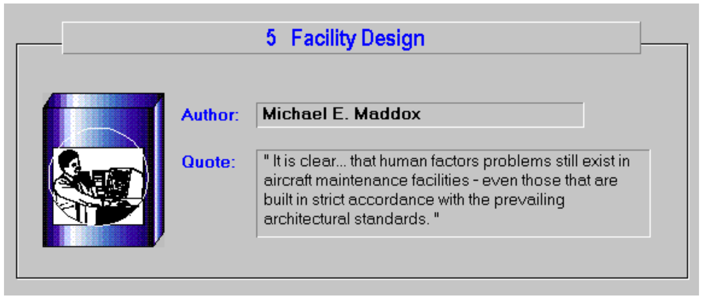
Chapter 5
FACILITY DESIGN



INTRODUCTION

Aviation maintenance has many features in common with other industries. The physical facilities in which aviation technicians work, however, are unique. No other industry uses aircraft hangars as its primary worksite. The primary reason for using hangars is obvious, of course. Aviation maintenance technicians work on airplanes, and hangars are needed to shelter aircraft and workers from the elements.

Aircraft hangars present a range of human factors issues. They are generally quite large and are built so that most of the floor area is unobstructed by structural support members. This design allows large aircraft to be moved and parked in the building. An example of the typical scale of a large aircraft maintenance hangar is shown in Figure 5-1.

Their vast areas and high ceilings make hangars difficult to light properly. Their large, unobstructed volume makes public address systems difficult to hear. Large, open doors make controlling temperature and humidity problematic. The use of elevated work platforms and scaffolding is common, due to the height of today's large jet aircraft. Individual workspaces tend to be clustered around the aircraft being maintained.

This chapter describes the fundamental concepts related to facility design. It also relates these concepts to specific issues in the aviation maintenance environment. Finally, it provides guidelines that can help readers base routine facility-related decisions on sound human factors principles.

Figure 5-1. Typical scale of a large maintenance hangar. (Courtesy of Delta Air Lines)

BACKGROUND

The design of large buildings is certainly not a new undertaking. Large factories, auditoriums, and warehouses are quite common.[1] In fact, many architectural studies of aircraft hangars have been conducted. Most of these studies, however, are of either the "Look how neat this big building is!"[2] or of the "This is a new technique for constructing big buildings"[3] variety. It is clear that human factors-related problems still exist in aircraft maintenance facilities-even those built in strict accordance with prevailing architectural standards.

Within the aviation maintenance industry, there are at least three major categories of workplaces, namely hangars, ramps, and shops. Of these, ramps are the least controllable in terms of workspace and environmental factors such as lighting and noise. Technical shops such as those in which avionics components are repaired are most like an office environment. They are relatively easy to control for workspace layout and environmental factors. Hangars represent a middle ground for controllability of work factors.

There are several components that need to be considered when discussing facility design. First, the content and layout of the overall workspace, which might be a hangar or ramp, needs to be evaluated. Second, the fixtures, tools, and work platforms that are either stored in or part of the overall workspace need to be considered. Third, the atmospheric, lighting, and sound environments (and their controls) should be characterized. Finally, individual workplaces within the overall workspace need to be evaluated.

Typically, facility layout and design is within the scope of expertise of two professional groups, architects and industrial engineers (IEs). Traditionally, architects concern themselves with the overall functional layout, structure, materials, and appearance of a building. This is evident in the published description of a new Delta hangar in Tampa, Florida.[4] Industrial engineers tend to analyze specific tasks or jobs and design those parts of a building directly related to those tasks. For example, IEs would typically lay out conveyor and assembly areas in a manufacturing facility.[5] Human factors professionals tend to get involved only when there are perceived problems with an existing facility. This is unfortunate, since practical human factors principles can be applied to facility design.[6]

Many working domains have been evaluated from a human factors perspective. These include nuclear facilities,[7] classrooms,[8] fire stations,[9] drug rehabilitation centers,[10] and space habitats.[11] Without question, the most-studied working facility is the "office" in the most general sense. Except for lighting,[12] there is no evidence in the published literature that aircraft maintenance hangars have ever been the subject of a human factors evaluation.

All the evaluations listed above have identified habitability and usability problems that can be solved by applying human factors methods and data. In one particularly thorough study of the maintainability of nuclear power plants, maintenance workers were asked to recount "critical incidents."[13] A *critical incident* is a situation that leads, or almost leads, to serious equipment damage or human injury. Of over 100 incidents cited, nearly 20% were directly related to some aspect of facility design.

Because of the sheer scale of aircraft maintenance facilities, we sometimes lose sight of the fact that they must accommodate people as well as airplanes. Issues related to physical compatibility, such as anthropometry and biomechanics, are discussed in Chapter 1. Guidelines in this chapter and in Chapter 6 contain data that facility designers can use to fit various facility features to maintenance workers.

Within the Human Factors and Ergonomics Society, the Environmental Design Technical Group is concerned with all aspects of the "built" work environment. The "built" environment includes buildings and all the things that go in or on them. Most aircraft maintenance organizations have access to a "facilities" group that is generally responsible for design and construction of all facility-related elements. If there is no in-house facilities group, an outside architectural contractor is usually hired to perform such work.

In practice, facilities people and architects rarely interact with human factors professionals. A legitimate question arises, however, as to whether human factors facility design guidelines differ from published architectural guidelines. If they do, does it really make any difference which are followed? One study that addressed this issue found that facility users rated classrooms that met human factors guidelines as more pleasant and usable than those that met only architectural guidelines.[14]

The truth is, many technical specialties have valuable skills and knowledge that can be applied to facility design. As with other complex endeavors, a professional team approach provides a much higher probability of a successful result than any individual profession acting alone. Thus, architects, construction tradespeople, human factors practitioners, industrial engineers, and maintenance workers all have something to contribute to facility design.

ISSUES AND PROBLEMS

There are many facility-related issues associated with aviation maintenance. These issues can generally be placed into one of the following categories:

- ingress and egress
- access to areas
- storage and retrieval
- work platforms
- sound and noise
- lighting
- heating, ventilation, and air conditioning (HVAC).

Each of these categories is described in more detail below.

Ingress and Egress

Despite the space-age terminology, ingress and egress issues simply relate to getting into and out of facilities. It seems contradictory to imagine any difficulty getting into or out of a facility with doors large enough to permit a jet aircraft to pass through them. However, maintenance facilities consist of many separate areas within large hangars. In addition, large hangar doors are often closed, especially during the winter. Such facilities must be designed to permit people and equipment quickly to get into, and, more importantly, to get out of all work areas.

Access

There are actually two subtopics within the access category. One relates to facility access by people who are disabled. This is the topic of Chapter 10, and we won't discuss it in detail here. The second topic concerns every maintenance worker's ability to have access to his or her work area. All elements of maintenance facilities must be designed to permit those working in the facility easily to find and move to their appropriate work areas. The problem of access is not that of having no path to a shop or office. Rather, ad hoc work areas placed in proximity to the aircraft being maintained clutter the hangar floor and can make access to individual work areas difficult.

Storage and Retrieval

Maintaining aircraft requires a lot of "stuff," including tools, fixtures, test equipment, raw materials, parts, portable work platforms, procedures, technical documentation, expendable supplies, etc. Facility design must provide storage locations that allow quick access to materials. For areas dedicated to particular kinds of work, e.g., to painting, all required tools and materials can be stored close to the work area. Certain materials, such as toxic chemicals, might require specialized storage areas. The intent of guidelines related to storage and retrieval is to allow workers quickly to store and retrieve whatever they need to do their jobs.

Sound and Noise

In the aircraft maintenance environment, many sounds are desirable and, in fact, necessary to the proper conduct of work. These sounds include person-to-person voice communication, telephonic communication, public address messages, and audio signals from test equipment or aircraft systems. Noise, on the other hand, is unwanted sound. Noise is not only distracting and stressful, it can cause permanent hearing loss. In the design of aviation maintenance facilities, the goals are (1) to make certain sounds easy to hear, and (2) to isolate and protect workers from noise.

Work Platforms

Commercial jet aircraft tend to be large. Most exterior, and many interior, parts are well beyond the reach of a maintenance technician standing on a facility's floor. To allow technicians to reach these areas, various work platforms are used in maintenance facilities. These include everything from common stepladders to movable nose and tail docks (see Figure 5-2) to sophisticated, roof-mounted telescoping scaffolds (see Figure 5-3).

Lighting

Figure 5-2. Movable dock scaffolding. (Courtesy of United Airlines)

Even though much aviation maintenance is performed during nighttime hours, humans are not particularly adept at performing precision work under low illumination levels. For the visual inspection tasks which make up a large proportion of routine aircraft maintenance, it is crucial that workers have an adequate level of the right type of lighting. Fortunately, much is known about appropriate lighting levels for various tasks. This is one of the few aspects of aviation maintenance facilities that has been studied from a human factors perspective. The sheer size and open volume of hangars present some challenging lighting problems.

HVAC

Humans work best within a fairly narrow range of temperature, humidity, and airflow. Conditions outside this range quickly degrade physical and mental capabilities, eventually becoming quite dangerous. This aspect of human performance has been studied extensively over the last few decades, and we have quite specific data regarding the amount and types of work that can be performed in various ambient environments. Especially in large open hangars, controlling temperature, humidity, and airflow is very difficult. A combination of facility design, workspace design, clothing, and procedures must keep workers within a safe range of ambient conditions.

Figure 5-3. Roof-mounted, telescoping work platform. (Courtesy of United Airlines)

REGULATORY REQUIREMENTS

There are three main sources of regulatory requirements directly related to the design of aviation maintenance facilities:

- OSHA Regulations
- National Building Codes
- Local Building Codes.

The Occupational Safety and Health Administration (OSHA) regulations are contained in the Code of Federal Regulations (CFR), Title 29, Parts 1900 to 1910.[15] Many of these regulations have been cited in Chapter 3, Workplace Safety. Table 5-1 lists the OSHA regulations that apply directly to facilities.

Table 5-1. Facility-related OSHA regulations

Topic	Covered In
Ingress and Egress	Subpart E Sections 35-40 and Appendix
Access, including Aisles and Passages	Section 22
Storage and Retrieval	Subpart N Section 176
Ladders, Work Platforms, & Scaffolds	Sections 25-29, 31
Elevating, Rotating, Vehicle-Mounted Platforms	Sections 66-67
Sound and Noise	Section 95 and Appendix
Lighting	
Near Exit Signs In Spray Booths Minimum for Operating Forklifts and Other Industrial Trucks	Section 37 Section 107 Section 178

Interestingly, none of the OSHA regulations directly address temperature and humidity control, heat stress, or related topics. Various types of ventilation are covered, but only as they relate to toxic or explosive environments. There are several sources of guidance for HVAC-related issues, including the National Safety Council.[16] These are cited in the Guidelines section.

The second source of facility-related regulatory requirements are national building codes, such as the National Electrical Code.17 These codes generally relate to the detailed structures and systems that comprise maintenance facilities. The purpose of these codes is to ensure that both residential and commercial facilities meet minimum standards of construction. They are not primarily concerned with, nor do they generally affect, human performance within maintenance facilities.

Finally, there are a number of local building codes with which any facility must comply. Local codes usually invoke all requirements of the national codes and may add certain provisions mandated by local governments. As with national codes, local building codes are primarily aimed at ensuring that construction meets minimum safety and functional standards. No local codes are cited in the *Guide*, since they generally do not affect human performance within aircraft maintenance facilities.

CONCEPTS

There are several human factors concepts that apply to a broad range of facilities, including those used for aviation maintenance. These concepts cross the boundaries of traditional design roles in that they are associated with a number of different technical specialties. Understanding these concepts helps readers evaluate various facility design issues from the perspective of the eventual users of those facilities.

Adaptation

Human senses are typically capable of operating over an extremely wide range of stimulation. However, the senses, especially sight and hearing, operate in a much narrower band that is more or less centered on the existing stimulus level. The senses are said to "adapt" to the prevailing level of stimulation. For example, the human visual system adapts to whatever level of illumination happens to be present.[18] Once a sense is adapted to the present conditions, it must readapt if the prevailing stimulus level changes. A good example of visual adaptation occurs when you walk from a darkened room into the bright sunshine. Initially, you are almost blinded by such a transition. Gradually, your vision adapts to the higher light level and you can function quite well. If you go back into the darkened room, your visual system must readapt.

Color Rendition

Color is an important aspect of many maintenance tasks. For example, many electrical wires are color-coded so they can be properly connected and traced. The color of an object depends on the color content of the light falling on or being produced by it.19 In fact, the color we see when we look at an object is simply what's left over after the object absorbs all of the colors it's going to absorb. Different types of light sources have different color compositions. This is common knowledge among people picking out house paint, wallpaper, furniture fabrics, etc. The color of these items in the store is sometimes not the same as when they are in a home.

Another common experience is seeing a red car illuminated with mercury vapor lamps in a parking lot. A car that appears bright red in the sunlight looks orange under mercury lamps. The reason is that mercury vapor lamps have very little red in their color spectrum. Color rendition is crucial in some maintenance tasks. Therefore, when designing facility lighting, color rendition requirements must be considered.

Environmental Stress

The concept of stress was discussed in Chapter 1. One type of stress is caused by elements in a worker's environment. Cramped physical spaces, poor lighting, noise, heat, cold, humidity, and lack of airflow can all cause a worker's performance to decrease.20,21 When several environmental effects are combined, stress levels, as indicated by poor performance or errors, can be higher than for individual causes. An important aspect of environmental stress is that it can result in both physical *and* mental impairments. For example, excessive heat causes the inability to concentrate, as well as the more obvious symptoms of physical distress.

