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STRESS AND ERGONOMIC DESIGN AND
EVALUATION OF PERSON-MACHINE SYSTEMS (U)

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FOR THE COMMANDER


for **KENNETH R. BOFF**, Chief
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PREFACE

This report was prepared in the Human Engineering Division, Crew Systems Directorate, of the Armstrong Laboratory (AL), Wright-Patterson Air Force Base, Ohio. The work was performed under Workunit 71841158. The assistance of Miss Sheila Radford in preparing the manuscript is sincerely appreciated.

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PROLOGUE

Western societies are utterly dependent on their machines for food, clothing, housing and medication. Machines are also essential for communication, travel, most social interactions and entertainment, and defense against enemies. The person-machine systems on farms, in mines and factories, and in the military make possible an extended life that is relatively safe, comfortable, and pleasurable. Machines greatly expand human capabilities. However, in our crowded materialistic mechanized society the pace of living is fast, as is the rate of technological change and obsolescence. Stress-induced mental and physical problems abound. Psychological stress is probably the major medical problem of modern society. A high price is paid for the good life.

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INTRODUCTION

Purpose

This paper presents a general overview of stress to sensitize the reader to stress in the work environment and the effects, both beneficial and harmful, of stress upon worker health. How stress may not receive adequate consideration in the design, test, and evaluation of person-machine systems is discussed. The text is application-oriented, in other words, it is written from an ergonomic viewpoint. The reader can become sensitized to workplace stress without having to learn complex details of stress physiology. Hence, only a brief and simple sketch of it is presented. Techniques for measuring stress and operator workload are also not included, since they are readily available elsewhere. To aid in understanding stress, examples are presented where stress impacts human performance. Since some readers may desire to peruse only certain parts of the paper, the various sections are written to be somewhat independent, resulting in some repetition.

Because operator stress plays a crucial role in the utility and suitability of person-machine systems, stress must be an explicit concern in the ergonomic design of such systems. This is often not the case. All too often, designers and developers of person-machine systems assume that, if the system does not impose appreciable discomfort, and if the mental and physical demands on the operator do not exceed operator abilities, then the system will be satisfactory. If the operator can perform necessary tasks, the system is adequate. Such an attitude can be costly to both system operators and system owners, and must be avoided. Some reasons are discussed for why unanticipated stress-related operator health problems do not become apparent before systems are in wide operational use. When faulty design details in post-production equipment cause stress-related worker problems, system modifications to fix the design can be extremely expensive. For the designers and developers of equipment and person-machine systems to succeed in minimizing or avoiding stress-related problems, they must be stress-conscious.

Some stress-related system operator health problems can be due, in part, to problems with the availability, selection, and training of test operators, improper, inefficient or faulty work procedures and system application, unavoidably stressful work situations, and stresses originating outside of the workplace. However, some stress-related problems are caused by design deficiencies that might not have occurred had system designers and test and evaluation personnel been more stress-conscious.

This paper examines stress in general, sources of stress and stress-related operator health problems, and stress consideration in system design, test and evaluation. One section examines the stress of operating with poor visual conditions. An appendix is

a stress checklist that contains many of the items mentioned or discussed in the text.

Stress

Any demand may cause a person to make a response specific to that demand. In addition to the demand-specific response, Dr. Hans Selye (1956) discovered that there is also a nonspecific biochemical response to any demand or need, i.e., to events and perceptions. The stress response, usually simply called stress, is nonspecific in that any demand, whatever its source, internal or external, psychological or physiological, causes the same biochemical reaction. Stress is not the demand on the organism, but the response to the demand. It is not so much what we face, but how we face it. The demand that triggers or causes stress is a stressor. Dr. Selye made his discovery while working with hospital patients after noting that many of them with different illnesses appeared to have very similar symptoms.

Selye's General Adaptation Syndrome has biological stress as its common denominator. The syndrome classifies reactions to stress and contains three stages. The transitions between stages are gradual, and Selye regards the stages as useful abstractions. The three stages are: the alarm reaction, the stage of resistance, and the stage of exhaustion.

(1) In the alarm reaction, the stressor causes the body to prepare for strenuous emergency activity, to fight or to flee from danger. Digestion slows or stops to divert more blood and energy to muscles, pulse rate and blood pressure increase to pump more blood, breathing becomes deeper and faster to supply more oxygen and eliminate more carbon dioxide, perspiration increases for cooling from anticipated strenuous activity, quick energy sources of sugars and fats are released into the blood, and muscles tense to prepare for action. Chemical changes prepare the blood to clot faster in case of injury. The nerve and gland activities are very complex.

(2) In the stage of resistance, the signs of the various changes in the body started in the stage of alarm decrease or disappear. The ability of the body to resist harmful stimuli and disease in this stage is higher than normal. However, when the stage of resistance is of long duration, there is atrophy (wasting away) of the thymus gland, which involves the immune system. Prolonged overstress also enlarges the adrenal cortex and causes atrophy of the lymphatic systems.

(3) The stage of exhaustion follows the stage of resistance if the resistance stage responses do not diminish. Maintaining the body in a condition to fight or flee is very hard on the body. The adaptive energy available to the body has been almost used up. The signs of the bodily changes occurring in the alarm stage that decreased or disappeared in the resistance stage reappear and do not diminish again. The resistance to disease and harmful stimuli apparent in the stage of resistance decreases, and illness or death

may occur.

The above discussion is a short and simplified outline of how stress can cause health problems, and only hints at the very complex physiology involved. For a fairly recent discussion of Selye's theory and related theory, such as those of Cannon (1914) and others, and of stress as a health problem, two recommended textbooks are Cox (1978) and Cooper (1983). Cooper's textbook also examines stress research methodologies, and shows how several of the many early research studies of stress, and some not so early, had badly flawed research methodology. Stress, particularly strong stress, evokes emotion. Lazarus (1977) suggests that emotions mediate adaptation to the environment.

In the above discussion of what can happen when someone is under harmful stress for an appreciable time, it might appear that stress is harmful. Indeed, when most people think about stress, they think of harmful stress or eustress. However, most stress is beneficial or good stress. From a biological viewpoint, stress is an adaptive mechanism that serves a useful purpose: it prepares the organism for physical activity to meet or satisfy demands. When a demand is met or satisfied and stress overcome, the body returns to normal. Stress becomes harmful when it is extreme or when it is unrelieved for an extended period of time due to the demand not being satisfied. Maintaining readiness for activity is hard on the body, and, in a sense, causes "wear and tear," i.e., causes bodily functions to break down, leading to a "stress illness." The most common stress-induced derangements are headache, chronic fatigue and gnashing of teeth. Illness can be the eventual result of the failure to fully recover from stress.

In the primitive world of early man, the stress response was very useful, even lifesaving, in that it provided the individual with the extra strength and endurance required to fight or flee. However, in the world of today, almost all of the threats or demands are social and psychological: except in sports, they are rarely physical. It is not possible to either physically attack or flee on foot from social and psychological threats. Physical actions that could be taken against people, things, or situations perceived as stressors are usually inappropriate, useless, or are forbidden by society. The net result is that there is no outlet for the extra energy produced in the stress response. Since the alarm reaction or response can't be turned off by physical action to satisfy the demand, a high state of physical readiness may then persist for up to days or even for years. In this case, stress is chronic and can eventually be debilitating.

