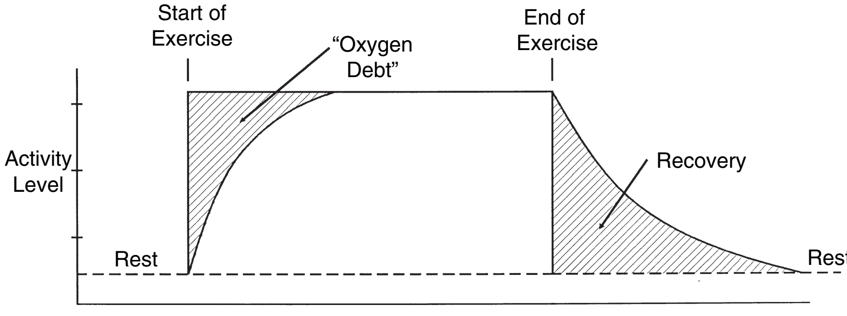


Figure 33-6. At the beginning of exercise the body develops and *oxygen debt* that is recovered when exercise ends.

TABLE 33-7 Energy Costs for Selected Activities[a,b]

Activity	Energy Cost lb oxygen/hr	kcal/min	Btu/hr
Sleeping	0.04–0.05	1.1–1.2	260–280
Resting, sitting	0.07	1.7	400
Writing	0.07	1.8	430
Typing	0.09	2.3	550
Playing musical instrument	0.11	2.9	690
Golf	0.21	5.4	1,290
Tennis	0.25	6.3	1,500
Swimming at 1 mi/hr	0.26	6.9	1,650
Cycling at 8–11 mi/hr	0.22	5.7	1,360
Walking slowly	0.15	3.8	900
Shoveling sand	0.27–0.30	6.8–7.7	1,620–1,830
Chopping wood	0.29	7.5	1,790
Digging	0.35	8.9	2,120
Climbing stairs	0.47	12.0	2,860
Marching double time	0.52	13.3	3,160

[a] From Webb, P., ed., *Bioastronautics Data Book*, NASA SP 3006, Superintendent of Documents, U.S. Government Printing Office, Washington, DC, 1964.
[b] Data are for a 167-lb person.

TABLE 33-8 Classification of Physical Work by Severity[a]

Grade of Work	Energy Cost lb oxygen/hr	l oxygen/min	kcal/min	Btu/hr
Very light	<0.10	<0.5	<2.5	<595
Light	0.10–0.19	0.5–1.0	2.5–5.0	595–1,190
Moderate	0.19–0.28	1.0–1.5	5.0–7.5	1,190–1,785
Heavy	0.28–0.38	1.5–2.0	7.5–10.0	1,785–2,380
Very heavy	0.38–0.47	2.0–2.5	10.0–12.5	2,380–2,975
Unduly heavy	>0.47	>2.5	>12.5	>2,975

[a] From Christensen, E. H., *Ergonomics Research Society Symposium on Fatigue*, H. K. Lewis, Ltd., London, 1953, p. 93.

Application

Knowledge of energy cost for activities is important in designing physical work for people. Capacity and the physiological limitations that can affect physical work must be known. Energy cost also is important for assessing the dangers of thermal environments because heat gain or loss must be balanced with the heat produced by the activity. Danger increases when activity and heat are combined. Understanding energy costs is important when selecting personal protective suits, particularly full body suits, which must have cooling systems to remove the waste heat from physical work. The movement restrictions of clothing often increase the energy expenditure levels higher than those shown in the tables.

33-6 BIOMECHANICS

Description

Biomechanics is the application of mechanics to biological problems. It builds on anatomy, anthropometry, and kinesiology, the study of human movement. Biomechanics involves kinematics—the geometry and patterns of movement. Kinematic variables are displacement, velocity, and acceleration. Biomechanics also involves kinetics—the forces, energy, power, and work involved in movement.