Frequency of Use

Frequency of use means that elements that are used most often should be placed so they are the most convenient to access.22 When frequency-of-use data are combined with knowledge about movements from one facility element to others, designers can ensure that frequently used areas are centrally located. In practice, the most frequently used areas will probably turn out to be those that are used by many people in order to do their jobs. Examples of frequently used areas in other industrial domains are supply stores, tool cribs, locker areas, etc.

Functional Grouping

The essence of the concept of *functional grouping* is that things that are used together should be placed together. Functional grouping is often used as the basis for laying out control boards or graphical user interfaces.22 In the context of facility design, functional grouping requires that workers performing similar job tasks should be located near one another. In fact, specialty shops are examples of functional grouping. The paint shop is in a specific area which is separated from the engine shop, the avionics shop, etc.

Functional grouping becomes a bit muddled in situations where various types of tasks are being performed in, on, or immediately around an aircraft. In such cases, there might be several areas in a hangar dedicated to the same types of tasks, but for different airplanes.

Illumination and Luminance

The concepts of *illumination* and *luminance* are associated with the quantity of light falling on or emanating from a surface, respectively.23 While it isn't really important to understand all of the mathematical intricacies associated with these concepts, it is helpful to understand the fundamental difference between them. Illumination is related to the amount of light *falling on* a surface or an object. The illumination of any point in a facility is dependent on the placement and light output of all light sources that can shine on that point. Luminance is related to the amount of light *coming from* an object, such as a video display terminal or a wall. Luminance is associated with our subjective impression of brightness.

One characteristic of illumination is worth noting. The source of illuminance is a light of some type. Permanent light sources in facilities are generally fixed to a ceiling or wall. As you move away from these light sources, the intensity of illumination decreases. In fact, it decreases predictably as the square of the distance. If you double the distance between an object and a light source, the illuminance measured at the object drops to one-fourth its previous level.

Luminance, on the other hand is associated with the object itself, rather than the relationship between an object and a light source. Our impression of the brightness of an object depends on its luminance. Luminance does not decrease as we move further away from an object, at least within a reasonable range of distances. The reason for this has to do with the way luminance is defined mathematically. At any rate, our experience is that a wall doesn't become less bright simply because we move away from it.

Noise-Induced Injuries

Noise causes a number of different types of injuries. Some noise-related injuries are temporary, but many are permanent.24 Almost all depend on a person's exposure to high levels of noise over some period of time. This time-intensity relationship is the reason that OSHA noise exposure standards are stated as time-weighted averages (TWAs). The so-called "action threshold" of 85 dB is an 8-hour exposure level. That is, if a worker is exposed to less than 85 dB continuously for up to 8 hours, then OSHA requires no mitigating action.

The relationship among the frequency content of noise, its SPL, and the duration of exposure is quite complex. Not all noise frequencies cause injuries that affect our ability to hear and understand speech. In fact, even without exposure to noise, our ability to hear pure tones decreases somewhat with age. However, certain noise-induced injuries are profound, dramatic, and affect our ability to lead a normal life.

Sound Pressure Level

Sound is a pressure-related phenomenon. The subjective sensation of hearing sounds is really caused by the structure of our ear converting pressure waves into electrical impulses. The subjective notion of loudness is related to the physical measure of sound pressure level, or SPL. The unit of measure for SPL is the "decibel." The decibel, which is used to express other phenomena in addition to sound, is really a ratio of two numbers. In the case of the SPL, the reference number is the minimum sound pressure at which humans can just barely detect sound.

Because our sense of hearing has such a huge dynamic range, SPL is defined as the logarithm of the sound pressure ratio of interest. The important thing to understand about the SPL (and the decibel) is its logarithmic nature. Doubling the pressure of a sound doesn't usually double its SPL. Actually, doubling the pressure of a sound increases the SPL by only 6 decibels (dB). Therefore, the pressure of a sound with an SPL of 80 dB, which is below the OSHA action threshold, is only *half* the pressure a sound with an SPL of 86 dB, which is above the OSHA threshold.

Speech Interference

Noise does more than just cause injuries based on its SPL. Certain types of noise, and even certain aspects of facilities, make normal speech communication very difficult.25 Human speech is concentrated in a relatively narrow band of frequencies. If noise is present in those frequency bands, then it tends to mask the words that are being spoken. Since person-to-person speech is such an important part of many maintenance tasks, the speech interference effects of noise might be more troublesome than its potential for causing injury.

The dimensions and materials of buildings can also have a marked effect on the intelligibility of the spoken word. Most of us have had the experience of listening to a loudspeaker in a public address (PA) system without being able to understand a single word being said. Often, this lack of intelligibility is caused by reverberations from walls and floors. Large aircraft hangars have all of the characteristics that cause such reverberation -- large volume; large, flat surfaces; and hard materials that reflect, rather than absorb, sound.

Task-Oriented Design

The most fundamental human factors concept related to facility design is that a facility should be viewed as a place where human workers perform tasks.26 This seems simplistic and, perhaps, too obvious even to be mentioned. However, it is important to realize that maintenance facilities are much more than just places to park airplanes. A careful study of the tasks that are going to be performed in a facility provides valuable insight into what areas a facility must have, where they must be located, and how each must relate to all others. A properly designed facility helps maintenance workers do their jobs. A poorly designed facility hinders workers.

Work Comfort Zone

It's not the heat; it's the humidity. As it turns out, this old saw has a basis in fact. Humans have a fairly narrow envelope or "zone" of temperature, humidity, and airflow within which they can work comfortably. There is a slightly larger zone within which it is possible to work, but at a reduced level of output. These zones depend on a number of variables, all of which interact.27 For example, the type of work being performed, combined with the type of clothing being worn, determines the amount of body heat being generated.

The basic concept of work comfort zones is simple to understand. After all, we all have experiences of being too hot or too cold while performing certain types of work tasks. We also realize that appropriate dress for one climate is not appropriate for a very different climate. Beyond the fundamental concept, however, lies a vast body of hard data that has been accumulated over a number of decades. We know what combination of conditions is likely to be perceived as comfortable. We also know when conditions combine to become unsafe or even life-threatening.

METHODS

Facility-related human factors problems can be identified with a number of fairly simple methods. Since nearly all facility-related aspects of human performance are directly observable or measurable, all of these methods involve some type of observation or measurement. Methods that were described in Chapter 1 may be directly applicable to tasks that readers will be asked to perform in facilities. A good example of such a method is Link Analysis, which has already been discussed in some detail. This method is listed and described in this chapter more in the context of facility design than as a general human factors technique.

Checklist Audit

The task analysis guidelines in Chapter 1 provide a series of checklists. The very first checklist (Table 1-1) relates to the physical environment in which a task is performed. While task analysis checklists can be quite useful for analyzing specific tasks, they tend to be cumbersome when the intent is to evaluate the whole of the workers' environment. In these cases, specific checklist-based audit materials have been developed to support facility evaluations. These audit checklists can be supplemented by computer-based analysis programs that can provide an evaluation of the data gathered during the audit.[28]

Critical Incident Technique

People who work in a particular job for any extended period of time know of incidents that caused injuries or equipment damage. Sometimes, situations arise that *almost* cause injury or damage, but something happens to allow the bad consequences of the situation to be averted. In common parlance, recounting such incidents or situations is known as telling "war stories." In human factors, we've put some structure around retelling war stories and call this the "critical incident" technique.

The idea behind the critical incident technique is quite simple. First, we want to identify incidents or situations that have caused, or have almost caused, personal injury or equipment damage. We do this by asking workers to tell us about such incidents. The premise is that such incidents are indicative of one or more problems in the workers' environment, training, tools, equipment, etc.13,29 Once the incidents are identified, we try to understand *how* and *why* the incident occurred. If one of the contributing factors to the incident is facility-related, then we can focus our efforts on eliminating or mitigating the contributing facility component.

The critical incident technique is a general human factors analysis method that can be adapted to a number of different maintenance areas. We don't know beforehand what the contributing factors for a critical incident might be. It might just as easily be a confusing procedure as a facility element. However, this method can be slanted towards facility-related factors by asking workers to recount any incidents they believe were caused by elements in the facility.

Direct Measurement

Many facility characteristics are amenable to direct measurement. For example, illumination and sound levels, temperature, humidity, airflow, stair angles, and other linear dimensions can be determined by measurement. In some cases, measuring a facility element requires some expertise, especially where sophisticated measuring instruments or techniques are involved. A good example of a fairly tricky measurement is that of sound levels. The person performing these measurements can radically affect their outcome depending on how the measuring instrument is used. However, other direct measurements require no particular technical training. An example is measuring the rise and run of a stairway.

Link Analysis

Link analysis was described in detail in Chapter 1. As opposed to overall facility audits, link analysis allows us to determine important associations among various *task-related* elements such as displays, controls, tools, locations, etc.22 Link analysis was originally used to help designers lay out control panels like those in aircraft cockpits and process plants. However, this technique is especially useful for facility-layout problems related to performing a specific task or set of tasks.

Link analysis is a conceptually simple method that requires observers to record the movements of workers as they perform certain job-related tasks. As more and more tasks are recorded, the observation data are combined to form a statistical picture of important associations among various areas in a facility. Once these associations are known, we can arrange facility components (and task elements) to minimize the distance among those areas with the strongest "links."

Questionnaires

This method was also described in Chapter 1. For facility design, questionnaires can be used to gather critical incident information and to solicit suggestions related to existing or planned facility changes. This may seem like a simple-minded approach to identifying facility problems - and it is. However, the most straightforward way of finding out what workers like and dislike about the facilities in which they work is to ask them. Workers are an extremely valuable information resource. After all, they perform their jobs in these facilities every day. Over time, they've seen what works and what doesn't. Questionnaires are a relatively cheap way to gather a lot of information quickly.30

Structured Interviews

A time-honored method of getting information is simply to ask another person. In fact, face-to-face interviews are the predominant means of gathering certain types of data.31 For example, marketing research firms use "focus groups" to identify the likes and dislikes of potential product consumers. A focus group is nothing more than a structured group interview. Structured interviews can be valuable for facility design, as well. Nobody knows more about the good and bad features of a facility than the people who work in it. The general idea of a structured interview is, first, to convene a group of maintenance technicians and inspectors and, then, to ask for specific information regarding the facility. The "structured" part of the technique means that a facilitator guides the interview, using an outline of the topics that should be discussed.

READER TASKS

Maintenance supervisors and planners have authority to affect the facilities in which they work. It is not so clear, however, that they do this by being directly involved in design tasks. It is more likely that the actual design of facilities is left to other people or groups. Supervisors affect the facility by initiating or approving requests to build or modify it.

In defining which facility-related tasks are reasonable for the intended readers of this *Guide*, we assume that these tasks would fall into one of two categories. The first category contains tasks related to initiating, reviewing, or approving new or modified facility elements. The second category contains tasks related to evaluating the status or usefulness of existing facility elements. Even within the same task, there might be certain steps or processes that are best performed by specially trained people. For example, if a supervisor is evaluating a facility for compliance with human factors guidelines, various technicians might be needed to perform specific measurements.

Certain aspects of maintenance facilities are beyond the scope of this *Guide*. For example, the fundamental structure, materials, construction methods, etc., are within the area of responsibility of the architects and engineers who actually design and build the facility. However, supervisors are probably expected to offer suggestions regarding placement of key areas within the overall facility, such as common areas, technical shops, storage areas, fixed scaffolding and work platforms, etc.

Specifying the Facility Layout

It's unlikely that supervisors and planners would make decisions regarding the construction details of an aircraft maintenance facility. However, these individuals will undoubtedly be asked to provide input regarding the overall layout of such a facility. There are many decisions that must be made when trying to lay out any type of building. Anyone who has ever built a home knows this. These decisions are made more difficult in the aircraft maintenance domain by the fact that the facility must accommodate airplanes. Thus, there is a tendency to think of the airplanes first and the people doing the maintenance work second.

A simple change of perspective can simplify many of the layout decisions that must be made in the early stages of facility design. In the GUIDELINES section, a few simple rules are given that allow readers to make certain basic layout decisions without resorting to complicated analysis methods.

Performing a Facility Audit

In order to address human factors problems, you must first find them. The methods described in the previous section can be used, alone or in combination, to identify facility-related problems. Performing an audit implies that certain characteristics of a facility are going to be measured, or otherwise quantified. You might elect to do an audit for a number of reasons. For example, it is wise to establish a facility baseline, simply to know how the facility compares to human factors guidelines and regulatory requirements. Also, results from the critical incident technique might point to a certain area in the facility as having been involved in a number of near-accidents.

Performing an audit requires direct measurements of various facility elements. It also encompasses interviews with workers, questionnaires, direct observation of worker tasks, and other methods.

Reviewing Facility Changes

In order to determine whether a proposed facility change conforms to sound human factors design principles, the change must be compared with applicable guidelines. In addition, sufficient analysis should have been performed prior to the actual design (or change) request to ensure that the new facility element is needed and will actually help workers perform their jobs. As part of the review and approval process, the person(s) who originated the facility change request should be asked to supply enough information for the reviewer to know when, how, and what human factors design criteria were considered.

Establishing Facility Standards

Often in the workplace, facility-related decisions are made on an ad hoc basis. That is, supervisors don't have a lot of time to analyze every proposal or decision, so they go with whatever seems right at the time. Experience in other industries has shown that this type of decision-making strategy ultimately results in a facility that looks as though it has been put together piecemeal.32 The parts simply don't fit together well, nor is there a common design strategy.