The number of psychological and psychosomatic illnesses in which long term or chronic stress is a major contributing factor is quite large. Such illnesses include high blood pressure, coronary heart disease, migraine and tension headache, stroke, depression, chronic back ache, asthmatic conditions, allergies, many skin conditions, colitis, and arthritis. Long-term stress is a condition in which,

in a sense, the individual is preying on himself.

When recovery from stress is more than total, there can be an improvement in the person: greater muscle strength, increased lung capacity, improved endurance, better blood circulation, improved muscular coordination, etc. Indeed, most stress is good stress in that stress arouses interest, maintains alertness, attention and concentration, motivates mental and physical activity, relieves boredom, increases stress tolerance, and makes possible life itself. An organism with no stress is a dead creature.

If all stresses were harmful, everyone would be in bad trouble, since everyone is subjected to so many demands: everyone every day has hundreds of small and brief demands, conscious and unconscious, hence small and brief stress responses. The number of different possible stress sources is vast. Charlsworth and Nathan (1982) compiled and discussed several classes of or sources of stress. Included on their list are emotional, family, change, work, phobias, commuting, pain, physical, chemical, disease, and environment.

Although stress is essential to both mental and physical well-being, for some people in some situations, stress can be harmful to mental or physical health. Stress that is or can be harmful may be illustrated by two examples in which the stressors are severe and have a potential for producing harmful stress. One is the mental stress from the death of a loved one, and the other is the physical stress from shoveling heavy wet snow when in poor physical condition. Later on, examples will be given where harmful effects occur from accumulated physical strain when the individual stressors appear to be very mild.

People differ, often greatly, in how strongly they respond to a mental or physical demand. Degree of stress arousal depends on how the demand is perceived, which depends on attitudes, beliefs, and values, as well as the time, place, and situation in which the demand occurs. A need or demand may be perceived by one person as posing a threat to well-being and this perception triggers a strong stress response. The same demand may not be regarded by another person as threatening, hence is not stressful. As an example, if two people are required to deliver the same speech to an audience, one person might be very anxious and highly stressed. The other person may look forward with pleasure and anticipation to making the speech and experience no anxiety while delivering it. One has learned to enjoy what may have once been dreaded, and the other has not.

When, through experience and learning, a stressor induces only a little stress, a stress that is at a more appropriate level, when it formerly caused too much arousal, it is commonly said that stress tolerance has increased. More stress is not then tolerated, as the terminology appears to imply. It is just that there is less arousal, i.e., less stress occurs. However, "stress tolerance" is a widely used and adequate term, and it is not advocated that it be replaced. One should keep in mind, though, that what is really meant is that a

stressor or a demand does not cause as much stress, i.e., there is less arousal: tolerance to demand has increased. One of the many benefits that is expected of education, training, experience and both mental and physical exercise, is an increase in stress tolerance. The ability to satisfy more demands or to more easily satisfy demands, as well as the ability to do so without excessive and possibly harmful stress, has increased. Increased ability to manage stress is often described by saying that ability to cope with needs and requirements has increased.

As noted earlier, one of the major goals in life is to increase stress tolerance. However, most people have never received any training specifically intended to increase their ability to manage stress. They are probably aware that they need to manage stress more effectively, and would be happier and more productive if they could, but they don't know how to go about it. Such training is available. Some industrial companies and other organizations have stress-reduction programs. Also, many books have been written on the subject. One good textbook is "Stress and the Bottom Line, A Guide to Personal Well-Being" by Gherman (1981). Another textbook well worth reading is "Stress Management, A Comprehensive Guide to Wellness" by Charlesworth and Nathan (1982).

STRESS-INDUCED HEALTH PROBLEMS IN THE WORKPLACE

In the workplace, operator health problems can occur when stress is excessive or cannot be relieved by activities that satisfy demands. Either mental or physical stress can have harmful physiological effects. As discussed earlier, because stress is a nonspecific biochemical response of the body, the physiological consequences and symptoms from many different sources of stress are similar.

Most system design and development team members are aware that harmful stress in the workplace adversely impacts worker and operator wellness and productivity. However, it appears likely that few of them are aware of the extent of workplace stress problems. Charlesworth and Nathan (1982) note that it is estimated that as many as 75% of all presenting medical complaints are stress-related. Of course, many of the problems are not job-related. Gherman (1981) notes that, for every one employee who dies from industrial hazards or accidents, there are 50 employees who die from cardiovascular diseases, which are often stress-related. He also says that inability to cope with emotional stress causes at least 85% of all industrial accidents. Sherman (1981) reports that, according to psychiatrists and physicians, as much as 20% of employee emotional problems are attributable to the workplace. For a review of occupational stress, the reader is referred to Salvendy and Sharit (1982), and to Smith (1987).

The human operator in person-operated systems may exhibit a variety of stress-related mental or physical symptoms that can indicate the potential for or the presence of health problems.

Total stress on the job is stress due to job demands augmented by stress brought to the job from other sources. Some harmful job-related stress is due to improper worker use of equipment or to improper or inefficient application of systems. However, some harmful stress is due to deficiencies in system design. As an example, work can be stressful when using displays on which it is difficult to discern essential image details. Stress from using displays that are inadequate for the user's tasks will be examined in a later section.

Excessive stress can occur in system operators when there is either information overload or task overload. However, not enough task load can also be stressful. System designers should not attempt to eliminate stress. Total elimination is both impossible and undesirable. Some operator stress is necessary: a task or a situation in which the demands upon the worker are few or weak can be stressful. The system designer's goal is to optimize stress, not to eliminate it.

When work tasks are too easy, workers may regard the work as not posing a challenge and become dissatisfied with both the work and the job. They can be bored and unhappy. Workers with such an attitude tend to have problems with attention, concentration and memory lapses. They tend to be inattentive to system demands and engage in fantasizing and daydreaming to relieve boredom. They tend to make mistakes, and this increases their frustration and stress. Such workers are likely to have low morale which is likely to be accompanied by or be manifested through poor work performance, depression, absenteeism, labor unrest, and possibly theft, vandalism and violence or other antisocial acts. Workers with low morale may quit, die or retire, partly from job stress, with attendant loss to the organization of experienced and trained personnel who might have been retained had system design been better and caused less stress.

In some systems the operator may perform a simple repetitive action in a situation where there is a limited variety of mental stimulation or of required operator action. At the other extreme of activity, significant stress can occur in tasks that require both continuous rapid error-free responses over long time periods and continuous mental concentration, and where the task or the material has little or no interest to the operator. An example of such work is inputting numerical data into a computer. Another example is performing a vigilance or surveillance task where close attention and concentration is necessary, but where anything to detect, to notice, or to respond to with some sort of action rarely occurs.

Workers in such systems must exert considerable mental effort to maintain attention to the observing task during long work periods. Even during short work stretches in situations where a lapse of mental concentration may be serious or even dangerous, observer attention can lapse due to the lack of mental stimulation and physical activity. Knowledge of this possibility is stressful.

