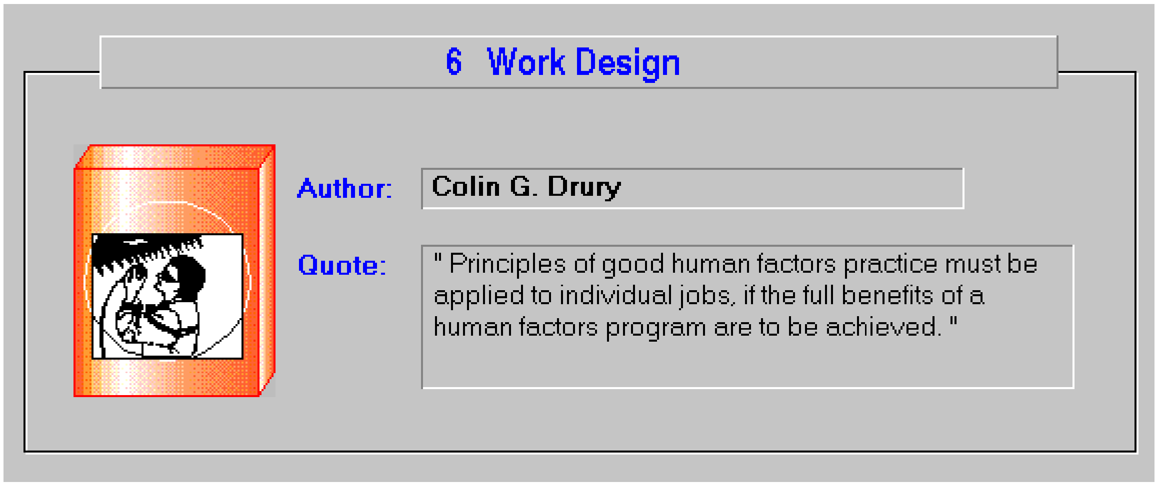
Chapter 6
WORK DESIGN



6 Work Design

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Quote: " Principles of good human factors practice must be applied to individual jobs, if the full benefits of a human factors program are to be achieved. "

INTRODUCTION

Chapter 5 provides guidelines for the process of designing the overall maintenance facility. Unfortunately, using proper facility design methods does not ensure that the workplaces within the facility support effective maintenance tasks. The design of the facility can directly affect the design of individual job tasks. It is a common experience to take extra steps during a job simply because the facility is inefficiently designed.

Principles of good human factors practice must be applied to individual jobs, if the full benefits of a human factors program are to be achieved. This involves both physical design of the workplace **and** design of the job itself. Workplace components include benches, seating, hand tools, and the workers' environment. Job design includes tasks that must be performed and interfaces among people doing a job, with the technical process, and with other people in the process.

Workplace design and job design are usually treated separately. However, for this *Guide*, it is worthwhile to recognize that the two are intricately connected. It is difficult to change a workplace without changing the way a job is done. Likewise, even slight changes in a job's structure or content can drastically effect what is an appropriate workplace.

Therefore, while we relate particular principles and rules to either workplace or job design, the topics are combined and referred to as *work design* in this chapter.

To put this chapter and **Chapter 5** into perspective, consider them to be hierarchical. Good facility design is a necessary, but not sufficient, prerequisite for effective work design. That is, a good facility design does not guarantee that individual workplaces will also be well-designed. Once a reasonable facility design is in place, then we can address individual workplaces and jobs using the methods and guidelines provided in this chapter.

BACKGROUND

Workplace redesign improves posture, productivity, quality, and safety. Job redesign increases job satisfaction and reduces process errors. As an example of workplace improvement in aviation maintenance, consider the redesign of assembly workplaces for complex electronic component assembly.[1] By providing better lighting, lightweight power tools, new adjustable chairs, and workbenches, the company recorded the following improvements over 18 months:

Productivity	+ 5%
Quality	+50%
Job Satisfaction	+60%
Injury Rates	eliminated

These improvements paid for themselves in productivity gains alone in less than six months.

Table 6-1. Improvements due to work design in a manufacturing cell.[3]

Measure	Before	After
Cycle Time (days)	7	0.3
Travel Distance (miles)	209	13
Work in Process (inventory)	>2,500	<1,000
Changeover Time (hours)	10	1.5
Cost per Part	$1.71	$0.81
Inventory Turns/Year	30	>100
Quality (# of defects)	?	0
Space Required (m3)	X	X-37

Similar results were found in a data entry office workplace. Ong[2] studied the data entry staff's performance at a Singapore airline before and after changes in the workplace's features and procedures. Operators were provided with document holders and foot rests to improve working postures; lighting was improved; and workers were given additional rest pauses. As a result, operators' hourly output increased by 25 percent. The error rate fell from 1.5 percent to 0.1 percent. There was also a notable reduction in reported musculo-skeletal aches and pains: neck and shoulder problems were reduced by more than half.[2]

Job design occurs at two levels:

- allocating functions between people and machines
- distributing people functions among different workers.

A typical example of job design's benefits involves redesigning a machining process as a machining "cell."[3] Tasks were assigned to an autonomous team of two people on each shift who were responsible for scheduling, **CNC** programming, preventive maintenance, delivery, quality, and machining. Cell design included many workplace improvements based on designs a team of operators, managers, and engineers developed. Results from the first three months of operations are shown in **Table 6-1**.

The importance of the physical fit between operator and workplace has been a part of aviation since the beginning of human factors in the 1940's. Military pilots' body sizes were used to ensure that a maximum number of pilots could reach controls and see displays.[4] In civil aviation, body size data have been used to design cockpits, passenger seating, and emergency exits.[5] Again, designers strive to ensure a proper fit between the "worker" and the "workplace."

Such data also have been applied to designing equipment maintenance tasks. Studies of the effects of accessibility on maintainability began three decades ago.[6] More recently, the military has been using Crewchief[7] software to simulate different body sizes of mechanics and inspectors. In civil aviation, the Boeing-777 received publicity[8] for using a similar model to ensure that components can be accessed, serviced, and removed. Although computer models are not essential for good workplace design, they add convenience to the process.

In job design, as contrasted with workplace design, much early work was targeted at flight crews, rather than the hangar. Allocating flying functions between operator and machine, i.e., between a pilot and a computer, improves pilots' effectiveness in controlling and managing flight segments.[9] Better allocation of tasks among flight crew members, i.e., Crew Resource Management (CRM)[10], has reduced errors in flight operations. CRM techniques, renamed MRM (Maintenance Resource Management), have been applied with equal success to **AMT**s.[11,12,13] (See **Chapter 16**.)

MRM is not the only route to job design, particularly for large, complex organizations such as aviation maintenance facilities. In military organizations, broad-scale job redesign led to dramatic serviceability and efficiency improvements in the **USAF**'s Tactical Air Command.[14] Other approaches to work design at several airlines have been presented at recent industry meetings.[15,16,17]

ISSUES AND PROBLEMS

Issues related to work design can generally be grouped into two categories: workplace design issues and job design issues. We briefly discuss each category below.

Workplace Design

Examples of poor workplace design can be found in many maintenance operations. Due to an aircraft's structural design, components may not be easily accessible, resulting in awkward postures, restricted space for movement, and decreased safety and performance.[18] In workshops, postural problems can be caused by benches located at inappropriate heights, by heavy power tools with ill-designed handles, and by uncomfortable chairs.

Poorly configured computer workplaces in offices require workers to adopt body and arm/hand postures that can lead eventually to injury (see **Chapter 3**). Injury data have been used to identify design problems and to guide ergonomic solutions for aircraft inspection tasks.[19]

Probably most **AMT**s have at least indirect experience with injuries caused by improper workplace design. However, an often overlooked consequence of poorly-designed workplaces is an increase in the number of job errors. The stresses caused by poor posture, excessive lifting strain, visual fatigue, and other workplace-induced effects, lead to a higher probability of committing errors. Reducing errors and ensuring airworthiness is always the overreaching goal in an aviation maintenance organization.

Appropriately designed workplaces with well-chosen access stands, benches, chairs, and tools can improve both safety and productivity. Improving lighting that reduces the need for close viewing improves working posture. Applying an ergonomics audit (see **Chapter 2**) to the broad spectrum of maintenance and inspection jobs can reveal examples of poor and of good design for elimination and emulation, respectively.

Job Design

Aircraft inspection and maintenance are part of a complex activity chain that includes scheduling, planning, and cleaning. For such tightly-scheduled activities, safe and efficient outcomes require that team members work together smoothly and intelligently. The consequences of poor job design include errors, delays, and frustration. When activities are not well-coordinated or when workers are unaware of how tasks are linked together, good teamwork cannot exist.

Symptoms of poor job design include disputes over who has authority; physical interference between activities, such as inspection and cleaning; and inability to respond smoothly to unplanned events, such as discovering an unusual structural defect. The symptoms also appear when team members are interviewed or surveyed to determine their job satisfaction and frustrations. Extreme job design problems are measured by absenteeism, rapid workforce turnover, and union grievances.

REGULATORY REQUIREMENTS

Few regulatory requirements are related to work design. Certain workspace and workplace dimensions are regulated by one or more governmental agencies. Specific **OSHA** requirements for access dimensions - for stairs, workstands, and passageways - are covered in **Chapter 5**. Beyond such specific requirements, there are several sources for standards, guidelines, and recommended practices.

For computer workplaces, **ANSI**/**HFS** 100/1988 (currently being revised) lists nominal workplace dimensions, screen design parameters, and work design characteristics.[20] For tasks that require moving loads, **NIOSH** provides the *Guidelines for Manual Materials Handling*.[19] The Department of Defense uses **MIL-STD**-1472D for human factors data, techniques, and design requirements. The latter sources, although not actual requirements for the aviation industry, serve as *de facto* standards for work design.

While there are regulations, standards, and guidelines related to workplace design, there are no similar standards for job design. Part 65 of the Federal Aviation Regulations (**FAR**s) defines certain roles for **AMT**s and inspectors. These regulations have a major effect on how aviation maintenance jobs are designed. However, recent work in the MRM (see **Chapter 16**) and training areas[8] demonstrate that effective job design changes can be successfully implemented.

CONCEPTS

While several concepts are associated with work design, most are not unique to this topic. These concepts are applied generally throughout the human factors discipline. Some are commonly applied outside the practice of human factors. Our intent in this section is to describe the concepts most directly applicable to work design and to show how they are used within the context of aviation maintenance.

Fitting the Job to the Worker

In the human factors world, we essentially have two choices when we try to fit the job and the worker together -- we can change the job or we can try to change the worker. We change the job by using the workplace and job design methods described in this chapter. We change the worker's behavior by selection, placement, motivation, and training. Our first choice always is to change the job before attempting to change the worker.

Even when we have to change the worker, it is worthwhile to first modify the job as much as possible. Proper workplace and job-design techniques provide the best foundation to support any required changes in worker behavior. Addressing workplace and job changes first minimizes the range of worker behavior to be modified. Proper workplace and job design also increases the probability that subsequent behavior changes can be successful.

The following are key principles for workplace design:

- Reduce unsafe, heavy, or uncomfortable loading on the body by using human size (anthropometric) data
- Design for the **range** of human capabilities in the intended population, not for the average
- Repeated actions by a worker may be unhealthy or unsafe, even if a single action of the same type is well within his or her capabilities.

The following basic principles of job design come from the fields of function allocation[21] and organization systems design[22]:

- Assign to workers tasks for which humans are well-suited; assign other tasks to machines or computers
- Combine tasks into satisfying and healthy jobs
- Design the technical and social systems together, rather than trying to adapt the social system to a pre-designed technical system.

Key Variances

Certain elements of any human-machine system affect its product or outcome more than other elements. For example, let's examine a well-defined task like drilling a hole in a piece of aluminum. The primary elements in this system include the aluminum, the drill, the drill bit, and the AMT. There are many elements in this simple system, such as the ambient working environment. However, let's list only those variables that are most directly related to the outcome of this task.

Variables that are most likely to affect the operation's outcome include the aluminum's type and condition, the drill bit's size and sharpness, the drill's rotational speed, the operator's ability to hold the drill at the proper drilling angle, and pressure applied to the drill. The elements or variables that can most dramatically affect the outcome of a task are called key variances.

Identifying key variances is an important step for making any system more efficient. A good way to think of this concept is that we are trying to get the biggest bang for our buck. The elements that have the biggest effect on the outcome of a task are also most likely to provide the biggest payback when they are improved. After we identify key variances in a maintenance task, we can build hardware, software, or worker-oriented processes, such as training, into the system to control the variances.