The alternative is to establish design standards that can be invoked for every facility change or addition. Standards can be tricky to implement, since each new facility change tends to be somewhat unique. However, by establishing such standards, supervisors ensure that the tendency is towards the standardized facility.

Specifying Purchased Components

Of all the tasks described in this section, specifying the human factors characteristics of purchased components might have the greatest impact on the human factors aspects of a facility. In most organizations, including those for aviation maintenance, a purchasing agent acts as the interface between those requesting products and those supplying them. In many cases, purchasing agents help users clarify the design of the product or service they are requesting. The usability of purchased products can suffer if the purchasing agent bears the entire responsibility for specifying human factors characteristics because most purchasing agents have little or no knowledge of human factors design criteria.

An alternative is for those who request facility-related products or services to also specify the required human factors characteristics. This ensures that the products will fit with the overall design philosophy of the facility. It also allows the purchasing group to know which aspects of the product can be traded-off for cost concessions from vendors.

GUIDELINES

The guidelines in this section are keyed to the reader tasks described above. Because facility design tasks cover such a broad range, these guidelines vary in their level of detail. Where guidelines are meant to be used to support a hands-on, "walking around" task, they are formatted to allow easy removal and copying. However, no single set of guidelines can cover every possible facility design situation. Therefore, readers should carefully review these guidelines and make any appropriate changes before using them for their facility-design work.

Facility Layout

Aircraft maintenance facilities can be grouped into two categories: those that accommodate airplanes inside the facility and those that do not. In the first category are all aircraft hangars. In the second, everything else. Facilities that must allow airplanes to be parked inside present the greatest design challenge. Therefore, these guidelines are directed toward such facilities. This same procedure, however, can be used to lay out a shop or office area by simply omitting the airplanes.

The overall dimensions and the general shape of an aircraft hangar are determined by the number and types of aircraft that it must accommodate simultaneously. Within that overall size and shape, all other functional areas must be arranged to allow the aircraft to be moved and parked in the building. It would be nice to think that the layout of a hangar is predicated on the type of work that people must do there. Realistically, however, those financing such high-cost facilities want to build the smallest practical volume that can accommodate the aircraft.

To make good layout decisions, supervisors and planners must not allow themselves to think from an aircraft-centered perspective. Rather, good layout, from a human factors perspective, depends on a user- or work-centered approach. Certainly, the design and layout of the facility must allow the aircraft to be moved in and out and placed in the proper position inside the building. Beyond that, however, layout becomes an issue of *what, where*, and *how often* job-related tasks and other activities will be done.33

The step-by-step procedure presented below can be used to define a rough layout for a new hangar facility. This procedure can't be used to define all of the details associated with constructing a large maintenance facility. However, it should allow a good first cut at locating important areas within the building.34

Step 1

Put together a group of people that includes planners, supervisors, and individuals from each of the craft areas that will be housed in the facility. The idea here is to take advantage of what these people have learned by working in other maintenance facilities. This group should stay together for the duration of the layout activity, which doesn't have to be done continually.

Step 2

Produce a large scaled, plan-view drawing of the of the hangar showing only the outside walls, known structural members, and required interior walls, if any. On this drawing, place scaled, plan-view cutouts of the largest aircraft the hangar will have to accommodate. Place the aircraft cutouts in their correct positions on the hangar floor. Sketch in any isolating interior walls that must be built for the aircraft. For example, if one area of the hangar is going to be a paint shop, then it will have to be separated from the rest of the hangar (see Figure 5-4).

Step 3

Sketch in the approximate locations of all fixed work platforms and scaffolding. These would include elements like nose and tail docks. Sketch in the approximate locations of all movable work platforms as they would be located to perform the most extensive maintenance required. At this point, you should have located nearly all of the areas that would be obstructed during maintenance (see Figure 5-5).

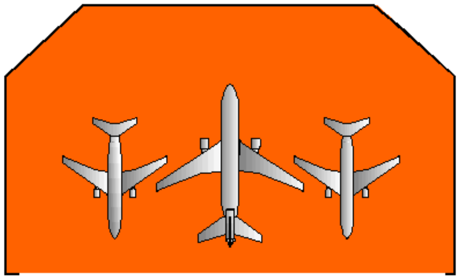


Figure 5-4. Plan view of the facility

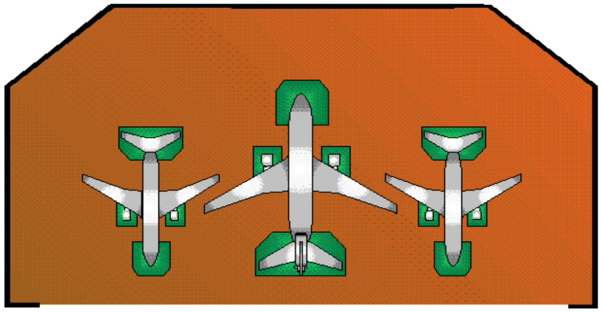


Figure 5-5. Plan view with work platforms

Step 4

Make a list of the functional areas that have to be used by all, or most, of the maintenance technicians in the course of their typical workday. This list should include at least the following:

- Check-in and Check-out Areas
- Break and Eating Areas
- Bathroom and Dressing Areas
- Storage Areas
- Tool or Fixture Cribs
- Safety and First Aid Areas.

Step 5

On the drawing, sketch in the approximate locations of each of the areas on the list developed in Step 4. Try to place these areas so they are about equidistant from the center of the work areas. Don't worry too much about the relative size of each area. Place the break and eating areas next to the bathroom area. Place the personal storage area next to the dressing area, if there is to be a dressing area (see Figure 5-6).

Step 6

Make a list of all individual work areas that have to exist in the facility. These areas include all bench shops, such as avionics, as well as open floor shops, such as engine and hydraulics. Add to this list any storage areas that are unique to a particular craft, such as painting. Also, add any laydown areas that will be required during various types of maintenance.

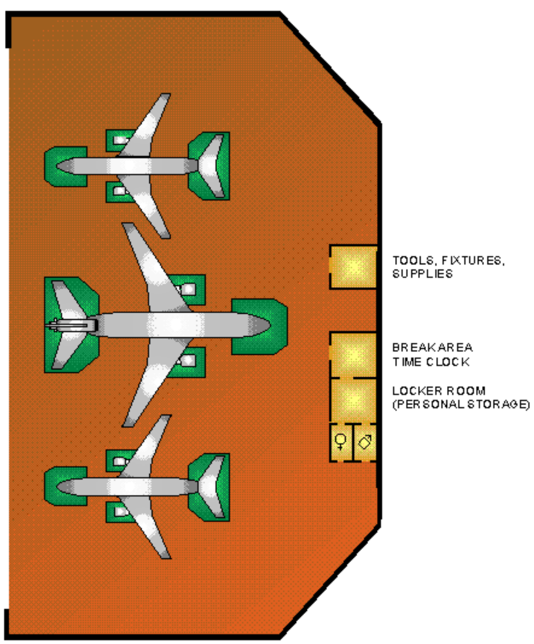


Figure 5-6. Plan view with common areas

Step 7

Assign one of the 4 "link values" to each pair of work areas listed in Step 6. The available values are "low," "medium," "high," and "required." The link value indicates how important it is that two areas be placed close to one another. Next, assign link values to each work area paired with the common areas listed in Step 4. It's a good idea to write down *why* certain link values are assigned, in case you want to go back and change things later.

Step 8

Starting with those work and storage areas that have "required" links with the common areas, begin to sketch in their location on the drawing. The first available space near the common areas goes to the work areas with the highest link values. Also, work areas that have high link values to other work areas should be laced next to one another (see Figure 5-7).

It's likely that some work areas have to be placed in certain hangar locations. For example, the paint shop has to be located in a hangar area that's isolated from other parts of the facility.

Step 9

Review what you've done so far. There may be good reasons why certain areas have to be located in ways that defy the link values. If some areas have to be moved around, go ahead and move them, but be sure to write down *why* you did this.

Step 10

Sketch in the aisles that will connect the airplanes, work areas, storage areas, and common areas. Also, sketch in any exit doorways you think should be in the facility. Don't worry about the details, but if you think a doorway should be extra wide, then you should indicate that on the drawing. Be sure to put outside exits in the common areas, especially the bathroom/dressing and eating/break areas (see Figure 5-8).

Step 11

Using the drawing, try to trace through some realistic activities that will occur regularly. See if there's a reasonable forklift path among various parking and work areas. Trace the path of a single technician moving among various shop and storage areas. Can everyone get to and from his or her work area? Can everyone get out of the building in case of an emergency? Can everyone get to a first-aid station quickly, especially facilities like emergency showers and eyewash stations?

Step 12

Have everybody on the layout team think about the final layout for a few days. Meet again to discuss any misgivings that have developed. Move things around if necessary. Give the labeled drawing to the architects and let them worry about fitting everything in the facility. Be sure to keep a copy of the drawing and all of the notes you made while doing the layout.

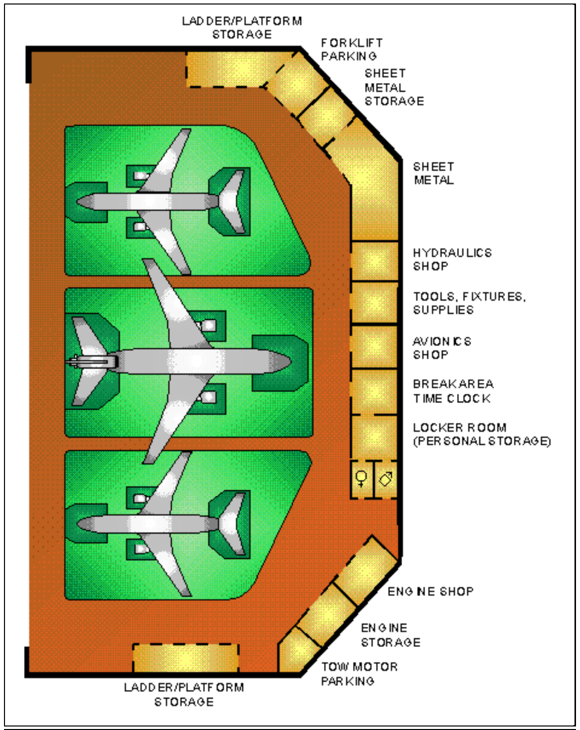


Figure 5-7. Initial work area layout

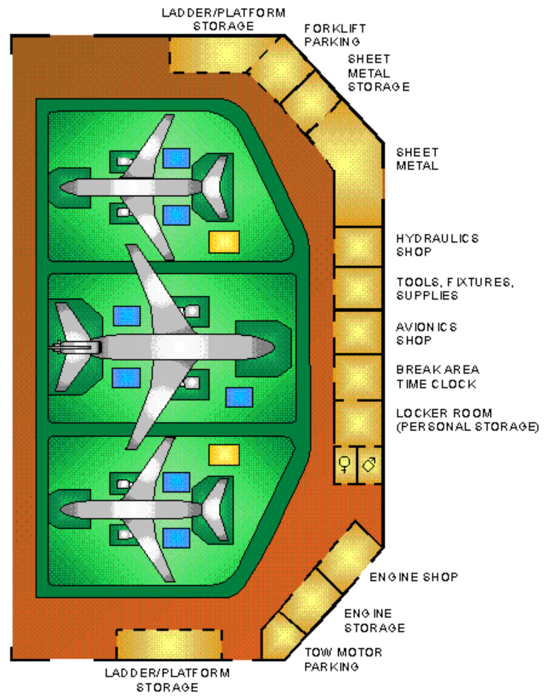


Figure 5-8. Aisles and exits

Facility Audit

A facility audit is intended to define the "as-built" state of the facility. This is *not* a design activity, since the facility has to be completely functional in order to perform such an audit. In architecture, an as-built audit is known as a post-occupancy evaluation (POE). POEs are becoming more and more popular as a way of assessing (1) how the facility's design basis has survived the construction process and (2) whether those features considered important by the designers are also thought to be important to the building's occupants.35,36

A facility audit shouldn't be confused with a job or task audit -- the goals of each of these are different. Job audits, which are covered in Chapter 6, are designed to determine whether workplace features support a particular job or task. A facility audit doesn't address any particular task. Rather, its intent is to look at the overall facility to determine whether it meets certain objective and subjective criteria. Although these facility criteria are certainly related to worker performance and safety, they are not task-specific.

Facility audits consist of a series of activities, each of which is designed to gather specific types of information. An audit should include the following activities:

- Direct Measurements
- Questionnaires/Opinionnaires
- Structured Interviews
- Checklist Walkthrough.

Some of these activities can be conducted in parallel. For example, there is no need to wait for all direct measurements to be made before sending out questionnaires. However, it is a good idea to gather all of the easily obtained information before conducting structured interviews. Guidelines for each audit activity are described below.

Direct Measurements

The "Facility Standards" subsection contains a number of recommendations related to various aspects of maintenance facilities. Most of these characteristics can be directly measured. For example, the ambient sound level can be measured with a sound level meter. Likewise, illumination can be measured with an illuminometer. Some of these measurements require special expertise on the part of the person making them. Large maintenance organizations are likely to have access to an Industrial Hygiene department which can almost certainly make any required measurement. Smaller organizations might have to contract for the services of an industrial hygienist or human factors consultant to make certain measurements.

Table 5-2 provides a list of all direct measurements that should be made during a facility audit. Where particular expertise is required for the measurement, this is noted in the table. As with the facility layout task, the location and value of direct measurements related to lighting, sound, and HVAC should be noted on a simplified drawing of the facility. To get a true picture of the facility, direct measurements should be made in actual working conditions and at various times during the year. For example, if work is performed during nighttime hours, then the measurements should be made during those hours. The goal is to understand the facility conditions in worst-case, best-case, and average-case scenarios.