Clearly, system operators may be over stressed when they have either too much or too little mental freedom, or if they are too busy or have too little to do. Workers can be subjected to considerable stress when, to an outside observer, the second-by-second stresses appear to be trivial. To avoid harm to health, an optimum balance is required between mental overload and mental underload. Either extreme exerts undesirable effects on the production of hormones and on mental well-being.

Not infrequently in tasks, such as those mentioned above, there is very little activity of major muscle groups, or there may be a relatively fixed position or posture. The lack of body movement and physical exercise can cause both mental and physical problems. For example, prolonged sitting or standing may cause a tired back or tired feet, restless legs, inadequate blood circulation in the legs, perceived physical stagnation, and, eventually, over months to years, possibly varicose veins. Preoccupation with physical discomfort can divert the attention of the equipment operator from tasks and from system and situation awareness. Providing some physical activity is essential, particularly during prolonged duty periods.

Although most people tend to think of a seated operator position as comfortable and restful, in work situations this is usually not true. Serber (1990), in examining chair design, notes that seating interrupts the natural balance and movement of the body. Observing a seated operator working for any appreciable period of time will reveal the squirming and other movements in the chair that indicate the stress imposed by the seated position. Leuder (1983) presents a general overview of approaches to comfort assessment relative to the design of office furniture and discusses the meaning of comfort. Posture and seating at work in such places as at the terminals of video workstations is important for minimizing operator stress. In a field study, Grandjean (1983) found that actual observers preferred settings distinctively different from recommendations in textbooks.

The stress that is imposed by infrequent interaction with other workers can be a mental health hazard. Humans are social animals: they need to interact with others, and are stressed when they can't. In addition, even with work that is interesting and enjoyable, most people require occasional work "breaks," even if of short duration. When rest or recuperation breaks do not occur, problems may arise. For example, work may slow down and errors may increase. Although management that is not stress-conscious may regard it as wasting valuable time, a short respite from work, usually called a coffee break, can be beneficial to both workers and system productivity, whether or not coffee is consumed.

Harmful operator stress can occur with tasks that demand speed, whether or not the individual mental and physical acts required by the tasks are difficult to perform. Workers can be victims of a rapid work pace set by the capability of system equipment or by management, rather than a pace acceptable to workers, a pace that workers can sustain for extended periods without harmful stress.

This is particularly true when the work is highly demanding. Of course, not all complaints about work pace are justifiable.

System operator complaints about any aspect of their work may indicate the presence of job-related conditions that impose undue stresses that may eventually result in health problems. However, the mere presence of complaints does not necessarily indicate that health problems are present, or that they may develop, or that they are attributable to the workplace. Some complaining on the job is natural and even healthy as a way of "letting off steam." For many people, complaining is a way of life, a way of interacting with other people. A total lack of complaints can be an alerting signal that something is wrong. Complaints in the workplace are often the result of stressful events occurring outside of the workplace: a quarrel with a spouse, a lack of sleep, a financial or a health problem, etc. Sometimes complaints are an attempt by frustrated individuals to "take it out" on the system. Also, workers are not always aware that a problem with well-being or with health, such as headaches, blurred vision, or an aching back, is caused by or is related to work stress.

The mental stresses of system operators are sometimes evident from their low morale, unhappiness, complaints, and the poor quality of their work. However, many individuals who are highly stressed by their work have high morale, like their work and their jobs, do not complain about their work, and do not engage in antisocial behavior. Typical examples in western cultures of such individuals are many of the physicians with too many patients, many of the hard-training aspiring professional athlete, many of the ambitious hard-charging company executive, and many housewives with children and a full-time job outside of the home. These examples, it will be noticed, are all of people who are busy most of the time. Some of the people in this example are among the many people who do not complain even when appreciable mental or physical damage has occurred from stress.

Many workers, particularly technical and scientific personnel, are stressed by information anxiety. It is induced by awareness of the increasing gap between what they think they understand and what they think they should understand, between what they want or need to know and what they actually know. An entire textbook by Workman (1984) is devoted to information anxiety.

The mental stress from concern over personal safety in some occupations, such as the police, the military, users of unsafe equipment, and those living in dangerous neighborhoods, is always present as anxiety. Whether or not personal physical danger is a matter of concern, people may be concerned about job retention, work skills, promotional opportunity, finances, spouses, etc. Living with anxiety, whatever its sources, is stressful and may eventually be debilitating. The general effects of stress are similar, as are the health problems.

REPETITIVE STRESS AND CUMULATIVE STRAIN

Cumulative or repeated trauma is thought to be responsible for as much as half of workplace injuries and disabilities. Lay people sometimes assume that a strong demand resulting in a strong stress response is required to cause mental or physical health problems. This notion is incorrect. Stress from various sources is additive so that total stress from many demands, none of which may be a very strong stressor, can be large enough to be harmful.

Accumulated strain from some types of applied weak physical forces repeated over a long time period, sometimes months to years, can result in health problems. This is analogous to the notion of the straw that broke the camel's back. When repetitive strains are perceived as weak, the stressed person may have no concern about them, may not even notice them, and may not even realize their potential for harm. An example to be discussed later is carpal tunnel syndrome from such tasks as using the keyboards of typewriters or computers.

Accumulated strain or the accumulated effects from stress may eventually become large enough to be apparent to the stressed person. By this time, some damage to health has occurred. Even then, the individual, not realizing the cause of the problem, may continue the stressful activity until significant damage has occurred and task performance has decreased or is difficult or painful. However, keep in mind that not all small stresses and small strains result in harm. For example, recovery from the strains imposed by physical exercise can be more than complete: muscles can become stronger, not weaker. The stress involved in learning to perform well at some mental tasks becomes negligible as one becomes proficient. Stress tolerance has increased. In discussing repetitive stress trauma, actually more properly repetitive strain trauma, Armstrong (1986) notes that such injury to the upper extremities is a major cause of lost work in many hand-intensive industries.

An example of a common health problem in the workplace due to cumulative strain from repetitive small strains is carpal tunnel syndrome. It is a collection of symptoms related to the carpal bones of the wrist and the radial nerve to the hand. In this syndrome, use of the hand and wrist is painful and the hand is weak. The pain and weakness are due to irritation of the radial nerve caused by pressure on it where it traverses a bone passage or tunnel. The injury can be due to a few very strong forces exerted by the wrist. However, it is frequently caused by strain from many repetitive weak forces exerted over a period of weeks to months, and, in some cases, over a period of years.

Carpal tunnel syndrome can develop in users of keyboards, such as typists, operators of video data display terminals, and computer workstation operators. The mouse used to control computer displays can also cause it. A support for the lower arm can help prevent carpal tunnel syndrome in keyboard operators. The use of devices other than the mouse, for example, a trackball, can help prevent it.

Several manufacturers supply special wrap-around wrist supports that help protect the wrists of industrial workers, athletes, and others who exert repetitive or strong wrist forces while using tools and moving or manipulating objects. Sports enthusiasts who play racquet games sometimes use these wrist support devices. Armstrong (1983) wrote an ergonomic guide on carpal tunnel syndrome and discussed selected attributes of people who develop the condition.