It is important to control key variances as close to their sources as possible. For example, in a cleaning process, the AMTs actually doing the cleaning can have the most direct effect on the outcome. Therefore, it is more efficient for AMTs to improve the process than to have an inspector try to affect it at a later stage. Cleaners should accurately assess how clean is clean enough, rather than saying "It's OK if it is not clean enough because the inspector will tell me."

Socio-Technical Systems

The tradition in aviation maintenance has been to consider the technical and social aspects of work as separate. Thus, facility designers are responsible for such elements as lighting and workstands while personnel/human resources departments are responsible for elements like job content, organization, and work scheduling. It is becoming increasingly clear, however, that there is considerable benefit in recognizing that the social and technical aspects of work interact as a "socio-technical system."

Oil refineries, chemical plants, and precision parts manufacturers have made improvements by joining and optimizing work's technical aspects, i.e., how functions can be performed correctly, and work's organizational aspects, i.e., how functions are combined into jobs. Such tight coupling of the social and technical elements of work sometimes occurs naturally. A good example is the assignment of **AMT**s to particular shiftwork schedules. The quality of work on various shifts is often as much a function of the available social support mechanisms as of the technical capabilities of workers. Considering both the social and the technical elements of shiftwork reflects this reality, producing better performance and higher worker satisfaction.

Systems Approach

Work design is based on a systems view of the world that includes the following premises:

- All elements in the aviation maintenance environment interact.
- Work design should proceed from the organization's high-level mission and objectives to individual job and workplace requirements.

The work design process is iterative. We typically expend considerable thought and effort in the initial design of work - The "Get it right the first time" concept. Regardless of the effectiveness of our first design, the benefits of incremental change through continuous improvement are substantial and should not be neglected.

The effort expended on the initial design of individual workplace elements should reflect how critical the element is to performance of the overall system. It is cost-effective to pre-design large, costly equipment items such as aircraft structures, control rooms, or fixed access stands. However, smaller items such as adjustable seating, hand tools, or computer workstations can be part of a continuous improvement program.

User Population

Systems or items we design will probably not be used by everyone. Most products, especially most technical products, are designed with a specific set of users in mind. The people for whom we design are known as the *user population* and can be defined by both physical and mental (or cognitive) characteristics. For example, we might characterize a user population by their body size distribution and by their range of skills and knowledge. A user population for work stands may be "all US males and females aged 20 to 65 years"; for computer-based workcards, it may be "all current inspection personnel."

The more detailed our description of the user population, the easier it is for us to simplify the work design and ensure it matches users' specific needs. However, a design must not be tailored for only current job incumbents. To do so might make the workplace unusable for people who are not now in the workforce.

METHODS

The methods used during the work design process are common to many other human factors activities. However, each method's emphasis changes, depending on why one is using the method. Our descriptions below focus on how to use the methods in work design. The discussions begin at the broad level and proceed to specific design elements.

Organizational Systems Analysis

Organizational systems analysis begins at the most general level of defining the organization and its interactions with its environment. It starts broadly so as to define technical variables that must be controlled and the social system that must control them. For example, the technical system in inspection defines defects that have to be found to maintain airworthiness and when the defects must be located. The social system consists of inspectors, planners and support personnel, including training, shared knowledge, goals, and communication systems. The high-level approach identifies required functions, i.e., what has to be achieved.

International human factors authorities recently identified the socio-technical systems approach as useful for improving aviation safety and efficiency.[23] This type of analysis established its usefulness by contributing to an understanding of airline maintenance in the United States. An **FAA**-sponsored study of eight U.S. maintenance bases examined the interaction of mechanics, foremen, and support staff, focusing on how technical goals are articulated and accomplished. Specifically, it used methods of socio-technical system analysis to examine cooperation and communication in the social system.[24]

The study found that maintenance people do not always completely understand their company's policies and goals or their individual roles in meeting the goals. The study confirmed that effective communication is the most important factor for ensuring coordination and good work performance. Effects of assigning a low priority to communication include the following:

- More jobs late due to maintenance
- Employee turnover higher than average
- Low morale among maintenance, inspection, planning, stores, and shop employees.

What and Who?

Defining *what* has to be done and *who* has to do it serves as the bridge between the overall organizational system and the detailed work design. Definitions are generated for job functions and for the user population.

Job functions describe transformations to be performed. For example, in a structural inspection task, a reasonable transformation might be the following: *Undetected* 1-inch crack in a pressure bulkhead mounting is transformed to *detected* 1-inch crack. Note that this description includes only what must be done, not how it will be accomplished. Functional analysis eventually provides a list of tasks to be performed.

We define users by both their physical characteristics and their range of knowledge and skills. The physical characteristics, along with detailed task elements, are used to design the physical workplace. Knowledge, skills, aptitudes, and task elements are used to identify work-related information requirements.

We do not generally have to measure the physical characteristics of our own **AMT**s, since data are available on the body sizes of many populations. Likewise, we probably won't have to measure the cognitive characteristics of our AMT population, since their employment and training records should contain enough data related to their knowledge and skill.

At this stage in the work design process, we concentrate on *what* and *who*, not *how*. As the design becomes more concrete, the human and machine roles can be more precisely defined. Using **task analysis** (see Chapter 1), the function definitions are used to generate task descriptions.

During this analysis, we do not concentrate only on the way things are now done. Instead, we try to identify functions that must be supported and define how they are best performed. Regardless of how they are generated, task descriptions and task analysis are the basis of detailed work design.

Detailed Design

Eventually, task analyses and population characteristics must be converted into real work design elements, such as workspaces, tools and fixtures, software applications, workcards, etc. The design procedures described below are typically used to transform the results of the preceding analytical activities into workplace elements.

Anthropometry is the study of human body sizes (see **Chapter 1**). It provides the basis for physical workplace design. Anthropometric data allow us to make quantitative decisions so that work benches, chairs, and hand tools will fit a known percentage of the population. For example, 51% of males and 1% of females in the US population can see over a shelf located 65 inches above the floor. These percentages increase to 100% of males and 95% of females for a shelf 57 inches high.

Similar data on how people see, read, and interpret written instructions and graphics are used to design information-related workplace elements. Most of these design data have been codified into rules and guidelines. For example, Simplified English allows relatively error-free transmission of written information. Certain fonts, formats, and page layouts can increase reading comprehension and reduce interpretation errors and confusion.

Prototype Testing

While guidelines can answer many design questions, user input is obtained most readily with simple tests on prototypes of workplace components. We often think of prototypes and mock-ups as applying only to physical elements, such as work benches and fixtures. However, it is equally feasible, and desirable, to build prototypes of written job aids, such as workcards, communication protocols, and general workplace procedures.

Prototype testing aims to ensure that the user population can actually use the components we have designed. Unfortunately, such tests are often used to elicit encouraging noises from powerless users reviewing a completed design. This is really a waste of time, since finished designs are rarely scrapped, even if they are only marginally usable. Instead, prototype testing should be seen as an early opportunity to identify problems and to modify components before they are placed into general use.

Physical mock-ups can be constructed with simple cardboard, foam core, and duct tape. They can be modified to ensure anthropometric fit. Modern word processors easily change documents' wording, fonts, and layout to reflect user input. Although the time required for prototype testing is a small fraction of the complete analysis-design-construction-implementation effort, its rewards are great.

READER TASKS

Work design is a systematic process involving a series of steps performed in a specific order. Following the concept of top-down design, work design addresses the most general issues before proceeding to detailed requirements. In this *Guide*, we describe work design in terms of an overall system design. Organizations that used this process to restructure the way they work report increased productivity, quality, and satisfaction.

Most steps in the design process require expert human factors assistance and the active involvement of both management and workers. Because of its complexity, the design process requires some level of expert human factors background or support. To help readers understand the organizational systems design process' general structure and flow, we first briefly describe each design step. Then, we describe the workplace and equipment design step in detail.

The Organizational Systems Design Process

Keeping the above caveats in mind, we offer steps leading to better work design. A suitable source for more detail is Taylor and Felten's *Performance by Design*.[22]

Step 1: Understand your system

Define the organization's boundaries, its technical and social systems' inputs and outputs. What is the organization's mission, and what goals fulfill that mission?

Step 2: Define key variances

To transform the system's input (un-repaired aircraft) into its output (inspected, repaired, and correctly-released aircraft), what key variables must be controlled? Begin by defining major operations performed on each system input, e.g., cleaning, opening, inspecting, repair, or release. List variables that are critical to the quality of each operation. These are the "key variances". For example, after cleaning a part, the visibility of defects in or on that part is the key indicator of the quality of the cleaning operation. Therefore, "visibility of defects" is a key variance.

Step 3: Control key variances

The idea behind identifying key variances is to increase their positive effects, that is, to control them. Each key variance must be controlled for the system effectively to transform input into output. Typically, there are many ways to control key variances. In the cleaning example, above, we could subject the part to several levels of inspection to ensure that it has been cleaned properly. However, this is not a very efficient control strategy.

It is much more efficient to control each variance as close to its source as possible. Therefore, our focus in the example should be on the **AMT**s who actually perform the cleaning operation. It is worthwhile to note that controlling key variances is both a social and a technical process. We must account for the "people" components of this step as well as the strictly technical components, such as test equipment. For example, it does little good to supply AMTs with the most modern cleaning equipment if we have established a working atmosphere in which workers are afraid to question each other's actions.

Step 4: Define and Allocate Functions

The first step for controlling a variance is to determine functions necessary for control. Although task analysis (see **Chapters 1** and **2**) can help, organizational systems design focuses more on transforming the product (function) than on a sequence of an operator's task (task steps). Once functions are defined, they must be allocated to machines, to people, or to both.[21] Machines must perform functions such as sensing X-rays, applying force necessary for riveting, or calculating optimum schedules, as these are beyond human capabilities. Functions that people must do include inductive reasoning, making decisions on complex fault indications, or signing-off repairs.

Functions between these extremes, in principle, could be performed by a human, by a machine, or by a combination of both. Examples of such functions include stepping through a checklist or classifying an eddy current indication. To allocate these functions to a human or to a machine, consider the following:

- Which will lead to the fewest errors?
- Which is the most reliable for long-term operation?
- Which best fits the set of tasks which comprise a job?

Allocating all functions that *can* be automated to a machine leaves people in the system with poorly-designed jobs. Such "leftover" jobs are likely to be error-prone and should be avoided.

Step 5: Design Workplace and Equipment

When the functions assigned to people and to machines are known, basic data are available for designing the workplace. See Chapter 2 for a **discussion of operator involvement in the design process**; it is a necessary part of any system designed to be implemented. We describe this step in detail below. This is the only step in the work design process that can or should be undertaken without expert human factors involvement.

Step 6: Design of the Social System

Parallel to detailed workplace and equipment design, functions must be organized into meaningful jobs. Jobs should not be assigned at random or for convenience, but to ensure that jobs are meaningful, satisfying, and healthy. Based on studies of stress-related workplace diseases, Karasek and Theorell[25] define healthy jobs as those with a high decision latitude. Unhealthy jobs have both a low decision latitude and a high perceived workload. Taylor and Felten[22] argue that a high-quality working life arises from the "four C's":

- Recognized COMPETENCE at the workplace
- Acknowledged CENTRALITY, or real relevance in applying that competence
- Shared COMMITMENT to the purposes of the enterprise
- Joint CONTROL on the product and process.

Both design prescriptions emphasize operators' control over their jobs. Most enterprises find that good jobs include some element of multi-functional teams empowered to change jobs and functions in a bottom-up manner to make process improvements.

Step 7: Design for Continuing Improvement

An organization fails when it cannot adapt to the changing environment, as the generations of former airlines show. Indeed, the life-span of a corporation, even one in the Fortune 1000, is 50-80 years, about the same as a person's. To adapt, an organization must be able to change itself more rapidly than the outside environment changes. One way to do this is continually to change and improve the way it accomplishes its mission. At the level of job and workplace design, this implies continuous improvement, involving both the workforce and subject matter experts as change agents. See **Chapter 2** for a discussion of how such a program could apply to workplaces and jobs.

Workplace and Equipment Design

Moving from the requirements of the organizational design process generates a working system that is relatively straightforward, at least in principle. The process uses classic human factors principles to "fit the job to the worker" as worker tasks are translated into tool sizes, workbench heights, control positions, workcards, etc.