Table 5-2. Direct measurements for a facility audit

Lighting (Requires special expertise)

Illumination: Measure at work level at locations distributed over the entire facility. Take special care to measure in areas that might be shaded. Record in ft-c and lux.

Reflectance: Measure illumination on and luminance of surfaces. Calculate reflectance in %. Measure ceiling, floors, walls, partitions, and equipment at various locations.

Glare: Measure direct viewing angle to lighting fixtures. Measure indirect glare for any high-reflectance (>70%) surfaces.

Color Rendition: Use color vision cards, such as Ishihara plates, or direct color measuring equipment to determine whether color rendition is appropriate.

(See also Color Rendition)

Sound (Requires special expertise)

Ambient Noise: Use a frequency-band sound level meter to determine sound levels and frequencies at various locations distributed over the facility. Record in dBA.

Reverberation: Measure reverberation time using ISO-3382 method only if reverb is judged to be a problem by workers. Record in seconds.

(See also Reverberation)

HVAC (Some items might require special expertise)

Temperature: Measure at floor level, work level, and head level at locations distributed over the entire facility. Record in degrees Fahrenheit and Centigrade.

Relative Humidity: Measure at work level at the same locations as temperature measurements are made. Record in %.

Airflow: Measure at work level at the same locations as temperature measurements are made. Record in feet/second (ft/sec) and meters/second (m/sec).

(See also Environmental Controls [HVAC])

Ramps, Steps, and Ladders

Inclination Angle: Measure using an incline meter (available at any building supply store). Record in degrees.

Rise and Run: Measure using a ruler or tape measure. Record in inches and centimeters (cm).

Step Overhang: Measure using a ruler or tape measure. Record in inches and cm.

Tread Width: Measure using a ruler or tape measure. Record in inches and cm.

Handrail Height: Measure using a ruler or tape measure. Record in inches and cm.

Tread and Handrail Diameter: Measure using a caliper micrometer. Record in inches and cm.

(See also Ramps through Stairs and Ladders)

Work Platforms

Height: Measure using a tape measure. Record in feet and meters.

Width and Length: Measure using a tape measure. Record in inches and cm.

Floor Material: Observe and note.

(See also Work Platforms)

Aisles, Corridors, and Exits

Width: Measure using a ruler or tape measure. Record in inches and cm.

(See also Exits)

Questionnaires/Opinionnaires

Direct measurements tell us whether certain facility conditions are within the recommended range. They don't tell us whether the workers believe that these conditions, or other facility features, cause them problems during their work; also, they won't tell us whether the assumptions used to develop the recommendations are realistic. By using questionnaires and opinionnaires, we can ask workers to tell us how they feel about various facility features and how they work and dress. Used in this way, questionnaires can help identify faulty assumptions and potential problem areas within the facility.

Table 5-3 is an example of a combined questionnaire/opinionnaire that you can use during a facility audit. This table is partly adapted from work done by Koli and Drury.[37] It contains items that ask for specific information, items that ask for opinions, and a final item that serves as a critical incident report. Note that the name, job title, and other fields that might be used to identify individual workers are completely optional. Allowing respondents to remain anonymous increases the chance that you will get information that reflects reality, rather than what workers think you want to hear.

Table 5-3. Example of a questionnaire for use during a facility audit

FACILITY AUDIT QUESTIONNAIRE

------Identification/Demographics------

(All information in this section is optional.)

Name:________________________________ Job Title:_______________________________

Gender: ___M ___F Age: ______ years Height: ____ft. ____in. Weight: ____lbs.

------HVAC------

1. How would you rate the overall physical effort normally associated with your job? Circle one.

low moderate high

2. From the chart below, please circle those items of clothing you normally wear at your job. If your clothing changes depending on the weather, indicate hot weather clothing with an "H" and cold weather clothing with a "C".

Men Women

Undershirt:	**Sleeveless "T"**	**Slip:**	**Full** **Half**
Trousers:	**Light** **Heavy** **Short**		
Shirt:	**Short Sleeve** **Long Sleeve** **Turtleneck** **Light** **Heavy**	**Blouse:**	**Short Sleeve** **Long Sleeve** **Sleeveless** **Light** **Heavy**
Tie:	**Yes** **No**	**Skirt:**	**Above knee** **Below knee** **Light** **Heavy**
Sweater:	**Long Sleeve** **Sleeveless** **Light** **Heavy**	**Sweater:**	**Long Sleeve** **Sleeveless** **Light** **Heavy**
		Dress:	**Short Sleeve** **Long Sleeve** **Sleeveless** **Above knee** **Below knee** **Light** **Heavy**
Vest:	**Light** **Heavy**	**Neckline:**	**High** **Low**
Jacket:	**Light** **Heavy**	**Jacket:**	**Light** **Heavy**
Coveralls:	Light Heavy	**Coveralls:**	Light Heavy
Socks:	Ankle Knee High	**Socks:**	Ankle Knee High Hose
Shoes:	**Loafer** **Low Lace-up** **Boot**	**Shoes:**	**Slip-on** **Low Lace-up** **Boot**

Table 5-3. Example of a questionnaire for use during a facility audit (cont.)

3. As far as being warm or cool, how do you feel right now? Place and "X" anywhere along this scale.

1	2	3	4	5	6	7
hot	warm	slightly warm	neutral	slightly cool	cool	cold

4. How would you like to feel right now? Circle one.

Warmer no change cooler

5. How do you feel during summer? Place an "X" anywhere along this scale.

1	2	3	4	5	6	7
hot	warm	slightly warm	neutral	slightly cool	cool	cold

6. How would you like to feel during summer? Circle one.

Warmer no change cooler

7. How do you feel during winter? Place an "X" anywhere along this scale.

1	2	3	4	5	6	7
hot	warm	slightly warm	neutral	slightly cool	cool	cold

8. How would you like to feel during the winter? Circle one.

Warmer no change cooler

------Lighting------

9. Do you wear corrective lenses while you are working? Yes No

10. If you circled "Yes" in Item 9, what type of lenses do you wear? Circle all that apply.
Single Rx glasses Bifocals Trifocals Contacts

11. When working outside an aircraft, do you often have to use extra lighting to perform your work?
Yes No

12. If you circle "Yes" in Item 11, what type of extra lighting do you use? Circle all that apply.
Flash light Light stand Drop light Head-mounted light

13. Do you sometimes have trouble reading written procedures because there's not enough light?
Yes No

Table 5-3. Example of a questionnaire for use during a facility audit (cont.)

14. While working outside an aircraft, have you ever had difficulty identifying a color or telling one color from another? Yes No

15. Are you aware of having any visual color weakness (color blindness)? Yes No

16. Do you often experience glare from the hangar lights? Yes No

------Audio Communication------

17. Do you normally wear earplugs or earmuffs? Yes No

18. Do you have difficulty understanding messages on the PA system? Yes No

19. Do you have difficulty talking with other workers who are in your immediate work area? Yes No

20. What is the maximum distance that you need to communicate by voice (without phones or radios)? _________feet

21. Do you have difficulty understanding people on the radio or telephone when you are inside the hangar? Yes No

22. Have you ever been told by a doctor or medical technician that you have any degree of hearing loss? Yes No

------Access------

23. Have you ever had difficulty getting up or down any of the fixed stairs, ramps, or ladders in the hangar? Yes No

24. If you circled "Yes" in Item 23, please indicate with which stair(s), ramp(s), or ladder(s) you had difficulty____

25. Do you ever drive a forklift or tug as part of your job? Yes No

26. If you circled "Yes" in Item 25, have you had any difficulty maneuvering that equipment in the hangar aisles? Yes No

27. Have you ever had difficulty getting into or out of your work area? Yes No

28. Have you ever had difficulty finding another area or workplace in the hangar? Yes No

29. Have you ever taken part in an emergency evacuation of the hangar-either a drill or the real thing? Yes No

30. Have you ever had difficulty getting out of the hangar in emergency conditions? Yes No

Table 5-3. Example of a questionnaire for use during a facility audit (cont.)

------Work Platforms------

31. When you have to work on a platform or scaffold, how much room is there for you and your tools? Place an "X" anywhere along this scale.

```
 1          2           3          4          5          6          7
 |----------|-----------|----------|----------|----------|----------|
```

1	2	3	4	5	6	7
totally inadequate	pretty crowded	slightly crowded	adequate	some room to spare	ample room to spare	wide open

32. Have you ever slipped on the floor of a work platform or scaffold? Yes No

33. Is slipping a common problem? Yes No

34. Have you ever overloaded a work platform? Yes No

------Critical Incident------

Have you ever seen or been involved in any accident or near accident that you think was caused, even partly, by the way the hangar itself is designed? If so, please briefly describe the event and what you think contributed to it.

____

(Use the back of the page, if you need more room.)

Thank you for your help. The information on this questionnaire will be combined with the information on all other questionnaires. We will not attempt to associate any response with you, personally. If you give us your name, we might contact you to give us more details about some of the information you supply. However, in no case will the information you give us be used in any way related to your performance review, pay scale, promotions, etc.

Structured Interviews

After you analyze the information provided by questionnaires, there are likely to be a number of topics that need to be explored in greater detail. Structured interviewing is a good method for addressing certain subject areas in depth. The specific subjects that you need to cover during interviews depend on feedback obtained from the questionnaires and the direct measurements, if they are done. However, the structured interviews will take on the general topical outline of the questionnaire forms, i.e., the type of information to be gathered is pretty much the same.

Structured interviews provide the flexibility of a person-to-person conversation, also allowing the people being interviewed to interact with one another. This helps bring out ideas and information that might be forgotten if they responded to a questionnaire. The major disadvantage of structured interviews is that they are subject to the interpersonal dynamics of any group discussion. People with strong personalities tend to dominate such discussions, even though the information they provide is typically no better than that of people with more retiring personalities.

To compensate for the effects of various personalities in an interview setting, a facilitator needs to be present to steer the discussions in the proper direction and to mediate any disagreements that arise. The facilitator should be someone who is trained in interviewing techniques and who is not part of the participants' organization. Table 5-4 shows a typical outline for a facility-related structured interview. There can be several interviews conducted with different participants. Ideally, each interview should include between 6 and 12 people, not including the facilitator.

Structured interviews should last about one-half day, and the output should be the responsibility of the facilitator (or a secretary assigned to the interview). The products of an interview should consist of written notes covering the essence of what participants discussed or decided.[38] Generally, the participants' identities should not be associated with the output of the interview. It is *not* a good idea to record structured interviews on audio or video tape. Recorders make the participants nervous and reviewing the recordings is very time-consuming.

Table 5-4. Typical topical outline for structured interview.

Introduction of Facilitator and Participants
Purpose of the Interview
Rules of the Interview
Description of the Facilities to be Discussed
Temperature, Humidity, and Airflow
Noise Levels and the Ability to Communicate
Lighting
Stairs, Ramps, and Ladders
Work Platforms
Aisles, Exits, and General Access
Critical Incidents
Summary

Checklist Walkthrough

Using the methods we've already discussed, it's possible to gather a lot of facility information. However, it's also possible to miss a lot. The main problem with these activities is that we have to know which questions to ask before we begin the activity. If we fail to ask something important, we might or might not get data associated with that issue. Also, in the interest of efficiency, we have intentionally left certain information out of the previous methods. The walkthrough addresses both the issue of asking the right questions and gathering the data that were left out of the other activities.

A facility review team conducts a facility walkthrough. The team is composed of essentially the same types of people as the Facility Review Group, with the addition of a human factors person. The review team actually walks through the maintenance facility with a structured checklist. The information they seek is keyed to the checklist. The big advantage a human review team offers is that they can notice things that aren't on the checklist. While the checklist provides structure, it doesn't close out examining other aspects of the facility that might catch team members' attention.

An example of a structured walkthrough checklist is provided in Table 5-5. This checklist is partly adapted from work done by Koli and Drury.[37,39] Each team member should carry a copy of the checklist while conducting the walkthrough. One member of the team, or an assigned secretary, should keep the "official" team notes. However, each review team member should also jot down a short note regarding any facility feature they find either significantly good or bad.

This checklist is a bit misleading, since it tacitly assumes that each topic area, such as "Lighting," will be addressed in serial order. In fact, this would be an inefficient way to conduct a walkthrough. What is more likely is that the review team will start in one part of the facility. They will examine every applicable topic for that area before moving to another area. They repeat this process until all relevant facility locations have been examined. Given the nature of this process, it is a good idea to make several copies of the checklist and to use one copy for each area to be audited.

It might be necessary to conduct multiple walkthroughs to observe the facility in several of its common operational modes. For example, perhaps it is advisable to walk through once during the daytime and once at night. Also, it might be wise to walk through once during the summer and once during the winter. Of all the activities related to facility audits, walkthroughs are probably the most appropriate to conduct periodically throughout the year.

After a round of walkthroughs is completed, the facility review team should meet to discuss its findings. In fact, the facility audit team, which might be the same as the review team, should meet to discuss the results of all audit activities. Facility problems should be identified, discussed, and prioritized. A plan should then be devised for addressing the highest-priority issues.

Table 5-5. Structured walkthrough checklist

General Observations

1. Is the area generally clean and free of trash, obstructions, and debris?
2. Are aisles and walkways clearly marked and clear of obstructions?
3. Is the signage adequate to convey a sense of location?
4. Have workers modified any of the signs or made signs of their own?
5. Are storage areas being used as intended?
6. Is there an obvious, well-marked exit from the area?
7. Are there well-marked parking areas for forklifts and tugs? Is the equipment parked there?