Repetitive physiological strain injury is not limited to the workplace: it is often found in athletes and others who engage in physical exercises. A common example is afforded by joggers and runners who use sidewalks and pavements. The sudden strong jarring forces exerted when feet impact the hard unyielding pavement strain muscles, tendons, ligaments, and joints. Each impact leaves a small strain. Recovery from the strains is incomplete, and the strain continues to accumulate. Eventually, injury can become sufficient to cause discomfort and even severe pain. Running on surfaces more yielding than pavement, wearing running shoes that have built in shock absorbers, or using shoe inserts that absorb much of the shock energy, can help to minimize or prevent injury.

Another example from sports where repetitive muscle forces can cause cumulative strain injury is "tennis elbow" found in tennis players. Both the powerful stroking of the racquet and the hard impact of the ball on the racquet head exert strong forces on the player's elbow. The residual strains accumulate until irritation and injury to the elbow makes hitting the ball painful. Golfers, from swinging golf clubs, can have cumulative strain injury to their elbows and wrists. Fairly common among hard-hitting table tennis players are cumulative strain problems with wrists, elbows and shoulders. Shoulder injuries appear to be the most common. The author knows several table tennis players with these problems.

The above examples illustrate injury to muscles, tendons, ligaments, joints and nerves. Repetitive small physical injuries to human sensory systems, for example, the visual and auditory senses, can also accumulate. Repeated very loud sounds, such as those at rock music concerts, can seriously reduce sensitivity to sounds, particularly to high frequency sounds. The result of attending only a few rock concerts may be only a negligible loss in auditory sensitivity, however, frequent attendance can result in a significant and permanent hearing loss. Hearing loss from loud sounds can also occur from the high energy sounds emitted by firing weapons and by other explosions, and by unmuffled engines, such as on chain saws. The air-operated riveting guns used to form heads on rivets by shipyard workers and workers who fabricate steam boilers produce sounds that are painfully loud. The permanent hearing loss, particularly at higher sound frequencies, occurring in people exposed for some time to loud sound is, not surprisingly, called boilermaker's disease, for it was first noticed among those workers. Ellis (1983) notes that, in our society, industrial noise is a major cause of traumatic hearing loss and is a major health hazard.

In recent years people have become acutely aware that loud sounds can cause hearing loss that can become permanent when exposure to such sounds is frequent. Wearing ear-protection devices that absorb sound energy is common. The designers and manufacturers of equipment are paying more attention to reducing equipment noise. This is due, in part, to the efforts of the Environmental Protection Agency (EPA), and to more court cases with huge cash awards granted to workers with permanent hearing losses from auditory-stress injury.

Repetitive or continuous mental or emotional stress can result in mental or psychological trauma. Many of the demands made on people are from chronic needs or wants, i.e., ones that are never fully satisfied or are constantly recurring. The stress from such mental and emotional demands can eventually be debilitating. Evidence for this statement is provided by the appreciable part of all patients in hospitals and other health-providing institutions that are there because of inability to adequately cope with mental stress, i.e., satisfy the demands of living without excessive stress, i.e., without excessive arousal. Many of the recipients of disability pay from industry and the military are victims of harmful long-continued mental stress. For example, disabled former prisoners of war who did not recover from the stress due to long-continued severe mistreatment. The continuous stress on the soldiers engaging in trench warfare in Europe in the first world war caused numerous battle casualties, soldiers no longer able to adequately function. In those days the condition was called shell shock. The stress tolerance of the victims in these examples was inadequate.

STRESS AND SYSTEM DESIGN AND DEVELOPMENT

Person-machine systems are designed to accomplish tasks and perform missions. They are thus goal oriented, and exist to satisfy needs. System worth, then, is determined by how well the system output satisfies the system owner's needs or desires. One of these owner needs is minimizing lifetime ownership cost. The owners of person-machine systems may be and should be liable for any work-related decrease in the well-being or the health of the operators of their equipment. Any decrease that results in monetary awards for job injury or for workman's compensation for disability is part of the lifetime cost of system ownership. Operator stress that results in errors, or system slowdown or downtime can also be very expensive.

Even if the owner of a system could avoid paying money for worker injury or health problems, the above considerations demand that stress-induced health problems be eliminated, if possible, and be minimized when total elimination is not feasible. The cost of implementing system changes that reduce or eliminate harmful job stresses can be a good financial investment.

The designers of person-machine systems are understandably concerned with avoiding over stress due to heat and high humidity,

lifting or moving heavy objects, too many tasks, excessive speed or muscular coordination requirements, etc. However, designing to avoid excess stress can be overdone, and may result in not putting enough stress on the worker. When work tasks are too easy to challenge workers or to keep them busy, as discussed earlier, workers may be dissatisfied and morale and other labor problems should be expected. Both a decrease in the quality of system output and health problems may occur.

Since system designers and developers cannot tailor human operators to fit machines, they must tailor the machines to fit the operators. Operator selection and training is limited in ability to modify the human component of systems. The task of system designers is then one of configuring a system that can accomplish its tasks and missions or goals, be suitable for use by available human operators, be manufacturable at a feasible cost, and have an acceptable lifetime cost of ownership, which includes disposal or recycling costs. All system components, other than the human operators, are designed to work with and perform adequately with the human and with the other machine components. System components must meet many specifications and standards and are tested under controlled conditions that are believed to be equivalent to use conditions to be sure that they are adequate.

In many systems, ergonomics experts work with other design team members to insure that the machine will fit the people who will operate it. Once a prototype of the equipment has been fabricated, preliminary tests and evaluations are conducted, and any deficiencies uncovered by them are corrected by making changes in equipment or in operating procedures. Frequently, particularly for equipment or systems intended for medical or military purposes, a final round of both testing and evaluation is conducted to insure that the changes made have corrected the problems. The designers then expect that the system will contain few, if any, errors or design deficiencies, and will be ready for mass production.

The system design, test, and evaluation efforts just discussed are somewhat idealistic. However, even when they have taken place as indicated, it sometimes happens that, after a system has been mass produced and is fully operational, unexpected stress-related operator health problems occur. The question is then asked "how did the system designers and developers go wrong?"

There are many ways in which system designers can "go wrong," i.e., there are many possible sources for design errors. Failure to detect system problems during the test and evaluation phases of system development frequently happens because of inadequacies in system testing. There are many ways in which system testing and evaluation can be inadequate. For example, there may be too little testing because testing may be dangerous or expensive. Also, it may be difficult to procure enough test personnel to conduct meaningful tests. It may be difficult to obtain a group of system test personnel whose characteristics differ little from

those of eventual system operators. To adequately select and train test operators can be quite difficult, time-consuming and expensive. Frequently, test operators are professional test pilots or other professional subjects. Occasionally, they are engineers or other personnel who just happen to be available. They may be selected from regular factory workers or military personnel who are believed to be very good.

On the other hand, the opposite may be true, as when operators are supplied by a supervisor who can spare only the worst workers. In addition, test personnel seldom receive the same training as later operational personnel. Although system test conditions are intended to duplicate or be equivalent to those encountered in the operational situation, frequently they are not equivalent. The result of these test problems is likely to be that too few test operators are used, test operators are used who are unlike later operational personnel, short work periods are used during system tests, and system testing is used that lasts for only a few days or a few weeks. Some of the results of devoting inadequate time to system testing will be discussed later in this section.