Use of data on link segment lengths, centers of gravity, moments of inertia, and mass, combined with measurement of linear and angular displacement and forces, allows development of analytical models to describe or evaluate what is going on during various activities. Use of static and dynamic analysis facilitates evaluation of lifting tasks, pushing, pulling, turning, swinging tools, and other motions. Film and video techniques allow viewing of the dangers involved in motion-related activities. Figure 15-1 illustrates a static model. The revised NIOSH lifting equations (Equations 15-1 and 15-2) incorporate knowledge of lifting task biomechanics.

Figure 33-7 diagrams the static loads in the forearm and hand. The reactive loads on the elbow must be created by the muscles acting at the elbow. The weight of the forearm and hand act at some distance (center of mass) from the elbow. For equilibrium, the load created by the segment masses must have a force and a moment at the elbow. The load on the hand creates an additional force and moment at the elbow, transmitted through the wrist joint. If the hand and arm were in motion raising the load, there would be additional inertial forces and moments added to the static components.

Application

There are many applications of biomechanics to safety problems. One application is analysis of resistance forces required for walking on surfaces. The longer the stride, the greater the frictional forces needed to prevent slipping. In a long stride, compared with a short stride, the legs extend forward and rearward further and have greater angles from vertical.

Another application is analysis of repeated motions involved in many jobs. Chapter 13 discussed cumulative trauma disorders (also called musculoskeletal disorders), and Chapter 15 included a discussion of manual materials handling problems and controls.

One can watch for other indicators of task-related biomechanical problems. Extreme joint flexion, unusual postures, large forces, forces not in line with body motion, vibration, and highly repetitive motions are all indicators of potential ergonomic problems. Table 33-9 is a checklist for ergonomic risk factors.

33-7 WORKPLACE AND EQUIPMENT DESIGN

Principles of Workstation Layout

The application of anthropometry, biomechanics, displays, controls, and other ergonomic components are integrated into the design of workstations and equipment. There are workstations for different postures, primarily standing and sitting. The discussion that follows includes only selected concepts, principles, and data for workstation design. Sanders and McCormick[4] identify four general principles for workstation layout: importance, frequency-of-use, functional, and sequence-of-use principles. These principles apply to