Lighting

8. Does the lighting appear to be fairly even in the area, or are there bright and dark spots?
9. Is there any noticeable flicker from the lighting system?
10. Are all of the facility lights in working order?
11. Have workers modified the light fixtures?
12. Are there battery-powered emergency lights near exits, stairs, and ramps?
13. Are technicians bending over their work to obtain a closer view?
14. Is supplemental task lighting being used in the area? Why?
15. Is there any obvious glare from the facility lights? Where and what type?
16. Do colors appear to be natural, or do they look strange?
17. Are light controls clearly marked and easy to reach?

Ramps, Stairs, and Ladders

18. Are there handrails on all ramps, stairs, and fixed ladders?
19. Is the cross-section of all handrails circular? If not, what shape are they?
20. Are all stair and stair ladder treads covered with non-slip material?
21. Are all landings covered with non-slip material?
22. Do open stairs and ladders have safety screens behind them?
23. Do all portable ladders have non-skid feet?

Sound and Noise

24. Can you understand what is being said on the PA system?
25. Have any PA speakers been modified by workers?
26. If hearing protection is required, are all people in the area wearing it?
27. Can you converse with someone 4 feet away without raising your voice?
28. Have any equipment enclosures been removed or left open?
29. Can you converse on the telephone and understand the person you are calling?
30. Can you converse on the radio and understand the person you are talking with?
31. Are workers using equipment that emits audio signals?

HVAC

32. Do you feel hot or cold?
33. Can you tell a difference in temperature between your head and your feet?
34. Is there any detectable air movement in the area? Is there too much?
35. Are supplemental fans or blowers being used in the area?
36. Are supplemental heaters being used in the area?
37. Is the area exposed directly to the outside?
38. Does it feel particularly humid in the area?
39. Can you detect any noxious smells or "chemical" odors in the area?

Miscellaneous

40. Have workers complained to you about a specific facility feature in the area?

Facility Change Review

Once the human factors basis for a facility has been established, it has to be actively maintained. That is, every substantive change made to a facility needs to be reviewed to make sure it doesn't degrade the facility's usability. Experience in other industries, especially in nuclear power plant control rooms, has demonstrated that without active change control the design basis tends to degrade over time.

There are many methods to review facility changes. One method that will probably work well in most aviation maintenance organizations is borrowed from the nuclear industry.40 This method requires that a facility review group (FRG) be established. The FRG ensures that any addition or modification to the facility is necessary, will not degrade the facility's existing functions, and conforms to established design guidelines.

The FRG should be composed of representatives from each of the following groups within the maintenance organization:

- Facilities
- Maintenance Planning
- Supervision
- Crafts
- Training

- Personnel.

The FRG acts as a *reviewer* of facility change requests, not as an originator of change requests. By having "sign-off" responsibility for change requests, the FRG acts as a gate through which any facility change must pass. The FRG examines each facility change request to ensure that its originator adequately considered certain issues. The FRG should be a standing panel meeting periodically to review facility change requests.

For the FRG method to work, the basis for their review must be made known to potential originators of facility change requests. The FRG essentially places the burden for considering human factors issues on the person or group requesting a facility change. By publishing their review criteria and distributing them through the organization, the FRG heightens everyone's sensitivity to human factors issues. Increased sensitivity increases the probability that a facility can maintain a reasonable human factors design basis throughout its service life.

Table 5-6 provides examples of the types of design considerations that originators of facility changes should be aware of. When the FRG meets to consider proposed facility changes, the originator(s) of those changes should be present to address any of the FRG's questions. The result of an FRG review is an Action Record; an example is shown in Table 5-7. If any question on the Action Record is answered "No" by the FRG, all further action on the change request should be suspended until the originator can address the issue to the FRG's satisfaction.

Table 5-6. Human factors considerations for facility changes.

The following considerations should be addressed by the originator(s) of facility-related change requests:

1. Does the proposed change(s) or addition(s) have definite and essential operational purposes? What are they?

2. Does the operational purpose(s) substantially affect the existing layout or functional design of the maintenance facility?
a) How is the proposed operational purpose presently achieved?
b) Which existing facility elements are used for this operation?
c) What are the alternatives for achieving this operation purpose?
d) Was each alternative fully reviewed and evaluated?

3. Is the facility change in this request primarily for use by workers performing maintenance tasks?
a) Will the change primarily affect maintenance technicians?
b) Will the change affect supervisors and planners?
c) Are there any non-maintenance tasks or workers affected?

4. Will any of the proposed changes affect existing facility elements-either during normal or emergency operation?
a) Does this change require a substantial change to the facility layout?
b) Does this change require new or modified emergency egress routes?
c) Does this change require the temporary disruption of an existing work area?

5. Are there regulatory requirements for this proposed change or addition?

6. Does the change conform to established human factors principles and guidelines?

7. Does the change retain the functional grouping of facility elements?

8. What are the training requirements associated with this change? What are the time considerations for training?

9. What procedure and other document changes are required to accommodate this change?

10. What effect, if any, will the proposed change(s) have on the following facility characteristics:
a) Sound levels
b) Light levels
c) Aisle widths
d) Work platforms
e) HVAC
f) Fire protection

Table 5-7. Example design for a Facility Review Group Action Record.

Facility Review Group (FRG)
Action Record

CN Number:_______________________

Proposed change presented by:______________________________

1. Was the purpose and scope of the proposed change adequately presented? YES NO

2. Was the necessity for the proposed facility change established? YES NO

3. Was the effect on existing maintenance operations satisfactorily addressed? YES NO

4. Were the training requirements adequately addressed? YES NO

5. Were procedural and operational changes adequately addressed? YES NO

6. Were the effects of the change(s) on facility maintenance adequately addressed? YES NO

7. Were provisions made to ensure compliance with Human Factors guidelines? YES NO

FRG Action:

Shall the proposed change be approved?

Supervision	YES	NO
Planning	YES	NO
Crafts	YES	NO
Training	YES	NO
Facilities	YES	NO

Disposition:
Acceptable YES NO

Remarks:

Action Record by: ___________________________ Date:________________________________

Facility Standards

Establishing facility design standards is somewhat tricky. On the one hand, standards serve a useful purpose by giving designers consistent design rules that ensure a minimum level of usability. On the other hand, standards lock designers into doing things in a way that may not be best for *all* situations. The following guidelines address some of the most fundamental facility design issues. They present values that are not likely to change frequently, since they are tied either to human physiological performance or to established regulatory policies.

These recommendations are derived from a number of sources, including applicable OSHA regulations,15 Wesley Woodson's *Human Factors Design Handbook*,41 Alvin Tilley's *The Measure of Man and Woman*,42 and MIL-HNDBK-759B.43 Where multiple recommendations existed, these were selected and combined to provide a reasonable range of dimensions. Where OSHA regulations are specific and prevailing, those values are used. No recommendation in this section violates an OSHA requirement.

Aisles and Corridors

People move along certain paths in a facility. In open areas, these pathways are called *aisles*. In walled areas, people move along corridors. The fundamental guidance for aisles, corridors, and ramps is that they have to be (a) unobstructed and (b) wide enough to accommodate the types of traffic they will support. Figure 5-9 illustrates recommended widths for various types of aisles and corridors.

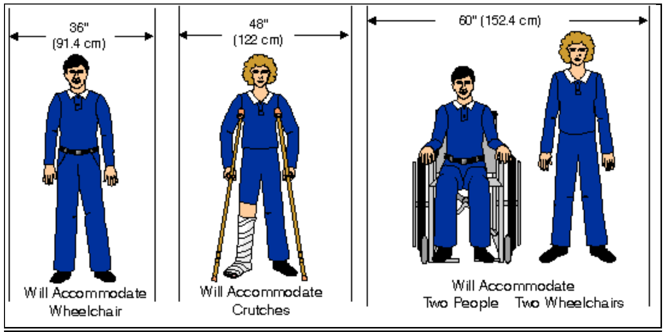


Figure 5-9. Recommended width for aisles and corridors.

When equipment is routinely moved along aisles and corridors, the pathway must be wide enough to allow people and equipment to use it simultaneously. In some cases, two pieces of equipment must be able to pass in the aisle. A common industrial requirement is for aisles to accommodate forklifts or tugs. Figure 5-10 illustrates the sizing requirements for aisles and corridors that must be used by people and equipment.

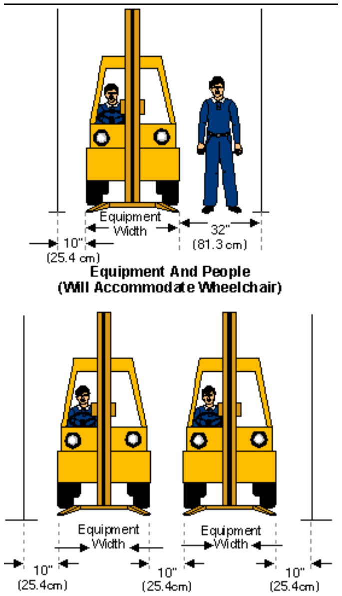


Figure 5-10. Aisle and corridor width for equipment and people

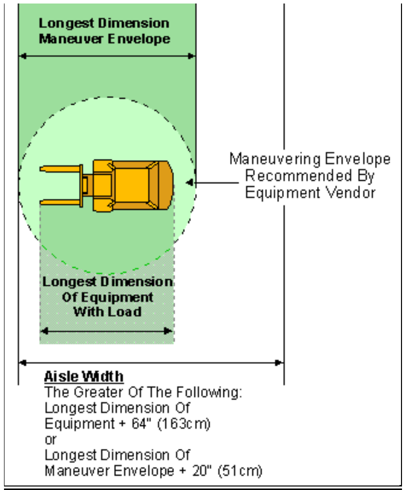


Figure 5-11. Aisle and corridor width when equipment maneuvering is required

Of course, the recommended dimensions shown in Figure 5-10 don't guarantee that there is enough room for any particular type of equipment to maneuver. Where equipment must turn around or handle loads within an aisleway, use the recommendations in Figure 5-11. These recommendations result in aisles with enough room for people to move around equipment, even equipment stuck crossways in the middle of the aisle.

Ramps

Ramps provide a smooth transition between two floor elevations. There are a number of reasons for using ramps instead of stairs, including accommodating wheeled industrial equipment and people with disabilities who cannot negotiate stairs. Both of these purposes cannot always be accommodated with a single set of design standards.

OSHA recognizes two different classes of ramps, cleverly named Class A and Class B. They vary mainly in their slope and width. Both Class A and Class B ramps are too steep for wheelchair access. The general recommendation for wheelchair ramps is for the slope not to exceed 1 in 12, nor for the longest run to a landing to exceed 30 feet. In addition, OSHA regulations require that any powered industrial truck driven up or down a ramp with a slope exceeding 10% be driven with the load upgrade.

Figure 5-12 shows ramp dimensions that accommodate both powered equipment *and* wheelchair users.

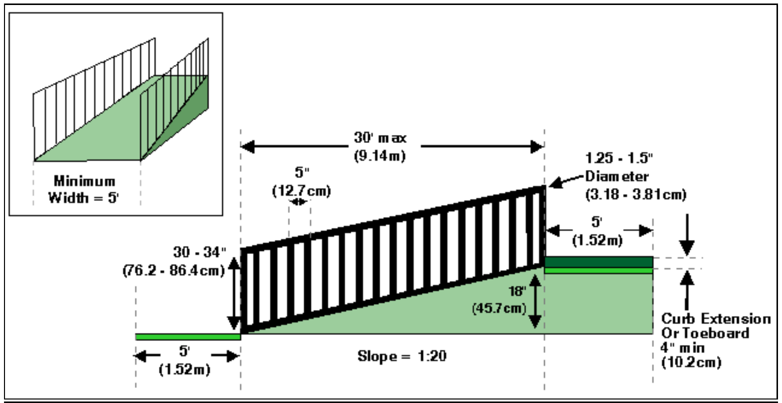


Figure 5-12. Ramp dimensions that will accommodate powered equipment and wheelchairs

Exits

The major concern of any facility designer should be the safety of the people who will be using the facility. Aside from the implications associated with the facility's structural integrity, the most obvious safety concern is people's ability to get out in an emergency. In OSHA terminology, this safety factor is known as "emergency egress." The most oft-cited situation requiring emergency egress is a fire. This is the most common actual situation, as well.

An individual egresses by leaving the facility via an exit. OSHA distinguishes three separate components of an exit: the exit access, the exit itself, and the exit discharge. There are many requirements associated with exit components such as the necessity of maintaining clean and unobstructed paths both to and from exits. The design characteristics most relevant to this *Guide* are the required exit dimensions.

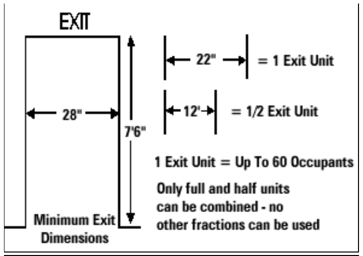


Figure 5-13. Minimum exit requirements and egress capacity calculation

The requirement for an exit's width is directly linked to the number of people who might have to use it in an emergency. "Exit," as used here, means all three parts of the exit. OSHA has provided a formula for determining the required width of an exit. A "unit" of exit width is defined as 22 inches. Fractional units cannot be counted, except for adding 12 inches (one-half unit) to one or more full unit. Each unit of exit width has the capability of accommodating between 60 and 100 facility occupants. Flat routes and Class A ramps can accommodate 100 people per unit of exit width. Class B ramps can accommodate only 60 occupants.

In addition to the exit capacity calculation, there is a requirement that any exit must have a minimum width of 28 inches and a minimum ceiling height of 7 feet 6 inches. Figure 5-13 graphically depicts these exit requirements.

