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ENGINEERING DESIGN HANDBOOK

MAINTAINABILITY GUIDE FOR DESIGN

HEADQUARTERS, U S ARMY MATERIEL COMMAND

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DEPARTMENT OF THE ARMY
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PREFACE

This revision replaces AMCP 706-134, published originally in **1961,** and all subsequent reprints. Changes introduced by this revision are:

a. A new Chapter **3** that is consistent with DODD 4100.35 and TM 38-703-2, *Integrated Logistic Support (ILS) Procedural Guide*

b. Addition of par. 27-5, Automotive Diagnostic Test Equipment Criteria, that provides guidelines which will enhance internal combustion engine powered materiel (ICEPM) maintainability by the use of automatic test equipment (ATE).

The Engineering Design Handbook Series of the Army Materiel Command is a coordinated series of handbooks containing basic information and fundamental data useful in the design and development of Army materiel and systems. The Handbooks are authoritative reference books of practical information and quantitative facts helpful in the design and development of Army materiel so that it will meet the tactical and the technical needs of the Armed Forces.

The highly technical nature of modern Army materiel and the nature of the service required of it, together with imposed or inherent limitations in design choices, have greatly intensified the problem of maintenance. Vital information has been collected from maintenance engineering experience and research. This information has yielded design principles that should be carefully considered in the design of all Army materiel and systems to assure the maximum practicable simplicity, reliability, maintainability and durability. This action must be pursued with a sense of urgency if the Maintenance Problem is to be dealt with effectively.

The objective of this handbook, *Maintainability Guide for Design,* is to influence design so that equipment can be (1) serviced efficiently and effectively if servicing is required, and repaired efficiently and effectively if it should fail, or **(2)** operable for the period of intended life without failing and without servicing, if possible. The designer who considers the technology of maintainability as one of the prime design considerations can play a vital part in the solution of the Maintenance Problem, whereas the designer who fails to do this adds to the intensity of the problem.

This handbook embraces information on the extent and nature of the Maintenance Problem as it exists today and the principles and techniques that, if included in future designs, will reduce this problem. Part One describes the extent of the Maintenance Problem in terms of the expenditure of money, men, and materiel. Part Two presents maintainability objectives, principles, and procedures. Part Three describes the nature of the Maintenance Problem in terms of the conditions under which weapon systems must be operated and maintained, from the logistical, human, and the environmental points of view. Part Four deals with design considerations that have general applicability to all types of Army materiel. Design considerations applicable to specific types of Army materiel are presented in Part Five. Specific references are listed after chapters or sections. **A** glossary of maintainability terms and a bibliography are included near the end of the handbook. An appendix presents a tabulation of Applicable Military Specifications, Standards and Publications.

The basic handbook draft was prepared by Information and Training Services, F. W. Dodge Company, Division of McGraw-Hill, Inc. under subcontract to the Engineering Handbook Office of Duke University, prime contractor to the US Army Materiel Command, for the Engineering Design Handbook Series. Some of the material was prepared originally for an earlier handbook, *Maintenance Guide for Ordnance Design.*

The Engineering Design Handbooks fall into two basic categories, those approved for release and sale, and those classified for security reasons. The Army Materiel Command policy is to release these Engineering Design Handbooks to other DOD activities and their contractors and other Government agencies in accordance with current Army Regulation 70-31, dated 9 September 1966. It will be noted that the majority of these Handbooks can be obtained from the National Technical Information Service (NTIS). Procedures for acquiring these Handbooks follow:

a. Activities within AMC, DOD agencies, and Government agencies other than DOD having need for the Handbooks should direct their requests on an official form to:

Commanding Officer
Letterkenny Army Depot
ATTN: AMXLE-ATD
Chambersburg, Pennsylvania 17201

b. Contractors and universities must forward their requests to:

National Technical Information Service
Department of Commerce
Springfield, Virginia 22151

(Requests for classified documents must be sent, with appropriate "Need to Know" justification, to Letterkenny Army Depot.)

Comments and suggestions on this Handbook are welcome and should be addressed to:

Commanding General
US Army Materiel Command
ATTN: AMCRD-TV
Washington, DC 20315

PART ONE
INTRODUCTION TO THE PROBLEM

CHAPTER 1
THE MAINTENANCE PROBLEM

1-1 GENERAL

The importance of maintainability in equipment design cannot be overemphasized. Technological advances in the past 25 years have had a dramatic and far-reaching impact on military activities. During World War 11, radar, the proximity fuze, fire-control computers, and high-speed tanks were important in our victory. Since that war, technology has increased the rapidity and range of our communications, and the precision and power of our weapons. To realize these potentialities, however, designers must give greater emphasis than ever before to those factors that will ensure that our equipment is reliable and maintainable in the field.

1-2 SIGNIFICANCE OF THE PROBLEM

Lack of satisfactory reliability and maintainability in military equipment has three serious effects. First, the success of vital military missions is jeopardized and the lives of military and civilian populations are endangered ; for example, excessive downtime of radar could cripple our air defense system. Second, support costs are heavy, imposing a strain on production, supply, and storage. The estimate that the cost of maintenance during the life cycle of a modern weapon, or weapons system, is in the order of 3 to 20 times the original cost of the equipment indicates the magnitude of the upkeep cost (Ref. 1). Third, many skilled maintenance men are needed, imposing a heavy logistical burden on the armed services. The shortage, the long training period, and rapid turnover of such men make this a particularly acute problem.

The maintenance problem is significant not only because of the cost in lives and dollars, but also because of the cost in decreased weapon-system effectiveness. A system that is down for repair for an excessive amount of time is only part of a system, and it must be supplemented by the expensive expedient of a complex of extra units, support systems, and personnel. The U S Army cannot afford this cost and is looking to maintainability as one of the means for alleviating this problem.

1-3 REDUCTION OF THE PROBLEM

Designers of Army materiel must incorporate qualities of maintainability based on scientifically developed criteria. Maintainability, as a science, must provide four fundamental ingredients (Ref. 2) :

(1) Means for scientifically identifying technical data that will permit the isolation of facts that have a direct and paramount impact on improvement of the combat or operational effectiveness of Army materiel.

(2) A scientific method to measure the qualities of maintainability that are incorporated into each newly developed item or system of Army materiel.

(3) A scientific means for rating and evaluating the indistinct concepts of maintainability.

(4) A scientific method of reviewing existing industrial and Army developments to correct deficiencies of commercial and Army items and equipments.

The minimum requirements necessary to achieve a science of maintainability are:

(1) Maintainability guidelines.

(2) Good maintainability principles.

(3) Specifics, when historical background warrants them.

(4) Simple maintainability measuring methods which will require the least amount and complication of work for the design activities and the contractual review actions.

(5) Controlling methods to insure maintainability is built-in.

(6) Recording methods for future statistical analyses to check effectiveness of the maintainability actions.

(7) Good communication (feedback) between maintainability engineer and design engineer.

Major contributions to reducing the maintenance problem should be made at the equipment-design level rather than at the level of maintenance-personnel training. Designers must *think* maintainability and incorporate their ideas at the design's inception. Teaching technicians to deal with countless contingencies, which could have been avoided by better design, requires prolonged training. Also, obsolescence and changes in successive production models of the same equipment may vitiate much training before it is completed. Table 1-1 shows the importance of engineering design to the maintenance of military electronic equipment.

Significant advances have been made in understanding the nature of the maintainability problem and in developing analytical tools for quantitative treatment. However, any investigation of maintainability soon uncovers the complexity of the total problem, and it is realized that only continued research will provide a complete solution to this problem. With the recognition of the maintenance impact on present systems and the advancing complexity of new programs, it is imperative that exploration of maintainability be continued (Ref. 4).

TABLE 1-1. RESPONSIBILITY FOR FAILURE IN ELECTRONIC EQUIPMENT (Ref. 3)

Cause of Failure	Total Failures (%)
Design	43
(1) Electrical considerations	
(a) Circuit and component deficiencies	(11)
(b) Inadequate component	(10)
(c) Circuit misapplication	(12)
(2) Mechanical considerations	
(a) Design weaknesses, unsuitable materials	(5)
(b) Unsatisfactory parts	(5)
Operation and maintenance	30
(1) Abnormal or accidental condition	(12)
(2) Manhandling	(10)
(3) Faulty maintenance	(8)
Manufacturing	20
(1) Faulty workmanship plus inadequate inspection and process control	(18)
(2) Defective raw materials	(2)
Other	7
(1) Worn out or old age	(4)
(2) Cause not determined	(3)

REFERENCES

1. Proposed Military Standard, *Maintainability Requirements for Weapons, Commodities and Systems,* Headquarters, U. S. Army Supply and Maintenance Command, Washington, D. C., 1964.
2. M. Harring, *Maintainability— A New Science,* presented to the 1964 Army O. R. Symposium Planning Committee, U. S. Army Supply and Maintenance Command, Washington, D. C., 12 February 1964.
3. *NEL Reliability Design Handbook,* U. S. Navy Electronics Laboratory, San Diego, Calif., 1956.
4. *Maintainability Engineering,* Vol. 2, RADC-TDR-63-85, Rome Air Development Center, Air Force Systems Command, Griffiss AFB, N. Y., 1963 (DDC No. AD 404 898).

CHAPTER 2
THE PROBLEM OF RELIABILITY AND MAINTAINABILITY IN DESIGN

2-1 GENERAL

Maintainability is a basic though not independent characteristic of materiel and equipment. However, the need for maintainability of materiel and equipment is affected by its reliability characteristics. Materiel readiness and requirements for supporting personnel are influenced by the emphasis given to materiel maintainability characteristics during equipment specification, design, and development, when inherent maintainability, consciously or unconsciously, is established. Improving maintainability after development is difficult and costly.

Less than 15 years ago, reliability requirements of machines and electronic equipment were seldom included in design specifications. Today, this quantitative property of machines and systems is increasingly included in military specifications along with explicitly stated acceptance criteria, test conditions, and evaluation data. Progress has also been made in reliability improvement, particularly in component parts where failure-rate reductions, in the early hours of part life, have been reduced in many cases by factors of 10 to 20. These reliability gains, however, have not always kept pace with the increase in system complexity. If current trends continue, a substantial design breakthrough will be required merely to keep pace with the increasing system complexity. That the trend in system complexity was, and is still, increasing is evidenced by Figure 2-1. The resulting trend in reliability in terms of mean-time-between-failures (MTBF) is shown in Figure 2-2.

No product can be assumed to be 100% reliable. If it has a reliability rating factor of 9570,

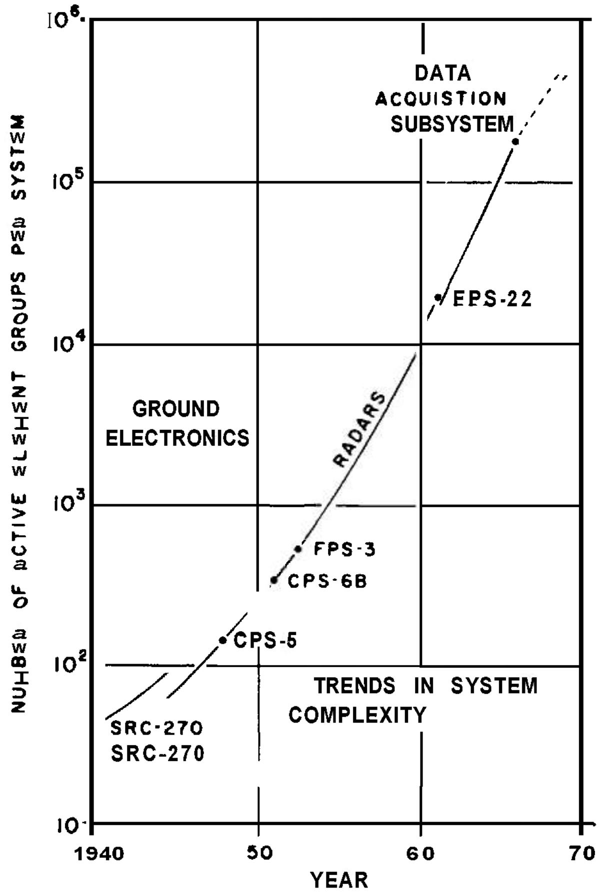

figure 2-1. Trends in System Complexity (Ground Electronic Equipment)

what becomes of the other 5% ? The field operational organization which receives an allotment composed of this 5% group has a reliability factor of 0% for their allotment. The reliability factor is therefore of no value to the soldier in the field. But he must have at all

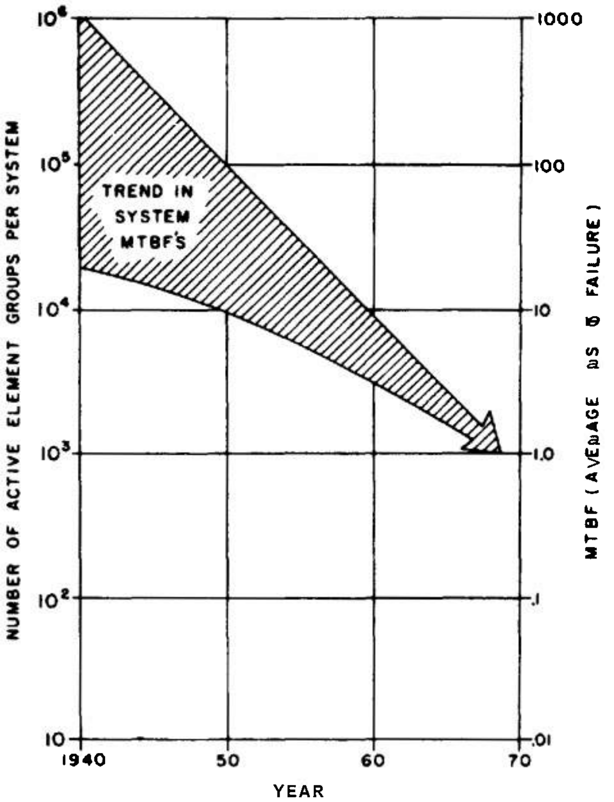

Figure 2-2. Trends in MTBF's (Ref. 1)

times 100% maintainability. His weapon is "GO" or "NO-GO." If he can maintain it, it is "GO"; if he cannot maintain it, it is "NO-GO." Reliability studies and tests at the design activity merely help the soldier to reduce his "NO-GO" periods. There is no trade-off *for maintainability*—either you have it, or you do not. Reliability ratings mean nothing to the soldier who is equipped with a commodity which will not work, but maintainability means everything. It is his only road to a serviceable product.

2-2 DESIGNING FOR MAINTAINABILITY

Although design for ease of maintenance has always been a part of effective engineering design, the military must pay increased attention to the new art of design for maintainability. It has been only in the last few years that systematic and formal attention has been given to this area of technology.

Design for maintainability offers the following advantages:

(1) Within broad limits, maintainability can partially compensate for hard-to-achieve reliability to obtain the required system availability.

(2) Increases in maintainability can be achieved at little or no added development cost.

(3) Maintainability built into the system during development can reduce operating costs.

(4) Initial results from increased maintainability can be expected to be large because of the relatively recent emphasis.

Today, maintainability concepts are being defined so they can be included in design specifications. Progress is being made in reducing these concepts to quantitative terms amenable to measurement, evaluation, and communication. There is also the general need to correlate the concepts of reliability and maintainability with each other and with their influence on such factors as system operational readiness, availability, and overall system effectiveness.

In the paragraphs that follow, a broad concept of maintainability will be adopted and terms defined. The first of these definitions are the following:

Maintainability (M). A built in characteristic of design and installation which imparts to the system or end item an ***inherent ability*** to be maintained, so as to lower maintenance manhours, skill levels, tools and equipment, maintenance costs, and achieve greater mission availability. It is composed of many factors, some of which are: inherent simplicity, ease of maintenance, environmental compatibility, safety characteristics, self-correcting characteristics, redundancy, standardization, skill level requirements, downtime minimizing, life cycle costing, logistic supportability, and mobility characteristics.

Maintainability engineering—the application of techniques, engineering skills, and effort, organized to ensure that the design and development of weapons, systems, and equipment provide adequately for their effective and economical maintenance.

Reliability (R). A characteristic of design which results in durability of the system, or end item, to perform its intended function for a specified interval and condition. It is accomplished by selection of the optimum engineering principle, adequate component sizing, material selection, controlling processes and procedures, and testing.

System *effectiveness*—a measure of the degree to which the equipment approaches its inherent capability and achieves ease of maintenance and operation. The relationships, assuming independence of factors, are as follows:

System Effectiveness =
Performance × Reliability × Availability
(How Well?) *(How Long?)* *(How Often?)*

If any of the factors on the right side of the equation falls significantly below unity, the effectiveness of the system is seriously impaired. Where one factor falls to zero, system effectiveness becomes zero.

2-3 SYSTEM EFFECTIVENESS

System effectiveness may be defined as a measure of customer satisfaction; i.e., the probability that the system will satisfy mission performance requirements when working within specified design limits, or how well it does its job when working properly. System effectiveness implies net worth or value of a product to its user (Ref. 2). The principal ingredients of system effectiveness are shown in Figure 2-3.

The effectiveness of many of today's weapon systems is seriously jeopardized by two extreme imbalances:

(1) Increased complexity, new performance requirements, and extreme environments have resulted in higher failure rates, greater requirements for maintenance, and lower availability of the present systems. Product capability often has been compromised by strong emphasis on performance characteristics without the necessary balance of effort toward quantitative treatment and control of the qualities of dependability.

(2) The costs of support for present military systems involve from 3 to 20 times the original procurement costs. Much of this high cost is due to lack of recognition and control of reliability, maintainability, and support factors during the successive stages of development, production, and service use. The principal system operational characteristics must be balanced against the elements of total cost. Up to the present time very little organized effort has been ap-

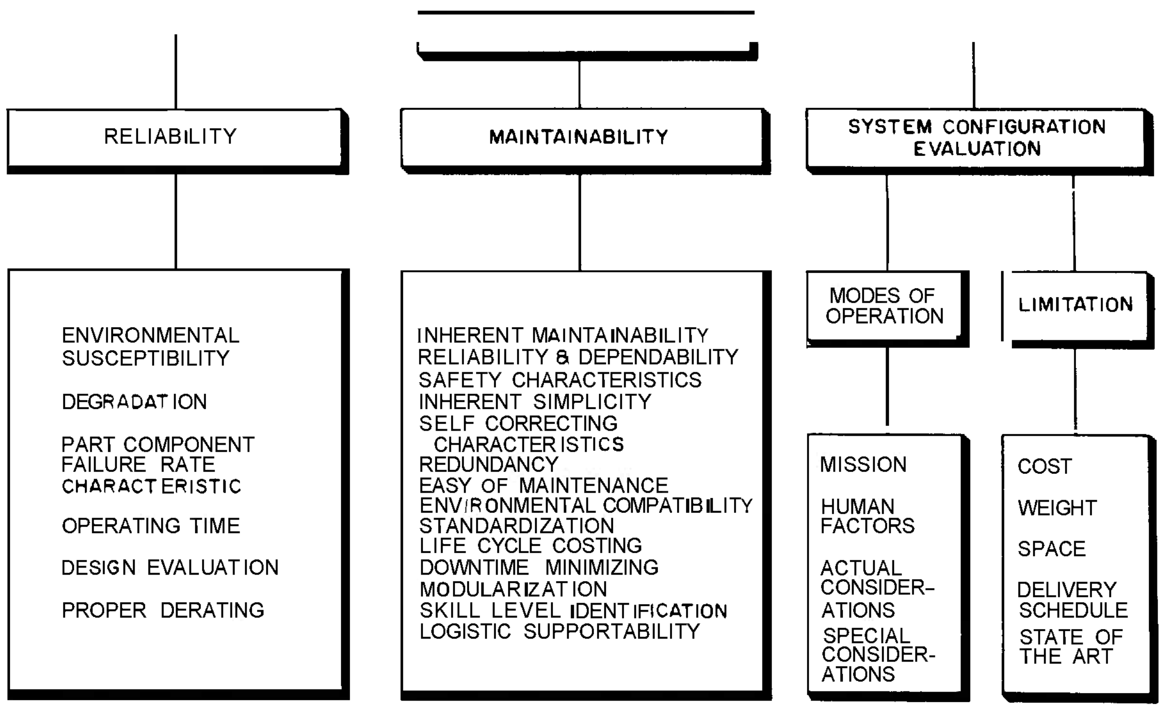

figure 2-3. Ingredients of System Effectiveness

piled to quantitative recognition and treatment of maintainability factors during the development and design phases. As a result, the cost of support, the requirements for maintenance time, and the unavailability of equipment are exceedingly high. The system maintainability characteristic has not been balanced against the other ingredients of equipment effctiveness and performance.

2-4 SYSTEM EFFECTIVENESS MEASURES VALUE OF DESIGN

The parallel between reliability and maintainability is useful; by using the two factors, the effectiveness of a system can be determined.

A possible model for system effectiveness, shown in Figure 2-4, illustrates the relationships among various system properties which together determine the effectiveness of a system. The model illustrates that system effectiveness depends directly on availability, which in turn is a function of reliability and maintainability. Availability, which is the probability that a system will be operating at any point in time, can be defined as

$$A_i = \frac{MTBF}{MTBF + MTTR}$$

where

$MTBF$ = mean-time-between-failure
$MTTR$ = mean-time-to-repair

The importance of this concept is that it is a measure of the system's ability to do its intended job. Basically, the user is not concerned with reliability, maintainability, or other design factors. His concern is the probability that the system will operate effectively when it is called upon to perform. In this sense it does not matter whether the system is 90% effective because of high reliability, high maintainability, or some combination of these and other factors (Ref. 3).

Although reliability and maintainability may not be interchangeable in actual design work, they can be considered equivalent when it comes

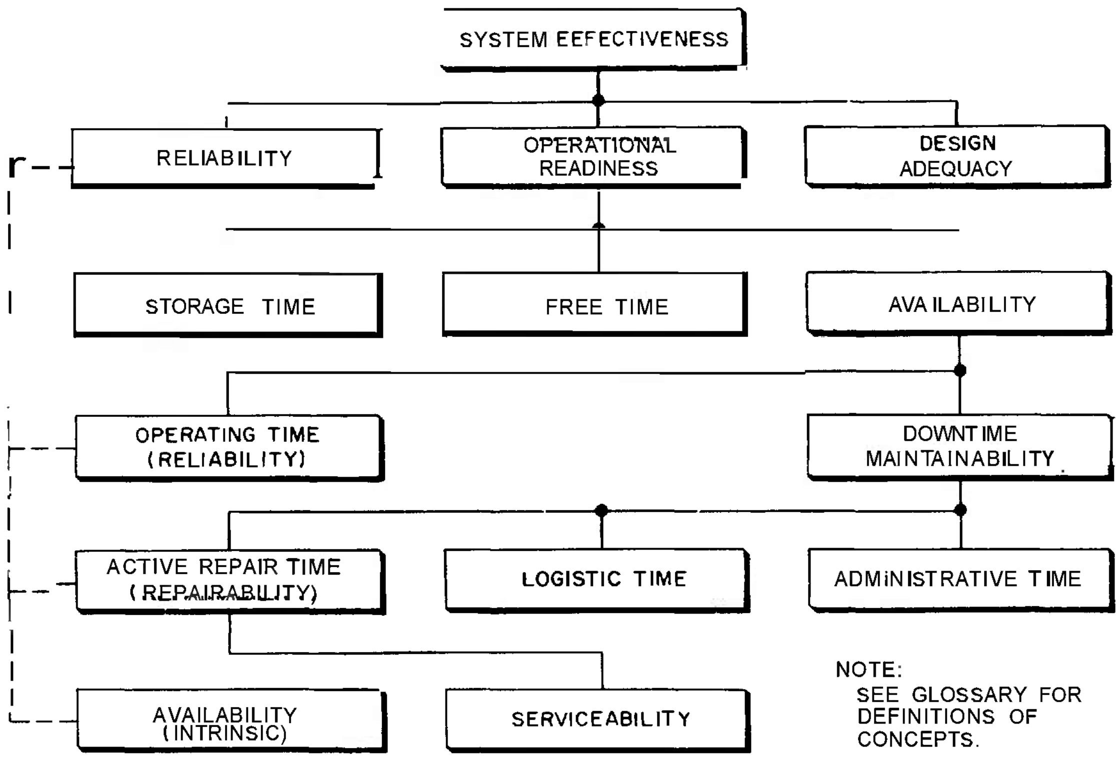

Figure 2-4. Maintainability and Reliability as Elements of Availability Are Crucial to System Effectiveness (Ref. 3)

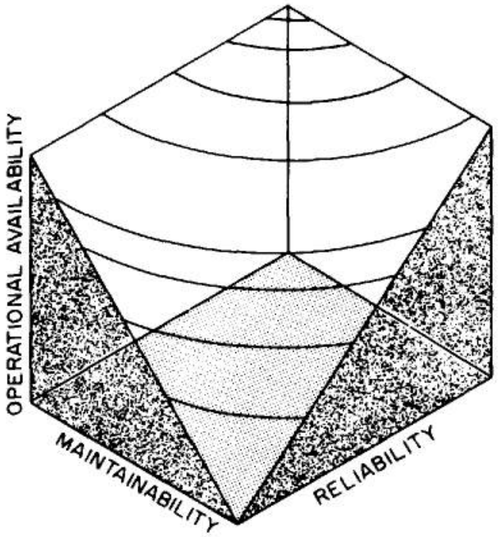

Figure 2-5. Trade-off Effects for Equal Percentages of Availability (Ref. 3)

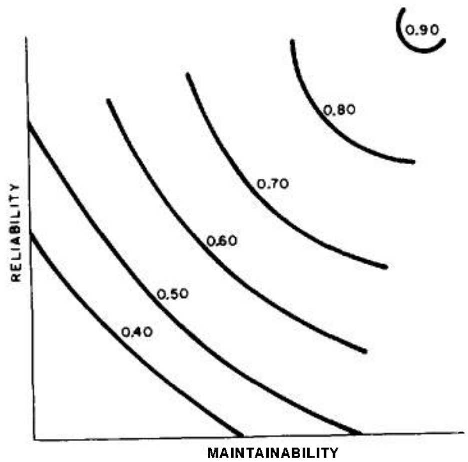

Figure 2-6. Curves of Figure 2-5 Translated into a Single Plane to Yield Plots of Availability (Ref. 3)

to availability. This is true since an increase in maintainability or reliability or both will increase the availability of the system. Thus, from a decision-making point of view, availability can be expressed as a function of maintainability and reliability as

$$A_s = f(R_s, M_s)$$

where

A_s = system availability
R_s = system reliability
M_s = system maintainability

Expressed geometrically, a hypothetical availability surface, illustrating competitive substitution of maintainability and reliability, would resemble that shown in Figure 2-5. This diagram actually illustrates the boundary limits of the system availability equation taken between zero and infinity.

Contour lines of the availability surface represent the same degree of availability. These iso-availability lines can be represented as shown in Figure 2-6. This actually is a physical representation of the trade-off problem.

Note that, for a given contour line of availability, the trade-off requires even greater sacrifices in one category to compensate for successively smaller gains in the other. See also Chapter 5, Paragraph 5-6.1 for an example in the use of availability for trade-offs in a weapon system.

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1. J. J. Naresky, "Air Force Reliability and Maintainability Research," SAE-ASME-AIAA *Conference Proceedings*, Aerospace Reliability and Maintainability Conference, June 29-July 1,1964.
2. *Maintainabilitg Engineering Guide,* RC-S-64-1, U.S. Army Missile Command, Redstone Arsenal, Ala., 1964.
3. D. A. Findley, Ed., "Maintainability," Electronic Design, 11, 38, 6 December 1963 (reprinted with permission).

PART TWO

GENERAL OBJECTIVES, PROCEDURES, AND TECHNIQUES

CHAPTER 3

MAINTAINABILITY AND RELIABILITY CONCEPTS, OBJECTIVES, AND RESPONSIBILITIES

3-1 GENERAL OBJECTIVE

The primary objective of maintainability and reliability is to assure that the equipment provided to the Army will be ready for use when needed; capable of successfully performing its assigned functions/missions, and fulfilling all of the required maintenance characteristics throughout its life cycle.

The US Army need for more maintainable and reliable equipment cannot be overstressed. The three basic needs of the soldier's equipment are performance, reliability, and maintainability. Maintainability *M* is the design characteristic which speeds return of the equipment to a mission capable state with the minimum requirements for time, resources, manpower, and technical **skill;** reliability *R* is the design characteristic which reduces or eliminates failure. Both are mandatory requirements. These are best accomplished by designing in maintainability and reliability at the ***earliest time of the acquisition process.*** It is DOD policy that the principles included in this document be included in every US Army commodity contract where there is a maintenance significance.

In order to meet maintainability goals, the principles of maintainability in Table 3-1 should be constantly applied as appropriate.

3-1.1 MAINTAINABILITY DESIGN GOALS AND CRITERIA

The principles indicated below represent examples of goals, and criteria for ***M.*** They are listed to show ***what is meant by M.*** They are by no means all the principles of ***M. M*** is a design action which "provides for equipment design so as to give equipment an ***inherent ability to be maintained': M*** should not be confused with Maintenance. All Maintenance Engineering Analysis actions are vitally affected by ***M*** inputs to design. The specification writer must use ingenuity to add, subtract, and refine the principles of M as they apply to the specific commodity. In addition, all applicable contracts will cite TM **38-703-2** for further guidance. For simple off-the-shelf commodities, only the qualitative requirements may be necessary for incorporation in contract specifications. For more exotic commodities, and especially where large quantities of the commodity are expected to be added to the inventory, highly detailed M requirements must be specified. (Reducing a single maintenance time, by ***M*** design, by 5 minutes x 100,000 items represents a large annual savings of maintenance manhours.) Do not ignore any item in this list without careful consideration; even electronic gear has bearings, gears, and seals; automotive equipment has radios; guns have computers; and all mobile commodities may suddenly be called upon to work at minus 65^{o}**F**. It is important to grasp the concept of how to apply these principles in converting them to M specification requirements. Take the first one as an example: "Reduce or eliminate the need for maintenance". **This** should immediately suggest such ***M*** design characteristics as:

(1) Will plastic gears, which never need maintenance, be suitable?

(2) Will cost constraints permit use of life sealed bearings?

(3) Can we use resistors, condensers, transformers, etc., which are adequate in size and sealed so as to preclude failure and thus maintenance?

(4) Should transistors vs electronic tubes be used and be satisfactory?

Wherever possible, each design criterion should be converted and ***quantified.*** Consider the item, "Insure that instrument panels, particularly for aircraft and vehicles, are hinged and/or readily removable as a unit for rapid servicing, testing, and calibration. Quick disconnects shall be provided".

TABLE 3-1. GENERAL PRINCIPLES OF MAINTAINABILITY

The areas below are the minimum points of maintainability to be considered when developing a system, commodity, or component:

3-1.1	Reduce or eliminate the need for maintenance.
3-1.2	Reduce the amount, frequency, and complexity of required maintenance tasks.
3-1.3	Provide for reduction of life cycle maintenance costs.
3-1.4	Reduce the required levels of maintenance skills and the training requirements for them.
3-1.5	Establish maximum frequency and extent of preventive maintenance to be performed.
3.1.6	Improve information for educational programs for maintenance.
3.1.7	Reduce the volume and reading complexity of maintenance publications.
3-1.8	Provide components which can be adjusted for wear and provide this adjustment so as to preclude tear down to attain to it, where practical.
3-1.9	Provide the characteristics in the commodity and its components which will result in the minimum downtime.
3-1.10	Insure that simple, adequate, and satisfactory maintenance technical data are available with the equipment when delivered.
3-1.11	Provide for time studies on removal and installation of major items of equipment.
3-1.12	Provide for repair times of components. Reduce the meantime to repair.
3-1.13	Provide optimum accessibility to all equipment and components requiring frequent maintenance, inspection, removal, or replacement. Avoid hiding this equipment.
3-1.14	Provide for rapid and positive identification of equipment malfunction or marginal performance. This should include, for example, logical trouble-shooting charts in fault-tree diagram form which list potential failures and method to correct them. Associate times to perform the correction as appropriate.
3-1.15	Insure the human factor aspects are satisfactory and that location and operability of controls and manual force limitations, etc., are adequate and accessible for hand, leg, foot, and body. Provide the human engineering aspects for access to maintenance points such as electrical, pneumatic, hydraulic, lubrication, and fuel servicing.
3-1.16	Provide optimum capability to verify performance, anticipate and locate malfunctions, and perform calibration.
3.1.17	Provide for adequate, clear, and rapid identification of parts and components which may be replaced or repaired.
3-1.18	Reduce the quantities and types of tools, tool sets, and equipment necessary to maintain the whole commodity. *Eliminate*, wherever possible, the need for special tools.
3-1.19	Plan design of commodity to utilize field organizational maintenance equipment and facilities which are normally available.
3-1.20	Reduce to a minimum the number and types of repair parts and components needed to support maintenance.
3-1.21	Insure utilization of military standard parts, components, types, and materials to the fullest possible extent, and identify all MIL-STD parts, components, and material with MIL-STD nomenclature.

TABLE 3-1. GENERAL PRINCIPLES OF MAINTAINABILITY (cont)

3-1.22	Utilize less critical materials, and less costly, rare, or difficult processes.
3-1.23	Provide for maximum interchangeability.
3-1.24	Provide maximum safety features for both equipment and personnel in the performance of maintenance.
3-1.25	Provide sufficient and adequate towing, hoisting, lifting, and jacking facilities for mobility and handling requirements.
3.1-26	Provide for maximum storage life with minimum storage maintenance rehabilitation.
3-1.27	Reduce amount of supply support required.
3-1.28	Insure engines/installations are rapidly replaceable as a unit with the minimum time and personnel.
3-1.29	Insure the commodity will not be dangerous to itself or to personnel maintaining it.
3-1.30	Insure necessary environmental compatibility for the commodity—e.g., corrosion, fungus, water, salt, spray, heat, cold, altitude, attitude, blown sand, snow and snow loads, wind, etc.—on the whole and on components of the weapon, commodity, or system.
3-1.31	Insure that there are no serious undesirable operating or maintenance characteristics affecting the maintenance personnel, or other personnel or equipment in the expected vicinity—i.e., **RADHAZ,** noise, etc.
3-1.32	Provide bearings and seals, sizes and types, which will require the minimum of replacement and servicing on a life cycle basis. Select adjustable ones to take care of wear.
3-1.33	Provide gears of adequate size and type to satisfy all overload requirements and be suitably derated on a life cycle basis.
3-1.34	Provide for the ease of inspection, replacement, and rapid adjustment in servicing of brakes and clutches, without the need of tear down.
3-1.35	Insure that all mechanical, electronic, electrical, hydraulic, and structual components are sufficiently derated to combat unexpected overload(s) which will result in an inoperable or degraded component and thus require maintenance.
3-1.36	Insure that advanced accessibility practices have been incorporated. These include rapid access to systems, components, and parts by use of rapid operating fasteners, covers, doors, etc., and a minimum of bolts, fasteners, etc.
3-1.37	Insure components requiring frequent maintenance are located to preclude the need to remove other components to gain access to the specific component.
3-1.38	Provide line-of-sight to components, wherever possible, for routine inspection, to eliminate the need to remove other equipment(s).
3-1.39	Insure that adjustment controls are rapidly accessible.
3-1.40	Provide adjustment control locking devices.
3-1.41	Provide sufficient and adequate test points and test features, and provide ease of accessibility thereto. Test points should be capable of accepting automatic test equipment when practical.
3-1.42	Insure that all test equipment and calibration equipment required for the commodity are available.

TABLE 3-1. GENERAL PRINCIPLESOF MAINTAINABILITY (cont)

3-1.43	Provide simplified go-no-go (self-diagnostic) automatic, built-in fault isolation capabilities and calibration equipment as feasible, practical, or cost effective.
3-1.44	Insure sufficient storage for spare modules (components/assemblies) and that modules are stored in the commodity. This applies to fuzes and other attrition items.
3-1.45	Insure that batteries are located for rapid servicing and replacement, and are vented as required.
3-1.46	Insure that weapons, systems, commodities, and special parts are repairable, except throwaway components and throwaway modules.
3-1.47	Insure that adequate and sufficient guards are installed over dangerous moving mechanisms.
3-1.48	Insure that adequate protection from dangerous electrical shock is provided for maintenance personnel.
3-1.49	Insure that no toxic fumes are emitted which will affect maintenance personnel.
3-1.50	Insure that all items are incorporated which will render the item explosion proof, when required.
3-1.51	Insure that fiie extinguishing equipment is installed and adequate.
3-1.52	Insure protection of personnel from nuclear radiation hazards.
3-1.53	Insure that the required warning devices are incorporated in the commodity.
3-1-54	Provide for easy, simple, and rapid refueling, relubrication, and filling of all reservoirs and containers.
3-1.55	Provide for rapid inspection apertures on gear boxes, housings and similar assemblies which will permit inspection, adjustment, or when practical, repair or replacement of vital items inside of these housings, without the need for major disassembly. These apertures may be plugs, bailed hinged covers, windows or doors, requiring no tools to open or close, where possible or practical.
3-1.56	Provide quick disconnect devices for rapid removal and assembly of components.
3-1.57	Insure that a minimum of fasteners are utilized and, where feasible, rapid operating fasteners, perferably operable without use of tools.
3-1.58	Insure that all lubrication plugs and fittings are adequate and readily accessible on the ***completed*** commodity.
3-1.59	Insure that sufficient and readily accessible drains are properly located in compartments, tanks, reservoirs, and sumps.
3-1.60	Provide for rapid cleanability (post operation and inspection).
3-1.61	Insure that, to the maximum possible extent, maintenance on the commodity can be accomplished by personnel in arctic gloves and clothing, in the open.
3-1.62	Insure that winterization requirements are incorporated.
3-1.63	Insure that the provisions for kits are in the commodity and are suitable and adequate. This includes hard points, electrical, hydraulic, mechanical connections or outlets, etc.

TABLE 3-1. GENERAL PRINCIPLESOF MAINTAINABILITY (cont)

3-1.64	Insure that all labels are stenciled, or attached to the commodity or component, and that they will read clearly after extensive use and abuse. This is particularly important as to part numbers; component ratings; and types of fuels, lubricants, liquids, and gases utilized.
3-1.65	Insure that lubrication charts, maintenance manuals, and operational manuals are either attached to the commodity or readily available.
3-1.66	Insure there are sufficient and adequate protection covers and attachments, securing devices, shipping and packaging tie-downs, seals, etc.
3-1.67	Insure that the design of the commodity is inherently self-packaging, whenever possible or practical. Self-packaging eliminates shipping crates, containers, etc., and permits ready reshipment without the need to replace the package.
3-1.68	Insure that instrument panels—particularly for aircraft and vehicles—are hinged and/or readily removable as a unit for rapid servicing, testing, and calibration. Quick disconnects shall be provided.
3-1.69	Insure that all electronic gear is readily removable with quick operating fasteners and disconnects for rapid replacement, servicing, testing, and calibration. Each unit will be removable without disturbing any other component of the commodity.
3-1.70	Insure that component modularization design is used, as appropriate. Design modules to be repairable. (A module can be a throwaway item in which case it should not be made repairable.)
3-1.71	Insure unitization design is utilized. (Unitization is the design feat of combining components of a system or function of a system into a removable assembly.)
3-1.72	Insure miniaturization in design is utilized, where suitable. (This feature reduces shipping, packaging, and transportation costs, and improves the commodity and maintenance handling.)
3-1.73	Insure commodity is designed for the minimum weight, taking into account reliability, durability, and maintenance freedom; example: do not design an item so light it is constantly breaking or malfunctioning.
3-1.74	Consider advantages of modular replacement vs part repair vs throwaway design.
3-1.75	Provide for ballistic verification (telemetry) (ordnance).
3-1.76	Provide easy and sure recognition of the malfunction to allow for rapid identification of the replacement action/repair required, and thus reduce the complexity of the maintenance task.
3-1.77	Review areas of possible improvement since they affect the probability that the diagnosis of the malfunction and completion of the repair required may be corrected successfully within a specified time with available personnel resources.
3-1.78	Establish minimum and maximum Meantime Between Failure (MTBF), Meantime To Repair (MTTR), and downtime for the equipment/item and include in the Maintenance Engineering Analysis Data. If a like/similar item was previously fielded, review and analyze the failure rates associated therewith and, considering new technologies, attempt to improve maintenance in this area.

This should be converted to: "The pilot's L. H. instrument panel will be capable of rapid removal and assembly. Removal time **4** min with 1 man, replace ready for service **6** min with 1 man". **A** copy of this list should be supplied with each contract for reference use by the contractor.

3-1.2 RELIABILITY DESIGN GOALS AND CRITERIA

The principles indicated in Table **3-2** represent examples of goals, and criteria for R. These principles are by no means all the principles of ***R*.** The specification writer must use ingenuity to add, subtract, and refine principles of R as they apply to the specific commodity. For simple off-the-shelf commodities only the qualitative requirements may be necessary for incorporation in contract specifications. For more exotic commodities, and especially where large quantities of the commodity are expected to be added to inventory, highly detailed ***R*** requirements must be specified. Do not ignore any item in this list without careful consideration; even electronic gear has bearings, gears, and seals; automotive equipment has radios; guns have computers; and all mobile commodities may suddenly be called upon to work at minus 65°F. It is important to grasp the concept of how to apply these principles in converting them to R specification requirement. Whenever possible, each item should be converted to specific requirements and ***quantified.*** **A** copy of this list should be sup plied with each contract for reference use by the contractor. In designing for ***R***, the principles expressed Table **3-2** should be followed to the greatest extent possible, and expanded as appropriate. When the contractor finds it is necessary to deviate from these principles, he should notify the procuring activity. These principles will be used as a guide for determining the contractor's compliance with R parameters and goals. 'This list does not exhaust the principles a contractor can use to achieve ***R*** and shall be supplemented by the contracting agency and/or contractor, as necessary.

3-2 CONCEPT

To achieve the maintainability and reliability goals, the principal factors affecting them must be identified, measured, specified, controlled, and improved as follows.

(1) ***Identification.*** The principal factors that limit equipment availability and/or contribute toward the high costs of support must be identified (qualitative).

(2) ***Measurement.*** The principal factors must be expressed in quantitative (measurable) terms.

(3) ***Specification.*** ***M & R*** requirements must be placed in procurement specifications by contract work statements (TM **38-703-2)** along with suitable methods for demonstrating and evaluating conformance with actual equipment/item requirements.

(4) ***Control.*** Control must be established and extended from product conception through development, production, and field use. Reasonably accurate prediction is necessary.

(5) ***Improvement.*** The end objective must be improvement.

3-3 RESPONSIBILITIES—MAINTENANCE/DESIGN ENGINEERING PERSONNEL

3-3.1 MAINTENANCE ENGINEERING PERSONNEL

Maintenance engineering personnel must be concerned, as equipment is being developed, with the establishing of **a** series of qualitative and quantitative requirements for the desired maintainability characteristics to insure that a p propriate qualitative and quantitative maintainability requirements are available for incorporation in requests for proposals and to assure that the desired availability will be designed therein. These maintainability and reliability requirements must be defined in specific, meaningful, and measurable terms, i.e.,

(1) **A** qualitative maintainability requirement is a nonquantitative statement of a needed feature or characteristic; e.g., provide drain plugs, stencil letters at filler necks, utilize quick opening fasteners, etc.

(2) A quantitative maintainability is a definite statement of resources and/or time for the performance of a given type of support task in the end product; e.g., repair time, downtime, turnaround time, number of personnel.

TABLE 3-2. GENERAL PRINCIPLES OF RELIABILITY

	The areas below are the minimum points of reliability to be considered when developing a system, commodity or component:
3-2.1	Design to preclude or minimize failure.
3-2.2	Design for simplicity.
3-2.3	Provide for redundancy when needed to achieve *R* goals.
3-2.4	Provide for periodic test, test equipment and/or checkout of components susceptible to failures (include in Technical Manuals and clearly state).
3-2.5	Use generous derating to provide safety factor; e.g., bearings, electronic components, motors, hydraulic components, structures, etc.
3-2.6	Provide bearings and seals of advanced design, and material which will be satisfactory for the life of the commodity and maximum anticipated overloads. Cost of bearings and seals shall be extensively weighed against life cycle maintenance replacement costs, loss of equipment, etc.
3-2.7	Provide for periodic lubrication, even in "sealed" components (i.e., ball bearings with seals capable of hypodermic needle lubrication).
3-2.8	Use bearings which do not require lubrication for many years of life and service (i.e., built-in dry lubricating characteristics).
3-2.9	Provide for simple periodic adjustment of components subject to wear.
3-2.10	Provide for self-adjustment of components subject to wear (examples: tapered roller bearings; end seals vs radial seals).
3-2.11	Increase commonality of components (standardization, etc.).
3-2.12	Identify failure modes, design to prevent initial failures, and provide adequate warnings.
3-2.13	Provide adequate safety factors between strength and peak stress values.
3-2.14	Use engineering designs with proven ***R***.
3-2.15	Use components with proven ***R***.
3-2.16	Use fewer parts to perform multiple functions, to assist in reducing errors or assembly, simpler check out tests, etc.
3-2.17	Consider human factors engineering ("Murphy Proof").
3-2.18	Use modular (component assembly) design to simplify field replacement of suspected faulty equipment.
3-2.19	Reduce stress on components to extend life (electrical, mechanical, and hydraulic).
3-2.20	Reduce peaks and variations in stress (i.e., provide against damage from spike voltages, high frequency vibration, etc.).
3-2.21	Provide for temperature stabilization by using heaters and/or air conditioners, when required for worldwide use.
3-2.22	Control humidity levels by sealing out water under all conditions of use and storage.
3-2.23	Provide for shock and vibration isolation or capability to withstand such conditions.

TABLE 3-2. GENERAL PRINCIPLES OF RELIABILITY (cont)

3-2.24	Reduce exposure to corrosive atmospheres, heat, and cold or increase capability to withstand such conditions.
3-2.25	Use corrosion resistant materials and/or protective coatings, plating, and metallizing. Avoid placing bare dissimilar metals in contact with each other.
3-2.26	Use self-sealing devices where fluids are involved, i.e., disconnect fittings which seal when parted.
3-2.27	Provide safing devices to prevent inadvertent disassembly or decalibration.
3-2.28	Provide guards, covers, seals, etc. to prevent unauthorized personnel from altering calibration or damaging components.
3-2.29	Provide ease of inspection for field maintenance personnel so as to ascertain impending failures.
3-2.30	Design to preclude or minimize failure or degradation in storage.
3-2.31	Provide warning devices which will warn of incipient failures.
3-2.32	Provide suitable diagnostic equipment to inspect for impending failures.
3-2.33	Use hermetically sealed modules (components/assemblies), where feasible, to preclude failure of these modules in service and storage and to prevent tampering. (This feature also assists the user in improving reliability by permitting exchange of questionable components.)
3-2.34	Use electrical contacts of adequate size and advanced material which preclude failure. Such contacts are disconnect plugs, relay contacts, ignition points, generator and motor brushes, etc. Techniques include use of advanced alloys, silver plating, noncorrosive metals, mercury switches, positive connections, brazed joints, etc.
3-2.35	Utilize wire insulation in coils (motors, generators, transformers, and power distribution systems, etc.) which can withstand high burning temperatures. (R is considerably increased by utilizing superior material.)
3-2.36	Utilize potting of component coils (and balung where appropriate) to prevent wires from chafing by vibration and shorting out coils.
3-2.37	Utilize adequate and proper filters on all systems carrying fluid. Utilize field cleanable types to minimize logistic support problems and thus running the risk of using clogged or dirty filters.
3-2.38	Utilize lubricants which have the widest safe temperature range. Avoid use of lubricants which harden with age.
3-2.39	Utilize electrical power wire insulation which will not crack or deteriorate with age, and is tough enough to withstand abnormal abuse both from the motion of the commodity or maintenance personnel's tools and strains.
3-2.40	Design to prevent misassembly of components, or omission of parts. Typical design errors are placing identical disconnect plugs side by side, components which have more than one method or assembly, blind assembly of parts not permitting rapid inspection of fasteners, etc.
3-2.41	Provide for nondestructive testing application wherever practical or possible.

TABLE 3-2. GENERAL PRINCIPLES OF RELIABILITY (cont)

3-2.42	Provide for automated assembly and inspection when necessary to assure reliability.
3-2.43	Provide for functional testing of the largest production quantity of the commodity permitted by the cost constraints of the program, to insure maximum reliability of the lot. (This applies to commodities which do not destroy themselves.)
3-2.44	Provide for sufficient safety features to meet safety regulations (e.g., dual safety of fuzes).
3-2.45	Provide designs which fail safe (e.g., controls or components which fail to "normal" or a safe operational level).
3-2.46	Provide for compatibility of explosives.
3-2.47	Provide sensing of proper launch signature (ordnance).
3-2.48	Review and analyze experience with similar/like equipment/items previously in existence concerning MTBF, MTTR, Meantime Between Maintenance Actions (preventive and corrective), Percent of Mission Accomplishment, High Mortality Repair Parts/Components/Assemblies to determine ways and means of affecting improvements for the equipment now being considered.
3-2.49	Identify standard parts, tools, and test equipment of proven reliability which would be compatible for use with the equipment/item under consideration.
3-2.50	Conduct prediction analyses concerning performance requirements to measure success or failure and possible trade-off areas as the equipment/item is developed and tested.

3-3.2 DESIGN ENGINEERING PERSONNEL

Design engineering personnel should be concerned with the following, considering equip ment developed:

(1) Improving reliability to reduce the need for maintenance. Reliability must be designed into items to insure the desired performance for their entire intended life cycles.

(2) Reducing the frequency of preventive (cyclic) maintenance. Reliability improvements will often save time and manpower by reducing the frequency of the preventive-maintenance cycle. This also means more operational time for the component and/or item concerned.

(3) Improving maintainability to reduce downtime. Test and repair procedures should be simplified to reduce the time required to locate and correct faults by providing ease of access, and simplification of adjustments and repair.

(4) Reducing the logistical burden. This implies reducing the logistical tonnage required to support equipment in the field, particularly in forward combat areas. Included is the full use of standard parts, components, tools, and test equipment. Also included is the interchangeability of parts, components, and assemblies.

(5) Reducing the requirements for highly trained specialists. This can be done by simplifying the operation and maintenance of equip ment, and utilizing the maintenance support positive (MS+) concept of modular design for maintenance in operational areas.

3-4 THE MAINTENANCE PROCESS

Maintenance is defined as those actions necessary for retaining materiel in, or restoring it to, a serviceable condition. Maintenance includes determination of condition, servicing, repair, modification, modernization, overhaul, and inspection. Three broad factors which can be used to measure maintainability are design, personnel, and support. Each can be considered as follows:

(1) *Design.* This encompasses all the design features of the equipment. It covers the physical aspects of the equipment itself; e.g., requirements for test equipment and tools, spare parts, training, and the personnel skill levels required to perform maintenance as dictated by design, packaging, test points, accessibility, and other factors internal to the equipment.

(2) *Personnel.* This includes the skill level of the maintenance men, their attitudes, experience, and technical proficiency, and other human factors which are usually associated with equipment maintenance.

(3) *Support.* This area covers logistics and the maintenance organization involved in maintaining a system. A short breakdown of support would include: the tools, test equipment, and spare parts on hand at a particular location; the availability of manuals and technical data associated with the equipment; the particular supply problems which exist at a site; and, finally, the general maintenance organization.

3-5 MAINTENANCE CLASSIFICATION

To specify maintainability, it is necessary to determine and define the various types of maintenance activities. Knowledge of the elements constituting a maintenance task will contribute to the ability to relate the affecting factors to maintenance time. The paragraphs which follow describe some of these activities.

Maintenance actions are precipitated by several causes and can occur in different locations. Total maintenance is composed of preventive, corrective, and servicing maintenance. These are defined as follows:

(1) *Preventive Maintenance.* The care and servicing by personnel for the purpose of maintaining equipment and facilities in satisfactory condition by providing for systematic inspection, detection, and correction of incipient failures, either before they occur, or before they develop into major defects. Adjustments, lubrication, and routine check-out are included in preventive maintenance.

(2) *Corrective Maintenance.* That maintenance performed on a nonscheduled basis to restore equipment to satisfactory condition by providing correction of a malfunction which has caused degradation of the item below the specified performance.

The two basic maintenance actions, preventive and corrective, can occur while the equipment is in or out of service. Thus, it is necessary to recognize not only the type of action, but also the operational status of the: equipment. Such considerations are important for the development of figures of merit for equipment maintainability.

(3) *Service Maintenance.* That maintenance of fueling, filling attrition containers (i.e., oxygen bottles, hydraulic reservoirs, loading ammunition, etc.).

3-5.1 TASK ELEMENTS

Figure 3-1 is a maintenance flow diagram illustrating the five major sequential steps performed during maintenance. These steps are:

(1) Recognition that a malfunction exists.

(2) Localization **of** the defect within the system to a particular equipment.

(3) Diagnosis within the equipment of a specific defective part or component.

(4) Repair or replacement of the faulty item.

(5) Check-out and return of the system to service.

Complementary to these steps are actions associated with assembly, disassembly, cleaning, lubrication, supply, and administrative activity.

Figure **3-1** also illustrates two supplementary paths: one during which obvious malfunctions can be isolated immediately, the other for instances requiring the technician to retrace his steps and perform additional analysis.

3-5.2 MAINTENANCE TASK CLASSIFICATION

Table 3-3 shows a matrix of maintenance tasks for which eight distinct combinations or classifications have been derived. Task classification **1 is** a corrective maintenance action performed at operational level and requiring the system to be down. The removal of a defective system component and its replacement with an operating component is an example of this class. The subsequent repair of the defective component at a location removed from the operating equipment is an example of class **7.**

The matrix makes it possible to order the spectrum of maintenance activities so that specifications and indices relating to the operating and

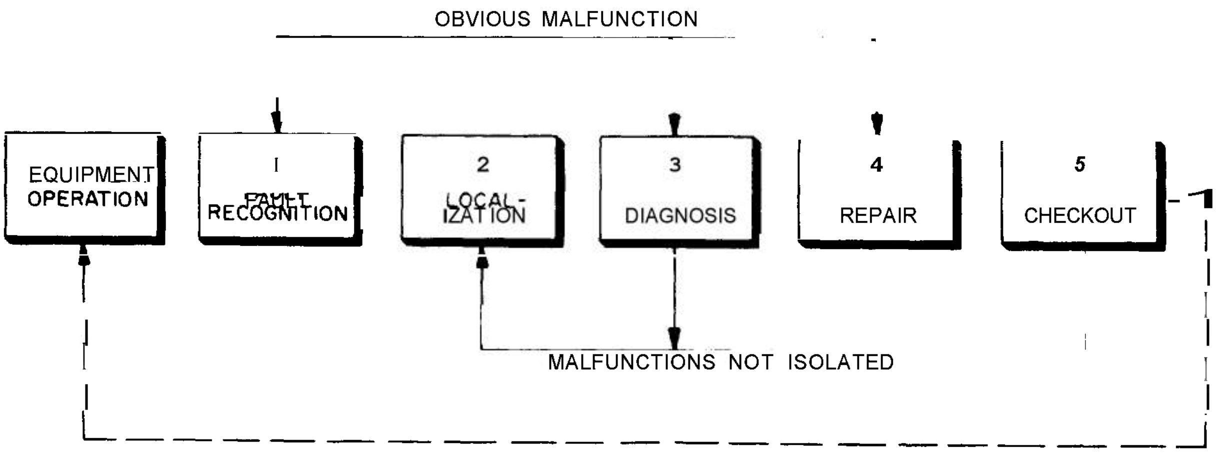


figure 3-1. Maintenance Flow Diagram

maintenance environment may be derived. It is readily apparent that only those maintenance actions requiring the system to be removed from service affect availability, whereas all maintenance actions affect maintainability as previously described.

TABLE 3-3. CLASSI'FICATIONMATRIX OF MAINTENANCE TASKS

		Task Classification (Read Down)							
		1	2	3	4	5	6	7	8
Area of Performance	Organizational Level	•	•	•	•				
	Higher Echelon					•	•	•	•
Type of Action	Corrective	•		•		•		•	
	Preventive		•		•		•		•
Equipment Operational Status	System Down	•	•			•	•		
	System Operating			•	•			•	•

3-5.3 DOWNTIMECLASSI FICATION

Figure 3-2 illustrates the relation of the various maintenance activities at the operation level to system downtime. Beginning with the cause of maintenance, either preventive or corrective maintenance is considered. Next, the process notes whether or not an equipment failure is present, and if so, if it is to be considered critical. This information permits the determination of the operational status of the equipment. The final classification made is to assign the resultant maintenance time to one of three categories—no downtime, deferrable downtime, or downtime. From the equipment operational standpoint, maintenance which requires downtime is most important; however, from a resource expenditure point of view, all maintenance requirements are of concern.

3-5.4 TOTAL DOWNTIME PER TASK

The relationships of downtime to other operational considerations are defined and illustrated in Figure 3-3.

Downtime is further described by the type of task, i.e., corrective or preventive. As indicated in the figure, corrective and preventive active times are considered appropriate for specification purposes since they are readily demonstrated by laboratory testing. Total downtime, which includes the nonactive factor, certainly would be of concern in operational use. Total downtime per task, therefore, is the total downtime expended in the accomplishment of each maintenance task.

3-6 MAINTAINABILITY DECISION STRUCTURE

Figure 3-4 shows the interactions between equipment attributes and maintenance actions. The structure can be used for presenting decision choices available to the system designer by providing system and support considerations pertinent to each maintenance action.

3-7 SPECI FICATIONS FOR MAINTAINABI LITY

Maintainability must be defined in specific, meaningful, and wherever possible in measurable terms. Whenever possible, specifications should quantitatively indicate desired maintainability as definitely as desired operational performance, e.g., probability of meantime to repair (MTTR) of 30 min with 3 men. There has been a lack of balance in the design and development of new equipment between influence for improved operational performance and influence for improved maintainability. The inability to measure maintainability has been, in part, responsible for this lack of balance.

In the past, maintenance practices depended upon the design engineer to consider ease of maintenance along with numerous other performance objectives. Performance was measurable; maintenance was not. Since the emphasis was on performance, improved performance and generally increased complexity resulted—but not reduced maintenance.

Inherent maintainability is created by equipment design which, in turn, is created in accordance with specified requirements. The inclusion of quantitative maintenance requirements as part of the procurement package will form an important foundation on which all subsequent maintainability, maintenance engineering, support philosophies, and logistics must be built.

Current military documents pertaining to the specification of maintainability are listed in Table 3-4. Additional pertinent Military Specifications and Standards relating to the design and maintenance of Army equipment are listed in the Appendix.