We use the collective term *workplace and equipment* very generally. The intent of work design is as follows:

- To determine what the human worker must do
- To identify information, tools, controls, and procedures required to do it
- To supply these elements in the proper size, form, and format.

To meet this intent, work design must consider the range of workplace and job elements contributing to effective task support. At the minimum, these elements include the following:

- workbenches
- chairs
- fixtures
- task lighting
- tools
- test equipment
- computer interfaces
- procedures
- workcards
- instruction manuals
- technical specifications

Of course, the human maintenance technician or inspector is central to all elements.

See this chapter's **GUIDELINES** section for specific information regarding steps in designing workplaces and equipment.

GUIDELINES

General levels of organizational design such as identifying goals, functions, and objectives don't lend themselves to generalized, prescriptive guidelines. There are no simple prescriptions, e.g., "Always work in teams," that are as applicable as workplace prescriptions, e.g., "Always locate tools within the operator's reach envelope." Organizations following simple prescriptions, such as "Buy better chairs," have not realized benefits because the main issues constraining quality, productivity, and satisfaction are social as well as technical.

This is why we do not recommend that readers attempt general, analytical tasks in the overall design process. These tasks require professional assistance. However, there are detailed tasks that can be undertaken with only a modicum of professional support. In this section, we provide guidelines for the general task of workplace and equipment design. Equipment includes items such as workbenches, tables, chairs, tools, and test equipment.

General Work Design Tasks

Before designing *anything*, it is necessary to understand what tasks and actions need to be supported. After fully defining tasks, we then determine relevant characteristics of workers who will be performing the tasks.

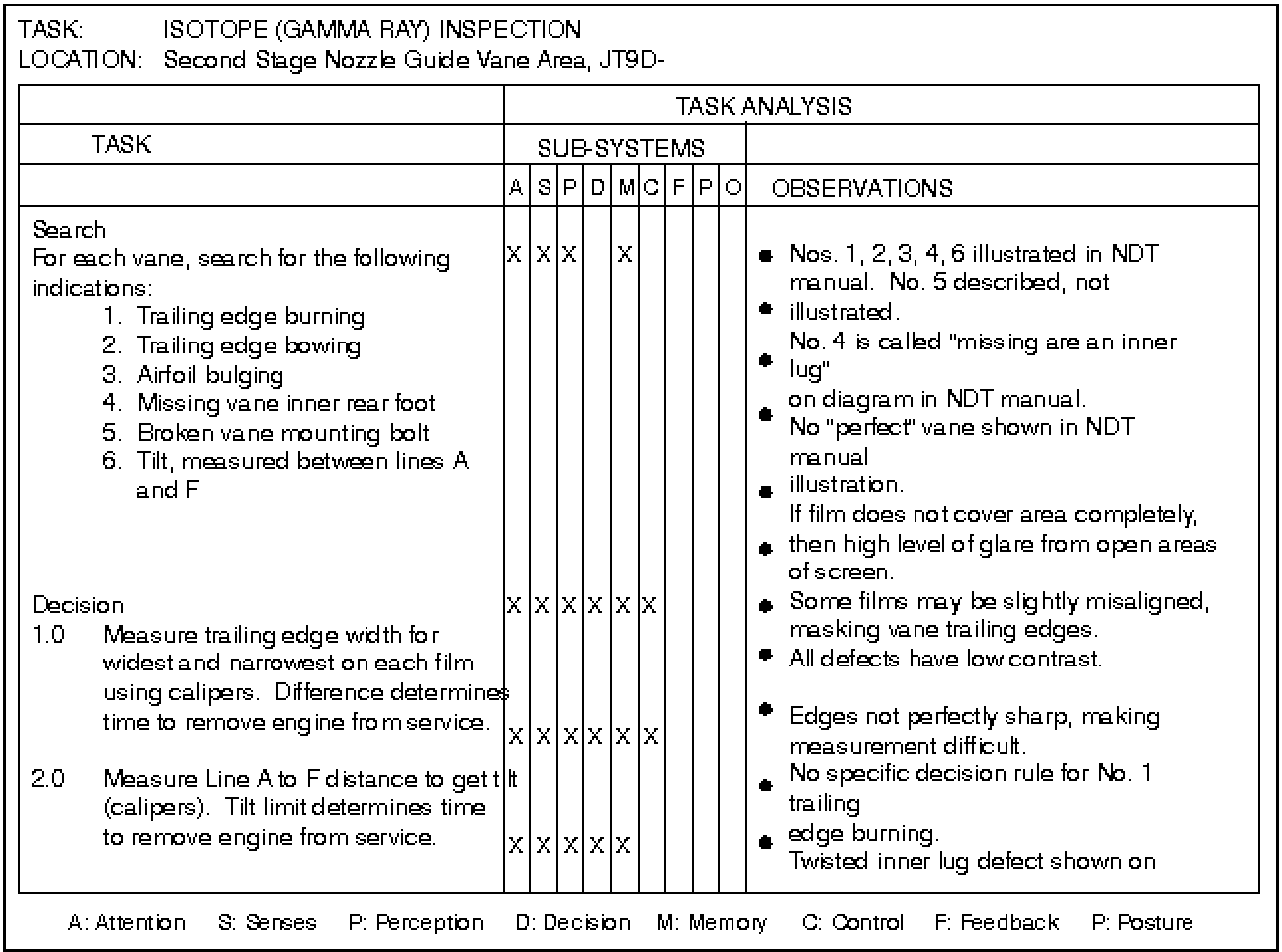
Define Tasks

Early in the design process, we define a set of functional requirements for the job being evaluated. In the overall design process described earlier, the requirements are developed in **Step 4**. The requirements now are expanded into individual tasks, and the tasks into steps. To accomplish this, we use task description and task analysis.

As an example of the level of detail necessary for task analysis, consider a common function such as "Landing Gear Maintenance." A task within that function might be, "Replace the nose landing gear tire." A reasonable sub-task would be, "Remove wheel from **NLG**." Task steps in this process need to be listed. Each step should include the object worked on, e.g., nut, the task step's nature, e.g., unscrew, and any tools used, e.g., socket wrench. Task definitions provide a list of objects and tools needed at the workplace, and the sequence of actions.

Actions often involve information processing as well as, or in place of, physical movement. **Figure 6-1** is an example task analysis form for an **NDI** activity.

There are many ways to perform task analysis. We can directly observe people actually doing existing tasks. There are two common methods for task analyzing of new tasks. First, we can identify a similar task, observe people doing it, and use logical judgment to bridge the gap between existing and new tasks. If no similar task exists (which is rare), we rely entirely on logical analysis.



TASK: ISOTOPE (GAMMA RAY) INSPECTION
LOCATION: Second Stage Nozzle Guide Vane Area, JT9D-

	TASK ANALYSIS									
TASK	SUB-SYSTEMS									
	A	S	P	D	M	C	F	P	O	OBSERVATIONS
Search For each vane, search for the following indications: 1. Trailing edge burning 2. Trailing edge bowing 3. Airfoil bulging 4. Missing vane inner rear foot 5. Broken vane mounting bolt 6. Tilt, measured between lines A and F	X	X	X		X					• Nos. 1, 2, 3, 4, 6 illustrated in NDT manual. No. 5 described, not illustrated. • No. 4 is called "missing are an inner lug" on diagram in NDT manual. • No "perfect" vane shown in NDT manual illustration. • If film does not cover area completely, then high level of glare from open areas of screen.
Decision 1.0 Measure trailing edge width for widest and narrowest on each film using calipers. Difference determines time to remove engine from service.	X	X	X	X	X	X				• Some films may be slightly misaligned, masking vane trailing edges. • All defects have low contrast.
	X	X	X	X	X	X				• Edges not perfectly sharp, making measurement difficult. • No specific decision rule for No. 1 trailing edge burning.
2.0 Measure Line A to F distance to get tilt (calipers). Tilt limit determines time to remove engine from service.	X	X	X	X	X					• Twisted inner lug defect shown on

A: Attention S: Senses P: Perception D: Decision M: Memory C: Control F: Feedback P: Posture

Figure 6-1. *Example task analysis form showing an NDI activity*

Define User Population

Human factors practitioners must define who will perform the task. A definition of the user population enables designers to consider users' capabilities and limitations in the design process.

Most maintenance tasks involve both physical **and** information-based elements. A typical **NDI** task involves physical access to a part, placement of the test probe and readout equipment, a step-by-step test procedure, interpretation of test results, and recording the results. Because of the mix of physical and information-based elements, we need to establish the user population's physical and cognitive characteristics.

The user population in maintenance and inspection is composed of technicians and inspectors working in the maintenance organization. Several factors simplify the job of defining this user population. First, almost all **AMT**s and inspectors have a common training background and similar work experience, differing only in specialization and years on the job. Aircraft maintenance workers and supervisors are drawn from the general population. They are not hired based on characteristics such as physical stature, strength, and gender. This user population is typically stable over time.

As far as physical body measurements are concerned, we can assume that there is nothing remarkable about aviation maintenance workers. We can use current population data for body dimensions. We further assume that users understand terminology used for aviation equipment and procedures.

Define Work Variation Requirements

We are all familiar with the idea that workers performing heavy physical tasks need to rest periodically. Most aviation maintenance tasks do not involve heavy physical exertion over long periods of time. However, there is ample research to show that repetitive, boring, and mentally-demanding tasks also reduce performance over the course of a normal work shift. These performance decrements can be the result of sensory fatigue, such as with demanding visual inspection tasks, boredom, tasks being too easy or too hard, lack of motivation, or other causes. As part of the work design process, we need to determine whether performance on certain tasks is likely to be subject to such problems. There are essentially two ways to reduce or eliminate task-related performance decrements: varying the task and providing periodic rest breaks (or some combination).[26]

Varying the task. A study by Murrell[27] showed that productivity improved dramatically when workers were allowed to alternate among different types of tasks through the course of their shift. Apparently, switching among tasks that require different types of resources, e.g., muscular versus mental, allows workers to recover from the fatigue of specific resources. The following guidelines should be considered when designing maintenance jobs:[26]

- Alternate tasks that are physically demanding with tasks that are perceptually demanding.
- Alternate tasks that have high perceptual demand with tasks that have lower perceptual demands.
- Alternate long-duration tasks with short-duration tasks.
- Design jobs and workspaces to promote frequent changes in posture. Require workers to significantly change their posture, e.g., move from a sitting to a standing position, *at least once per hour*.
- Provide frequent breaks for workers performing continuous monitoring tasks, especially for tasks that are machine-paced. Monitoring performance degrades significantly after about one-half hour.

Providing periodic rest breaks. It has been known for many years that providing short periodic rest breaks results in more consistent (and productive) job performance than requiring continuous work with only a single lunch period. In one such study, conducted in 1959,[28] the performance of workers given a 5-minute break each hour was compared with that of workers given only a lunch break. Workers on the continuous schedule began the shift working faster than those on the rest-break schedule. However, by the end of the shift workers on a continuous schedule were much slower than the others. Overall, workers on the rest-break schedule were *more* productive than their counterparts.

We should note here that "rest" breaks don't necessarily mean periods of no work. Breaks can simply be a change from one type of work to another, as described above. The point to be made is that simply being on the job does not guarantee that workers are being productive. For certain types of jobs, providing frequent rest breaks will actually improve performance.

Physical Equipment Design

In this section, we delineate steps required to move from specific task requirements to physical workplace equipment design. Most steps relate to choosing correct physical dimensions for the equipment in question. Although two general design steps are described above, we repeat issues dealing directly with physical equipment design.

Define User Physical Dimensions

Data pertaining to users' body dimensions can either be found in databases of body measurements, i.e., in anthropometry, or generated from observing and evaluating carefully chosen people in a full-size mockup. Either way - or, as is more usual, both ways - poor fit between the worker and the task can be reduced or eliminated before costly hardware is designed or procured.

A population of potential users, such as **AMT**s, does not coincide exactly with any existing database of body measurements. The safest assumption is that a user population is drawn from the general US population. Because the United States has been a melting-pot for generations, we have high variability in body sizes. A design that fits a large fraction of the US population generally accommodates overseas populations without major modification.

Since civil aircraft and equipment are designed for an international market, designing for the majority of the US population is good strategy on the part of US manufacturers. It's a good strategy also for designing physical equipment in the maintenance environment because it ensures that a design will be inclusive, not exclusive. Although most **AMT**s currently are male, Caucasian, and older,[29] designing for this group will make it difficult for a more diverse **AMT** population to perform the job.