Stairs and Ladders

Another way of moving between floor elevations is to use stairs or ladders. Actually, a range of devices can be used to bridge two elevations. The preferred device depends on the vertical distance to be spanned and the available horizontal distance within which the transition can be made. OSHA allows fixed stairs to be angled between 30 and 50 degrees from the horizontal. Portable ladders should be placed at an optimum angle of 75 degrees from horizontal. Fixed ladders can be placed between 75 and 90 degrees from horizontal.

As a practical matter of comfort and energy expenditure, fixed stairs should be angled between 30 and 35 degrees from the horizontal. Spanning the angular range of between 35 and about 75 degrees are special industrial stairs called "stair ladders." In the aviation workplace, stair ladders would most likely be used as part of portable or fixed work platforms. In the range of about 68 to 80 degrees, portable ladders are the best bet. Beyond this range, use fixed ladders.

Figure 5-14 shows the angular ranges for different types of vertical transitions. In choosing a particular transition method, keep in mind that OSHA doesn't allow portable ladders to be used for routine, i.e., frequent or everyday, movement of people or materials.

Figures 5-15 through 5-18 show the recommended dimensions for fixed stairs, stair ladders, portable ladders, and fixed ladders.

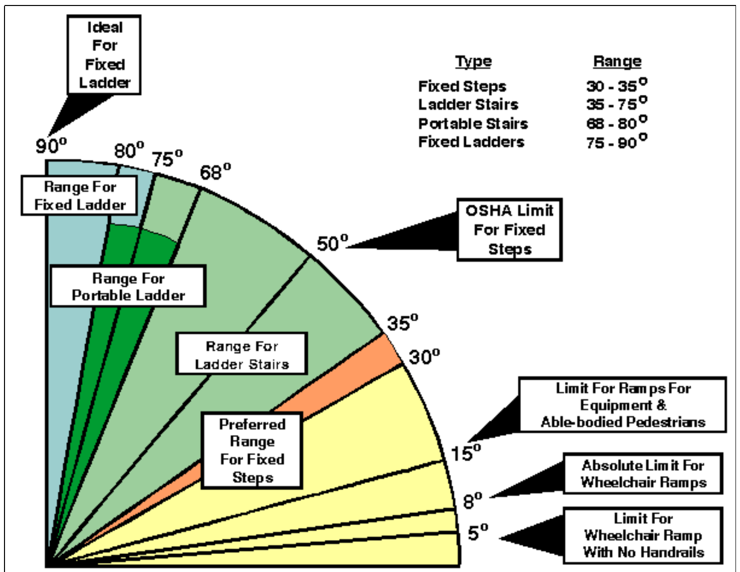


Figure 5-14. Angular limits and recommendations for vertical transitions

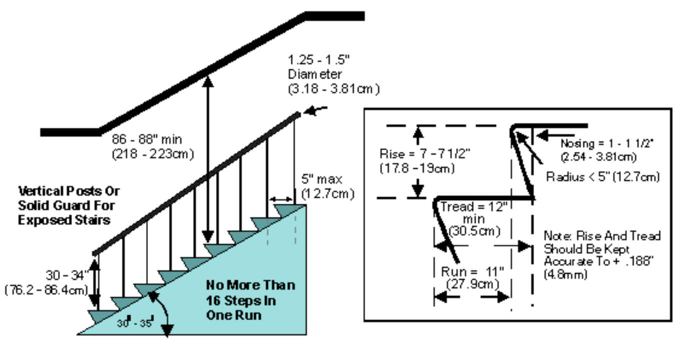


Figure 5-15. Recommended dimensions for interior stairs

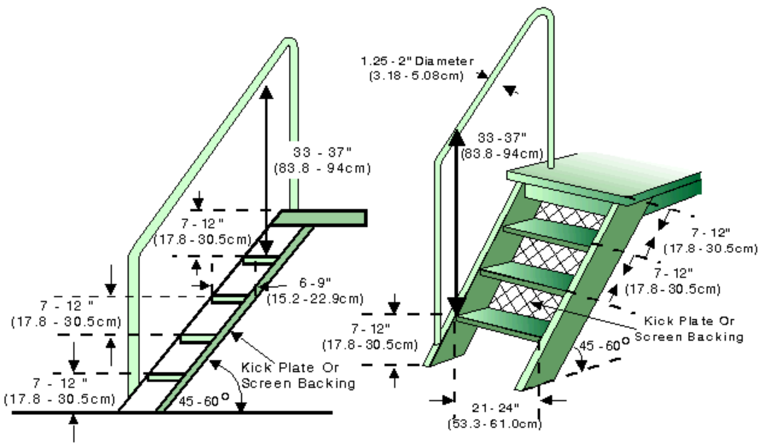


Figure 5-16. Recommended dimensions for stair ladders

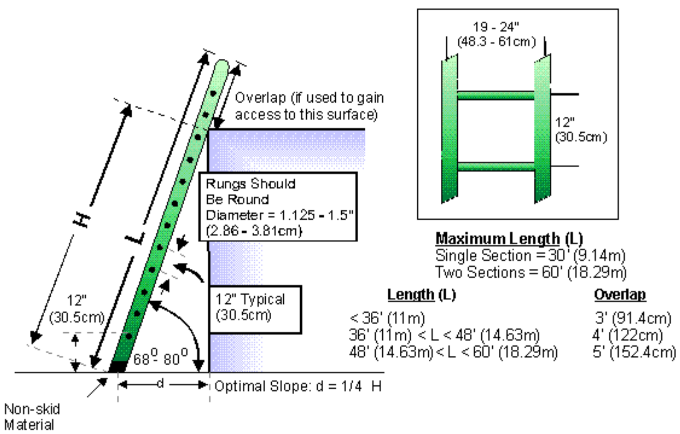


Figure 5-17. Recommended dimensions for portable ladders

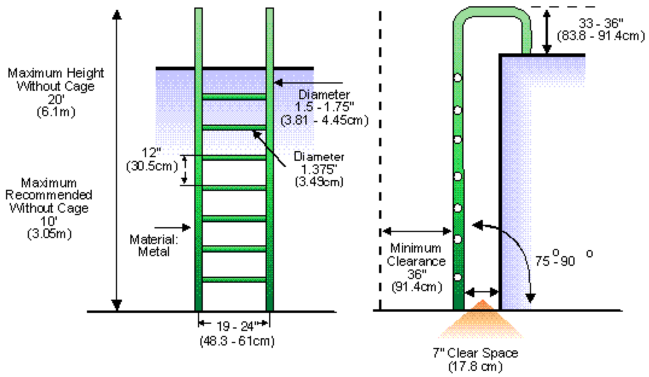


Figure 5-18. Recommended dimensions for fixed ladders

Work Platforms

Aviation maintenance facilities use a number of different work platforms. These platforms enable technicians and inspectors to get close enough to aircraft parts to do their jobs. In most cases, work platforms are elevated above ground level. The act of getting up to and down from work platforms is addressed by the recommendations for stairs and ladders. However, work platforms themselves have characteristics that are subject to human factors design principles.

There are three important human factors aspects of work platforms: overall size, conformance to the work area, and guarding against falls. Of these characteristics, only the overall size of the platform depends on the tasks to be performed and the workers performing them. For example, the work area required by a single individual dressed in normal work clothes and carrying a few tools is much less than that required by several workers dressed in bulky protective clothing and using large test equipment. Also, a worker in a wheelchair requires more area than a standing worker.

Conformance and guarding can be considered to be universal requirements, regardless of the task. For example, if the platform is located 10 feet or more off the floor, safety harnesses should be used in addition to guard rails --*regardless* of the task(s) being performed. Figure 5-19 shows the recommended dimensions for each aspect of work platforms.

The floor of a work platform should either be made of, or coated with, a non-slip material such as expanded metal or abrasive tile (respectively).

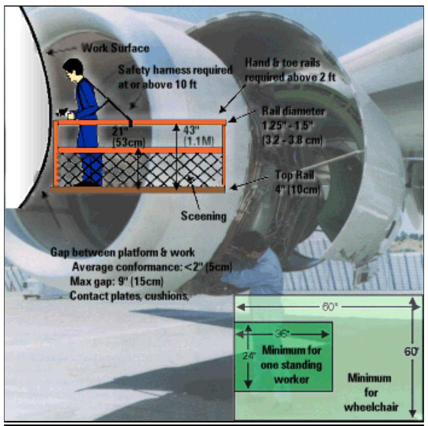


Figure 5-19. Recommended dimensions and features of work platforms

Environmental Controls (HVAC)

The issue of establishing a safe and comfortable working environment might seem conceptually simple. The heart of the matter is maintaining a worker's internal body temperature, the so-called "core" temperature, within a certain narrow range. We know a lot about how various environmental and work factors affect body temperature. For example, we know that both the core temperature and the subjective feeling of comfort are affected by air temperature, radiant heat, humidity, air velocity, type of work, and clothing. Thus, for specific jobs and workers, we can analyze these factors and determine the appropriate range for each factor.

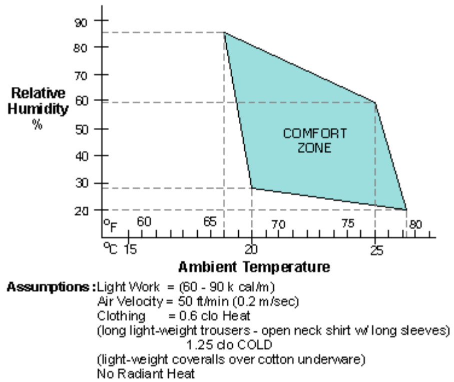


Figure 5-20. Thermal comfort zone for typical hangar-type work

While establishing a comfortable work environment is fairly straightforward for individual jobs and tasks, it is not so easy for an entire facility. In a maintenance hangar, different types of jobs are being performed simultaneously. Therefore, a comfortable environment for a technician performing eddy current testing on a wing skin might not be the same as a comfortable environment for a mechanic drilling and riveting inside an aircraft. About the best we can do from a facility standpoint is to try to keep its atmospheric variables within a reasonable envelope.

Once the envelope is established, we have to depend on the workers to alter their clothing or their local workspaces to account for major departures from our assumptions. Figure 5-20 shows a commonly accepted thermal comfort zone.16,25,44 These values apply to work periods of up to 8 hours. For extended work beyond 8 hours, the comfort zone should be pulled in slightly (by about 1 degree F on each side).

Lighting

Workers' ability to perform various types of maintenance and inspection tasks largely depends on appropriate lighting in their work areas. Lighting is characterized by its intensity and its color rendering ability. Lighting can also be characterized as "facility" or "task" lighting. Facility lighting is the illumination provided by the common facility lighting system, including light fixtures and windows. Task lighting is illumination supplied for a specific task. It includes drop lights, portable light stands, interior aircraft compartment lights, and flashlights.

Intensity. In the aviation maintenance domain, proper facility lighting is particularly important. Most scheduled maintenance is done inside a hangar during nighttime hours. The intensity of illumination is measured in lux, which is the metric equivalent of the foot-candle (ft-c). Each foot-candle is equal to about 10 lux. The level of illumination that is "adequate" depends on the type of task being performed. To give an idea of the range of "adequate" illumination, consider the following:

- **OSHA** requires that EXIT signs be illuminated with no less than 5 ft-c (about 50 lux).
- Difficult inspection tasks or fine bench work can require illumination of up to 500 ft-c (5000 lux).

Even for general facility lighting, there is no single minimum illumination that can be cited as appropriate. Some experts recommend that infrequently visited areas such as storage rooms can be lit sufficiently with as little as 15-20 ft-c (150-200 lux).45 However, if we assume that it is not desirable to have to provide supplemental lighting for *every* task being performed in a hangar, the overall illumination level should be maintained at between 75 and 100 ft-c (750-1000 lux).46,47,48

Distribution. It is important to keep light levels fairly even throughout the work areas. The most common recommendation is to keep the ratio of highest to lowest illumination in and around a work area to 3-to-1 or less.48 In general, we want to provide even, diffuse, shadow-free, glare-free illumination in all areas of a facility used by people. The best way to diffuse light and minimize shadows is to use a large number of small light sources rather than a few large fixtures. By itself, however, the placement of fixtures will not eliminate shadows or bright spots.

Regardless of the placement of light fixtures, the floor area beneath the wing of a large transport aircraft is likely to be shielded from full direct lighting. To raise the illumination level in such areas, the hangar's ceiling, walls, floors, and fixed equipment must be painted so that they reflect a good part of the light falling on them. Reflectance is normally specified in "percent." A reflectance value of 50% means that the surface reflects half of the light falling on it. Figure 5-21 shows the recommended reflectance values for these facility elements.48

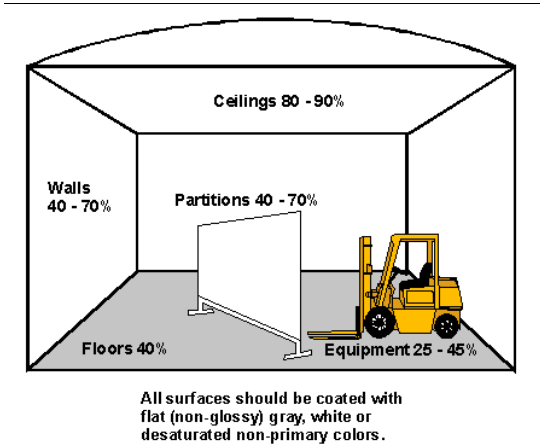


Figure 5-21. Recommended reflectance values for facility elements

Glare. Preventing glare is a prime concern in hangar lighting design. There are two types of glare-direct and indirect. Direct glare occurs when people look directly at light sources, either windows or light fixtures. Indirect glare is caused by light reflected from highly reflective surfaces. Figure 5-22 illustrates both types of glare. The problems caused by direct glare increase as the light sources get closer to a viewer's normal line of sight. The worst performance problems occur when a light source is directly in the viewer's line of sight. These problems decrease as the light source is raised above the line of sight. The so-called "direct glare zone" is taken as that between 0 and 45 degrees above the line of sight. In practice, light sources should be placed at the highest available angle to the viewer's line of sight.23,25

Because of the high clearances found in aircraft maintenance hangars, most light fixtures are placed well above the floor. By a judicious selection of fixture type, diffusers, reflectors, etc., direct glare problems can be minimized. Figure 5-23 shows the recommended viewing angles that will prevent direct glare problems. It also shows an example calculation of the horizontal and line-of-sight distance of an observer from a fixture that meets the recommended viewing angle criterion.