3-8 MAINTAINABILITY ACTIONS

Maintainability is that part of the maintenance problem which must be designed into an equipment or system and, therefore, is under the control of the designer. Although complex maintenance organizations and supply systems, as well as manpower shortages, contribute significantly to the problem, too frequently, poor equipment design from a maintenance standpoint contributes heavily and compounds the overall maintenance problem. This puts the burden of solving a large part of the maintenance problem on the design engineer. With this in mind, the tenet for design

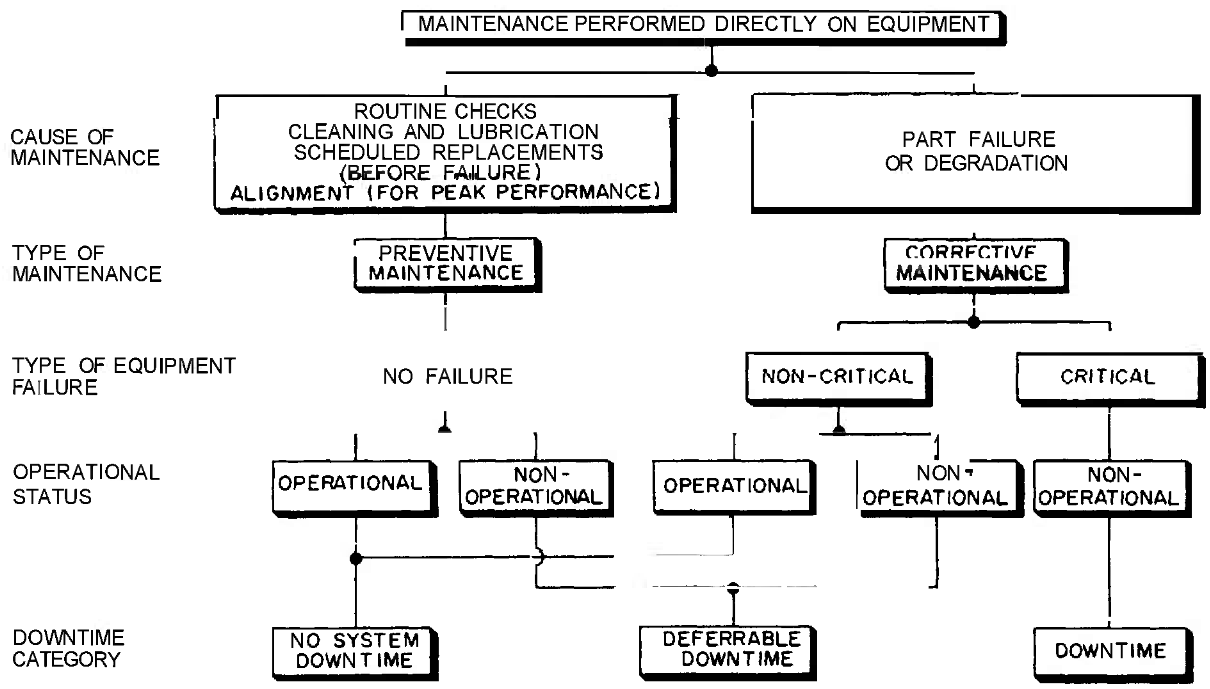
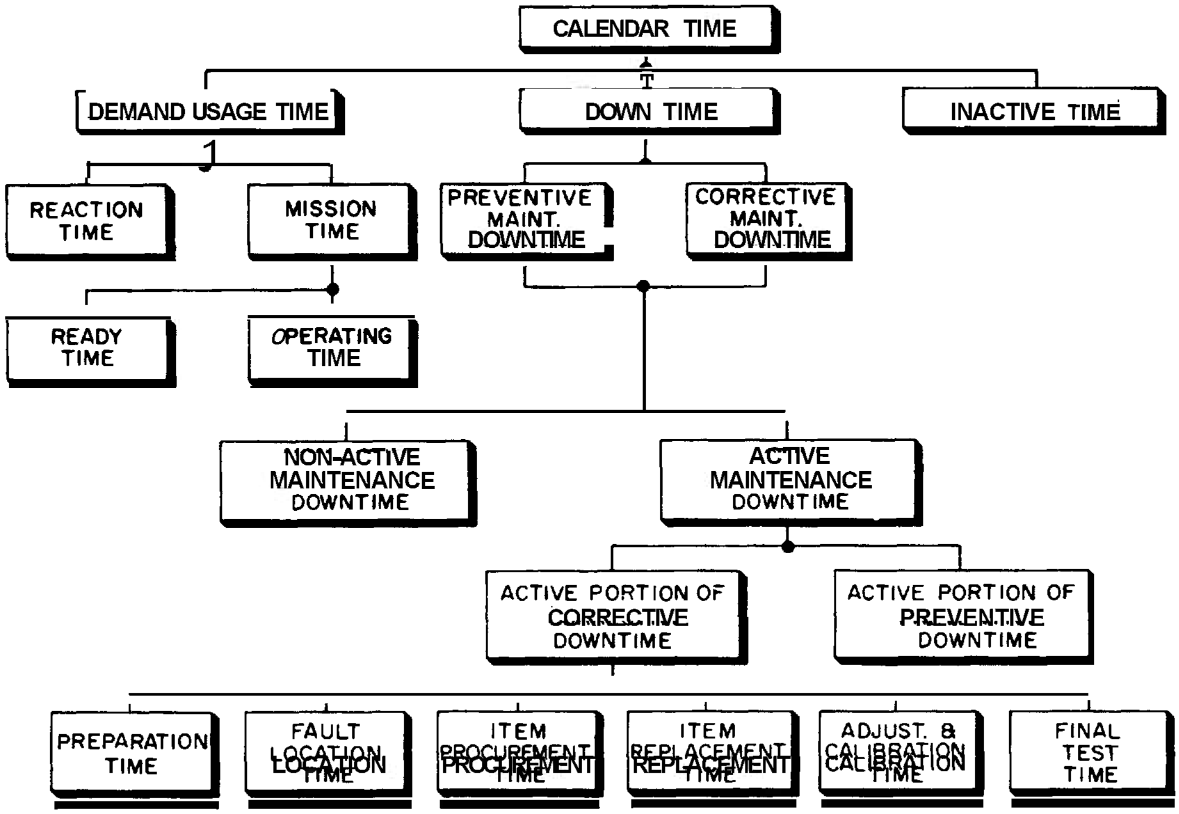


Figure **3-2. Downtime Classification**



DEFINITION OF CONCEPTS*

Calendar Time. The period of investigation, during which the equipment was scheduled to be in operation for a specified period, and non-operational (or **off)** during the remaining period.

Total Downtime. That portion of calendar time during which a system is not in condition to perform its intended function : includes active maintenance time (preventive and corrective) ; supply downtime due to unavailability **of** needed items ; and waiting and administrative time.

Active Maintenance Downtime. That time during which preventive and corrective maintenance work is being done on the system.

Nonactive Maintenance Time. That part **of** calendar time spent on administrative activities, excessive supply time (such as off-base procurement), and other general areas which preclude operation but cannot be considered productive towards maintenance task accomplishment.

* **Refer to glossary.**

Figure 3-3. Operation Profile

Figure 3-4. Maintainability Decision Structure *(Ref. 4)*

(Located in back of manual.)

TABLE 3-4. MAINTAINABILITY SPECIFICATIONS

Military Specification	Title	Description
Missile Command		
MIS-10017, 6 Sep 63	*Human Factors Engineering in Development of Missile Systems*	Defines general requirements to be followed by development contractor in applying principles of human factors engineering. Provides for consideration of man-machine relation in design of equipment and systems.
RCR-870, 20 Jan 64	*Maintainability Program Requirements for Missile Weapons Systems and Associated Equipment*	Establishes a specification for use with Army Missile Command research and development efforts to provide optimum requirements and procedures for equipment maintainability programs.
Electronics Command		
MIL-M-55214 (EL), 8 Feb 63	*Maintainability Requirements, General:* for *Electronic Equipment*	Establishes general maintainability design requirements and provides procedures for use in evaluating maintainability of electronic equip ment design in terms of quantitative maintainability scores. Utilizes weighting factors for various attributes.
BuShips		
NAVSHIPS 94323, April 1962	*Maintainability Design Criteria Handbook* for *Designers of Shipboard Electronic Equipment*	Provides general discussion of maintainability concept, ship board environment, and maintainability design criteria. Includes much human factors engineering data.
DOD-BuWEPS		
MIL-HDBK-217, 8 Aug 62	*Reliability Stress and Failure Rate Data* for *Electronic Equipment*	Provides a standard reference for failure rate data for certain electronic components and provides derating curves for loading and temperature variances.

TABLE 3-4. MAINTAINABILITY SPECIFICATIONS (cont)

DOD MIL-STD-721B, 22 Apr 64	*Maintainability Terms and Definitions*	Provides accepted Department of Defense definitions of terms used in maintainability engineering. Also provides breakout of time-related units in order that a standard understanding of these may be possible.
MIL-STD-470	*Military Standard, Maintainability Program Requirements (for systems equipment)*	Principal DOD policy document on Maintainability
MIL-STD-471	*Maintainability Demonstration*	DOD Standard Demonstration Procedures
MIL-STD-472	*Maintainability Prediction*	DOD Standard Prediction Techniques
MIL-STD-473	*Maintainability Verification/Demonstration/Evaluation for Aeronautical Systems*	Includes the whole program for all commodities (not just aircraft). Will supersede MIL-STD-471.

engineers might be: "If we can't design equipment to last forever, let us at least design it so we can keep it going as long as possible, and so we can fix it in a hurry when we need to, with the men available and the tools available."

The designer should first consult the maintenance support plan, described in Chapter 4, and then augment this information by contacting, primarily, the knowledgeable military personnel concerning the capabilities and limitations of operating and maintenance personnel where the equipment will be used, how it will be used, and how it will be supported. In selecting parts for the design, the designer should first consider the use of proven parts with the idea of keeping the use of new and novel components to a minimum. He should be willing to accept what others have done unless appreciable improvements can be demonstrated that do not compromise reliability and ease of repair. However, new design philosophies must not be penalized by being restricted to existing hardware. The final development models should be made simple and reliable, and include those ease-of-maintenance features consistent with the overall design.

The designer should also avoid creating unnecessary maintenance problems by building in maintenance "booby traps". These traps invite errors which are more the responsibility of the designer than they are of the maintenance technician. The ease with which a maintenance task can be performed is directly related to the way in which a system has been put together (see Table 3-5 as an example of a quantitative approach).

Every designer should attempt to view the maintainability requirements from the standpoint of the maintenance technician. Better still, he should literally put himself in the shoes of the maintenance man by actually performing maintenance and assembly on the hardware he has designed. Designers should remember that their product suffers proportionately to the amount of time it is out of commission, as probably does the maintenance man who has to repair it.

The designer should also bear in mind for future maintenance problems the familiar

TABLE 3-5. MIL-M-55214 (EL), MAINTAINABILITY INDEX FOR TYPICAL MAINTENANCE DESIGN FEATURE

Maintenance Design Feature	Consequence Areas—Weighting Factors				
Internal Accesses	Downtime	Maintenance Time	Logistics Requirements	Equipment Damage	Personnel Injury
1. Place access openings to permit direct access for performing job procedure.	2	3			
2. Provide sufficient access room for all tasks requiring use of one hand.	3	3			
3. Provide sufficient access room for tasks requiring insertion of one hand or both, with tools, cables, etc.	3	3			
4. If technician must see what he is doing, provide sufficient access size to permit sight while hands (and arms) are inserted.	3	3		4	4
5. Make any irregular extensions easy to remove before unit is handled.	1	2			
6. Provide integral rests or supports for units to prevent damage to delicate parts when unit is on bench.	3	3		4	
7. If an adjustment control under an access would be difficult or dangerous to locate, provide a tool guide attached to the access.	1			2	
8. Cover edges of accesses with internal fillets or rubber, fiber, or plastic protection if they might otherwise injure hands or arms.				3	3

Maintainability Evaluation Procedure:

1. For each of the five columns, score the weighting factors for all design features either YES or NO.
2. Score YES for those features adopted and present in every possible application of the equipment.
3. Score NO for those features absent from the design. including those not employed to maximum extent possible.
4. Total each of the five columns and perform the following computation for each column:

$$\text{Maintainability (M)} = \frac{Y}{Y+N} \times 100$$

where
Y = Total of YES weighted factors.
N = Total of NO weighted factors.

5. In order for equipment to be considered as acceptable, it must meet the minimum acceptable score for each consequence area (as set forth in Maintainability Requirement).

"Murphy's Law"—If it is possible to do it wrong, someone will surely do it! Unfortunately, the results of doing it wrong too often end in tragic loss of equipment and destruction of equipment. (See Chapter 31 for vivid examples of what can happen when "somebody did it wrong".) The designer could be the real culprit if he deliberately ignores his responsibility of designing his equipment to be easily and effectively maintained. Therefore, in designing equipment, the philosophy of "go right or no go", and "work right or no work" should be used wherever possible.

REFERENCES

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CHAPTER 4
COORDINATING DESIGN—PROGRAM PLAN FOR MAINTAINABILITY

4-1 GENERAL

It is the policy of the Department of the Army that maintainability of materiel and equipment will be achieved by :

(1) Designing maintainability into materiel rather than it being attained through subsequent modifications as a result of tests, field complaints, or product improvements.

(2) Effective planning, programing, and managerial direction.

(3) Adequate research, engineering, design, development, and evaluation.

(4) Efficient administration of logistical and operational procedures designed to preserve inherent maintainability.

(5) Establishing data sources of critical information on maintainability for design and planning activities.

To assume that this policy is achieved by the design activity, the starting point in the maintainability program is the development of a carefully thought out maintenance support plan. This plan, in general terms, should indicate who will accomplish what echelon of maintenance, expected time required to accomplish the maintenance, type of test equipment to be provided, maintenance units in existence or to be organized to service or support the new equipment, and milestones to demonstrate and evaluate the validity of the plan. It is the management tool designed to identify action elements of maintenance support which require timely execution and completion by the agencies responsible for each element of maintenance support.

The maintenance support plan must be implemented and updated to run concurrent with equipment design, development, production, and concept of field operation. Such a program is *mandatory* to meet the requirements of military specifications calling for maximum equipment availability and reduced maintenance costs.

AR 750-6 (Ref. 2) provides the policies and assigns the responsibilities for integrated maintenance support planning, for the preparation of maintenance support plans and logistical support plans, and for the coordination and distribution of these plans by the preparing agency. As defined by this regulation, the elements of maintenance support are:

(1) Trained military and civilian maintenance personnel.

(2) Requirements for new or changed military and civilian skills.

(3) Military and civilian instructor and operator personnel.

(4) Repair parts.

(5) Special and common tools and test equipment.

(6) Support and ground handling equipment.

(7) Technical manuals.

(8) Technical assistance.

(9) Maintenance load.

(10) Modification work orders.

(11) Calibration.

Maintenance support plans should be prepared for each supportable end item or weapon system of new materiel which will be issued to troops and which is not covered by an adequate, previously published maintenance support plan or Department of the Army equipment manuals. Guidance for implementing AR 750-6 is given in AMCR 750-15 (Ref. 3), which prescribes the policy, responsibilities, and procedures for maintenance support planning during the development, testing, and procurement of materiel.

4-2 TYPICAL MAINTAINABILITY ENGINEERING PROGRAMS

In order to implement the maintainability program, the maintenance support plan must be designed to meet the following objectives:

(1) Be sufficiently flexible to permit revision and updating at any point in the program.

(2) Show the various tasks and milestones, and approximate times required to accomplish each.

(3) Show each key event, and the coordinated sequence of occurrence, and the interrelationship of events.

(4) Provide valuable impetus for determining project costs and the most economical allocation of personnel.

The paragraphs which follow describe the organization, program tasks, key events, and major milestones which must be considered in the implementation of a typical maintainability and maintenance support plan (Refs. 4 and 5). The scheduling of the key events of such a program are presented in Figure 4-1. A brief summation of the implementation of another maintainability and maintenance support plan is shown in Table 4-1, included at the end of the chapter.

4-2.1 ORGANIZATIONAL NEEDS

The maintainability management control function must provide for integration of efforts and operations up through high organizational levels. Personnel trained in maintainability technology should be employed in each phase of the program from preliminary planning through final field evaluation. Organizational needs require:

(1) *Coordination.* Individual tasks necessary to accomplish program objectives coordinated by project teams operating on many levels within the project. Personnel with training and experience commensurate with the scope of the tasks are a prerequisite for each team.

(2) ***Program indoctrination.*** Orientation and indoctrination of all persons, government and contractor, responsible for conducting the maintainability program. Particular emphasis should be directed toward familiarizing each member with all important aspects of the system design, operation, and maintenance philosophies to be utilized.

4-2.2 PERSONNEL REQUIREMENTS

Personnel should include, but not be limited to, maintenance engineers, military specialists, circuit design analysts, statisticians, data analysts, human factors engineers, and mathematicians. The number of specialists in each category will vary with the size of program. A limited maintainability program generally requires fewer specialists, but this reduction in turn demands more diversified capabilities for each participant.

4-2.3 PROGRAM TASKS

The major tasks considered here should be provided for in a comprehensive maintainability program (scope of tasks to be consistent with magnitude of particular development program).

4-2.3.1 QMR/SDR Planning Phase

Maintainability inputs are to be included in Qualitative Materiel Requirements (QMR) and Small Development Requirements (SDR). These requirements must be realistic with respect to other pertinent requirements of design, reliability, operation, and logistics so that a proper balance can be achieved between system effectiveness and total cost.

4-2.3.2 Project Definition Phase

Proposals for new systems should include quantitative maintainability objectives as an inherent portion of the performance objectives. A maintainability program and appropriate documentation, including the maintainability objectives, and a plan for achievement, accom-

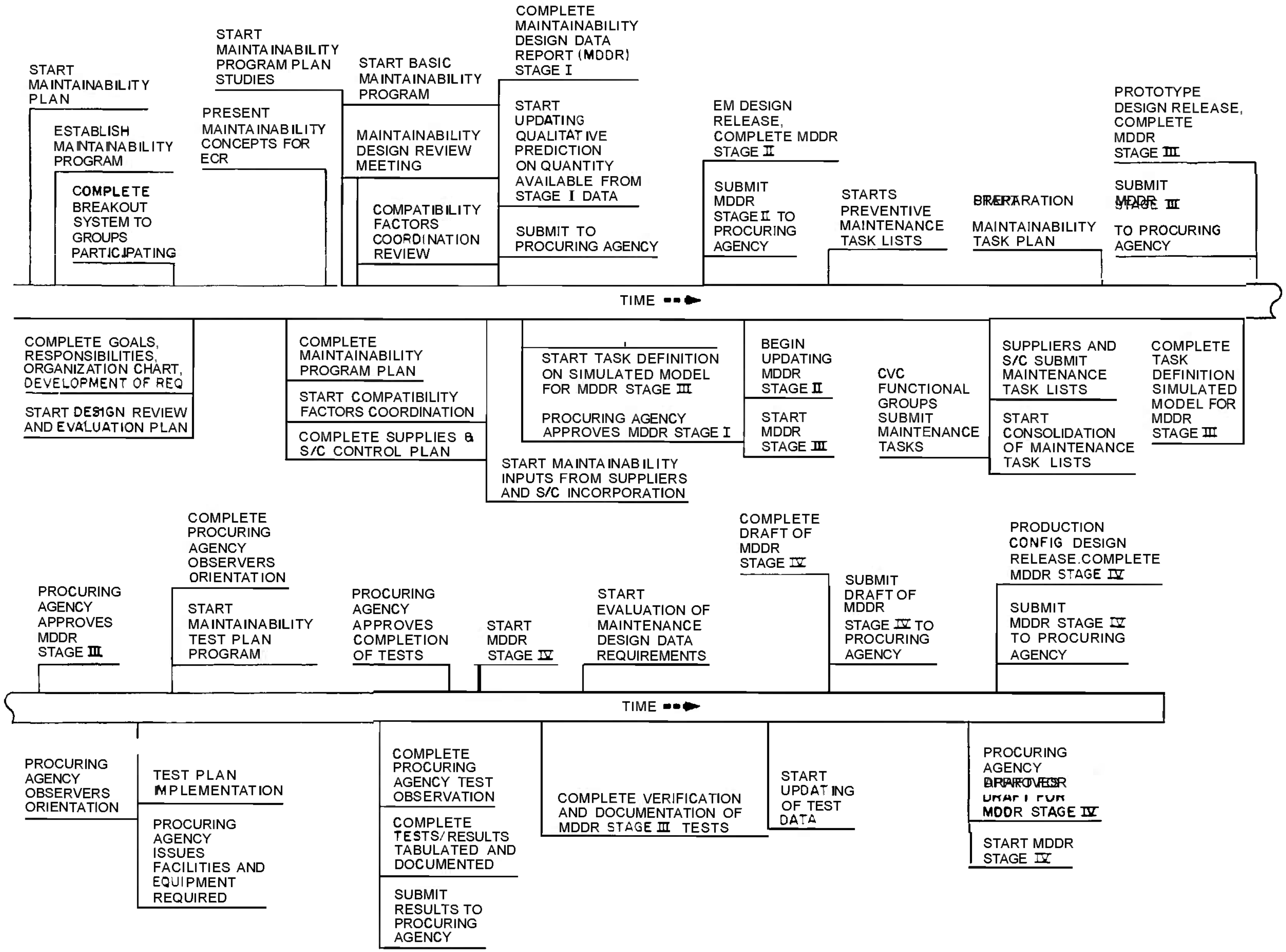

figure 4-1. Key Events and Task Scheduling of a Typical Maintainability Program (Ref. 6)

plishment, and evaluation should be included (see Chapter 5).

4-2.3.3 Development Program Phase

The Development Program Phase should include or provide for the following essential elements in accordance with AR700-51, 10-001 (Army Authorized Data List):

(1) *Program plan.* Contains maintainability objectives, plans, goals, and milestones for accomplishment and evaluation which can be demonstrated on a time basis. This plan can also serve as a guide for all design, production, and product assurance engineers (see Chapter 5).

(2) *Mathematical model.* Provides goals for maintainability, availability, etc., to serve as a standard for demonstrating the design achieved. This model can also be used in determining the maintainability status and effectiveness of the system during all stages of design, development, and testing.

(3) *Specification review.* Emphasizes the importance of maintainability as part of the overall contract. Upon award of the contract a complete and thorough study of maintainability and other related product assurance specifications should be made.

(4) *Prediction and analysis.* Provides preliminary maintainability predictions based on data supplied through integrated test program.

(5) *Training program.* Maintainability-orients all engineering personnel participating in equipment or system development.

(6) *Human factors engineering.* Reviews equipment design concepts for logic, display control configurations, and operations with emphasis on system maintainability.

(7) *Change control.* Procedure assures that design changes required for and affecting maintainability are carefully reviewed.

(8) *Scheduled design reviews.* Insures and demonstrates that maximum maintainability has been achieved throughout development cycle (see Chapter 5).

(9) *Methods for considering design trade-offs.* Considers in early development phase, the designs which, while conforming to maintainability specifications, do not always meet other specified requirements; i.e., operational requirements, reliability, economic limitations, and performance requirements (see Chapter 5).

(10) *Vendors indoctrination **program.*** Provides subcontractors with maintainability guidelines and specifications.

(11) *Demonstration and task.* Conducted in accordance with MIL-STD-471 to obtain maintainability data that cannot be evaluated by analytical methods, or as required to verify that maintainability requirements have been met.

(12) *Scheduled evaluation and improvement.* Evaluates data feedback from demonstrations, tests, and field areas for supporting design improvement recommendation and for verification of maintainability predictions.

4-2.3.4 Production Phase

During this phase, the maintainability requirements and objectives must be consistent with those established during design and development, i.e., with the maintenance support plan. Close surveillance must be provided to assure that quality assurance requirements and maintainability specifications are met. Considered in this phase are:

(1) *Quality Control.* Maintains high quality in workmanship and manufacturing standards with respect to maintainability. Poor quality control practices must be isolated and corrective action initiated to preclude maintainability problems in the field.

(2) *Modification and change control.* Establishes coordination procedures between design and manufacturing activities to insure that changes or modifications to equipment design are agreed upon before they are initiated. In all cases the designer must concur with the changes.

4-2.3.5 Operational Phase

The final validation of maintainability predictions is accomplished during this period. This phase includes:

(1) *Initial development stage.* Based upon evaluation of data accumulated relative to design tests, engineering costs, user tests, system demonstrations, transportation, storage assembly, emplacement and check-out. Analyze data and make recommendations for product improvement for future equipment.

TABLE 4-1. IMPLEMENTATION OF A MAINTAINABILITY AND MAINTENANCE SUPPORT PROGRAM (Ref. 6)

Task or Function	Responsible Activity
Analyzation by logistics engineering of the type, purpose, function, and utilization of the equipment; qualitative and quantitative maintainability requirements; customer maintenance concepts; organization; and policies. Establish the following maintainability program:	
Define system requirements	System engineering
System concept	System engineering
Analyze maintainability and logistic requirements	Logistics engineering
Preliminary maintenance concept and maintainability guidelines	Logistics engineering
Preliminary maintainability procedures, functions, and goals	Logistics engineering
Preliminary maintenance support procedures and functions	Logistics engineering
Preliminary maintainability and logistics costs	Logistics engineering
Design reviews	System engineering
Trade-offs	System engineering
Revised maintainability data and goals	Logistics engineering
Revised maintenance support data	Logistics engineering
Maintainability and logistics plan	Logistics engineering
Equipment design	Engineering
Equipment design	Engineering
Maintainability and Logistics plan	Maintainability and logistics
Maintainability functions (updating)	Logistics engineering

Task or Function	Responsible Activity
Personnel skills and training program	Logistics engineering and training
Support equipment requirements (updating)	Logistics engineering
Shares and documentation program	Supply support
Publications program and implementation	Publications
Government furnished equipment (GFE)design	Logistics engineering
Vendor and/or subcontractor equipment design	Customer
Field support and field engineering plans	Logistics engineering
Maintainability test plan	Logistics engineering
Modification and status	Configuration control
Phase III—Production and Test Maintainability equipment reviews conducted by logistics engineering. System, subsystem, and supporting equipment tests include review, evaluation, and validation of the following:	
Prototype production	Manufacturing
Maintainability testing and publications verification program	Maintainability and publications
Maintainability design verification	Maintainability
Design changes and recommendations	Maintainability
Engineering change board	System engineering
Revision of maintainability data	Maintainability
Revision of support equipment	Logistics engineering
Finalization of prototype spares requirements	Supply support

TABLE 4-1. IMPLEMENTATION OF A MAINTAINABILITY AND MAINTENANCE SUPPORT PROGRAM (Ref. 6) (cont)

Task or Function	Responsible Activity
Maintainability and maintenance reviews conducted, and a logistic support program implemented during the testing and user phase for the following tasks:	
System test plan	Reliability test and evaluation
Logistic test plan	Logistic support division
Support of system testing	Engineering
Verification of maintainability goals	Maintainability
Verification of logistic support function	Logistic support division
Test report and recommendations	Maintainability
System test summary	Reliability test and evaluation

(2) *Field operating stage.* Analyze active maintenance data from all equipment sites and use to validate predicted maintainability figures. Unsatisfactory Equipment Reports (UER), Equipment Improvement Reports (EIR), and the Army failure reporting system (TAERS) will be utilized. (see Chapter **7,** Paragraph **7-2.3).**

REFERENCES

1. AR **750-6,** *Maintenance Support Planning.*
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CHAPTER 5
MAINTAINABILITY REVIEWS AND TRADE-OFF TECHNIQUES

SECTION I
IN-PROCESS REVIEWS

5-1 GENERAL

AR 705-5 (Ref. 1) specifies that maintainability activities relating to or part of a development program will be examined during in-process reviews (IPR's). The IPR is a review of a materiel development project conducted at critical points of the development cycle. Its purpose is to evaluate the status of the project, accomplish effective coordination, and facilitate proper and timely decisions bearing on the future course of the project to assure the materiel's ultimate acceptability for use by the Army.

In-process reviews offer various departments or agencies involved in a project the opportunity to analyze the subsystem from their respective points of view or discipline. It is at these meetings that trade-offs can be evaluated and problem areas investigated. The objectives, responsibilities, and procedures governing the conduct of in-process reviews on all development projects for which the U S Army Materiel Command (AMC) has been assigned responsibility are established in AMCR 70-5 (Ref. 2).

5-2 OBJECTIVES OF IN-PROCESS REVIEWS

The objectives of IPR's are:

(1) To evaluate whether the development objectives—the military characteristics and/or operational requirements specified in the Qualitative Materiel Requirement (QMR) or the Small Development Requirement (SDR)—can be and are being met. (The QMR is the basic specification for the product.)

(2) To insure the materiel's ultimate overall acceptability for use by the Army.

(3) To provide the development agency with a coordinated developer/user/Department of the Army staff decision on the course of the development action to be followed. This applies particularly to those areas involving trade-offs between the various military characteristics specified in the QMR or SDR.

(4) To increase efficiency in the use of materiel.

(5) To reduce development time and costs.

(6) To simplify operational and maintenance requirements.

In-process reviews are conducted by the pertinent command under AMC involved in the process of procurement of materiel. They are normally held at the following points in the development cycle:

(1) *Technical characteristics review.* Held upon receipt by the developing agency of the QMR or SDR, and prior to finalizing the technical characteristics. Insures that the developer understands the requirement and has properly stated it in terms of technical characteristics.

(2) *Engineering concept review.* Held upon completion of the engineering concept. Insures that the contractor or in-house facility is not commencing a program that is beyond the state-of-the-art, or contains too many high risk areas. Insures also that all feasible engineering approaches are being utilized.

(3) *Design characteristics review.* Held upon completion of determinations of design characteristics, and prior to release of the design for development. Appropriate consideration must be given to updating the QMR, if necessary, to avoid development of hardware that does not fullv satisfy the stated requirements.

(4) *Prototype systems review.* Held after delivery of prototype development hardware.

(5) *Service test review.* Held prior to commencement of service test, or combined service test/engineering test. Insures that all aspects of the test program, both completed and to be conducted, thoroughly measure the ability of the materiel to meet the QMR.

5-3 TYPES OF IN-PROCESS REVIEWS

In-process reviews are classified into the following two types:

(1) *Formal IPR.* Required at the discretion of the Department of the Army upon approval of QMR. Conducted by conference between representatives of the following agencies:

(a) AMC
(b) U S Army Combat Developments Command (CDC)
(c) Office of the Chief of Research and Development, Department of the Army
(d) Office of the Deputy Chief of Staff for Logistics, Department of the Army
(e) Assistant Chief of Staff for Force Development, Department of the Army
(f) United States Continental Army Command (for training aspects only)
(g) The using agency (as defined in AR 705-5)
(h) The supporting agency
(i) When deemed appropriate, the contractor, and other commands and agencies having a direct interest in the matters to be considered.

(2) *Informal IPR.* Conducted on all projects for which formal reviews are not specified. Normally conducted by correspondence, or by conference if necessary. Participants include the same agencies required in formal reviews.

5-4 IN-PROCESS REVIEW CHECKLIST

Two types of analysis techniques are needed to perform in-process reviews: quantitative and qualitative. Quantitative techniques make use of prediction data to determine areas and features requiring improvement. Qualitative techniques make use of the reviewers' knowledge and experience augmented by reference material.

To assist maintainability design reviewers, a checklist for maintainability features should be prepared. This checklist should encompass the major factors important to maintainablity, as well as individual features deemed important to the class of equipment under review. This checklist could also be used to assist personnel unacquainted with maintainability to perform the design review when experienced personnel are not available.

Tables 5-1 through 5-5 present checklists for five categories of design review points, which could be easily adapted to specific projects or programs (Ref. 3). The categories represent discrete portions of a normal development program where definite decisions must be made before progressing to the next stage.

TABLE 5-1. SYSTEM PLANNING REVIEW CHECKLIST

1. System concept } Interfaces
2. Maintenance concept } Interfaces
3. Design concept } Interfaces
4. Vendor/subcontractor design review programs
5. Funding for design reviews
6. In-house design review schedule
7. Design review criteria and parameters applicable to ensuing reviews
8. Facility concepts—tools, test equipment, personnel, etc.
9. Identification of risks entailed in decision paths

TABLE 5-2. MECHANICAL/FUNCTIONAL REVIEW CHECKLIST

Informal Review
1. Use of Standard Circuits (where applicable)
a. Does this also standardize test equipment?
b. Does it reduce or eliminate critical adjustments?
c. Are circuit types kept to a minimum?
d. Have techniques for troubleshooting started to take shape?
e. Do standards exist for calibrating test equipment?
f. Should unusual test equipment be considered.?
2. Circuit Simplicity
a. Can auxiliary networks be removed without deteriorating function?

TABLE 5-2. MECHANICAL/FUNCTIONAL REVIEW CHECKLIST (cont)

b. Is built-in test equipment the best answer?
c. Can adjustable circuits be further reduced?
d. With the existing inputs and outputs, can any component be simplified or complexity reduced?
e. Is complicated singularity or simplified redundancy better in any section?

3. Adjustment Requirements
a. Are adjustments held to a minimum?
b. Will component selections be made that will hold their settings?
c. What test equipment and techniques will be required for adjustments?
d. Will adjustments be in mandatory sequence, or are they independent?
e. What tools will be required for adjustment?
f. Is there interaction during adjustment?
g. Can adjustments compensate for tolerance change?
h. Will periodic adjustment or alignment be needed?
i. Are adjustments and test points compatible?,
j. Will factory settings require readjustment on installation or during replacement?
k. Will adjustment movement direction correspond to indicator movement? Zero center?
l. Will attachment of test equipment unbalance any circuits?

4. Test Points
a. Can test connections be maintained during adjustment?
b. Are there sufficient test points?
c. Are they identified as to function or use?
d. Are they compatible with planned test equipment?
e. Are they positioned relative to one another to minimize the electrical shock hazard?
f. Are they designed so that no damage to system can occur by introduction of unwarranted signal?

5. Built-In Test Equipment
a. Is all of the built-in equipment required during the mission?
b. Can auxiliary equipment do as well without reducing effectiveness?
c. Does the test equipment dynamically test parameters in question? Is it effective in predicting failures or is it to be used only after failure indication?
d. After any failure indication can mission be completed on reduced basis? Has this been adequately documented?
e. Are identifications and markings adequate?

6. Maintenance Plan
a. Does the existing maintenance plan include coverage for all problems encountered including test and calibration equipment?

7. Relationship to Other Disciplines
a. Have all other affected disciplines been kept current? Have they received adequate data for impact evaluation?
b. Should extra meetings be held to clarify problems?
c. Will all disciplines agree on solutions? Have minority opinions been documented/distributed adequately?
d. Have trade-offs been justified/validated?
e. Will testing reduce the life of item being tested? (None, some, appreciably, significantly?)

Formal Review—Subjects for Consideration

1. Maintenance plan
2. Standard circuits and electromechanical elements
3. Modular vs. nonmodular decisions
4. Adjustments required—criticality
5. Test points—adequacy, location
6. Built-in test equipment
7. Simplicity of design
9. Relationship with other disciplines
9. Support requirements
10. Advance planning for spares and manuals
11. Product safety

Formal Review—Checklist

1. Has an assembly specification been prepared?
2. Have characteristics of the critical parts been specified?

TABLE 5-2. MECHANICAL/FUNCTIONAL REVIEW CHECKLIST (cont)

3. What are the assembly requirements and tolerances?
4. If no specification is prepared for critical components, how is acceptability to be determined?
5. How is the completed assembly to be tested?
6. What is labor and material cost per unit?
7. What are the mounting arrangements?
8. How are connections made to the assembly?
9. What is the effect of frequency interference?
10. What are the effective signal level limits?
11. Over what bandwidth must the assembly operate?
12. How and where will component parts be obtained?
13. How will it be assembled in the plant?
14. What environmental tests will the assembly be capable to meet?
15. What effect will assembly failure have on system operation?
16. How many are required per system?
17. What is assembly estimated life or mean-time-between-failures?
18. What trade-offs can be made to improve life?
19. What interface problems are anticipated? How are they to be handled?
20. What electrical tests are required to prove specification compliance?
21. What are the safety hazards involved with equipment design?

TABLE 5-3. EXPERIMENTAL/BREADBOARD REVIEW CHECKLIST

Informal Review

1. Are maintenance and test equipment requirements compatible with the maintenance plan?
2. Is design such that circuit damage will not result from careless adjustment procedures?
3. Have factory and maintenance test equipment been minimized and coordinated with other units?
4. Are special techniques required in repair, replacement, or alignment of units?
5. Are testing, alignment, and repair procedures such as to require minimum knowledge by repair personnel?
6. What special tools and test equipment are required?
7. Can every fault of any type which can occur be detected by use of proposed test equipment and procedures?
8. Have items subject to early wear-out been identified?
9. Have voltage dividers been provided for test points for circuits carrying more than 300 volts?
10. Will circuits tolerate use of a jumper cable?
11. Have all precautions been taken to protect personnel from mechanical, electrical, chemical, radiation, etc., hazards associated with the equipment?
12. Are special calibration features required?

Formal Review—Subjects for Consideration

1. Criticality of design as it affects maintenance—special parts selection, procedures, or spares?
2. Calibration requirements—are field Calibrations reduced to minimum?
3. Test point application—enough of right type confirmed by tests?
4. Testing techniques and adequacy—any unusual methods or skills required?
5. Packaging concepts—what is to be the repairable unit? Is it accessible?
6. Reliability vs spares—reliance on reliable parts or on replacement? Trade-offs on spares vs space, weight, and cost. In-commission rate vs reliability figure of merit.
7. Support requirements—special equipment required for maintenance? Kind of skills and number of personnel? Specialized training required? Manuals?
8. Logistic interfaces—specially selected components required to make it work?
9. Ease of maintenance in the planned environment.
10. Cost of maintenance and possible savings
11. Personnel hazards involved during manufacture, operation, and maintenance.

TABLE 5-4. PROTOTYPE RELEASE REVIEW CHECKLIST

Informal Review

1. Is this the best volume utilization, allowing for maintenance?
2. Will this type of construction allow plug-in replacement to shorten downtime, or is removal and replacement time longer than repair-in-place time?
3. Will this type construction survive the lifetime environment — shipping, temperature, humidity, shock and vibration? Will there be hot spots?
4. Will special tools or fixtures be needed for adjustment, test, or repair?
5. Can repairable subassemblies be tested and repaired at the bench without special tools or protection?
6. What are the techniques and location for repair — on site, in depot, in factory?
7. Will cooling be adequate during maintenance?
8. Have guide pins been provided to facilitate installation of plug-in units?
9. Are plug-in units keyed to prevent insertion errors?
10. Has protection been provided for cabling around corners or near sharp edges?
11. Are grommets provided wherever necessary?
12. Will design minimize chance of soldering iron burns?
13. Can units be dynamically tested in place?
14. Is there clear access to all removable items?
15. Are all test points readily accessible as installed?
16. Are all adjustment points accessible as installed?
17. Is there adequate provision for protection of test and maintenance personnel against injury?
18. Is each assembly self-supporting in the desired positions for testing and maintenance?
19. Can assemblies or units be laid on a bench in any position without damaging components?
20. Are displays located for easy observation during testing?
21. Do functionally related controls and displays maintain functional or physical compatibility, i.e., direction of motion and physical proximity?
22. Do design, arrangement, and installation allow adequate working space?
23. Do chassis and panel fasteners require special tools? Are there too many, thus hampering access?
24. Are units light enough for ease of removal? Have adequate handling devices been provided?

Formal Review

1. Specification compliance:
   Maintainability goal vs. attained maintainability.
2. Producibility vs maintainability:
   Will any maintainability features be compromised by necessary production techniques?
3. Failure records vs maintainability:
   Have failures and corrective actions revealed any loopholes in maintainability?
4. Engineering changes vs maintainability:
   Will any changes made or completed compromise maintainability?
5. Are there any last minute changes that can be made to improve maintainability?

TABLE 5-5 SUPPORT FACILITIES REVIEW CHECKLIST

Objectives

1. Tools and shop facilities
2. Test equipment
3. Personnel requirements
4. Skill and training requirements
5. Documentation requirements
6. Installation requirements
7. Loading (peak usage demands)
8. Spares requirements and distribution
9. Transportation requirements

Criteria

1. Adequacy of planning or coverage
2. Criticality of objective to mission accomplishment
3. Timeliness of planning, development, and delivery
4. Availability of existing materiel
5. Standardization
6. Trade-offs
7. cost
8. interface compatibility
9. Failure effects

Checklist

1. Are maintenance and test equipment requirements compatible with the concept established for the system?
2. Does any unit require special handling? Has the handling facility been provided?
3. What adjustments are required after installation of unit and of the system?
4. Is periodic alignment, adjustment, or servicing required? How often?
5. Are the procedures for testing, alignment, or repair written to require minimum knowledge on the part of maintenance personnel? Are they too specific?
6. Have all special tools and test equipment requirements been identified? Has action to procure special tools and test equipment been started?
7. Have all shop facilities requirements been identified and provided for (all types of power, heating and resealing, and evacuating, etc.)?
8. Have shipping methods, containers, and lead time been planned? Are containers designed to permit testing of contents without removal from package?
9. Are the planned manuals and charts the best that can be provided?
10. Has an adequate data collection system been established?
11. How are spares to be selected?
12. Where will spares be maintained?
13. What effect will lead time have on spares provision or replacement?
14. What are the spares packaging and storage requirements? Are there any exceptions?
15. Is the spares policy compatible with the design (prime) packaging concept?
16. Do any spares require servicing, testing, or adjustment?
17. Do any spares have limited shelf life? Replacement schedule established?
18. Are there special parts spares that should be procured in lifetime quantities to avoid reprocurement problems?
19. What calibration facilities will be required?
20. Are the spare parts, manuals, and maintenance plan for test equipment established?

SECTION II

TRADE-OFF TECHNIQUES

5-5 GENERAL

Designers of military equipment, or the maintainability engineer or group, are seriously in need of simple and practical procedures by which trade-off of significant factors can be accomplished. The necessity for this capability is accentuated as the numerous military specifications calling for trade-offs are implemented.

The term "trade-off," as it applies to maintainability, can be defined as the process by which a designer can evaluate one or more proposed maintainability design considerations in terms of possible effects in other areas, and to make an intelligent decision based upon these evaluations. Essentially, the designer is weighing, or trading-off, the advantages to be gained from each maintainability design change against possible disadvantages in deciding whether or not the change should be incorporated into the equipment. Some examples in the case of trade-offs are presented in the paragraphs which follow (Refs. 4 and 5).

5-6 MAJOR SYSTEM TRADE-OFFS

To meet overall system requirements within a budgeted cost and fixed frame time, trade-offs are often necessary among the major system parameters. Trade-offs within the major parameters are also necessary to attain the specified levels for each parameter. In the case of maintainability, a trade-off may be effected with reliability to achieve the desired availability. At the same time, however, mission requirements may dictate a minimum maintainability requirement, below which a trade-off may not be made. In this situation, trade-offs among the parameters of maintainability (design, personnel, and support), or among the components of the system, may be necessary to achieve the required maintainability level. The following paragraphs give techniques for performing these trade-offs with the system, between components (subsystems) of the system, and between maintainability tests.

5-6.1 SYSTEM AVAILABILITY TRADE-OFF

The all important goal in equipment design is equipment availability. The availability of a weapon system is determined principally by its maintainability — the ease with which it can be kept ready to respond to the tactical need *when* ***needed.*** The requirement for maintainability must be periodically reassessed as design progresses, on the basis of a practical analysis of the inherent "repairability" characteristic of the design. Availability is dependent upon the probability of system repair and return to operational status, and is dependent on reliability and maintainability through the following relationship :

$$A_i = \frac{MTBF}{MTBF + MTTR}$$

where

A_i = inherent availability ; the probability that a system or equipment, when used under stated conditions, without consideration for any scheduled or preventive maintenance and in an ideal support environment, will operate satisfactorily at any given time. Excludes ready time, supply downtime, waiting or administrative downtime, and preventive maintenance downtime.

$MTBF$ = mean-time-between-failures.

$MTTR$ = mean-time-to-repair ; the average time required to detect and isolate a malfunction, effect repair, and restore the system to a satisfactory level of performance.

Since availability reflects two fundamental measures of system dependability, namely, MTRF and MTTR, its use in analytically evaluating a system appears advantageous.

5-6.1.1 Nonredundant System

Figure **5-1** illustrates the use of availability for trade-offs for a weapon system. The system is depicted as containing five subsystems for which the reliability and maintainability have been predicted. Table **5-6** summarizes the **MTBF,** *MTTR,* and inherent availability for each subsystem of the nonredundant system (Figure **5-1 (A)**). The system availability, A_s, is calculated by forming the product of the individual availabilities, assuming independence of A_i as follows:

$$A_s = A_1 \times A_2 \times A_3 \times A_4 \times A_5$$

Using this formula, the availability for weapon system A is:

$$A_s = (0.98039) \times (0.99502) \times (0.83333) \times (0.90909) \times (0.99502) = 0.73534$$

5-6.1.2 Redundant System

If the maintainability of an equipment has been improved to the state-of-the-art or the budgetary limitations and still does not meet the specified level, a trade-off may be made with reliability to attain the desired availability. Examination of Table **5-6** shows that subsystem **3** has the lowest availability; thus by providing an alternate redundant subsystem, total system availability is improved. The availability for

TABLE 5-6. WEAPON SYSTEM AVAILABILITY WITHOUT REDUNDANCY

Subsystem	MTBF	MTTR	A_i
1	100	2	0,98039
2	200	1	0.99502
3	25	5	0,83333
4	50	5	0.90909
5	400	2	0,99502
Resultant A_s = 0.73534			

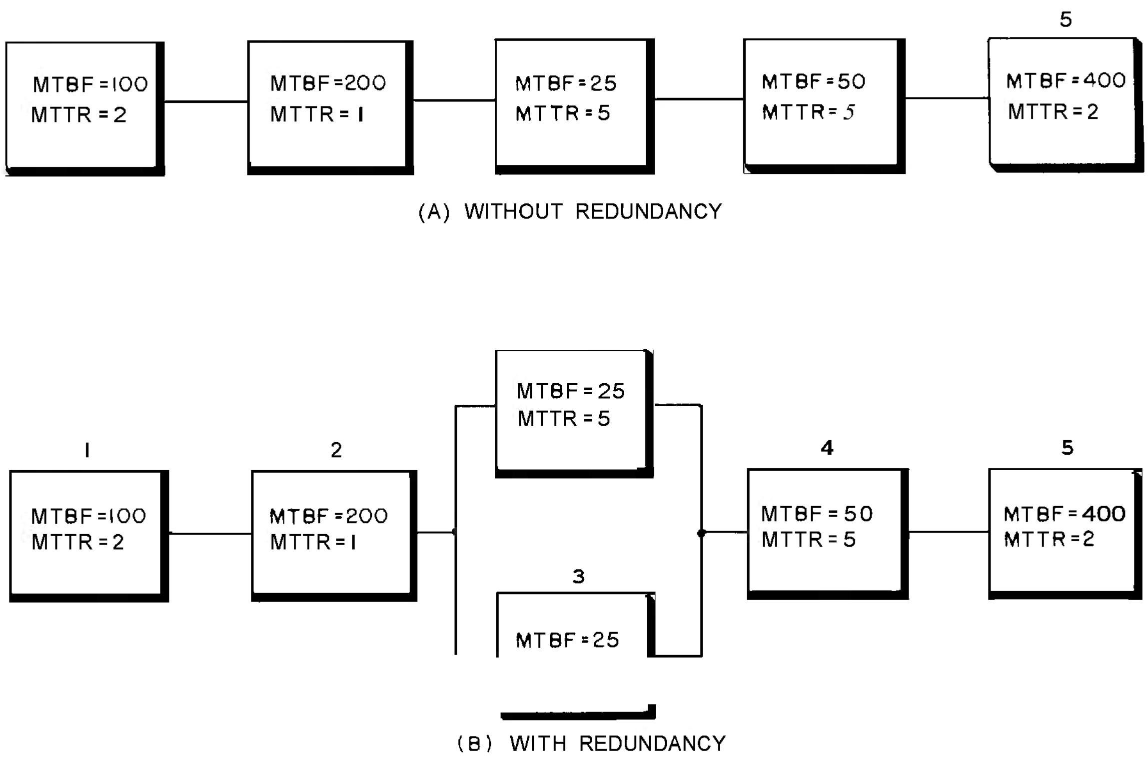

Figure 5-1. Using Availabilitv for Trade-offs in a Weapon System

redundant subsystem 3 (Figure 5-1(B)) is calculated as follows:

$$A_{3r} = 1 - (1 - A_3)^2$$

where

A_{3r} = subsystem redundant availability

Substituting the value for A_3 gives

$$A_{3r} = 1 - (1 - 0.83333)^2 = 0.97222$$

Substituting the value for A_{3r} in the system availability equation gives:

$$A_s = (0.98039) \times (0.99502) \times (0.97222) \times (0.90909) \times (0.99502) = 0.85790$$

The introduction of redundancy for subsystem 3 has resulted in an increase in total system availability.

5-6.1.3 Basic System Plus Support Equipment

An alternate method increasing availability is to increase the maintainability of the system through a trade-off between the design and support parameters. This can be accomplished by placing much of the burden on the support parameter. As an example, assume that a sophisticated maintenance check-out equipment is developed for the weapon system (Figure 5-1), which reduced the maintainability requirements for the weapon system by one-half. The availability achieved by this alternate method is given in Table 5-7 and is calculated as follows:

$$A_s = (0.99009) \times (0.99751) \times (0.90909) \times (0.95238) \times (0.99751) = 0.85296$$

TABLE 5-7. WEAPON SYSTEM AVAILABILITY TRADE-OFF WITH SUPPORT EQUIPMENT AND REDUNDANCY

Subsystem	MTBF	MTTR	A_i
1	100	1.0	0.99009
2	200	0.5	0.99751
3	25	2.5	0.90909
4	50	2.5	0,95238
5	400	1.0	0.99751
Resultant A_s = 0.85296			

TABLE 5-8. SUMMARY OF WEAPON SYSTEM PARAMETERS

Configuration	Development cost	Availability
I Basic System	$500,000.00	0.73534
II Redundant System	$550,000.00	0.85790
III Basic System Plus Support Equipment	$560,000.00	0.85296

Again a substantial gain has been achieved but at a greater system cost. An additional degradation factor may be the potential unavailability of the support equipment. This factor may be analytically treated to incorporate the degradation into the weapon system availability.

5-6.1.4 Selection of Best Method

To select the best method for improving availability, the relative cost for each approach must be estimated for the example given. Table 5-8 gives the development costs for each configuration (assuming equal performance capabilities). From this data, configuration II is shown to have the highest availability with the least increase in development cost,

5-6.2 COMPONENT AVAILABILITY TRADE-OFF

The technique described for trading off maintainability against reliability at the system level is also applicable at the subsystem, equipment, and component levels. Basically, at the component level, the costs of increasing reliability and maintainability through redesign are calculated for various levels of each attribute. The availability for each combination of reliability and maintainability levels is calculated along with the associated development cost. These data are then tabulated, as in Table 5-8, and the method for improvement is selected on the basis of mission requirements and budgetary limits.

5-7 MAINTENANCE TESTING TRADE-OFFS

The checkout of a complex equipment and system can be accomplished either individually or by a combination of the following testing concepts (Ref. *6)*:

(1) *System tests.* Exemplified by a control system, transmitter system, or navigational system; an integrated grouping of associated elements which accomplish an operational task. This requires the system to be subjected to stimuli necessary to simulate operational conditions and the response evaluated for abnormalities.

(2) *Component tests.* Typified by amplifier units, power supplies, memory storage devices, or displays; an integrated group of associated elements which perform a defined function and are packaged in a transportable or removable unit. The test is performed to demonstrate whether a component or individual elements within a component are operating within tolerances.

(3) *Static tests.* Performed through use of non-varying stimuli, such as signals with constant or zero current. The item under test is not subjected to the variety and magnitude of stresses encountered while in operation.

(4) *Dynamic tests.* Tests which simulate or reproduce functional modes, and in so doing exercise individual elements of unit under test.

(5) *Open-loop tests.* Measures direct response of an item to changes in the several parameters (including external requirements and characteristics of other items) affecting it without regard to remainder of the system. However, no adjustments are made to stimuli because of that response.

(6) *Closed-loop tests.* Represents response of an item to changes in the several parameters affecting it, and where feedback through other systems is taken into account.

(7) *Marginal testing.* Provides information relative to the ability of components to operate under full range of design parameters. Upon application of stimuli (varying bias voltages, frequency, mechanical speeds, or temperature under controlled conditions) during field maintenance, individual piece-parts or components can be made to function close to the design tolerance limits. The test can be used to detect component degradation or to establish a confidence level of performance.

The decision to use one or another type or combination of testing techniques entails consideration of factors such as: the stability of the circuit, type of system, cost, personnel training and skill, time permitted for testing, test information required, maintenance level at which tests will be performed, readout instrumentation required, sequencing of tests, environment and installation, and whether testing of a particular kind reduces life of item.

5-7.1 CATEGORIES OF TEST EQUIPMENT

The four types of test equipments defined below are representative of equipment currently in use.

(1) *Special purpose (SP).* Test equipment designed for a unique use pertaining to a particular system.

(2) *General purpose (GP).* Test equipment usable in different systems; generally available as an "off the shelf" item in government or commercial inventories.

(3) *Built-in test equipment (BITE).* Equipment which is an integral part of prime equipment or system; cannot be readily detached or separated from basic equipment. Normally typified by "press-to-test" procedures.

(4) *Automatic test equipment (ATE).* Equipment considered to be separate from system to be tested. Capable of automatically testing and evaluating many test parameters by providing required input stimuli.

5-7.2 SELECTION OF TYPES OF TEST EQUIPMENT

A decision regarding the proper type of test equipment to be used must be made in the early stages of prime equipment design—as early as the drafting of the maintenance support plan will allow—and should be firm by the system and sub-system development stage. The factors involved in this decision include: the mission and operational characteristics of the equipment, the anticipated reliability, the maintenance structure, equipments and personnel available to the user, the operational environment, logistical support requirements, development time, and cost. Table 5-9 compares special purpose, general purpose and built-in test

TABLE 5-9. FACTORS IN TEST EQUIPMENT SELECTION

Factor	Element	Rating: Built-in	Rating: Special Purpose	Rating: General Purpose
Maintenance Technician	Personnel acceptance	High	Medium	Low
	Personnel safety	High	High-Medium	Medium-Low
	Complexity of test equipment operation	Low	Medium	High
	Time to complete tests	Least	Medium	Most
	Personnel training time	Least	Medium	Most
	Tendency to over-depend on test equipment	High	High	Low
Physical Factors	Limits on size of test equipment	Minimum limits—depends on prime equipment and application		Maximum limits—limited by portability
	Limits on weight of test equipment	Minimum limits—depends on prime equipment application		Maximum limits—limited by portability
	Complexity of "wiring in" test equipment	High	High	Low
	Need for additional test points in prime equipment	None	None	Many
	Wasted space in work areas	Least	Some	Most
	Storage problems	None	None	Many
	Need for traffic considerations	Low	Medium	High
Maintainability and Reliability	Probability of test equipment damage	Low	Low	High
	Probability of damage to prime equipment caused by testing	Low	Low	High
	Effect on prime equipment operation when repairing test equipment failures	Some	Slight	None
Logistics	Cost to incorporate test equipment	High	Medium-High	None
	Test equipment procurement time	High	Medium	Low
	Design engineering effort	High-Medium	High-Medium	Low
	Compliance of test equipment to same specifications as prime equipment	Must	May	May

TABLE 5-9. FACTORS IN TEST EQUIPMENT SELECTION (cont)

Factor	Element	Rating		
		Built-in	Special Purpose	General Purpose
Application	Advantage of long duration and high frequency usage in given location	High	High-Medium	Low
	Versatility of application	Low	Low	High
	Opportunity for incorrect usage	Low	Low	High
	System adaptability to new test equipment	Low	Medium	High

equipments in regard to these factors.

The design engineer must determine the most important factors for a given equipment and make his decision accordingly. The paragraphs which follow present design criteria to aid the engineer in making this decision. Recommendations for the design of specific types of test equipment are given in Chapter 23, Section IV.

5-7.3 TRADE-OFF OF AUTOMATIC VS MANUAL TEST EQUIPMENT

In general, the type of prime equipment and the operational requirements determine the type of test equipment required. The following factors should be considered in determining the trade-off between automatic and manual test equipment (Ref. 8).

(1) Development time

(2) Cost

(3) Operational plan of deployment of end item.

(4) Amount of testing to be done (maintenance load)

(5) Readiness requirements of prime equipment

(6) Maintenance echelon involved (organizational, direct support, general support, depot)

(7) Simplicity or complexity of the automatic test equipment itself.

Automatic test equipment (ATE) should be considered only when one or more of the following conditions are present :

(1) Turn around time or downtime must be held to an absolute minimum.

(2) Many repetitive measurements must be made.

(3) Readiness requirements dictate its use.

(4) Maintenance loads warrant its use.

Automatic test equipment is costly and creates a considerable maintenance problem of its own. Every effort should therefore be made to specify standard portable test equipment unless the support agency, the echelon of maintenance, or the specific nature of the equipment dictates its use.

5-7.4 MAJOR TRADE-OFF AREAS

Three major trade-off areas for automatic vs manual test equipment are:

(1) *Level of test.* The trade-offs required to define the depth of penetration of each test function in the equipment.

(2) *Degree of test equipment automaticity.* The trade-offs required to define the details necessary for implementing ATE usually involve answers to the following questions :

(a) How should the test equipment be programmed ? (Punched tape, manual set-up of parameter values by operator, magnetic drum)

(b) How should test results be displayed? (Go/no-go lights, meters, color-coded read-out, etc.)

(c) Should testing be stopped when an out-of-tolerance condition is detected or should testing branch automatically into an isolation routine?

(3) *Extent of built-in test equipment.* The trade-offs necessary to optimize BITE in terms of its design configuration and eventual quantity.

For each of these three trade-off areas the following questions usually must be answered:

(1) Does a problem exist?

(2) Can we define the problem?

(3) What are the possible solutions?

(4) Which of these solutions is considered best?

(5) Are any special data required? If so, what is the nature of these data?

(6) What course of action is recommended? Table **5-10** indicates some of the answers to these problems.

5-7.5 TRADE-OFF OF BUILT-IN VS PORTABLE TEST EQUIPMENT

Making the trade-off of built-in versus portable test equipment is a difficult decision. Built-in test equipment has a high cost in terms of weight and volume, and possible degradation of reliability of prime equipment. Some of the factors to be considered in making this trade-off are listed below. The advantages and disadvantages of BITE are summarized in Table **5-11.**

(1) cost

(2) Weight

(3) Space

(4) Degradation of reliability of prime equipment

(5) Functional check versus malfunction isolation

(6) Level of test

(7) Number of measurements required.

5-7.6 TEST EQUIPMENT SELECTION GUIDE CHECKLIST

Table **5-12** presents an example of how some of the important trade-off features can be considered in the selection of test equipment.

5-8 NATIONAL SECURITY INDUSTRIAL ASSOCIATION (NSIA) TRADE-OFF TECHNIQUE

The Maintenance Reliability and Maintainability Panel of the Maintenance Advisory Committee (NSIA) has developed trade-off techniques to improve the maintainability of equipment and systems by making it possible to determine conveniently, and with reasonable accuracy, which of several maintainability design considerations or changes to pilot test models are most worthy of being incorporated into the end item. This technique makes it possible for those involved in the development process to base decisions upon the comparison of numerical values calculated for each proposed change, and which reflect the relative merits or demerits of each case. The technique is such that each particular design feature change is considered individually and evaluated (or traded-off) in terms of its effect upon any and all end-item functional parameters.

It should be noted that the NSIA technique is just one method for quantitatively evaluating possible trade-offs. The method has a certain element of arbitrariness inherent in it, a characteristic of all operations research techniques.

5-8.1 METHOD OF EVALUATION

When a design alternative exists, each **of** the various parameters involved, i.e., performance, reliability, safety, human factors, environmental influence, etc., is assigned a numerical value ranging between **−100** and **+100** (see Figure **5-2**). The +100 end of the scale indicates that a design is considered *necessary.* **A −100** rating indicates that the design approach is *unacceptable.* The value of zero is applied when it is considered that the advantages resulting from the change balance out the disadvantages. All other values fall somewhere between these extremes.

Each rating is then multiplied by an integer weighting factor of between **1** through **4,** depending on the relative importance or effect that the proposed change will have on the end item function in that specific parameter. The algebraic sum of the weighted numerical factors are obtained; divided by the sum **of** the weighting factors; and finally compared to arrive at a decision.

TABLE 5-10. TEST EQUIPMENT TRADE-OFFS (Ref. 8)

Question	Level of Test	Degree of Test Equipment Automaticity	Extent of Built-In Test Equipment
1. Do any problems exist?	Yes	Yes	Yes
2. What are the problems?	Lack of a timely definition of the Maintenance Plan	Lack of adequate trade-off studies between such factors as necessity vs cost, cost vs time, and automaticity vs reliability improvement	Lack of a timely definition of the Maintenance Plan Lack of information concerning extent of built-in test equipment in the Maintenance Plan Lack of adequate trade-off studies between such factors as necessary vs cost, cost vs time, and relative reliabilities of built-in and external test equipment configurations
3. What possible solutions are available?	Early definition and customer approval of the Maintenance Plan	Early definition of the test equipment approach including any trade-off studies	Early development and customer approval of the Maintenance Plan Contractor or vendor should develop test equipment approach including trade-off studies
4. Which solution is considered to be best?	Early and frequent contacts between the customer's maintainability engineers and the vendor		Early and frequent contacts with the contractor and vendor
5. What special data or information are required?	Applicability and performance of militarized test equipment	Fine detail on the Maintainability Concept Vendor should develop the trade-off capability	Fine detail on the Maintainability Concept
6. What course of action is recommended?	Improved communication between customer and vendor Early decisions on preferred approaches	Fine detail on the Maintainability Concept Vendor should develop the trade-off capability	(Same as in columns 2 and 3)

TABLE 5-11. ADVANTAGES AND DISADVANTAGES OF BUILT-IN TEST EQUIPMENT

Advantages	Disadvantages
1. Minimizes requirements for external support equipment.	1. Resulting hardware is heavier, larger, and requires more power. Requires compromise on parts of designer as to minimum number and types of tests that could be performed on tactical equipments without exceeding weight and size limitations.
2. Minimizes downtime required to troubleshoot equipment. Also decreases service-induced failures and possible injury to repairman by allowing fault isolation to be performed without needless probing into interior of equipment.	2. Increases complexity of prime equipment, thus increasing development effort, cost, and time. Increases also maintenance to be performed on prime equipment and system.
3. Identifies performance degradation by operating personnel in sufficient time to avoid serious breakdowns.	3. Difficult to calibrate test facilities due to inability to separate these facilities from prime equipment.
4. Increases system confidence through availability of monitoring facilities.	4. Requires additional self-checking features to insure that degradation of test facilities does not go unnoticed.
5. Assures that modifications of prime equipment are made concurrently with integral test facilities.	5. Requires extreme caution in selection of tests to be performed. Change in procedures of later date requires equipment redesign. Inflexibility in this area is limiting factor.