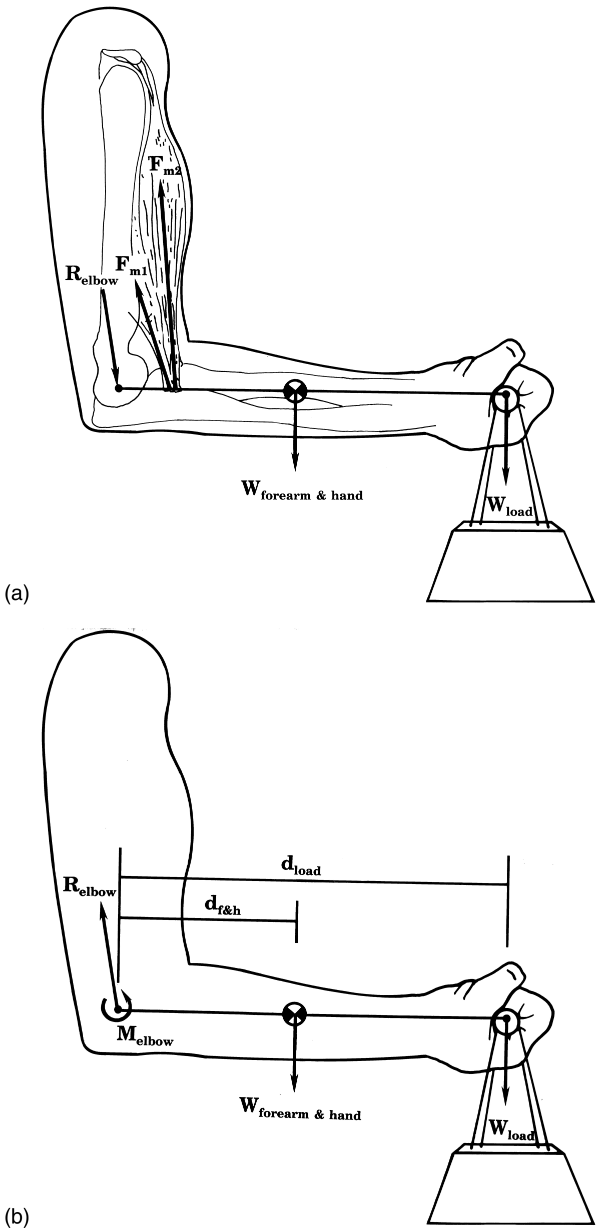


Figure 33-7. Example of a biomechanical analysis of the forearm and hand. (a) The reaction force at the elbow must equal the sum of that produced by the forearm and hand. The muscles balance the moment created by the forearm and hand and the weight. (b) The forces and moments are simplified in a free-body diagram.

location and arrangements of components. Items should be placed within reach and view and they should be organized to distribute tasks between hands or between hands and feet.

Importance Principle How important a component is to the overall operation of a system must be considered. Important components should be directly in front of an operator. There are several schemes to judge importance.

TABLE 33-9 Checklist for Ergonomic Risk Factors[a]

Upper extremity	
Shoulder	Elbow held above mid torso
	Hand working above shoulder
	Reaching behind torso
Forearm	Inward rotation with bent wrist
	Outward rotation with bent wrist
	Repetitive twisting
Wrist	Palmar flexion
	More than 30′ extension
	Ulnar or radial deviation
Hand	Pinching
	Cold
	Vibration
High local force concentrations	Anywhere on skin, base of palms, or back of fingers
Low back	
Twisting	With or without load
Bending	More than 15′ with load
Load	Held large distance from body
	Large size or weight
Frequency	Continuous lifting throughout shift

[a] From Armstrong, T. J., "Ergonomics and Cumulative Trauma Disorders," *Hand Clinics*, 2:553–565 (1986).

Frequency-of-Use Principle Another principle for layout considers how often components are used in operating a system. A display or control that is used very frequently should be given a location that is very convenient for the operator.

Functional Principle This principle suggests that things that are functionally related should be grouped together. The grouping may be based on conceptual factors, such as flow of fluid through a piping system. Grouping by similarity, for example, keeping all electrical system controls together or all hydraulic system controls together, exhibits another type of functional relationship.

Sequence-of-Use Principle Another principle for layout considers the order in which one reads displays or operates controls. Those things that are operated in sequence should be located together and in sequential order.

Standing Work Surfaces

Workstation height is very important. Consideration of anthropometrics together with task will determine the preferred height. Table 33-10 lists recommended standing work surface heights for three types of tasks. For lifting tasks, the surface height is somewhat reduced, and when someone must press downward or generate downward forces, lower heights are preferred to make it easier to generate the force and keep the elbow nearly straight. In general, the forearm should be extended slightly beyond horizontal so that the shoulder muscles do not have to carry as much weight of the arms. Work surface edges should be rounded to prevent local forces on the arms, and seated workers at standing height work stations should have foot rests.

TABLE 33-10 Recommended Work Surface Heights[a]

Type Task	Male	Female
Standing		
Precision work, elbows supported	43.0–47.0	40.5–44.5
Light assembly work	39.0–43.0	34.5–38.5
Heavy work	33.5–39.5	31.0–37.0
Seated		
Fine work or assembly	39.0–41.5	35.0–37.5
Precision work (e.g., mechanical assembly)	35.0–37.0	32.5–34.5
Writing or light assembly	29.0–31.0	27.5–29.5
Coarse or medium work	27.0–28.5	26.0–27.5

[a] From Ayoub, M. M., "Work Place Design and Posture," *Human Factors*, 15:265–268 (1973).

Seated Work Surfaces

Preferred work surface heights for seated activities vary with task. Minimal muscle activity to support the arms occurs when the forearms are horizontal or sloping downward a small amount and when upper arms are vertical near the body. Extended and raised arms will fatigue faster. Table 33-10 lists recommended work surface heights for seated work. Although standard desk heights are 30 in, the height should be adjustable where possible. Keyboard heights should be lower than the work surface height. However, the slope of the keyboard can affect the preferred height necessary to minimize the extension of the wrist.