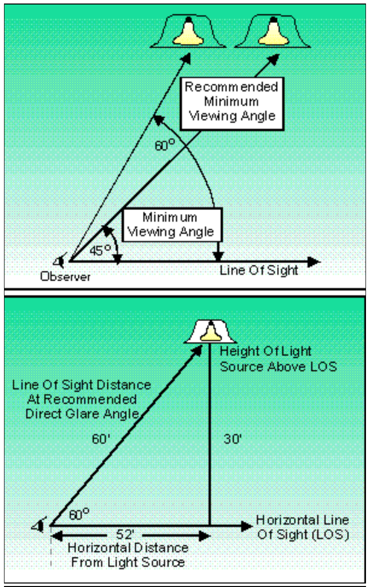


Figure 5-23. Recommended viewing angles to avoid direct glare

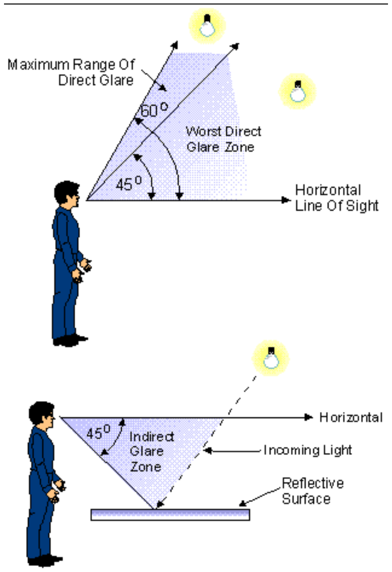


Figure 5-22. Direct and indirect glare

The effects of indirect glare, while not generally as debilitating as those of direct glare, can drastically reduce performance. Indirect glare is relatively easy to control, however, by coating reflecting surfaces with flat paint, by moving light sources out of locations where they cause reflections, or, if light sources can't be relocated, by equipping them with diffusers or polarizing lenses.

Color. The final issue related to lighting is color rendition. Different types of light sources have varying abilities to render certain colors. Natural daylight has the best color rendering ability, since it contains all natural (spectral) colors. Each artificial light source emits a particular spectrum of light.45 That is, each source contains more of some colors than others. For example, mercury vapor lights have very little red in their spectrum. An object such as an electrical wire that appears red in daylight appears orange (or even black) when viewed under a mercury vapor light.

The basic problem for designers is that the lights providing good color rendition, such as incandescent bulbs, tend to be very inefficient. Efficient light sources convert a given amount of electrical power to more visible light than inefficient sources. Conversely, lights that tend to be very efficient, such as high-pressure sodium, are notoriously poor at reproducing certain colors. Daylight fluorescent lights, which are fairly good at reproducing colors, are in the middle of the available efficiency range.

There are two approaches to solving the color-rendering problem. The first is to use a large number of light fixtures and to mix them among at least two different, high-efficiency, types. For example, alternating mercury vapor and high-pressure sodium lamps provides a broad color spectrum at the hangar's working level. The second approach is to use a very efficient type of lighting for the overall facility, regardless of its color rendering capability and to supplement color-sensitive tasks with task lighting. The task lighting to be chosen must have a broad color-rendering capability.

This section has covered a lot of recommendations related to lighting. These issues are condensed in Table 5-8. Findings and specific recommendations for task lighting, including flashlights and larger portable lights, can be found in reference 12.

Sound and Noise

Much of the information that aviation maintenance technicians and inspectors need to do their jobs comes to them in the form of audio communications. We include in this category person-to-person voice exchanges, telephonic transactions, information received via radio and public address links, and audio tones from test equipment or automatic monitoring systems.

Table 5-8. Recommendations related to facility lighting.

Lighting Levels

Lowest recommended level:	15-20 ft-c (150-200 lux)	Should be used only for infrequently used areas
Normal recommended level:	75-100 ft-c (750-1000 lux)	Adequate for many normal maintenance tasks

Illumination Ratio

Maximum recommended ratio:	**3-to-1**	**Brightly lit areas no more than 3 times the illumination of dimly lit areas nearby**

Distribution of Illumination

Use a large number of regularly-spaced small lights rather than a few large lights

Recommended reflectance of various surfaces:	**Ceiling -**	**80-90%**
	Walls and partitions -	**40-70%**
	Floors -	**40%**
	Equipment -	**25-45%**

All finishes should be matte

Glare Prevention

Direct Glare: Place lights so they are at least 45 deg. above the horizontal line of sight. 60 deg. is better.

Indirect Glare: Place lights so they are not in the reflected viewing path.

Color Rendition

Try to balance the color spectrum of lighting. Do not use only sodium or mercury vapor lamps. Either mix light types or use deluxe daylight fluorescent.

Measurements - see Table 5-2

Intensity. As we noted in the CONCEPTS section, the intensity of sound, called its sound pressure level (SPL), is measured in decibels. The decibel scale is logarithmic, not linear. A sound that has an SPL of 40 dB is *10 times* more intense than a sound with an SPL of 20 dB. Figure 5-24 shows SPLs for some common sounds.

From a facility design perspective, the overall task is to minimize unwanted sounds, which we call "noise," and to maximize the probability of workers being able to hear required audio information. OSHA regulations define a worker's noise exposure in terms of "dosage," based on the well-tested premise that the effects of noise exposure are cumulative and increase in proportion to the time-weighted average (TWA) of the worker's exposure. For workers who incur an 8-hour noise dose equivalent to 85 dBA, companies must begin an active program of hearing conservation. The "A" in dBA means the noise is measured using a particular spectral weighting (the A-scale) in the measuring instrument. For continuous noise of 90 dBA or above, workers must wear some form of hearing protection device.[49]

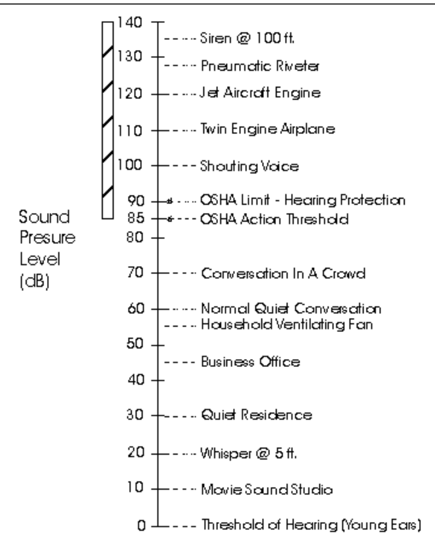


Figure 5-24. Sound pressure levels for some common sounds

Noise Reduction. There are three opportunities for reducing the noise exposure of individual workers (see Figure 5-25).50

Noise can be reduced:

- At the source
- Between the source and the worker
- At the worker.

Source noise control is the most attractive of the three methods because we don't have to worry about controlling noise that isn't produced. Source noise control is most effective when it is addressed as a purchasing issue. That is, if we specify that purchased equipment must be quiet, we avoid the problem of noise exposure. If we have to control noise at the worker level by using hearing protection devices, then we have essentially conceded that we cannot control ambient noise in the facility. Therefore, only the noise control method of focusing between the source and the worker can be addressed with facility design.

There are three ways of reducing noise between the source and the worker: location, insulation, and reflective absorption.51,52 These methods are summarized in Table 5-9. They can be used alone or in combination.

Location refers to placing noise-producing equipment away from the place(s) where workers are located. A common example of this method is locating air compressors outside buildings and running compressed air lines to locations where they are needed.

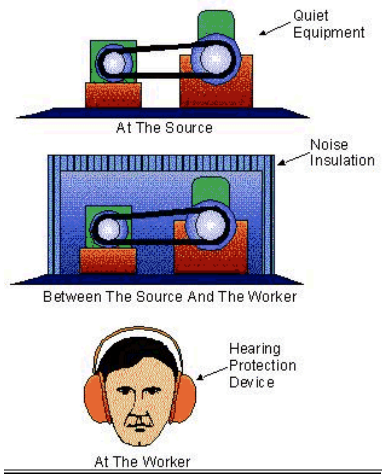


Figure 5-25. Methods for reducing facility noise

Insulation is conceptually simple. It amounts to putting sound-absorbing material between the noise source and the worker. The sound waves must pass through this material to reach the worker. Also, certain types of equipment can be mounted on vibration isolators, which reduce the sound coupling between the equipment and the facility.

Table 5-9. Methods for reducing facility noise.

Method	Description
Location	Place noise-producing equipment far away from locations where workers are performing their jobs. Example: Placing air compressors outside the facility
Insulation	Place sound-absorbing material between the noise source and the workers. Isolate the noise source from the structure of the facility. Example: Mount rotating equipment on vibration isolators. Surround equipment with enclosed, sound-absorbing housings.
Reflective Absorption	Place sound-absorbing materials on large, flat, and hard reflecting surfaces, such as ceilings, walls, and floors. Example: Use acoustic tile on suspended ceilings. Mount eggcrate foam panels on walls

Reflective absorption is a fancy term for putting sound absorbing materials on walls, ceilings, floors, and other surfaces that can reflect sounds. Large, flat, hard surfaces reflect sounds that are directed toward them. Reducing the reflected sound levels can significantly reduce the overall facility noise level. A common absorptive material is foam rubber shaped into an eggcrate or honeycomb.

The final method of reducing noise is to provide workers with some type of hearing protection device (HPD). If the noise SPL is 90 dBA or higher in a particular area, OSHA regulations *require* the use of HPDs. The most common types of HPDs include plugs inserted into the ear canal, caps which seal the ear canal near the outside opening, and muffs which completely enclose the outer ear. Two common complaints regarding HPDs are that they are uncomfortable and that they interfere with speech communication.

The effectiveness of HPDs has been shown to decrease significantly because of users' inability to properly insert them into the ear canal.53 A recent study has also shown that HPDs can interfere with speech. Ironically, those HPDs that provide the greatest protection at high noise levels also interfere with speech at lower noise levels.54 Newer hearing protection technologies such as active noise cancellation are under development now and might reduce or eliminate some of these problems.55

Workers' ability to transmit and receive audio information depends on two factors: low overall noise level *and* intelligibility of the audio sources. We've already discussed ways of reducing noise levels in a facility. Making audio systems intelligible is another matter entirely.

Facility elements that relate to audio systems include public address (PA) systems and "quiet" locations that can be used for telephonic or radio communication. Three characteristics determine the intelligibility of public address systems: loudness, frequency reproduction, and reverberation.

Loudness. Loudness is the subjective impression associated with the objective SPL of a sound. Loudness does not correspond directly to SPL. That is, a sound with an SPL of 80 dBA will not necessarily be perceived as one-third louder than a sound with an SPL of 60 dBA. To be heard and reliably understood, speech has to be about 10 dB above ambient noise levels.25

Frequency. Human speech is not spread evenly across all sound frequencies. Instead, it is concentrated at frequencies between about 200 and 4000 Hz. Public address systems that emphasize speech (as opposed to other audio signals) must concentrate their power in these frequencies.

Reverberation. Reverberation is a phenomenon that prevents sounds from decaying as rapidly as they should. The common perception of reverberation is the familiar "echo" present in airline terminals, auditoriums, etc. Reverberation is characterized by its time constant, sometimes called the "reverberation period." The reverberation period is the time it takes for a sound to decay 60 dB from its original level.56

As the reverberation period gets longer, its negative effect on speech intelligibility becomes greater and greater. The acceptable reverberation period increases as the volume of the facility increases. Figure 5-26 shows how the acceptable maximum reverberation time varies with facility volume.57 Even for very large volumes, reverberation periods over about 2 seconds are considered unacceptable. Reverberation periods of 4-6 seconds render speech almost completely unintelligible.

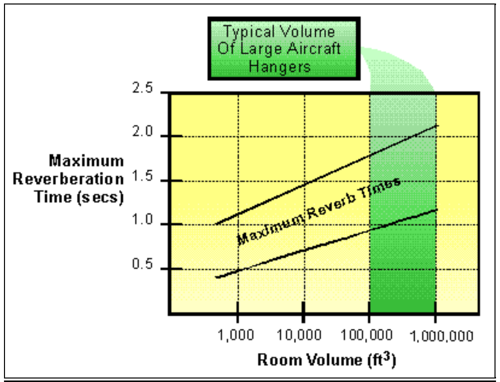


Figure 5-26. Acceptable maximum reverberation periods for different volumes. Adapted from Everest, 1978.

In order to preserve these reverberation characteristics in their proper range, facility PA systems should embody certain features. First and foremost, a PA system should consist of a large number of small speakers instead of a few large speakers. The speakers and amplifiers should be designed so that they concentrate most of their output into the range of frequencies most common in human speech. The speakers should be mounted so their output fields slightly overlap. These design features allow the sound level of each speaker to be set relatively low, and the overall sound pattern in the facility will be much more even and diffuse. It should be possible for a listener walking along a path passing by several speakers not to detect much difference in loudness.