TABLE 5-12. TEST EQUIPMENT SELECTION GUIDE CHECKLIST (Ref. 6)

Trade-Off Item	Type of Test Equipment					units
	Automatic			Manual		
	Special Purpose	General Purpose	Built-in	Special Purpose	General Purpose	
Clock time per test. Note (1)	7	10	5	135	140	min,
Man-time per test by AFSC (quality)	Note (2)	Note (2)	Note (3)	Note (4)	Note (5)	
3 skill level	20	25	12	160	175	min.
5 skill level	18	22	12	150	160	min.
7 skill level	15	18	12	140	145	min.
Facilities required						
Shelter	Rain cover	Rain cover	None	Rain cover	Rain cover	
Power	220v, 400 cps	220v, 400 cps	None	110v, 400 cps	110v, 400 cps	
Transportation	Tow truck	Tow truck	None	Pickup truck	Pickup truck	
Resources required						
Test 1	Air pressure	Air pressure	None	Air pressure	Air pressure	
Test 2	None	None	None	None	None	
Test 3	Liquid helium	Liquid helium	None	Liquid helium	Liquid helium	
Delivery schedule	12	12	8	6	3	months

TABLE 5-12. TEST EQUIPMENT SELECTION GUIDE CHECKLIST (Ref. 6) (cont)

Trade-Off Item	Type of Test Equipment					Units
	Automatic			Manual		
	Special Purpose	General Purpose	Built-in	Special Purpose	General Purpose	
Procurement cost	$5,000,000	$3,000	$6,000	$900,000	$100,000	
Estimated test equipment down-time per cycle	0.1	0.1	0.09	0.005	0.005	hr
Man-time to repair test equipment per cycle by AFSC						
3 skill level	10	10	12	1.5	0.04	hr
5 skill level	6	6	8	1.0	0.02	hr
7 skill level	3	3	4	0.5	0.01	hr
Facilities required to repair test equipment	Shop and depot	Shop and depot	Field, shop, and depot	Shop	Shop	
Resources required to repair test equipment by line entry and dollar conversion						
20% spares	$ 500,000	$300,000	6250,000	$100,000	$50,000	
60% spares	750,000	500,000	425,000	120,000	65,000	
80% spares	1,000,000	750,000	700,000	150,000	75,000	
Mobility compatibility	(All Systems Compatible With Mobility Requirements)					
Test accuracy requirements	*0. 01 *0. 01	*0. 001 *0. 01	*0. 01 *0. 01	*0. 001 *0. 01	*0. 001 *0. 01	volts cps
Equipment accuracy capability	*0. 001 *0. 01	±0. 01 ±0. 1	*0. 001 *0. 01	±0. 001 *0. 01	*0. 01 *0. 1	volts cps
Environmental compatibility	(All Systems Compatible With Environmental Conditions)					
Versatility (percentage of other test equipment can do)	60%	100%	80%	80%	100%	
Equipment weight	3,000	4,000	1,000	700	800	lb
Equipment cubage	360	400	100	30	40	cu ft
Cost of operation and support per cycle (or life)	$5,000	$5,000	$4,000	$10,000	$10,000	

Notes:

(1) Four tests per cycle
(2) Five men required
(3) Three men required
(4) Eight men required
(5) Ten men required
Special test equipment maintenance time included.

+100 —	NECESSARY
+ 90 —	
+ 80 —	
+ 70 —	VERY DESIRABLE
+ 60 —	
+ 50 —	
+ 40 —	DESIRABLE
+ 30 —	
+ 20 —	
+ 10 —	
0 —	NO EFFECT
− 10 —	
− 20 —	
− 30 —	UNDESIRABLE
− 40 —	
− 50 —	
− 60 —	VERY DESIRABLE
− 70 —	
− 80 —	
− 90 —	
−100 —	UNACCEPTABLE

Figure 5-2. Scale of Numerical Values for Various Degrees of Desirability of a Design Feature for Use in Defermining Proper Trade-off

5-8.2 APPLICATION OF NSIA TRADE-OFF TECHNIQUE

At the U. S. Army Engineer Research and Development Laboratories (ERDL), Fort Belvoir, Va., this trade-off technique has been used in a maintainability study for an item **of** Army equipment, a diesel-driven tractor (Ref. 9). The study was conducted to ascertain the degree of desirability of proposed design changes to improve the maintainability of the item. Evaluation was made by means of a complete teardown **of** the equipment through organizational level **of** maintenance under simulated field conditions.

5-8.2.1 Design Problem

The specific problem was to redesign the connecting elements of the front, center, and rear sections of the tractor so that three organizational maintenance personnel could, in one hour, install or remove the center section from the front and rear sections, and uncouple or couple-up the front and rear sections. In addition, the operation had to be performed with the tools and support equipment available at the organizational level. Table **5-13** illustrates the application of the trade-off technique to the problem, and the concluding results. A graphic summary of the evaluation is presented in Figure **5-3.**

5-8.2.2 Precautions for Use of NSIA Technique

To reduce or minimize any bias that **may** be introduced through subjective evaluation, the following precautions should be considered when making a maintainability evaluation:

(1) Evaluations should only be made by individuals qualified to do so, i.e., experts.

(2) Evaluations of a single area of consideration should be made, whenever possible, by more than one expert on an independent basis, and the algebraic average of all evaluations used. If evaluations cannot be made independently, they should be made on a group basis. The larger the number of *qualified* evaluators that comprise the group, the more accurate and unbiased the final evaluation should be.

(3) Any bias that might be introduced by the opinion of an individual, or a group, is modified in its effect upon the final value because it is only one of several other factors. It is necessary, therefore, that *all* possible areas of influence be listed as parameters for consideration and evaluation and that each parameter be evaluated with respect to *all* possible areas of influence to maximize this effect.

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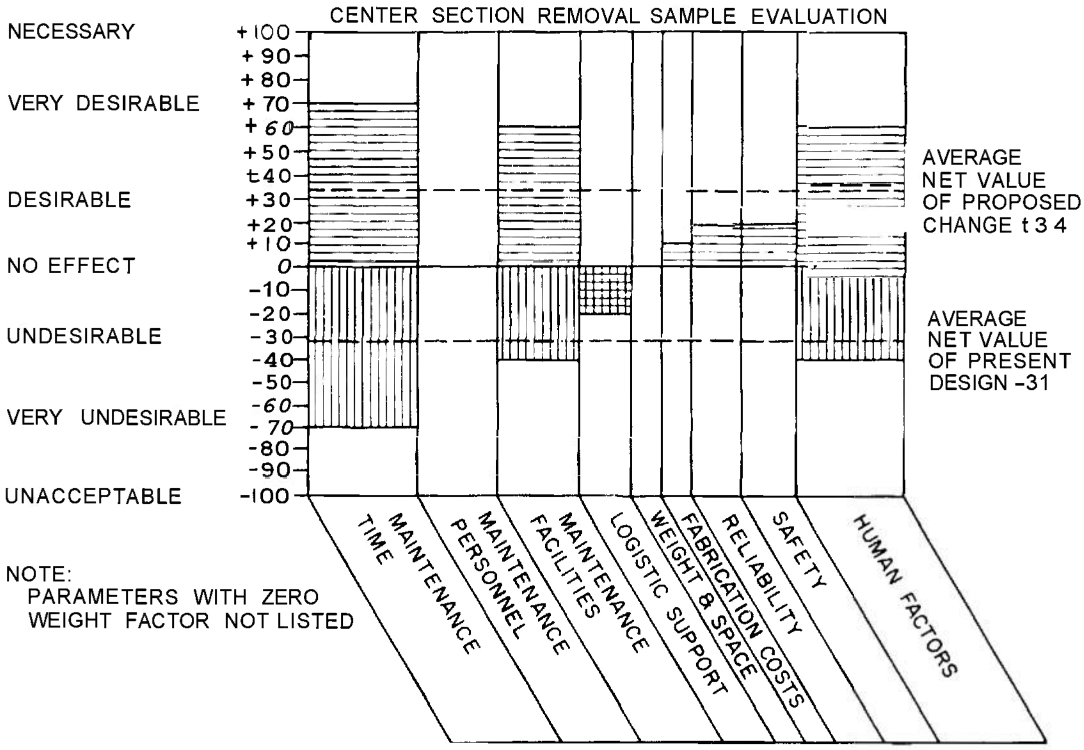

Figure 5-3. Tractor Center-Section Removal Trade-off Evaluation, Graphic Summary

TABLE 5-13. TRACTOR CENTER-SECTION REMOVAL TRADE-OFF EVALUATION

Parameters	Consideration	Relative Weighting	Basic Reading		Adjusted Value	
			Present	Proposed	Present	Proposed
Maintenance Time	Present - 8 hours Proposed - 1 hour	4	-70	+70	-280	+280
Maintenance Personnel	Present - 1 mechanic and 2 helpers Proposed - 1 mechanic and 2 helpers	3	0	0	0	0
Maintenance Facilities	Present - Special tools and crane Proposed - Crane, no special tools	3	-40	+60	-120	+180
Logistic Support	Present - Special bolts, gaskets Proposed - Standard parts	2	-10	-10	-20	-20
Weight &	No net effect	1	0	0	0	0
Performance	No net effect	0	0	0	0	0
Fabrication cost	Proposed will Cost some more	1	+10	-20	+10	-20
Production Schedule	No net effect	0	0	0	0	0
Reliability		-	-30	+20	-60	+40
Safety			-30	+20	-60	+40
Environmental Influence			0	0	0	0
Human Factors	Proposed design will provide simpler and faster installation	4	-40	+60	-160	+240
Operation	No net effect	0	0	0	0	0
Totals		22			-690	+740

Calculations: Average net value—present design: -690 ÷ 22 = -31
Average net value—proposed design: +740 ÷ 22 = +34

Conclusion: The desirability of the proposed change, after considering effect on all parameters, is indicated by the magnitude of the total spread between the average net values -31 and +34 for a total value of 65 (see associated graphic summary chart, Figure 5-3).

CHAPTER 6
MAINTENANCE MANUALS

6-1 GENERAL

Maintenance manuals provide instructions on the maintenance of materiel and are the communication link between the design engineer and the maintenance technician. They are as important to the technician in the maintenance support of the materiel as the engineering drawings are in its manufacture. The use of the principles of maintainability in the development of hardware generally leads to substantial reduction in the cost and bulk of maintenance manuals. Some difficulties encountered by maintenance technicians which are not directly related to maintainability engineering, and which the design engineer should be aware of, are:

a. *Failure to use maintenance manuals.* Maintenance technicians who have received technical training, although schooled in the general principles of maintenance, may not be familiar with the manuals issued with new equipment.

b. *Availability of maintenance manuals.* Maintenance technicians are not normally trained in the administrative procedures for obtaining maintenance publications. Therefore, the technician, in many cases, does not know how to obtain the manuals he needs to maintain and repair the equipment for which he is responsible.

c. *Identification.* Technicians are trained as maintenance specialists; they are not specialists in the procedures required to identify and requisition specific manuals prepared to support specific equipment.

d. *Utility.* Newly trained maintenance technicians may find the transition from training texts to manuals actually used for the maintenance of equipment in the field difficult. Therefore, some time is lost by technicians acquainting themselves with new formats and methods of dealing with maintenance information. It should also be realized that there is a high rate of turn-over of unit maintenance personnel, because of reassignments and short enlistment periods.

e. *Comprehension and retention of data.* The design, operational, and maintenance complexity of Army materiel is ever increasing due to technological advances. Maintenance technicians are, therefore, faced with an increased volume of operational and maintenance information required to be used in their daily maintenance operations. They must refer to these data and understand them. Extreme care should be taken to assure that the technician is not expected to read and comprehend at a level higher than should be expected of his MOS, grade, and maintenance level. Instructions should be written to avoid requiring the technician to make mathematical calculations, including simple additions or subtractions; consolidate or integrate information from different sources; collect, process, or report any unusual or complex data; post data from one form to another; or keep permanent records.

6-2 TECHNICAL DATA REQUIREMENTS FOR MANUALS

The following items relate to the condition and adequacy of technical data required in maintenance manuals for the performance of maintenance:

a. *Availability.* The availability of technical data determines whether maintenance manuals are adequate for the performance of maintenance requirements on equipment. Technical writers and illustrators preparing maintenance manuals must be provided with a designated source and free access or availability for these data. When modifications are performed on equipment, revised data should be supplied with the modification to update the existing manuals.

b. ***Clarity.*** Technical data provided to technical writers and illustrators preparing maintenance manual manuscripts must be readily understood, clear, and concise. There must be close rapport between design and maintenance engineers to foster correct technical coverage. Failure of the writer or illustrator to understand the data may result in inadequate, confusing, or lengthy narrative in the maintenance manual.

c. ***Accuracy.*** Technical data provided to technical writers and illustrators of maintenance manuals must be factual. Failure to provide factual data may result in writers and illustrators including data in maintenance manuals which will endanger personnel and equipment.

d. ***Completeness.*** The scope of technical data provided to technical writers and illustrators of maintenance manuals must cover all operational and maintenance functions to be performed at each maintenance level. Technical data beyond the scope required should not be provided. The inclusion of unessential data in maintenance manuals increases the content and confuses the manual user.

6-2.1 REQUIREMENTS FOR THE PREPARATION AND DISTRIBUTION OF MAINTENANCE MANUALS

Department of Defense, Department of the Army, and U S Army Materiel Command regulatory documents provide policies governing requirements for the preparation of Army maintenance manuals. These regulatory requirements are constantly changing as new techniques are developed and adopted for the presentation of technical data. Technical writers and illustrators of Army activities and contractors preparing maintenance manual manuscripts have available those necessary regulatory documents for guidance and compliance. Printing of maintenance manual manuscripts for distribution as official Army documents is governed by Public Law which requires the printing to be done by the Government Printing Office, or under a Government Printing Office contract. Distribution and supply of Army maintenance manuals are responsibilities of The Adjutant General.

6-2.2 RECOMMENDATIONS FOR THE PREPARATION OF MANUALS

The following suggestions are presented to improve the general content of technical manuals :

(1) Writing of the manual should start early in the equipment design cycle. It should be a joint effort of the technical writer, illustrator, design engineer, test engineer, and maintenance engineer.

(2) All instruction manuals for maintenance and operation of equipment must be carefully reviewed and edited by persons familiar with the design of the equipment for which the manual is written. These individuals should also be familiar with the training and technical capabilities of the repairmen who will perform the servicing.

(3) Instructions must be prepared specifically for each category of maintenance. One set should spell out procedures for operator or crew maintenance, another for organizational, another for direct support, etc., rather than all instructions being combined into a single set.

(4) Instructions should contain only information relevant to the job.

(5) Code symbols used on the equipment should also be consistent with those used in the job instructions.

(6) Manuals are most effective in indicating actions to be taken in a series where each action is a discrete response to some discrete stimulus. Checking procedures and the correcting of unitary maladjustments are examples of such behaviors.

(7) Whenever new models of equipment are introduced into the Army supply system, maintenance manuals must be available. Instructions on old models of equipment being phased out of the supply system should not be rescinded until all old models are withdrawn from use.

(8) Instructions should be kept current with the equipment modifications. This is especially important when power voltages or signal characteristics change from one model to the next.

(9) Keep language simple. Avoid terms unfamiliar to personnel who will use the manuals.

(10) All test points should be clearly indicated and explained in maintenance guides.

These are best shown by having written text explanations of figures shown on diagrams, drawings, or photographs. The text should include data on tolerable outputs.

(11) Stock numbers needed for ordering replacement components should be presented with all parts lists. Care should be taken to show some sort of illustration for each part, such as exploded views, so that the matching of actual components with stock numbers can readily be accomplished.

(12) Checklists should be included since they are useful in presenting instructions to experienced technicians.

(13) Information included in tables for maintenance should be directly usable by the technician without his having to make any data transformations. Engineering test data may be valueless unless translated into indications the technician can observe on the equipment. Each table should specify when and how it is to be used.

6-3 OPERATOR AND MAINTENANCE INSTRUCTIONS

Operator and maintenance instructions are descriptions of procedures in a form suitable for a maintenance person. Operator and maintenance instructions are based on the allocation of specific operator and maintenance functions to categories of maintenance in the Maintenance Allocation Chart (MAC). Operator and maintenance instruction procedures reflect the maintainability features that are built into the equipment for efficient and effective operation and performance of maintenance. Although the design engineer probably will not be responsible for the development of operator and maintenance instruction procedures, he may have an important role in defining the need for operator and maintenance functions to be performed, as set forth in the MAC, and insuring technical accuracy of operator and maintenance instruction procedures.

6-3.1 IDENTIFICATION OF REQUIRED OPERATOR AND MAINTENANCE PROCEDURES

Every maintenance operation should be specified by procedures. Failure to specify required procedures will reduce maintenance effectiveness by causing excessive trial-and-error performance on the part of the technician. For example, failure to specify troubleshooting procedures may result in excessive maintenance and downtime; it may also degrade reliability through excessive operation and handling of the equipment for maintenance.

In most development programs, there are established requirements for task analysis information. This information is normally used to determine human engineering design and training requirements. At the point in the development program where equipment design is confirmed, these task descriptions can be used to provide information for procedure development. The following factors may be used as a guide to assist in the comprehensive identification of procedures :

(1) *Area.* Defined by the location at which maintenance is performed :bench checkout area, combined systems test area, etc.

(2) *Segments.* Defined by the type of maintenance performed and the ground support cycle: acceptance check, recycle, preventive maintenance, etc.

(3) *Functions.* Includes inspecting, checking, troubleshooting, adjusting, replacing, repairing, servicing.

(4) *Equipment Breakdown.* Identifies the basic units on which maintenance must be performed.

6-3.2 DESIGN OF PROCEDURES—GENERAL

The following recommendations should be considered when designing procedures :

(1) Coordinate procedures with equipment layout to require minimum communication between technicians at different locations and minimum retracing of steps.

(2) Keep procedures as brief as possible, particularly for operational areas.

(3) Design procedures to eliminate or facilitate decision making by the technician. Make the series of steps as invariant as possible without degrading the efficiency of maintenance operations.

(4) Specify for each procedure the condition of the equipment, such as proper control settings, prior to beginning the procedure. Specify how to set up equipment for the procedure and how to shut down the equipment after the procedure.

(5) Provide procedures which do not require working near dangerous voltages or unprotected delicate components. If this is not possible, incorporate protective and precautionary steps in the procedure, making sure that these are apparent when the operator or maintenance technician begins the procedure.

(6) Provide servicing procedures which, insofar as possible, can be performed through accesses rather than requiring dismantling of equipment, and which utilize standard servicing equipment rather than special ones.

(7) Develop procedures for periodic exercise of idle equipment to lubricate internal parts and otherwise prevent deterioration. Consider environmental factors in determining frequency of such preventive maintenance.

(8) Identify time required for each task and ensure that this is compatible with operational requirements.

(9) Do not be unnecessarily specific in stating how, and with what tools, a particular task is to be accomplished unless it is absolutely necessary. For example, do not say "use a 1-in. box wrench" or "hold nut between thumb and forefinger of right hand."

6-3.2.1 Procedures for Team Tasks

The following principles should be considered when providing maintenance instruction procedures for team tasks:

(1) Standardize individual tasks in order that a given team member can specialize on a particular function.

(2) Provide the supervisor with an overview of the task so he is aware of each individual's responsibilities.

(3) Do not require the supervisor to act as a working member of the team when these functions may be performed by a less highly trained individual.

(4) Standardize procedures from site to site.

(5) Assign the most critical tasks to the most experienced and competent team members.

(6) If possible, separate task functions so that the accomplishment of tasks assigned to a given team member is not dependent on the completion of tasks assigned to another team member. If coordinated tasks are required, provide procedures which integrate all task functions.

6-3.2.2 Procedures for Checking and Troubleshooting

The effectiveness of checking and troubleshooting procedures depends to a considerable extent upon the design of equipment to permit access to information concerning equipment status. Specific coordination between procedures design and the design of equipment must be accomplished during development to optimize total maintenance design. The following recommendations should be considered by the designer:

(1) Develop comprehensive and detailed troubleshooting procedures. The technician needs more than design drawings for effective troubleshooting; he needs explicit instructions on how to locate malfunctions. Procedures are required which allow the technician to precisely locate the trouble.

(2) Develop troubleshooting procedures that locate all possible malfunctions. Do not make procedures dependent upon especially skilled personnel for the location of infrequent troubles. Design troubleshooting procedures so they can be performed without error by personnel having:

(a) Average intelligence.

(b) Little or no directly relevant education.

(c) Brief technical training.

(d) Little or no job experience (see also Chapter 8).

(3) Use probability data for developing sequence of troubleshooting procedures when it is available from empirical data or when it can be estimated validly on the basis of engineering experience.

(4) Troubleshooting procedures should be as self-evident as possible from the design of the troubleshooting equipment. Where this is not possible because of overriding standardization considerations, design troubleshooting procedures to use an optimum strategy of systematic checks, adjustments and replacements.

(5) Relate troubleshooting procedures to verification or confidence checks. Troubleshooting normally begins with a routine check, either to determine whether or not the equipment is operational or to verify that reported malfunction symptoms actually exist. Routine checks typically provide much information that is useful in diagnosing possible sources of trouble.

(6) Use the information obtained from routine checks to narrow the possible sources of trouble. Do not repeat routine checks in troubleshooting checks.

(7) Use patterns of symptoms as well as individual indications from routine checks to determine appropriate troubleshooting procedures.

(8) Provide for a flexible order of troubleshooting checks if this will increase the efficiency of troubleshooting. The optimum troubleshooting strategy typically will be one which is guided at each step by new information obtained. Inflexible troubleshooting usually will be inefficient.

(9) Specify an order of troubleshooting checks which maximizes the amount of information obtained per unit of time. In general, the check which will yield the most information at any given time is the one having closest to a 50% probability of yielding an out-of-tolerance indication.

PART THREE
FACTORS AFFECTING MAINTAINABILITY

CHAPTER 7
LOGISTICAL SUPPORT

7-1 GENERAL

Rapid technological advance has resulted in tremendous demands for logistical support for our complex equipment. These new equipments, although greater in fire power, further compounded the problem because of the need for a flexible, modern-type Army, an Army that must be able to disperse and hide, and converge and fight—an Army that must be able to *shoot, scoot* and *communicate*.

Immediately after the United States entered World War 11, the great variety and complexity of equipment was such that requirements for repair parts exceeded supply capabilities. Although both Army and contractor-operated schools were established, maintenance men could not be trained fast enough for the task of ultimately maintaining the new equipment pouring from the factories. Under the pressure of designing and producing new equipment, performance was the principal criterion ; maintenance was secondary.

Even though much of the equipment used in Korea was made for World War II and not in good condition, and the action was limited in scope, logistics problems were identified early ; many errors were avoided and important maintenance concepts evolved.

7-2 LOGISTICAL OBJECTIVES

Modern army logistics is the process of providing the equipment, supplies, and services, and assuring the continuity of this support, to enable troops to fight under any conditions or in any type of warfare. Modern Army logistics has three key functions — modernization, mobility, and management. This chapter discusses each of these functions.

7-2.1 MODERNIZATION

This is the process of determining the kinds of items needed to carry out missions to provide the best available designs and materials to equip troops with new and improved items after they have been accepted for production. In this process of developing and improving new items, improved performance and improved maintenance must go hand in hand. This involves increasing the reliability and maintainability of individual components and of overall systems (Refs. 1 and 2).

7-2.2 MOBILITY

This is a more elusive element of modern army logistics than modernization because it cannot be easily measured. It involves the responsiveness of support to the combat situation, including the logistic capability to support tactical actions on the atomic weapon battlefield. It is not only the ability to move from one place to another, but also the ability to fight without requiring an uninterrupted flow of heavy logistical tonnage. One measure of mobility is the length of time a unit can move and fight without resupply.

To provide effective mobility, supply austerity is necessary. Some other requisites will be discussed at more length in the paragraphs that follow (Refs. 3, 4, and 5).

7-2.2.1 What Is Mobility?

Mobility is not merely wheels, tracks, wings, and other means of locomotion, but a quality that can be built into items or incorporated into organizations. Mobility is the ability to move or be moved from one location to another and to be logistically supported in response to strategic or tactical requirements. Mobility is particularly important because of the great distances that may be traveled to engage enemy forces, the great mechanized forces of the possible enemy, the necessity to maintain forces capable of engaging that enemy effectively in both nuclear and nonnuclear warfare, and our concept of operations when nuclear weapons might be used. It has three broad aspects—strategical, tactical, and logistical.

7-2.2.2 Absolute Mobility

Modern armies must achieve absolute mobility, and this includes all three aspects of the problem. Strategical mobility means equipment can be readily transported by bulk carriers of the airways, railways, and seaways. To rate high in strategical mobility, the equipment should be compact, lightweight, and designed to facilitate loading and unloading, including the ability to withstand the shock that may result from air drop.

Tactical mobility means the equipment can move or be moved over all kinds of terrain, including floating on inland waters. This characteristic depends on special military design features such as the capability of survival in the heat, cold, mud, and dust where the Army does its fighting. An important aspect of tactical mobility is the capability of ground vehicles to use a minimum of fuel and many kinds of fuel.

The most important aspect of absolute mobility is logistical mobility. Logistical mobility is another way of saying reliability and maintainability. A vehicle, for example, might be compact and light, it might have an economical, multifuel engine and be capable of crossing the most difficult terrain ; but, if it lags behind because of operating failures and cannot be quickly repaired, it has no mobility.

7-2.2.2.1 *Mobility and Transportability.* The maintainability engineer should take into account during the design period that all U S Army weapons, commodities, or systems (not including permanent construction facilities) may have to be moved or transported at some time. This movement or transportation may be from one building to an adjacent building, or around the world.

The maintainability engineer should consult with mobility engineers who are equipped to assist in problems of transport, selection, and adaptation of vehicles and shelters ; equipment layout and installations ; mounting techniques ; shock and vibration reduction ; lighting; fire extinguishing ; power entrance connections ; as well as heating, air conditioning, and ventilation systems for mobile equipments.

Mobile systems generally must be capable of transport over land, sea, and air. The degree of transportability depends on the end use of the equipment. Equipments used within the continental United States have wide latitude for rail and sea transport. Equipments designed for global applications have more stringent weight and size restrictions. For example, in various sections of Europe, railroad tunnels and bridges are built for narrow gage roads. This imposes width and height restrictions greater than those for equipment designed to be used only in the United States.

7-2.2.2.2 *Air Transportability.* Unless otherwise specified, all weapons commodities or systems should be designed in accordance with MIL-A-8421. In designing for air movement, the transportable item should meet at least the following requirements :

(1) be of minimum practical weight—item plus container ;

(2) be of minimum practical size—item plus container ;

(3) be capable of being transported by available cargo aircraft; (See Table 7-1 for dimensional and ramp-loading criteria for some Army and Air Force aircraft).

(4) be capable of withstanding altitude up to 50,000 ft in unpressurized aircraft;

(5) be capable of withstanding temperature ranges between +165°F. and −67°F.

7-2.2.2.3 ***Rail Transportability.*** Equipment to **be** shipped by rail should not exceed the following:

(1) 124-inch width or 72-inch height in the shipping configuration ;

(2) 80,000 lb for transport on a standard 40-ft flatcar ;

(3) the standard railroad clearances as defined in the Berne International Outline. (See Reference 8 for detailed information in this area.)

7-2.2.2.4 ***Road Transportability.*** Equipment normally to be shipped by road should conform to the following :

(1) be designed to meet the mobility requirements set forth in MIL-M-8090 (ASG) ;

(2) not exceed 78,000 lb gross weight, including the supporting vehicle ;

(3) not exceed axle loads of 18,000 lb, and be limited to 16,000 lb if the axles are less than 7.5 ft apart.

7-2.2.2.5 ***Inclination, Shock, and Vibration.*** All equipment should be capable of withstanding the general inclination and shock requirements specified in MIL-S-901, and the general Type I vibration requirements specified in MIL-STD-167. In addition, equipment should be packaged to withstand the shock and vibration criteria set forth in Table 7-2.

7-2.3 MANAGEMENT

The task of maintenance management for the Army, with its critical relationship to operational readiness, is one of dealing with technical

TABLE 7-1. DIMENSIONAL CRITERIA FOR SOME ARMY AND AIR FORCE AIRCRAFT (Refs. 6 and 7)

	Type	Cargo Compartment (Usable Space)			Loading Aperture		Ramp Data			Cargo Hook Capacity (lb)
		Length	Width	Height	Width	Height	Length	Ground Angle	Floor Angle	
C-119G	Fixed Wing	36'11"	9'2"	7'8"	9'2"	7'8"	16'0"	14"	14"	(1)
C-123B	"	28'9"	9'2"	8'2"	9'2"	8'2"	8'3"	15"	15°	(1)
C-124A	"	77'0"	11'3"	11'6"	(5)	11'8"	28'4"	17"	11.5"	(1)
C-130A	"	41'0"	10'0"	9'0"	10'0"	9'0"	10'5"	12.5"	12.5"	(1)
C-132A	"	81'10"	11'10"	11'2"	(4)	12'0"	15'9"	9"(2)	9"	(1)
U-1A	"	12'8"	4'4"	4'11"	3'10-1/2"	3'9"	10'6"	15"	15"	(1)
YAC-1	"	28'9"	6'1-1/2"	6'2"	6'1-1/2"	6'2"	(1)	(1)	(1)	(1)
H-21	Heli-copter	19'9"	4'1"	5'2"	3'9"	4'11"	(1)	(1)	(1)	5,000
H-34	"	13'4"	4'11"	5'10"	4'5-1/2"	4'0"	(1)	(1)	(1)	5,000
H-37	"	30'4"	7'3"	6'6"	''3-1/2"(3	5'2"	10'6"	13"	13"	10,000
HU-1A	"	3'9-1/2"	7'8"	4'8"	3'9-1/2"	4'0"				2,500

Notes:
(1) Not applicable.
(2) Ramp toe incline 15°.
(3) Straight in loading.
(4) Tapers from 9'4" at top to 12'1" at bottom.
(5) Tapers from 8'11" at top to 11'4" at bottom.

TABLE 7-2. GENERAL TRANSPORTATION SHOCK AND VIBRATION CRITERIA

Source of Shock	Acceleration (g's)	Duration (ms)	Frequency (cps)	Double Amplitude
Truck	8	5 to 40	2 to 27	±1.3 g's
Rail	30 (bumping shock)	4 to 80	27 to 52	0.036 in.
Aircraft	5.5 (vertical) 1.5 (lateral) 0.8 (longitudinal)	10 to 30 10 to 30 10 to 30	52 to 500	±5 g's
Handling	30	15		
Drop (packaged units only)	24 in. drop on concrete			

complexity, broadened by infinite variety, further multiplied by a fantastic range of environmental and mission requirements. The maintenance manager is faced by a highly dispersed Army—posed at combat ready-complicated by the vast distance and channels of communication through which a feedback of vital use-experience and performance data must be retrieved, evaluated, and acted upon. Some of the goals of this vast effort are to:

(1) Assure that the Army's priority combat equipment is ready.

(2) Give combat support that will result in maximum combat effectiveness.

(3) Organize effort in support of combat force needs.

(4) Assure economy of effort.

7-2.3.1 The Army Maintenance Management System

The Army Maintenance Management System (TAMMS) has been engineered to promote maximum materiel readiness by increasing equipment reliability and maintainability and improving logistical support. The system (Figure 7-1) is designed to answer the following questions (Ref. 9):

(1) What is the unit materiel readiness?

(2) Is the army maintenance system effective?

(3) What are the maintenance resource requirements?

(4) Does equipment meet the reliability criteria?

(5) Does equipment meet the maintainability criteria?

(6) What is the equipment density by unit, type, model, series, and class?

(7) What is equipment service life?

(8) Are modification work orders applied? Is there a plan for efficient application of work orders?

TAMMS policies and procedures are contained in the following Department of the Army publications:

AR 750-5, Maintenance of Supplies and Equipment: Prescribes *the* policies for maintenance operators.

TM *38-750, The Army Equipment Record Procedures (TAERS):* The basic manual in the TAMMS system, this TM provides equipment record procedures to be used for control of operation and maintenance of all Army equipment.

TM 38-750-1, Maintenance Management—Field Command Procedures: Details the Field Command Procedures for processing the maintenance data recorded by TAERS into usable maintenance information at the organizational, support, and installation levels.

T*M 38-750-2, Maintenance Management—National Agency Procedures:* Describes the National Agency Procedures for processing the data generated by TAERS into usable information, for maintainability engineering supply management, research and development procurement, production, and quality assurance.

TM 38-750-3, Maintenance Management—Depot Procedures: Describes the procedures for management of the Army Major Overhaul and Maintenance of Materiel Program.

FM 38-5, Logistics, Maintenance Management: A treatise on maintenance management which provides guidance in the use of TAERS for programming, scheduling, budgeting, production control, and repair parts supply.

The following paragraphs briefly describe the Army's plan of action for implementing the maintenance goals of the TAMMS system.

7-2.3.2 Operation ARM (Army Ready Materiel)

Operation ARM is the Army's plan of action to assure the maintenance supported availability of materiel that is combat ready and capable of successful missions. To implement the plan, an Integrated Equipment Record Management System has been set up to provide commanders and maintenance managers at all levels with meaningful information, i.e., input information from operational units which when evaluated and analyzed will serve as the basis for maintenance decisions and action (Refs. 10 and 11).

Figure 7-2 shows some of the typical input data sought and output actions resulting from this system. These system data can also be utilized to weight those maintenace-significant factors deemed essential to mission accomplishment:

(1) Does it provide firepower?
(2) Does it influence communications?
(3) Does it affect mobility?
(4) Does its status readily change with the presence or absence of maintenance?
(5) Is its battlefield dependability relatively assured by simple care or is it readily replaceable?

Some of the significant design and management actions affected by, or resulting from the use and availability of the data collected by this world wide system are listed in Table 7-3. Availability of full and complete data from all commands, worldwide, is expected ultimately to provide a potential for immediate detection of maintenance trends, problem areas, or problem items. Such an analysis was recently made of information derived from TAERS for the period 1 Feb 63 through 15 June 63. Figure 7-3 shows some of the significant data compiled during this period, which is representative of the infinite variety of statistics and projections available. Other examples of the application of the data in measuring availability and maintainability are illustrated in Figure 7-4. A projection of vehicular component reliability is shown in Table 7-4.

7-3 LOGISTICAL FUNCTIONS AND MAINTENANCE SUPPORT PLANNING

At the present time, weapon systems and related equipment are generally mass produced and distributed worldwide for use in varying environments. The degree to which the weapon system succeeds or fails depends on the measure of care exercised in discharging the following eight logistical functions :

(1) Research and development.
(2) Standards and specifications.
(3) Purchase and inspection.
(4) Identification and cataloging.
(5) Requirements and funding.

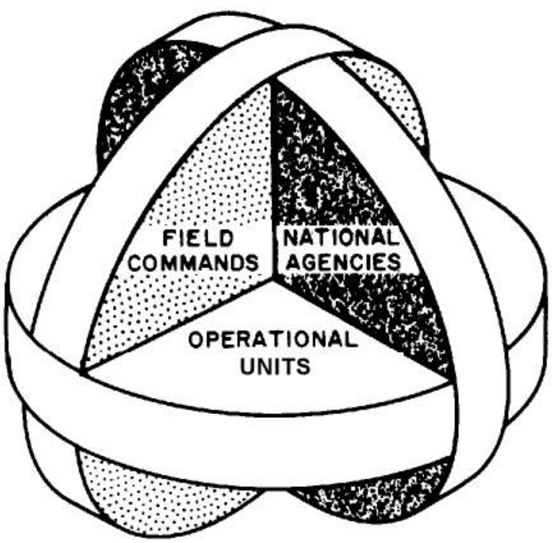

Figure 7-1. TAMMS—The Army Maintenance Managemenf System

(6) Supply and stock control.
(7) Storage and issue.
(8) Repair and servicing.

Proper sequential accomplishment of these functions will result in weapon systems that are reliable and maintainable, and are backed up by a fully implemented logistical support system. The second, third, and fourth logistical functions constitute the technical description of the weapon system. Standards and specifications describe and qualify the parts, assemblies, components, and the system; they make up the technical language for use among the contracting officer, the contractor, and the Army Materiel Command (AMC) inspectors. Purchase and inspection combine the standards and specifications with drawings to constitute the basis for the contracting officer to solicit proposals from contractors and for the AMC acceptance-inspection system. Identification and cataloging assign to each repair part, assembly, and component a Federal Stock Number, if it does not already exist in the Federal Supply System, to avoid duplication and to exercise control in the remainder of the logistical functions.

The fifth, sixth, and seventh logistical functions are important parts of the entire logistical support system. Quantitative requirements, combined with adequate funds, indicate that marginal and unusable portions of a system can be salvaged and replaced in accordance with a planned replacement program, and that adequate stocks of repair parts can be procured and distributed. Under these circumstances,

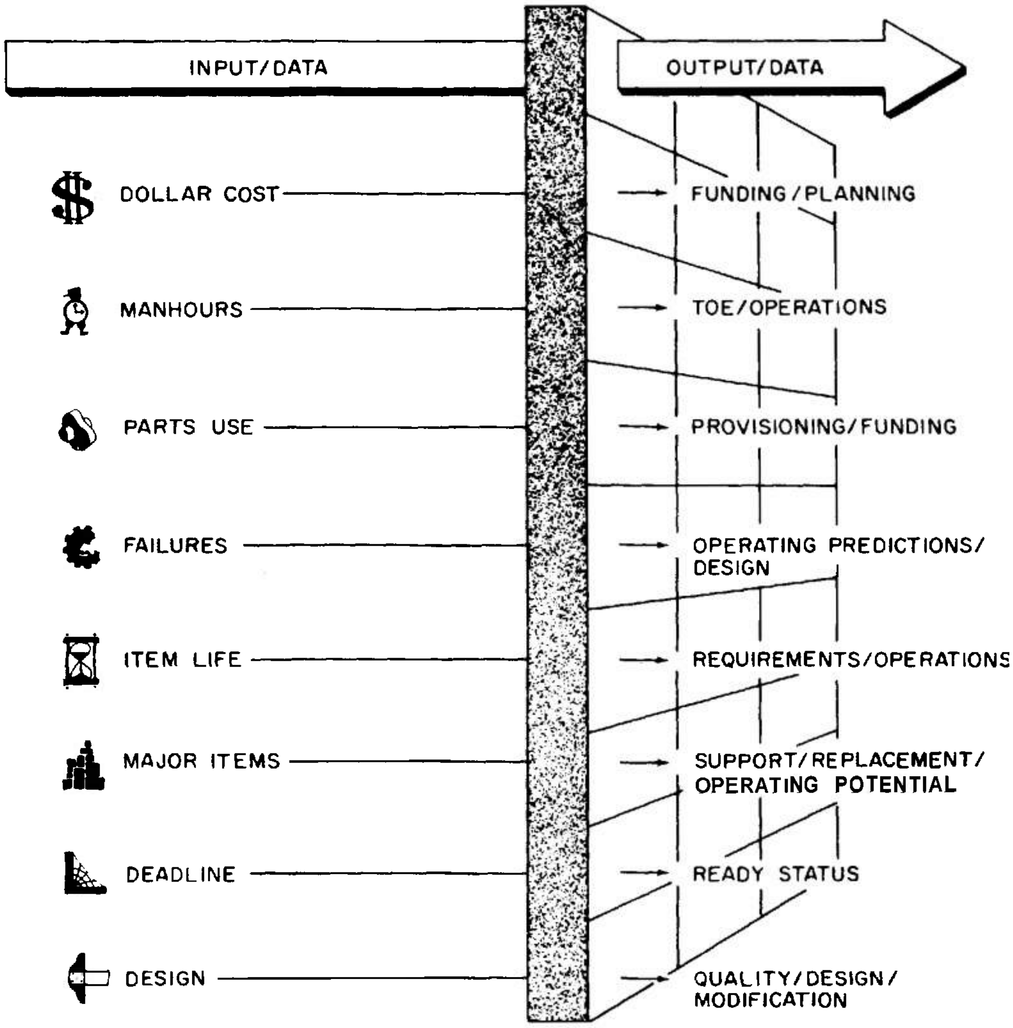

figure 7-2. Integrated System Input Data and Output Actions

maintenance proceeds in accordance with plans, but, when system replacement cannot be programmed or when repair parts and components are not available, maintenance becomes a makeshift operation that is executed without consideration for economy of effort or ultimate cost.

Although supply and maintenance are often considered together, they are complementary and must be responsive to each other. A shortage of supply increases the burden on maintenance. Increased maintainability in equipment, on the other hand, reduces the demand on supply. Storage and issue has become an increasing maintenance problem because of the necessity for maintaining equipment in a constant ready-for-issue condition.

Optimum maintenance support planning can only be achieved through utilization of systematic and scientific procedures which consider compatibility of maintainability design concepts and policies contingent on decisions arrived at by analysis of maintenance support formulas. The following paragraphs present in detail the application of quantitative techniques in the development of maintenance support plans.

TABLE 7-3. SIGNIFICANT DESIGN AND MANAGEMENT ACTIONS AFFECTED BY, OR RESULTING FROM, USE AND AVAILABILITY OF WORLDWIDE SYSTEM DATA

1. Measuring equipment and weapon reliability rates and validating predicted engineering reliability criteria.
2. Measuring equipment and weapon maintainability rates and validating predicted engineering maintainability criteria.
3. Validating technical training criteria and determining requirements for, and the adequacy of, on-the-job training.
4. Validating maintenance manpower requirements and the necessary skill level mix of the maintenance work force.
5. Validating prescribed maintenance requirements at all levels (organizational, direct support, general support, and depot).
6. Measuring scheduled and unscheduled maintenance requirements for each type, model, or class category of equipment or weapon in the Army.
7. Providing bases for factual determination of materials actually consumed in the maintenance process at all levels and for predicting future material requirements.
8. Providing *quantitative* data for determining maintenance resource requirements essential to sustaining weapons and equipment at varying degrees or rates of operational readiness.
9. Providing data essential to the development of factors for planning and programing future maintenance work loads by converting operating programs and force structure levels into maintenance requirements.
10. Providing the basis for detecting the requirements for the validation of equipment and weapons modification program.
11. Providing for a continuing assessment of equipment and weapons maintenance demand rates.
12. Providing the basis for validating equipment operating life expectancy and removal intervals.
13. Providing feedback of data required in the establisment of improved criteria **for** maintainability and reliability characteristics in the design of future weapons and equipment required by the Department of Defense.

PERCENT DOWNTIME IN DIRECT SUPPORT MAINTENANCE BY TYPE OF DELAY

	IN TRANSIT	AWAITING REPAIR	SHOP TIME	MWO
WEAPONS - RIFLE, 106 MM, M40A1/M79				
WORLD-WIDE	25%	33%	40%	2%
CONUS	27	35	36	2
USAREUR	40	25	35	0
USARAL	0	0	0	0
USARPAC	3	38	59	0
COMBAT VEHICLES-CARRIER, PERSONNEL, FT, ARMD, M113				
WORLD-WIDE	32%	33%	27%	8%
CONUS	22	26	29	23
USAREUR	39	39	21	1
USARAL	0	0	0	0
USARPAC	25	22	36	17
USARSOUTHCOM	0	0	0	0
TACTICAL AND SUPPORT VEHICLES - TRUCK, UTILITY, 1/4 TON, M151				
WORLD-WIDE	33%	38%	22%	7%
CONUS	25	50	12	13
USAREUR	39	30	30	1
USARAL	12	65	19	4
USARPAC	35	19	36	10
USARSOUTHCOM	0	0	0	0
ELECTRONIC AND COMMUNICATIONS EQUIPMENT-RADIO SET, AN/GRC-19				
WORLD-WIDE	33%	35%	32%	0%
CONUS	27	36	37	0
USAREUR	38	35	27	0
USARAL	80	0	20	0
USARPAC	38	42	20	0
USARSOUTHCOM	24	0	76	0
AIRCRAFT-HELICOPTER, UTILITY, UH-1B				
WORLD-WIDE	26%	8%	55%	11%
CONUS	22	6	58	14
USAREUR	0	0	0	0
USARAL	0	0	0	0
USARPAC	59	24	15	2
USARSOUTHCOM	0	0	0	0
SPECIAL PURPOSE EQUIPMENT - TRUCK, FORKLIFT, 6,000 LB				
WORLD-WIDE	25%	34%	35%	6%
CONUS	21	34	43	2
USAREUR	18	33	25	24
USARAL	0	0	0	0
USARPAC	47	42	11	0
USARSOUTHCOM	0	0	0	0

Figure 7-3. Analysis of Information Derived from TAERS for the Period 1 Feb 1963 Through 15 June 1963 (Ref. 11)

TABLE 7-4. PROBABILITY OF OPERATING VEHICULAR COMPONENTS WITHOUT A FAILURE REQUIRING SUPPORT MAINTENANCE

Item Nomenclature	Tracked—2,000 miles			Wheeled—10,000 miles	
	M60 %	M4842 %	M113 %	M151 %	M35 %
Engine	97	99	96	99	99
Clutch	NA	NA	NA	99	100
Fuel system	100	98	98	100	100
Exhaust system	100	99	98	100	100
Cooling system	100	99	97	99	100
Electrical system	97	96	97	99	100
Transmission	97	99	98	99	99
Transfer case	NA	NA	99	100	99
Propeller shaft	NA	NA	NA	100	100
Front axle or final drive	100	99	99	98	100
Rear axle	NA	NA	NA	100	100
Brakes	100	100	100	100	100
Wheel and tracks	100	98	98	99	100
Controls	97	57	98	100	100
Frame, brackets	100	100	100	100	100
Springs, shock absorbers	100	99	100	100	100
Hood, sheet metal	NA	NA	NA	100	100
Cab, body or hull	100	96	99	100	100
Turret	63	77	NA	NA	NA
Winch	NA	NA	NA	NA	100
Bumper guards	NA	NA	NA	100	100
Miscellaneous accessories	100	100	100	100	100
Fire extinguisher system	100	100	100	NA	NA
Armament	93	91	99	NA	NA
Sighting & fire control	88	91	NA	NA	NA
Auxiliary generator	NA	99	NA	NA	NA

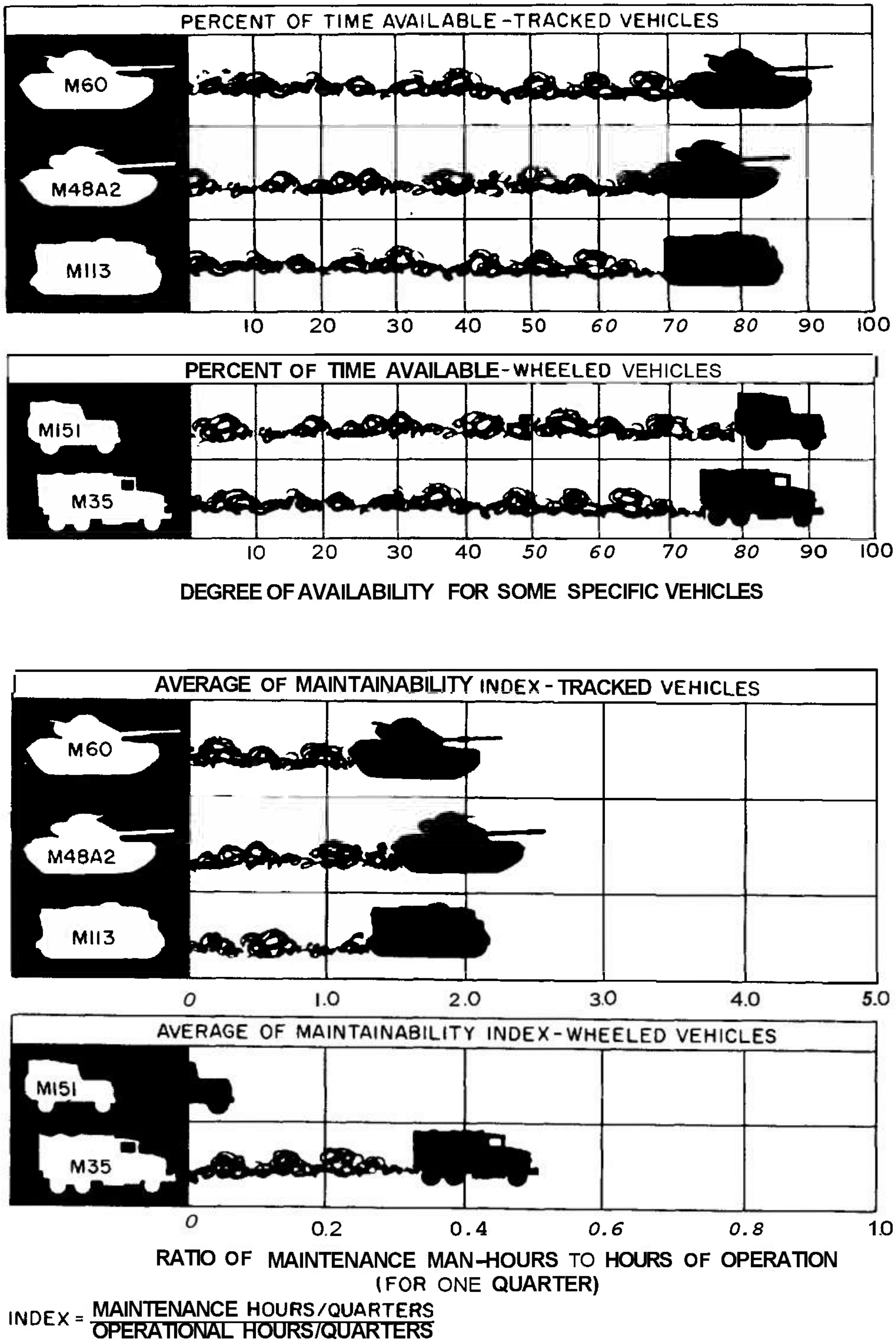

Figure 7-4. Examples of Type of Information Available from World-Wide System Data

7-4 THE MODERN ARMY MAINTENANCE SYSTEM CONCEPT

To maintain combat readiness, designs must be planned for support as well as for performance. At Frankford Arsenal, a modern Army Maintenance System Concept has been developed to reduce and simplify maintenance support problems in the field (Refs. 12, 13, and 14).

7-4.1 BACKGROUND

In the past, maintenance support planning consisted basically of design review; the design was firm and was supported by providing for repair parts, tools and test equipment, training, publications, and maintenance support (field and depot). When it became apparent that the skills, materials, and funds could not be made available in sufficient quantities, methods had to be devised that reduced and simplified maintenance support activities of existing equipment and which represented new development items (product improvement and design participation).

Initial efforts led to the "throwaway concept," i.e., unserviceable items be replaced rather than repaired. This was later followed by the "modified support" concept; i.e., logistical support which applied to equipment that was supported by modules and/or assemblies, individually, or combined with piece-parts. This resulted in the development of the maintainability design criteria (Figure 7-5) which considered transistorization, self-testing devices, automatic checkout systems, miniaturization, micro-miniaturization, simulation, and continued emphasis on standardization and multipurpose devices.

The foregoing support and maintainability design concepts present the possibility that the option exists to select the optimum combination, i.e. *to specify the type of support for which equipment should be designed.* In an attempt to provide the maintenance engineer with a tool to quantitatively assist him to select the optimum method, several design criteria have evolved.

The first approach to the problem was a "rule of thumb" formula (Figure 7-6) which considered the cost of repair, the number of items repaired, the total logistical cost of supporting an equipment, and the cost of new procurement.

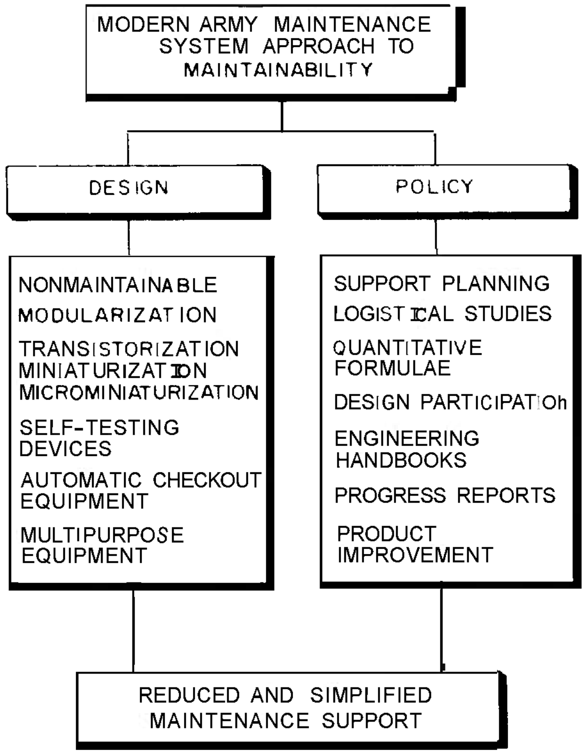

Figure 7-5. Modern Army Maintenance System Approach to Maintainability

7-4.2 MAINTENANCE SUPPORT FORMULA PROGRAM

The "rule of thumb" formula led to the development of the maintenance support formula program (Figure 7-7) the basis of which is the maintenance support formula shown in Figure 7-8. This formula represents a systematic approach for determining the cost of introducing a line into the Army supply system and the cost of supporting the line until obsolescence is reached. A cost analysis is made for each of the possible design support concepts; i.e., nonmaintainable,* modular, and piece part, and then a cost comparison is made.

* Nonmaintainable support — logistical support applied to equipment which, because of design, cannot be repaired and must be replaced when unserviceable.

ITEM	Rebuild cost	No. Rebuilt Per Year	No. Peculiar Line Items	Procurement cost
CIRCLE, AIMING, MI	125	484	105	174
125 X 484 = 60,500				
2000 X 105 = 210,000				
PRESENT SUPPORT				
= 270,500				
2 X 484 X 174 = 168,432				
SAVINGS = 102,068				

COST OF PRESENT SUPPORT = A X B + $2000C*

COST OF DIRECT REPLACEMENT = 2B X D**

Item 1 Minus Item 2 = Yearly Savings (if positive no.) If Difference is Negative Number, Nonmaintainable Concept not Feasible.

* $2000 is the Amount Estimated to Keep a Line Item of Supply in the Army Depot System, Based on the Number of Line Items and the Depot Complex Operating Cost.

**The Cost of Repairs at Maintenance Levels Below Depot are Considered Equal to the Depot Rebuild Cost. Convenience Factor 2 is therefore used to Save the Time and Cost of Acquiring Field Repair Data.

figure 7-6. Rule of Thumb formula

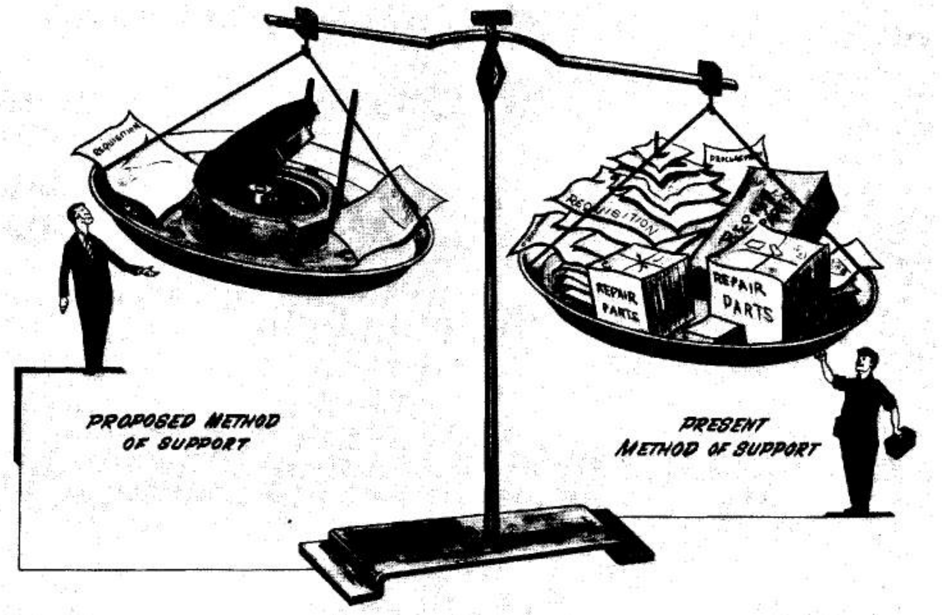

Figure 7-7. Maintenance Support Formula Program

The significant factors for which costs are compiled are:

(1) *Initial costs.* The cost of introducing a line item into the Army Supply System. These costs include:

(a) research and development.
(b) industrial costs (procurement and production).
(c) supply and maintenance (Field Service Design Participation).
(d) new publications.
(e) new part number cataloging.
(f) training of instructors.
(g) new tools, facilities, and test equipment.

(2) *Phase-in costs.* The cost associated with the support of new equipments currently being phased into the Army supply system, and support of old equipments until required densities of new equipment are attained.

(3) *Recurring costs.* The cost of supporting the item once its expected density is reached. These costs include:

(a) holding inventory.
(b) ordering.
(c) replenishment.
(d) publications.
(e) training.
(f) tools, test equipment, and facilities upkeep.

MAINTENANCE SUPPORT FORMULA

$$\frac{CRDU + CHDU}{CLPD + CLPP + 2(CPRT) + CMTT + CLCU} = X$$

where the principal parameters in the Disposal-at-Failure Concept* are:

CRDU = Annual Replenishment Cost
CHDU = Holding Cost

and where the principal parameters of recurring cost in the piece-part repair concept are:

CLPD = Cost of Labor, Parts, and Overhead
CLPP = Cost per Year of Labor, Overhead, and Parts for Items Repaired in Field
2(CPRT) = Cost of Procuring, Requisitioning, and Holding Repair Parts**
CMTT = Cost of Maintenance Training
CLCU = Cost of Replacements Due to Losses and Consumption

If X is > 1, recurring costs of disposal-at-failure concept are likely to be greater than those of the piece-part repair concept. Under these circumstances, it is unlikely that major items can be economically considered as a disposable unit (it does not mean that some or all of components making up major unit are not economically disposable items).

If X is ≤ 1, recurring costs of disposal-at-failure concept are likely to be no greater than those of piece-part repair concept. In this case, it is likely that major items can be economically considered as a disposable unit.

Note: Costs computed on yearly basis,

* Disposal-at-Failure Concept: Logistical Support Requiring Disposal of Unserviceable Equipment Even Though it Was Designed Originally to be Maintained.

**Efficient Supply Management is Achieved When Requisitioning and Procuring Cost Equals the Holding Cost for Storing Repair Parts. Convenience Factor 2 is Therefore Used to Double the Cost of Requisitioning and Procurement.

Figure 7-8. Maintenance Support Formula

(g) maintenance labor and maintenance overhead.

By using the analytical process afforded by the maintenance support formula, many areas requiring improvement, such as design changes, needless repair part stockage, excessive training programs, improper maintenance techniques, etc. can be more easily investigated and evaluated.