Seating

There are many anthropometric dimensions important for seating. Where possible, seat pan height and back rest height should be adjustable. Most of the weight of the torso bears on the interface between the ischial tuberosities of the pelvis and the seat pan. Part of the leg weight carries to the floor through the feet. Cushioning material and seat pan contour are important in distributing the weight over as large an area of the seat pan as possible so as to minimize concentration of loads and interruption of blood circulation to tissues involved. The seat pan height should be low enough so leg weight does not bear heavily on the front edge of the seat pan and does not interfere with circulation. Foot rests may be necessary when seat pans are not adjustable or do not adjust low enough for short-legged workers. Seat pan depth should be adjustable, often through forward and backward movement of the seat back. The goal is to provide good support for the lower and middle part of the back. Table 33-11 lists recommended dimensions for office chairs. Look for adjustable features to accommodate users.

Other factors are important in seating. Too often there is no place for factory workers who are seated to place their legs. As a result, they sit with their legs turned and torsos twisted, which leads to back problems. If workers must turn from side to side, seat pans should swivel. Vibration absorption is essential for some seated activities, such as driving a truck.

To rise from a seated position requires positioning the center of gravity of the body over the feet. Some people, particularly the elderly, have problems getting out of low, soft seating because the problem of moving the center of gravity forward is compounded by

TABLE 33-11 Recommended Dimensions for Office Chairs[a]

Seat	
Height from floor	16–20.5 in[b]
Width (breadth)	17.7 in
Length (depth)	15–17 in[c]
Pan angle	0–10° or adjustable in this range
Seat back-to-pan included angle	90–105°, adjustment preferred
Backrest	
Height	Variable with task and back angle
Width	At least 12.5 in in the lumbar region
Armrest	
Inside distance	At least 17.2 in

[a] From ANSI/HFS 100, *Human Factors Engineering of Visual Display Terminal Workstations*.
[b] Operators with popliteal heights of less than 16 in may need a footrest.
[c] Chairs with seat depths exceeding 16 in shall provide relief to the back side of the knee (such as contouring).

the need to raise it upward to move to the front of the seat. Some chairs have features that assist the user from a seated to a standing position.

Seats in automobiles cannot have the seat pan at the desired height. As a result, the seat pan and seat back are tilted. The tilt increases as the distance between floor and seat pan becomes smaller. Steeply tilted seat backs require the driver to tip the head forward to see, increasing neck muscle activity.

The support system for seats is important for safety. The fewer support legs or casters and the smaller the support area formed by the legs or casters, the greater the chances are of tipping a chair over. Most office chairs today have five support legs and casters to improve stability.

VDT Workstations

Questions about health and various disorders in reference to use of computers rose with expanded use of computers in offices and other operations. Disorders associated with the use of computers and computer terminals have varied origins.

There are eye and vision problems. Having the right eyeglass prescription and correct viewing distance in the prescription is important. Having the right monitor solves many problems: on some screens characters become wiggly from radio interference and circuitry problems; older systems have low-resolution characters; reflective glare from screen surfaces can make viewing of characters difficult; poor color choice can affect character discrimination. Bright background colors can create visual afterimages, which is called the McCollough effect. Adjustable brightness and contrast controls should be included with a monitor.

There are also problems of workstation layout. Putting the screen and keyboard at the right height are important. The correct seating adjustment is also important because the back needs proper support from the chair. Extended use of improperly adjusted heights causes arm, shoulder, and neck muscles to become fatigued, producing pain that can continue well after leaving work. The normal viewing angle is approximately 15° to 20° below horizontal from the eyes because people are not as comfortable looking straight ahead. Copy stands should be close to the screen, and the screen and keyboard should be directly in front of the user. Some monitors now come with bases that permit adjusting the tilt. For people who normally work for extended periods (more than 1 or 2 hr) at a computer workstation, breaks and changes in activity can help reduce problems.