Systems can go wrong when the tailoring of the machine to fit the human operator does not result in a good fit. Fitting the machine to the human is achieved by taking into account human characteristics and capabilities. System changes are made until the designers think that an adequate fit has been achieved. The fit is thought to be adequate when the system appears to be able to accomplish its purpose or mission with an acceptable minimum of harmful stress and cost to the human. When the fit of the machine to the operator is good, demands on the operator are compatible with human sensory, muscular, glandular, and mental abilities and limitations. When the fit is poor, reduced performance of both the operator and the person-machine system can, sooner or later, occur, along with stress-related operator health problems. To minimize stress that may be harmful, fit the machine to the human operator.

Fitting the machine to the man requires attention to human factors data which concerns human characteristics: abilities, strengths, limitations, physical dimensions, requirements, etc. Some of the necessary facts for using people as components in person-machine systems have been formulated as human engineering, sometimes called human factors or ergonomics, specifications, standards, and recommendations. These formulations, plus data on human characteristics relevant to person-machine system design, are the subject matter of a truly vast literature. In this report, only a few references and a short bibliography are given to lead the reader into this literature. The Department of Defense (1989) publishes a military standard on human engineering design criteria for military systems, equipment and facilities. Every few years a new updated version is published. The recent and most extensive and comprehensive data collection on human perception and performance is the three volume engineering data compendium edited by Boff and Lincoln (1989). The two-volume Handbook of Perception and Human Performance edited by Boff, Kaufman and Thomas (1986) is

also encyclopedic in coverage. Salvendy (1987) is the editor of the Handbook of Human Factors, a large and excellent source of ergonomics information.

System designers and developers sometimes decide to ignore one or more human factors recommendations to avoid the cost in money, weight, space, etc. required for implementing them. A human factors recommendation may not be implemented because system designers have no data on the cost to human or system performance of not doing so. The designers may decide that the performance of the hardware would be better if the recommendation is not implemented. They may think that the cost to the human operator of not implementing would likely be no more than a minor irritation or inconvenience. When these assumptions are correct, hardware performance, as well as system performance, is improved. Sometimes, of course, the assumptions are incorrect. Sometimes, recommendations made by human factors specialists are ignored by engineers because they do not appear to make sense to the engineers or because designers have doubts about their validity. Even when human factors recommendations are accepted by a design team, the implementation can be inadequate.

Another problem occurs when two system recommendations call for incompatible hardware characteristics, such as a wide field of view combined with a very low instrument weight in an optical display instrument. For this example, neither recommendation can be optimally implemented, and the adopted compromise may not be a good one. The system design team may not be aware that a design decision violates a human factors principle. They may not even know about it. This can occur even when one or more members of the test and evaluation team are human factors specialists or consultants.

Sometimes ergonomic input to the design team may occur only after much, or even most, of the design effort has been completed, or even after some system components have already been purchased or fabricated. When implementing ergonomic advice appears to require extensive redesign work, the advice may be ignored. Later on, any system modification required to correct a system found to have serious human factors design deficiencies can be very expensive.

A common cause for design deficiencies that result in harmful stress to system operators is poor compromises made during system design. Any system is designed with compromises. Often, it will be found that improving one system characteristic can only be done at a cost to another desirable characteristic. Within limits imposed by equipment technology, human operator requirements and system cost, designers play a trade-off game until they reach an acceptable balance between conflicting demands and requirements. Because of the need to make compromises, it is not possible to fully implement some design features thought to be desirable. In addition, sometimes what is optimum for the person may not be optimum for the person-machine system. It is necessary to optimize

the system.

Obtaining acceptable trade-offs requires using data on the effect on operator performance of variation from optimum values cited in textbooks, handbooks, and human factors standards and recommendations. Unfortunately, almost no such trade-off data is available. Without such data, it is usually impossible, in advance of actual system use, to determine how much any one design compromise may cost in operator stress, or in either operator or person-machine system performance. Usually, of course, the costs of the trade-offs will never be known.

A source of design error that is not uncommon occurs when systems are designed without taking into account the effects upon system operation of long work periods. A system that works well for a short time, such as an hour or two, during system tests and evaluations may impose serious stress on system operators when it is operated for several hours. Work period durations when tests and system evaluations are performed should be similar to those expected in operational use. However, because system tests may be dangerous or may be very expensive, tests may be conducted with short work periods. In the long run, tests with work periods of adequate duration, by detecting sources of harmful stress, thus allowing them to be reduced or eliminated, can reduce the lifetime cost of system ownership.

Also mentioned earlier were design deficiencies not revealed during tests and evaluations in which test operators work for only a few weeks or a few months. When a system is new to the test operators, their attitude and motivation is often quite different from that of those who have used the system for some time. New operators may regard operating it as interesting, challenging, and a welcome break from routine. Workers with this attitude often maintain motivation and a high level of work performance over the duration of system tests and evaluations. They may experience less stress and be able to cope with it. However, in operational system use, the newness, novelty, and challenge of system operation are eventually lost. Work may then become routine drudgery, and interest, motivation, morale, and operator performance may suffer. As noted early in this section, workers with such attitudes are likely to be under considerable mental stress. The system can then be headed for operational problems, problems that were not anticipated by the system developers.

STRESS PROBLEMS WITH INADEQUATE VISUAL CONDITIONS

In most military and industrial situations, task and goal accomplishment is largely dependent upon information derived from vision. Other information sources also play a role, but vision is usually paramount. Any unfavorable visual condition may be a source of stress, possibly harmful stress. An example where an equipment operator will be subjected to visual stress, i.e., have a stress response, is driving a vehicle at night on winding streets without street lights or driving in a fog.

Concern, and even appreciable apprehension, may be felt about possible collision with other vehicles or with pedestrians and potholes, and about unanticipated turns in the road. In this example, of course, unless driving under such conditions is frequent, or unless the driver is unusually stressed by such conditions, or the stress contribution from driving is adding to an appreciable stress from other sources, stress does not become distress and stress recovery may be essentially complete.

In many civilian and military systems there are displays or display systems, for example, video display terminals, automobile dashboards, head-up displays in aircraft, etc. Optical devices, such as magnifiers, microscopes, binoculars, and telescopes, that provide virtual images to their users are also display devices. Displays are frequently sources of stress complaints, and mental or physical health problems sometimes result from user stress.

One type of display that is quite common is the cathode ray tube (CRT). In recent years, other types of displays have begun to replace CRTs in some applications, particularly when lighter weight, less power consumption, less volume, or more ruggedness is desired. Examples of devices or technology that can replace CRTs in some applications are liquid crystal displays (LCDs), light emitting diode displays (LEDs), vacuum fluorescence displays (VFDs), photochromics, electroluminescent displays (ELDs), (ELDs), plasma displays, and field emission displays (FEDs). These displays are all flat-panel displays. They can have display user problems similar to those encountered by people who use CRT displays.

Whatever the image source or the type of display, when the display user cannot easily and quickly obtain desired or needed information from it, and sometimes when the observer can, harmful vision-induced or vision-related stress may be present. Many of the stress-related vision problems of display users occur because system designers have violated one or more ergonomics principles and practices. Such principles and practices are available as human factors data, recommendations, specifications, and standards. In addition to the general references given earlier, two recommended data sources specific to the design of visual displays are the Human Factors Society (1988) publication on the human engineering of video terminal workstations, and the human factors data base for the design and selection of cathode ray tube and other display systems written for the U. S. Navy by Meister (1984). A few deficiencies of displays that contribute to user stress will be examined in the following paragraphs.