Figure 7-9 illustrates the tangible results obtained on one item of Army equipment by utilization of the formula. In addition, this concept also highlights the significance of logistical support and stresses the fact that optimization in this area can only be achieved by *design configuration and logistical support control.*

7-4.3 DEVELOPMENT PROGRAM FOR ATTAINING LOGISTICAL DECISIONS

To provide guidance for the maintenance engineer and enable him to *design for support,* partciular design configurations must be predicted which will result in the most desirable logistical support policy with due consideration to the impact on the Army in terms of combat readiness, availability, mean-time-between-failures, storage, transportation, mobility, etc. Figure 7-10 illustrates a development program which will enable the maintenance engineer to evaluate and select from a variety of design configurations and support policies those which will help him arrive at the proper logistical decisions. With the use of the maintenance support formula, this evaluation would be performed by the development agency during the Qualitative Materiel Requirement (QMR) and Feasibility Stages (Figure 7-10) *before* firm design decisions are made. Final decisions would be reserved for the Program Definition Stage.

To specifically express the Army's logistical requirements, *forced* coordination between the pertinent operating elements of the development agency (i.e., research and development, production and procurement, and supply and maintenance) must be initiated. Accomplishing this, *forced* evaluation of the alternatives between design and support policies will result.

A suggested method for accomplishing forced coordination and evaluation is illustrated by the logistical data sheet shown in Figure 7-11. Considered in the data sheet are:

(1) The significant factors which affect an item of equipment during any portion of its life cycle (initial, phase-in, and recurring activities).

(2) The possible design and support considerations available.

(3) A means for developing costing data for each of the possibilities. (The annual expenditures estimated for the years covering the initial period of development, the phase-in transition from old to new equipment, and the recurring costs of maintenance.)

Inputs for the data sheet would be supplied

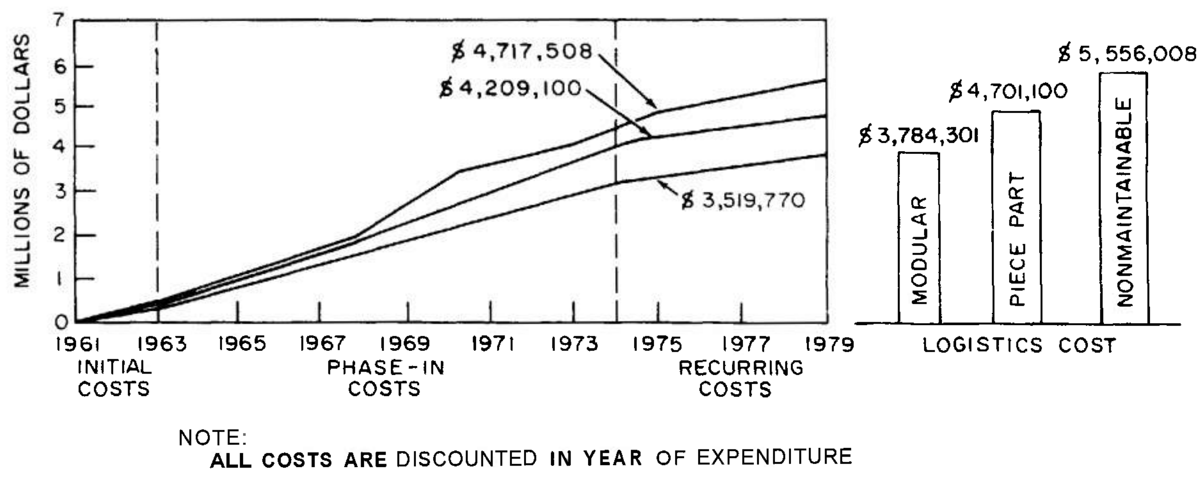

figure 7-9. Maintenance Support Formula—Application to 7×10 Binoculars

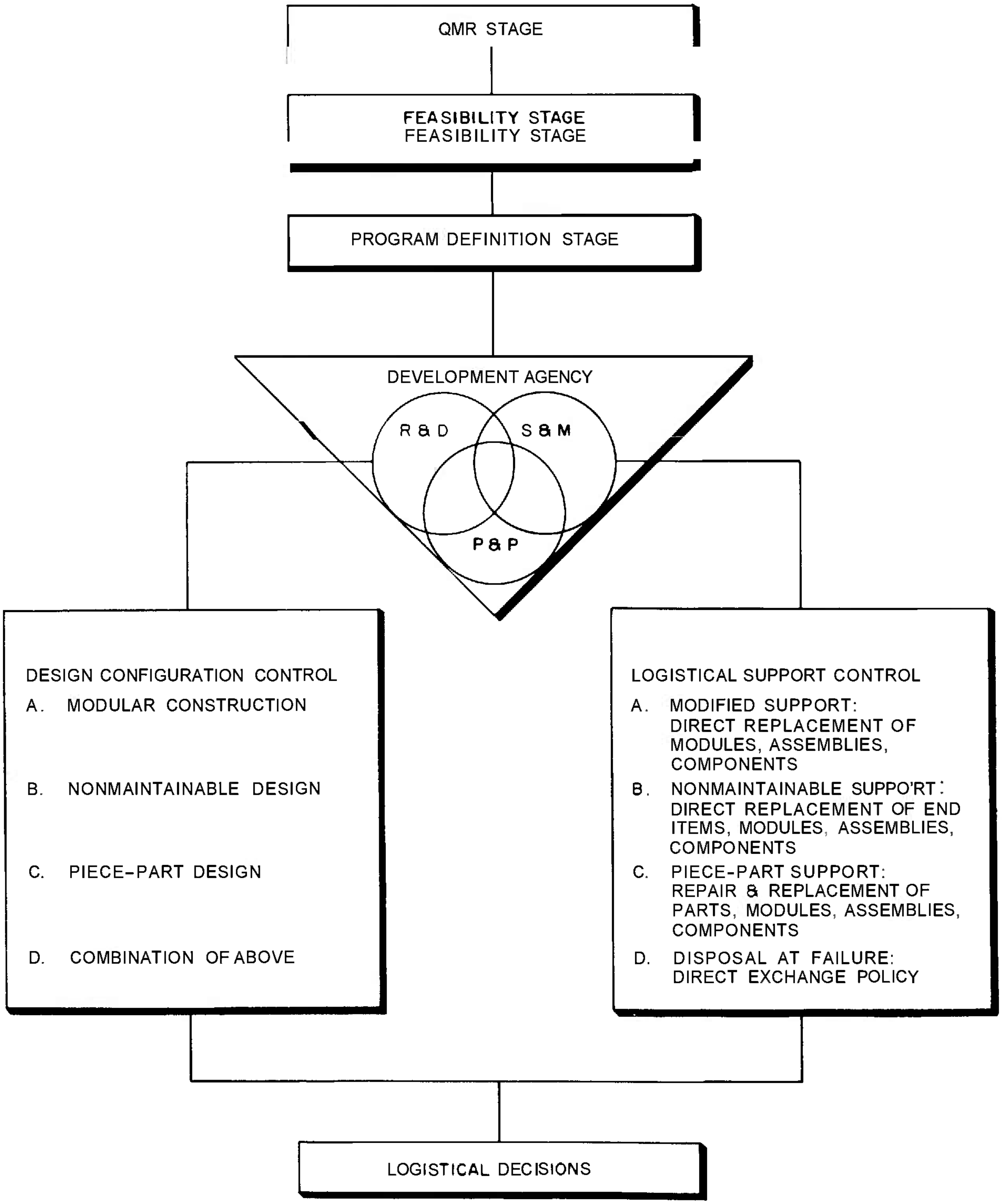

Figure 7-10. Development Program for Attaining Logistical Decisions

by the pertinent operating element of the development agency. Formal approval of the evaluation by each of the operating elements would provide a means whereby logistical decisions could be made in a quantitative manner. This combination of effort can provide the Army with meaningful measurements to produce scientific decisions. From these decisions can be determined the best method of supporting equipment in terms of economics and logistics.

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CONCURRENCE	☐ R&D		☐ P&P	☐ NICP		☐ NMP
Design Support Factors	Design Configuration - Logistical Costs					
Initial Actions	Qty	Factors (Constants)	Piece-Part	Modular	Non-Maintainable	Disposal At Failure
Research and Development						
Production and Procurement						
Maintenance Engineering						
Publications		X dollars per page				
Cataloging		50 per line item				
Training		6 per man - hour				
Tools - Test Equipment						
Recurring Actions						
Replenishment						
End Items						
Components						
Holding - 15%						
Requisitions		8 per requisition processing cost				
Proc-Directives		100 per procurement directive processing cost				
Maintenance						
Field-Labor Overhead						
Depot-Labor Overhead						
Totals						

Figure 7-11. Logistical Data Sheet

CHAPTER 8
MAINTENANCE PERSONNEL SKILL AND AVAILABILITY

8-1 GENERAL

It is vitally important for the design engineer to consider the skills required and the personnel available to operate and maintain the equipment he designs. Equipment that requires skill levels higher than those that can be made available cannot be successfully maintained. If the maintenance skill level required is much in excess of that available, the equipment can be a liability instead of an asset because it wastes maintenance manpower and supply-channel effort.

It is difficult to obtain and retain skilled military maintenance personnel. Therefore, everything possible must be done by the designer of equipment to build in maintenance features that would be unnecessary for effective maintenance by highly skilled technicians.

As the complexity of equipment increases, the time required to train the operator or maintenance specialist also increases. The current normal military enlistment tour is three years (Ref. 1). While a considerable number of persons re-enlist one or more times, there is no obligation for an individual to do so. Thus, there is a definite factor of diminishing returns in a long training program. In a study of Army electronics personnel, for example, it was found that "for every ten men trained as radio, microwave, or radar repairmen, generally one re-enlists while the other nine enter civilian employment" (Ref. 2). Equipment should therefore incorporate maximum simplicity to permit the shortest possible training time so that the technician's effective service after training can be proportionately increased.

Complex equipment will generally require greater skill to operate and be more difficult to service. Because of this, it is more vulnerable to human failure when the user is under tension or emotional stress. This can be a critical problem in combat or emergency situations.

8-2 THE TYPICAL MAINTENANCE TECHNICIAN

In the design of Army equipment, the user skill level should be considered from the initial design stage through the life cycle of the product. The optimum design goal should be equipment that can be operated and repaired effectively by the least experienced personnel with little or no outside assistance. For development purposes, the "typical" Army technician shall be assumed to possess the following characteristics (Ref. 3) :

(1) *Age.* The median of the age distribution is 21.2 years, with 55% of all technicians between 20 and 22 years of age.

(2) *Average civilian education.* The average number of years of civilian education is 12. Only 15% will have attended college and less than 1% will have graduated from college. Only 1 out of each 1000 will possess an engineering degree.

(3) *Average service education.* Formal service schooling will consist of 19 weeks, to include basic training, specialty training, and weapon system training.

(4) *Applicable civilian experience.* None.

(5) *Applicable army experience.* Overall average is approximately 3.5 years, but the technicians who will perform most of the work (nonsupervisory) can be expected to have 2.3 years of experience.

(6) *General limitations.* The "typical" Army operator or maintenance technician should *not*

be required to :

(a) read at higher than the 9th-grade reading level.
(b) perform arithmetic calculations, even simple addition and subtraction.
(c) consolidate or integrate information from multiple sources.
(d) collect, process, or report any unnecessary or complicated data.
(e) post data from one form to another or keep any permanent records.

NOTE :

The error rates for the above operations, when performed at the weapon site as part of other maintenance duties, tend to be prohibitive.

The manpower profile of potential Army electronics personnel shown in Table 8-1 illustrates some of these points.

The line maintenance man is bored, critical, and anxious for discharge. As a result, he is not particularly receptive to training. *This means that designing maintainability into equipment is about the only way to improve maintenance,* other than devising detailed "cookbook" type manuals which will anticipate actions required by a technician (Ref. 5).

8-3 CATEGORIES OF MAINTENANCE

Military maintenance is usually stratified into several levels that generally correspond both to the skill of the peronnel and to the degree of difficulty of the maintenance task. Stratification by level of maintenance in the military is made essential by the demands for tactical deployment of the equipment, but it is also a solution to the problem of efficiently using maintenance

TABLE 8-1. PROFILE OF POTENTIAL ARMY ELECTRONICS PERSONNEL (Ref. 4)

Sample	1000 enlisted men in Basic Combat Training during September and October 1961
Enlistment information	14 of the 1000 had enlisted for training in electronics
Term of service	2 years, 59%; 3 years, 41%; more than 3 years rounds to zero
Background information	4 out of the 1000 were considered qualified for an electronics assignment without further training

Education	% of Sample	% of Group Scoring Above 100 on EL*
Information missing	8	14
Less than 12 yr	29	22
12 yr	46	42
Some college	17	63
4 yr college or more	5	70

School Subjects (high school or higher)	% of Sample	Major College Subject	% of Sample
Trigonometry and chemistry	8	None	84
Trigonometry	2	Engineering	3
Geometry	13	Physical science	2
Algebra and chemistry	3	Other	11
Chemistry	1		
Physical science	30		
Physics	8		
None	24		

men of varying skills. Periodic check-outs of electronic equipment, for instance, require a major portion of maintenance time (Refs. 6 and 7). This type of work, however, normally does not require a high level of skill and can be assigned to the less skilled man, releasing the more skilled men to perform the difficult repair jobs.

The Department of the Army has grouped all maintenance into four categories : organizational, direct support, general support, and depot (Ref. 8). Equipment design must adequately take into account the actual skills available at each maintenance level. Table 8-2 shows the categories and levels of maintenance in a theater of operations. A detailed description of each maintenance category is presented in the paragraphs which follow.

8-3.1 ORGANIZATIONAL MAINTENANCE

Organizational maintenance is that maintenance normslly authorized for, performed by, and the responsibility of a using organization on equipment in its possession. This maintenance consists of functions and repairs within the capabilities of authorized personnel, skills, tools, and test equipment. (This function was formerly known as 1st and 2nd echelon maintenance.)

Organizational level personnel are usually fully occupied with the operation and use of the equipment, and have a minimum of time available for detailed maintenance or diagnostic check-out. Usually, the least skilled maintenance men are associated most closely with the operation of the equipment. Maintenance at this level is normally restricted to periodic checks of equipment performance, cleaning of the equipment, front panel adjustments, and removal and replacement of some components. Personnel at this level usually do not repair the removed components but forward them to the next higher level.

Maintenance performed by the equipment operator usually consists only of inspecting, cleaning, servicing, preserving, and adjusting the equipment. Maintenance done by the organization's repairman consists of making minor repairs and replacements.

TABLE 8-2. CATEGORIES OF MAINTENANCE IN A THEATER OF OPERATIONS (Ref. 2)

Category	Organizational Maintenance		Direct Support Maintenance	General Support Maintenance	Depot Maintenance
Former Echelon	First	Second	Third	Fourth	Fifth
Done Where	Wherever the Equipment is	In Unit	In Mobile and/or Semi-Fixed Shops		In Base Depot Shop
Done by Whom	Operator	Using Unit	Division/Corps/Army		Theater Commander Zone and/or Z/I
On Whose Equipment	Own Equipment				
Basis	Repair and Keep it		Repair and Return to User		Repair for Stock
Type of Work Done	Inspection Servicing Adjustment Minor Repairs and Modification		Inspection Complicated Adjustment Major Repairs and Modification Major Replacement Overload from Lower Echelons		Inspection Most Complicated Adjustments Repairs and Replacement Including Complete Overhaul and Rebuild Overload from Lower Echelons

Mobility requirements generally limit the amount of tools, test equipment, and supplies available at the organizational level. The design engineer can, therefore, expect to find personnel skills of limited specialization at this level and should plan equipment maintenance and servicing requirements accordingly.

8-3.2 DIRECT SUPPORT MAINTENANCE

Direct support maintenance is that maintenance normally authorized and performed by designated maintenance activities in direct support of using organizations. This category of maintenance is limited to the repair of end items or unserviceable assemblies in support of using organizations on a return-to-user basis. (This function was formerly known as 3rd echelon maintenance.)

Materiel that the using organization cannot repair is repaired by a direct-support unit provided it is within the latter's capability. Direct support also furnishes supplies and other services directly to the user. Direct-support units are designed to provide close support to combat troops and facilitate tactical operations. This mobility requirement limits the equipment and supplies, and, therefore, the repair jobs that can be undertaken.

Military maintenance personnel at this level, however, are generally more skilled and better equipped than those at the organizational maintenance level and are charged with performing more detailed maintenance. At this level, failed components and equipment are repaired by replacement of parts and subassemblies.

Maintenance is performed by specially trained units in direct support of a "using" organization. These units are authorized larger amounts of spare parts and maintenance equipment than the using organization which the unit supports by technical assistance and mobile repair crews when necessary.

Direct-support units of fixed capabilities have been established and made an organic part of certain major combat units. Nonorganic, direct-support units help provide 100% direct support. They are of company and detachment size but can be organized into battalions and groups in any specific situation.

8-3.3 GENERAL SUPPORT MAINTENANCE

General support maintenance is that maintenance authorized and performed by designated organizations in support of the Army supply system. Normally, general support maintenance organizations will repair or overhaul materiel to required maintenance standards in a ready-to-issue condition based upon applicable supported Army area supply requirements. (This function was formerly known as the 4th echelon maintenance.)

This level of maintenance is performed by units organized as semifixed or permanent shops. They exist to serve lower levels within a given geographical area. General-support units include companies and detachments specializing in general supply, ammunition supply, maintenance (by commodities), and other services. These units perform work that overflows from direct-support companies, but rarely deal directly with the equipment user. A general-support unit's primary maintenance function is to repair those items that cannot be repaired by direct-support units.

Units at this level must possess a certain mobility so they can remain within convenient working distance of the direct-support units. Rapid movement, however, is not as imperative here as in direct support. Some mobility is sacrificed so that they can have more time and facilities to perform their services.

A high degree of specialization can be expected at the general support level of maintenance because personnel are usually trained in schools to become experts in specific components of equipment. Mobility requirements are also less stringent and permit more complex maintenance operations.

8-3.4 DEPOT MAINTENANCE

Depot maintenance is that maintenance which, through overhaul of economically repairable materiel, augments the procurement program in satisfying overall Army requirements and, when required, provides for repair of materiel beyond the capability of general support maintenance organizations. (This function was formerly known as 5th echelon maintenance.)

Depot maintenance level organizations are stable and mobility is no problem. Equipment of extreme bulk and complexity can be used, if required. The high volume possible in these shops lends itself to effective use of assembly line techniques. This, in turn, permits use of relatively unskilled labor for the greater part of the workload, with a concentration of highly skilled specialists in key positions.

Depot maintenance is performed in shops in the continental United States or (for selected items) in shops established by the overseas theater commander. However, most depot maintenance is located remotely from the theater of operation and performs services for several such theaters.

This level of maintenance provides the major supply base in an overseas theater for end items and for the parts and supplies required to maintain and repair the end items. Facilities are available for completely overhauling and rebuilding equipment. Assembly line methods are used whenever practical and normal support of supply is accomplished on an overhaul-and-return-to-stock basis.

Depot maintenance functions also include repair and reclamation services that are beyond the capabilities of general support maintenance. Operation of these installations by troops, however, is not mandatory. If the local labor market can provide the required skills, the bulk of the work may be done by native labor under military supervision.

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CHAPTER 9
BASIC HUMAN FACTORS

SECTION I
HUMAN BODY MEASUREMENTS AND HUMAN SENSORY CAPACITIES

9-1 THE PROBLEM

World War II demonstrated that a military weapon is only as good as its operators and maintenance men. Machines and equipment performed at maximum capacity only if the operators and mantenance men did what they were supposed to do, in the proper sequence, and at the proper time.

Operators and maintenance men fail to do their jobs properly for a variety of reasons: fear and fatigue, hasty or inadequate training, and incompetency — a result of inadequate selection. They also fail because machines and equipment are designed without sufficient attention to the mental and physical capabilities of the men who operate or maintain them.

9-2 HUMAN FACTORS ENGINEERING

Human factors engineering is a factor which relates man's size, strength, and other capabilities to the necessary work. *Failure to consider these factors will result in increased maintainability problems.* Human factors engineering began when psychologists were called in to make critical investigations of, for example, physical limitations in aviation and behavior in naval combat information centers. Its goal was to provide designers with the probable characteristics of the individuals who would operate and maintain machines and equipment.

Human factors engineering today draws on psychology, physiology, physics, anthropology, and medicine, and requires close alliance between engineers and psychologists. Human factors engineers consider complex military equipment as man-machine systems, including as design considerations the capabilities and limitations of the man under various conditions.

To minimize diagnostic time, necessary human factors must be considered and equipment designed to facilitate quick, accurate, and positive action by the technician. These maintainability factors, some of which are also human factors, are considered in this chapter. This section discusses human body measurements and human sensory capacities, and Section II presents recommendations for the selection and design of controls and displays. The human factors requirements for handles are covered in Chapter **23,** Paragraph **23-6.**

9-3 HUMAN BODY MEASUREMENTS (ANTHROPOMETRY)

One important consideration in designing for maintainability is information on body measurements. This information is required in the earliest design stages to ensure that equipment will accommodate operators and maintenance men of various sizes and shapes. This section describes the sources of anthropometric measurements available to the designer, indicating some of the types of information and giving examples of the more common measurements, with cautions as to their use.

9-3.1 SOURCES AND USE OF INFORMATION ON BODY MEASUREMENTS

The designer has two basic sources of information on body measurements : anthropometric surveys, in which measurements of a sample of the population have been made, or experiments under circumstances that simulate the conditions for which he is designing. Which of these sources or what combination is used depends on the availability of adequate anthropometric surveys and on the cost of experiments in both time and money.

Anthropometric data are usually presented in percentiles, ranges, and means (or medians). With information of this type, the designer, who usually will not be able to accommodate all possible sizes, can decide where to make the cutoff. He must, of course, design equipment so that all members of the population for which it is designed can operate and maintain it; but at the same time, he might have to inflict less efficient or less comfortable circumstances on a small percentage of the population, i.e., those individuals having extreme measurements.

9-3.2 TYPES OF BODY MEASUREMENTS

Both static and dynamic body measurements are important to the designer. Static measurements include everything from measurements of the most gross aspects of body size, such as stature, to measurements of the distance between the pupils of the eyes. The measurements required will depend on the particular equipment being designed. The more common static measurements, having received the most attention from anthropometrists, are most readily available and are the most reliable because of the large and numerous samples on which they are based.

Unlike static body dimensions, which are measured with the subject in rigid standardized positions, dynamic body measurements usually vary with body movements. Dynamic measurements include those made with the subjects in various working positions, and functional arm and leg reaches. Static dimensions corresponding to functional reaches would be anatomical arm and leg lengths. Dynamic dimensions in equipment design relate more to human performance than to human "fit" (Ref. 1).

9-3.3 EXAMPLES OF BODY MEASUREMENTS

Figure 9-1 illustrates body dimensions to be considered in equipment design. Associated also with body dimensions is the application of force. The human being is so organized, muscularly, that he can exert more force, with less fatigue, if the machine has been designed to fit his capabilities. The following conclusions on the application of force and the strength of body components should be of value to the designer (Ref. 3):

(1) The amount of force that can be exerted is determined by the position of the body and the members applying the force, the direction of application, and the object to which it is applied.

(2) The greatest force is developed in pulling toward the body, (see Figure 9-2). Pull is greater from a sitting than from a standing position. A momentary pull can be as great as 250 lb, whereas the maximum steady pull is about 65 lb.

(3) The maximum force exertable increases with the use of the whole arm and shoulder, but using only the fingers requires the least energy per given amount of force applied.

(4) Push is greater than pull for side-to-side motion, with about 90 lb being the maximum.

(5) The maximum handgrip for a 25-year-old man is about 125 lb. Usually, the stronger hand can exert an average of 10 lb greater than the other.

(6) Arm strength reaches its maximum at about age 25, drops slightly between 30 and 40, and declines about 40% from age 30 to 65. Hand strength declines about 16.5% during the same period. These figures vary, however, depending upon conditions — a stamp collector's strength will not hold up like the strength of a man who performs manual labor.

Associated with force is weight lifting capacity. Figure 9-3 shows the maximum weight that can be lifted a given distance from the ground or floor. The curve is based on data from 19 male subjects whose average age was 21.6 yr, average weight was 161.2 lb, and average height was 69.5 in. They lifted objects of convenient size and shape and had unlimited room to do it in. Before a designer could use these figures, he would have to determine if the conditions for which he is designing would be the same.

9-4 HUMAN SENSORY CAPACITIES

The following data is presented to help the designer to a better understanding of the sensory capacities of the maintenance man as they apply to color coding, shape coding, parts identification, and noise.

9-4.1 SIGHT

Sight is stimulated by electromagnetic radiations of certain wavelengths, commonly called the visible portion of the electromagnetic spectrum; The various hues (parts of the spectrum), as seen by the eye, appear to differ in brightness. In daylight, for example, the eye is most sensitive to greenish-yellow light that has a wavelength of about **5500** angstrom units (Ref. **6).** The eye also sees differently from different angles.

The limits of color vision are illustrated in Figure **9-4.** One can perceive all colors while looking straight ahead. Color perception, however, begins to decrease as the viewing angle increases. **As** shown in the figure, green disappears at about 40° off the level view in the vertical plane, and red disappears at above 45°. Yellow and blue can be distinguished over a larger area. Therefore, if equipment has color-banded meters or warning lights of different colors that are in such a position as to be near the horizontal or vertical limits of color differentiation, the user will not be able to distinguish among the colors.

Color-weak people (so few people are absolutely color blind they can be ignored) will not see colors the way "normal" people do, and any color coding will be lost on them. Colors should, therefore, be selected which color-weak people do not confuse, such as yellow and blue, or color coding should be augmented with shape coding (see Paragraph **9-6.10.3).**

At night, or in poorly illuminated areas, color makes little difference, and at a distance, or if the point source is small (such as a small warning light), blue, green, yellow, and orange are indistinguishable : they will appear to be white. **A** further phenomenon of sight perception of light is apparent reversal of color. When staring at a red or green light, for instance, and glancing away, the signal to the brain may reverse the color. This has caused accidents. Too much reliance should not be placed on color where critical operations may be performed by fatigued personnel. Whenever possible, red filters, having wavelengths longer than 6500 angstrom units should be used (Ref. **7).** If this is not possible, then warning lights, at least, should be **as** close to red as possible. Colors such as red-amber or reddish purple are satisfactory.

9-4.2 TOUCH

As equipment becomes more complex, it is necessary that the maintenance man use all his senses most efficiently. Man's ability to interpret visual and auditory stimuli is closely associated with the sense of touch. The sensory cues received by the skin and muscles can be used to some degree to convey messages to the brain that relieve the eyes and ears of part of the load they would otherwise carry.

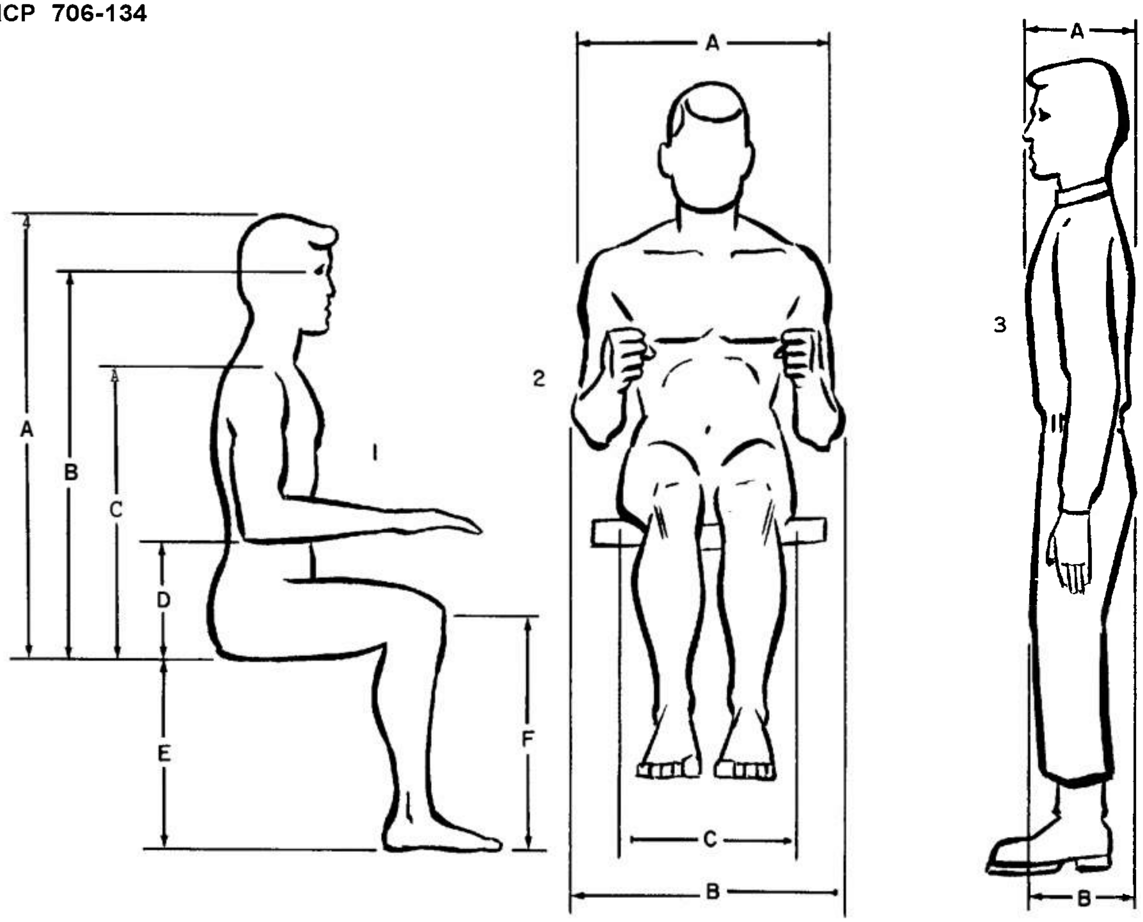
For example, the control knob shapes illustrated in Figure 9-10 can be easily recognized by touch alone. Many of these knob shapes could be adapted for use when the user must rely completely on his sense of touch, as, for instance, when a knob must be put in an out-of-the-way place.

9-4.3 NOISE

It is difficult to gage precisely the effects of noise on humans. Figure **9-5,** illustrating the effects of sound intensities at various frequencies, may be used as a general guide.

Man's reaction to noise extends beyond the auditory system : it can contribute to such feelings as well-being, boredom, irritability, **or** fatigue. Work requiring a high degree of muscular coordination and precision, or intense concentration, may be adversely affected by noise. When sound exceeds a level of about **120** db, it begins to produce a physical sensation of feeling, or tickle, and at levels above **130** db it can become painful.

In addition to affecting the performance **of** maintenance technicians in tasks not dependent upon auditory tasks, excessive noise can make oral communication ineffectual or impossible, and can damage hearing. Consequently, the interior noise levels in maintenance or control areas (vans, huts, etc.) in which communication of information, either direct or electrical, is critical, should not exceed the levels given in Table **9-1.** These levels should permit reliable communications with raised voice at a distance

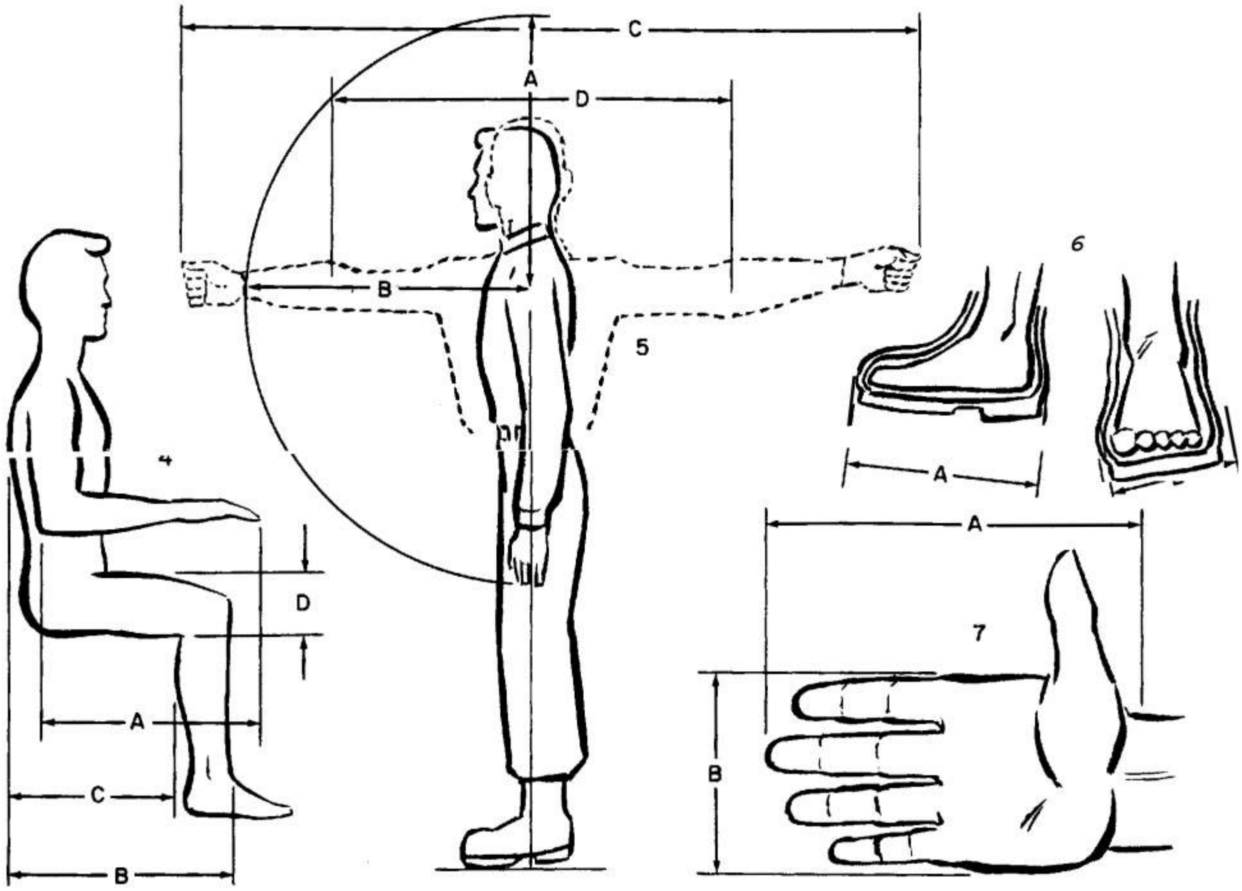


			SMALL MAN	LARGE MAN	LARGE MAN (heavy clothing)
HEIGHT		Height (stature)*	65.5	74.0	75.0
	1A	Sitting height (erect)*	33.5	38.0	40.5
	1B	Eye height-(normal sitting) (internal canthus)	28.0	31.5	32.0
	1C	Buttock-shoulder height (acromial height)	22.7	26.5	27.0
	1D	Buttock-elbow height	7.4	10.8	10.8
	1E	Seat height (popliteal height)	16.7	19.2	19.2
	1F	Knee height	21.0	24.5	25.0
WEIGHT		Weight (pounds) (no equipment)	130.0	201.0	226.0
TRUNK	2A	Shoulder width (bi-deltoid)	16.5	20.0	26.0
	2B	Elbow width (bi-epicondylar-elbows)	15.3	20.3	31.5
	2C	Seat width	13.0	16.5	23.0
	3A	Chest depth	7.5	11.0	15.5
	3B	Abdominal depth	8.0	13.0	18.0

*Allow 2.6 inches for helmet.

Note: Small man represents the 5th percentile—only 5% of the population are smaller than the values given. Large man represents the 95th percentile—only 5% of the population are larger than the values given.

Figure 9-1. Body Dimensions for Use in Equipment Design (Ref. 2)



			SMALL MAN	LARGE MAN	LARGE MAN (heavy clothing)
HEAD		Head length (front to back)**	7.2	8.2	11.5
		Head width (side to side)**	5.6	6.4	11.0
HAND	7A	Hand length	7.0	8.2	9.5
	7B	Hand width	3.2	3.8	5.5
ARM	4A	Elbow-finger length	17.3	20.1	21.3
THIGH	4B	Buttock-knee length	21.5	25.5	27.5
	4C	Seat length	17.5	20.5	20.5
	4D	Thigh clearance height (thigh thickness)	4.8	6.5	8.0
FOOT	6A	Foot length	11.0	12.7	15.3
	6B	Foot width	4.0	4.5	6.3
REACH	5A	Overhead reach (functional)	77.8	89.5	89.5
	5B	Arm reach— anterior (functional)	29.0	35.0	35.0
	5C	Arm span	65.9	75.6	78.0
	5D	Elbow span	34.0	39.0	41.0

**Helmet length = 12.0 inches, width = 10.3

figure 9-1. Body Dimensions for *Use in Equipment Design (Ref. 21 (cont)* of 3 to 4 ft. Equipment in operation or maintenance tasks shall not require personnel to be exposed to noise levels that exceed the maximum acceptable specified in Table 9-2.

The following recommendations should also be considered to reduce the effects of noise :

(1) In designing equipment which necessitates maintenance activities in the presence of extreme noise, reduce the amount of noise produced, where possible, by proper acoustical design, mufflers, soundproofing, and other devices.

(2) Keep sound levels in maintenance areas which require presence of the maintenance technician below 85 decibles (db re 0.0002 dyne/cm^2).

(3) Provide warnings to prevent unprotected maintenance personnel from entering areas with noise levels above 150 db, even for short periods. Exposure to such high noise levels may result in disorientation, nausea or vomiting. There is considerable variation in judgments of a single, overall minimum noise level that is potentialy harmful, i.e., which can cause permanent hearing loss. In general, levels above 100 db are not considered safe; levels below 90 db are not considered harmful.

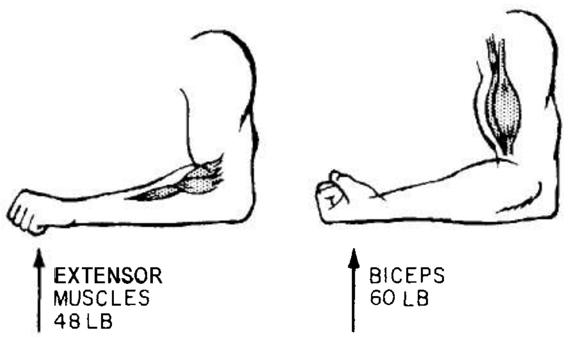


Figure 9-2. Amount of Force That Can be Exerted by the Arm in Two Positions (Ref. 41

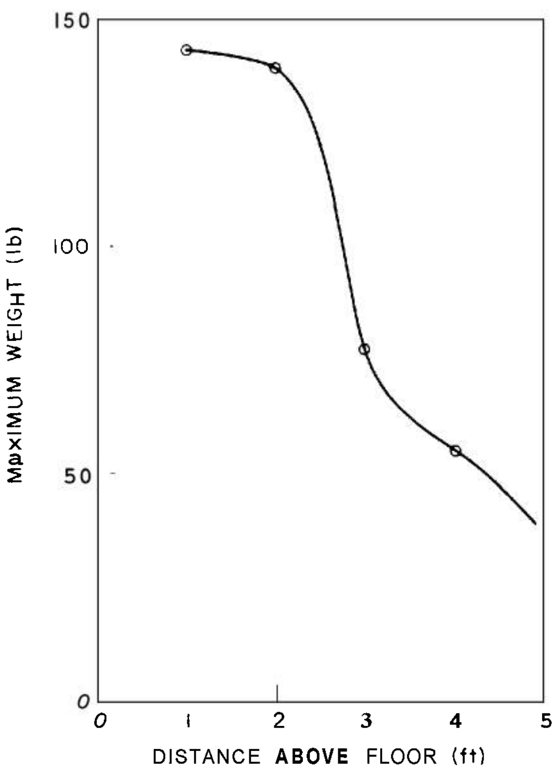


Figure 9-3. Maximum Weight Lifting Capacity (Ref. 51

9-4.4 VIBRATION AND MOTION

Vibration may be deterimental to the maintenance technician's performance of both mental and physical tasks. Large amplitude, low frequency vibrations contribute to motion sickness, headaches, fatigue, eye strain, interfe<-ence with depth perception (depth perception fails at frequencies of 25-40 cps and again at 60-90 cps), and interference with the ability to

TABLE 9-1. MAXIMUM NOISE LEVELS FOR COMMUNICATION

Frequency Bands (cps)	Maximum Level (db re 0.0002 microbar)
below 75	79
75-150	73
150-300	68
300-600	64
600-1200	62
1200-2400	60
2400-4800	58
4800-10000	57

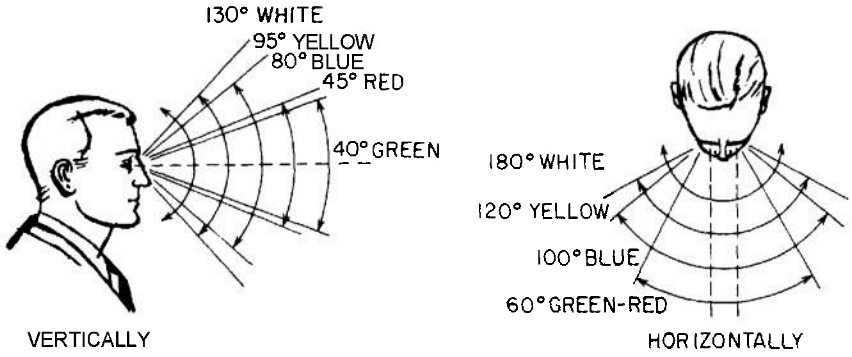


Figure 9-4. Approximate Limits of Normal Color Differentiation (Ref. 3)

read and interpret instruments. As the amplitude of vibration decreases and the frequency increases, these symptoms become less pronounced. However, vibration of low amplitude and high frequency can be fatiguing.

Some design recommendations to be considered for reducing the effects of vibration and motion are as follows (Ref. 9) :

(1) Design equipment to resist vibration and shock or to be isolated from such action by shock absorbers, cushioned mountings, springs, or fluid couplings.

(2) Where possible, consider the position of the operator and maintenance technician in the performance of their work on equipment that is subject to vibration.

(a) Seated personnel are most affected by vertical vibrations ; prone personnel by horizontal vibrations.

(b) Use damping materials or cushioned seats to reduce vibration transmitted to a seated technician's body. Avoid vibrations of 3 to 4 cps, since this is

TABLE 9-2. MAXIMUM ACCEPTABLE NOISE LEVEL FOR ARMY MATERIEL COMMAND EQUIPMENT*

Frequency Bands (cps)	Maximum Acceptable Noise Level (db re 0.0002 microbar)
below 75	120
75-150	115
150-300	109
300-600	101
600-1200	93
1200-2400	89
2400-4800	89
4800-9600	91

*Continuous Noise As Opposed to Impulse Noise

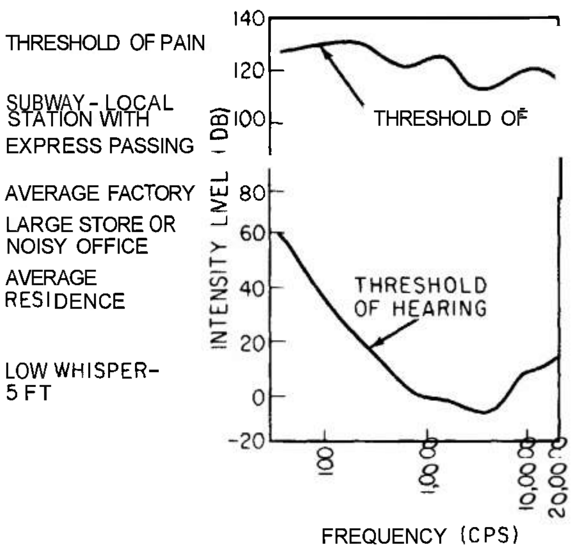


Figure 9-5. Sensations of Sound Intensities at Various Frequencies (Ref. 3)

the resonant frequency of the vertical trunk of a man when seated.

(3) For critical maintenance operations requiring letter or digit discrimination, ensure that the equipment containing the printed material is free from vibration produced by machinery.

(a) Avoid vibrations in excess of 0.08 mil amplitude. (1 mil = 10^{-3} in.).

(b) Where it is not possible to provide vibration-free displays, increase display size and/or illumination to improve speed and accuracy.

SECTION II

DESIGN RECOMMENDATIONS FOR CONTROLS AND DISPLAYS

9-5 CONTROLS

The proper design of controls is an important factor affecting operator performance in most man-machine systems. Controls should be selected so that their movements conform to those of the associated display, equipment component, or vehicle. The function and direction of conventional control movements, shown in Table 9-3, should be consistent with that of the controlled object or display. The general situations in which linear (or near-linear) and rotary controls should be used are shown in Figure 9-6, and when force and range settings are the primary considerations, the controls recommended in Table 9-4 should be used.

General design guidelines for controls (knobs, selector switches, cranks, toggle switches, levers and pushbuttons) are given in Table 9-5. Special recommendations relating to the design of aircraft controls are presented in Chapter 31, Paragraph 31-9.2.2. Other design recommendations that should also be considered are presented in the following paragraphs.

9-5.1 KNOBS

Specify knobs under the following conditions:

(1) When precise, accurate adjustment of a continuous variable is required.

(2) When little force is required.

(3) When conservation of panel space is not critical.

(4) When coding by color, size, or shape is desired.

Consider also the following general recommendations:

(1j Design control knobs with a minimum of resistance, but incorporate sufficient resistance to guard against accidental or inadvertent movement.

TABLE 9-3. CONVENTIONAL CONTROL MOVEMENTS (Ref. 2)

Function	Control Action
On	Up, right, forward, pull (switch knobs)
Off	Down, left, rearward, push (switch knobs)
Right	Clockwise, right
Left	Counterclockwise, left
Up	Up, rearward
Down	Down, forward
Retract	Rearward, pull, counterclockwise, up
Extend	Forward, push, clockwise, down
Increase	Right, up, forward
Decrease	Left, down, rearward

(2) When a knob is used for discrete settings, the accuracy of settings can be enhanced by increasing the holding action of the detent. This will result, however, in a slower selection speed.

(3) When a knob is used for fine adjustments (Figure 9-7), there should be between 60" and 80" of movement from just detectable misalignment in one direction to just detectable misalignment in the other.

(4) Design an audible click into controls that are used for discrete settings so the operator will have an additional cue to accurate setting of the knob.

(5) Secure control knobs with set screws which are large and accessible enough to be tightened or loosened with a standard size screwdriver. Where possible, set screws should be located at the end of the knob rather than at the side, since the screws will be easier to replace in this position (see Figure 9-8). When it is necessary to locate the set screw on the side of the knob, ensure that access to the screw is not obstructed by other controls. Shafts should have a flat or indent to assure positive contact between the set screw and the shaft.

In determining the size and shape of knobs, consider the manner of operation and the available panel space, namely :

(1) When rapid (though perhaps less accurate and less controlled) adjustment is required, specify small diameter, rather than large diameter knobs.

(2) Knobs less than 0.75 in. in depth should be knurled to prevent the hand operating them from slipping.

(3) Serrated knobs of more than 0.75 in. in depth to prevent slipping. Serrations should be close and evenly spaced.

(4) The shape of knobs should be determined by function and use.

(5) Knob shapes similar to those shown in

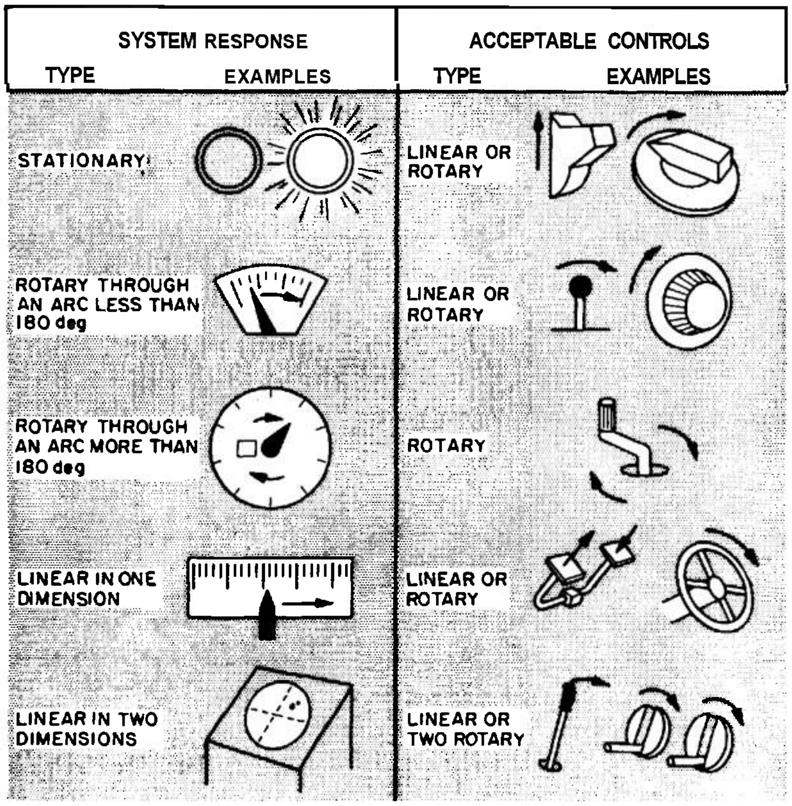


Figure 9-6. Acceptable Controls for Vurious Types of System Responses (Ref. 1)

Figure 9-9(A) are recommended when *more* than one full turn is required.

(6) Figure 9-9(B) illustrates knob shapes recommended when less than one full turn is required.

(7) All knobs that perform the same function should have the same shape.

(8) For knobs that must be recognized by touch alone, use easily recognizable knob shapes (see Figure 9-10).

Use bar and pointer knobs for discrete positioning operations, as, for example:

(1) Specify pointer-type knobs to indicate a marking or to indicate relative position from a fixed point.

(2) Use bar rather than pointer knobs when rotation is more than 360°.

(3) Specify bar or pointer knobs when only two or three settings are used.

Use concentrically ganged knobs under the following conditions:

(1) When the operations to be performed are sequential, or if going from one knob to the next is often done without visual reference.

(2) When used sequentially, they are located so that the front (smallest) knob is used first, the back (largest) is last.

(3) So that coarse settings are made with a small, inner knob; fine adjustments with a large, outer knob.

(4) If inadvertent operation of adjacent knobs or small delays are not important. Addition of shields on ganged knobs will reduce errors made on adjacent knobs.

(5) In cases where knobs of larger diameter are required, regardless of arrangement.

(6) When detent knobs or combinations of detent and continuous-rotation knobs are used.

(7) If space behind the display must be conserved.

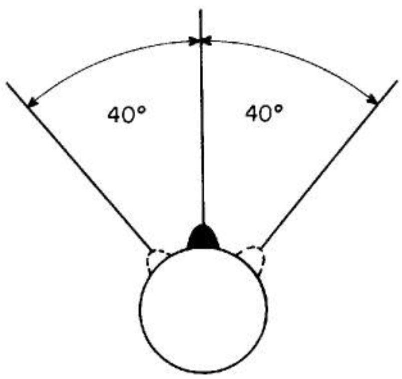


Figure 9-7. Desirable Knob Movement for Fine Adjustment

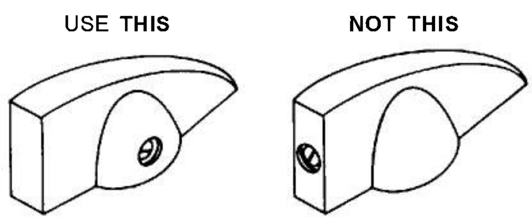


Figure 9-8. Set Screws for Control Knobs

TABLE 9-4. RECOMMENDED CONTROLS WHERE FORCE AND RANGE OF SETTINGS ARE IMPORTANT (Ref. 1)

For SMALL Forces And . . .	Use . . .
Two discrete settings	Hand pushbutton, foot pushbutton, or toggle switch.
Three discrete settings	Toggle switch or rotary selector switch.
Four to 24 discrete settings	Rotary selector switch,
Small range of continuous settings	Knob or lever.
Large range of continuous settings	Crank.
For LARGE Forces And . . .	**Use. . .**
Two discrete settings	Detent lever, large hand pushbutton, or foot pushbutton.
Three to 24 discrete settings	Detent lever.
Small range of continuous settings	Handwheel, rotary pedal, or lever.
Large range of continuous settings	Large crank.

TABLE 9-5. GENERAL DESIGN GUIDELINES FOR CONTROLS (Ref. 10)

Control	Type of Use	Recommended Separation (in.)		Size (in.)		Resistance		Displacement	
		Min.	Desirable	Min.	Desirable	Min.	Max.	Min.	Max.
Knob	One hand, randomly Two hands, simultaneously	1 3	2 5	Dia 0.375 in. Depth 0.5 in.	Dia 4 in. Depth 1 in.	Fingertip operation with smal dia (1 in.) 4.5 oz-in	Fingertip operation with smal. dia (1in.): 6 oz-in.		
Rotary selector switch (moving pointer, fixed scale)	One handed turning	Has not been determined.		Pointer length: 1 in. None	None Pointer width: 1in.	12 oz	48 oz	For visual positioning, 15° between detents; for nonvisual, 30°	Between adjacent detents: 40"
Rotary selector switch (fixed pointer, moving scale)		Has not been determined.		Knob dia 1 in. Knob depth 0.5 in.	Knob dia 4 in. Knob depth 3 in.	12 oz	48 oz	For visual positioning, 15"between detents; for nonvisual, 30°	Between adjacent detents: 40°
Toggle switches	One finger randomly	0.75	2	Tip 0.125 in., lever arm length 0.5 in.	Tip 0.125 in., lever arm length 2 in.	10 oz	40 oz	Between adjacent control PSNS—40°	120"
Lever	One and two handed operation	Has not been determined.		Length determined by mechanical advantage required.		For hand grasping: 2 lb	1 hand push-pull: 30 lb 1 hand right-left 20 lb 2 hand push-pull 90 lb 2 hand right-left: 30 lb	None set by operator performance	Fore-Aft mvt: 14 in. Lateral mvt: 38 in.
Push-buttons	One finger, randomly One finger, sequentially Different fingers, randomly or sequentially	0.5 0.25 0.5	2 1 0.5	0.5		10 oz	40 oz	0.125 in.	1.5 in.

TABLE 9-5. GENERAL DESIGN GUIDELINES FOR CONTROLS (Ref. 10) (cont)

Control	Type of Use	Recommended Separation (in.)		Size (in.)		Resistance		Displacement	
		Min.	Desirable	Min.	Desirable	Min.	Max.	Min.	Max.
Crank	One hand, randomly	2			For heavy loads: 20-in. radius min. For min. loads & very high rpm rate (upto 275): 4.5-in. radius	For small cranks (less than 3.5-in. radius) & high speed operation: 2 lb For large cranks 5—8-in. radius & high speed operation: 5 lb Precise setting (adjusting between 0.5 and 1 rotation): 2.5 lb	For small cranks (less than 3.5-in. radius) & high speed operation: 5 lb For large cranks 5—8-in. radius & high speed operation: 10 lb Precise setting (adjusting between 0.5 and 1 rotation): 8 lb	Determined by desired control display ratio.	

Do not use concentrically ganged knobs under the following conditions :

(1) When the knobs are in continuous rotation or have low friction.

(2) When frequent inadvertent operations of adjacent knobs cannot be tolerated.

9-5.2 SELECTOR SWITCHES

Consider the following general recommendations :

(1) Specify rotary selector switches for multiple positioning and for selection of three or more discrete positions.

(2) On fixed scales, the selector switch could be a moving pointer type knob (generally a bar type with a tapered tip).

(3) On rotary selector switches having covered scales, provide a skirt opening which permits the technician to view one major adjustment mark above and below the desired adjustment. Design the skirt so that the scale is readily visible when the control is being manipulated (see Figure 9-11).

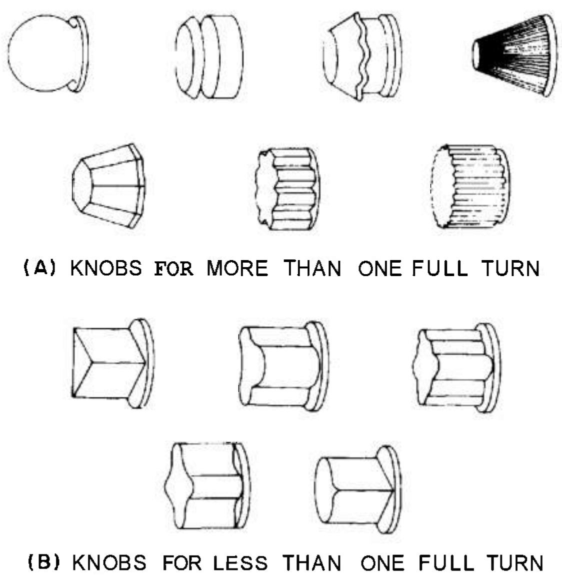


Figure 9-9. Recommended Knob Shapes

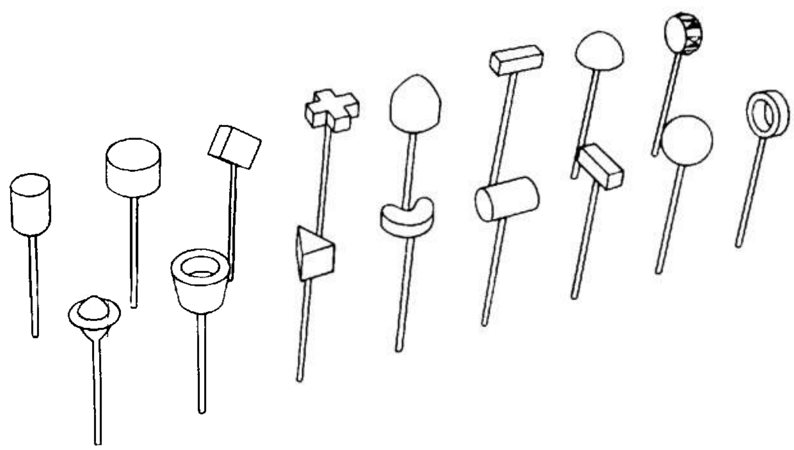


Figure 9-10. Easily Recognizable Knob Shapes (Ref. 31

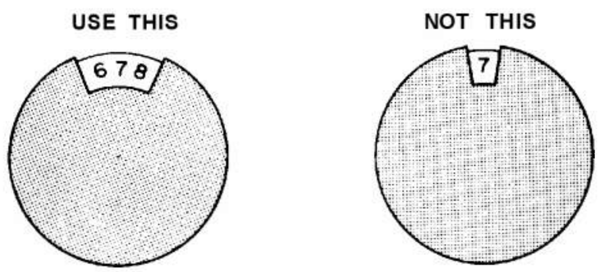


Figure 9-11. Visibility of Scale in Rotary Selector Switches

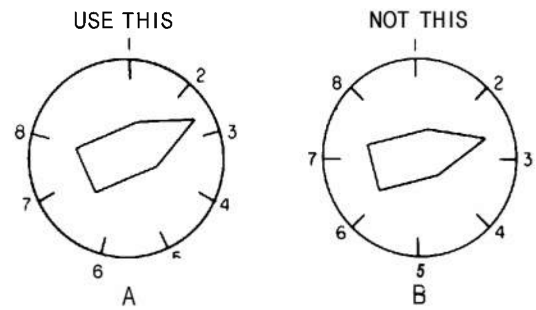


figure 9-12. No Two Selecfor-Swifch Positions Should be 180° from Each Other

(4) Use selector switch rather than require cable connections and disconnections for a number of test conditions.

(5) Avoid having any two positions 180" from each other. This situation, which might lead to setting errors and in reading the wrong end of the moving pointer, can be prevented by using less than the optimum (45°) separation, as shown in Figure 9-12.

(6) Design switches so that detent stops offer enough resistance to movement so that settings can be made by touch alone.

(7) Control loading should be sufficient to offset the resting weight of the operator's hand so that removing the hand will not inadvertently move the switch.

(8) Do not incorporate more than 24 positions in one rotary control.

(9) Provide stops at the beginning and end of the range of control positions.

(10) Position the pointer knob close to the scale to minimize parallax.

9-5.3 TOGGLE SWITCHES

Specify toggle switches when the following conditions exist:

(1) Control functions require no more than three (preferably one or two) discrete positions.

(2) Space limitations are severe.

(3) Fast and accurate operation is required.

(4) Switches are to be used in groups and position checking is necessary.

(5) "Blind" setting or checking of position might be required.