Figure 6-2 and the associated data table (**Table 6-2**) contain anthropometric data reasonably estimating the United States' current population.[30] These data allow for clothing dimensions, shoes, and gripping positions. More precise data are available of people measured under highly controlled and repeatable conditions, typically nude and with reach measurements made to the tips of the fingers, rather than to the position of a gripped tool.

Male and female data are separate because each dimension is approximately normally distributed within each gender. However, adding the two genders together produces a non-normal distribution that is harder to deal with statistically.

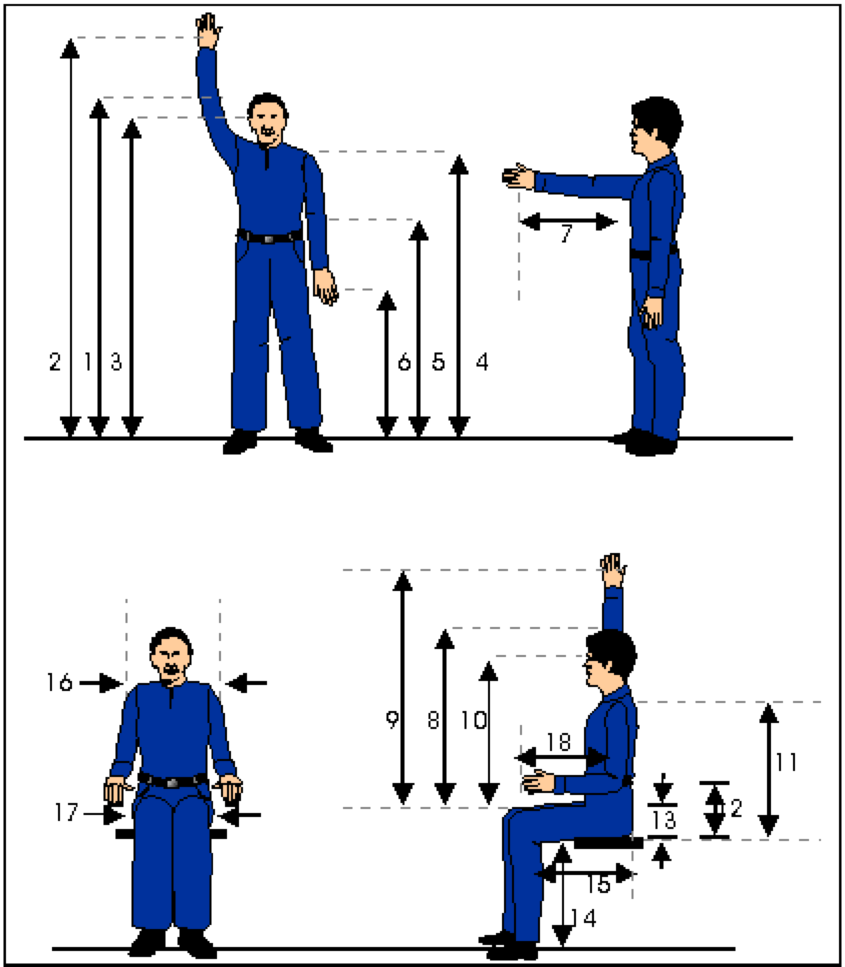


Figure 6-2. *Anthropometric measurement points*

We can use data in **Table 6-2** to ensure that our design accommodates known percentages of both male and female populations. No data are included on range of motion or on maximum strengths. When a simple **mock-up** is built, complex three-dimensional range-of-motion restrictions quickly become evident in a way that data tables do not facilitate. Strength data are important, but need some application of work physiology to be successfully used, particularly with repeated movements. If mock-up users feel that applied force is likely to be a problem, consult an ergonomist/human factors engineer.

Table 6-2. Anthropometric data for the current US population (unit of measure is inches)

	Male	Female

Dimension	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**
Standing						
Stature (1)	64.6	68.9	73.2	60.0	64.0	68.0
Overhead reach (2)	79.6	85.0	90.4	75.3	80.9	86.5
Eye height (3)	60.9	64.9	68.9	56.2	59.8	63.4
Shoulder height (4)	52.8	56.8	60.8	47.6	52.1	56.6
Elbow height (5)	40.7	43.7	46.7	38.3	40.6	42.9
Knuckle height (6)	27.3	29.9	32.5	25.5	28.2	30.8
Forward reach (7)	18.6	24.4	30.2	19.5	23.8	28.1
Sitting						
Seated height (8)	31.0	33.5	36.0	28.0	30.6	33.2
Overhead reach (9)	45.1	50.6	56.0	42.9	47.2	51.5
Eye height (10)	27.1	29.4	31.7	25.4	27.4	29.4
Shoulder height (11)	20.9	22.9	24.9	19.6	21.2	22.9
Elbow rest height (12)	7.4	9.5	11.6	7.1	9.1	11.1
Thigh thickness (13)	4.8	5.8	6.8	4.1	4.9	5.7
Seat height (14)	16.6	18.2	19.9	16.0	17.2	18.4
Seat length (15)	17.6	19.2	20.9	16.9	18.9	20.9
Shoulder breadth (16)	17.4	18.7	20.0	14.9	16.2	17.5
Hip breadth (17)	13.3	14.8	16.3	14.2	15.8	17.5
Elbow reach (18)	12.7	14.2	15.7	10.9	12.7	14.5
Weight (lb.)	129	183	238	96	146	197

Computer-based anthropometric data tables, such as Body Size^{TM}, are very convenient to use. These tables can calculate virtually any population percentile of interest. In practice, data tables are such a small part of ergonomic design that the cost of computerized tables is rarely justified outside specialized human factors groups.

Define Population Percentiles

The decision at this point is what percentage of the population defined above will our design accommodate. The easy answer is "100%." But this literally means using the *Guinness Book of*

Records; it means that all doorways will be 9 feet high. A more practical approach is for the basic design to fit a large percentage of the population and then to use special-purpose modifications for the small fraction of users un-able to use the basic design. When costs of accommodating all potential users are reasonable, accommodate all in the basic design. For example, corridors are usually designed to accommodate two or three less-extreme users; they can be designed, instead, to clear the widest person in the population.

The traditional choice of design percentiles has been "5th percentile female to 95th percentile male" for most civilian applications and "2nd percentile female to 98th percentile male" for the military. Since the range of body sizes in the military is somewhat curtailed by selection, there is not much practical difference between these two design guides.

For the civilian guide, the 5th percentile female excludes the 5% of smaller (or lighter, or with shorter reach, etc.) females and almost no males. The 95th percentile male includes 95% of males and almost all females. Thus, "5th percentile female to 95th percentile male" includes all but 5% of females and 5% of males, i.e., it includes 95% of a mixed population. **Table 6-2** is arranged so that these two "design percentiles" are shown together in the center of the table.

Choosing percentiles is one of the design trade-offs. A highly accommodating design may be more costly initially. However, the larger the fraction of the population the basic design fits, the less costly any recurrent post-fitting will be. We recommend the "5th percentile female to 95th percentile male" standard as a first step. If you need other percentiles, consult data compilations (see **references 34 and 35**) and ensure that an experienced ergonomist/human factors engineer is part of the design team.

There are few workplaces for which single-gender design is appropriate. As traditional job roles fade, the only remaining gender-segregated facilities will probably be rest rooms and locker rooms.

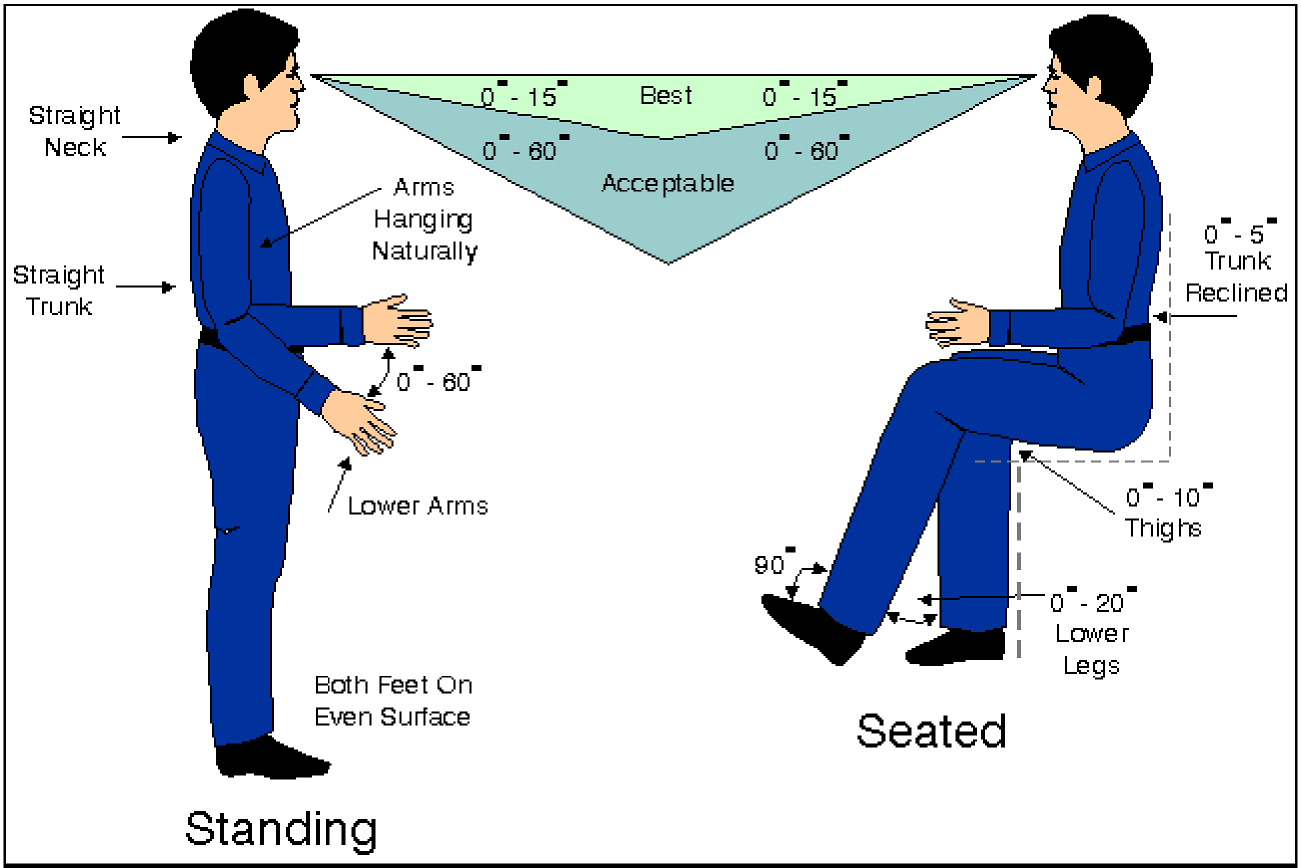


Figure 6-3. *Good postures for standing and seated work.*

Use Pre-existing Solutions

Standard solutions for problems in anthropometric design exist in many common workplaces. By defining our user characteristics in terms of the overall US population, we can avail ourselves of pre-existing workplace solutions. There are good solutions for standing workplaces at benches, for seated workplaces, for doorway and walkway design, for size and angle of steps/ladders, and for grip sizes of handles and hand tools.

Many standard solutions are given below. They all allow people to assume postures giving long-term comfort, efficiency, and safety. Typical recommended postures are shown in **Figure 6-3**.

For recurrent design elements, there is no need to go further than this section. Task-specific elements like a special holding fixture can be added to the basic designs, saving a tremendous amount of time and energy during design.

Standing Workplace Dimensions. For standing workplaces, the work height, i.e., the point the hands touch, should be 2 inches or more below elbow height. This height is a compromise between three factors:

- Manual dexterity is best just below elbow height
- Physical load handling capacity is best somewhat lower, about waist height

- Visual control is best as high as possible, certainly above elbow height.

Because elbow heights vary (see **Table 6-2**), work point heights should also. A bench or counter surface with different heights available can accommodate different people and tasks. The standard 39-inch US counter height is rarely ideal as height should be adjustable from approximately 36.5 to 44.5 inches to meet the "2 inches below elbow height" criterion.