Video displays have been the source of considerable stress to system operators and complaints from them. There are many possible causes for stress from using imaging displays. A common cause is using them in rooms or enclosures that are unsuitable because the room illumination degrades display quality with attendant stress on the display user. Ideally, rooms and enclosures would be designed to be suitable for the displays used in them.

The surfaces of displays, such as CRTs and devices replacing them, reflect some of the light incident upon them. Display users usually have tasks that require illumination of the work place, and this results in some room light being reflected from the display, including light from light fixtures, windows, walls, ceiling, and even from the face and clothing of the display user. Some of the light sources are reflected as visible images and can be quite annoying. Mixing in with display image light, reflected light, whether or not it forms images, reduces the image contrast of the display, making fine image details more difficult to see. Reduced visibility adds to operator stress and may reduce both operator and system performance.

Not infrequently, enclosure illumination is turned down to minimize reflected light. However, when the luminance of the display appreciably exceeds the light level in the room, the display becomes an uncomfortable, even mildly painful, glare source. Display glare can be unpleasant, because the light adaptation level of the eyes is determined by the level of the light received from the entire field of view. Here, display luminance is too high for the eye's adaptation level.

The glare effect of a bright display viewed in a dimly lit enclosure can be experienced by anyone at night. Turn on a home television set on a dark night, turn off the room lights, and allow only a little light or no light to enter the room from adjacent rooms. When the display is either turned up from low brightness to maximum brightness, or the reverse, it can be seen that glare is worse at higher levels of display screen luminance.

When, due to anti-glare measures and devices, very little unwanted light is reflected from the display, room lighting can be high to provide adequate illumination in the enclosure. There are several things that can be done to minimize unwanted display reflections. Reflections can be minimized by using antireflection coatings on the face of the display, properly placing baffles and light shields, and attaching to the display antireflection devices. Glare-reducing measures are essential when displays are used in intense ambient light, for example, in an aircraft cockpit in bright sunlight. Isensee (1983) examined the perception of and the discomfort from flicker and from direct and reflected glare, finding that video luminance had the greatest impact on comfort.

For some systems, such as helmet-mounted displays, display conditions require highly luminous display images. One way to obtain high luminosity is to use a green CRT phosphor, since some green phosphors are very efficient in generating light. Displays in one color only, i.e., monochrome displays, can cause the user to have visual problems. Green displays, for example, are quite deficient in red light. This causes visual sensitivity to red light to increase, while sensitivity to green light decreases. When, after observing a green image display for some time, the observer stops using the display, everything appears to be redder

than usual: colors appear abnormal. The color shift may persist for some time. Due to pink tinted perception, the condition is called "pink eye." Recovery back to normal vision appears to be complete, and the condition is believed to be entirely harmless. However, some display users are annoyed by the pinkish perception, i.e., it is a source of stress to them.

In graphic displays there may be thin lines, or other display image features that are angularly small at the observer's eye and which are much brighter than the display background upon which they appear. Their very high contrast with the rest of the display may be unpleasant: they are a glare source. When the image features are not white, color after-images may be perceived with a hue complimentary to that of the feature hue. With a white light display, after-images may undergo a series of color changes called a flight of colors. The after-images of most observers usually quickly disappear, but they may persist for a second or more. Some observers are distracted and bothered by such images, while most observers tend to ignore them, becoming oblivious to their presence.

Another problem for some people is visual fatigue from viewing displays. Visual fatigue can be due, in part, to the glare problem discussed above. Visual fatigue can also be partly due to observer astigmatism that could be corrected by wearing proper spectacles. Yet another cause can be inaccurate visual accommodation (eye focus) when the display image is not close to the resting focus distance of the eye, i.e., the resting point of accommodation. The problem of eye accommodation distance is discussed by Ostberg (1980).

Optical situations that can impose appreciable stress on some observers are sometimes of no consequence to others. An example is provided by users of binoculars that are slightly out of optical alignment. People differ appreciably in the visual and perceptual effect of a given amount of optical misalignment. Several observers may not notice that anything is wrong with the binoculars, and can use them for hours with no noticeable ill effects. However, one user who may not notice anything wrong, may quickly develop a bad headache. For yet another user, the optical misalignment is too large, and eyestrain is immediately experienced and worsens with use. If only the first few observers noted above, those with no viewing problems, had been used in testing and evaluation, the binoculars would have been judged as satisfactory.

Another example that illustrates the need for an adequate number of system test observers is provided by people who are unusually sensitive to blinking, flickering, or intermittent light. For most people, such lights are only an easily-ignored mild annoyance, but for some people, however, such lights or lighting conditions are intolerable: they are constantly annoying or distracting, and cause tenseness, nausea or drowsiness. Johnson (1963) found that, for a fourth of helicopter pilots, the chopping of overhead light by the rotor blades of helicopters was a problem.

Examples are easily found of systems in which there is no apparent loss of system performance despite visual conditions very unfavorable to and very stressful to the system operator. An example is landing an aircraft when facing the sun. The sun is a powerful glare source. In addition, the aircraft windscreen may be dusty or dirty and have a large residue from insect impacts, so that it scatters bright light. When facing the sun, the scattered light may be almost blinding, making the runway nearly invisible. This is a quite common situation for aircraft pilots. Despite the poor visibility and high stress, landings are almost invariably satisfactory. However, note the word "almost:" even one bad landing can be a disaster. As this example shows, it is unsafe to conclude from only the successful completion of a task or job, that a system is satisfactory or that operators are not unduly stressed.

Research whose findings are compatible with the above example was performed by Kraft (1977). He examined day and night aircraft landing quality using a series of optically distorting panels in a flight simulator. For simulated night conditions, runway approaches were satisfactory even with badly distorting simulated windscreens, but runway approaches were a little higher and a little faster, with a more rapid later descent and a harder touchdown. Despite severe simulated visual conditions, daytime landings were acceptable. The poor visibility stressed the pilots, and they would have been under more stress in real landings with the additional stress provided by real danger.

Another example where no noticeable loss of systems performance occurred despite appreciable worker stress from unfavorable visual conditions is provided by the workplace illumination systems in the machine shops at Wright-Patterson Air Force Base and at Tinker Air Force Base. Both shops had installed very powerful lamps to obtain bright workplace illumination. Shop workers, mostly machinists, at both shops were quite unhappy with the new lighting system, and complained of eyestrain, poor vision, and headaches.

The managers of these shops requested the author of this report to examine workplace illumination and recommend illumination system changes that would provide satisfactory shop illumination. The shop workers were interviewed and the visual conditions at the shops were examined. Work areas were found to have dark shadows, strong reflected glare from the polished metals used in aircraft repairs and parts fabrication, and unpleasantly bright glare from the light fixtures. The glare made it difficult to read the scales on micrometers, calipers and other shop equipment. It was obvious that lighting conditions made shop work difficult and stressful, and that the complaints from shop workers were based on facts and were fully justified. Workplace illumination was satisfactory after the recommended changes were made in the shop lighting systems. The installers of the original shop illumination systems had been aware of the need to strongly illuminate the workplace. However, they had not implemented, and possibly had not been aware of, the need to minimize glare. Here is a case where management had not noticed

any drop in productivity after the original high-intensity lamps had been installed. It was worker complaints from visual stress that led to required changes in the illumination systems.