Do not specify when the following conditions exist:

(1) The switch must be coded.

(2) More than three positions are required.

(3) Accidental activation cannot be tolerated.

Mount toggle switches vertically wherever possible.

(1) The switch should move upward for ON, START, or INCREASE.

(2) The switch should move downward for OFF, STOP, or DECREASE.

(3) If switches must be mounted horizontally, a motion forward or to the right should correspond to ON, START, and INCREASE, and a motion rearward or to the left should correspond to OFF, STOP, and DECREASE.

Consider also the following:

(1) When one panel contains a number of toggle switches, they should all be OFF at the center position to facilitate checking the switch position.

(2) When used as momentary contact switches, place them in such a position that inadvertent activation is minimized. For example, place a switch of this kind near the bottom of a panel with the direction of movement upward. Design spring tension in a spring-loaded switch so that it is sufficient to return the switch to its normal position, but also so that it does not require undue force to hold the switch in the active position.

9-5.4 LEVERS

Use levers when the following conditions exist:

(1) Where large mechanical forces or displacements are involved and where multidimensional movement of the control is required.

(2) For levers perpendicular to the floor, knob handles or grips should be between the waist and shoulder of the operator. For levers parallel to the floor, hand grips should be placed approximately 28 in. above the floor for the standing operator to be able to exert the greatest lifting force.

(3) Levers should be pushed for greatest accuracy.

(4) For maximum push, place 29 in. from the seated operator's backrest.

(5) For fastest operation of a lever mounted in front of the operator, use a fore-and-aft direction. But, if a lever is mounted in front of the operator and must move in a lateral direction, more force can be applied moving toward the left with the right hand than by moving toward the right with the right hand.

(6) Maximum push or pull for the seated operator is obtained with the elbow at 135°, hand grip at about elbow height, and lever moving in a vertical plane passing through the height of the shoulder joint.

(7) Increasing the friction of the lever tends to increase accuracy. The addition of viscous damping or mass will help to maintain a more even rate of movement.

(8) Torque increase should be sensed as the terminal movement position is approached.

(9) Detent pressure should be provided on discrete position levers.

9-5.5 PUSHBUTTONS

Pushbuttons should be used where:

(1) Space is at a premium.

(2) There is a need for a momentary-contact control.

(3) The necessity exists for activating a locking circuit in a high frequency-of-use situation.

(4) Only one or two positions are needed.

(5) Coding by color, size, or shape is required.

(6) Grouping is required.

(7) Rapid switching between one of two positions is necessary.

(8) A tester to be designed is a hand-held unit. In this case specify pushbuttons in preference to trigger-type controls.)

Additional recommendations are as follows:

(1) Surface should be flat or concave to fit the finger (see Figure 9-13).

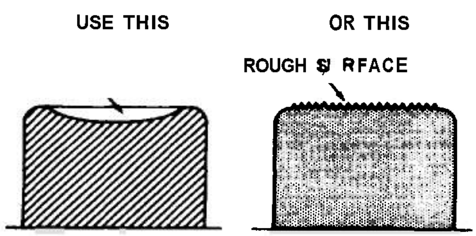


Figure 9-13. Pushbutton Surface Should Be Concave or Have Rough Surface

(2) Surface should provide a high degree of frictional resistance to prevent slipping.

(3) Size should be large enough so that it can be pushed repeatedly without discomfort.

(4) When the operator will have many push-buttons to activate, and other tasks demanding his attention, consider using pushbuttons with raised (or lowered) forms to reduce the possibility of error.

(5) Spring load for momentary-contact switches.

(6) Provide an audible click or detent to indicate that the control has been activated.

(7) Arrange pushbutton in a horizontal rather than vertical array.

9-5.6 CRANKS

Use cranks under the following conditions :

(1) Select cranks for tasks involving at least two rotations of a control. Specify cranks when turning speeds are above 100 rpm.

(2) For operations involving rapid turning and accurate settings, use a combined hand-wheel and crank; the crank to permit rapid transversing, and the handwheel, gripped by the rim, to permit accurate settings.

(3) Handle shape should allow the maximum amount of contact with the surface of the hand, and the handle should turn freely around its shaft (see Figure 9-14).

The location of the crank depends on its speed, load, and on the operator's position :

(1) Place for the standing opertor **36** to 48 in. above the floor.

(2) For light loads, with high rpm, locate so axis of rotation is perpendicular to the frontal plane of the operator's body. Mount on either side rather than the center of the frontal work area.

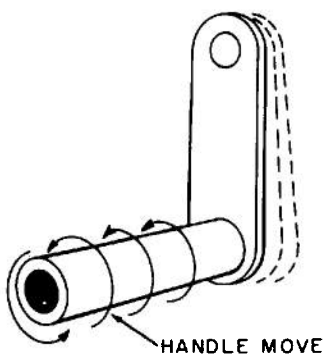


Figure 9-14. lever Handles Should Move Freely

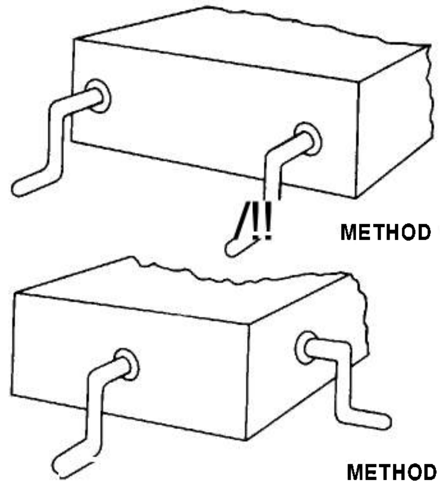


Figure 9-15. Positioning Two Cranks Thaf Are To Be Rotated Simultaneously

(3) For heavy loads, use large side-position crank with axis of rotation parallel to the frontal plane of the operator's body.

(4) For two cranks rotating simultaneously, place the cranks as suggested in Figure 9-15.

(5) To increase the amount of control the operator has when the crank is to be rotated slowly, weight the crank to increase the inertia.

(6) To keep a pointer on a moving target, use a high-speed crank (up to 200 rpm.) to make the movement more accurate and controlled.

(7) If the ratio of fast-to-slow crank operating speed is greater than **2** to **1**, i.e., the fastest speed is more than twice the slowest speed, allow the operator a choice of two gear ratios.

(8) Provide each crank with three possible positions: IN position for rapid slewing in either direction, OUT position for fine adjustment, and a middle or neutral position to keep inadvertent movement from affecting the control. The crank should be spring loaded to return to the neutral position when pressure is released.

9-6 DISPLAYS

The function of a display is to provide the operator with information on which he can act. The information is usually presented by dials and scales, counters, scopes, warning lights and buzzers, and printed material. The ultimate goal in selecting displays is to choose those that provide the operator with the exact amount of information required to carry out the functions of the system, but which present him no more information than he will have to use.

9-6.1 SELECTING THE APPROPRIATE DISPLAY

Use dials, scales, gages, or meters for the following conditions:

(1) To indicate direction of movement or orientation in space.

(2) To distinguish increasing or decreasing trend of the values measured by the instrument.

(3) When only an approximate reading is important.

(4) For check reading rather than continuous monitoring.

Use direct-reading counters for the following conditions:

(1) For rapid and accurate reading of stationary or slowly changing quantitative information.

(2) As an indication of revolutions in multirevolution indicators.

(3) When economy of panel space is important.

Use scopes (cathode-ray tubes) in the following situations:

(1) For primarily continuous monitoring activity.

(2) To monitor direction of movement of another vehicle (as in radar).

(3) To monitor or check read frequency or amplitude waves (as sampling the output of a radar transmitter).

Use lights in the following situations:

(1) For qualitative go/no-go indicators, on-off indicators, malfunction indicators, emergency warning lights (use flashing signals), inoperative equipment indicators, caution indicators, and indicators for operability of separate components.

(2) For critical information when there is sufficient space on the panel (legend lights—words or numbers that are lighted from behind).

(3) As warm-up indicators.

Use auditory displays (buzzers, bells, etc.) for the following situations (see also Paragraph 9-6.8):

(1) To notify the operator of the end or that he is approaching the end of an operating cycle.

(2) As an emergency or warning device.

(3) When the immediate reaction of the operator is important.

Use auditory displays with, or as alternatives to, lights in the following situations:

(1) When environmental lighting conditions are such that lights might not be easily detected.

(2) When the operator will be occupied monitoring lights, dials, counters, and scopes.

(3) When multiple signals (warning, emergency, malfunction) are needed.

(4) When extreme redundancy is required.

Table 9-6 lists the relative advantages and disadvantages of the four basic indicator types.

9-6.2 SCALES

In most cases, a circular scale is preferable to a straight scale. In straight scales, the horizontal is generally recommended over the vertical. When a number of instruments must be checked, the circular scale with moving pointer should be used. When designing an instrument with fixed pointer and moving scale, the unused portion of the scale should be covered. When several scales are on one dial, use some method such as the following by which the scales can be easily identified.

(1) Use the same numerical progression for all indicators.

(2) Use maximum contrast between scale face and markings.

(3) Arrange numbers on scales so that they are easily read.

(4) Locate numbers so that they are not obscured by either the bezel or the pointer.

(5) Design circular scales so that the numbers increase clockwise.

(6) Design straight- or drum-type scales so that the numbers increase from left to right or bottom to top.

(7) On stationary scales, numbers always should be in the upright vertical position.

(8) On moving scales, orient all numbers so as to be upright at the reading position.

TABLE 9-6. RELATIVE EVALUATION OF BASIC SYMBOLIC-INDICATOR TYPES

Method of Use	Moving Pointer	Moving Scale	Counter	Flag
Quantitative reading	Fair	Fair	Good: required minimum time with minimum reading error.	Do not use.
Qualitative and check reading	Good: location of pointer and change in position easily detected.	Poor: difficult to judge direction and magnitude of pointer deviation.	Poor: position changes not easily detected.	Good: presence of flag easily detected.
Setting	Good: has simple and direct relation between pointer motion and motion of setting knob; pointer position change aids monitoring.	Fair: has somewhat ambiguous relation between pointer motion and motion of setting knob.	Good: most accurate method of monitoring numerical settings, but relation between pointer motion and motion of setting knob is less direct.	Not applicable.
Tracking	Good: pointer position readily monitored and controlled; provides simple relationship to manual control motion; provides some information about rate.	Fair: not readily monitored; has somewhat ambiguous relationship to manual control motion.	Poor: not readily monitored; has ambiguous relationship to manual control motion.	Not applicable.
General	Good: but requires greatest exposed and illuminated area on panel, and scale length is limited.	Fair: offers saving in panel space because only small section of scale need be exposed and illuminated, and long scale is possible.	Fair: most economical in use of space and illuminated area; scale length limited only by number of counter drums, but is difficult to illuminate properly.	Useful for qualitative readings; may take little room.

(9) On indicators that use moving scales and fixed pointers, the numbers should increase clockwise around the dial face, and movement of the dial face should be counterclockwise.

(10) All major scale divisions should be numbered.

(11) The height-to-width ratio of numerals should be 5:3.

Number progression on scales should be consistent with normal habit patterns, namely:

(1) The optimum design is one with a major, numbered, graduation mark for each 10 units and a minor, unnumbered, graduation mark at each unit. (Numbering the minor graduations tends to decrease the reading accuracy.)

(2) Design scale so that an adequate reading can be obtained by reading to the nearest whole number.

(3) When numbered scales require interpolation, the intervals should progress by 10's or by 20's.

(4) Use graduation intervals of 1, 5, or 10. (See Figure 9-16.)

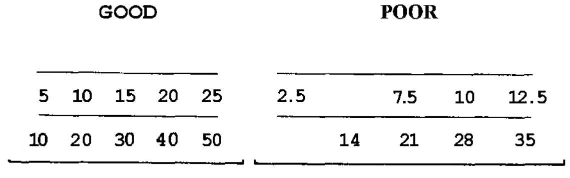


Figure 9-16. Scale Number Progression

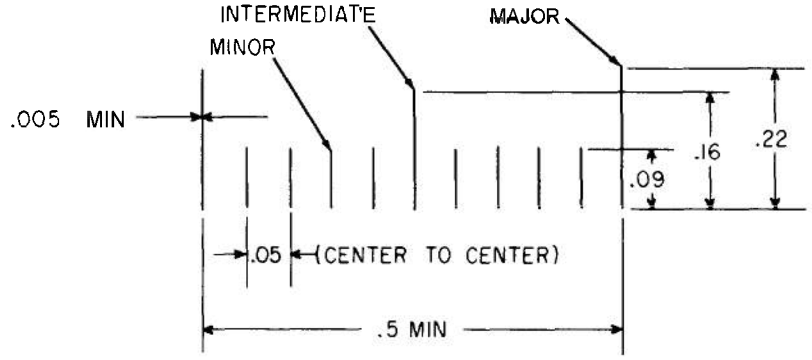


Figure 9-17. Graduation Intervals (Inches)

(5) For feet and inches, use intervals of **1, 3,** or 6.

(6) For pounds and ounces, use intervals of **1, 2, 4,** or 8.

(7) For scales such as clocks or compasses, the following progressions are best :

3	6	9	12
30	60	90	120
1	10	100	1000

All scales on the same equipment should have similar number arrangement and progression ; also make scale breakdown and numbering similar on all adjacent dials. Size, height, and number of scale markers should be carefully selected. Line markers should be the same width as the pointer. The optimum width for both is one-tenth of a division width. Additional recommendations are as follows:

(1) Provide sufficient markers so that interpolation on a scale need be no more accurate than one-fourth the space between two marks.

(2) Mark-height-to-mark-separation ratio should be from 1: 1 to **2: 1.** This ratio should never go as high as 5 : 1.

(3) Do not make the height ratio of major to intermediate marks more than 1.5 to 1.

(4) Make the height ratio of intermediate to minor marks at least 1.5 to 1.

Select graduation intervals approximately equal to the degree of accuracy required in reading the indicator, namely :

(1) Scale divisions should not exceed the inherent accuracy of the instrument or the accuracy with which the instrument must be read.

(2) Figure 9-17 gives recommended minimum dimensions and spacing for graduation intervals.

(3) The number of graduation marks between numbered intervals should not exceed **9.**

Scale reading accuracy depends on the linear separation of graduation marks ; accordingly, the following should be considered :

(1) To reduce the size of errors made, use finer scaling.

(2) To reduce the number of errors in interpolation (in terms of the proportion of the intervals in which errors were made, increase the distance between markers. The optimum distance is 0.25 to 0.5 in.

(3) In scales graduated by tens, the accuracy of reading to tenths of divisions increases as the distance between graduation marks increases to about 0.75 in.

(4) For greatest accuracy in reading scales to units, the distance allocated to each scale unit should be between 0.05 and 0.1 in.

Avoid the use of scales with irregular distances between intervals. Consider the following guidelines :

(1) Desirable graduations of a linear scale and two types of irregular scales are illustrated in Figure 9-18.

(2) Do not precede scale intervals that require maximum reading accuracy and speed in interpolation by scales of shorter interval length.

(3) For expanded scales, graduation by units or twos is better than graduation by fives or tens.

Staircase scales can be used to avoid confusion and to aid in interpolation. The staircase scale (Figure 9-19) is one in which the unmarked scale graduations increase in length from the lesser division to the higher.

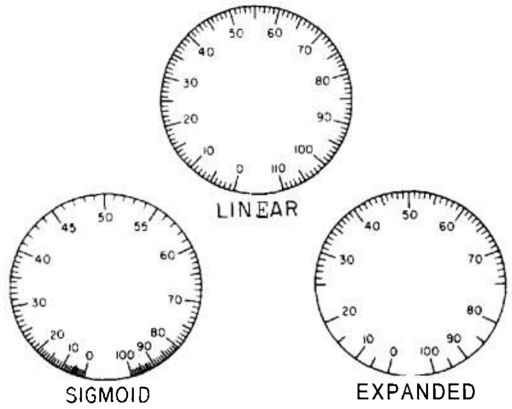


figure 9-18. Linear and Irregular Scales

Figure 9-19. Staircase Scale

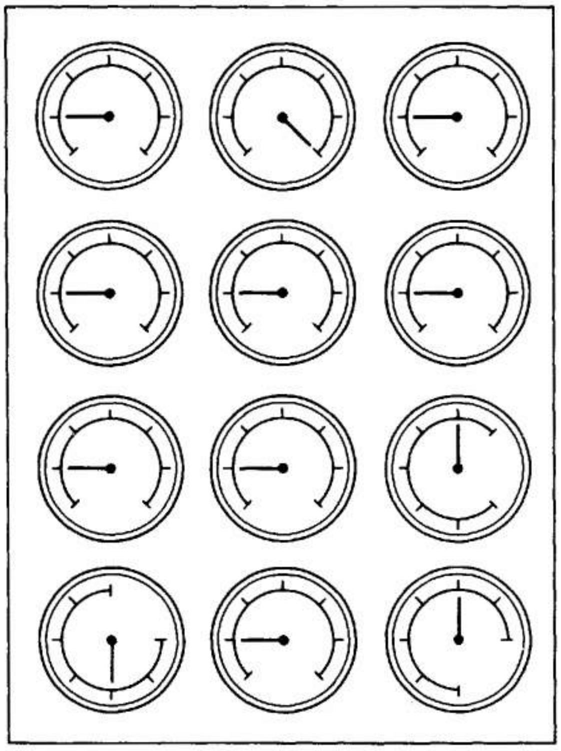


figure 9-20. Check-Reading Dials

The critical regions of a circular scale should be assigned to the 9-, 12-, 3-, or 6-o'clock position. Additional recommendations in this area are as follows:

(1) On a semicircular scale, place critical readings in the center of the scale.

(2) On a linear scale, avoid placing critical scale markings on or near either end of the scale.

(3) On a vertical scale, avoid placing critical scale markings at the top of the scale.

(4) Dials that range over low scale values and are numbered by tens, should be so oriented that the scale region over which the most frequent or critical quantitative readings are made appears in the left half.

When designing indicators that are to be used extensively for check-readings, indicate the desired readings or range on the scale. With a group of such dials, orient them so all pointers are in the same relative position at the correct reading (3-, 6-, 9-, or 12-o'clock position). Thus, if one or more dials shows an incorrect reading, it is immediately apparent (see Figure 9-20).

Circular scales should have a scale break, and the scale zero should be near the bottom. When using a moving pointer and a fixed scale, provide an obvious scale break, between the two ends of the scale, of not less than 1.5 divisions (except on multirevolution instruments).

9-6.3 DIALS AND DIAL FACES

No one type is best under all conditions. The designer must consider the proposed use, the limitations imposed by conditions, such as lack of panel space, and the relationships of the various dials that constitute the particular display. The following recommendations should be considered.

(1) A fixed-face dial is usually preferable to a fixed-pointer dial.

(2) Use dials with fixed pointers and moving scales when a large range of values will be included, when panel space must be conserved,

and when only quantitative readings are required. Only a portion of the scales should be exposed on dials of this type, but two numbers should be visible at all times to provide a reference for reading direction.

(3) If vertical or horizontal direction is being measured, use a vertical dial for vertical movement; a horizontal dial for horizontal movement.

(4) In general, circular dials should have diameters of from 1 to 4 in. Investigation has shown that when a panel contains many dails, 1.75-in.-diameter dials are check-read more rapidly and accurately than larger or smaller dials.

(5) Design dial faces as simply as possible.

(6) Delete from dial faces all useless material, such as company trade names, model, and serial numbers.

(7) Each dial should be restricted to one quantitative scale and not more than two qualitative or check scales.

(8) Place numerals on the side of the graduation marks away from the pointer to avoid having the numeral covered by the pointer. If space is at a premium, place numerals inside the marks to avoid constricting the scale.

Dial windows should be less brittle than ordinary glass and resistant to scoring. On trans-illuminated dials, use a fluorescent or clear plastic disc with an embossed pointer.

9-6.4 POINTERS

Pointers should be designed to be as simple as possible; all unnecessary "frills" should be avoided. Recommendations for pointer design are as follows:

(1) Pointers should extend to, but not overlap, the minor scale markings, as shown in Figure 9-21(A).

(2) The pointer should be as close to the dial face as possible to minimize parallax, as shown in Figure 9-21(B).

(3) If the pointer is to be used for reciprocal readings, the two ends of the pointer should be easily identified, as shown in Figure 9-21(C).

(4) The recommended pointer angle is as shown in Figure 9-21(D).

(5) The pointer tip should be the same width as the narrowest scale markers and should be visible in both daylight and artificial lighting.

(6) Fully visible pointers are superior to partially covered pointers.

(7) When check or qualitative readings are necessary, the fully visible pointer should be used.

(8) When only quantitative readings will be made, a partially covered pointer can be used.

(9) Paint pointer numbers and scale markers the same color.

(10) Pointers should be located to the right of vertical scales and at the bottom of horizontal scales.

(11) There should be no more than two tips on a single pointer shaft.

(12) When the design of an instrument seems to call for multiple pointers, analyze for sources of human error.

(13) As an alternative to multiple pointers, consider using subdials or counters to augment the primary pointer.

(14) Numerical readings should increase by the movement of a pointer up, to the right, or clockwise.

(15) Where plus and minus values around a zero value are displayed, design so that plus values increase with movement of the pointer up or to the right, and minus values increase with movement down or to the left.

(16) For an instrument mounted in an array with other instruments, consider the total arrangement in arriving at pointer orientation.

(17) If the instruments will be separated vertically, align the pointer to read in tolerance at the 10-o'clock position.

(18) For horizontally separated instruments, or where there will be several rows separated

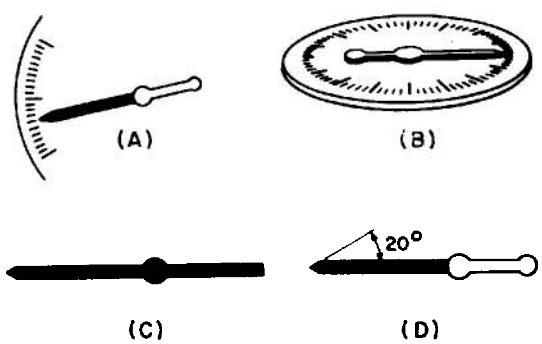


Figure 9-21. Pointer Design

both horizontally and vertically, align pointers at the 9-o'clock position.

9-6.5 COUNTERS

Use direct reading counters instead of dials when only a quantitative reading is necessary and when the scale length would make a dial too complex. Avoid counters when the following conditions exist:

(1) When a setting must be put into an indicator rapidly.

(2) When the data change rapidly (more than two per second).

(3) When a qualitative reading (change in direction or magnitude) is required.

(4) When several instruments must be monitored simultaneously.

The following design recommendations should also be considered:

(1) Mount counters as close to the panel surface as possible to provide maximum viewing angle and minimum parallax and shadow.

(2) Avoid large horizontal spacing between number drums on counters.

(3) Counters should read horizontally, from left to right, rather than vertically.

(4) When the visible area of the counter drum around each number is small, make the counter frame the same color as the drum.

(5) Numbers on counters should have a height-to-width ratio of 1:1. Numerical reading should increase with upward drum rotation. This is especially important when a manual control is used to set numerical values into the counter. All digits should "snap" in, not "glide" in. Numbers should not follow each other faster than about two per second. "Glide" action might be preferred in those instances where the range of readings is low and the numbers change very slowly, but the window must be large enough for the operator to see both numbers during the transition.

(6) Do not show useless digits when presenting information on a counter.

(7) When numbers are large and the last digits have little or no value, replace with stationary zeros.

(8) When numbers are small and zeros might ordinarily appear in the drums at the extreme left, blank out these drums completely when no numerical value is to appear.

(9) When a counter is used to indicate sequencing, the equipment should be designed to reset automatically upon completion of the sequence. To set numbers on manually-operated counters, use knobs in preference to thumb wheels.

(10) Make the control display ratio such that one revolution of the knob equals about 50 counts, i.e., the right-hand drum rotates 5 times.

(11) Clockwise rotation of the knob should increase the numbers on the counter and provide upward movement of the drum, as shown in Figure 9-22(A).

(12) Do not space numbers too far apart; or crowd them too close together, as shown in Figure 9-22(B).

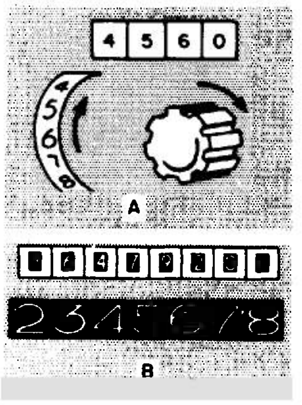


Figure 9-22. Counter Design

9-6.6 SCOPES

When plotting is not required, a 5- to 7-in. scope diameter is adequate. The shape of the bezel or frame around a scope should be dictated by the type of presentation. Use a round frame for a PPI presentation and a rectangular frame for an A-scan device. Consider also the following:

(1) Design to insure maximum viewing efficiency.

(2) Surround with nonreflecting surfaces and edges.

(3) When high ambient illumination cannot be avoided, provide hoods or recess the face.

(4) Avoid direct light reflection wherever possible.

(5) Use filters on flat-face tubes to reduce surface reflections.

(6) Provide grid markers to increase the accuracy of interpolation.

(7) Equip with a cursor or pantograph for accurate reading. Electronic cursors are useful in eliminating parallax and increasing accuracy.

(8) When waveforms must be matched, provide standards that are visible to the operator while he is doing the matching.

9-6.7 LIGHTS

Light indicators should be used sparingly. Lights used infrequently should be concealed but easily accessible and visible when required. Lights should be located on or near the controls with which they are associated. But, if the control is not near the operator's normal line of sight, the light should be placed where it will be seen quickly even though it may not be near the control. The following design recommendations should also be considered :

(1) Provide indicator lights to give the operator information on equipment status.

(2) Provisions should be made to prevent reflected sunlight from making lights appear as illuminated. Frost or otherwise treat all indicator and warning lights.

(3) Provide warning lights near all danger points.

(4) A warning device, such as legend lights, should tell the operator what corrective action is needed. Such lights should be clearly labeled, the labels adequately illuminated, and the wording of the labels clearly indicating what should be'done.

(5) Provide a press-to-test capability so the operator can rely on warning lights being operative. As an alternative, design each warning light with two lamps in parallel so that if one burns out the other will still provide a warning.

(6) When there are many lights on a single panel, provide a master light that indicates when any portion of the system is operating out of tolerance.

(7) Lights should be provided on all testers to indicate that warm-up is completed.

(8) Provide lights to notify the operator of the end or approaching end of the cycle.

(9) Color code lights as shown in Table 9-7.

TABLE 9-7. COLOR CODING OF INDICATOR LIGHTS

Red	Amber or Yellow	Green	White	Blue	Indicator Size
Immediate action, unsatisfactory or hazardous condition (malfunction, action stopped, failure, stop action)	Impending or unsatisfactory condition requiring alertness or caution (delay, check, recheck)	Equipment is operating or in satisfactory condition (go ahead, in tolerance, acceptable, ready)	Neutral status (functional or physical position, action in progress)	Action in progress, standby	0.5-in. dia
Extreme emergency					1-in. dia,* flashing 3-5 sec. (ON time should be at least 0.1 sec. and slightly shorter than OFF time)
	Extreme cautionary conditions indicating impending danger				1-in. dia,* steady

*These indicators should be approximately twice as bright as 0.5-in. dia lights.

(10) Make warning lights at least as bright as the brightest source on the panel, but they should be at least five times as bright as the surroundings. To maintain this brightness contrast, provide a brightness level control. Lights should not be so bright, however, that they interfere with any control setting or meter reading necessary to the operations involved.

(11) For flashing lights, make provisions for lights to illuminate steadily, if flasher device fails.

9-6.8 AUDITORY WARNING DEVICES

The principal characteristics and special features of different types of auditory alarm and warning devices are presented in Table 9-8. Design recommendations for auditory alarm and warning devices are presented in Table 9-9. Additional desirable characteristics for auditory presentations are as follows:

(1) It must be easily detectible.

(2) The signal should hold the operator's attention.

(3) It must be distinctive and quickly and accurately identifiable.

(4) Use undulating or warbling tones, and make the sound at least 20 db above threshold. Use a tone of lower frequency than the background noise, but do not use frequencies below 500 cps. Do not use signals that give the operator discomfort or that exceed his capability for responding.

(5) Do not use continuous, high pitched tones as warning signals above 2000 cps.

(6) Make the initial sound in a warning system as brief as possible to reduce the need for overlapping or simultaneously monitoring reception. Require simultaneous monitoring of two or more auditory channels only when each channel contains information directed toward a single operation and when none of the information is contradictory.

(7) Avoid signals that require interpretation

TABLE 9-8. TYPES OF ALARMS, THEIR CHARACTERISTICS AND SPECIAL FEATURES (Ref. 1)

Alarm	Intensity	Frequency	Attention Getting Ability	Noise Penetration Ability	Special Features
Diaphone (foghorn)	Very high	Very low	Good	Poor in low frequency noise Good in high frequency noise	
Horn	High	Low to high	Good	Good	Can be designed to beam sound directionally Can be rotated to get wide coverage
Whistle	High	Low to high	Good if intermittent	Good if frequency is properly chosen	Can be made directional by reflectors
Siren	High	Low to high	Very good if pitch rises and falls	Very good with rising and falling frequency	Can be coupled to horn for directional transmission
Bell	Medium	Medium to high	Good	Good in low frequency noise	Can be provided with manual shutoff to insure alarm until action is taken
Buzzer	Low to medium	Low to medium	Good	Fair if spectrum is suited to background noise	Can be provided with manual shutoff to insure alarm until action is taken
Chimes and gong	Low to medium	Low to medium	Fair	Fair if spectrum is suited to background noise	
Oscillator	Low to high	Medium to high	Good if intermittent	Good if frequency is properly chosen	Can be presented over intercom system

while the operator is performing a repetitive task.

(8) Separate auditory channels used by different operators.

9-6.9 LIGHTS VS AUDITORY PRESENTATIONS

Some signals are better suited for auditory than for visual presentation and vice versa. Table 9-10 summarizes the situations in which one form of presentation is preferred over the other.

Situations in which either auditory presentations or lights may be used are as follows:

(1) For signals already anticipated by the operator.

(2) For responses that are discrete, short, and follow another presentation quickly.

Situations in which both auditory and light presentations may be used are:

(1) Where environmental conditions handicap data presentation through either auditory or visual sense alone, e.g., low illumination or high noise levels.

(2) For warnings of extreme emergency.

(3) Where great redundancy is desirable.

9-6.10 PANEL LAYOUT

Controls that the operator manipulates to change the state of the equipment are located on a panel. Also located on the panel are the displays that indicate what he should do, when he should do it, and whether he has done it adequately. Besides considering the general recommendations given here, the designer should ana-

TABLE 9-9. DESIGN RECOMMENDATIONS FOR AUDITORY ALARM AND WARNING DEVICES

Conditions	Design Recommendations
1. If distance to listener is great.	1. Use high intensities and avoid high frequencies.
2. If sound must bend around obstacles and pass through partitions.	2. Use low frequencies.
3. If background noise is present.	3. Select alarm frequency in region where noise masking is minimal.
4. To demand attention.	4. Modulate signal to give intermittent "beeps" or modulate frequency to make pitch rise and fall at rate of about 1-3 cps.
5. To acknowledge warning.	5. Provide signal with manual shutoff so that it sounds continuously until action is taken.

TABLE 9-10. LIGHTS VS AUDITORY PRESENTATIONS

Use Visual Presentation if:	Use Auditory Presentation if:
1. The message is complex.	1. The message is simple.
2. The message is long.	2. The message is short.
3. The message will be referred to later.	3. The message will not be referred to later.
4. The message deals with location in space.	4. The message deals with events in time.
5. The message does not call for immediate action.	5. The message calls for immediate action.
6. The auditory system of the person is overburdened.	6. The visual system of the person is overburdened.
7. The receiving location is too noisy.	7. The receiving location is too bright or dark adaptation integrity is necessary.
8. The person's jpb allows him to remain in one position.	8. The person's job requires him to move about continually.

lyze the operations to be performed, and the environmental conditions under which the equipment will be operated, i.e., to determine whether the maintenance man's clothing will demand certain changes in design, or whether nighttime operation, operation under conditions of low illumination, or operation over extended periods of time will impose stresses on the maintenance man.

9-6.10.1 Placement of Controls and Displays—General

General recommendations to be considered in coordinating the placement of controls and displays are as follows:

(1) Place frequently used or critical controls and displays in preferred locations (see Figure 9-23).

(2) Make all controls and displays accessible and readable. Controls and displays should be designed so that the maintenance man can visually check their positions or readings accurately, regardless of the angle from which he views them.

(3) All controls and displays used in a given procedure should be located on the same panel. When two or more controls must be activated simultaneously or in rapid sequence, place them so that they can all be reached from a fixed position. Displays likely to be read together should be grouped together. Consider the following guidance relative to the grouping of controls and displays:

(a) Grouping can be achieved by spatial location, or by color, size, or shape coding (see Paragraph 9-6.10.3 for coding of controls and displays).

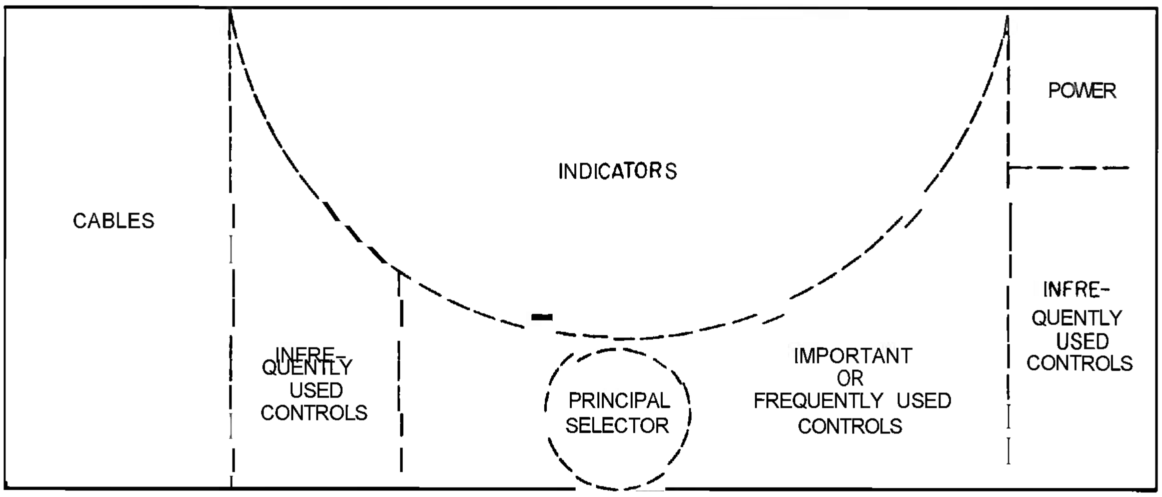
(b) If spatial grouping is used, the group can be isolated by enclosing it with a white line or by using fields of different colors as backgrounds. It should be noted, however, that the more groups of this type that are used, the less effective they are.

(c) Controls and displays should be grouped according to the system to which they pertain. On a complex panel, for instance, the controls for a particular system should be placed close together.

(d) Controls operated by the right hand should be located below or to the right of their associated displays.

(e) Controls operated by the left hand should be located below their associated displays. They can also be located to the left of the display provided that direction-of-motion relationships are not violated.

(f) When concentric (ganged) knobs are associated with displays, the displays should be arranged in a row from left to right. The front (small) knob should control the left display, the middle knob the middle display, and the back knob the right display.



(g) When the manipulation of one control requires the reading of several displays, place the control as near as possible to the related displays and beneath the middle display.

(4) When controls and displays are located on separate panels and both panels are mounted at approximately the same angle relative to the operator, the controls on one panel should occupy positions corresponding to those of their associated displays on the other panel. The two panels when installed should ***never*** face each other. Factors to be considered are:

(a) When there are a large number of displays on the same panel they should be arranged with either each display directly above its associated control, or, with all displays in the upper portion and all controls in the lower portion of the panel. Each control then should occupy the same relative position as its associated display.

(b) Mount controls on the same plane as the displays they control.

(c) Displays and controls should move in the same plane of space.

(d) When a toggle switch is used with a counter, the frontal plane is preferred for mounting.

(e) Align dials horizontally rather than vertically. If dials are horizontally aligned, mount them so that the "normal" position of the pointer is at 9 o'clock. If dials must be vertically aligned, mount them so that the "normal" position of the pointer is at 12 o'clock.

(f) Place controls so that one control is not located behind another of similar height.

(g) Place controls with forward movement at the top of a vertical panel and controls with rearward movement below them.

(h) Do not place more than two controls of the same kind and shape side by side except in the case where a crowded and complex control panel makes a whole series of similar controls difficult to locate.

(i) Separate controls or displays that **can** be easily mistaken for one another. Discrimination can be increased between two similar controls by an increase in their physical separation.

(5) Arrange controls and displays in the sequence of their use; for example:

(a) Group controls that are always used in a fixed sequence, or for a particular function, to facilitate their use and effect economy of operation motion.

(b) Place controls and displays so their relative positions will coincide with the sequence in which they will be used. Indicate their sequence of operation by numbering (see Figure **9-24**).

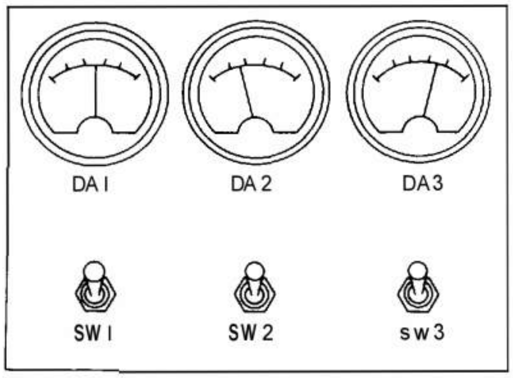


Figure 9-24. Arrangement and Numbering of Controls and Displays Used in Sequence

9-6.10.1.1 ***Placement of Controls.*** The following factors should be considered in the placement of controls :

(1) Frequently used controls should be designed for right-hand operation and should be grouped together unless there are overriding reasons for separating them.

(2) If a frequently used control must be placed outside the central area of the panel, provide an indicator light in the central area to indicate when the control should be activated.

(3) Cover, or place to one side, controls that are infrequently used, especially if they might be inadvertently activated.

(4) All controls should be within the maximum reach of the operator when seated.

(5) Arrange controls to allow for continuous movement, e.g., from left to right, through an arc, etc.

(6) Place controls that are to be operated simultaneously close to each other.

(7) Frequently used controls should be located where they can be seen and operated without disassembling or removing any part of the installation.

(8) Occasionally used controls should be mounted behind hinged doors or recessed in the panel to prevent inadvertent use.

(9) Seldom used adjustment controls should have shaft locks or screwdriver slots.

(10) All maintenance controls should be located on one side of a unit, a side that will be accessible in the normal installation.

(11) Place controls so that there is an equitable distribution of work load between the right and left hands. The right hand should be used for those operations requiring the finest adjustments.

(12) Place all controls of a similar type so that they turn on and off in the same direction.

(13) The relative position of controls should not be changed from one piece of equipment to another piece of similar equipment. If it is necessary to change the position of controls, the shape of the handles on the controls being changed remain the same as they were originally.

(14) Place controls to reduce the possibility of inadvertent activation, damage, or personnel injury. Take into consideration that:

- (a) The best position for knobs least likely to be accidentally touched is directly to the left and above the knob to be operated.
- (b) Accidental touching is less frequent in a vertical array than in a horizontal array.

(15) Locate controls so they can be operated with the least expenditure of energy. The following factors should be considered:

- (a) For maximum force, place levers at shoulder height for standing operators and at elbow height for seated operators.
- (b) Place frequently used controls so that operators will *not* be forced to maintain awkward positions (reaching way up or holding the arm extended) for long periods of time. Infrequently used, but critical controls should be located so they do not require excessive stretching.
- (c) Do not exceed the reach of the average operator when laying out controls.
- (d) Assign to the hands the controls that require high precision or speed of operation, and assign the major load to the right hand.
- (e) Assign to the feet controls that require large application of force.

9-6.10.1.2 Placement of Displays. Consider the following factors in the placement of displays:

(1) Frequently monitored displays should be within the operator's normal line of vision.

(2) Infrequently used displays can be in the periphery of the visual field.

(3) The viewing distance to displays should not exceed 28 in. and should never be less than 13 in.

(4) Place all displays that are to be used together at the same viewing distance.

(5) Warning lamps should be within 30" of the normal line of vision and adjacent to the control with which the operator is to take action.

(6) Mount displays perpendicular to the line of sight. The maximum deviation for displays, other than scopes, should be ± 45°. The maximum deviation for scopes should be 30".

9-6.10.1.3 Placement of Receptacles and Plugs. Consider the following factors when attaching receptacles and plugs to control panels:

(1) Cable connections, receptacles, and plugs should be placed on the left side of the panel in a separate section. When possible, angle this section back away from the place of the panel, or else use right angle connectors (see Figure 9-25).

(2) Receptacles should be placed so that the larger or more bulky cables are at the bottom and the smaller ones nearer the top, with the power receptacle and fuses at the very top.

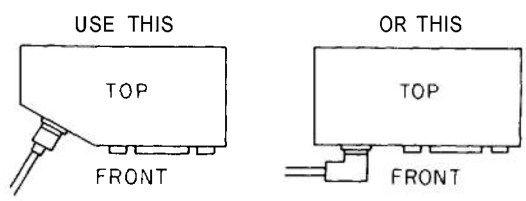


Figure 9-25. Control Panel Cable Connections

9-6.10.2 Panel labeling

The following factors should be considered when labeling panels:

(1) Identify all controls and displays by clear and unambiguous labels. Label instruments according to what is measured, *not* by the name of the instrument. For example, use RPM not tachometer and VOLTAGE not voltmeter.

(2) Controls should be labeled by function and direction of movement.

(3) Place high-contrast, arrow-type pointers at the extremity of the control movement to show direction of movement, and place labels at the tips of the arrows.

(4) Use abbreviations only if you *know* that they will be familiar to the operator.

(5) Where two controls or displays are identical, use labels that are also identical.

(6) Position labels **on** controls or immediately adjacent to them; if adjacent, place labels above, if possible, so they are not masked when the controls are manipulated.

(7) Labels should be consistently in the same place, some labels under and others over what they identify (see also Chapter **13**).

9-6.10.3 Coding of Controls and Displays

Code information only when necessary. Make codes as simple and common as possible. Use shape, size, or color coding or code by grouping of controls and displays. Additional guidance is as follows:

(1) When controls are to be operated by touch alone, code by shape or size. Recommended shapes for coding of operating controls are illustrated in Figure **9-26**.

(2) Use size coding when only two or three controls are involved.

(3) Size and shape coding can be used in combination because ability to discriminate shape is relatively independent of size discrimination.

(4) Avoid shape and size coding if the operator might be wearing thick gloves.

(5) In shape coding, select shapes that can be easily identified.

(6) Make all shapes used in different applications sufficiently different from each other to avoid confusion. As a minimum test of adequacy, do not use any combination of shapes that cannot be readily discriminated visually.

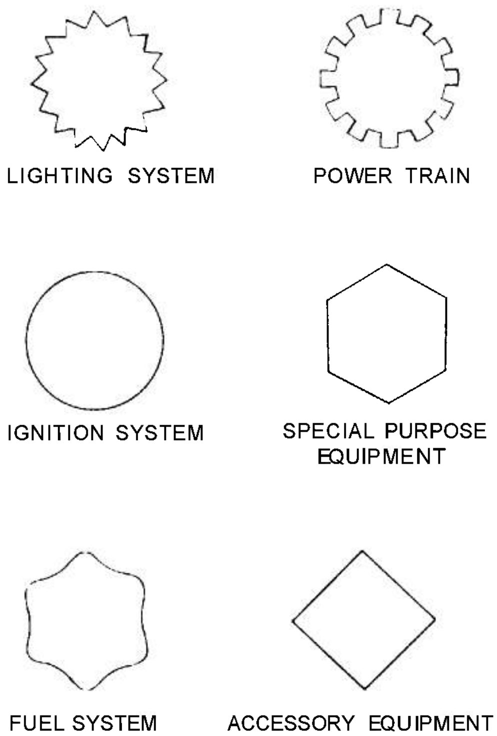


Figure 9-26. Recommended Shapes for Coding of Operating Controls *(Ref. 2)*

(7) Make all controls used for a similar purpose or function of the same shape.

(8) In shape coding hand controls, specify shapes that are comfortable and provide for adequate grasping, especially where large forces must be exerted. Consider the type of gloves the operator might be wearing. Do not permit sharp edges or corners where rapid or forceful actions are anticipated.

(9) Shape coding is recommended when a group of rotary controls on a single panel are used for widely different functions.

(10) Levers that are in close proximity and cannot be readily discriminated from each other, should have shape coded handles.

(11) When color coding controls and displays, the pattern should be consistent with regard to function. Factors to be considered are:

(a) Keep the meaning of a particular color consistent throughout a prime equipment.

(b) Give the fewest possible meanings to each color.

(c) Try to make the meanings attached to colors congruent with common usage and existing standards, e.g., use red for STOP.

(d) Colors seen by reflected light might lose their identity at low levels of illumination or under colored lighting conditions.

(e) Color coding is effective only if the colors used provide ample contrast with the background.

(f) Color coding is most effective when combined with other coding methods.

(12) When coding controls and displays by grouping, group them by similarity of function or by sequence of use and, insofar as practicable, maintain a similar orientation of related indicators.

Consider the following recommendations:

(a) Use location coding for "blind" controls. Space controls far enough apart to establish a position habit pattern.

(b) Controls that are "blind" should be forward and slightly below shoulder height.

(c) Controls or control groups that are in front of or immediately above the operator should be arranged in horizontal rows 6 to 10 in. apart.

(d) Place controls that are mounted to the side or back of the operator 12 to 16 in. apart.

9-7 CONTROLS AND DISPLAYS CHECKLIST

Table 9-11 summarizes some of the important maintainability design recommendations pertaining to controls, indicators, and displays. The checklist contains several items which were not discussed separately in the text. These items are included here because ther necessity in the design is so obvious that they might otherwise be inadvertently overlooked. In using the check list, if the answer to any question is *no,* the design should be restudied to ascertain the need for correction.

TABLE 9-11. CONTROLS AND DISPLAYS CHECKLIST

Controls

1. Are all adjustments located on a single panel?
2. Are controls located where they can be seen and operated without disassembly or removal of any part of installation?
3. Are front panel maintenance controls covered with an access door?
4. Are controls placed on panel in the order in which they will be normally used?
5. When controls are used in a fixed procedure, are they numbered in operational sequence?
6. For concentric shaft vernier controls, is larger diameter control used for the fine adjustment?
7. Do knobs, for precision settings, have a 2-in. minimum diameter?
8. Are controls labeled with functional statement?
9. Are control position markings descriptive rather than coded or numbered?
10. Are control scales only fine enough to permit accurate setting?
11. Except for detents or selector switches, are controls used which have smooth, even resistance to movement?
12. Are selector switches used which have sufficient spring loading to prevent indexing between detents?
13. Are spring-loaded pushbuttons used which require no excessive finger pressure?
14. Are tool-operated controls operable by screwdriver or other medium size standard tool?
15. Are coaxial knobs adequately coded to avoid confusion?
16. Are calibration instructions placed as close to the calibrating control as possible?
17. Are adjustment controls easy to set and lock?
18. Is visual, auditory, or tactual feedback provided for all physical adjustment procedures?

TABLE 9-11. CONTROLS AND DISPLAYS CHECKLIST (cont)

19. Is some type of indexing provided for adjustment controls? (It is difficult to remember positional settings without some marking : indexing can also show gradual deterioration in performance as settings change from time to time.)
20. Are designs avoided which may develop excessive backlash, and cause needless adjustment?

Displays

1. Are all displays used in system checkout located so they can be observed from one position?
2. On units having operator displays, are maintenance displays located behind access doors on operator's panel?
3. On units without operator panel, are maintenance displays located on one face accessible in normal installation?
4. Are display scales limited to only that information needed to make decision or to take some action?
5. When center-null displays are used, is circuit designed so that if power fails indicator will not rest in the in-tolerance position?
6. Are all-or-none type displays used if they will convey sufficient information?
7. Are moving-pointer, fixed-scale indicators used for adjustment procedures?
8. Are numerical scales used only when quantitative data is required?
9. Are scales provided with only enough graduation for required accuracy without interpolation?
10. Is special calibration point provided on scale or on a separate overlay if edges and midpoint of tolerance range are not sufficient for accurate calibration?
11. Are auditory signals used to supplement lights for displays not constantly watched and where changes in indication must be noted immediately?
12. Are displays which provide tolerance ranges coded so both the correct reading and tolerance limits are easily identified?
13. Do displays which require arithmetic transformation have transformation factor clearly indicated on, or close to, the display in question?
14. Are irregular scale breakdowns avoided?
15. Are critical warning lights isolated from other less important lights for best effectiveness?
16. Do displays which can or may not be watched cohtinuously, but which require continuous monitoring, have a suitable auditory warning backup?

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CHAPTER 10
GEOGRAPHICAL-ENVIRONMENTAL CONDITIONS

SECTION I
THE MILITARY ENVIRONMENT

10-1 THE PROBLEM

World War II showed the influence of geographical environment on the operation and maintenance of U S Army equipment. The need for maintaining equipment for constant availability regardless of climatic hazards (Figure 10-1) and terrain made "stop-gap" corrective measures mandatory. Such "stop-gap" measures became undesirable when the emergency no longer existed. (Ref. 1).

Since World War II, engineers and scientists have continued improvements in designs and materials to overcome environmental problems. Also, operation, maintenance, and testing in the field under climatic conditions are continuing at Fort Greely, Alaska (Arctic testing) ; Yuma, Arizona (desert testing) ; and Fort Clayton, Panama Canal Zone (tropical testing). Operation, maintenance, and testing under more "normal" environmental conditions are carried out at such stations as Aberdeen Proving Ground, White Sands Missile Range, and the Electronics Proving Ground, Fort Huachuca.

It is important to note that conditions considered normal in the military environment are decidedly abnormal in the civilian environment. For example, tank or truck operations off paved roads is "normal" in the military environment.

10-2 NORMAL CONDITIONS

Many components used in military equipment are either commercial items or military items manufactured by commercial companies. In civilian applications, vehicle engines and other components are expected to have a life of 100,000 miles but fail in 2000 miles in military applications because of the climate and terrain encountered (see Figure 10-2). In the design of ground vehicles for operation in a military environment, the design facility should have as its goal, unless otherwise directed, the following:

(1) Wheeled and tactical vehicles should be operable for 25,000 miles without field or depot maintenance.

(2) Tracked vehicles should be operable for 5000 miles without field or depot maintenance.

The highway engineer has been important in civilian automotive design and development. Without his proficiency in designing roads, civilian vehicles today would be quite different. As the civilian vehicle becomes more and more dependent on good roads, the difference between it and the off-road vehicle will become greater and greater. Thus, the development of military vehicles compatible with the military environment will probably not come through normal progress in the automotive industry. A segment of the automotive industry has developed off-road vehicles for road construction, logging and oil fields, but the objectives of this segment of the industry and those of the military differ, particularly in the area of size and weight.

10-3 COST CONSIDERATIONS

The cost of military equipment increases when special tooling is required for manufacture, and these costs must be amortized over short production runs. To keep costs down, commercial components, rather than components of special design, should be used wherever possible ; however, the gap between the requirement for 90% reliability and the 30 to 40% actually realized must be eliminated. To close this gap, while still using commercial components, the components must be protected by ancillary equipment, derating, redundancy, or improved inspection procedures. The adaptation of commercial components to the military environment comes under the heading of environmental engineering.

10-4 ENVIRONMENTAL ENGINEERING

This branch of technology must insure that the equipment and its components will meet expressed criteria in the environment in which the Army must live. The need for equipment that operates anywhere has added climate and terrain criteria to the evaluation of performance efficiency. The destructive effects of induced environments (shock, vibration, chemical agents) and natural environments (wind, sand, dust, humidity, and solar radiation) are not to be ignored; however, they play a minor role compared to the relentless attack of induced moisture-either directly or in support of fungi, bacteria, and galvanic action. The combination of moisture and high ambient temperature leads all others in destructive effect. In a secondary role is the effect of low ambient temperatures in rendering materials more sensitive to rapidly applied loads. These destructive phenomena, however, can be guarded against by some combination of design, materials, protective finishes, and packaging.

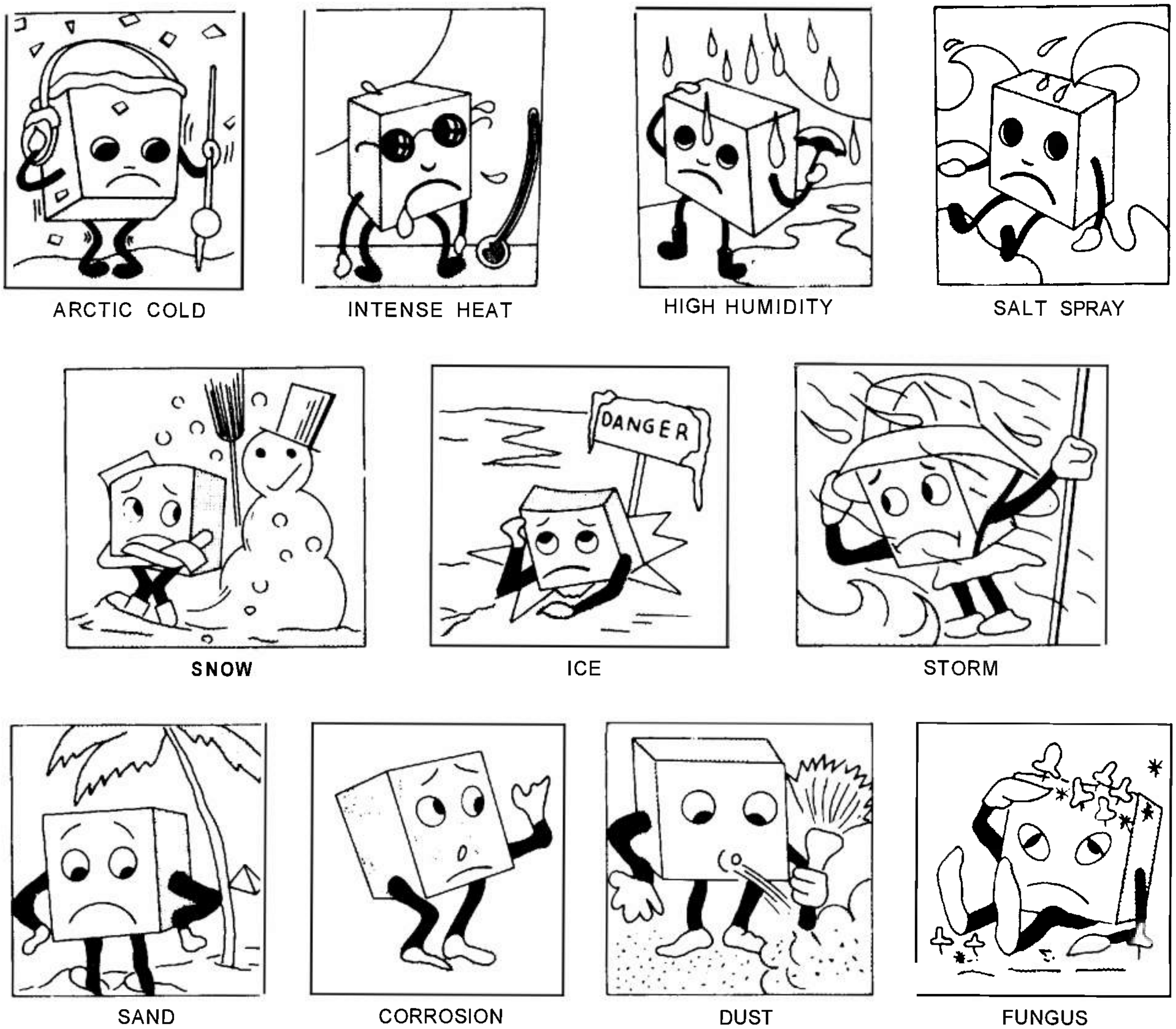


Figure 10-1. Climatic Hazards

SECTION II

EFFECTS OF CLIMATE AND TERRAIN ON EQUIPMENT

10-5 GENERAL

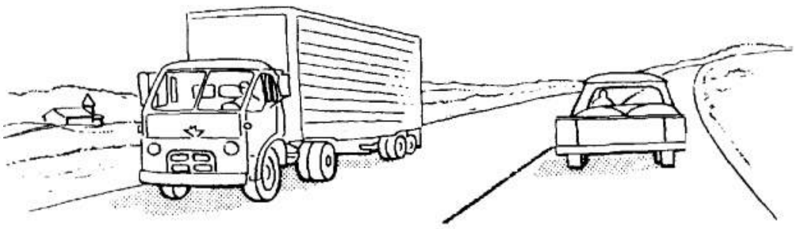
When the patterns of climate, terrain, and deterioration of materials are superimposed on the earth's surface, their boundaries coincide to a remarkable degree. There is a definite correlation between climate and deterioration of materials, and an even more definite correlation between terrain and problems of operation and maintenance resulting from deterioration of materials. A knowledge of these patterns of climate, therefore, is the first step in understanding problems associated with the deterioration of materials and the design, operation, and maintenance of equipment. The full range of military environments is included in MIL-STD-210.

10-6 TROPICAL CLIMATES

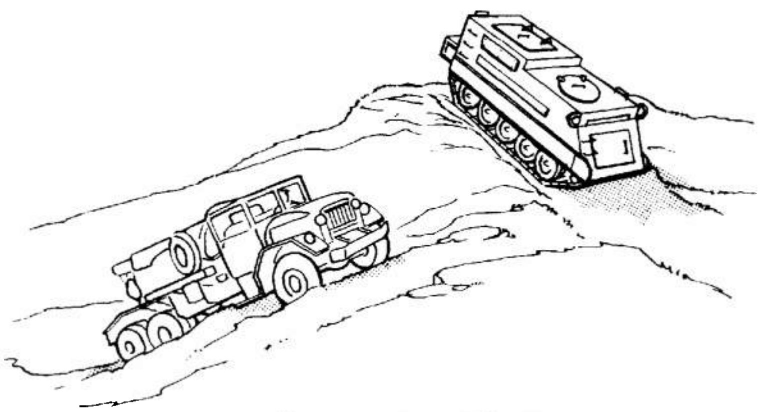
Tropical climates are generally defined as those in which the mean monthly temperature never goes below 64.9°F. The outstanding common characteristics of tropical regions are high ambient temperatures and high humidity. These two conditions cause most problems of deterioration and of design, operation, and maintenance. The temperature extremes for electronic equipment operating in the tropics is shown in the following chart:

CONDITION	TEMPERATURE EXTREMES	
Damp heat, high relative humidity, heavy seasonal rainfall, mold growth, destructive insects	Day: +40°C (104°F). Night: +20°C (+77°F). Exposed surfaces: +70°C (+158°F).	Humidity can approach saturation.

The following major problems are associated with tropical areas: corrosion of steel and copper alloys caused by electrolytic action ; fungus



CIVILIAN ENVIRONMENT



MILITARY ENVIRONMENT

Figure 10-2. ***Civilian and Military Environments***

growth on organic materials, such as canvas, felt, gasket materials, and sealing compounds, and even on the optical elements of fire-control equipment ;deterioration through corrosion and fungus growth in insulation, generating and charging sets, demolition and mine-detection equipment, meters, dry cell batteries, storage batteries, cables, and a variety of lesser components. Termites may attack all wooden parts not impregnated with a repellent agent and are especially attracted by plywood bonded with a vegetable glue.

10-6.1 FUNGUS PROTECTION

Corrosion, rotting and weakening of materials can be caused by fungus. Materials inert to the growth of fungi should, therefore, be used whenever possible in the design of U. S. Army equipment.

In general, synthetic resins such as melamine, silicone, phenolic, fluorinated ethylenic polymers with inert fillers such as glass, mica, asbestos and certain metallic oxides provide good resistance to fungus growth. A list of materials generally considered fungus inert are listed in Table 10-1. Materials which are nonresistant to fungi are listed in Table 10-2. As shown in this table, not all rubber is fungus resistant, and antifungus coatings generally are impractical for this material. When fungus resistant rubber is needed, it should be so specified to insure that the manufacturer furnishes a suitable compound.