The low power from individual speakers reduces any tendency for reverberation because the sound from any individual speaker decays before it can reflect from surrounding surfaces. If this design is combined with the placement of sound absorption material on large reflecting surfaces, the PA system should be adequately loud and understandable. One exception is workers who are wearing hearing protection. When ambient noise levels are below 85-90 dBA, most hearing protection devices interfere with understanding speech. At ambient noise levels above these values, PA systems aren't going to be heard anyway.

Even facilities with generally low ambient noise levels might have periods in which noise levels rise. To accommodate such periods, noise-insulated areas should be provided to allow telephone and radio communication. These areas can take the form of 3-sided booths or small enclosed rooms in which ambient noise levels are reduced to below 70 dBA when facility noise levels are at their highest levels.

Purchase Specifications

The advantages of embedding human factors rules and principles into an organization are described in Chapter 2. In many cases, the biggest impact of integrating human factors into everyday operational procedures shows up in the purchasing function. By automatically making human factors requirements a part of every purchase order, maintenance supervisors are freed from having to remake decisions for each purchase.

As far as the overall facility is concerned, there are only a few purchasing standards that need to be put in place. These involve stairs, ladders, ramps, surface finishes, and noisy equipment. While there are many other principles and standards that apply to aircraft maintenance tasks, most of these involve individual workspaces, rather than the entire facility.

Stairs, Ladders, and Ramps

The recommendations presented in the Facility Standards section of this chapter should be invoked as a part of each purchase bid and order for such facility components. Simply reproduce the appropriate figures from this document and make them part of your purchase document.

Surface Finishes

The only technical issue related to surface finishes is the reflectance of those finishes. When a purchase document applies to an interior surface of a maintenance hangar, then it should require the finish to be matte (flat) and the reflectance to be within the range specified in Figure 5-21. Likewise, if the purchase document involves a piece of equipment to be used in the hangar, its reflectance should be between 25 and 45%.

Equipment Sound Levels

Recall that the best way to reduce overall facility noise levels is to make sure that noise-producing tools and equipment are as quiet as possible. There are many ways to specify the sound levels of purchased equipment. Probably the most widely understood method is to use what are known as "NC" values. These values come from a series of curves developed over 2 decades ago.58 The curves are officially named "preferred noise criterion" (PNC). They specify a maximum SPL across a wide frequency spectrum. Various performance studies have shown that noise levels not exceeding certain PNC curves are "acceptable" for various activities.

For example, people who work in office environments usually find that noise conditions not exceeding PNC-35 are acceptable. The air conditioning industry uses PNC-35 as its criterion for how noisy equipment can be. Noise in the PNC-50 to PNC-60 range is barely acceptable for speech and telephone communication. To ensure that purchased equipment doesn't compromise workers' ability to communicate by voice and telephone, adopt a noise standard of PNC-45 in purchase specifications.

WHERE TO GET HELP

There are at least three sources of help for facility-related issues and questions. The Human Factors and Ergonomics Society (HFES) is a good source of general human factors information, including that related to facilities. The HFES is located 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

Within the HFES, the Environmental Design Technical Group (EDTG) specializes in "the human factors aspects of the constructed physical environment." As of the end of 1997, the EDTG had 164 members. You should note that technical groups of the HFES don't have paid staff like the overall organization. The Chair of each technical group is a volunteer, elected position that often changes year to year. The central office of the HFES will always have the latest information related to technical groups.

For help with specific facility-related measurements, as well as with issues beyond the scope of human factors, both the National Safety Council (NSC) and the American Industrial Hygiene Association (AIHA) can be helpful. Industrial hygienists are often responsible for meeting regulatory policies related to noise, air quality, toxic emissions, etc.

Contact the National Safety Council at the following address:

National Safety Council
1121 Spring Lake Drive
Itasca, IL 60143-1315
Phone: (630) 285-1121
Fax: (630) 285-1315
Web site: http://www.nsc.org

Contact the AIHA at the following address:

American Industrial Hygiene Association
2700 Prosperity Ave., Suite 250
Fairfax, VA 22031
Phone: (703) 849-8888
Fax: (703) 207-3561

FURTHER READING

Technical Handbooks

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General Safety

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EXAMPLE SCENARIOS

The scenarios below present some of the typical kinds of tasks related to facility design that you can expect to encounter in the workplace. The purpose of including these scenarios in the *Guide* is to demonstrate how the authors foresee the document being used. For each scenario, we describe how the issues raised in the scenario can be resolved. There is usually more than one way to approach these issues, so the responses given below represent only one path that *Guide* users 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 - Noise Limits

You've budgeted a certain amount of money for buying new equipment. Included in your budget are several pneumatic tools and portable air compressors.

Issues

1. How can you determine the noise levels that these new tools and compressors will emit?
2. What should you tell the Purchasing Department regarding the noise limits that this new equipment must meet?

Responses

1. This is an issue that will come up again and again. The term "noise levels" in Issue 1 could easily be changed to any measurable characteristic for a piece of equipment. For instance, we might just as well ask how we could determine the illumination level of a particular type of bulb. There are really only two practical ways of determining a physical characteristic: measurement or specification. In the first method, we actually measure the characteristic of interest. In the second method, we rely on a vendor's specification to tell us the value of the characteristic.

The *Guide* addresses the method of direct measurement in the Facility Audit section. Measuring noise levels is described in Table 5-2. Note that some special expertise and equipment is required to perform these measurements. You should also note that these measurements can only be made if the equipment in question is present in the facility or available at some other site. This is the drawback of using direct measurement to help define equipment to be purchased. If the equipment isn't there yet, it's not easy to measure it.

2. The issue of purchase specifications is addressed in the GUIDELINES section. In the subsection related to equipment sound levels, the *Guide* briefly describes the existence of "preferred noise criterion" (PNC) curves and recommends that purchased equipment meet the PNC-45 noise standard. This discussion also notes that noise in the PNC-50 to PNC-60 range is the maximum allowable if we want to preserve telephonic and voice communication.

Scenario 2 - Facility Accessibility

You've been told that you have to make your loading dock accessible to people who use wheelchairs or crutches.

Issues

1. What is the maximum slope allowed for such a ramp?
2. How long can the ramp be prior to a flat landing?
3. How wide should the ramp be?
4. Does the ramp need a railing? If so, how high should it be above floor level?

Responses

This is a pretty straightforward situation and is directly addressed in the *Guide*. The Facility Standards section contains information related to all physical components of a facility, including ramps. Figure 5-12 contains the answers to all of the issues in this scenario.

1. Figure 5-12 shows the recommended slope of the ramp to be 1:20, i.e., one foot of rise for each 20 feet of horizontal run.

2. Figure 5-12 show that the maximum uninterrupted ramp length is 30 feet.

3. Figure 5-12 shows that the width of all ramps should be a minimum of 5 feet.

4. As shown in Figure 5-12, ramps need railings, and they should be 30-34 inches above floor level.

Scenario 3 - Temperature Control

Several AMTs have complained that the avionics shop is too hot.

Issues

1. What kinds of measurements would you take to check on this complaint?
2. Where would you make the measurements?
3. What temperature/humidity range should be maintained in the shop?
4. How would the AMTs' clothing affect your findings?

Responses

The way these issues are phrased, it's fairly obvious that you need to do some direct measurement of certain environmental conditions. Environmental characteristics are covered in at least three places in the chapter. First, the concept of a "work comfort zone" is described. Next, Table 5-2 lists the measurements that need to be made for temperature-related issues. Finally, Figure 5-20 shows the recommended work comfort range for most tasks.

1. Figure 5-20 shows the recommended work comfort zone as a temperature-humidity envelope. This figure also shows that one of the assumptions related to the work comfort zone is that airflow is at least 50 ft/min. Thus, we can infer from this figure that we have to measure temperature, relative humidity, and airflow.

2. Figure 5-20 references Table 5-2, which describes where these measurements need to be made. Temperature should be measured at floor level, work level, and head level at various locations in the shop. The same is true for relative humidity and airflow.

3. The temperature-humidity range that should be maintained in the shop is shown in Figure 5-20.

4. The discussion in Environmental Controls (HVAC) generally states that we should try to maintain the temperature, humidity, and airflow within the limits of Figure 5-20 and then depend on individual technicians and inspectors to adjust their clothing accordingly. Therefore, clothing wouldn't really affect our findings. However, our findings might affect the type of clothing we would recommend for workers in the area. For example, if we find that we are at one or the other extreme of the comfort zone, we should try to adjust the temperature or humidity. If we can't change the temperature and humidity, we can recommend that people dress either more or less warmly.

Scenario 4 - Movable Workspaces

You want to build a movable work platform that will allow two technicians to service an area near the rear stabilizer of a particular aircraft. This type of work requires that each technician have a rolling toolbox within reach. The rear stabilizer on this aircraft is 17 feet above ground level, but the technicians will have to work at chest height.

Issues

1. How large an area should the work platform have? How would you go about determining what the area should be?
2. Does the work platform need a guard rail? Why or why not?
3. Do the technicians need to wear safety harnesses? Why or why not?
4. How much weight should this work platform be able to handle?

Responses

This scenario is a bit more involved than the previous three. Most of the requested information is available in the *Guide*. However, there are two elements that are *not* present in the chapter.

1. Most of the information in this scenario can be found in Figure 5-19. The first issue relates to how much area the work platform should contain. We can see from Figure 5-19 that the minimum area for one worker is 24 inches by 36 inches. We could infer from this recommendation that two workers would require a minimum of 48 inches by 72 inches.

We haven't said in the scenario, however, how the two workers must stand, relative to each other. What we haven't included in Figure 5-19 is how to consider toolboxes and other material needed on the platform. Once we know how the workers must stand and move relative to each other and their toolboxes, we can reasonably estimate the required size of the work platform. We should always allow about 18 inches between the edge of the work platform and any obstructions such as toolboxes.

2. The work platform in this scenario definitely needs a guard rail, since it will be located more than 2 feet above the floor. This information is contained in Figure 5-19.

3. The workers on this platform should be wearing safety harnesses, since the platform will be located more than 10 feet above the floor. This information is contained in Figure 5-19.

4. The design weight of floors and platforms is the subject of local and national building codes. OSHA specifies that as a minimum each person should be assumed to weigh 200 pounds and have access to 50 pounds of equipment. Also, OSHA recognizes three classes of scaffolds and work platforms (CFR 29 Part 1910, Section 29); light, medium, and heavy, with the following design loadings:

Light - designed and constructed to carry a working load of 25 pounds per square foot (PSF)

Medium - working load = 50 PSF

Heavy - working load = 75 PSF.

These characteristics are listed in Figure 5-19.

In this scenario, we know the work platform has to support at least 2 workers and 2 rolling toolboxes. If we assume the workers weigh 200 pounds each and that a rolling toolbox can also weigh 200 pounds, then the platform must be able to support a total of 800 pounds. However, local and national building codes might require more conservative assumptions. Therefore, whoever actually designs the platform must consult such codes in order to get the design approved by local authorities.

Scenario 5 - Storage

There's just not enough room in the existing storage areas to keep large, seldom-used parts, such as landing gear struts, APUs, etc. You would like to set aside a new area for storing these items, but the only place to do so is adjacent to an exit door. These items are normally palletized and moved with a forklift. The forklift is approximately 4 feet wide, 10 feet long, and can turn in a 12-foot circle.

Issues

1. What is the absolute minimum width of clear passageway that you must keep to the exit?
2. How wide must the aisle be to allow the forklift to move items into and out of the new storage area?
3. Can you locate the aisle so that there is enough room for people to pass, even with the forklift somewhere in the aisle?

Responses

This scenario combines issues of aisles, in which both people and equipment must co-exist, and exits which have certain absolute requirements associated with them.

1. Since we're going to put this storage area near an exit, we *must* ensure that people can still get to the exit in an emergency. Figure 5-13 shows that the absolute minimum width of an exit, including the paths leading to and from it, is 28 inches. This minimum could be extended, depending on the number of people who need to get out of the area. In practice, we would have to know how many people need access to the exit in order to size it.

2. This second issue concerns the amount of room needed to maneuver a forklift in the aisle adjacent to the storage area. Figure 5-10 says that the aisle needs to be at least 20 inches greater than the longest dimension of the maneuver envelope of the equipment. We've told you that this equipment can turn in a 12-foot circle. If we assume that the pallet being handled by the forklift doesn't extend beyond the forks, we can say that our aisle must be 12 feet plus 20 inches wide.

3. This issue is pretty tricky. We have to assume a worst-case scenario to determine whether this is really possible. Let's assume that a person in a wheelchair must get to this exit in an emergency. Assume further that a forklift stalls sideways in the middle of the aisle. From Figure 5-10, we know that we need an *absolute minimum* clearance of 32 inches for the wheelchair. Therefore, we need at least 32 inches on each side of a crossways forklift, which will occupy 10 feet of aisle width. Thus, if the aisle is about 16 feet wide, then we can be assured that a 32-inch path will always be available. Also, although we really don't address this in the *Guide*, we have to ensure that the forklift doesn't block the exit doorway. We can do this in a number of ways. Probably the most straightforward is to place a physical barrier across the aisle about 5 feet from the doorway. This barrier needs to keep forklifts out, but let people in wheelchairs through. One possibility is to embed steel poles in the floor on 40-inch centers. If these poles are 4 inches in diameter and 3 feet high, then they will still allow 36 inch spaces between them.

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