REVIEW OF STRESS AND SYSTEM DESIGN

Stress is an adaptive biochemical response to mental or physical need or demand. It prepares the body to act to satisfy the demands of living, to maintain functionality. A person with no stress is dead. Stress arouses interest, and helps to maintain alertness, attention, concentration, motivation, morale and physical fitness. Because many needs or demands are always present, stress is always present. Stress is good when it helps to satisfy demands and the recovery from stress is complete. When recovery is more than complete, ability to perform has increased. Stress is harmful when demands are not satisfied and recovery from stress is not complete. A prime function of mental and physical activity, upbringing, and education and training, is to increase stress tolerance.

With increased stress tolerance, a lesser and more appropriate degree of stress arousal or response occurs so that a demand may be satisfied with less stress. Keep in mind that stress is not the demand, but the response to the demand. As Hans Selye said, it is not what you face, but how you face it. People learn to take demands in stride, i.e., they learn to control the strength of the stress response to demands. How much stress is experienced depends upon who is stressed and when and where the demand occurs. People can differ greatly in stress tolerance. A demand that arouses a stress response helpful to one person may cause harmful stress in another.

In a person-machine system, after too much stress has caused human performance to fall to an unacceptable level, the human cannot be simply discarded and replaced. The human is not a throw away system component. Person-machine systems that impose harmful stress on system operators are morally and ethically unacceptable, and are not economically feasible. Their lifetime cost of ownership is too high. To obtain equipment operators with adequate tolerance to system demands, special selection and training may be used. However, human adaptability is limited. Attempts to obtain a forced fit of operators to machines usually result in systems that impose too much stress on their operators. One can expect that eventually the performance of the operators of such systems and the performance of the systems will degrade and the systems may fail. Machines must be tailored to fit the humans who operate them.

To achieve an acceptable fit of machines to people, system designers must be stress-conscious. Attention must be paid to demands that contribute to stress, and to the ability of system operators to meet or satisfy demands without incurring excessive or long duration stress. The difficulty of performing the individual components of tasks and the mental and physical work pace and workload must be compatible with human abilities. The

designers of systems must also be alert to cumulative strain from some types of repetitive physical activities.

Work or operator stresses that may eventually produce health problems are often undetected until after systems have been mass produced and are in operational use. Nondetection is more likely to occur when system designers are not sensitized to stress, i.e., are not stress-conscious. A common cause for design errors that result in harmful stress is inadequacies in the pre-production system tests and evaluation. Too few test operators may be used, and their abilities and training may be unlike those of later users. Work test sessions may be too short and tests may not be conducted long enough for stress-caused problems to surface. The conditions in which tests and evaluations take place may differ from later use conditions. Although adequate tests and evaluations are expensive, the money saved by inadequate tests can be far outweighed by the costs of modifications required in post-production equipment later found to have serious design errors.

Design errors with potential for harmful stress may occur when ergonomic recommendations, specifications, and standards are not implemented. This can happen because designers are not aware of some of these formalized human needs and abilities, or because they are not correctly implemented. In balancing conflicting or contradictory requirements, some poor compromises may be made. Some requirements may be disregarded because of dollar cost or inconvenience or reduced machine performance, or because they do not make good sense to the design team. When deciding whether or not to implement an ergonomic requirement, consideration must be given to possibly-harmful stress on equipment users if they are not implemented.

To minimize the number of harmful stresses and to optimize stress levels, system design teams should be stress-conscious during all phases of system design, test, and evaluation. This is more likely to happen when the design team includes at least one specialist in human factors or ergonomics.

APPENDIX

STRESS CHECKLIST

The following list includes some of the material in the text and some related material. It is not intended to be a complete listing of considerations and design factors that might have an undesirable impact upon operator stress.

1. Does operation of the equipment or the system allow users to take rest breaks?
-Yes -No
2. Are workers provided with hearing protection devices in work areas that have intense sounds?
-Yes -No
3. Does work involve uncomfortable, awkward or unnatural motions or postures?
-Yes -No
4. Is the worker confined or restrained so as to be unable to stretch, change posture, etc., i.e., is there a lack of body movement?
-Yes -No
5. Does the system alert the user to errors in procedure?
-Yes -No
6. How well can system operators track the using situation and system status?
-Easy -Difficult -Not possible -Not evaluated
7. Are operators provided with feedback as to the accuracy or quality of their input to system operation?
-Yes -No
8. During long periods when system operation requires little mental or physical activity, are tasks provided to maintain alertness, concentration and awareness of the situation and of system status and functioning?
-Yes -No
9. In partially or wholly automated systems, when automatic control fails or degrades, will the human have to take an appreciable time before assuming control?
-Yes -No
10. Are visual displays relatively free from light reflections from light fixtures, walls, direct window light, or sunlight?
-Yes -No

11. Is the fidelity of auditory systems sufficient to provide accurate speech perception?
 Yes No
12. Does equipment contain reliable danger warning devices?
 Yes No
13. Are dangerous devices provided with adequate guards, shields, or safety power cut off switches?
 Yes No
14. When dangerous conditions occur, does the system permit quick easily available reliable escape from the danger or from the workplace?
 Yes No
15. When first aid is required, is access to operators easy and quick?
 Yes No
16. If airborne dust or if noxious gases or fumes are present, are workers provided with proper protective breathing masks?
 Yes No
17. Is the system compatible with the abilities and requirements of the system operators?

A. Workload			B. Work Pace		
	Mental	Physical		Mental	Physical
Too high			Too fast		
Too low			Too Slow		
Adequate			Satisfactory		

C. Task difficulty		
	Mental	Physical
Too difficult		
Adequate		
Not assessed		

18. Are the memory requirements of system operators for equipment or system operation satisfactory?
 Excessive Satisfactory Not assessed

19. What kinds of procedure or operation aids are present?

	Only user memory	Follow the manual	User Checklist	Computer Prompting	Status display
Yes					
No					

20. Is cumulative harmful strain from repetitive demands on muscles, tendons, and ligaments likely?
 _Possible _Likely _Unlikely _Unknown

21. Operator Tasks

	Interesting	Meaningful	Clearly Defined	Routine	Challenging
Yes					
No					
Not evaluated					

22. Quality of sensory input to the system operator.

	Visibility of environment	Display Quality	Auditory Quality	Workplace Illumination
Adequate				
Marginal				
Inadequate				
Not Evaluated				

23. Has careful attention been paid to special screening and selection of system users?

	Motion sickness	Dynamic Visual acuity	Fear of heights	Flicker Sensitivity
Yes				
No				
Unknown				

24. What is done about the complaints and suggestions of test and user personnel?

	Collected	Examined and analyzed	System changes implemented
Yes			
No			
Unknown			

25. What about the hazards of equipment use or system application?

	Hazards present	Danger minimized	Warning labels	Users cautioned
Yes				
No				
Not examined				

26. First aid equipment and supplies.

	Available	Adequate
Yes		
No		

27. Are users confident in the reliability and safety of the equipment and of the system?

Confident not confident Uncertain

28. What is the quality of instructions, operational manuals, and procedure documents?

	Clearly Written	Unambiguous	Amply illustrated	Use tested
Yes				
No				
Not evaluated				

29. Are system operators constantly informed of system status?

Yes No

30. What about communication and contact with other operators in the system?

	Ease, Quickness	Auditory clarity	Visual Contact	Accessibility for first aid	Social contact
Adequate					
Inadequate					
Unknown					

31. What is the quality of provisions for operator comfort?

	Seating	Desks & Tables	Physical restraints	Movement Freedom
Adequate				
Inadequate				
Not Evaluated				

Not
evaluated

32. Are system tests and evaluations adequate for detecting design errors or faulty operating procedures that may cause harmful or excessive stress for system users?