Keyboards have become extremely common control devices with the expansion in the use of computers. There are models that have each half of the keyboard slightly rotated. This feature helps position the keys in line with the arms and hands. Arms and hands cannot be positioned perpendicular to a straight keyboard because of the width of the body. To use a straight keyboard, one must bend the wrists, thus putting some strain on the wrists. Workers should change tasks to reduce the intensity of keyboard data entry and find opportunities to stretch and relax the muscles and tendons involved in typing. Those involved in data entry should look for ways to avoid keyboard data entry, such as through the use of automated systems, optical character recognition, and importing data directly from files. One way to minimize potential trauma from keyboard work is to find ways to avoid keyboard tasks. The other methods are likely to improve productivity in addition to reducing risk of repeated motion disorders.

Maintainability

Too often designers think of normal use and operation of equipment and they forget the tasks related to maintenance and repair.

Designs that incorporate maintainability concepts will reduce errors during maintenance activities and help prevent unnecessary damage to components because workers cannot see or reach into areas where work is carried out. Access points and panels should be convenient and large enough for the work involved. Small holes are needed for hands and arms; large ones for putting the head, shoulders, or entive body into a compartment. There should be viewing ports as well. There are ways to code components so that one does not confuse them. There are ways to design connectors and fittings so that the wrong components are not placed in the wrong locations. References listed in the bibliography provide insight into many techniques for incorporating human factors principles into maintainability. Many involve safety.

33-8 DESIGNING FOR THE WORKFORCE

The Changing Workforce and Population

The demographics of the workforce are changing. The number of women in traditionally male jobs is increasing, and the age of the United States population is increasing and will continue to do so into the twenty-first century. More than in the past, we also look to integrate the disabled into society: most people with disabilities are employable. There are implications for safety related to these changes in the work force. Changes in employment laws reflect these changes and challenge the employer to ensure that the workplace is designed for all people. Manufacturers and designers of products and environments must meet these changes in demographics as well.

Women

Women are capable of most jobs men are, but they have faced problems obtaining protective clothing that fits and workstations designed to accommodate their size. Workstation furnishings need to adjust to fit people of all sizes, regardless of gender. Lifting and bending tasks pose equal dangers for men and women, but statistics indicate that women have higher rates of carpal tunnel syndrome than men. The increasing number of women in previously male-dominated jobs has focused more attention on workstation and task design. Subsequent redesign and reevaluation will reduce risks for everyone.

The Elderly

Typically, the capacities of the elderly are less than those of younger product users and workers. These capacities involve strength, range of motion, and duration of activity as well as diminished vision and hearing. Conditioning can restore some strength and motion for the elderly and treatment may restore vision and improve hearing. Currently, there is a growing sensitivity to the need to design for those with reduced capabilities because of aging. For example, lighting standards now include an adjustment factor for people older than 55 years when selecting illumination levels.

The Disabled

Medicine today extends the life of many people with disabilities. For example, today the survival rate for victims of automobile crashes is much higher than in the past. The unfortunate part is that many of these victims have some permanent disability. Today, people with disabilities from disease and injury are part of the mainstream of society. Federal and state laws require that public buildings, transportation, and certain housing include accessibility for the handicapped. Employment laws prohibit an employer from denying employment to someone who is disabled because the workplace cannot accommodate them. There is even a federal law that mandates that federal agencies ensure that office equipment (including computers) be accessible by disabled individuals.[5]

EXERCISES

1. A warning sign is to be located so it is readable from a distance of 20 ft. Sometimes reading conditions are expected to be unfavorable, but more than 1 fc. The message is important. How high should the letters be?
2. You are to design a VDT workstation that includes use of a keyboard from a seated position. Identify the recommended dimensions or range of dimensions for the following:
   (a) seat height
   (b) seat depth
   (c) seat pan slope
   (d) back rest slope or angle
   (e) clearance between the seat pan and the underside of the work surface
   (f) floor-to-table distance
   (g) keyboard height
   (h) viewing distance
   (i) viewing angle from horizontal
3. You are to design access to the top of a tank trailer. The vehicle operator must climb to the top to check on filling and to seal the hatch. A ladder device must be provided at the midpoint along the trailer length to reach the fill hatch on top. Sketch your design solution. Identify key dimensions and note the source of your data. The basic dimensions of the truck are shown in Figure 33-8.
4. You are to redesign and reconfigure the control/display panel shown in Figure 33-9. The panel is part of a machine that makes sand molds for castings. The panel contains lights, push buttons, selector switches, and selectors that center themselves in