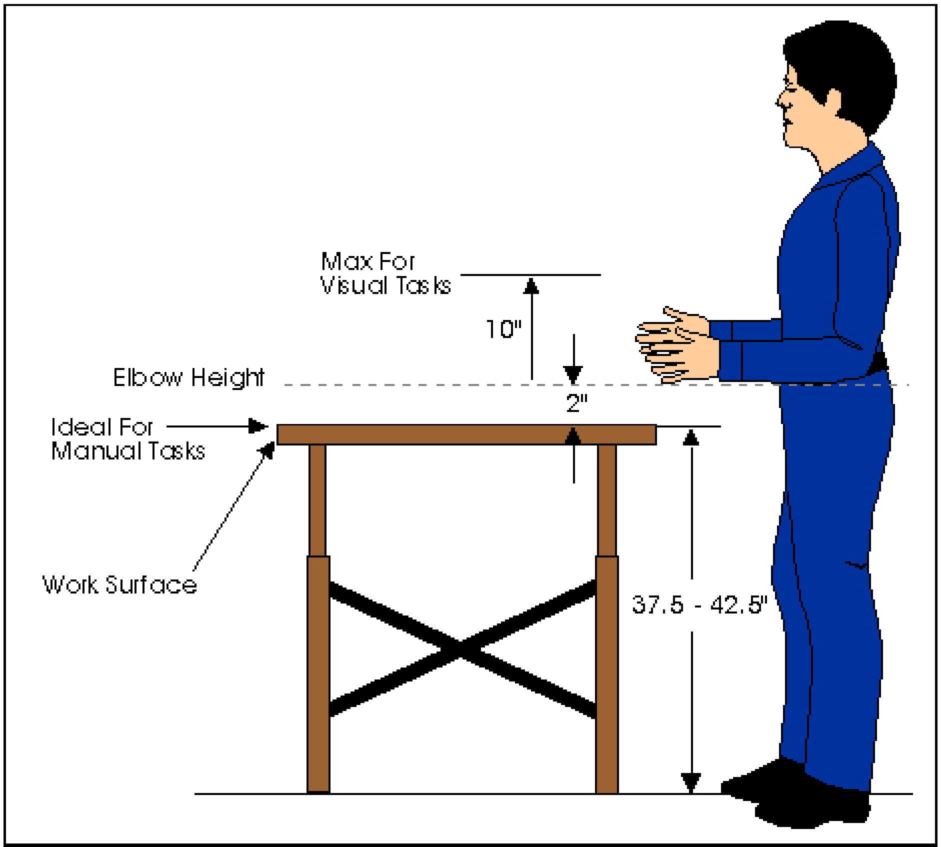


Figure 6-4. *Standing workplace dimensions*

When visual requirements predominate, as they do in many maintenance and inspection tasks, work points can be up to 10 inches above elbow height, with elbow-height padded edges to support the elbows and prevent static loading of the shoulder muscles. Improved lighting and task contrast can reduce visual requirements, allowing the work surface to be lower. Soft standing pads can improve comfort in long-term standing jobs.[31] **Figure 6-4** depicts the dimensions and adjustments associated with standing workplaces.

Seated workplace dimensions. Recommended design dimensions for seated workplaces appear in **Figure 6-5**. These recommendations come from a variety of sources.[20,30,32] As for standing workplaces, counter height is less important than the workpoint's height. Again, note that good lighting and task contrast can ease visual requirements.

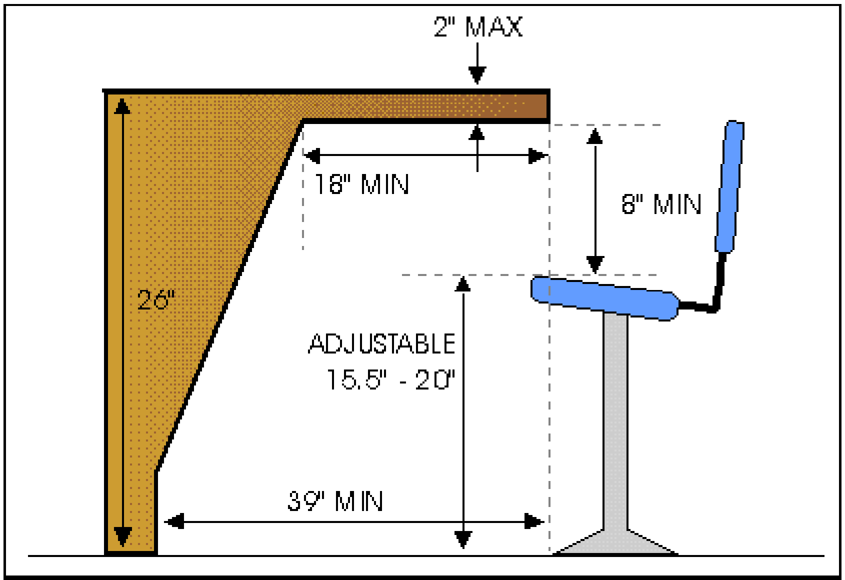


Figure 6-5. *Seated workplace dimensions*

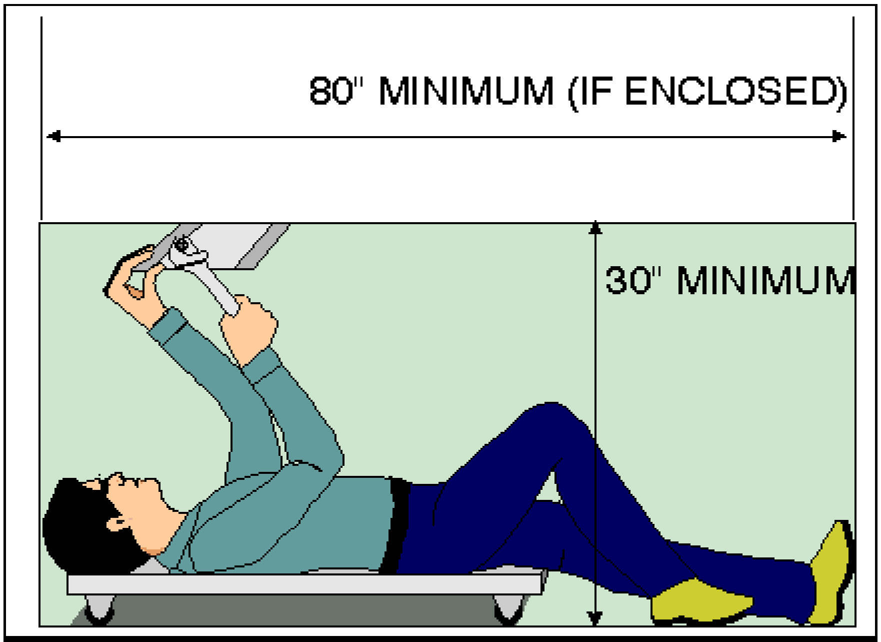


Figure 6-6. *Horizontal workplace dimensions*

Horizontal workplace dimensions. For certain aviation maintenance tasks, it is sometimes necessary for technicians to work while laying on their back (or stomach). For such horizontal workplaces, the recommended minimum design dimensions are shown in **Figure 6-6**. These recommendations come from military and industrial sources.[33,34] Horizontal workplaces are to be avoided, if possible. Workers are subject to falling objects and fluids when working in a laying down position. Also, properly lighting the work area for such a posture is difficult.

Computer workplace dimensions. The recommended dimensions in **Figure 6-7** are for workplaces with a screen and a keyboard. These recommendations are from the Human Factors Society/ANSI Standard 100/1988.[20] For standing computer workplaces (only recommended for occasional use) adjust the keyboard height to elbow height (Figure 6-4) and place the monitor screen in the 0° to 60° downward viewing angle shown in Figure 6-7.

Chair design. There are many good papers on the design[35] and evaluation[36] of chairs for workplaces. Dimensions in Figure 6-8 are compiled from a variety of sources.[32,36]

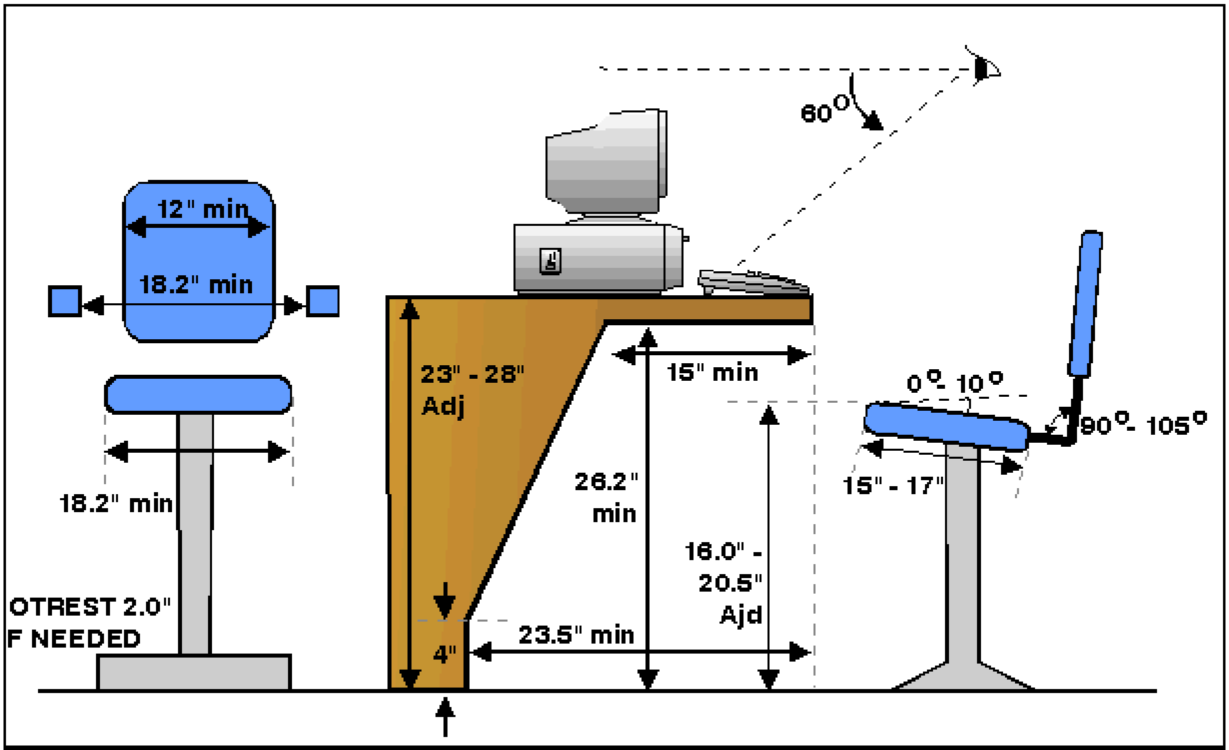


Figure 6-7. Computer workplace dimensions

Handle design. The hand/handle interface is important to ensure that operators easily move and control equipment and tools. Figure 6-9 shows guidelines for handle design.[37]