A. Test personnel

- (a) Are there enough test personnel to do significant testing?
_ Yes _ No

- (b) Are test personnel similar to eventual system users?

	Selection	Training	Ability	Attitude	Motivation
Yes					
No					
Unknown					

- B. Are tests of sufficient duration to reveal user stress problems?

	Individual test sessions	Long term, i.e., extended testing
Adequate		
Too short		
Unknown		

- C. Are test conditions similar to eventual user conditions?

	Same hazards	Similar environment	Same procedures
Yes			
No			

REFERENCES

- Armstrong, T. (1983). An ergonomic guide to carpal tunnel syndrome and selected personal attributes, Akron, Ohio, American Industrial Hygiene Assn.
- Armstrong, T.J., R.G. Radwin, and D.J. Hansen (1986). "Repetitive trauma disorder: Job disorders and design." Human Factors, 1986, 28 (3), 325-336
- Boff, K.R., and J.E. Lincoln (1988). Engineering Data Compendium. Human perception and performance, Volumes I, II, and III. Harry G. Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio 45433-7022
- Boff, K.R., L. Kaufman, and J.P. Thomas (1986). Handbook of perception and human performance, Volumes I and II, New York: John Wiley & Sons
- Cannon, W.R. (1914). "The interrelations of emotions as suggested by recent physiological researchers," American Journal of Psychology, 25, 256-282
- Charlesworth, E.A., and S.W. Richardson (1982). Stress management, a comprehensive guide to wellness. Biobehavioral Publishers and Distributors, Inc. Houston, Texas 77001
- Cooper, C. L. (1983). Stress research. University of Manchester, New York: John Wiley & Sons
- Cox, T. (1978). Stress, University Park Press, Baltimore
- Department of Defense (1989). Human engineering for military systems, equipment and facilities (MIL-STD-1472D), Washington, D.C.
- Ellis, N.C. (1983). "Continuous noise and sensorial health loss: a case study," Human Factors, 1983w, 25(4), 425-429
- Gherman, E.M. (1981). Stress & the bottom line. AMACOM, New York, N.Y.
- Grandjean, E., W. Hunting, and M. Piderman (1983). "VDT workstation design: Preferred settings and their effects," Human Factors, 1983, 24(2), 161-175
- Hopkins, V.D. (1992). "Human factors issues in air traffic control," Human Factors Society Bulletin 35(6) June 1992
- Human Factors Society (1988). American national standards for human factors engineering of visual display terminal workstations, Santa Monica, California

Johnson, L.C. (1963). "Flicker as a helicopter flight problem," Aerospace Medicine, 1963, 34, 306-320

Isensee, S.H. and C.E. Benett (1983). "The perceptual flicker and glare on computer CRT displays," Human Factors, 1983, 25(2), 177-184

Kraft, C.L., C.D. Anderson, C.L. Elworth, and C. Larry (1977). Windscreen quality and pilot performance. Technical Report AMRL-TR-77-39, October 1977, Air Force Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force System Command, Wright-Patterson Air Force Base, Ohio 45433-7022

Meister, D. (1984). Human engineering data base for design and selection of cathode ray tube and other display systems. Technical Report NPRDC-TR-84-51 July 1984. Navy Personnel Research and Development Center, San Diego, California. AD-A145 704

Lazarus, R.S. (1977). "Cognitive and coping processes in emotion." In A. Monat and R. Lazarus, Editors (1987). Stress and Coping. New York: Columbia University Press

Lueder, R.K. (1983). "Seat comfort: A review of the construct in an office environment," Human Factors, 1983, 25(6), 701-711

Ostberg, O. (1980). "Accommodation and visual fatigue in display work." In Ergonomic aspects of visual display terminals, Edited by E. Grandjean and E. Vigliani (1980), pp. 41-52. London: Taylor and Francis

Salvendy, G., Editor (1987). Handbook of human factors. New York: John Wiley & Sons. Inc.

Salvendy, G. and Sharit, J. (1982). "Occupational stress", In G. Salvendy, Editor (1982). Handbook of Industrial engineering, pp. 1-15. New York: John Wiley & Sons, Inc.

Selye, H. (1956). The stress of life. New York: McGraw-Hill

Serber, H. (1990). "New developments in the science of seating," Human Factors, 1990, 33(2), 1-3

Smith, M.J. (1987). "Occupational stress," In G. Salvendy, Editor (1987). Handbook of human factors, pp. 845-860. New York" John Wiley & Sons

Wurman, R.S. (1989). Information anxiety, New York: Doubleday

BIBLIOGRAPHY

- Goodson, J.E., and J.W. Miller (1959). "dynamic visual acuity in an applied setting," Aerospace Medicine, 1959, 30 755-763
- Gopher, D. (1959). "On the psychophysics of workload: Why bother with subjective measures?," Human Factors, 1984, 25, 519-532
- Jones, J.C. (1970). Design methods, London: John Wiley & Sons
- Ketchell, J.M., and L.L.Jenny (1969). Electronic and optically generated aircraft displays. A study of standardization requirements, JANAIR Report No. 680 505. Office of Naval Research, Washington, DC AD 684 849
- Luxenberg, H.R. and J.R.L. Kuehn, Editors (1968). Display systems engineering, New York: McGraw-Hill Book Company
- Matthews, M.L., J.V. Lovasik, and D.K. Mertins (1989). "Visual performance and subjective discomfort in prolonged viewing of chromatic displays," Human Factors, 1989, 31(3), 259-271
- Meister, D. (1971). Human factors: Theory and practice, New York: John Wiley & Sons
- Murch, G. (1982). "How visible is your display?," Electro-Optical System Design, March 1992
- Ray, M.S. (1985). Elements of engineering design: An integrated approach, Englewood Cliffs, New Jersey: Prentice Hall
- Rehmann, J., E.S. Stein, and B.R. Rosenberg (1983). "Subjective pilot workload assessment," Human Factors, 1983, 25(3), 297-307
- Rouse, W.B. (1986). "On the value of information in system design: A framework for understanding and aiding engineers," Information Processing and Management, 22(2), 217-228
- Rouse, W.B., and K.R. Boff, Editors (1987). Behavioral perspectives on designers, tools, and organizations. New York: North Holland
- Sharit, J., and G. Salvendy (1982). "Occupational stress: review and reappraisal," Human Factors, 24, 129-162
- Van Cott, H.P., and R.C. Kincade, Editors (1972). Human engineering guide to equipment design, Superintendent of Documents, U.S. Government Printing Office, Washington, DC