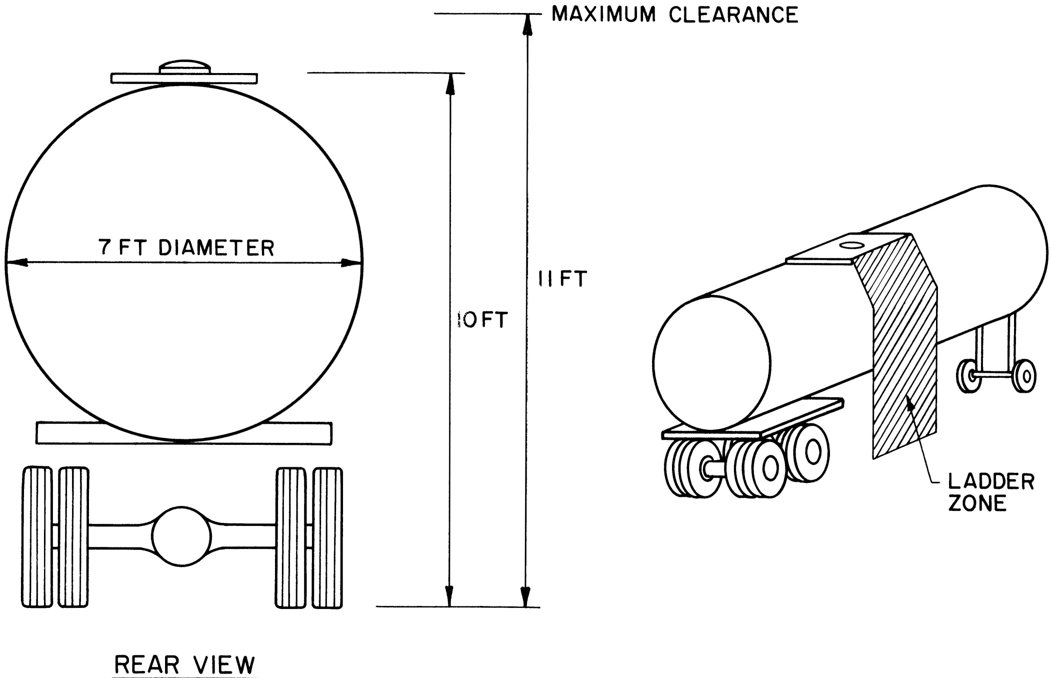


Figure 33-8. Diagram for Exercise 3.

a neutral position when not being held. The panel has a five-row and five-column layout. The solution should follow principles of ergonomic design and need not fit in the same panel. The functions of the machine are as shown in Figures 33-10 and 33-11. The automatic and manual modes for the molding machine control components are described in the sequence of functions listed in Table 33-12.

5. Locate the software that adjusts the operation of a computer mouse or game control. Change each setting to see what impact the adjustments have on the ability to use the control device effectively. Identify what control parameter each adjustment affects.