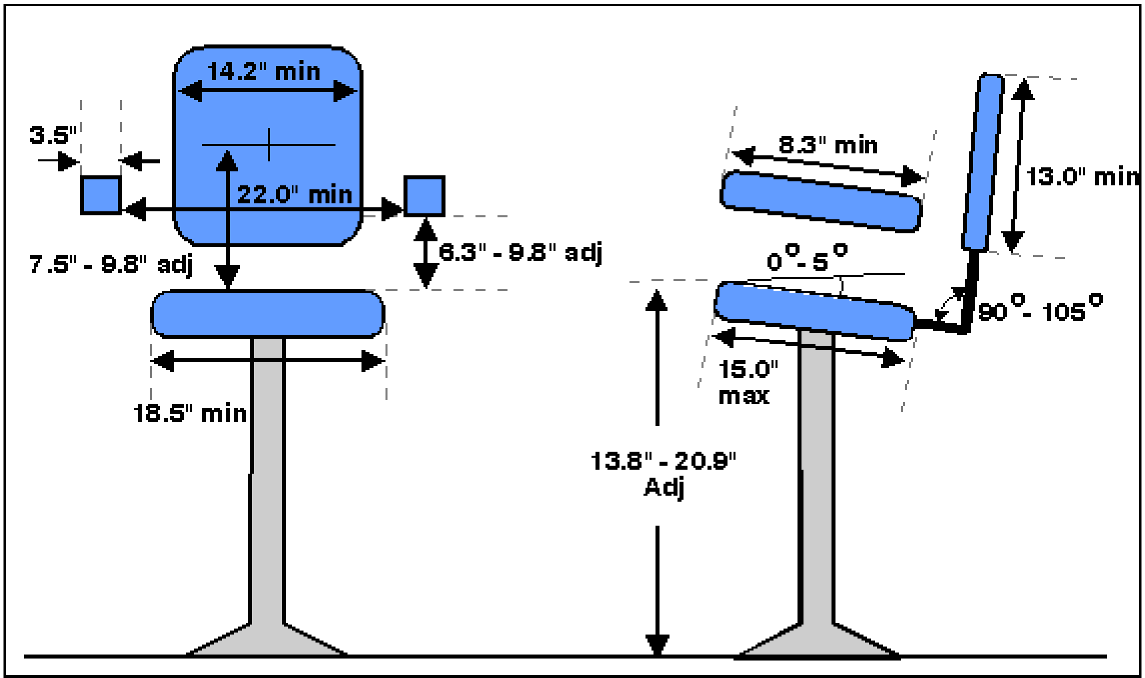


Figure 6-8. Chair dimensions

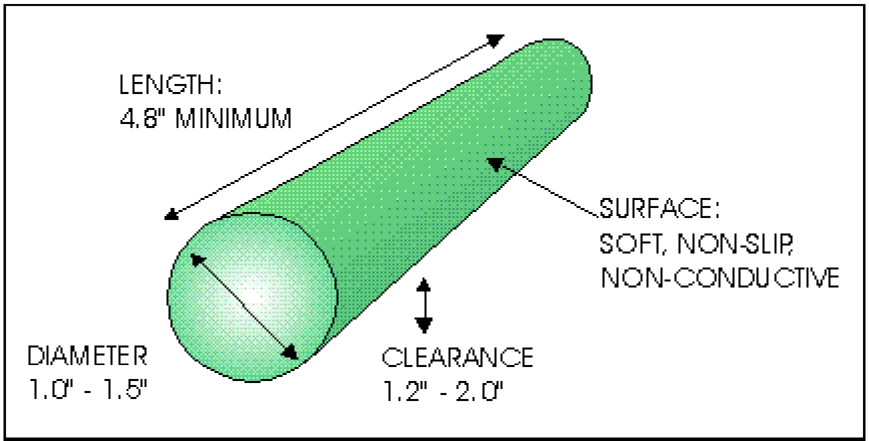


Figure 6-9. Handle dimensions

Hand tool and power tool design. For ease of use and accuracy of control, tools should be as light and well-balanced as possible. Power cords and air hoses should be light and flexible. The main principle of tool design is using the body to best advantage by ensuring that torque and forces are effectively transmitted through the tool to the task. For example, since axial torque is critical for screwdrivers, they should have a larger diameter handle than handles used for carrying.

Power tool handles should allow the wrist to remain in a neutral position. **Chapter 3** describes why a neutral wrist posture is essential to safety. The rule is to bend the handle, not the wrist. That is why a pistol grip drill is good for drilling horizontal holes, and a straight-through grip is better for drilling vertical holes on a surface at bench height. Pistol grips can also be effective for overhead use. **Figure 6-10** shows appropriate handles for different tasks.

There are a number of commercially available hand tools that incorporate ergonomic principles in their design. These tools tend to be slightly more expensive than their non-ergonomic counterparts, but various studies have shown them to be quite effective in reducing tool-related injuries. For a more complete discussion of hand tool and power tool design see **references 33 and 38**.

Use Anthropometric Design Principles

We cannot use body size data to design without principles for applying those data. For example, reasoning that a design should accommodate the "average" person, hence using the 50th percentile, would be an error. The tallest 50% of the population could not use a door designed for the "average person." Conversely, The shortest 50% of the population could not reach a storage shelf designed for the "average person." There are extensive sets of design principles available,[32] and we include a simple set here. To go beyond this set, consult the references and an experienced human factors engineer.

Principle 1-Design for the RANGE of users. As above, designing for the average person will not work. We need to design for the range of users, i.e., for the population percentiles we choose to include. This process splits into two principles:

- Design reach dimensions for the small person
- Design clearance dimensions for the large person.

Thus, reach dimension data in **Table 6-2** give the highest storage shelf accommodating the 5th percentile female as having a maximum overhead reach height of 75.3 inches. Conversely, the clearance height of an access door should be at least 73.2 inches, using stature data. As noted, doorways in buildings are usually much higher than the minimum since cost does not increase much with additional doorway height. For access doors on aircraft, a larger "hole" requires considerable additional structural weight to maintain strength, so careful sizing is necessary.

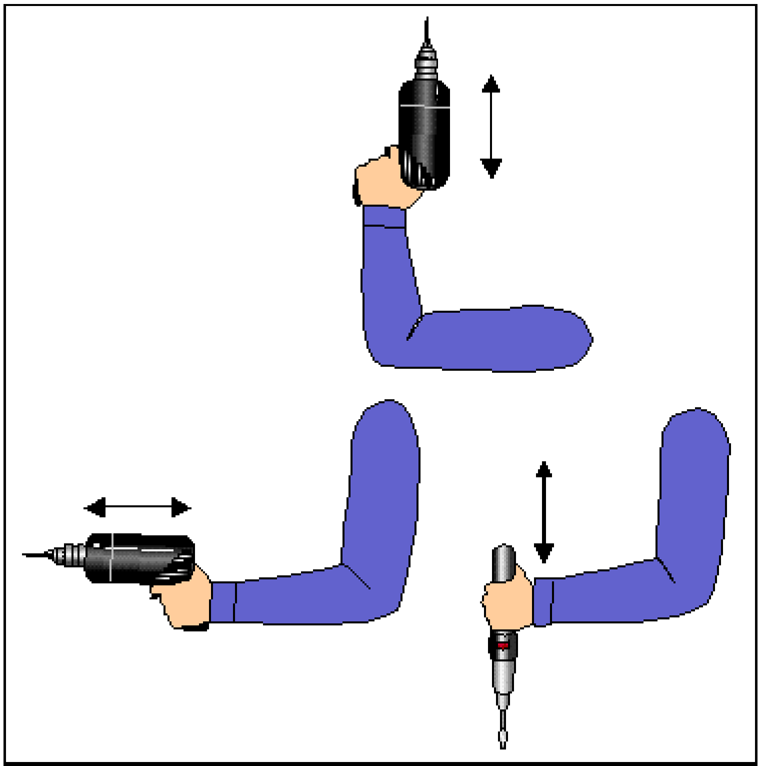


Figure 6-10. *Choose hand tool handles to keep the wrist straight*

Reach dimensions include a chair's height above the floor (reaching the floor with the feet), and the depth of a hole includes hand access (reaching the end of the hole with the hand). Clearance dimensions include knee and foot room under a bench, the width of a chair seat between armrests, and the width and height of access ways for whole body or arm entry.

Principle 2-Avoid static muscle loads. A muscle contraction uses energy and produces waste products; it requires continued blood flow to bring energy sources and remove waste. A muscular contraction itself squeezes the muscle's blood vessels, slowing or stopping blood flow. Rhythmic or dynamic activity such as walking or sawing alternately contracts and relaxes the muscle, pumping blood through. Static loading such as bending over or gripping cuts off blood supply, causes pain, and increases heart rate and blood pressure. Avoiding long-term static muscle contractions is a primary aim of workplace and equipment design.

Using this principle is sometimes obvious, sometimes not. Avoiding work requiring bending or reaching to a floor-level or an above-shoulder position reduces static loading. So does placing the workpoint just below elbow height to relax the upper arms and shoulders (see **Figures 6-3** and **6-4**). Use tool handgrips that yield and are not slippery to reduce the static grip forces required to maintain accurate control of the tool. This principle strongly suggests providing body support, the next principle.

Principle 3-Provide body support. Supporting the body is one way to reduce static loading. We typically sit to type or read, reducing static loading of the postural muscles in the legs, and, when the chair has a usable backrest, in the trunk. Modern work surfaces have padded wrist-rests along the edge closest to the operator.

Body support should allow flexibility and not force the body into a single posture. No single posture, however good it is, is comfortable for a long period. Bars often have a foot-rail for patrons to move alternate legs into a flexed position (this has the benefit of keeping patrons at the bar longer). Even temporary rests like prop stools, i.e., sit/stand workplaces, can improve health and comfort for prolonged tasks. Chairs should allow sideways as well as fore and aft body movement, rather than being "fitting." Footrests may bring heights of the workplace, seat, and floor into a suitable relationship.

Support should also be used for hand tools. If an operator must grip a tool for long periods, a strap along the handle allows the gripping muscles to relax while the tool hangs from the back of the hand. Cameras have used such straps for years.

Principle 4 - Provide adjustability. One size fits (nearly) all for dimensions of things such as door heights. Other dimensions provide no fixed solution for fitting ranges of human bodies. For example, a chair small enough to allow the feet of a 5th percentile female to reach the floor would be 16.0 inches (see **Figure 6-2**). Taller people could use this chair for short periods, so long as they could bend and stretch their legs. However, if the task required continuous work at a bench or desk, an adjustable chair would be necessary. Data in **Table 6-2** indicate that the chair must adjust between 16.0 and 19.9 inches. This range is based on floor-to-seat distance for the two design percentiles. In practice, the range is often reduced by use of adjustable footrests.

Adjustability of work surface heights is also desirable. Typically, this is provided for computer work stations, not for shop benches, although there is no anthropometric difference between the two. Office workers tend to be less tolerant of poor working conditions such as noise, poor seating, or dim lighting than factory workers. Many industrial-strength workbenches are produced with rapidly adjustable heights.

For adjustability to be beneficial, it must be easy for the worker. Design factors promoting workplace adjustability are included in **Table 6-2**.[33] Even when workspace design allows easy adjustability, workers' use of the adjustability is dependent upon how much time and effort are needed to make changes and the perceived benefits of adjustability. Employees frequently require training to understand how to adjust the workplace, why individualized adjustment is important, the physiological well-being principle behind the adjustment, and which work postures are healthy.

Use anthropometric data to decide when adjustability is needed. Avoid unnecessary adjustability, as it increases cost, complexity, and maintenance requirements.

Principle 5-Provide clearance for movements. Anthropometric data in **Table 6-2** apply to static postures, although workers rarely remain still at work. Indeed, one might observe that static anthropometry data are useful only for packaging frozen bodies! Such data provide a good starting point, but extra clearance for movement is also necessary. Up to some large clearance value, the more clearance, the better a persons can perform the job. After a certain point, more space serves no purpose. **Figure 6-11** offers data[39] on speed and errors negotiating corridors of different widths.

Note that speed drops dramatically and errors reach 100% at about human shoulder width, i.e., between 15 and 20 inches. Beyond 36 inches, errors are zero and speed is maximum. Between 20 and 36 inches, the more room, the better the performance.

This idea has been extended to define four zones for aircraft maintenance access tasks[19]:

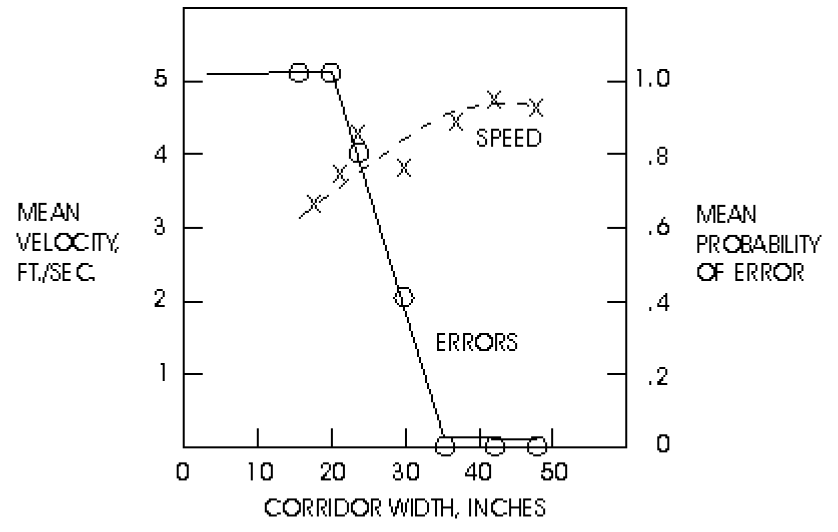


***Figure 6-11.** Speed and errors associated with various corridor widths*

- **Zone 0** Unrestricted Zone. Enough room for unimpeded work
- **Zone 1** Worker Response Zone. Restrictions force worker compensations
- **Zone 2** Performance Restricted Zone. Restrictions cause performance to suffer
- **Zone 3** Anthropometrically Restricted Zone. Restrictions so severe that task is impossible.