TABLE 10-1. FUNGUS-INERT MATERIALS (Ref. 3)

Metals	**Plastic materials using glass, mica or asbestos as a filler**
Glass	**Polyvinylchloride**
Ceramics (steatite, glass-bonded mica)	**Polytetrafluoro-ethylene**
Mica	**Monochlorotrifluoro-ethylene**
Polyamide	**Polyethylene**
Cellulose acetate	**Isocyanate**
Rubber (natural or synthetic)	

For specific requirements on the prevention of fungus growth, consult MIL-E-16400, MIL-M-11991, MIL-P-11268, and MIL-T-152. See also Reference 2 for detailed information concerning fungal and bacterial deterioration of material.

The maintainability engineer should also realize when designing equipment to resist fungi, that, in general, it is not significant to know whether or not a specific kind of fungus is present in a given geographical location. But it *is* significant to know that any susceptible material is going to be degraded microbiologically wherever the temperature and humidity are suitable for microbial growth. It may or it may not be the same species of fungi in Florida, New Guinea, or Europe, but, regardless of location, there are fungi there which can do the damage.

10-6.2 CORROSION-RESISTANT MATERIALS

Materials selected should be corrosion resistant or should be protected by plating, painting, anodizing, or by some other surface treatment to resist corrosion. Surfaces required to be acid-proof should be given additional surface treatment. Metal surfaces not painted should be protected by other suitable means, e.g., encapsulating, and should be selected in accordance with MIL-S-5002. The use of any protective coating that will crack, chip or scale with age or extremes of climatic and environmental conditions should be avoided. Some good protective finishes for various metals are given in Table 10-3.

It is difficult to make definite comparisons of the corrosion-resistant properties of metals, since their resistance varies with the chemical environments. However, in vehicle design, the metals most commonly used for their corrosion resistant properties are:

Titanium	Chromium
Molybdenum alloys	Zinc
Stainless steel	Nickel
Pure aluminum	Tin
Cadmium	Copper alloys

The aluminum and magnesium alloys are seriously degraded by corrosion and should be avoided.

TABLE 10-2. MATERIALS SUSCEPTIBLE TO FUNGUS FORMATION (Ref. 4)

Material	Fungus Proofing Specification	
Cork	MIL-T-12664	Treatment, mildew resistant, Class 1
Cotton, duck and twill	MIL-D-504	Dyeing and after treating process, Class B
Duck, cotton	MIL-D-10860 (MIL-D-504 is preferred to avoid copper bearing agents.)	Duck, cotton, fire, water, weather, and mildew resistant
Felt, wool	MIL-M-2312	Mildew-resistance and moisture-resistance treatment for felt, wool
Felt, hair	MIL-F-5030	Felt, hair
Leather	0-L-164	Leather dressing; mildew preventive, Type I, Class A or B
Linen	MIL-T-3530	Treatment, mildew resistant, for thread and twine (Use Class 2)
Melamine resin compound with cellulose filler	MIL-V-173	Varnish, moisture and fungus resistant for the treatment of communications, electronic and associated electrical equipment
Paper and cardboard		
Phenolic resin compound with cellulose filler	MIL-V-173 MIL-V-1137*	Varnish, moisture and fungus resistant for the treatment of communications, electronic and associated electrical equipment
Plastic materials using cotton! linen, or woodflour as a filler, notably the general purpose (Type PBG) grade	MIL-V-173 MIL-V-1137*	Varnish, moisture and fungus resistant for the treatment of communications, electronic and associated electrical equipment
Rope, natural fibre	T-R-616 (Avoid copper bearing agents.)	Rope; mildew resistant
Rubber (only certain compositions)	None	No treatment specification applies, but a grade of rubber meeting the fungus test requirement of MIL-I-631, Par. 4.6.16 will be fungus resistant, even though the title is "Insulation, Electrical Synthetic-Resin Composition, Nonrigid. *'
Thread, twine, natural fibre	MIL-T-3530	Treatment, mildew resistant, Class 2
Webbing, cotton	MIL-W-530	Webbing, textile, cotton, general purpose, natural or in colors
Wood	TT-W-571	Wood preservative; recommended treating practice

TABLE 10-2. MATERIALS SUSCEPTIBLE TO FUNGUS FORMATION (Ref. 4) (cont)

Material	Fungus Proofing Specification	
Adhesives	MIL-A-140A	Adhesive, water-resistant, waterproof barrier-material
Insulation	MIL-I-631C	Insulation, electrical, synthetic-resin composition, nonrigid
Fabrics, etc.	MIL-M-5658	Mildew proofing of fabrics, threads and cordages; copper processes for
Fabrics	MIL-M-46032	Mildew-resistant treatment (for fabrics) copper processes
Electrical Equip	MIL-T-152A	Treatment—moisture- and fungus-resistant, of communications, electronic, and associated electrical equipment
Fabrics	MIL-T-3509	Treatment—fire, water and mildew resistant (for tent liner fabrics)
Fabrics, etc.	MIL-T-11293	Treatment—mildew-resistant, copper processes (for fabrics, thread, and cordage)
Rope	MIL-T-16070A	Treatment—mildew-resistant, for rope
Wax	MIL-W-956	Wax, fungus-resistant
Wire, insulated	MIL-W-8777A	Wire, electrical, copper, etc.
Wax	MIL-W-10885B	Wax, impregnating, waterproofing, for laminated paper tubes, etc.

MIL-E-5272C Environmental Testing, aeronautical, etc.
MIL-E-4970A Environmental Testing, ground support equipment, etc.
MIL-E-5400E Electronic equipment, aircraft, etc.
Fed. Spec. CCC-T-191b Textile Test Methods
Fed. Test Method STD. No. 141 Paint, Varnish, Lacquer, etc.

*"Varnish, Electrical-Insulating," required under certain circumstances per Spec. MIL-P-11268, Par. 3.18.1, Table IV.

TABLE 10-3. PROTECTIVE FINISHES FOR VARIOUS METALS (Ref. 3)

Material	Finish	Remarks
Aluminum alloy	Anodizing	An electrochemical-oxidation surface treatment for improving corrosion resistance; not an electroplating process. For riveted or welded assemblies, specify chromic-acid anodizing. Do not anodize parts with nonaluminum inserts.
	"Alrok"	Chemical-dip oxide treatment. Cheap. Inferior in abrasion and corrosion resistance to the anodizing process, but applicable to assemblies of aluminum and nonaluminum materials.
Copper and zinc alloys	Bright acid dip	Immersion of parts in acid solution. Clear lacquer applied to prevent tarnish.
Brass, bronze, zinc diecasting alloys	Brass, chrome, nickel, tin	As discussed under steel.
Magnesium alloy	Dichromate treatment	Corrosion-preventive dichromate dip. Yellow color.
Stainless steel	Passivating treatment	Nitric-acid immunizing dip.
Steel	Cadmium	Electroplate; dull white color, good corrosion resistance, easily scratched, good thread anti-seize. Poor wear and galling resistance.
	Chromium	Electroplate; excellent corrosion resistance and lustrous appearance. Relatively expensive. Specify hard chrome plate for exceptionally hard abrasion-resistant surface. Has low coefficient of friction. Used to some extent on nonferrous metals, particularly when die-cast. Chrome-plated objects usually receive a base electroplate of copper, then nickel, followed by chromium. Used for build-up of parts that are undersized. Do not use on parts with deep recesses.
	Blueing	Immersion of cleaned and polished steel into heated saltpeter or carbonaceous material. Part then rubbed with linseed oil. Cheap. Poor corrosion resistance.
	Silver plate	Electroplate; frosted appearance, buff to brighten. Tarnishes readily. Good bearing lining. For electrical contacts, reflectors.

TABLE 10-3. PROTECTIVE FINISHES FOR VARIOUS METALS (Ref. 3) (cont)

Material	Finish	Remarks
Steel (cont)	Zinc plate	Dip in molten zinc (galvanizing) or electroplate of low-carbon or low-alloy steels. Low cost. Generally inferior to cadmium plate. Poor appearance and wear resistance. Electroplate has better adherence to base metal than hot-dip coating. For improving corrosion resistance, zinc plated parts are given special inhibiting treatments.
	Nickel plate	Electroplate; dull white. Does not protect steel from galvanic corrosion. If plating is broken, corrosion of base metal will be hastened. Finishes in dull white, polished, or black. Do not use on parts with deep recesses.
	Black oxide dip	Nonmetallic chemical black oxidizing treatment for steel, cast iron and wrought iron. Inferior to electroplate. No build-up. Suitable for parts with close dimensional requirements, such as gears, worms and guides. Poor abrasion resistance.
	Phosphate treatment	Nonmetallic chemical treatment for steel and iron products. Suitable for protection of internal surfaces of hollow parts. Small amount of surface build-up. Inferior to metallic electroplate. Poor abrasion resistance. Good point base.
	Tin plate	Hop dip or electroplate. Excellent corrosion resistance, but if broken will not protect steel from galvanic corrosion. Also used for copper, brass and bronze parts that must be soldered after plating. Tin plated parts can be severely worked and deformed without rupture of plating.
	Brass plate	Electroplate of copper and zinc. Applied to brass and steel parts where uniform appearance is desired. Applied to steel parts when bonding to rubber is desired.
	Copper plate	Electroplate applied preliminary to nickel or chrome plates. Also for parts to be brazed or protected against carburization. Tarnishes readily.

10-6.3 DISSIMILAR METALS

Dissimilar metals far apart in the galvanic series (Table 10-4) should not be joined directly together. If they must be used together, their joining surfaces should be separated by an insulating material, except if both surfaces are covered with the same protective coating.

For more detailed coverage of corrosion and corrosion protection of metals, see MIL-HDBK-721 (Ref. 5). Refer also to MIL-E-5400 and MIL-E-16400 for listings of acceptable corrosion resistant materials.

10-6.4 MOISTURE PROTECTION

The exclusion of moisture from equipment in the tropics considerably eases the maintenance problems. For example, Figure 10-3 illustrates the effect of moisture on the lowering of resistance of insulating materials. To help minimize such effects on insulating and other materials due to moisture, the following guidelines should be considered :

(1) Choose materials with low moisture absorption qualities wherever possible.

(2) Use hermetic sealing whenever possible. Make sure the sealing area is kept to a minimum to reduce danger of leakage.

(3) Where hermetic sealing is not possible, consider the use of gaskets and other sealing devices to keep out moisture. Make sure the sealing devices do not contribute to fungal activity, and detect and eliminate any "breathing" that may admit moisture.

(4) Consider impregnating or encapsulating materials with fungus-resistant hydrocarbon waxes and varnishes.

(5) Do not place corrodable metal parts in contact with treated materials. Glass and metal parts might support fungal growth and deposit corrosive waste products on the treated materials.

(6) When treated materials are used, make sure they do not contribute to corrosion or alter electrical or physical properties.

Where these methods are not practical, drain holes should be provided, and chassis and racks should be channeled to prevent moisture traps. Additional information on moisture protection can be supplied by the Prevention of Deterioration Center, National Research Council, 2101 Constitution Ave., Washington, D. C. Refer also to MIL-E-5400 and MIL-E-16400 for listings of acceptable moisture resistant materials.

TABLE 10-4. GALVANIC SERIES OF METALS AND ALLOYS

Anodic End (most easily corroded)	
Group	**Metal**
I	Magnesium Magnesium alloys
II	Zinc Galvanized iron or steel Aluminum (5058. 5052, 3004. 3003. 6063. 6053)
III	Cadmium Cadmium plated iron or steel Mild steel Wrought iron Cast iron Ni resist Lead-tin solders Lead Tin
IV	Chromium Admiralty brass Aluminum bronze Red brass Copper Silicon bronze Phosphor bronze Beryllium copper Nickel Inconel Monel Type 400 corrosion resisting steel Type 300 corrosion resisting steel Titanium
V	Silver Gold Platinum
Cathodic End (least susceptible to corrosion)	

10-7 DESERT REGIONS

Desert regions occupy approximately 19% of the earth's land surface. The outstanding attribute of all deserts is dryness. Of the many definitions of a desert, a widely accepted one is

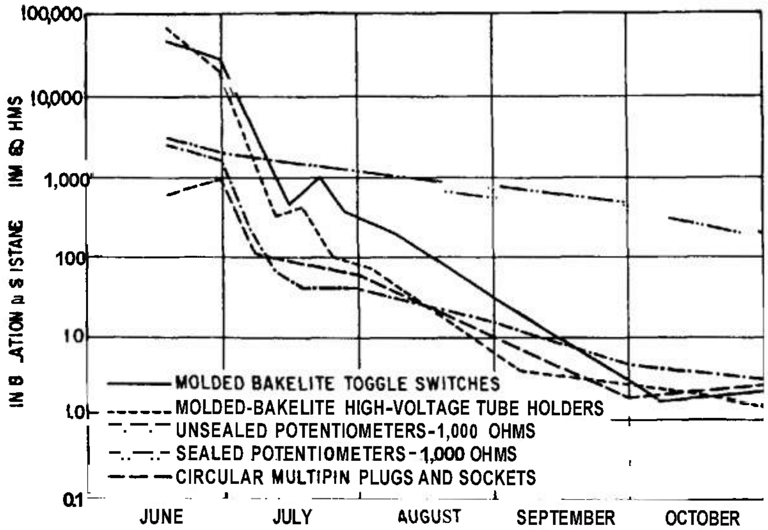


Figure 10-3. Drop in Insulation Resistance of Typical Electronic Components Exposed for 5 Months in Tropical Jungle (Ref. 61

an area with annual rainfall of less than 10 in. Deserts are further characterized by a clear atmosphere and intense solar radiation, which results in temperatures as high as 126°F and ambient levels of illumination as high as 3000 foot-lamberts (Ref, 7). This intense solar radiation combined with terrain which has a high reflectance can create high levels of glare. Other characteristic phenomena associated with deserts are atmospheric boil and mirages. Design for desert areas should also consider sand and dust which nearly always accompany dryness.

The high day temperatures, solar radiation, dust and sand, combined with sudden violent winds and large daily temperature fluctuations, may create many of the following maintenance problems : heat can lead to difficulties with electronic and electrical equipment, especially if these have been designed for modern climates; materials such as waxes soften, lose strength, and melt; materials may loose mechanical or electrical properties because of prolonged exposure ; fluids may lose viscosity ; joints that would be adequate under most other conditions may leak. Heat can also cause the progressive deterioration of many types of seals found in transformers and capacitors. Capacitors of some types develop large and permanent changes in capacity when exposed to temperatures above 120°F.

The temperature extremes for electronic equipment operating in a desert environment is shown in the chart below.

Conditions	Temperature	
Dry heat, intense sunlight, sand dust, destructive insects	Day high: +60°C (+140° F), air +75°C (167° F), exposed ground Night low: -10°C (+14° F) Large daily variation: 40°C (72° F), average.	Relative humidity 5%

The following factors should also be considered :

(1) Dry cells have a short life in hot environments, and, at temperatures above 95°F deteriorate rapidly.

(2) Wet batteries lose their charge readily.

(3) Tires wear out rapidly.

(4) Paint, varnish, and lacquer crack and blister.

(5) The absorption of solar radiation by objects raises their temperatures well beyond the point where personnel can handle them without protection.

Relays, all types of switching equipment and gasoline engines are especially susceptible to damage by sand and dust. The sand and dust hazards are severe problems not only to finely machined or lubricated moving parts of light and heavy equipment, but also to personnel. Sand and dust get into almost every nook and cranny and in engines, instruments, and armament. Desert dust becomes airborne with only slight agitation and can remain suspended for hours so that personnel have difficulty in seeing and breathing. The most injurious effects of sand and dust result from their adherence to lubricated surfaces, but glass or plastic windows and goggles can be etched by sand particles driven by high winds.

10-8 ARCTIC REGIONS

In arctic regions, the mean temperatures for the warmest summer month is less than **50°F** and for the coldest month, below **32°F.** The extreme low temperatures of these regions change the physical properties of materials. Blowing snow, snow and ice loads, ice fog, and wind chill cause additional problems.

Problems associated with the operation and maintenance of equipment seem to be more numerous in arctic regions than elsewhere, and are caused mainly by drifting snow and extreme low temperatures. The temperature extremes for electronic equipment are shown in the following chart :

Conditions	Temperature
Low temperature, driving snow, icedust	Exposed arctic: -70°C (-94" F), extreme -40°C (-40" F), common Subarctic: -25°C (13° F), common

With the exception of inhabited areas, vehicle transportation is uncertain and hazardous because of the absence of roads. Travel from base to base is over rugged, snow-and-ice or tundra-covered terrain. Tracked vehicles must be used for travel off the road. Drifting snow can enter a piece of equipment and either impede its operation, or melt and then refreeze inside as solid ice. Then, when the unit generates heat, the melted snow will cause short circuits, form rust, or rot organic materials.

The subzero temperatures may produce the following effects ; volatility of fuels is reduced ; waxes and protective compounds stiffen and crack ; rubber, rubber compounds, plastics, and even metals in general lose their flexibility, become hard and brittle, and are less resistant to shock. At a temperature of —30°F, batteries are reduced in current capacity by 90% and will not take an adequate charge until warmed to **35°F.** The variations in the capacitance, inductance, and resistance of electrical components and parts can become so great as to require readjustment of critical circuits.

10-9 SUMMARY OF ENVIRONMENTAL EFFECTS

The environmental conditions under which unsheltered equipment should be designed for satisfactory operation are given in Table **10-5.** A summary of the major environmental effects is given in Table **10-6,** and the failure modes of electronic components due to some of these environments are presented in Table **10-7.**

NOTE

Tables **10-5, 10-6,** and **10-7** are located at the end of this chapter.

SECTION III

EFFECTS OF CLIMATE ON PERSONNEL

10-10 GENERAL

Successful maintainability design must incorporate consideration of the effects of the working environment on human performance. Consideration should be given to the environmental factors (temperature, humidity, illumination, dust, etc.) affecting the ability of personnel to perform as required.

10-11 TEMPERATURE EXTREMES

Although the effects of temperature on human performance are not completely understood, it is known that certain temperature extremes are detrimental to work efficiency. As the temperature increases above the comfort zone, mental processes slow down, motor response is slower, and error likelihood increases. As the temperature is lowered, physical fatigue and stiffening of the extremities begin. The tolerable limits for heat and cold for normally clothed personnel are given in Table 10-8 at the end of this chapter.

10-11.1 HEAT

The heat factor is probably the most important factor in reducing the operational efficiency of personnel. Figure 10-4 illustrates the increase in average number of mistakes made per hour as the temperature increases. Figure 10-5 illustrates that a man can tolerate a much hotter temperature with dry air than he would be able to tolerate if the air were humid.

The following design recommendations should be considered in this area:

(1) Where possible, provide air conditioning if temperatures exceed 90°F. In any event, proper ventilation should be provided in equipment trailers or other locations where personnel are performing monitoring, servicing, or other maintenance tasks.

(2) When line maintenance technicians will be working for extended periods inside equipment which is exposed to the sun, provide air conditioning for their use during maintenance. Or provide portable air conditioners if this is not possible.

(3) Where feasible, employ reflector and absorbant surfaces on equipment which must be maintained while exposed to the sun to reflect or absorb heat as appropriate.

(4) Where frequent maintenance, such as checking or adjusting a component, is impossible or delayed because of excessively high temperatures, redesign the equipment so the component which must be frequently maintained is in a cooler area. If this is not possible, provide for cooling of the component in its existing area.

10-11.2 COLD AND WINDCHILL

Maintenance personnel on duty in the arctic are handicapped, physically and psychologically. When a man is cold or afraid of the cold,

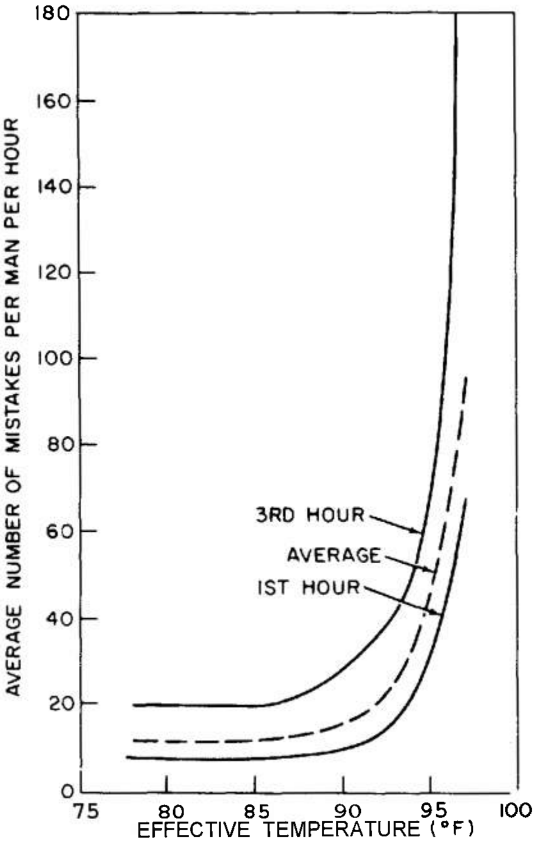
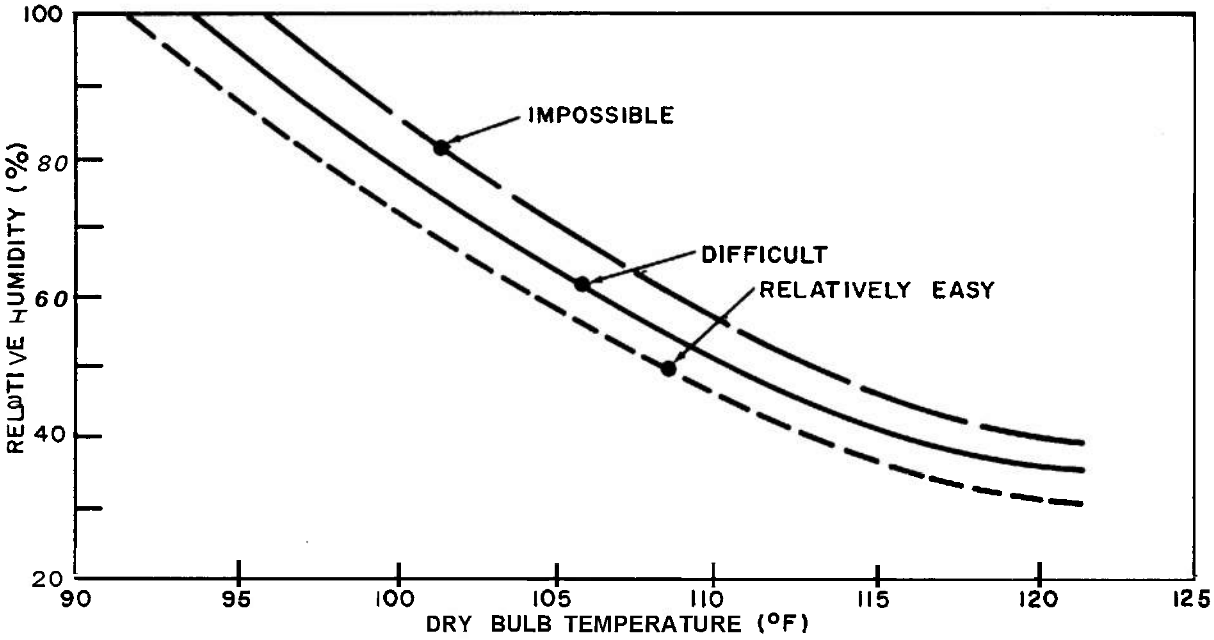


Figure 10-4. Error Increases Due to Temperature Rise (Ref. 10)



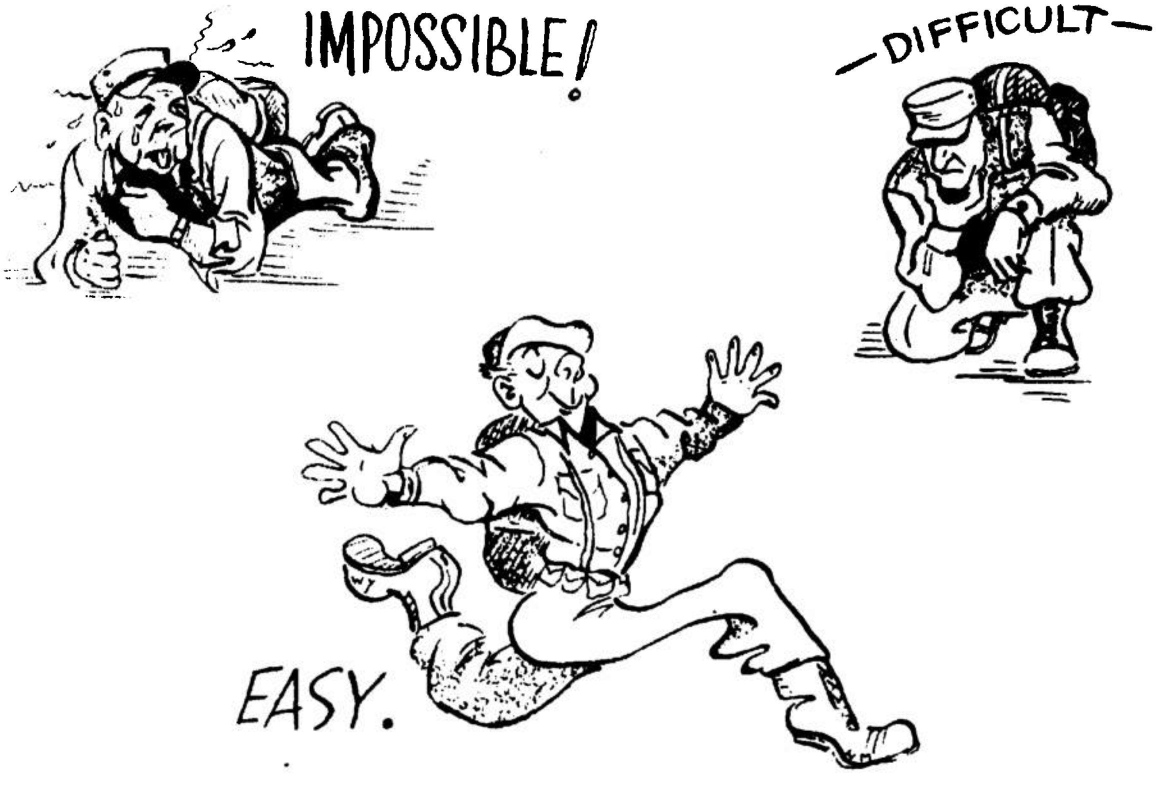


figure 10-5. Effects of Humidity and Temperature on Personnel (Ref. 10)

his efficiency and incentive may be impaired, In spite of the best in arctic clothing, it has been found that the personnel suffering increases rapidly as the temperature drops below —10°F. Personnel need all their energy to use tools of any kind in the open. For these reasons, maintenance in the arctic is unique in that, for the most part, those measures that are normally within the capabilities of the trained operator of equipment in temperate zones necessarily revert to the maintenance man located at the organizational unit level (formerly second echelon maintenance category) in the polar zone. Also, a considerable number of the tasks that a maintenance man would normally perform revert to direct support maintenance or higher unless adequate shelter is provided. Without shelter and heat, most adjustments are impossible. With heavy gloves out in the open, even the simple task of removing or inserting screws becomes extremely difficult; with screws less than 0.25 in. in length, impossible.

When a worker is properly dressed, he can perform down to some point between 32° and 0°F for 30 minutes without interference from the cold itself (see Figure 10-6). The figure also illustrates that the function of decrement in performance across temperatures is a positively accelerating one. A unit drop in temperature has progressively greater effect on performance as one goes down the temperature scale.

The following features should also be considered by the designer:

(1) Provide heated working areas for maintenance personnel working in arctic environ- procedures and design equipment to require ments. For line maintenance activities, specify a minimum sustained amount of working time. For example, use quick-disconnect servicing equipment.

(2) Provide for drying of equipment which is to be returned to out-of-door arctic temperatures after shop maintenance has been performed on it. Moisture which has condensed on such equipment will cause it to freeze with possible resultant damage to equipment and subsequent increased maintenance.

(3) Design for maintenance accessibility of winterized equipment in arctic zones. Consider the following:

(a) Winterization equipment, such as preheaters, should be placed where they do not interfere with accessibility for inspection, servicing, or other maintenance tasks.

(b) In locating access doors and panels, consider the formation of ice and the presence of snow or rain.

(c) Provide access openings and work space large enough to accommodate personnel wearing arctic clothing.

(d) Provide drains that can be operated by personnel wearing heavy gloves. Drains should be easily accessible to permit draining of liquids to prevent damage due to freezing.

(4) Where a technician may suffer freezing of his bare hand in maintaining equipment such as liquid oxygen lines, provide sufficient access and internal work space to permit him to wear a protective glove.

No general index, such as effective temperature, is available for expressing all of the factors involved in cold exposure, but the Windchill Index is a commonly used scale for expressing the severity of cold environments. This index is an empirical expression for the total cooling power of the environment, and, although it is not based on human cooling and is probably not even very accurate as an expression of physical cooling, it has come into use as a single-value, practical guide to the severity of temperature-wind combinations.

A windchill chart is shown in Figure 10-7. It may be used as a guide to the severity of exposure conditions for men who are appropriately dressed and not wearing heated garments. Under bright, sunny conditions, the values on the chart should be reduced about 200 kg-cal.

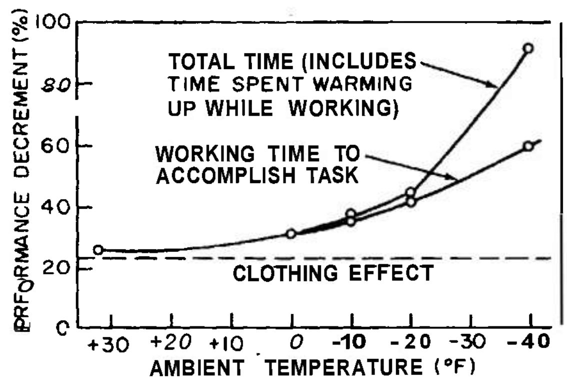


Figure 10-6. Change in Performance-Decrement at Different Ambient Temperatures (Ref. 11)

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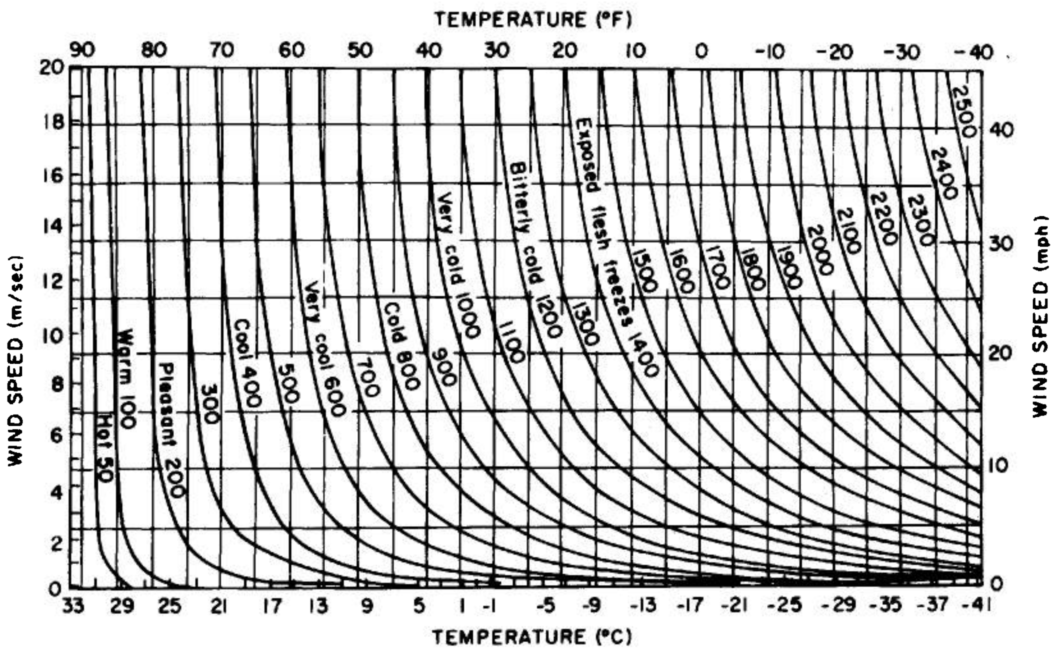


Figure 10-7. Windchill Chart (Numbers on Curves Represent Windchill in kg-cal/m²hr) (Ref. 12)

TABLE 10-5. ENVIRONMENTAL REQUIREMENTS FOR UNSHELTERED EQUIPMENT

Environment	Environmental Limits
Temperature	
Standard area	
Operating	-29 to 52°C (-20 to 125°F)
Nonoperating	-54 to 54°C (-65 to 130°F)
Cold weather area	
Operating	-40°C (-40°F) if operator is unsheltered
Operating	-54°C (-65°F) if operator is sheltered
Nonoperating	-62°C (-80°F) for 3 days and achieve rated capacity after 30 minutes preheating and warm-up
Desert and tropical areas	
Operating	52°C (125°F)
Nonoperating	71°C (160°F) for 4 hours per day indefinitely
Humidity	
Operating	Up to 100% at 37°C (100°F) including condensation
Nonoperating	Up to 100% including condensation
Solar Radiation	Endure a solar intensity of 360 BTU per square foot, per hour for a period of 4 hours at 52°C (125°F)
wind	Withstand wind pressures up to 30 pounds per square foot of projected surface, either empty or under load
Barometer pressure	
Operating	From 30 to 16.8 inches of merc'ury (0-15,000 ft)
Nonoperating	From 30 to 5.54 inches of mercury (0-40,000 ft)

TABLE 10-6. SUMMARY OF MAJOR ENVIRONMENTAL EFFECTS (Ref. 3)

Environment	Principal Effects	Typical Failures Induced
High temperature	Thermal aging:	Insulation failure
	Oxidation	Alteration of electrical properties
	Structural change	
	Chemical reaction	
	Softening, melting and sublimation	Structural failure
	Viscosity reduction and evaporation	Loss of lubrication properties
	Physical expansion	Structural failure
		Increased mechanical stress
		Increased wear on moving parts
Low temperature	Increased viscosity and solidification	Loss of lubrication properties
	Ice formation	Alteration of electrical properties
	Embrittlement	Loss of mechanical strength
		Cracking, fracture
	Physical contraction	Structural failure
		Increased wear on moving parts
High relative humidity	Moisture absorption	Swelling, rupture of container
		Physical breakdown
		Loss of electrical strength
	Chemical reaction:	Loss of mechanical strength
	Corrosion	Interference with function
	Electrolysis	Loss of electrical properties
		Increased conductivity of insulators
Low relative humidity	Desiccation:	Loss of mechanical strength
	Embrittlement	Structural collapse
	Granulation	Alteration of electrical properties
		"Dusting"
High pressure	Compression	Structural collapse
		Penetration of sealing
		Interference with function

TABLE 10-6. SUMMARY OF MAJOR ENVIRONMENTAL EFFECTS (Ref. 3) (cont)

Environment	Principal Effects	Typical Failures Induced
Low pressure	Expansion	Fracture of container
		Explosive expansion
	Outgassing	Alteration of electrical properties
		Loss of mechanical strength
	Reduced dielectric strength of air	Insulation breakdown and arcover
		Corona and ozone formation
Solar radiation	Actinic and physicochemical reactions:	Surface deterioration
	Embrittlement	Alteration of electrical properties
		Discoloration of Materials
		Ozone formation
Sand and dust	Abrasion	Increased wear
	Clogging	Interference with function
		Alteration of electrical properties
Salt spray	Chemical reactions:	Increased wear
	Corrosion	Loss of mechanical strength
		Alteration of electrical properties
		Interference with function
	Electrolysis	Surface deterioration
		Structural weakening
		Increased conductivity
Wind	Force application	Structural collapse
		Interference with function
		Loss of mechanical strength
	Deposition of materials	Mechanical interference and clogging
		Abrasion accelerated
	Heat loss (low velocity)	Accelerates low-temperature effects
	Heat gain (high velocity)	Accelerates high-temperature effects
Rain	Physical stress	Structural collapse
	Water absorption and immersion	Increase in weight
		Aids heat removal

TABLE 10-6. SUMMARY OF MAJOR ENVIRONMENTAL EFFECTS (Ref. 3) (cont)

Environment	Principal Effects	Typical Failures Induced
Rain (cont)	Water absorption and immersion (cont)	Electrical failure Structural weakening
	Erosion	Removes protective coatings Structural weakening Surface deterioration
	Corrosion	Enhances chemical reactions
Water immersion	Corrosion of metals	Structural weakness, seizure of parts, contamination of products
	Chemical deterioration	Dissolving out and changing of materials
	High pressures (13 lb at 30 ft depth)	Mechanical damage
		Blockage of small parts, meters, etc.
	Nibbling by termites	Damage to plastic cables or other organic insulating materials, causing shorts
Fungi	Growth of molds, hyphae	Damage to optical equipment; leakage paths in high impedance circuits; blockage of small parts, meters, etc.; breakdown of mechanical strength of all organic materials
Temperature shock	Mechanical stress	Structural collapse or weakening Seal damage
High speed particles (nuclear irradiation)	Heating	Thermal aging Oxidation
	Transmutation and ionization	Alteration of chemical, physical and electrical properties Production of gases and secondary particles
Ozone	Chemical reactions:	Rapid oxidation
	Crazing, cracking	Alteration of electrical properties
	Embrittlement	Loss of mechanical strength
	Granulation	Interference with function
	Reduced dielectric strength of air	Insulation breakdown and arcover
Explosive decompression	Severe mechanical stress	Rupture and cracking Structural collapse

TABLE 10-6. SUMMARY OF MAJOR ENVIRONMENTAL EFFECTS (Ref. 3) (cont)

Environment	Principal Effects	Typical Failures Induced
Dissociated gases	Chemical reactions;	Alteration of physical and electrical properties
	Contamination	
	Reduced dielectric strength	Insulation breakdown and arcover
Acceleration	Mechanical stress	Structural collapse
Vibration	Mechanical stress	Loss of mechanical strength
		Interference with function
		Increased wear
	Fatigue	Structural collapse
Magnetic fields	Induced magnetization	Interference with function
		Alteration of electrical properties
		Induced heating

TABLE 10-7. FAILURE MODES OF ELECTRONIC COMPONENTS (Ref. 8)

Component	Vibration Effects	Shock Effects	Temperature Effects	Humidity Effects	Salt Spray Effects	Storage Effects
Biowers	Brinelling of bearings		Shorts; lubricant deterioration	Corrosion	Corrosion	Lubricant deterioration
Capacitors:						
ceramic	Increased lead breakage; piezoelectric effect; body and seal breakage	Lead breakage; piezoelectric effect, body and seal breakage	Changes in dielectric constant and capacitance; lowered insulation resistance with high temperature		Corrosion; shorts	Decreased capacitance; silver-ion migration
electrolytic	Increased lead breakage; seal damage; current surges	Lead breakage; seal damage; current surges	Increased electrolyte leakage; shortened life; increased current leakage; large change in capacitance increased series resistance with low temperature	Decreased insulation resistance; increased dielectric breakdown; increase in shorts	Corrosion; shorts	Electrolyte deterioration; shortened life; increased chances for explosion; shorts
mica	Lead breakage	Lead breakage	Increased insulation resistance; silver ion migration; drift	Silver migration	Shorts	Change in capacitance
paper	Increase in opens and shorts; lead breakage	Opens; increased dielectric breakdown; shorts; lead breakage	Changes in capacitance; increased oil leakage; decreased insulation resistance; increased power factor	Decreased insulation resistance; increased power factor	Shorts	Decreased insulation resistance; increased dielectric breakdown; increase in shorts
tantalum	Opens; shorts; current surges; lead breakage	Opens; lead breakage;	Electrolyte leakage; change in capacitance insulation resistance; series resistance	Decreased insulation resistance; increased dielectric breakdown; increase in shorts	Corrosion	Electrolyte leakage; decreased insulation resistance; increase in shorts

TABLE 10-7. FAILURE MODES OF ELECTRONIC COMPONENTS (Ref. 8) (cont)

Component	Vibration Effects	Shock Effects	Temperature Effects	Humidity Effects	Salt Spray Effects	Storage Effects
Choppers	Increase in phase angle and dwell time	Contacts open; change in phase angle and dwell time	Decrease in phase angle; variation in dwell time		Corrosion	Change in phase angle
Circuit breakers	Premature activation	Premature close or open	Failure to function; premature function	Corrosion	Corrosion	Change in characteristics
Clutches, magnetic	Creep	Intermittent operation	Hot spots in coil	Falloff in torque	Binding	
Coils	Loss of sensitivity; detuning; breaking of parts, leads, and connectors	Lead breakage; detuning; loss of sensitivity	Warping, melting; instability; change in dielectric properties	Electrolysis; corrosion	Corrosion; electrolysis	
Connectors:						
standard	Separation of plugs and receptacles; insert cracks; opening of contacts	Opening of contacts	Flashover, dielectric damage	Shorts; fungus; corrosion of contacts; lowered insulation resistance	Corrosion	Deterioration of seals; corrosion of contacts
interstage	Insert cracks; opening of contacts	Opening of contacts	Flashover, dielectric damage	Shorts; fungus; corrosion of contacts; lowered insulation resistance	Corrosion	Deterioration of seals; corrosion of contacts
Crystals	Opens	Opens	Drift; microphonic	Drift		Drift
Crystal holders	Intermittent contact	Intermittent contact		Change of capacity		
Diodes	Opens	Opens	Change in voltage breakdown; increased current leakage; increase in opens and shorts	Increased current leakage	Corrosion of lead and case	Increased current leakage

TABLE 10-7. FAILURE MODES OF ELECTRONIC COMPONENTS (Ref. 8) (cont)

Component	Vibration Effects	Shock Effects	Temperature Effects	Humidity Effects	Salt Spray Effects	Storage Effects
Gyros	Drift	Drift; leaks	Drift			Induced drift
Insulators	Cracking; elongation	Cracking	Epoxy cracking; ferrite separation (arcing); moisture condensation (insertion loss)	Moisture condensation (insertion loss); reduction in dielectric strength and insulation resistance	Reduction in dielectric strength and insulation resistance	
Joints, solder	Cracking; opens	Cracking; opens	Loss of strength	Fungus	Corrosion	At room temperature, strength increased; at low temperature, strength decreased
Magnetrons	Arcing; "FM"-ing	Seal breakage		Arcing	Corrosion	Leaks; gassiness
Motors	Brinelling of bearings; loosening of hardware		Shorts; opens; deterioration of lubricants	Binding of bearings; shorting of windings; corrosion	Corrosion binding of bearings	Oxidation
Potentiometers	Increased noise; change in torque and linearity; wiper brush bounce; open circuit	Increased noise; change in torque linearity, and resistance; open circuit	Increased noise; change in torque, linearity, and resistance; decreased insulation resistance with high temperature	Increased noise; change in torque, linearity, and resistance; decreased insulation resistance	Decreased insulation resistance increased corrosion; binding	Increased noise; change in torque, linearity, and resistance; decreased insulation resistance
Relays	Contact chatter	Contact opening or closing	Open or shorts; decreased insulation resistance with high temperature	Decreased insulation resistance	Corrosion of pins	Oxidation of contacts causes open circuits; decreased insulation resistance

TABLE 10-7. FAILURE MODES OF ELECTRONIC COMPONENTS (Ref. 8) (cont)

Component	Vibration Effects	Shock Effects	Temperature Effects	Humidity Effects	Salt Spray Effects	Storage Effects
Resistors	Lead breakage; cracking	Cracking; opens	Increased resistance; opens; shorts	Increased resistance; shorts; opens	Change in resistance, lead corrosion	Change in resistance
Resolvers	Intermittent brush operation; brinelling of bearings; cracking of terminal board; loosening of hardware	Intermittent brush operation; cracking of terminal board; loosening of hardware	High breakaway voltage; shift in electrical axis; opens; shorts; deterioration of lubricants	Corrosion that causes expansion and blistering of potting compound; shorting of winding; pinion corrosion	Corrosion; binding	Oxidation; deterioration of lubricants
Servos	Brinelling of bearings; loosening of hardware; cracking of terminal board	Loosening of hardware; cracking of terminal board	Oil throw-out, breakdown of grease; high breakaway voltage	Corrosion that causes blistering of potting compound; shorting of winding; pinion corrosion	Corrosion that causes rotor binding; salt crystals in bearings and on motor	Deterioration of grease with age; oxidation of brushes and slip rings
Switches	Contact chatter	Contact opening	Oxidation of contacts	Pitted contacts; arcing	Oxidation and corrosion; pitted contacts	Oxidation of contacts
Synchros	Intermittent brush operation; cracking of terminal board; brinelling of bearings; loosening of hardware	Intermittent brush operation; cracking of terminal board; brinelling of bearings; loosening of hardware	High breakaway voltage	Corrosion that causes expansion and blistering of potting compound; shorting of winding; pinion corrosion	Corrosion	Oxidation
Thermistors	Lead breakage; case cracking; open circuit	Lead breakage; case cracking; open circuit	Increased shorts and opens	Change in resistance	Lead corrosion; change in resistance	Change in resistance

TABLE 10-7. FAILURE MODES OF ELECTRONIC COMPONENTS (Ref. 8) (cont)

Component	Vibration Effects	Shock Effects	Temperature Effects	Humidity Effects	Salt Spray Effects	Storage Effects
Transformers	Shorts: opens; modulation of output	Shorts; opens; modulation of output	Reduced dielectric; opens; shorts; hot spots; malformation	Corrosion; fungus; shorts; opens	Corrosion; shorts; opens	Deterioration of potting and dielectric
Transistors	Opens; functional disintegration	Opens; seal breakage	Increased leakage current; changes in gain; increases in opens and shorts	Increased leakage current; decreased current gain. If sealed, no effect	Increased leakage current; decreased current gain. If sealed, no effect	Seal leakage; changes in parameters
Tubes, electron	Opens; shorts; microphonics; loosening of elements; changes in characteristics	Opens; shorts; changes in characteristics	Shorts; temporary change in characteristics; formation of leakage paths; increased contact potential; shorting of heater life, gassiness; bulb puncture	Change in characteristics; leakage path; arcing	Shorts; corrosion; leakage path; arcing	Change in characteristics; leaks; gassiness
Vibrators	Intermittent	Intermittent	Lag	Case corrosion	Case corrosion	Decrease in frequency

TABLE 10-8. TOLERABLE LIMITS OF TEMPERATURE (Ref. 9)

Condition	Temperature (°F)
Comfort zone, summer	56 to 75
Comfort zone, winter, light work	63 to 71
Comfort zone, winter, heavy work	55 to 60
Physiological limits, at rest, heat	156 for 30 min. at 10% humidity 107 for 30 min. at 90% humidity 500 for 2 min., air absolutely dry 200 for 35 min., air absolutely dry 122 for 120 min., air absolutely dry
Physiological limits, at rest, cold	38 for 5 hours at 3 mph air velocity 44 for 4 hours at 9 mph air velocity
Physical stiffness of extremities begins	50 and under
Physical fatigue begins	75 and over
Mental activities and complex performance begins to deteriorate	85 and over

CHAPTER 11
MAINTENANCE FACILITIES AND EQUIPMENT

11-1 GENERAL

The maintenance mission includes the servicing and repair of equipment having various degrees of complexity, under varying conditions. The "tools" required for this mission include facilities and equipment ranging from the simple hand implements of **a** tool kit, through support vehicles and mobile shops, to huge depots capable of rebuilding all types of military equipment. Also, special tools play an important role in saving time and manpower, if available when needed.

11-2 FACILITIES

The maintenance performed will depend to some extent on the available shelter. Field organizations must be prepared to set up their own shelter, especially when rapid troop movement is in progress or expected. Also, heat and light must be provided, as should air conditioning, if required. Mobile shops built on truck chassis and on trailers have been found practical. The van bodies used for these units are readily adaptable to a wide variety of equipment.

General support maintenance organizations (formerly known as 4th echelon maintenance) can handle fairly large jobs, using a standard shop van and a trailer for equipment. These shops handle jobs such as truing armature commutators, making replacement fastenings, and similar job-shop work. In emergencies, however, such jobs as truing axle housings after straightening can be handled without difficulty.

11-3 HAND TOOLS

Because hand tools and electronic and electrical test equipment make up the bulk of maintenance equipment, they are treated in detail in this handbook. Chapter **5** and Chapter **23,** Section IV treat the design of test equipment. Hand tools are discussed here.

Once a fault is located, some sort of action is required by the technician to correct it. This action can be aimed at adjusting or replacing the cause of failure. According to data obtained on training devices, approximately 77% of these actions will require the use of some kind of tool (Ref. 1).

Tools (as discussed here) include only hand tools used in the course of maintenance work for inspection, adjustment, servicing, removal, or replacement of component parts. In a survey of the use by maintenance men of hand tools, **95%** were used infrequently. The remaining 5% consisted of screwdrivers, pliers, wrenches, and soldering irons (Ref. **2**). Most, but not all of the hand tools examined were common to the equipment manufacturers, the schools, and the field. Over **2,400** hand tools of more than 80 types were studied. Figure **11-1** shows the frequency with which **33** of the more than 80 types of hand tools are used on electronic equipment.

The varieties of the major types of hand tools required for maintenance are directly dependent on the types and sizes of nuts, bolts, and screws used in the equipment. The survey showed that designers tend to use a wider variety of fastener sizes than is necessary. Ideally, only one size of screw, bolt, and nut should **be** used. This would require only one size of screwdriver and wrench. While it is realized that this ideal situation is not practical, it serves to emphasize the importance of what many design engineers may consider trivial.

11-3.1 GENERAL CONSIDERATIONS IN TOOL DESIGN

The necessary maintenance operations and characteristics of the equipment involved determine tool requirements. Tool requirements must be considered and specified as one of the integral steps in designing any equipment. The neglect of considering tool requirements until equipment design and procedures are final may result in the need for many special tools or an unnecessarily wide variety of standard tools.

A comprehensive list of tools needed for all maintenance tasks should accompany each equipment or system. Tools should be tried out during developmental testing of the equipment or system to uncover duplications and omissions. Tools should be compatible with the equipment on which they will be used and with the job to be performed.

Tools should be designed for maximum simplicity, practicality, and universality. The development of weapon systems along functional lines has too often resulted in the development of tools which are applicable only to a specific piece of prime equipment or which can be modified for application to other situations only with great difficulty. Consideration of tool design *early* in weapon system development, before procedures and designs are final, will result in fewer special tools and devices. Tools which will be needed in a weapon system may be directly derived early in the planning stages from consideration of necessary maintenance operation and the proposed design of the prime equipment.

11-3.2 SPECIFIC DESIGN RECOMMENDATIONS

The following paragraphs give some specific

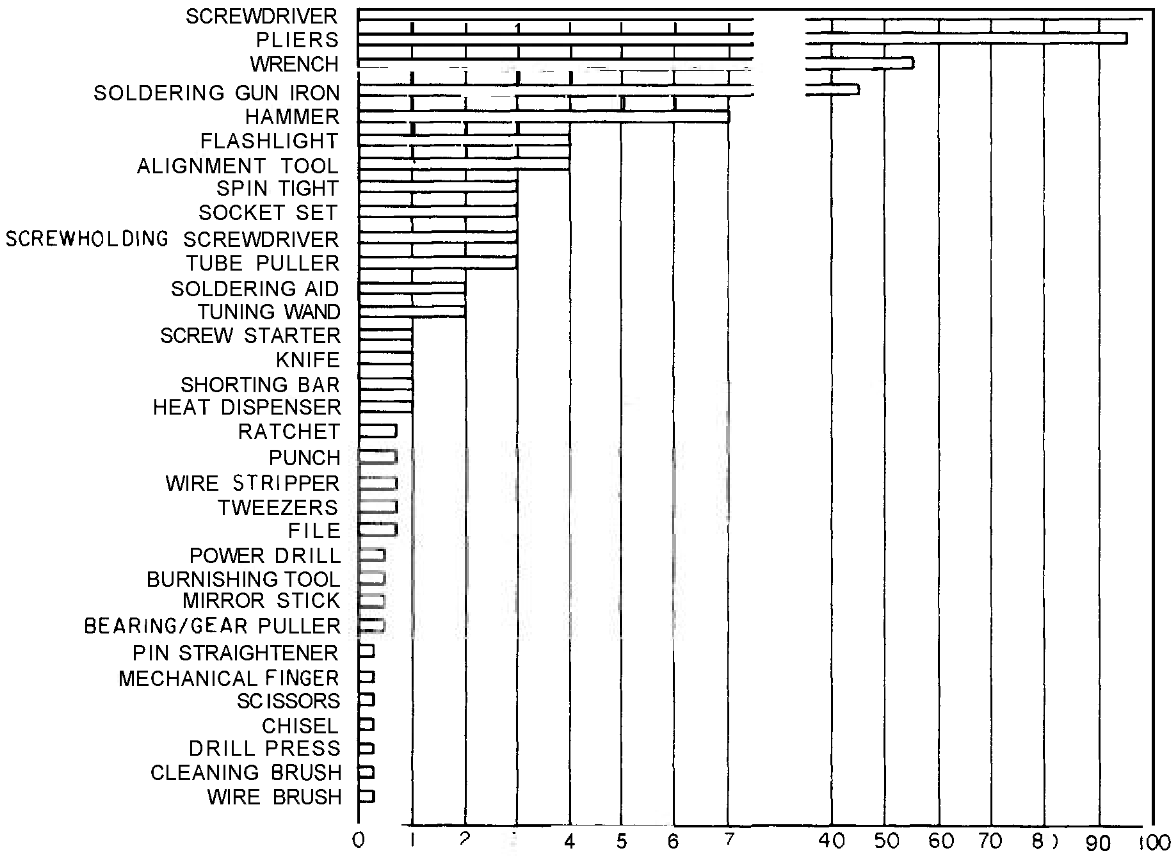


Figure 11-1. Frequency With Which Hand Tools Are Used at Least Once in 427 Maintenance Tasks on Electronic Equipment (Ref. 21

recommendations in the design of hand tools:

(1) *Minimize or eliminate the requirements for special tools.* This requirement should be considered *mandatory* on the part of the design engineer. Use special tools only when a common tool cannot be utilized or when a special tool will optimally facilitate a maintenance task in terms of reduced time and increased accuracy. However, special tools already in the supply system should be considered for special applications in which common tools will not be adequate. Insure that newly designed special tools are available when the equipment requiring their use is completed.

(2) Screwdrivers for small-size adjustment screws should be provided with a funnel-like guide that will aid placement of the screwdriver on the adjustment point, as shown in Figure 11-2(A).

(3) Magnetized screwdrivers, if they will not adversely affect electronic circuits, should be provided to hold free screws that cannot be held easily with the fingers. If magnetized screwdrivers are not desirable, screwdrivers should have clips. Design the clip so that it can be slid up the screwdriver shaft when not in use, as shown in Figure 11-2(B).

(4) Push-type tools should be provided wherever screws must be rotated through many revolutions, provided the attendant resultant force on the equipment will not be harmful (see Figure 11-2(C)).

(5) In general, require only those tools normally found in the maintenance technician's tool kit.

(6) Minimize the number of sizes and varieties of tools required. Consider the use of adjustable rather than fixed-head wrenches. While an adjustable tool may serve the function of a large number of fixed-size tools, carefully consider the amount of space available for tool operation as adjustable tools usually require more clearance than standard fixed-size tools. Also, adjustable tools, if not properly adjusted, have a tendency to "slip." Thus, if delicate adjacent items can be damaged or put out of adjustment by a "slipping" tool, consideration should be in favor of a fixed size.

(7) For each level of maintenance, provide lists of all special tools necessary to perform the authorized work, together with the equipment items requiring their use.

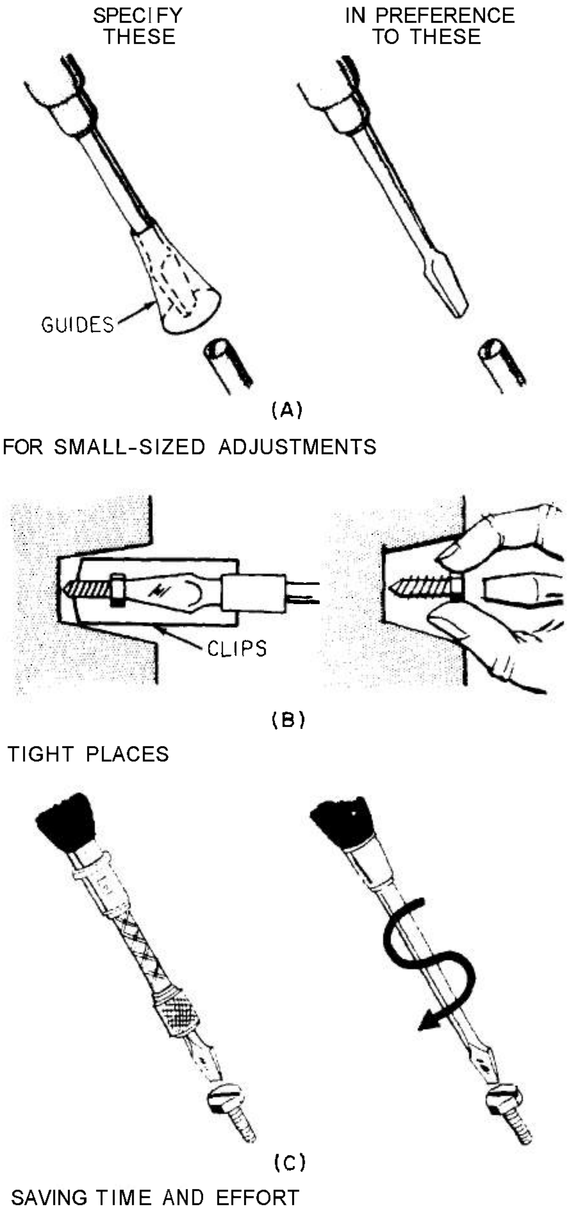


Figure 1J-2. Screwdrivers for Various Purposes

(8) Design equipment to preclude the need for torque wrenches. The design activity should review each special requirement in an attempt to eliminate the need by design changes.

(9) If torque wrenches or guns are used **for** factory assembly of equipment, provide maintenance personnel with similar equipment. In doing so, there will be a minimum of damaged fasteners and components from attempting to remove factory assembled fasteners with inadeauate tools.

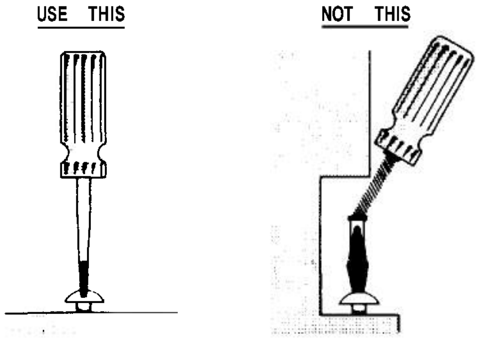


Figure 11-3. Use Only Straight Screwdrivers

(10) Specify tools which are compatible with the design of the equipment on which they will be used as well as with the job to be performed. For example, specify a tool size which is consistent with the size of the prime equipment. Specify lever handles rather than screwdriver handles when high torque is to be applied, and provide tools which are consistent with working space available on the prime equipment.

(11) Provide for the use of speed or power tools such as ratchets, speed screwdrivers, or power wrenches when demanded by torque requirements or space limitations.

(12) Provide maintenance personnel with socket wrenches and accessories (breaker bars, extensions, and joints). These enable the technician to assemble a tool for many different uses.

(13) Use positive snap-locking action for connecting sockets to the various components of a socket set. Design them so they can be easily connected and disconnected.

(14) Provide remotely controlled tools where feasible and where such tools will reduce maintenance time and man-hour expenditure. For example, when an area of adjustment is located a great distance from its associated display, adapt the adjustment tool or device so that it can be remotely operated from the display area. This will permit adjustment by one maintenance technician, eliminating the necessity for communicating with a second man. A direct feedback of display information to the technician making the adjustment should enhance accuracy.

(15) Provide wrenches or socket tools with variable torque settings for operation of bolts which require a precise amount of torque tightening.

(16) Provide ratchet screwdrivers where torque requirements are low and space is limited. They require only one-handed operation and usually require less clearance.