REVIEW QUESTIONS

1. What does the word *ergonomics* mean?

2. Describe what the field of ergonomics is about.

3. How is ergonomics applied?

4. Identify three things that people are good at and three that machines are good at.

5. Name two fundamental principles of ergonomics.

6. What is anthropometry?

7. Much anthropometric data are given in percentiles. Describe how to apply percentile data in design.

8. Name three principles for applying anthropometry in design.

9. Describe the six elements in the people—machine interface.

10. Name two kinds of displays.

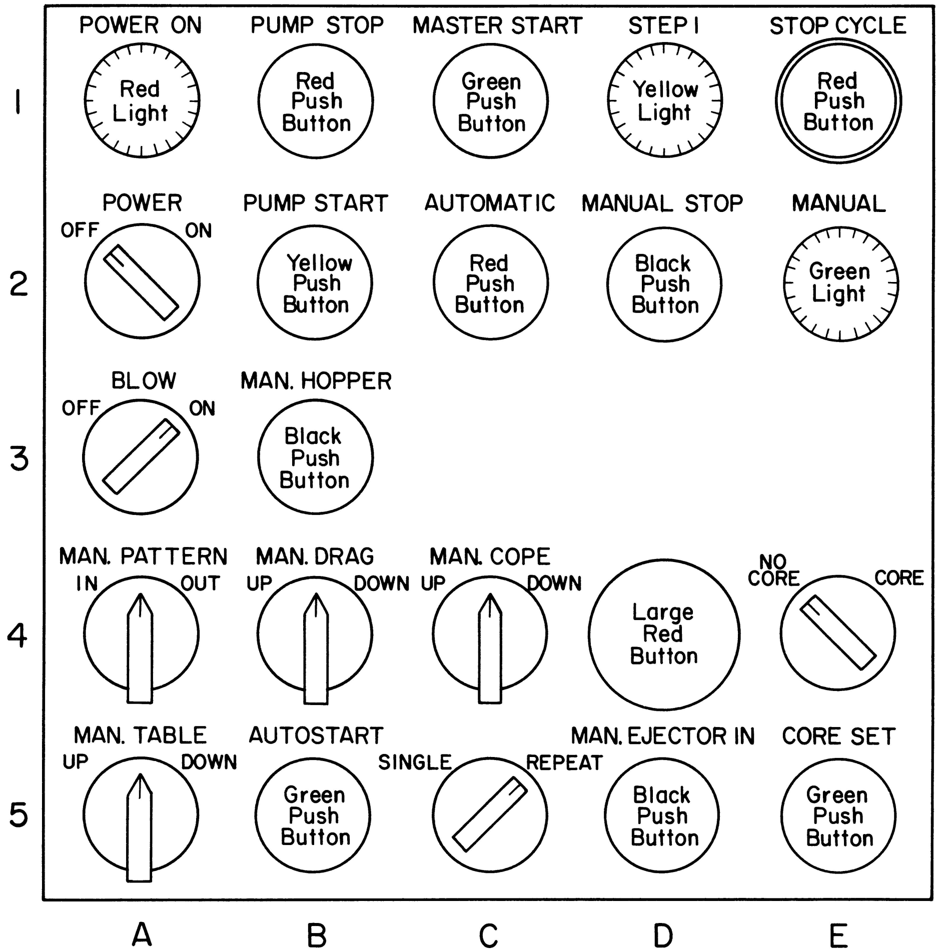


Figure 33-9. Current panel layout for Exercise 4.

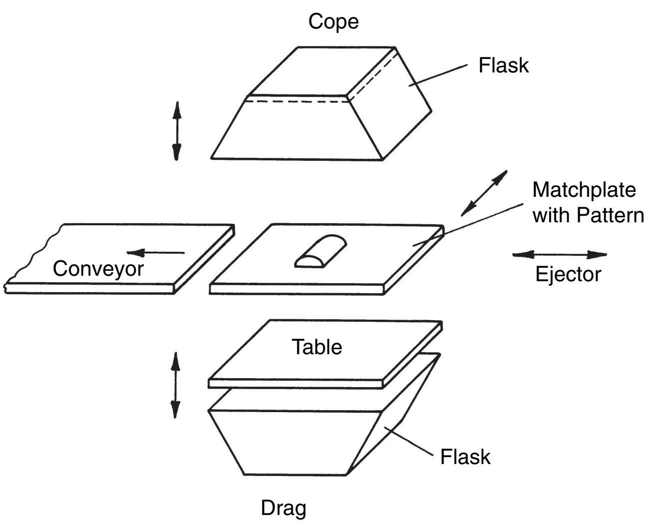


Figure 33-10. Functional diagram of machine components for Exercise 4.