The effect of increasing available space in Zones 1 and 2 is either to increase performance or to reduce stress.

Setting clearances requires a decision for each design. It is impossible to work in Zone 3, and there is no necessity to increase access for Zone 0. Between these extremes, there may be trade-offs between initial and long-term costs. Where performance is costly and critical, for example in the pilot's cockpit, any restriction interfering with the task is unacceptable. In the past, maintenance tasks have been seen as less costly and critical than cockpit tasks. However, recognition of the effects of maintenance and inspection errors and the availability of anthropometry design tools[7,8] are changing this view.

Computer-based anthropometric models are static and do not account for the space-performance relationship (**Figure 6-11**). There are data on space-performance relationships in aviation for emergency exits from aircraft[5] (**Figure 6-12**), and for access dimensions for tool use[6] (**Figure 6-13**). Such data can help justify including sufficient space in a design.

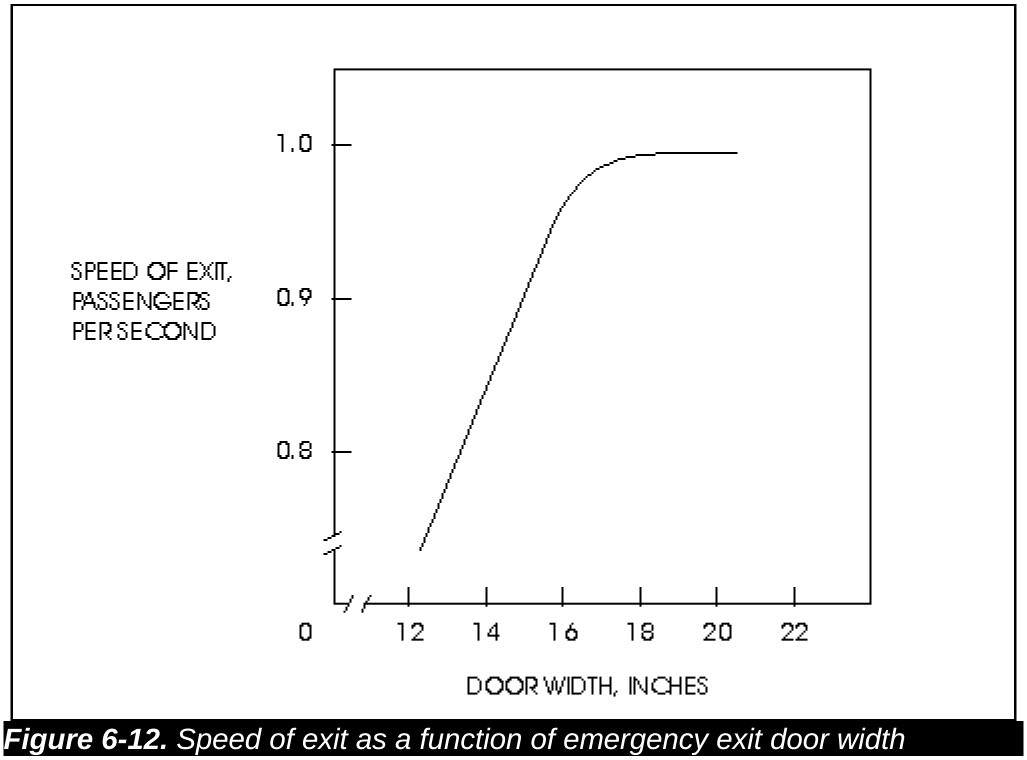


Figure 6-12. *Speed of exit as a function of emergency exit door width*

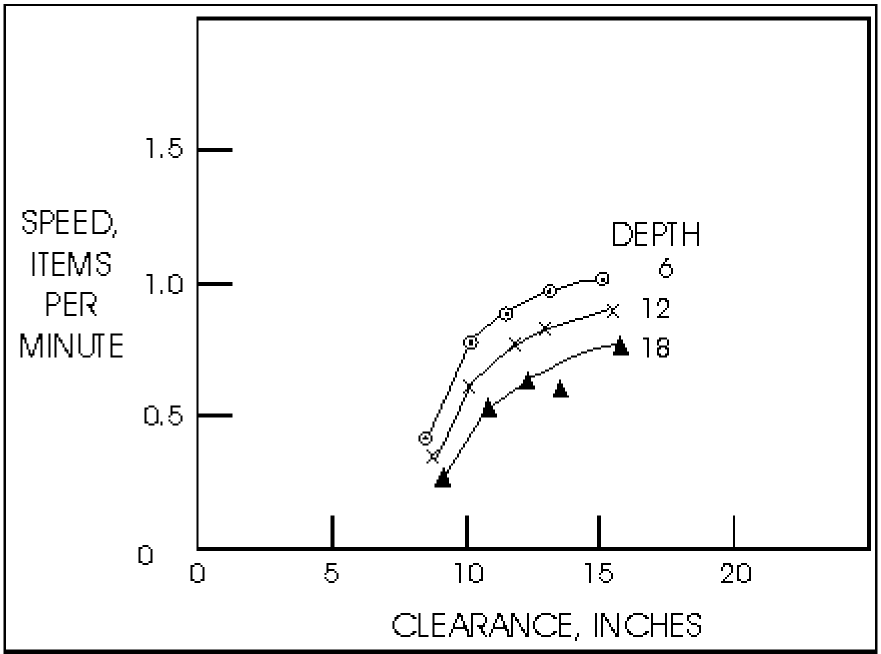


Figure 6-13. *Speed of maintenance task performance as a function of hand opening clearance*

Principle 6 -Avoid repetitive motions in non-neutral body postures. The fastest growing category of industrial injuries is known as repetitive strain injuries (RSIs) or cumulative trauma disorders (CTDs).[40] These disorders are caused by a combination of excessive internal forces, high repetition frequencies, and non-neutral posture (see **Chapters 2** and **3**). Two CTDs of most concern are upper extremity and back injuries. The risk of CTDs can be reduced or eliminated by ensuring that people can work with their joints in close-to-neutral positions.

CTDs of the upper extremities can be reduced by ensuring that the shoulder and wrist remain in neutral postures, i.e., with the upper arm hanging in a relaxed position vertically below the shoulder and with the hand parallel to the forearm. This can be achieved by setting the workpoint at the correct height for the hand or tool in use and by using tools and equipment that do not require deviation or wrist flexion or extension. This often means using tools with bent handles, not bending the wrist.

Postural causes of back injuries are forward trunk flexion and twisting between pelvis and shoulder. Trunk flexion requires small back muscles to exert very high forces to maintain trunk stability, increasing forces on the spinal discs. A weight as small as 10 pounds, held in the hands while bending forward, can exert a dangerous compressive force of 700 pounds on the spinal discs. This is enough to cause disc damage in some people. When this force - or even a much smaller force - is repeated, injury can occur more rapidly.

Twisting the spinal column weakens natural support structures around the discs and can increase injuries. Design to avoid reaching, bending, or twisting, with a minimum load in the hands. Do not store objects too low, and do not have workers reach over obstacles to lift equipment and parts.

These prescriptions for workplace design are meant to ensure neutral body postures. They are much easier to practice in fixed workplaces, than in and around an airframe structure. Electronic, brake, and seating shops are relatively simple to design with these guidelines. Much can be done for airframe-oriented jobs. Good handles make equipment easier to grasp and move. Equipment stands can prevent workers from bending to floor level. Temporary seats and body pads provide body support in awkward areas, eliminating unsupported reaching and bending.

Use Simple Mock-ups for Fitting Trials

The most neglected practical step in designing workplaces and equipment is using simple mock-ups to check for fit. Spending half a day building a mock-up and another day in fitting trials can optimize an initial design. A simple, inexpensive mock-up can help find and eliminate problems. Fitting trials ensure worker input into design and help all concerned discover novel design solutions. The four-point approach below makes the process simple and effective.

Point 1-Use the initial design to build a mock-up. The initial design from anthropometric data tables, guidelines, or computer models should be the starting point for a building a mock-up, using simple, inexpensive materials. Existing walls, filing cabinets, and room dividers can model the workspace. Expandable wooden fencing is useful for giving a flexible wall. Work surfaces can be made from adjustable modular workstations like those sold for secretaries. An adjustable office chair provides flexible body support, if the worker is seated.

Special-purpose equipment, such as curved bulkheads, portable test equipment, or fixed built-in test equipment, can be constructed from the "foam core" architects use for their models. This material can be cut with a knife and joined with wood or paper glue to construct surprisingly strong "equipment" rapidly. Equipment controls and displays can be simulated with simple drawings on the foam; for more realism, make photocopies of real equipment and glue the copy on the mock-up.

A mock-up should be simple and adjustable, not so elaborate as to discourage changes during fitting trials. Workers should be able to make changes with a knife, glue, and duct tape to test effects rapidly at low cost.

Point 2-Choose Workers for Fitting Trials. Choose "workers" for fitting trials by using **Table 6-2** in reverse. Since a 95th percentile male is 73.2 inches tall, a male 73.2 inches tall is a rough approximation of a 95th percentile operator. Similarly, find people to represent 5th, 50th, and 95th percentile male and female workers. Remember that no person is the same percentile in all body dimensions. A slim person could be 75th percentile in height and 50th percentile in weight.

Two groups of body dimensions correlate reasonably well. Lengths of the body's long bones (arm lengths, finger lengths, and leg lengths) correlate with stature. Girths around or across waist, arms, shoulders, and thighs correlate with body weight. An AMT's height and weight give a reasonable indication of most other body dimensions, although males and females differ in body proportions, as may racial groups. For the fitting trials, selecting subjects by height and weight gives a good enough approximation for industrial workplace design.

Point 3-Conduct Initial Trials. Initial trials allow the design team to change the mock-up. The team, including the "design percentile" subjects, perform required tasks in the mock-up, as defined in the first design step, and comment on good and poor workplace features. Include required tools in these trials, although they are not fully functional in the mock-up. Note poor body postures (bending, reaching, twisting), poor hand/wrist postures, and lack of clearance for tasks.

Solicit desired mock-up changes from the team, but do not critique them until all have been recorded. Cut and change the mock-up to simulate desired changes, and continue the process until the mock-up is acceptable. Do not allow design engineers to eliminate mock-up changes on grounds of cost. The mock-up evaluation serves to get the physical design right; compromises between physical design and other considerations should be made ***after*** the trials.

Point 4-Conduct Fitting Trials. Initial mock-up trials are usually sufficient to "fix" the design. If certain dimensions are critical for task performance, use a broader range of workers to fit these dimensions to the user population. Workers of sizes between the "design percentiles" can provide accurate values of critical dimensions. If no single value is suitable, adjustability is required.

As each worker uses the mock-up to simulate task performance, the design team finds the tolerable range of the critical variables. If all tolerable ranges overlap, the dimension can be fixed. If they do not, determine the minimum adjustment to accommodate all users.

WHERE TO GET HELP

Work design is a fundamental component of human factors expertise. Because it is so basic, there are many individual human factors practitioners, as well as human-factors-oriented consulting companies that can be used as resources for the activities we describe in this chapter. In addition, there are a number of courses that address these issues in detail. Typically, these courses are offered periodically at a number of locations, including major academic institutions.

General Help

We have taken the position in the *Guide* that we will not recommend or endorse consultants or consulting organizations. However, both the Human Factors and Ergonomics Society (HFES) and the Board of Certification in Professional Ergonomics (BCPE) make available lists of their members. The HFES will also supply a list of its members who act as consultants in specific technical areas, including work design.