(17) Design equipment so that only straight type screwdrivers can be used (see Figure 11-3). Offset screwdrivers are not satisfactory because there is a lack of normal force on the screw head slots and the slots become damaged easily. However, the use of offset screwdrivers reduces the amount of space required to turn a screw and because of space limitations, may be the only solution. The overhead space requirement for offset tools is shown in Figure 11-4, and two special type offset tools for removing fasteners are illustrated in Figure 11-5.

(18) Use drills with floating chucks for drilling fastener holes for rivets. These will insure that the hole is drilled at the proper right angle so that maximum fit tolerances are reached.

(19) Provide adequate gripping surfaces on the handles of tools. Knurling, grooving, or shaping the handle to fit the hand are desirable.

(20) Specify the use of plastic, heat- or cold-resistant handles on tools which are to be used in extremely hot or cold climates. The use of metal handles is undesirable, particularly for cold climates.

(21) Design holding tools such as pliers or clamps so that they are skid-proof and do not mar or scratch holding surfaces.

(22) In evaluating the finish to be applied to tools, the designer should consider that tools having a dull finish prevents reflected glare in areas of high illumination. However, dull-finished tools are often overlooked when closing assemblies, etc., causing loss of tools and possible damage to the equipment. The designer should therefore consider carefully the advantages and disadvantages of this type of finish

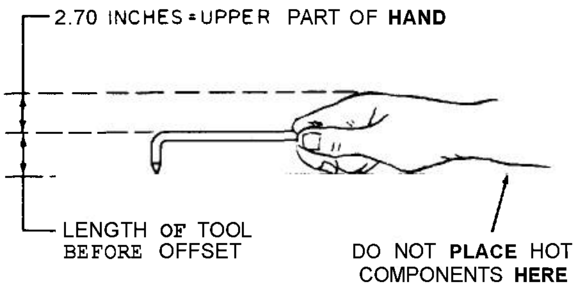
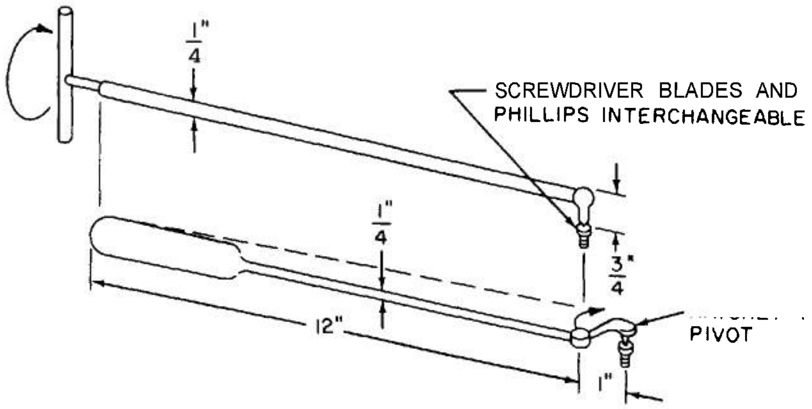


Figure 11-4. Overhead Space Requirements for



in relation to the potential application of the tool.

(23) Design spanner wrenches to that they are operable from various angles to avoid obstructions in operation.

(24) Provide the technician with templates for making surface control adjustments (rigging) or for mounting links, arms, rods, or other such parts on a flat surface. Provide markings on the templates which show the desired setting or placement of the control or part.

(25) Provide high speed soldering devices which will melt connections being serviced without damaging adjacent elements. This is especially important in new microminiaturized equipments.

(26) Provide clamping devices to remove small plug-in assemblies (see Figure **11-6).** much more closely than could be accomplished This will allow packing small plug-in units if it were necessary to use fingers to pick them **up.**

(27) Provide long-nosed hemostat-type pliers which can lock and hold their grip and be used as heat dispensers.

(28) Provide thin "reach-in" grasp and withdrawal types of hand tools; for example, a fuse puller having small tips to allow ease-of-return of fuse to holder.

(29) Provide small L-shaped prying apparatus to loosen plug-in micromodules of small assemblies. Bevel the end used for prying to facilitate component removal.

(30) Provide printed circuit card extenders, card extractors, and heat dissipating tool for soldering purposes.

11-3.3 SAFETY RECOMMENDATIONS

Some safety features to be considered in the design and use of hand tools are:

(1) Provide adequate insulation on tool handles or other parts of tools which the technician is likely to touch while doing maintenance work near voltages in excess of 50 volts.

(2) Provide tools which are spark resistant if they are to be used in areas where fire **or** explosion hazards exist.

(3) Provide storage for tools so that they cannot fall and cause personnel injury.

(4) Eliminate sharp corners and edges on tool chests.

(5) If tool chests are too large be handled easily by one man, provide casters or a sufficient number of handles to facilitate moving. Locate the handles so the chest will be balanced when it is being moved.

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2. **C.** R. Bilinski, *Utilization* of *Hand Tools in U. S. Navy Electronic Equipment Maintenance,* NEL Report *888,* U S Navy Electronics Laboratory, San Diego, Calif., **1959.**

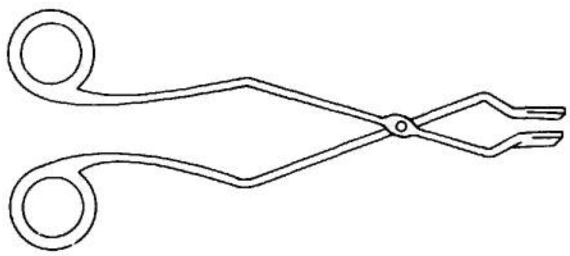

Figure 11-6. Micromodule Remover

PART FOUR
CONSIDERATIONS FOR GENERAL DESIGN APPLICATION

CHAPTER 12
ACCESSIBILITY

12-1 GENERAL

Inaccessibility is a prime maintainability problem. Ineffective maintenance is often the result of inaccessibility. The technician will tend to delay or omit maintenance actions, make mistakes, and accidentally damage equipment if he cannot adequately see, reach, and manipulate the items on which he must work. Accessibility, however, when considered separately, does not constitute maintainability. The mere fact that a technician can "get at something" does not mean that he can maintain it.

Accessibility can be defined as the relative ease with which an assembly or component can be approached for repair, replacement, or service. A component is accessible if the steps required are few and simple; inaccessible if the steps are many or are difficult to perform. *Inaccessibility cannot be tolerated in U S Army equipment to be used in combat.*

Poor accessibility to routine service points and parts of equipment reduces the efficiency and increases the time of the maintenance operation. If it is necessary to dismantle a given component completely or partially to reach a given part, the availability of the equipment decreases and maintenance costs increase. Controls, check points, inspection windows, and lubrication, pneumatic and hydraulic replenishing points are built into the equipment so that it can be kept operating at peak performance. If these service points are inaccessible, routine maintenance becomes difficult.

The greater the number of steps a maintenance operation requires, the greater the risk of error. For example, when access to a disabled component requires disassembly and reassembly of parts that are in the way, there is a possibility of introducing further malfunctions. Also, except for bench work in the shop, space is not usually available in the field for laying out parts as they are removed from the equipment. Disassembled parts may be lost while being disassembled and reassembled or while awaiting reassembly nearby.

Access is made more difficult when there is little space for hands and tools. In such cases there are also risks of injury to personnel as well as to material. Inaccessibility also has psychological aspects. The greater the number of accessory steps and the greater the discomfort involved, the more readily the mechanic might perform other tasks less demanding of him; periodic maintenance activities, such as checks and adjustments or troubleshooting, might be unduly postponed or neglected entirely. Inaccessibility is a human factors engineering problem. The contribution of the human factors engineer can be important in helping the design engineer make a task analysis of the mechanic's job.

12-2 FACTORS AFFECTING ACCESSIBILITY

Access must be provided to all points, items, units and components which require or may require testing, servicing, adjusting, removal, replacement, or repair. The type, size, shape, and location of access should be based upon a thorough understanding of the following:

(1) Operational location, setting, and environment of the unit.

(2) Frequency with which the access must be entered.

(3) Maintenance functions to be performed through the access.

(4) Time requirements for the performance of these functions.

(5) Types of tools and accessories required by these functions.

(6) Work clearances required for performance of these functions.

(7) Type of clothing likely to be worn by the technician.

(8) Distance to which the technician must reach within the access.

(9) Visual requirements of the technician in performing the task.

(10) Packaging of items and elements, etc., behind the access.

(11) Mounting of items, units and elements, behind the access.

(12) Hazards involved in or related to use of the access.

(13) Size, shape, weight and clearance requirements of logical combinations of human appendages, tools, units, etc., that must enter the access.

12-3 MAINTENANCE ACCESSES

An access should be provided wherever a frequent maintenance operation would otherwise require removing a case or cover, opening a connection, or dismantling a component. An access should be designed to make the repair or servicing operation as simple as possible. During design, the parts to be reached through each access should be noted, and the operations to be performed on each part using that access should be studied. Accesses include entrance doors, inspection windows, and lubrication, pneumatic, and hydraulic servicing points. Recommended equipment accesses are given in Table 12-1.

12-3.1 OPENINGS FOR PHYSICAL ACCESS

Make accesses the shape necessary to permit easy passage of components. Use a hinged door, instead of a cover plate held in place by screws or other fasteners, where physical access is required. If lack of space prevents the use of a hinged opening, use a cover plate with captive quick-opening fasteners. If a hinged access or quick-opening fastener will not meet stress, pressurization, safety, or other requirements, use the *minimum number* of the *maximum practical size* screws consistent with those requirements. On hinged access doors, place the

TABLE 12-1. RECOMMENDED EQUIPMENT ACCESSES (Ref. 1)

Desirability	For Physical Access	For Visual Inspection Only	For Test and Service Equipment
Most desirable	Pullout shelves or drawers.	Opening with no cover.	Opening with no cover.
Desirable	Hinged door (if dirt, moisture or other foreign materials must be kept out).	Plastic window (if dirt moisture or other foreign materials must be kept out).	Spring-loaded sliding cap (if dirt, moisture or other foreign materials must be kept out).
Less desirable	Removable panel with captive, quick-opening fasteners (if there is not enough room for hinged door).	Break-resistant glass (if plastic will not stand up under physical wear or contact with solvents).	
Least desirable	Removal panel with smallest number of largest screws that will meet requirements (if needed for stress, pressure, or safety reasons).	Cover plate with smallest number of largest screws that will meet requirements (if needed for stress, pressure, or safety reasons).	Cover plate with smallest number of largest screws that will meet requirements (if needed for stress, pressure, or safety reasons).

hinge at the bottom or provide an integral prop, so that the door will stay open without being held when the equipment is in its normal position (see Figure 12-1). However, if due to vibration the door may inadvertently become loose and drop down, thus becoming a safety hazard, consideration should be given to the use of a top hinge.

If situational and environmental factors such as climate, dirt, or danger from falling objects preclude an uncovered opening, use a hinged or sliding cover, as illustrated in Figure 12-2.

Provide a small access opening on large access panels to facilitate frequent maintenance tasks. Frequent tasks, such as visual inspection and fluid replenishment, should not require the removal of huge panels that are required only for infrequent tasks.

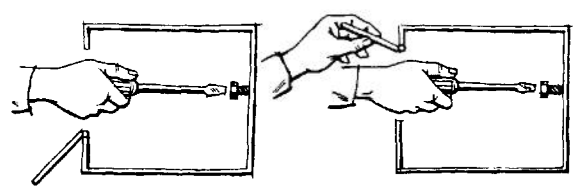

Figure 12-1. Support Hinged Access Doors at the Bottom (Ref. 2)

12-3.2 ACCESSES FOR VISUAL INSPECTION ONLY

Use no cover unless exposure is likely to degrade equipment or system performance. If the entrance of dirt, moisture, or other foreign materials is a problem, use a plastic window. If physical wear or contact with solvents will cause optical deterioration of plastic, use a break-resistant glass window. If glass will not meet stress or other requirements, use a quick-opening metal cover.

12-3.3 ACCESSES FOR TOOLS AND SERVICING EQUIPMENT

Use no cover unless exposure is likely to degrade equipment or system performance. If the entrance of dirt, moisture, or other foreign materials is a problem, use a spring-loaded sliding cap. If a cap will not meet stress or other requirements, use a cover plate with quick-opening fasteners.

12-4 LOCATION OF ACCESSES

The location of accesses for maintenance should be dictated by the way in which units are installed. Determine which faces of the unit will be accessible in the normal installation and place accesses on one of these faces. All accesses, displays, controls, cables, etc., should be

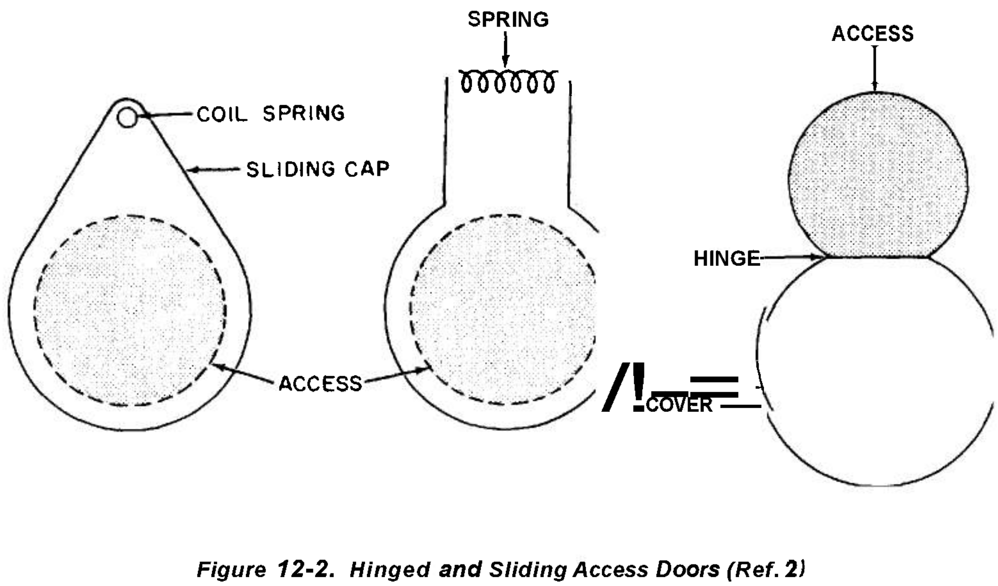

Figure 12-2. Hinged and Sliding Access Doors (Ref. 2)

put on the same face of a unit wherever possible, because it is usually difficult to keep more than one face readily accessible.

Place access openings for maximum convenience in performing the job. Determine what the technician will have to do through a given access and place the access to accommodate that operation. For some operations, it might be better to place the access to the side instead of directly over the operation. Design for location of accesses:

(1) Only on unit faces that will be accessible in normal installation.

(2) To permit direct access and maximum convenience for job procedures.

(3) On the same face of the equipment as the related displays, controls, test points, cables, etc.

(4) Away from high voltages or dangerous moving parts, or provide adequate insulation, shielding, etc., around such parts to prevent injury to personnel.

(5) So that heavy units can be pulled out rather than lifted out.

(6) So that the bottom edge of a limited access is no lower than 24 in. or the top edge no higher than 60 in. from the floor or work platform.

(7) To conform to heights of work stands and carts related to use of the access.

12-5 SIZE OF ACCESSES

Determine what the technician will have to see before deciding on the access size. If the technician must see what he is doing inside the equipment, the access might need to be large enough for the technician's hands and arms and still leave an adequate view of what he is doing. Sometimes an access door and a window might be required (see Figure 12-3). In some instances, a small hole that admits a screwdriver or a grease gun is sufficient access to an equipment. Other times, the maintenance man may have to get a hand or, perhaps, his whole body in an equipment.

The size of access openings is determined by the size and shape of the part, component, or assembly to which access is desired; whether or not the object must be removed and replaced through the openings; movements of the human body member or members required once access

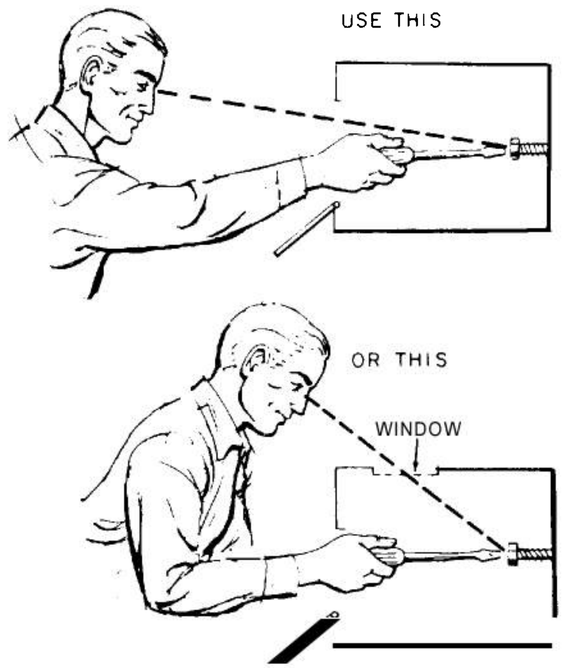

Figure 12-3. Providing Visual Access

is gained (turning, pulling, pushing, etc.); and the size of the body member or members required to enter through the access opening. The first two factors can only be determined by an analysis of the task or tasks involved. The last two factors are determined by body measurements. The first of these last two factors is determined by dynamic body measurements; the last is determined by static body measurements (see Chapter 9).

Table 12-2 shows the minimum access requirements for one-handed tasks and Figure 12-4 illustrates the minimum access dimensions for two-handed tasks. The minimum aperture dimensions for tasks that require penetration of a regularly clothed technician's head, shoulders, or whole body are given in Table 12-3. In using this table, consideration must be given to whether or not access must be made by technicians wearing arctic clothing.

12-6 SHAPE OF ACCESSES

Access openings should be designed in whatever shape necessary to permit passage of the required items and implements. The openings need not necessarily be round, square, or rec-

TABLE 12-2. APERTURE DIMENSIONS FOR ONE-HANDED TASKS

Task	Dimensions: Bare hand technician wearing ordinary clothing (in.)	Dimensions: Arctic jacket and mittens (in.)
Smallest square hole through which empty hand can be inserted,	3.5	-
Smallest square hole through which hand and 8 in. screwdriver with 1 in. dia handle can be inserted.	3.75	-
Inserting component.	Width: 4.5 Height: (Dia. of component) 1.75	-
Inserting empty hand held flat.	Width: 4.5 Height: 2.25	6.5 5
Inserting hand closed as a fist. (Thumb outside of fist.)	Width: 5.125 Height: 4.25	7 6
Reaching through access to elbow depth	Width: 4.5 Height: 4	7 6
Reaching through access to shoulder (full arm's length).	Width: 5 Height: 5	7 6
Inserting miniature vacuum tube.	Dia: 2	-

TABLE 12-3. APERTURE DIMENSIONS FOR REGULARLY CLOTHED TECHNICIAN

Body Member or Position	Dimensions
Passing head breadth.	7 in. wide
Passing shoulder width.	20 in. wide
Passing body thickness.	13 in. wide
Passing through access in crawling position.	31 in. high 20 in. wide
Passing through access in kneeling position. (with back erect).	20 in. wide 64.5 in. high
Two men passing through access abreast (standing).	36 in. wide

tangular. If a removable access plate must be attached in a certain way, e.g., to prevent damage to equipment mounted on the back of the access plate, shape code the access plate to prevent incorrect attachment, as shown in Figure

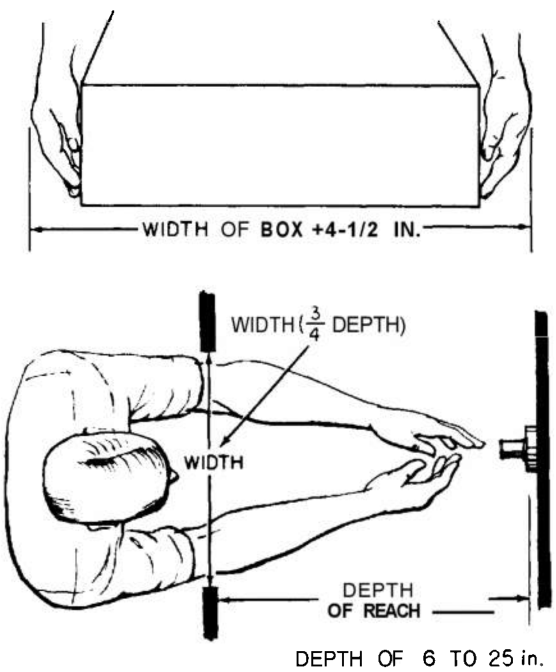

Figure 12-4. Minimum Access for Two-Handed Tasks

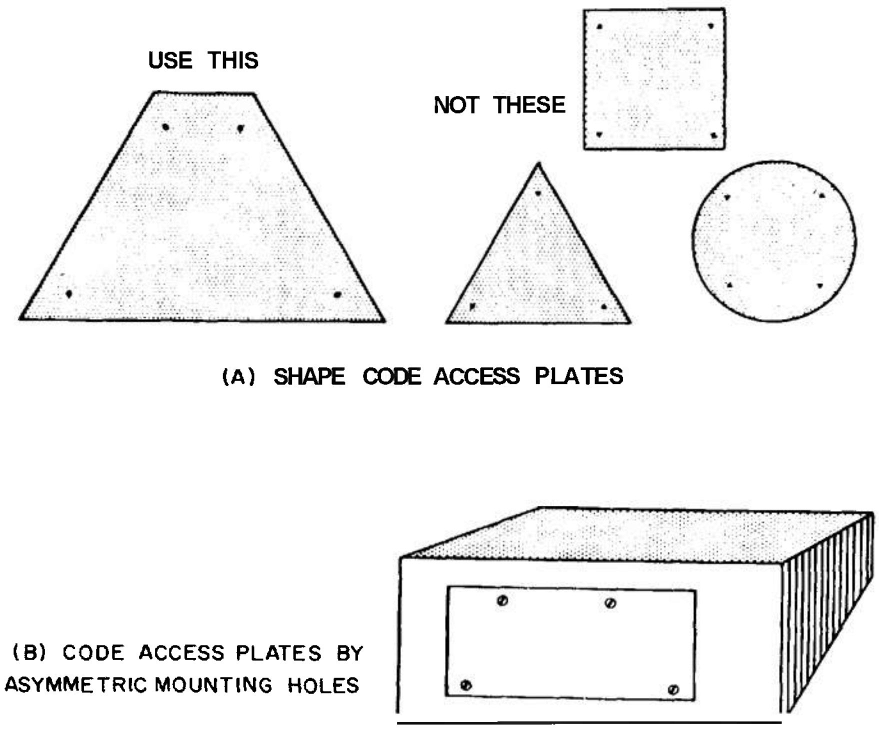

Figure 12-5. Removable Access Plates To Prevent Incorrect Attachment (Ref. 2)

12-5(A), or use asymmetric mounting holes, as shown in Figure 12-5(B).

12-7 OTHER DESIGN RECOMMENDATIONS

Additional recommendations that should be considered in the design of accesses are:

(1) Label each access with the items accessible through it as well as the auxiliary equipment to be used at the access.

(2) Label each access with a unique number, letter, or other symbol designation so that each one can be clearly identified in job instructions and maintenance manuals.

(3) Provide an indication of the position for insertion of components and connectors through small accesses. Use matching stripes, dots, or arrows on the cabinet and on the component to be inserted. Where space permits, a drawing of the pin position may be used (see Figure 12-6).

(4) Locate accesses to prevent contact of parts of the body placed into the access with hot or extremely cold components, toxic substances, moving parts, electrical current, or sharp edges. Also, ensure that the access location does not

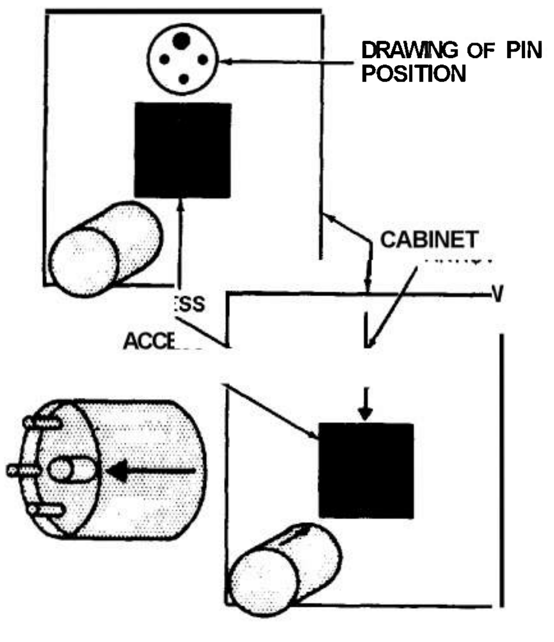

Figure 12-6. Code Component Installation Position (Ref. 2)

require the maintenance technician to assume postures that might cause body parts outside of the access to come in contact with these danger sources.

(5) Use a locking device on large access doors which might fall shut and cause damage or injury.

(6) Round the edges of access openings, or provide a rubber, fiber, or plastic covering if sharp edges could injure the technician's hands or arms.

(7) Provide visual access for maintenance operations which must be performed in areas where there is danger from nearby electrical circuits. If visual access cannot be provided, thoroughly insulate exposed wires and provide location diagrams as a guide to the maintenance technician. Where adjustment points are located near high voltages, provide screwdriver guides to these adjustments to prevent contact with dangerous voltages.

(8) Provide safety interlocks on accesses leading to equipment with high voltage. If the equipment circuit must be ***on*** during maintenance, provide a cheater switch that automatically resets when the access is closed (see also Chapter **15).**

(9) Make access openings to batteries large enough to permit two-handed operation (see Figure **12-4).** To these dimensions should be added the dimensions of the largest piece of equipment to be inserted through the opening.

(10) When batteries are installed in compartments, provide quick-disconnect plugs and a sliding tray receptacle for the battery, to permit access for inspection, test, or replacement. placement.

(11) Provide access to all fuses to avoid the necessity of removing other units to replace fuses.

(12) Provide self-sealing fuel, water-alcohol, and oil tanks with an access door of such size that the entire interior of the tank is available for inspection, cleaning, or other maintenance without removing the tank.

(13) Locate hydraulic reservoirs so they are visually accessible for refilling. **If** the technician cannot see the fluid level, the hydraulic fluid may overflow and damage nearby components.

(14) In using split bearings, optimize **ac**cessibility by making the plane **of** the split of the bearing correspond with access ports. **For** example, split the crankshaft bearing on an engine connecting rod to permit bearing removal through the external access without necessity of removing the crankcase cover (Ref. **3).**

(15) Where accesses are located over dangerous mechanical components which can cause serious injury, design the access door so that it turns on an internal light automatically when opened. Also provide a highly visible warning label on the access door.

(16) Provide for rapid inspection apertures on gear boxes, housings, and similar type of assemblies to permit inspection, adjustment, or when practical, repair or replacement of vital items inside of these housings without the necessity of major disassembly. These apertures may be plugs, windows, bailed hinged covers, or doors requiring no tools to open and close.

12-8 SECURING ACCESS PLATES

If screws must be used to secure plates, and there is more than one access to the equipment, use the same size screws for each plate, if possible. If practicable, the tool used to remove an access plate should be the same one that will be used to service or remove the components to which the plate offers access.

for securing both access plates and component
Table **12-4** lists the screws, nuts and washers parts. This list was compiled for wide application after study by the U S Army Tank-Automotive Center.

Only standard fasteners have been included. Indiscriminate use of fasteners, such as socket, Phillips, clutch, square, oval, round, fillister and flat head screws and bolts and castle, wing, jam, and plain hexagon nuts increases the number and kinds of tools required and **may** create problems of inaccessibility. In using Table **12-4,** the following guides will be helpful :

(1) Use Unified National Fine (UNF) screws in every possible application when self-locking nuts are also used or when tapped holes are provided.

(2) Use Unified National Coarse (UNC) screws only when they must ***go*** into iron, aluminum, or bronze.

(3) Use spring-type lockwashers with UNC screws.

(4) Use flat washers only for applications in which slotted holes are necessary.

(5) Use 0.375-in. or larger screws for exterior mounting and 0.25-in. screws or larger **for** interior mounting.

12-9 NUTS AND BOLTS SPACING

Finger room for starting nuts and screws that are used for mounting parts, components, and assemblies must be provided; nuts and bolts must not be located so close to a barrier or to each other that a wrench cannot properly engage them (see Figure 12-7).

To maintain uniform contact pressure in a gasketed joint, the pitch should not be excessive — perhapsfive to six bolt diameters.

12-10 SPATIAL REQUIREMENTS FOR USE OF HAND TOOLS

A major maintenance difficulty is caused by the decreased space provided in many of the newer equipments. Although new equipment tends to be smaller, hand tools have remained much the same size. Particular spatial problems exist when the handle of the tool requires **a**

TABLE 12-4. ATTACHING HARDWARE (Ref. 4)

Hardware	Length (in.)	Nominal Diameter—(in.)					
		0.25	0.375	0.5	0.675	0.75	1
Hexagon head cap screws: Steel, cadmium, or zinc plated	0.5	3	55				
	0.625	5	57				
	0.75	6	58				
UNF: MS 35296- UNC: MS 35297-	1	8	60	109			
	1.25		62	111	160		
Steel, corrosion resistant, passivated UNF: MS 35308- UNC: MS 35307-	1.5		64	113	162	185	
	1.75		65	114	163	186	
	2		66	115	164	187	230
Aluminum alloy UNC (only): MS 35313-	2.5			117	166	189	232
	3			119	168	191	234
	4				172	195	238
Naval brass UNC (only): MS 35309-	5				176	199	242
	6					201	244
Lockwasher steel phosphate finish: MS 35338-		63	65	67	69	70	72
Flat washer steel, cadmium or zinc plated: MS 15795		210	214	218	220	222	226
Hexagon locknut **(UNF)** steel plated: MS 20365- steel, corrosion resistant, passivated: MS 20500-		428	624	820	1018	1216	1614

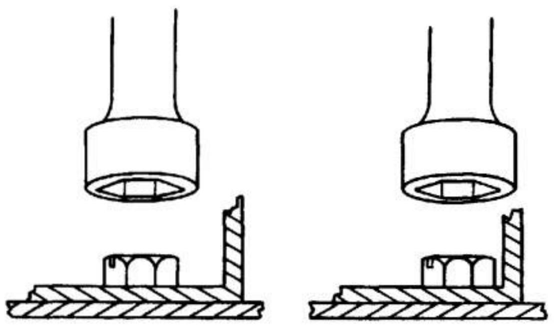

Figure 12-7. Placing Of Bolts And Nuts For Wrench Clearance

sweeping movement for performing its function, as, for example, with box wrenches, offset screwdrivers, and socket head screw wrenches. The length of such a tool determines the radius of its sweep and, in turn, determines the amount of working space required. In a hypothetical bolt requiring 18 turns for the nut to be tightened, the following actions are necessary within the equipment when using a ratchet-type wrench (Ref. 5).

(1) When a full turn is possible, 18 full turns will require approximately 20 sec.

(2) When only a half turn is possible, 36 half turns will require approximately 30 sec.

(3) When only a quarter turn is possible, 72 quarter turns will require approximately 40 sec.

Equipment should allow, for each nut to be removed in maintenance, at least a quarter turn for the hand tool or, preferably, a half turn. Because of the structure of the wrist, it is easier for the maintenance man to apply half or quarter turns than full turns when using a hand tool. With a wrench, the finger sometimes can be manipulated instead of the wrist (particularly in the initial, easy twists). With tools of the screwdriver type, however, the wrist plays an important role. Such tools are generally no wider than the width of the screw or nut they remove or replace; their working space requirements, therefore, are related to depth.

To provide sufficient working space for the screwdriver-type of tool, it is desirable to have an overhead clearance of no less than the full length of the tool itself, plus the length of the fastener, plus at least 3 in. for the technician's hand (see Figure 12-8). A minimum size (stubby) screwdriver (about 3 in. long) would require an overhead clearance of at least 6 in. A space less than this would probably require use of an offset screwdriver, but, even then, overhead clearance would have to be the initial height of the screw plus the height of the shank and the blade. Also, radial freedom of movement would be required.

To use a screwdriver-type tool with maximum effectiveness, it is necessary to have sufficient working space to accommodate the full length of the screwdriver plus the length of the maintenance man's hand, wrist, and forearm. In congested equipment, however, personnel frequently hold the tool from the side, thus reducing the space requirements lengthwise, but, also, reducing the force that can be applied. In such cases, it is easy to shear the driver recess or allow a fastener to remain not completely tightened.

12-11 SPLIT-LINE DESIGN

Housings for units such as radios, containers, etc., should incorporate split-line design (suitcase design). The unit may have equipment in both "halves" or have a hinged or removable cover. Many suitable versions are acceptable, including book type, slip-off cover type, hinge-out unit type, etc. The main feature is instant

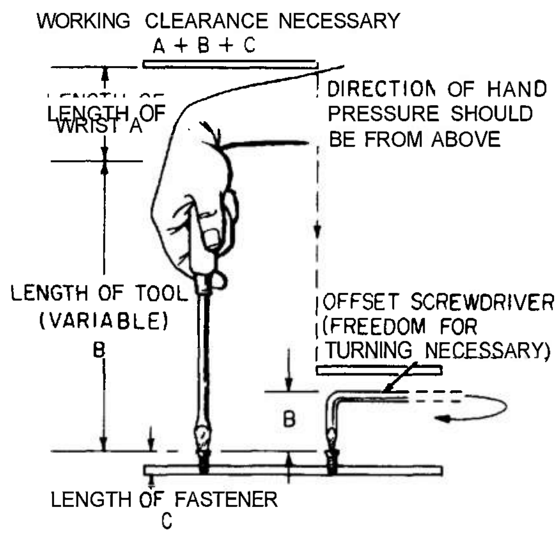

Figure 12-8. Working Space Requirements For Hand Tools Within Equipment (Ref. 5)

accessibility to all internal components. Delicate equipment such as instruments or electronic devices should have a simple, effective seal around the split line to keep out contaminants. Fasteners should be the minimum required to perform the function and should be reliable, rugged, and easy to operate. No loose fasteners should be used. When locks with keys are used on any type of door or housing, the key must be turned to lock or unlock the housing. The housing should not be able to open or lock inadvertently.

12-12 ACCESSIBILITY CHECKLIST

Table 12-5 summarizes some of the important design recommendations to be considered when designing for accessibility. The checklist contains several items which were not discussed separately in the text. These items are included here because their necessity in the design is so obvious that they might otherwise be inadvertently overlooked. In using the checklist, if the answer to any question is *no,* the design should be restudied to ascertain the need for correction.

REFERENCES

1. C. T. Morgan, et al., Ed's. *Human Engineering Guide to Equipment Design,* McGraw-Hill Book Co., Inc., N. Y., 1963.
2. J. W. Altman, et al., *Guide to Design of Mechanical Equipment for Maintainability,* ASD-TR-GI-381, Air Force Systems Command, Wright-Patterson AFB, Ohio, 1961, (DDC No. AD 269 332).
3. C. R. Bilinski, *Utilization of Hand Tools in U S Navy Electronic Equipment Maintenance,* NEL Report 888, U S Navy Electronics Laboratory, San Diego, Calif., 1960.
4. *Tracked Vehicle Design Practices Guide,* U S Army Tank-Automotive Center, Warren, Mich., 1958.
5. *Handbook of Instructions for Aircraft Ground Support Equipment Designers* (HIAGSED), Air Research and Development Command, Washington, D. C., 1958.

TABLE 12-5. ACCESSIBILITY CHECKLIST

1. Is optimum accessibility provided in *all* equipment and components requiring maintenance, inspection, removal, or replacement?
2. Is a transparent window or quick-opening metal cover used for visual inspection accesses?
3. Are access openings without covers used where this is not likely to degrade performance?
4. Is a hinged door used where physical access is required (instead of a cover plate held in place by screws or other fasteners)?
5. If lack of available space for opening the access prevents use of a hinged opening, is a cover plate with captive quick-opening fasteners used?
6. If a screw-fastened access plate is used, are no more than 4 screws used?
7. On hinged access doors, is the hinge placed on the bottom or is a prop provided so that the door will stay open without being held if unfastened in a normal installation?
8. Are parts located so that other large parts which are difficult to remove do not prevent access to them?
9. Are components placed so that there is sufficient space to use test probes, soldering iroiis, and other required tools without difficulty?
10. Are units placed so that structural members do not prevent access to them?
11. Are components placed so that all throwaway assemblies or parts are accessible without removal of other components?
12. Is equipment designed so that it is not necessary to remove any assembly from a major component to troubleshoot to that assembly?

TABLE 12-5. ACCESSIBILITY CHECKLIST (cont)

13. Can screwdriver operated controls be adjusted with the handle clear of any obstruction?
14. Are units laid out so maintenance technicians are not required to retrace their movements during equipment checking?
15. Is enough access room provided for tasks which necessitate the insertion of two hands and two arms through the access?
16. If the maintenance technician must be able to see what he is doing inside the equipment, does the access provide enough room for the technician's hands or arms and still provide for an adequate view of what he is to do?
17. Are irregular extensions, such as bolts, tables, waveguides, and hoses easy to remove before the unit is handled?
18. Are access doors made in whatever shape is necessary to permit passage of components and implements which must pass through?
19. Are units removable from the installation along a straight or moderately curved line?
20. Are heavy units (more than about 25 lbs) installed within normal reach of a technician for purposes of replacement?
21. Are provisions made for support of units while they are being removed or installed?
22. Are rests or stands provided on which units can be set to prevent damage to delicate parts?
23. Is split line design utilized wherever possible and necessary?
24. Are access points individually labeled so they can be easily identified with nomenclature in the job instructions and maintenance manuals?
25. Are accesses labeled to indicate what can be reached through this point (label on cover or close thereto)?
26. Are accesses labeled to indicate what auxiliary equipment is needed for service, checking, etc. at this point?
27. Are accesses labeled to specify the frequency for maintenance either by calendar or operating time?
28. Are access openings free of sharp edges or projections which could injure the technician or snag clothing?
29. Are parts which require access from two or more openings marked to so indicate in order to avoid delay and/or damage by trying to repair or remove through only one access? Are double openings of this type avoided wherever possible?
30. Are human strength limits considered in designing all devices which must be carried, lifted, pulled, pushed, and turned?
31. Are environmental factors (cold weather, darkness, etc.) considered in design and location of all manipulatible items of equipment?

CHAPTER 13
IDENTIFICATION

13-1 GENERAL

Identification is an inherent ingredient of maintainability. The maintenance technician's task will be more difficult, take longer, and, consequently, increase the risk of error if he cannot readily identify components, parts, controls, and test points for maintenance operations. However, identification, when considered separately, does not constitute maintainability. The fact that an item is adequately labeled does not mean that a technician can maintain it.

Identification can be defined as the adequate marking or labeling of parts, components, controls, and test points to facilitate repair and replacement during maintenance operations. Proper identification is present if the component is readily identified for repair, replacement, or service with minimum effort by the technician.

13-2 TYPES OF IDENTIFICATION

Various types of identification are described in the paragraphs which follow.

13-2.1 EQUIPMENT IDENTIFICATION

Equipment should be marked for identification in accordance with MIL-STD-130 by stamping, engraving, permanent labeling, or other permanent methods. Each item, except detailed assemblies and parts, should be identified with a securely attached, permanent-type, water, oil, gasoline and corrosion resistant name plate. The name plate should conform to military specifications and be permanently and legibly marked with the following information :

- Contract Order or Task No.
- Item Name (noun first)
- Specification No.
- Manufacturer's Part No. (or Government Standard Part No.)
- Serial No. (when available)
- Stock No. (when available)
- Manufacturer's Name and Address

Equipment identification should include pertinent data with regard to its function, capacity, capabilities, limits, ranges, frequency, and current requirements. Weight, rpm, horsepower, and other basic information should also be included. Connections for electrical assemblies should be marked in accordance with MIL-STD-195, and all insulated wire should be color or number coded as prescribed in MIL-STD-681. Markings pertaining to mobility should be in accordance with MIL-A-8090 and those pertaining to air transportability should be in accordance with MIL-A-8421.

13-2.2 INSTRUCTION PLATES

Permanent instruction plates should be attached to the item in an easily visible and suitable location. Instruction plates should describe or illustrate, as required, basic operating instructions, calibration data, simple wiring or fluid flow diagrams, warning and safety precautions, calibration and adjustment instructions, location of test points, transistors and other pertinent electronic equipment, valve settings, ignition settings, type of fuels, oils, or greases applicable, and other similar data required to perform routine maintenance. When necessary, a permanently attached pocket or similar device should be attached to the equipment for containing various maintenance aids such as signal flow diagrams, diagnostic procedures, pictorial presentations, and maintenance records.

Precautionary markings in the form of CAUTIONS and WARNINGS should be provided as necessary to warn personnel of hazardous conditions and precautions to be observed to ensure safety of personnel and equipment.

13-2.3 PARTS IDENTIFICATION AND REFERENCE DESIGNATIONS

MIL-STD-16 governs the formation and application of reference designations, and requires that the unit numbering method shall be used on all new equipment. This method provides adequate flexibility for numerous uses of the same assembly without having to alter the reference designations within it, and also permits the addition and rework of assemblies within an equipment without having to alter reference designations previously assigned.

Designations should be clear and easily distinguished in subdued lighting at a distance of 28 in. Black markings should be used on light backgrounds such as light-gray painted surfaces, unfinished brass, aluminum, and all bright, plated surfaces. White markings should be used on dark backgrounds such as medium-gray painted surfaces. Table 13-1 gives recommended numeral and letter heights in inches for a 28-in. viewing distance. For other viewing distances, multiply the given values by distance in inches divided by 28.

Where the color of the surface will vary because of variations in the material or finish, alternate colors for characters should be specified to obtain maximum contrast between characters and backgrounds. This applies particularly to zinc-plated, chromate, or phosphate surfaces and plastics.

13-2.3.1 Marking of Parts

Each part shown on a drawing or schematic diagram should be identified by a designation referring to parts descriptions given elsewhere on the drawing or diagram. The wiring diagram prepared in accordance with the schematic diagram should carry designations for wires, sockets, plugs, receptacles, and similar parts. Mechanical parts that might require replacement should carry standard designations. Frames, brackets, levers, bearings, pulleys, and similar parts should be marked during manufacture. On semifixed electrical items, such as fuses and resistors that are ferrule-clip mounted, the electrical rating should be shown in addition to the standard designation. On items having critical polarity or impedance ratings, these ratings should also be shown. Where complexity of the assembly warrants, a concise wiring diagram affixed to the unit is desirable.

Nature of Markings	Low Brightness, down to 0.03 ft-lambert (in.)	High Brightness, down to 1.0 ft-lambert (in.)
Critical markings—position variable (numerals on counters and settable or moving scales)	0.20 to 0.30	0.12 to 0.20
Critical markings—position fixed (numerals on fixed scales, control and switch markings, emergency instructions)	0.15 to 0.30	0.10 to 0.20
Noncritical markings (instrument identification labels, routine instructions, any markings required for initial familiarization only)	0.05 to 0.20	0.05 to 0.20

Terminals on all assemblies and parts should be suitably marked, and the wiring should include all terminal markings.

The following rules should be used in the marking of parts :

(1) Make markings accurate and sufficient to identify the referenced part.

(2) Locate markings on or immediately adjacent to the referenced. part in a consistent manner that will eliminate any possibility of confusion,

(3) Make markings permanent enough to last the life of the equipment.

(4) Place markings so that they are visible without removing other parts.

(5) Orient markings so that they can be read with the unit in the normal installed position.

(6) Mark stacked parts and modules so that they can be individually recognized.

(7) Identify individually enclosed or shielded parts on the outside of the enclosure.

(8) Mark identically the fixed and removable parts of **a** plug-in subassembly.

(9) Identify clearly individual sections of dual parts.

13-2.3.2 Location of Markings

Designation markings on equipment should be placed on or immediately adjacent to the part. Small electrical parts, such as resistors, capacitors, and terminals affixed to mounting boards or terminal strips, should be identified by markings on the boards. Items that are not board mounted should be identified by markings on the chassis. Multiple terminals should be identified by markings on the component or adjacent chassis.

Where a part projects through an electronic chassis, the markings should be made on the wiring side. Terminals of transformers, relays, capacitors, and all socket-mounted items, except standard vacuum tubes, should be marked adjacent to each terminal. Receptacles for plugs, modular units, and similar parts that are accessible from the top side should have both bottom- and top-side identification.

13-3 MARKING PROCESSES

A marking process should be selected after consideration of type of surface, location, engineering change requirements, and durability. Designations are applied either directly to the part, framework, panel, or chassis supporting the apparatus or by the attachment of separate plates bearing the designations. The more commonly used methods of applying the characters are decalcomania transfer process, engraving, etching, photo-contact process, rubber stamping, silk screening, steel stamping, and stenciling. Special features which pertain to each of these processes are as follows :

(1) *Decalcomania transfer.* Open-letter-type decalcomania transfers can be applied to metallic, plastic, or organic-finished surfaces, **A** lacquer-type adhesive holds the characters to the surface after the paper backing has been removed. An over-coating of lacquer or varnish generally is applied. Decalcomanias having water-soluble coatings, however, should not be used.

(2) *Engraving.* Engraving is the cutting **of** characters into the material surface with a tool. Cost of engraving is high, and production is slow. Wearing qualities, however, are excellent.

(3) *Etching.* Photoetching is applied to metal surfaces only. Reverse etching is normally specified. In this process the characters are printed or drawn to an enlarged scale and a photographic reproduction, reduced to the proper size, is made on the surface to be marked. The characters are then treated to make them resistant to acid. The acid eats out the background, leaving the characters raised.

(4) *Photo-contact process.* The photo-contact process should be used where precision markings are required, such as on dials. This process can be applied to metallic and nonmetallic materials. If excessive wear is to be encountered, raised markings are not recommended.

(5) *Rubber stamping.* Rubber stamps are widely used for markings, but legibility may be affected by smudging. The application of such marking is awkward especially when the length of the stamp is greater than eight times the height. This type of marking does not have the durability of some other processes, and water-soluble inks should not be used.

The advantages of this method are the ease of application to small and restricted areas and the ease of correction during manufacture **or** later, in the field, to take care of development changes. The disadvantage is chiefly one of appearance; the characters are not clear, are subject to smudging, and can be applied in irregular lines.

(6) ***Silk screening.*** Some of the advantages of the silk screen process for marking parts are that it is relatively inexpensive, a wide variety of materials and items can be marked, and almost any size object can be marked. Also, it is particularly suitable and economical for small- and medium-sized production runs.

(7) ***Steel stumping.*** This method of marking provides identification of mechanical parts at low cost. Care must be taken, however, to insure that the stamping process does not damage the part.

TABLE 13-2. MARKING PROCESSES AND RECOMMENDED GOTHIC STYLE TYPES (Ref. 2)

Marking Method	Preferred Gothic Type Style (Capitals)	Alternate Gothic Type Style (Capitals) (Specify Only if a Design Requirement)
Engraving	Gorton Condensed	Gorton Normal or Extra Condensed
Steel stamping: Hand (Part identification)	Gorton Condensed	Gorton Extra Condensed
Power press (Instruction messages)		
Etching: Electrical	Gorton Condensed	Gorton Extra Condensed
Chemical or photo (Metal nameplates, designation plates, information plates, etc.)	Futura Medium Condensed	Futura Demi-Bold
Sand casting	Gorton Normal	Gorton Condensed
Rubber stamping Stenciling Photo-contact	American Type Founders (ATF) News Gothic Condensed	American Type Founders (ATF) News Gothic Extra Condensed
Printing	American Type Founders News Gothic Condensed (plus lower case)	American Type Founders (ATF) New Gothic Extra Condensed (plus lower case)
Screen printing	1. Futura Medium Condensed (for characters above 0.125 in.) 2. Futura &mi-Bold (for Caution and Warning Signs and for Characters 0.125 in. and less)	
Decalcomania transfers Aluminum foil labels	Futura Medium Condensed	Futura Demi-Bold

(8) Stenciling. If stenciling is to be applied to plastic, specify stenciling before impregnation. Where MIL-M-7911 identification-marking procedures apply, the cover coating may be omitted, provided the stenciling ink used meets the requirements of Federal Specification TT-1-558.

13-4 SPECIFYING CHARACTER STYLES

The preferred style of Gothic characters for the various marking processes is given in Table 13-2. In specifying the style of characters to be used in marking, give the name, style and, when necessary, font number of the type. The size should be the character's height either in inches or in printer's points depending on the marking procedure involved.

The recommended character sizes, indicated below, are based on fractional character heights. When the printer's point system is required, refer to Table 13-3 to determine the point size equivalent to a given fractional character height. Additional information can be obtained from a printer's typeface book.

(1) Characters of 0.125 in. height on large parts, and 0.062 in. characters on all other parts are preferred. On small parts, where space is limited, 0.031 in. characters may be used.

(2) Except for equipment identification and information plates, the size of characters should be restricted to the point sizes equivalent to the above when possible. Point sizes equivalent to 0.5 in. characters could be used for DANGER and CAUTION signs.

TABLE 13-3. CHARACTER HEIGHT FOR VARIOUS SIZES OF TYPE

Condensed Title Gothic No. 11		Futura	
Size (pt.)	Height (in.)	Size (pt.)	Height (in.)
6	0.048	6	0.0468
6	0.062	8	0.0625
8	0.078	10	0.0937
8	0.090	12	0.1093
10	0.120	14	0.1250
12	0.145	16	0.1406
16	0.190	18	0.1562
20	0.240	24	0.2187
24	0.300	30	0.2812
30	0.375	36	0.3750
36	0.450	42	0.4375
42	0.520	48	0.4843
48	0.610	60	0.6093
60	0.780	72	0.7187
72	0.900	84	0.9375

13-5 LABELING

Labels are lettered indications of the name, identifying number, and function of equipment which are affixed on or near the relevant equipment. They may also include warning signals of a lettered nature and abbreviated instructions, both lettered and diagrammatic, for operating or maintaining equipment. It is sometimes better to over-label than to under-label. Equipment is often separated from operation and instruction manuals, and labeling can be a satisfactory substitute. The following paragraphs present recommendations for the color, lettering, organization, and placement of labels. Also presented are some recommendations for designing various types of labels (identification, warnings, or instructions) and labels for specific subsystem equipment.

13-5.1 COLORS FOR LABELS AND SIGNS

Provide color combinations of printing and background which will maximize legibility. The best color combinations in descending order are :

blue on white
black on yellow
green on white
black on white
green on red
red on yellow

If color codes, labels and signs are necessary, select colors on the basis of recognizable differences. The following four colors are considered ideal for surface coding because they are easily recognizable by both normal and color deficient observers.

Color	FED-STD 595 Code No.
black	37038
white	27875
yellow	23655
blue	25102

13-5.2 ORGANIZATION AND WORDING OF LABELS

(1) Make labels brief but adequately explanatory. Use brief, familiar words. Use abbreviations only when meaningful. Use key action words instead of abbreviations where possible (see Figure 13-1).

(2) When labels contain a number of steps to be performed sequentially, itemize the steps rather than presenting them in paragraph form (see Figure 13-2.)

(3) Make codes and labels on equipment consistent with both the instruction manuals and the parts catalogs.

(4) Specify labels that read horizontally rather than vertically (see Figure 13-3).

(5) Specify arrows that are as clearly recognizable and identifiable as possible when read at a distance. The direction of arrows with sharp angles and clean lines is less easily misinterpreted at a distance than that of arrows with wider angles and broader overall width-to-length ratios (see Figure 13-4).

13-5.3 PLACEMENT AND POSITIONING OF LABELS

(1) Place labels so they will not be obliterated by grease, filings, dirt, or moisture. Where a label is particularly susceptible to being covered by materials dropping from above, mount the label in a vertical position (see Figure 13-5).

(2) Place labels on similar pieces of equipment in the same relative position.

(3) Ensure that labels are not hidden by units and parts, and that they do not crowd each other or obscure other useful information.

(4) Where components and parts look very similar but are not functionally interchangeable, physical keying should be used to preclude incorrect installation. The design goal in these instances should be the concept of "go right or no *go.*" However, if physical keying is impossible, label the part on several sides with precautions; about interchangeability, or use distinctive markings that correspond with markings in the assembly in which the part is to be placed (see Figure 13-6).

(5) Provide labels or other marking devices which clearly designate the position of controls. A rider may be attached to the shaft with markings indicating on valve controls; for example (Figure 13-7), the fully opened and fully closed positions.

(6) Place labels consistently in the same place in relation to the instruments on a panel (see Figure 13-8). Preferably, labels should be above controls or displays to prevent their being obscured by the technician's hand manipulating the controls (see also Chapter 9).

13-5.4 WARNING LABELS

(1) Install appropriate warning labels when the technician or mechanic must consult a technical manual before working on the component.

(2) Make, warning labels as informative as possible, consistent with the space available (see Figure 13-9). The content of the information will vary, but should inform the technician:

(a) Why a dangerous condition exists.

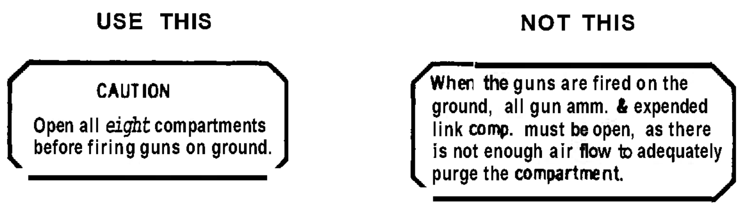

Figure 13-1. Use Brief Labels (Ref. 3)

USE THIS	NOT THIS
ASSEMBLING INJECTOR TAPPING TOOL	ASSEMBLING INJECTOR TAPPING TOOL
1. Replace defective part 2. Install nut and washer on hand-tap shank	First replace the defective part from supply. Install nut and washer on hand-tap shank.
3. Install Rollpin in nut 4. Check tapping tool for proper operation	Next, place the Rollpin in the nut. Upon completion, check the tapping tool for proper performance.

figure 13-2. Use Step-by-Step Instructions

(b) Places to avoid.
(c) Behavior to avoid.
(d) Sequence to follow to obviate the danger.
(e) Where to refer for more information.

(3) Erect high visibility warnings when personnel may be subjected to harmful noises or sudden increases or decreases in pressure.

(4) Display tolerance or safety load limits of apparatus prominently on the apparatus.

(5) Prominently display labels instructing the technician in hazardous situations: for example, instructions for opening and closing (see Figure 13-10.)

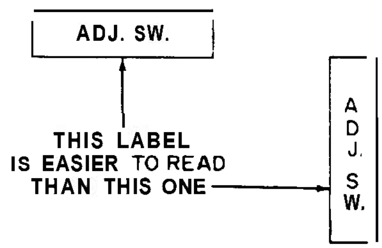

figure 13-3. Use Horizontal Labels and Nameplates

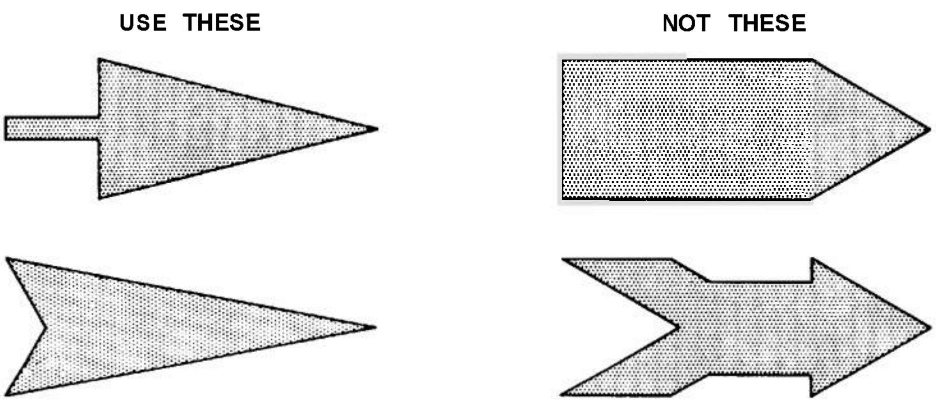

Figure 13-4. Use Arrows With Narrow Width-to-Length Ratios (Ref. 3)

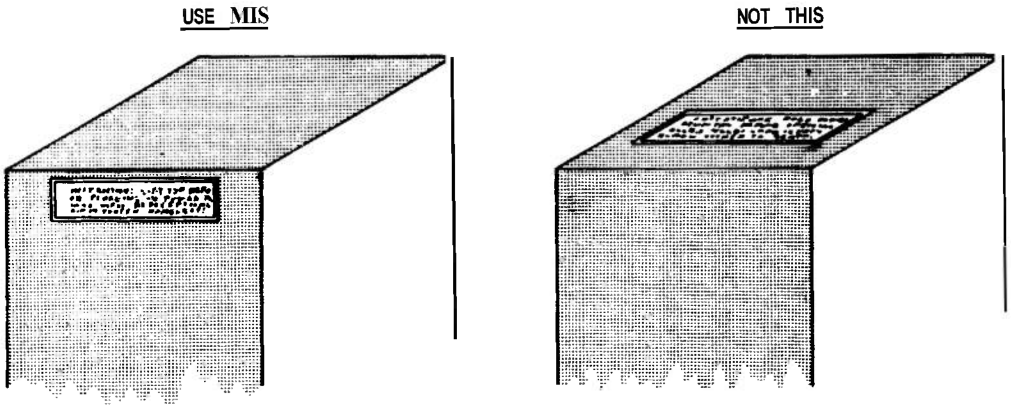

Figure 13-5. Positioning of Labels

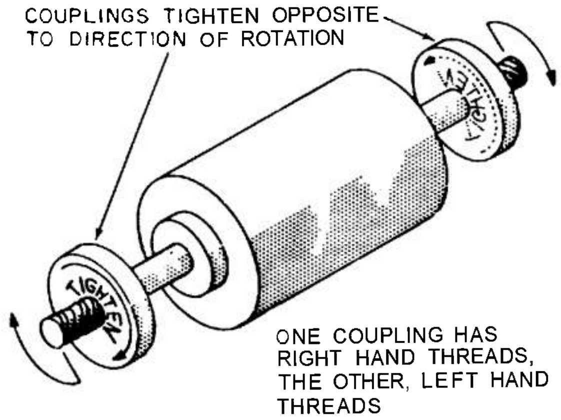

figure 13-6. Label Components to Preclude Incorrect Information (Ref. 31

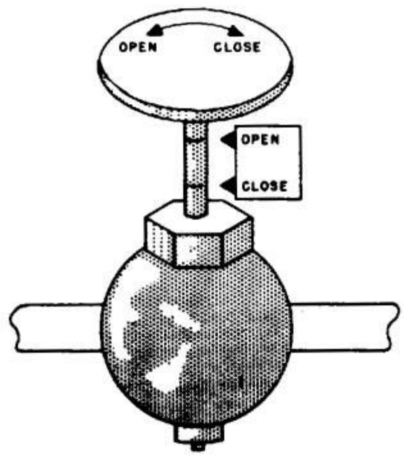

Figure 13-7. labels for Valve Controls (Ref. 31

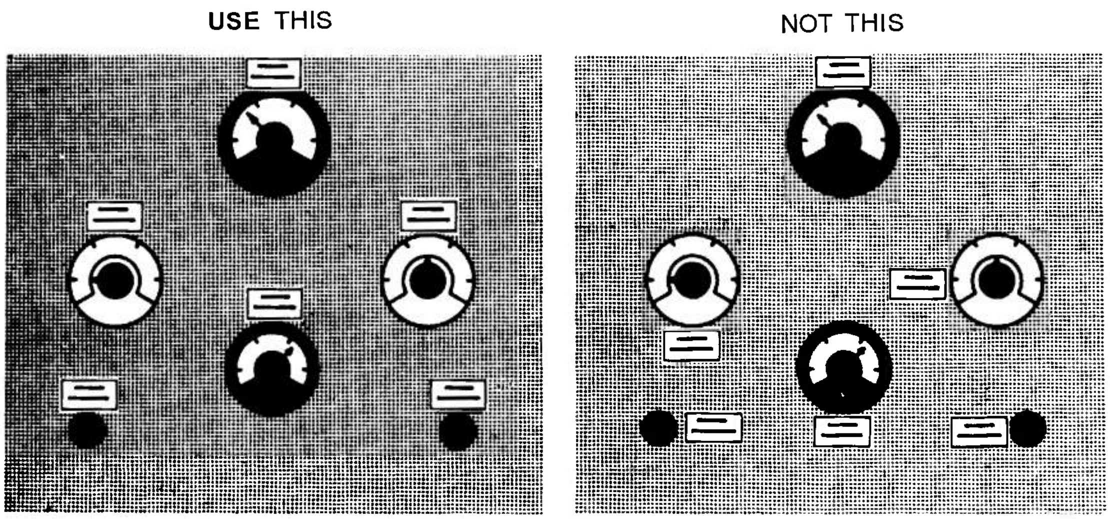

Figure 13-8. labels Should Be Above Related Controls or Displays

USE THIS — NOT THIS

WARNING

This equipment contains a cartridge actuated emergency escape system equipped with an explosive charge.