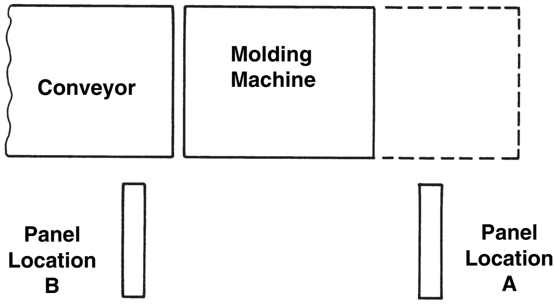


Figure 33-11. Plan view of machine and panel layout for Exercise 4.

TABLE 33-12 Task Descriptions and Control Use for Exercise 4

	Components Involved		
Function	Selector Switch	Push Button	Light
Energize machine			
Turn power on	A2		A1
Turn sand pump on		B2	
Turn blow valves on	A3		
Select options			
Single or repeat	C5		
Core or no core	E4		
Automatic cycle or manual (default) cycle		C2 E2	
Position to start (step 1)			
Manual step the cycle to step 1		C1 & D2 together	
When at step 1			D1
Start cycle (automatic) (may be single or repeating cycle)			
Autostart		C1 & B5 together	
Stop cycle to insert core (see core/no core option) and continue cycle		E5	
Cycle complete			D1
To repeat cycle automatically (see single/repeat option)			
To stop at end of single cycle (see single/repeat option)			
Stop or interrupt automatic cycle			
Stop cycle		E1	
Start actions for manual mode (Default)			
Manual step to step 1		C1 & D2 together	
Manual pattern movement		C1 & A4 together	
Manual drag movement		C1 & B4 together	
Manual cope movement		C1 & C4 together	
Manual table movement		C1 & A5 together	
Manual ejector		D5	
Manual hopper		B3	
Stop manual actions			
Release the buttons			
Deenergize the machine			
Turn blow valves off		A3	
Turn sand pump off		B1	
Turn power off	A2		
Emergency power off		D4	

11. What are three characteristics that display characters should have?
12. What is coding? Give three examples.
13. What is compatibility? Give three examples.
14. What is the difference between pursuit and compensatory tracking tasks?
15. What is the difference between discrete and continuous controls?
16. What is the control/display ratio?
17. Why is control movement important in control tasks?
18. What are the four methods for creating control resistance?
19. Describe five methods for preventing accidental activation of controls.
20. What are the two main ways in which the body converts fuel to energy output?
21. Describe the significance of energy expenditure when wearing personal protective clothing, particularly full suits.
22. What is biomechanics? Kinesiology? Kinematics? Kinetics?
23. What are the four principles for workstation layout?
24. With reference to safety, why is maintainability an important part of ergonomics?
25. Name three changes in the work force and population that place greater emphasis and demands on ergonomics in design of products and workplaces.

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SAE J98, Safety for Industrial Wheeled Equipment
SAE J99, Lighting and Marking of Industrial Equipment on Highways
SAE J107, Operator Controls and Displays on Motorcycles
SAE J115, Safety Signs
SAE J128, Occupant Restraint System Evaluation—Passenger Cars
SAE J137, Lighting and Marking of Agricultural Equipment on Highways
SAE J138, Film Analysis Guides for Dynamic Studies of Test Subjects
SAE J153, Safety Considerations for the Operator
SAE 154a, Operator Enclosures—Human Factor Design Considerations
SAE J185, Access Systems for Off-Road Machines
SAE J209, Instrument Face Design and Location for Construction and Industrial Equipment
SAE J223, Symbols and Color Codes for Maintenance Instructions, Container and Filler Identification
SAE J264, Vision Glossary
SAE J284, Safety Alert Symbol for Agricultural, Construction and Industrial Equipment
SAE J287, Driver Hand Control Reach
SAE J268, Rear View Mirrors—Motorcycles
SAE J297, Operator Controls on Industrial Equipment
SAE J386, Operator Restraint Systems for Off-Road Work Machines
SAE J389b, Universal Symbols for Operator Controls on Agricultural Equipment
SAE J826, Devices for Use in Defining and Measuring Vehicle Seating Accommodation
SAE J833, USA Human Physical Dimensions
SAE J834a, Passenger Car Rear Vision
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SAE J899, Operator's Seat Dimensions for Off-Road Self-Propelled Work Machines
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