The Board of Certification in Professional Ergonomics is the largest of the certification organizations for human factors practitioners. They produce a list of certificants, but do not recommend individuals to help with particular problems. They are located in Washington state at the following address:

Board of Certification in Professional Ergonomics
PO Box 2811
Bellingham, WA 98227
Phone: (360) 671-7601
Fax: (360) 671-7681
Web site: http://www.bcpe.org
Email: bcpehq@aol.com

The Human Factors and Ergonomics Society (HFES) is usually a good source all types of human factors information, including work design issues. They produce several publications and videos, including an annual Directory of Consultants. The HFES is located in California, at the address below:

Human Factors and Ergonomics Society
PO Box 1369
Santa Monica, CA 90406
Phone: (310) 394-1811
Fax: (310) 394-2410
Web site: http://hfes.org
Email: hfes@compuserve.com

For help with specific work design problems, a good source of information is the Office of

Aviation Medicine (AAM) in the **FAA**. The AAM sponsored the development of this *Guide*. It also sponsors a good deal of human factors research and development each year. Since part of the charter of the FAA is to help the commercial airline industry address human factors problems, the AAM is a good starting point for inquiries related to such problems. Contact the AAM at the following address:

Ms. Jean Watson
Office of Aviation Medicine
Federal Aviation Administration
800 Independence Ave., SW
Washington, DC 20591
Phone: (202) 267-8393

Another source for workplace and equipment design information is the Crew System Ergonomics Information Analysis Center (CSERIAC), a Department of Defense Information Analysis Center located at Wright-Patterson Air Force Base, Ohio. Managed by the University of Dayton Research Institute, CSERIAC will conduct detailed literature searches. It also produces a number of pre-researched reports, which are for sale.

CSERIAC Program Office
AL/CFH/CSERIAC Bldg 248
2255 H Street
Wright-Patterson AFB, OH 45433
Phone: (513)255-4842
Fax: (513)255-4823

For help with organizational systems design, the following is a good starting point:

Human Factors and Ergonomics Society

Organization Design and Management (ODAM) Technical Group

Contact through the HFES main office (see above)

Training Courses

There are many training courses offered each year related to work design. Some specifically address this topic, while others provide a more general human factors background. We do not endorse any particular training course. However, we have listed below some of the organizations that routinely offer such training. Both The University of Michigan and The University of Wisconsin have provided human factors courses for many years. Most of these courses provide Continuing Education Unit (CEU) credits.

The Institute of Industrial Engineers (IIE)
IIE Member and Customer Service
25 Technology Park/Atlanta

Norcross, GA 30092
Phone: (800) 494-0460
Fax: (770) 263-8532
E-mail: cs@www.iienet.org
Web site: http://www.iienet.org/

Center for Professional Development
The University of Michigan
273 Chrysler Center
2121 Bonisteel Blvd.
Ann Arbor, MI 48109-2092
Phone: 734-647-7200
Fax: 734-647-7182
Email: shortcourses@umich.edu
Web site: http://cpd.engin.umich.edu

North Carolina Ergonomics Resource Center
703 Tucker Street
Raleigh, NC 27603
Phone: (919) 515-2052
Fax: (919) 515-8156
Web site: http://www2.ncsu.edu/ncsu/CIL/NCERC/index.html

The American Society of Safety Engineers
Department of Education
1800 East Oakton Street
Des Plaines, IL 60018
Phone: (708) 692-4121
Fax: (708) 296-9221
Web site: http://www.asse.org

The University of Wisconsin - Madison
The College of Engineering
Department of Engineering Professional Development
432 North Lake Street
Madison, WI 53706
Phone: (608) 262-1299 or (800) 462-0876
Fax: (608) 265-3448 or (800) 442-4214
Web site: http://epdwww.engr.wisc.edu

EXAMPLE SCENARIOS

The scenarios below represent some typical programmatic tasks one can expect to encounter in the workplace. We include these scenarios in the *Guide* to demonstrate how the authors foresee the document being used. For each scenario, we describe how issues raised in the scenario can be resolved. There is usually more than one way to approach these issues, so responses below represent only one path users of the *Guide* might take.

As a general rule, always start to look for information by using the Search function. There will be instances that you already know where required information is located. However, unless you frequently use specific sections of the *Guide*, you might miss information pertaining to the same issue located in more than one chapter. The Search will allow you to quickly search all chapters simultaneously.

Scenario 1 - Advantages of Systematic Work Analysis

Your manager is notorious for trying the latest trendy ideas, many of which fizzle quickly. This time, he read a popular paperback book advocating the Socio-Technical Systems approach to organizations. At the Monday meeting, he is greeted with some skepticism in his enthusiasm to start an STS program in the hangar this week. As you dig into the matter during the week, you realize that such a program, if done properly, may lead to real benefits.

Issues

1. What is the Socio-Technical Systems approach to organizations?
2. How would you tell a skeptical set of middle managers, supervisors, and **AMT**s that an **STS** program would be a good thing?

Responses

1. In the **CONCEPTS** section of this chapter, we describe the Socio-Technical Systems approach as combining technical aspects of work with its social components. This approach would be concerned about fitting a workbench to workers' body dimensions, as well as social implications of isolating a worker from his or her peers to work at the workbench.

2. Even trendy managers can have good suggestions: the problem is to dispel widely-held skepticism when this happens. To do so, you need both proof that the **STS** approach will work and a long-term commitment from management.

Use examples from the **BACKGROUND** section of the chapter to demonstrate how **STS**' concepts can work. Further reading (**references 11-15** for example) provide examples of the importance of long-term follow through. Such data are easy to collect and present. It is much more difficult to get a manager to maintain a long-term commitment. If it does not seem that you can change the manager's style, STS may be premature in your organization.

Scenario 2 - Furniture Selection

It is time to buy new furniture for the maintenance offices. Seven people there perform clerical work, data entry, typing, and arranging meetings. Catalogues offer a bewildering array of different chairs: all claim to be ergonomic. You decide to perform systematic evaluation of the five top contenders, using samples the suppliers provide. To undertake a fitting trial, you need to select a user population and appropriate population percentiles. The current clerical staff is 6/7 female and does not include any noticeably large or small people.

Issues

1. What is an appropriate user population for the fitting trial?
2. What are the appropriate upper and lower population percentiles for the fitting trial?
3. How you would recruit people for fitting trials?

Responses

1. ***User population*** is described in the CONCEPTS section of the chapter. It includes anyone likely to use the chairs in a clerical job. The main issue is choosing appropriate subjects for fitting trials to represent the user population properly. The question is, can we restrict fitting trials to an existing set of job incumbents, i.e., to people now working in the office?

The appropriate user population is "all those who *could become* clerical staff in the maintenance offices." Any more restricted definition of user population excludes potential staff who happen to exceed the range of the current clerical workers' anthropometric measures.

2. The first **anthropometric design principle** in the GUIDELINES section is to design for the full range of users. Although the present clerical staff includes only one male, there is no reason to believe we will select future office workers on the basis of gender or stature. Thus, we will choose people for the fitting trial based on the smallest female and largest male we reasonably expect to hire. These population percentiles are "5th percentile female" to "95th percentile male." Appropriate values for such body dimensions are contained in **Table 6-2**.

3. We don't directly address this issue in the *Guide*. Based on the scenario's description, we conclude that recruits should come from the maintenance group, as far as possible. As clerical duties are widespread in most organizations, other clerical staff can be recruited. Assuming that six subjects were needed, they should represent large, medium, and small males and females-ideally in both height and weight. This may be impossible in the available subject pool, but at least extreme male and female percentiles for height should be included.

Scenario 3 - Workstand Clearance

Current stands used to service flaps of your F-100 fleet are only 60 inches below the flaps, so operators must bend down to work. You can easily adjust stands for a different working height, but you cannot continually adjust them for each user.

Issues

1. What height should stands be below the flaps so that a large number of **AMT**s can reach the flaps, but very few will hit their heads on them?
2. Are there conditions under which we cannot get a reasonable solution for this problem?

Responses

1. This scenario can be completely addressed with the information in **Table 6-2**. We have two requirements. **AMT**s must reach the flaps, and they must have enough clearance so they don't bump their heads. To determine a fixed height for work stands, we need to choose the following:

- A minimum distance below the flaps so that 95% of males can pass without banging their heads. The appropriate dimension from **Table 6-2** is #1, stature, is 73.2 inches for a 95th percentile male.
- A maximum distance below the flaps so that 5th percentile female workers can reach the work area. The appropriate dimension from **Table 6-2** is #2, overhead reach, is 75.3 inches for a 5th percentile female.

These data indicate that the work platform must be no less than 73.2 inches and no more than 75.3 inches below the flaps.

2. Yes, there are. This example provides a feasible solution. If we accommodated a wider user range, say 2nd percentile female and 98th percentile male, the minimum clearance distance would be greater than the maximum reach distance. When this happens in real life, we weigh consequences of error at each side of the range. In our example, banging heads is probably a greater safety hazard than the requirement for the smallest operators to use a supplemental footstool or ladder. In this case, reaching too high is better than not having enough clearance to work safely.

Scenario 4 - Computer Workspaces

Your schedulers' and support people's jobs require them to spend several hours per day working on computers. They are complaining about sore wrists, aching backs, eyestrain, and numb feet. You suspect these complaints are workplace-related.

Issues

1. Where would you find data for a simple checklist measuring whether current workplaces have the recommended dimensions?
2. After you make the measurements, how would you use these data to help people adjust their workplaces to make the best possible use of available furniture until more ergonomic equipment arrives?

3. Are there social implications to these complaints? What are they and how might you go about addressing them?

Responses

1. **Figures 6-3** and **6-6** contain information you need to develop a checklist for the present workplaces. The checklist might include the following types of measurements:

The downward angle of view to the computer screen is

___ 0-15 degrees

___ 16-60 degrees

___ More than 60 degrees

___ Angle is up, not down

Is the trunk reclined between 0 and 5 degrees?

Do both upper arms hang naturally at the sides?

2. To help people use existing furniture optimally, develop a short training session and information package based on **Figures 6-3** and **6-6**. For each "wrong" answer in the checklist, develop alternative interventions and help each worker make the changes. For example,

- If the angle of view to the computer screen is up, not down, lower the screen with an adjustable arm or clear enough desk space to place it in the 0-15 degree downward area.
- If the downward viewing angle is greater than 60 degrees, raise the screen using an adjustable arm, a shelf, or even a pile of telephone directories.

3. In this scenario, you are dealing with an example of potential workplace injuries. As with any situation in which workers' health and safety is compromised, there are significant social elements. Of course, there is the overriding technical issue of possibly decreasing airworthiness because of errors induced by the pain and fatigue cited in the description. In addition, workers must feel that they are important enough to warrant management's immediate concern for and action to maintain their health.

There are several steps managers can take to address the social elements in this scenario.

- Take workers' complaints seriously. Don't assume that their symptoms are imaginary or that these symptoms will simply disappear over time.
- In this particular situation, immediately rotate people through different job tasks more frequently. Try to minimize the amount of time they perform continuous work on the computers. This will accomplish two things. First, it will show that you are concerned enough to take immediate action. Second, it will minimize the risk of injury while buying time to "fix" the problem.
- Explain to the workers exactly what you are doing and why you are doing it. This would be an excellent place to explain the potential ergonomic basis for their symptoms and how you are going to alleviate those symptoms.

Addressing the social elements of work design does not require that managers find a "perfect" solution or that they invest in another tool or piece of test equipment. Social problems typically have social solutions. The mere fact that someone cares enough about the workers to address their problems is a major component of the solution.

Scenario 5 - Hand Tools

Your mechanics use many hand and power tools, and the human factors task force has identified them as a source of concern.

Issues

1. Prepare a checklist to examine the current tools for fit of their handles to the hand.
2. How far can you use design guidelines and to what extent would you have to use anthropometric data and fitting trials to determine which tools need most urgent attention?
3. Would you expect the tools receiving most complaints from **AMT**s to be those your survey shows having the worst handles?

Responses

1. **Figure 6-9** contains information you need to prepare this checklist. The following items can be taken from Figure 6-9:

- Is the handle diameter between 1.0 and 1.5 inches?
- Is the handle length at least 4.8 inches?
- Does the handle have a non-slip surface?
- Is the hand clearance at least 1.2 inches?

This information can be supplemented with information in the discussion of "**Hand tool and Power tool design**" in the GUIDELINES section.

2. We don't directly address this issue in the chapter. A rule-of-thumb is that you generally depend on design guidelines for products or systems that have been well-researched over a long period. This is true for hand tool handles. Published design guidelines should be adequate in most cases. If anthropometric data and fitting trials are required, you may need ergonomic advice from a professional.

3. Users are generally good at spotting mismatches between what they need to do and a tool's ability to let them do it. The checklist example provided in **#1** (above) looks for mismatches between task demands and human capabilities. It should predict which tools are most likely to generate complaints. However, complaints are also generated by poor-quality tools or those tools only marginally capable of doing the job. You should evaluate all user complaints.

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