DANGER

Figure 13-9. Warning Labels Should Be As Informative As Possible

13-6 IDENTIFICATION CHECKLIST

Table 13-4 lists some items to check for proper identification. Several items are included which were not discussed separately in the text. They are included here because their necessity in the design is so obvious that they might otherwise be inadvertently overlooked. In using the checklist, if the answer to any question is *no*, the design should be restudied to ascertain the need for correction.

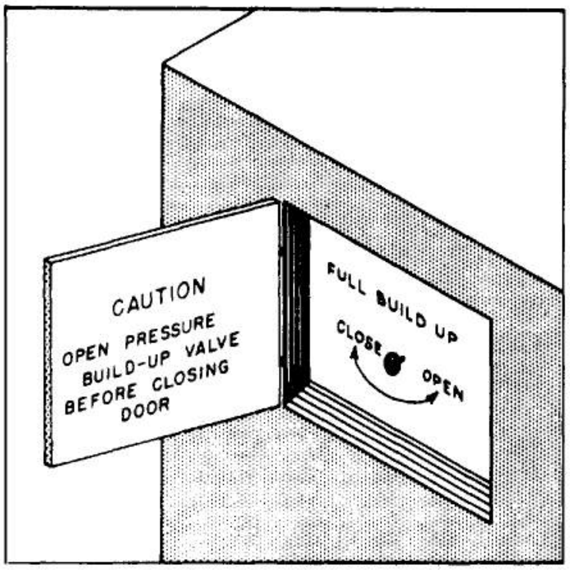

Figure 13-10. Placement of Labels for Hazardous Tasks (Ref. 3)

TABLE 13-4. IDENTIFICATION CHECKLIST

1. Are all units labeled and, if possible, with full identifying data?
2. Are parts stamped with relevant characteristics information?
3. Are structural members stamped with physical composition data, (e.g., can be welded; is inflammable, etc.)?
4. Is each terminal labeled with the same code symbol as the wire attached to it?
5. Are labels on components or chassis (not parts) etched or embossed in lieu of stamping or printing?
6. Are labels placed for full, unobstructed view?
7. On equipment utilizing color coding, is meaning of colors given in manuals and on an equipment panel?
8. Is color coding consistent throughout system, equipment, and maintenance supports?
9. Are numeral and letter designs used which have simple configurations similar to Leroy Lettering Guides and are extra flourishes avoided?
10. Are capital letters used for labels and standard capitalization and lower case type for extended text material?
11. Are display labels imprinted, embossed, or attached in such a way they will not be lost, mutilated, or become otherwise unreadable?
12. Do display and control labels clearly indicate their functional relationship? Are displays labeled by functional quantity rather than operational characteristics (i.e., gal, psi, ohms, etc.)?
13. Does displayed printed matter always appear upright to the technician from his normal viewing position?
14. Do display labels appear on every item which the technician must recognize, read, or manipulate?
15. Does display of the sequence of use of controls appear as a number on each control (for fixed procedure operation)?
16. Are display labels attached to each test

TABLE 13-4. IDENTIFICATION CHECKLIST (cont)

point and do they show in-tolerance or limits which should be measured at that point?

17. Are schematics and instructions attached directly to, or adjacent to chassis for all units which may require troubleshooting?
18. Do display labels on component covers provide relevant information concerning electrical, pneumatic, or hydraulic characteristics of the part?
19. When selector switches may have to be used with a cover panel off, is a duplicate switch position label provided on the internal unit so technician does not have to refer to label on the case or cover panel?
20. Are display codes explicitly identified either in printed job instructions or directly on the panel, part, line, etc.?
21. Are displays labeled so they correlate with notations found in system diagrams, in technical manuals, or related literature?
22. Do display schematics on separate assemblies show clearly any relationships to other or interconnecting schematics?
23. Are color codes for identifying test points or tracing wire or lines easily identifiable under all conditions of illumination and are they resistant to damage or wear?
24. Is functional organization of displays and controls emphasized by use of such techniques as color coding, marked outline, symmetry of grouping, and/or differential plane of mounting?
25. Are all potted parts labeled with current, voltage, impedance, terminal information, etc.?
26. Do display indications on storage spaces identify various items to be stored there?
27. Do access covers have permanent part number marked on the cover?
28. Are lubrication points accessible and labeled properly?
29. Are labels used to indicate direction of movement of controls, especially where lack of such knowledge may result in damage to equipment?

REFERENCES

1. TM 21-62, *Manual of Standard Practice for Human Factors in Military Vehicle Design,* Human Engineering Laboratories, Aberdeen Proving Ground, Md., 1962.
2. *Military Equipment Design Practices,* Bell Telephone Laboratories, Whippany, N. J., 1964.
3. J. W. Altman, et al., *Guide to Design of Mechanical Equipment for Maintainability,* ASD-TR-61-381, Air Force Systems Command, Wright-Patterson AFB, Ohio. 1961. (DDC No. AD 269 332).

CHAPTER 14
INTERCHANGEABILITY

14-1 GENERAL

Interchangeability can be defined as the capacity of any given part, unit, or material to be substituted for a like part, unit, or material in accordance with the concepts described for standardization (see Chapter 18). Two types of interchangeability can be present: (1) functional interchangeability exists if two given items serve the same function; and (2) physical interchangeability exists if two items can be mounted, fastened, connected, etc., in the same manner and in the same places. However, where physical interchangeability exists, functional interchangeability is highly desirable.

14-2 INTERCHANGEABILITY PRINCIPLES

In units requiring frequent servicing and replacement of component parts because of wear or damage, every part should be completely interchangeable with every similar part in every unit.

In units expected to function satisfactorily without replacement of parts, it may be uneconomical to insist that parts be strictly interchangeable. The parent unit itself should be interchangeable with all other similar units, but the parts of one parent unit need not be interchangeable with those of another.

There are two broad classifications of interchangeable parts: *universally* interchangeable parts, which are required to be interchangeable in the field even though manufactured by different facilities, and *locally* interchangeable parts, which are interchangeable with other like components made in the same facility but which are not necessarily interchangeable with those made in other facilities. the essential requirement is for the unit to assemble with the main product.

14-3 INTERCHANGEABILITY REQUIREMENTS

Interchangeability requirements should be determined from consideration of field conditions as well as from that of economy of manufacture and inspection. Liberal tolerances are essential for interchangeability. Specifying tolerances closer than required is uneconomical in cost and time. Tolerances should be assigned to component features for position, concentricity, symmetry, alignment, squareness, and parallelism when the control of these factors is important for correct functioning or correct assembly. Tolerances assigned to components should be reviewed carefully, however, to prevent unnecessary difficulties in production or inspection from being imposed without real functional or assembly necessity.

Tolerances for detailed parts should be as large as possible consistent with the function of the part. For example, do not specify 0.001-in. limits if 0.005-in. will suffice. Tight tolerances do not themselves increase quality or reliability; on the contrary, unnecessarily close requirements may increase manufacturing costs without tangible gains in accuracy.

Insofar as is possible and practical, and where interchangeability design considerations do not degrade equipment performance, increase cost, or reduce inherent maintainability or reliability, equipment should be designed with the minimum number of sizes, types, assemblies, subassemblies and parts possibly requiring replacement. Like assemblies, subassemblies, and replaceable parts should be according to MIL, AN or MS standards where possible and should be electrically, mechanically, hydraulically or otherwise interchangeable, both physically and functionally, regardless of manufacturer or supplier. They should be easily interchangeable without physical or electrical modifications, except that leads, pipe lines or control rods, etc., may be shortened when satisfactory results are accomplished with common maintenance tools. To facilitate procurement of replacement components, the design should not be based on the use of components of special manufacture if suitable units of standard manufacture and design are available. All components having the same manufacturer's part number should be directly and completely interchangeable with each other with respect to installation and performance. Changes in manufacturer's component numbers should be governed by the drawing number requirements of MIL-D-70327, and guidelines on interchangeability and replaceability for all U S Army equipment should conform to MIL-1-8500.

14-4 INTERCHANGEABILITY CHECKLIST

Table **14-1** gives some design guidelines to be considered when incorporating interchangeability into new equipment. The checklist contains several items which were not discussed separately in the text. These items are included here because their necessity in the design is so obvious that they might otherwise be inadvertently overlooked. In using the checklist, if the answer to any question is *no,* the design should be restudied to ascertain the need for correction.

TABLE 14-1. INTERCHANGEABILITY CHECKLIST

1. Does functional interchangeability exist where physical interchangeability is possible?
2. Does complete interchangeability exist wherever practical?
3. Is sufficient information provided on identification plates and within related job instructions so the user can adequately judge whether two similar parts are interchangeable?
4. Are differences in size, shape, and mounting avoided when they do not reflect functional properties of the unit?
5. Is complete interchangeability provided for all items intended to be identical, interchangeable, or designed to serve the same function in different applications?
6. Do mounting holes and brackets accommodate units of different makes, such as engines of the same type and horsepower, built by different manufacturers?
7. Are identical parts used wherever possible in similar equipment or a series of a given type, such as using the same bore and stroke for a series of internal combustion engines?
8. Are parts, fasteners, connectors, lines and cables, etc., standardized throughout the system and, particularly, from unit to unit within the system?
9. Are cable harnesses designed so that they can be fabricated in a factory and installed as a unit?
10. Is complete electrical and mechanical interchangeability provided on all like removable components?
11. Are bolts, screws, and other features the same size for all covers and cases on a given equipment?
12. Is interchangeability provided for components having high mortality?
13. Where complete interchangeability is not practical, are parts or units designed for functional interchangeability and are adapters provided to allow physical interchangeability, wherever practical?

CHAPTER 15

SAFETY

15-1 GENERAL

Safety precautions designed into equipment are necessary usually as safeguards to lapses of attention. If a mechanic must divert attention from his task to be intent on observing safety precautions, the remainder of his attention might be inadequate for doing his job well; it will certainly take him longer to do the job. Safety measures should, therefore, take into account behavior liabilities such as these.

Design of any equipment must embody features for the protection of personnel from electrical and mechanical hazards and, also, from those dangers that might arise from fire, elevated operating temperatures, toxic fumes, etc. There are various methods of incorporating adequate safeguards for personnel, many of these methods being implicit in routine design procedures. Certain procedures, design practices, and related information are of such importance as to warrant special attention. Personnel are our most valuable commodity. *Equipment dangerous to personnel is not maintainable.*

The information in this chapter is devoted to safety considerations relating to electrical hazards, and hazards pertaining to fire and toxic fumes, implosion and explosion, instability, and nuclear radiation. Safety considerations for munitions, weapons, and aircraft materiel are covered in Chapters 28, 29, and 31, respectively.

15-2 ELECTRICAL HAZARD

15-2.1 ELECTRIC SHOCK

The principal contingency to guard against is shock. Even a small shock is dangerous. Burns or nervous system injuries are not the only possible effects ; equipment damage and additional physical harm to personnel can result from the involuntary reactions that accompany electrical shock.

Potentials exceeding 50 volts rms are possible electric shock hazards. Research reveals that most deaths result from contact with the relatively low potentials, ranging from 70 to 500 volts, although, under extraordinary circumstances, even lower potentials can cause injury (Ref. 1). Many severe injuries are caused, not directly by electric shock, however, but by reflex action and the consequent impact of the body with nearby objects.

The effect of electric shock will depend on the resistance of the body, the current path through the body, the duration of the shock, the amount of current and voltage, the frequency of the current, and the physical condition of the individual. The duration of short electric shocks which could possibly cause a heart attack is given in table 15-1.

The danger to personnel from electric shock should be avoided by suitable interlocks, grounding means, enclosures, or other protective devices. Some contact with electric potentials can be expected where maintenance personnel are,

TABLE 15-1. POSSIBLE HEART ATTACK FROM SHORT ELECTRIC SHOCKS (Ref. 2)

Duration	DC	AC (60 cps)	AC (10,000 cps)
0.03 sec	1300 ma	1000 ma	1100 ma
3.0 sec	500 ma	100 ma	500 ma

by the very nature of their duties, exposed to live terminals. Both shocks and burns, however, can be minimized by greater care in design, and by a better understanding of electrical characteristics.

15-2.2 PREVENTION OF ELECTRIC SHOCK

There are several methods of attaining adequate personnel protection, such as enclosing the components and providing access-door safety switches operated either by door pressure or by a locking mechanism ; automatic operation of the main equipment switch when the door is opened ; automatic grounding of components when the unit is opened for access to the components, etc. The primary methods of electric shock prevention are described in the following paragraphs.

15-2.2.1 Safety Markings

Markings should be provided to warn personnel of hazardous conditions and precautions to be observed to ensure safety to personnel and equipment.

Warning signs marked "CAUTION—HIGH VOLTAGE," or "CAUTION _ VOLTS," should be placed in prominent positions on safety covers, access door, and inside equipment wherever danger might be encountered. These signs should be durable, easily read, and placed so that dust or other foreign matter will not, in time, obscure the warnings. Because signs are not physical barriers, they should be relied on only if no other method of protection is feasible (see also Chapter 13). Electrical equipment should be marked, as required, in accordance with Article 510 of the National Electric Code.

15-2.2.2 Safety Color

The predominant color of equipment designed for safety, protective or emergency purposes should be Insingia Red, Color No. 11136 of FED STD 595.

15-2.2.3 Safety Warning Devices

Suitable bells, horns, vibration devices, lights, or other signals should be provided and located where they may be easily and obviously sensed by personnel required to take corrective action. Mutliple safety installations should be installed when required. The principal characteristics and special features of different types of auditory alarm and warning devices are presented in Chapter 9, Paragraph 9-6.8.

15-2.2.4 Safety Switches

Three types of safety switches that can be utilized to prevent electric shock are interlocks, battle-short switches, and main power switches. Each type is described separately in the following paragraphs.

15-2.2.4.1 ***Interlocks.*** A switch that automatically opens the power circuit when an access door, cover, or lid of a piece of equipment is opened is a sample safeguard. Where the equipment must be worked on with the power on, interlocks must be provided with some means for closing the circuit when the door is opened. In this case, visible means must be provided to show that danger exists.

Interlock switches are used to remove power during maintenance operations. Each cover and door providing access to potentials greater than 40 volts should be equipped with interlocks. Interlock systems should also be provided to ground capacitors having a discharge time greater than 5 seconds when the enclosure is opened (Ref. 1).

An interlock switch is ordinarily wired in series with one of the primary service leads to the power supply unit. It is usually actuated by a removable access cover thus breaking the circuit when the enclosure is entered. Where more than one interlock switch is used, they are wired in series. Thus, one switch might be installed on the access door of an operating subassembly and another on the dust cover of the power supply.

Selection of type of interlock switch must be based on reliability. The type shown in Figure 15-1 has proven most satisfactory.

Because electronic equipment must often be worked on with the power on, a switch enabling maintenance personnel to bypass the interlock system should be mounted inside the equipment. The switch should be so located that reclosing of the access door or cover automatically

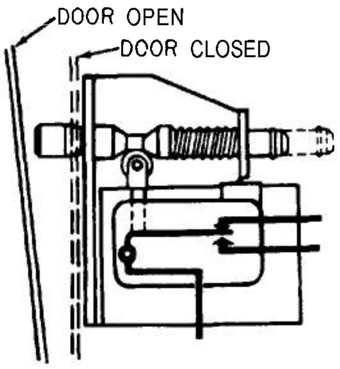

figure 15-1. Door Interlock Switch

restores interlock protection. Also, a panel-mounted visual indicator such as a neon lamp should be provided and a suitable nameplate to warn personnel when interlock protection is removed.

15-2.2.4.2 ***Battle-Short Switch.*** A battle-short switch, or terminals for connection of an external switch, should be provided to render all interlocks inoperative. The panel-mounted or remotely controlled battle-short switch is designated for emergency use only. The circuit consists of a single switch, wired in parallel with the interlock system. Closing the battle-short switch places a short circuit across all interlock switches, thus assuring incoming power regardless of accidental opening of interlock switches.

15-2.2.4.3 ***Main Power Switch.*** Each equipment should be furnished with a clearly labeled main power switch that will remove all power from the equipment by opening all leads from the main-power service connections.

Main power switches equipped with adequate safeguards protect against possible heavy arcing. Safeguards such as barriers, which shield fuses and conducting metal parts, and protective devices, which prevent opening the switch box with the switch closed, should be provided as protection for personnel. Switches incorporating such safeguards are standardized, commercially obtainable equipment.

15-2.2.5 *Discharging Devices*

Because high-grade filter capacitors can store lethal charges over relatively long periods of time, adequate discharging devices must be incorporated in all medium- and high-voltage power supplies. Such devices should be used wherever the time constant of capacitors and associated circuits exceeds **5** sec. They should be positive acting, reliable, and automatically actuated whenever the enclosure is opened. Shorting bars (Figure 15-2) should be actuated, either by mechanical release or by an electrical solenoid, when the cover is opened.

Good insurance is provided by the automatic charge-draining action of a bleeder resistor permanently connected across the output terminals of a d.c. power supply. Although bleeder current is an added load on the power supply, the system should be designed to carry this slightly additional load. The bleeder resistance should be the lowest value, without presenting excessive loading, through which the capacitors can discharge quickly after the power is switched off.

In circuits where large, high-voltage capacitors must be operated without adequate bleeding (as in high-voltage radar apparatus), capacitors must be discharged by automatic interlocks. For high-voltage capacitors, such discharging 'devices should be equipped with large resistors rated at **200** watts and **10,000** ohms, to limit discharge current and the possibility of damage (Ref. 1).

The bleeder serves two purposes : to improve the regulation of the device, and to provide a discharge path for the filter capacitors when the charging source is removed or the line voltage is removed. If no adequate bleeder exists, e.g. for discharging the full load of the capaci-

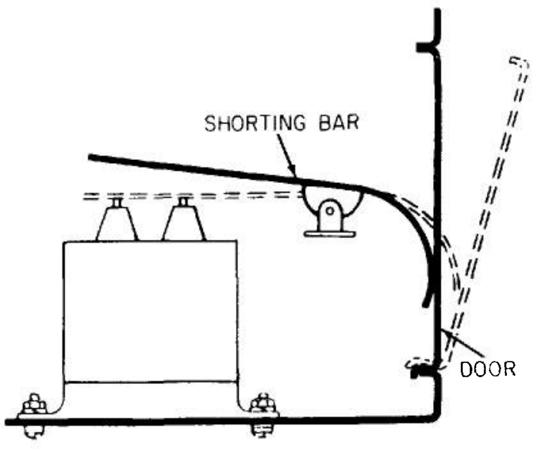

Figure 15-2. Shorting Bar Should Be Actuated When Cover is Opened

tors in one minute, then some means should be provided for discharging the capacitors before any maintenance work starts. A shorting or grounding rod with a well-insulated handle is often provided. It is probably better to discharge capacitors somewhat more slowly than is possible with a dead short to ground, and for this reason, a resistor with a high power rating and of several thousand ohms is often provided (Ref. 3).

15-2.2.6 Grounding

Various grounding techniques are used to protect personnel from dangerous voltages in equipment. All enclosures, exposed parts, and chassis should be maintained at ground potential using the same common ground.

Specifications for the reduction of electrical noise interference should be consulted to determine the maximum permissible resistance of a grounding system. Reliable grounding systems should be incorporated in all electronic equipment. Enclosures and chassis should not be used as electric conductors to complete a circuit because of possible intercircuit interference.

A terminal spot welded to the chassis provides a reliable ground connector. For aluminum chassis where welding is not feasible, a terminal properly secured by a machine bolt, lockwasher, and nut is satisfactory (see Figure 15-3).

A grounding lug should not be included as part of a "pile up" that includes any material subject to coldflow. The machine screw used should be of sufficient size so that eventual relaxation will not result in a poor connection. A lockwasher is necessary to maintain a secure connection. All nonconductive finishes of the contacting surfaces should be removed prior to inserting the screw. Riveted elements should not be used for grounding because these cannot be depended upon for reliable electrical connections.

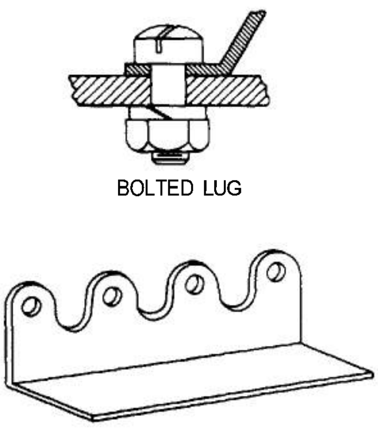

Figure 15-3. Grounding Methods

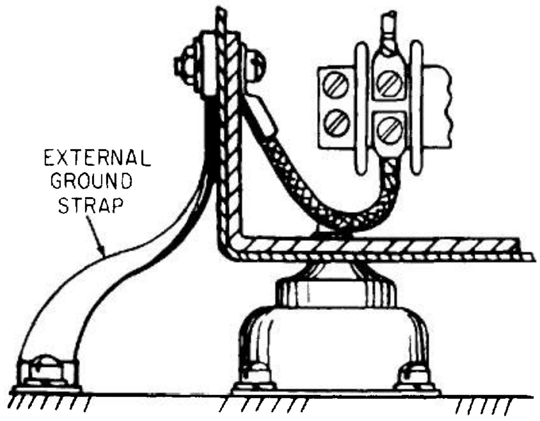

figure 15-4. Cabinet Grounding System

The common ground of each chassis should connect to a through-bolt, mounted on the enclosure and clearly marked "ENCLOSURE GROUND," which in turn should connect to an external safety ground strap. For best design, the external ground conductor should be fabricated from a suitably plated flexible copper strap capable of carrying at least twice the current required for the equipment (see Figure 15-4).

Electronic test equipment (see Chapter 23, Section IV) should be furnished with a grounding pigtail at the end of the line cord. Signal generators, vacuum-tube voltmeters, amplifiers, oscilloscopes, and tube testers are among the devices that should be so equipped. These leads are to be used for safety grounding purposes. Thus, if a fault inside the portable instrument connects a dangerous voltage to the metal housing, the dangerous current is bypassed to ground without endangering the operator.

Where power supply lines are not grounded, for such purposes as reducing interference, these leads can be bypassed through capacitors to ground, but the total current, including leakage, that the capacitor is likely to permit, should not exceed 5 ma. (Ref. 1).

Panel mounted parts, especially jacks, are occasionally used in power lines, test apparatus, and other supplementary equipment. Such items should be connected to the ground leg of the monitored circuit rather than in the ungrounded, high-voltage line.

15-2.2.7 Fusing

All leads from the primary service lines should be protected by fuses. Fusing of circuits should be such that rupture or removal of a fuse will not cause malfunction or damage to other elements in the circuit.

Fuses should be connected to the lead side of the main-power switch. Holders for branch-line fuses should be such that, when correctly wired, fuses can be changed without the hazard of accidental shock. At least one of the fuse-holder connections should be normally inaccessible to bodily contact, and this terminal should be connected to the supply line; and the accessible terminal should be connected to the load. Figure 15-5 shows the correct wiring of the instrument type of fuse holder to prevent accidental contact with the energized terminal (see also Chapter 23, Section V).

15-2.2.8 Power Lines

Safety considerations should not be confined to high-voltage apparatus. It is important that attention be given to the hazards of power lines.

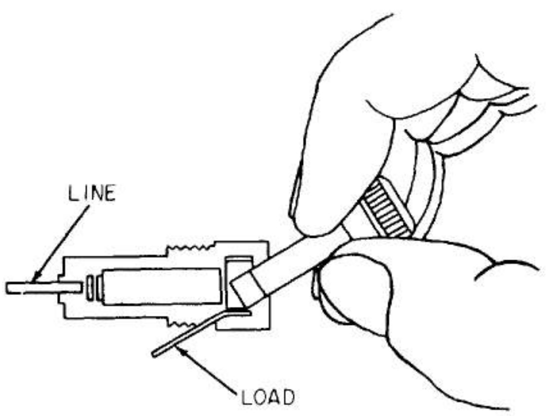

Figure 15-5. Correcf Manner of Wiring Instrument-Type Fuse Holder

Severe shocks and serious burns are known to result from personnel contacting, short-circuiting, or grounding the incoming lines. Both sides of the power lines and all branches should be fused to prevent a main power line malfunction caused by a transformer or motor failure that would result in grounding of the primary supply line.

15-3 MECHANICAL AND OTHER HAZARDS

To minimize the possibility of physical injury, all edges and corners should be rounded to maximum practical radii. This is especially important for front-side edges and door corners. Thin edges should be avoided and construction should be such that the unit can be carried without danger of cutting the hands on the edges.

To prevent hazardous protrusions from surfaces, flathead screws should be used wherever sufficient thickness is available; otherwise panhead screws should be used. All exposed surfaces should be machined smooth, covered or coated to prevent the possibility of skin abrasion. Small projections, in areas where rapid movement can cause injury, should not be left uncovered. Recessed mountings are recommended for small projecting parts such as toggle switches and small knobs located on front panels.

Shields and guards should be made part of the equipment to prevent personnel from accidentally contacting rotating or oscillating parts such as gears, couplings, levers, cams, latches, or heavy solenoid equipment. Moving parts should be enclosed or shielded by guards. Where such protection is not possible, adequate warning signs should be provided. High temperature parts should be guarded or so located that contact will not occur during normal operation. Guards should not prevent the inspection of mechanisms, the failure of which will cause a hazardous condition. Guards should also be designed to permit inspection without removal whenever possible.

Ventilation should be provided so that no part or material attains a temperature which will tend to damage or appreciably reduce its normal useful life. No exposed parts of the equipment should, under any condition of operation, attain temperatures hazardous to personnel. Forced air is permitted through replaceable, renewable, or cleanable dust filters. Air exhaust openings should not be located on front panels or other locations which expose personnel to direct drafts.

Some housings, cabinets, and covers require perforations to provide air circulation. In these, the area of a perforation should be limited to that of a 0.5-in. square or round hole. High-voltage, rotating, or oscillating components within should be set back from the perforated surface far enough to prevent accidental contact by personnel. If this cannot be done, the size of the perforations should be reduced.

Where access to rotating or oscillating parts is required for maintenance, it might be desirable to equip the protective covers or housings with safety switches or interlocks. The cover or housing should bear a warning sign such as:

CAUTION
KEEP CLEAR OF ROTATING PARTS

Electronic chassis in their normal installed positions should be securely enclosed. Stops should be provided on chassis slides to prevent pulling the chassis too far out and dropping it. Suitable handles or similar provisions should be furnished for removing chassis from enclosures. Bails or other suitable means should be provided to protect parts when the chassis is removed and inverted for maintenance, and to protect the hands as the chassis is placed on the bench.

15-3.1 FIRE

All reasonable precautions should be taken to minimize fire hazards. In particular, any capacitors, inductors, or motors that are possible fire hazards should be enclosed by a noncombustible material having minimum openings. Because many equipments are installed in confined spaces, materials that can produce toxic fumes should not be used. Finished equipment should be carefully checked for verification of protective features in the design. Avoid materials that under the adverse operating conditions will liberate gases or liquids that are, or may combine with the atmosphere to become, combustible mixtures. Design equipment that will not emit any flammable vapors during storage or operation. Provide suitable warnings or automatic cutoffs to operate if such vapors are emitted during operation. Equipment should not produce undesirable or dangerous smoke and fumes.

Where known fire hazards exist, or may be created by the equipment itself, provide hand-operated, portable fire extinguishers. Locate extinguishers so they are easily and immediately accessible, and provide those suitable for the type of fire most likely to occur in the area. The three general classes of fires are as follows:

Class A. Fires occurring in ordinary combustible materials such as wood, paper, and rags, which can be quenched with water or solutions containing water.

Class B. Fires occurring in flammable liquids such as gasoline and other fuels, solvents, greases, and similar substances, which can be smothered by diluting, eliminating air, or blanketing.

Class C. Fire occurring in electrical equipment such as motors, transformers, and switches, which must be extinguished by a nonconductor of electricity.

15-3.2 TOXIC FUMES

All reasonable precautions should also be taken to eliminate the hazards from toxic fumes. The exhausts from internal combustion engines for example, contain numerous hazardous substances. From the standpoint of practical health hazard control, however, the most important constituents are carbon monoxide from gasoline engines, and aldehydes and nitrogen oxides from diesel engines. Figure 15-6 illustrates the effects of carbon monoxide on human beings. Table 15-2 gives a brief list of common toxic agents and their maximum allowable concentrations.

Caution should be used in the interpretation of these charts, because toxicology is a rather complex science and does not lend itself simply to the summary given by the charts. In fact, the information can be misleading and dangerous if the user tends to apply numbers based on one kind of exposure to quite different exposure conditions. For general maximum allowable concentration figures such as those based on exposure for an eight-hour working day, Reference 4 should be investigated. The maintainability engineer should remember that toxicology

TABLE 15-2. COMMON SOURCES AND MAXIMUM ALLOWABLE CONCENTRATIONS OF SOME TOXIC AGENTS (Ref. 3)

Common Source	Toxic Agent	Maximum Allowable Concentration (ppm)
Fuels and propellants	Ammonia	100
	Aniline	5
	Ethyl alcohol	1,000
	Gasoline	250
	Kerosene	500
	Methyl alcohol	200
	Nitrogen tetroxide	5
Engine exhausts (including rocket engines)	Aldehydes:	
	Acetaldehyde	200
	Acrolein	0.5
	Formaldehyde	5
	Furfural	5
	Carbon dioxide	5,000
	Carbon monoxide	100
	Bromine	1
	Nitrogen dioxide	5
	Sulfur dioxide	5
Hydraulic fluids	Butyl cellosolve	50
	Diacetone	50
	Aryl phosphates	0.06
	Dioxane alcohol	100
Fire extinguishants	Carbon dioxide	5,000
	Carbon tetrachloride	25
	Chlorobromethane	400
	Methyl bromide	20
Oil sprays and fumes	Aldehydes: (see above)	
Refrigerants	Carbon dioxide	5,000
	Freon	1,000
	Methyl bromide	20
	Sulfur dioxide	5
Smoke	Phosgene (see also engine exhausts)	1

involves life and death, and that a professional toxicologist should be consulted for data pertaining to specific exposure conditions.

15-3.3 IMPLOSION AND EXPLOSION

Equipment that may be operated, maintained, or stored in an explosive atmosphere should be designed so as to eliminate the possibility of an explosion. All electrical equipment that will be used in the vicinity of flammable gases or vapors should be explosion-proof. Danger to personnel from an explosion should be avoided by separation of hazardous substances from heat sources and by incorporation of spark arrestors, suitable vents and drains, and other fire prevention measures.

The cathode ray tube is a special hazard in that physical damage can result from implosion. If the tube is accidentally nicked or scratched, resultant implosion might not occur until days later. The tube face therefore, should be shielded by a shatterproof glass attached to the panel. Signs warning personnel that the neck of the

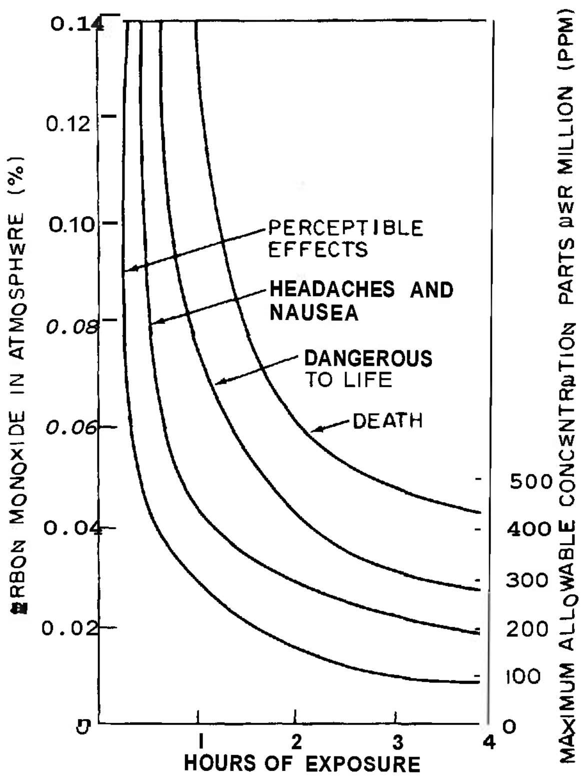

Figure 15-6. Effects of Carbon Monoxide for a Given Time on Human Beings (Ref. 2)

tube is easily broken, and must be handled with caution, should be posted inside the equipment.

The terminal end of cathode ray tubes should be located within the equipment housing whenever possible. If the terminal end does extend outside the equipment housing, a strong cover for the tube should be provided. The cover should be firmly anchored to the main structure of the housing to withstand shipping and rough handling and to prevent external pressures from being exerted on the wires and terminal end of the tube.

15-3.4 INSTABILITY

Design all equipment to provide maximum stability. Give particular consideration to maintenance stands, tables, benches, platforms, and ladders. Use non-skid metallic materials, expanded metal flooring, or abrasive coating on walkways, catwalks, and all surfaces used for climbing. On steps and ladders, use non-skid treads or cover them with abrasive material. Design ladders and steps so they can be deiced with hot water or steam. Place hand grips on platforms, walkways, stairs, and around floor openings. Ordinarily these hand grips should be fixed; if not, they may be folding or telescoping, normally concealed, or flush with the surface. Such hand grips should remain securely folded when not in use, and tools should not be required to move them from the folded position.

To prevent accidental or inadvertent collapse or lowering of elevating stands and platforms, incorporate self-locking, foolproof devices in the equipment. Where stands have high centers of gravity and can be overturned by winds, use anchors or outriggers. Also, to prevent overloading, indicate the capacity in pounds on stands, hoists, lifts, jacks, and similar weight-bearing equipment (see also Chapter **26**, Paragraph **26-6**).

Design equipment for maximum safety and stability when it is moved up an incline, such as a cargo ramp, or lifted by cranes for shipping. Provide a suitable marking indicating the location of the center of gravity (Figure **15-7**) and jacking points. When moving up an incline, the weight distribution on the vehicle wheels may change—more weight will be taken by the rear wheels—and this will possibly exceed the allowable ramp loading on heavier types of equipment. Also, the closer the center of gravity acts to the rear contact point, the greater tendency the vehicle will have to overturn during sudden acceleration forward or hard braking while rolling backward.

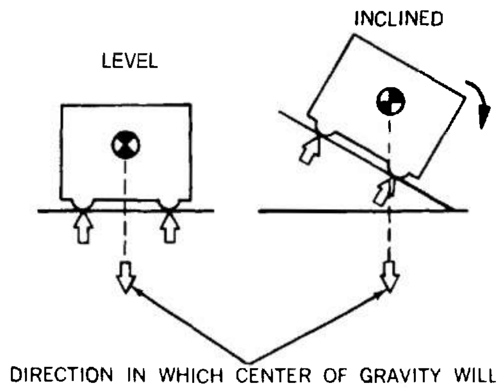

Figure 15-7. Effects of Incline on Center-of-Gravity Location of Equipment

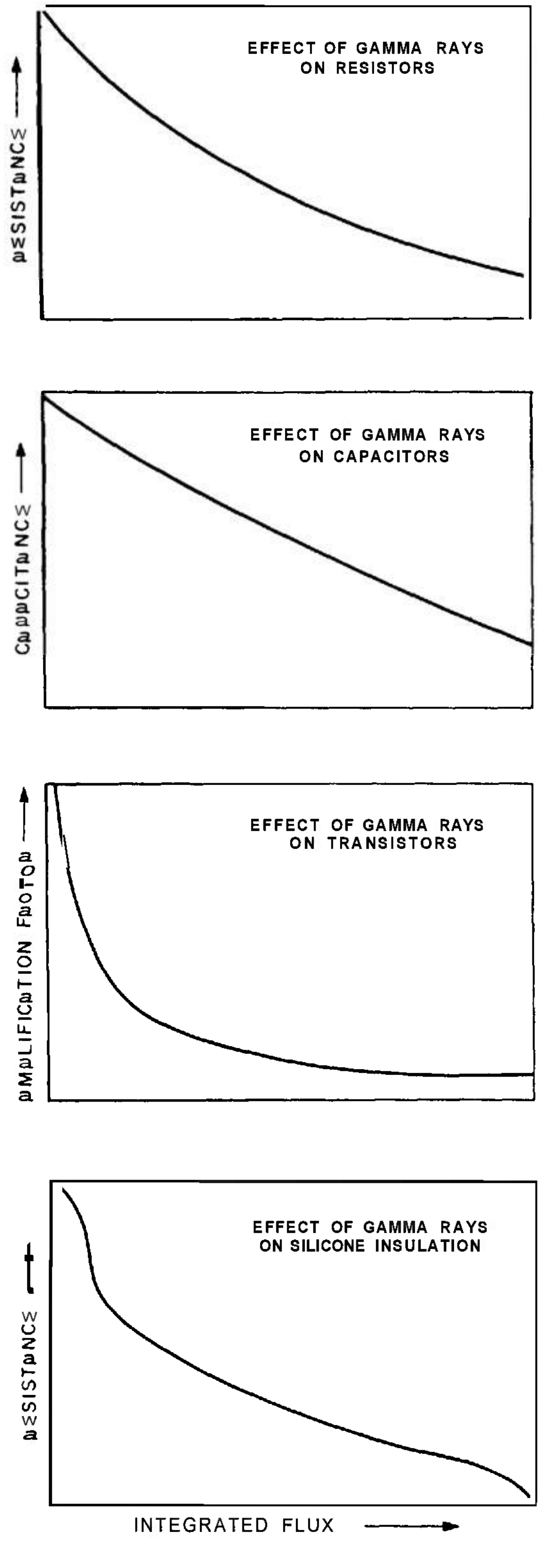

Figure 15-8. Effects of Gamma Radiation on Various Materials (Ref. 7)

15-3.5 NUCLEAR RADIATION

The effect of gamma radiation on various materials is shown in Figure **15-8.** Additional information pertaining to the radiation resistance of many other materials can be found in References 5 and 6. Hazards to personnel and equipment resulting from nuclear radiation and detonation should be investigated by personnel trained in investigating and controlling such hazards.

15-4 SAFETY CHECKLIST

A summary of the general safety features to be considered by the design engineer for the protection of equipment and personnel is given in Table **15-3.** The checklist contains several items which were not discussed separately in the text. These items are included here because their necessity in the design is so obvious that they might otherwise be inadvertently overlooked. In using the checklist, if the answer to any question is *no*, the design should be restudied to ascertain the need for correction.

TABLE 15-3. SAFETY CHECKLIST

1. Are mechanical guards provided on all moving parts of machinery and transmission equipment in which personnel may become injured or entangled?
2. Are edges of components and maintenance access openings rounded or protected by rubber, fiber, or plastic protectors to prevent personnel injury?
3. Are portable hand-operated fire extinguishers provided where fire hazards exist or may be created, and are they of the correct type?
4. Are fire extinguishers placed where they are readily accessible, but not immediately adjacent to points where fire would probably originate?
5. Are audible warning signals distinctive and unlikely to be obscured by other noises?
6. Are fault location systems designed so as to detect weak or failing parts before the emergency occurs?
7. Are critical warning lights isolated from other less important lights for best effectiveness?

TABLE 15-3. SAFETY CHECKLIST (cont)

8. When selecting warning lights, are they compatible with ambient illumination levels expected? (A dim light will not be seen in bright sunlight, and a bright light may be detrimental to dark adaptation.) Are dimmer controls utilized if necessary?
9. Do displays which cannot or may not be watched continuously, but which require continuous monitoring, have suitable auditory warning backup?
10. Is a transparent window or removable cover installed over fuses so they can be checked without removing the entire component case?
11. Are color code techniques utilized which define operating and danger ranges to simplify checkreading?
12. Are control circuits and warning circuits designed so they are never combined?
13. Are on-off or fail-safe circuits utilized wherever possible to minimize failures without operator knowledge?
14. Are bleeding devices provided for high-energy capacitors which must be removed during maintenance operations?
15. Are covers, structural members, and similar electrically neutral parts of electrical systems grounded or protected from contacting personnel or tools?
16. Do vehicle electrical systems include suitable provisions to prevent sparking and other conditions which might cause fire or explosion when van usage involves volatile and/or combustible materials?
17. Are tools and equipment which are used in an explosive atmosphere nonsparking and explosively safe?
18. Are jacking and hoisting points clearly, conspicuously, and unambiguously identified?
19. Are all liquid, gas, and steam pipelines clearly labeled or coded as to specific personnel or equipment hazard properties?
20. Do hatches have a positive lock for the open position and is this lock simple to operate and capable of withstanding all the rigorous requirements of a tactical vehicle in a combat situation?
21. Are struts and latches provided to secure hinged and sliding components against accidental movement which could cause injury to personnel during maintenance operations?
22. Are limit stops provided on drawers or fold-out assemblies which could cause personnel injury if not restrained?
23. Are conspicuous placards mounted adjacent to high-voltage or very hot equipment?
24. Do switches or controls which initiate hazardous operations, such as ignition, crane moving, etc., require the prior operation of a related or locking control?
25. Are dangerous voltages located away from internal controls such as switches and adjustment screws?
26. Are components and live wires that retain dangerous voltages when the equipment is off located where a technician is not likely to touch them by accident?
27. Are safety interlocks used wherever necessary?
28. Are components located and mounted so that access may be achieved without danger to personnel from electrical charge, heat, sharp edges and points, moving parts, and chemical contamination?
29. Are mechanical components which require use of heavy springs designed so that the spring cannot be inadvertently dislodged and cause personal injury or damage to component?
30. Are warning plates provided where mechanical assemblies, linkages, springs, etc., are under constant strain or load?
31. Are adjustment screws and commonly replaced parts located away from high voltages or hot parts?
32. When internal combustion engines are a part of the equipment, are the exhausts routed properly to prevent a concentration of carbon monoxide in the cab?
33. Are exhausts for vans or trailers designed so that gases are directed away from the enclosure or compartment?

TABLE 15-3. SAFETY CHECKLIST (cont)

34. When equipment may involve the exposure of personnel to dangerous gases, are warning signals provided to indicate when a dangerous concentration is approached?
35. In designing vehicles and their components, are materials used which will not produce hazardous environments under severe operating conditions? (Some materials, such as lead, cadmium, and polytetrafluoroethylene, will liberate toxic gases or liquids when exposed to extremely high temperatures. Other materials may liberate substances which are, or may combine with the atmosphere to become combustible or corrosive.)
36. Are exhaust pipes of internal combustion engines pointing upward to lessen danger of igniting flammable liquids which may collect on the ground or floor?
37. Are warning lights provided to indicate fire or excessive heat in areas not visible to drivers of vehicles?
38. Is the correct type fire extinguisher mounted on vehicles at the driver's position?

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CHAPTER 16
SERVICING

16-1 GENERAL

Ease of servicing is one of the most important ingredients of maintainability affecting preventive maintenance routines. The purpose of preventive maintenance is to avoid or detect incipient electrical and mechanical failures in equipment, and to ensure that appropriate action is taken *before* expensive and time consuming repairs or replacements are required. Periodic and systematic maintenance of all equipment is important not only because of the possibility of equipment breakdown, but also because of the danger of impairing overall weapon system effectiveness. All military material is serviced on a systematic schedule. One or more of the following service operations are usually performed.

(1) Oiling and greasing,
(2) Filling and draining,
(3) Cleaning and preserving,
(4) Adjusting and aligning.

Each of these service operations is discussed in the paragraphs that follow.

16-2 OILING AND GREASING

Oiling and greasing (lubrication) of equipment is of vital importance. The best designed equipment, viewed from combat efficiency, performance, maintainability, and reliability standpoints, can *and does* fail completely due to inadequate and improper lubrication. In many items, lubrication is the only maintenance required for long maintenance-free service. Equipment designs are sometimes produced with little thought given to the vast number of maintenance hours reuuired in the field for periodic lubrication and checking of oil levels. Rapid lubrication maintainability should be built into the equipment and equated on an equal design importance with the proper functional design of the equipment. Particular attention to lubrication requirements should be given to electronic and electrical equipment. Synchros, switch shafts, generators, motors, and relay arms have been a serious source of malfunction and of subsequent destruction of the equipment.

16-2.1 LUBRICANTS

Working surfaces subject to wear or deterioration should be provided with appropriate means of lubrication. Commercial grade lubricants should be used wherever possible. Equipment should be designed to use only one type of oil and one type of grease. When this is not practical, the types and grades should be kept to a minimum. Where a special lubricant is required for performance or prevention of destruction of the equipment, such as high or low temperature operational requirements, each lubrication fitting having this requirement should be clearly labeled with letters 0.25-in. high, giving the grease or oil specification placed as close to the fitting as is suitable.

Lubrication, besides reducing friction and wear between moving parts, can also conduct heat of friction away from parts, serve as a seal to exclude undesirable substances from the area being lubricated, and act as a carrier for a rust preventive, antifriction agents, extreme pressure additives, etc. Correct lubrication is an important factor in obtaining good performance from many parts. The choice, generally, will be an oil or a grease.

For an oil to provide satisfactory lubrication, it must prevent the moving parts from touching each other, that is, a continuous oil film must separate the parts. Lubrication under these conditions is called hydrodynamic or fluid-film lubrication. The ability of a lubricating oil to form and maintain a fluid film depends primarily on viscosity, that property of a fluid or semifluid that causes it to resist flow.

The viscosity of all oils is high but varies with temperature. A commonly used measure of a fluid's change of .viscosity with temperature is its viscosity index. If an oil becomes extremely thick at low temperatures and extremely thin at high temperatures, it is said to have a low viscosity index. Any mechanism that is expected to operate in ambient temperatures ranging from − 65°F to over 100°F should use a lubricant having a high viscosity index.

Grease is a smooth "plastic" mass generally made by combining a lubricating oil with a metallic soap. Lubricating is performed largely by the oil, but the soap imparts additional properties. A brief discussion of the properties of specific greases follows :

(1) Calcium-soap or lime greases are smooth and buttery with good resistance to water. They cannot, however, be used for extended periods above 150°to 160°F.

(2) Sodium-soap greases are fibrous in texture and relatively water soluble. Their melting point, above 325°F., allows them to be used at high temperatures.

(3) Aluminum-soap greases range from smooth to stringy but are not fibrous. Because of their adhesiveness, or tackiness, and resistance to water, they are used on cams, chains, and oscillating surfaces. They are unsuitable, however, at temperatures over 180°F.

(4) Barium-soap greases are multipurpose greases. They are waterproof, have a melting point of above 375°F, and are very adhesive.

(5) Lithium-soap greases are also multipurpose with melting points of above 350°F. They have good water resistance and work stability.

Synthetic oils, because of their chemical structure, have a greater tendency to creep than petroleum oils, (The term "creep" refers to the tendency of the oil to advance along the lubricated surface, into crevices, up the sides of walls, and to permeate and pass through its container.) This characteristic also shows up in greases made from them, particularly in units on the shelf awaiting service. An estimated shelf life of units lubricated with a synthetic oil-base grease would be two years, whereas with a petroleum-base grease, it would be three to four years. For equipment in regular operation, however, the life of the two types should be about the same.

Oils and greases are used for a considerable range of speeds and operating temperatures. The choice is determined by considering the factors listed in Table 16-1. Refer also to Chapter 31, Paragraph 31-20.8 for additional guidance relating to the use of lubricants.

TABLE 16-1. FACTORS DETERMINING CHOICE OF LUBRICANT

Factors	Use Grease	Use Oil
Temperature	Not excessive	High (over 200"F)
Speed	Moderate	Extremely high
Protection	Required	Dirt conditions not excessive
Servicing	Operation without servicing	Lubricate from a central oil supply

16-2.2 LUBRICATION FITTINGS

Equipment should be designed to utilize the minimum number of lubrication fittings. Typical lubrication fittings are illustrated in Figure 16-1. This requirement also applies to sealed bearings which should be capable of being relubricated even though such lubrication may be difficult. All grease fittings should conform to specification MIL-F-3541, and all electronic lubrication design should conform to specification MIL-L-17192.

Grease fittings should be readily and easily accessible. Where a grease fitting is not easily accessible, extension lines should be built into the equipment to bring the grease fitting to an accessible location on the outside of the equipment. The fitting end of the line should be securely anchored to withstand rough use. Specify fittings of the same size and of a standard type throughout the equipment. The use of grease cups, exposed oil holes, and oil cups should be avoided.

The following design features relating to lubricants and lubrication fittings are also recommended :

(1) Consider the use of a central mechanism for applying lubricant. This will cut down on servicing time and will reduce the amount of dirt that is introduced through multiple lubrication fittings.

(2) Provide lubrication fittings and reservoirs for all types of plain annular and plain self-aligning bearing installations. Where plain bearings are used at the connection of structural members having a relative motion during operation that exceeds 3°, install lubrication fittings in the structure surrounding the bolt or shaft (see Figure 16-2). It is not necessary to provide a means for lubricating plain bearings fabricated of oil-impregnated sintered metal (bronze or iron) provided they will not be expected to maintain lubricity beyond the life of the lubricant with which they were impregnated. In applications where the amount of lubricant contained in the bearing is not sufficient to last for the life required, provide lubrication fittings or reservoirs so that they will contact the outer surface of the sintered bearing. Incorporate sealing provisions in all plain bearing installations so as to prevent the progress of contamination between the moving surfaces and into the lubricant.

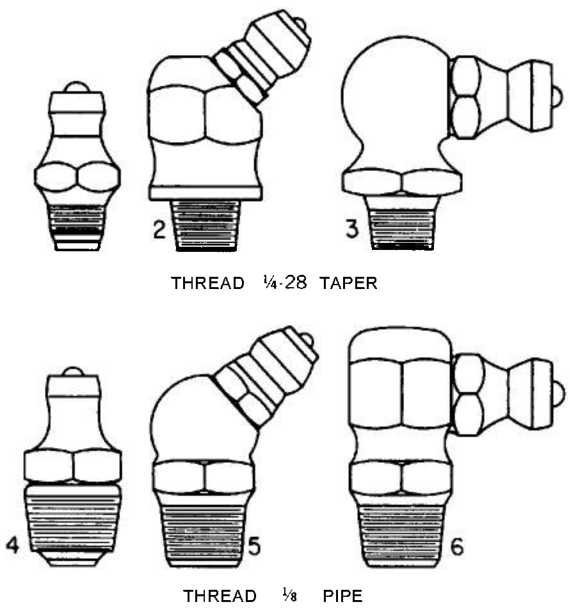


Figure 16-1. Typical Lubrication Fittings

(3) Oil seals should be easy to replace. Design to avoid blind fitting. Seal seatings and lands should be provided with adequate openings for driving the seals out. Oil seals should retain their elasticity during long periods of storage.

(4) Dipsticks should be provided for measuring oil levels, and they should be graduated to show the amount required for filling. Contrast between the finish of the gage and clear thin oil should be provided by specifying metal with a dark, dull finish. Locate oil dipsticks and other such level indicators so that they may be fully withdrawn without touching other pieces of equipment.

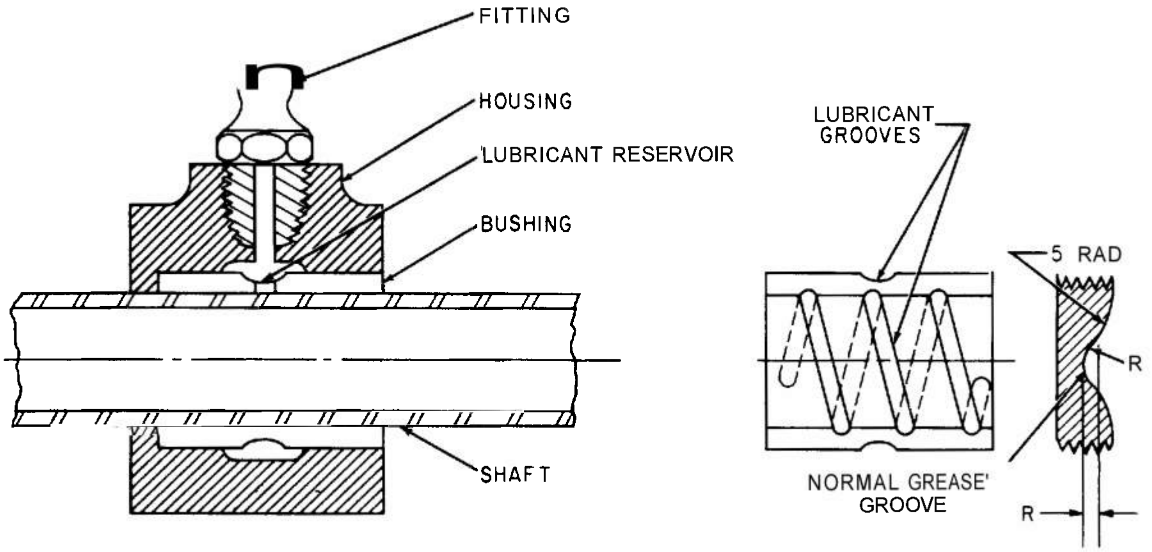
(5) Provide magnetic chip detectors equipped with warning lights in lubricating systems rather than electrical detectors. While most electrical chip detectors require complete oil drainage, it is unnecessary to drain the oil when inspecting magnetic chip detectors. In electrical detectors, particles similar to carbon sludge or graphite, while harmless to engine operation, will produce an indication of the test light, falsely indicating a maintenance problem. Magnetic plugs should conform to MS35844 and should be used as practical throughout all fluid handling systems. Particular attention should be given to sumps or crankcases, gear boxes, positive displacement pump inlets, and wherever iron or steel chips may endanger the life or operation of equipment.

(6) Equipment should be designed to operate on as few different types and grades of standard lubricants as possible. Oil filters should be standard in range and size, and filter elements should be easily removed and replaced.

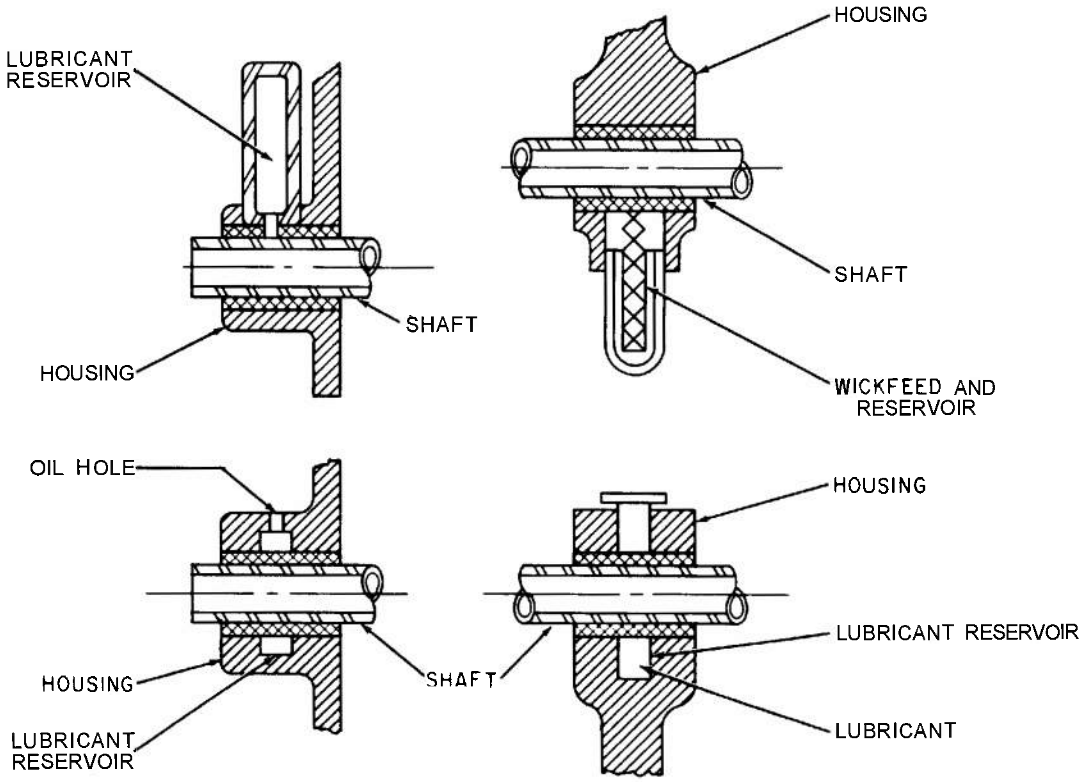
(7) Avoid designs that require high-pressure lubricants.

(8) A built-in automatic lubrication system is desirable for an equipment when it must operate continuously for long periods of time, especially in dusty conditions or when its lubricants tend to be forced from bearing surfaces by heavy impact or vibration loads.

(9) Provide a lubrication schedule for all lubrication requirements which shows frequency with which lubrication is required, type of lubricant, specific points requiring lubrication, methods and cautions to be observed.



LUBRICATION FITTING, LUBRICANT RESERVOIR, AND LUBRICATION GROOVES FOR PLAIN BEARING-BUSHING INSTALLATION



LUBRICATION FITTING AND LUBRICANT RESERVOIR FOR SINTERED-BEARING INSTALLATION

figure 16-2. Installation of Bearing Lubrication fittings

(10) When using pressure oiling instead of the gravity fill method, provide adapters for use of equipment with conventional filler parts.

(11) When possible, select a lubricant which can be used in a given equipment for both operational and storage purposes to reduce maintenance time in changing lubricants when equipment is to be stored. Consider the use of prelubricated gears, bearings, etc., packaged in available stripable plastic to meet this requirement.

(12) If lubrication points are not feasible, provide easy access to the equipment for direct lubrication.

(13) Design lubrication points with a reservoir area to reduce the frequency of required lubrication.

(14) Provide guards around lubrication points which may be serviced while equipment is operating. This applies to locations where the maintenance technician may accidentally insert his hands, arms, legs, or tools into operating equipment, thereby causing injury to himself or damage to tools and equipment.

16-2.3 LUBRICATION CHARTS

Lubrication charts should be provided with each equipment. The material of the chart should be waterproofed and oil-proof, and printed on material suitable for rough handling. All necessary information for lubrication, including specification numbers, types, and grades for regular and special lubricants, should be included on the charts in the largest case letters that the size of the chart will permit. Suggested lubrication time intervals should also be included.

16-3 FILLING AND DRAINING

16-3.1 GENERAL

No daily operation of maintenance should be given more attention than the details relating to the ease and rapidity of refueling and reoiling. Fuel, exotic fluids and gases, oil, hydraulic fluids, water, compressed air, etc., systems should be designed to permit the most rapid *total overall* inspection. The necessity for opening doors and hatches for inspection, or to gain access to service points or filler caps, should be reduced. Servicing points for checking, filling, and draining fuel, lubricant, hydraulic fluid, coolant, etc., should be readily accessible, but protected. The need for special tools should also be eliminated wherever possible.

16-3.2 FILLING REQUIREMENTS

The following design recommendations should be considered :

(1) Fuel tanks should be designed and fabricated to eliminate or minimize internal corrosion and the interiors of tanks should be accessible for inspection and cleaning.

(2) The fuel outlet should be located at least 0.75 in. above the bottom of the sump or bottom of the tank, or at the bottom of the sump or tank with a 0.75-in. standpipe.

(3) Fuel tanks should be capable of accepting fuel at 50 gpm when tank capacity exceeds 50 gal. Tanks having capabilities of less than 50 gal. should be capable of being filled within 1 min. Fuel tanks should be capable of being filled at the 50-gpm rate when using a standard 1.375-in.-dia. nozzle, 16 in. long. The filler neck should have a flexible seal to fit such a nozzle, and an opening other than the filler neck itself for venting displaced air.

(4) The tank filler should be located to prevent, as much as possible, the entrance of dirt, water, and foreign matter into the fuel tank.

(5) For gravity-filled tanks, the tank filler should be located to permit use of 1 to 5 gal. cans, as well as forced-nozzle filling. Filler necks should also be located to permit use of rigid spout fuel nozzles conforming to MIL-N-4180 and MIL-N-728. (Filler necks for exotic fuels, such as oxygen, hydrazine, ammonium perchlorate, hydrogen, peroxide, etc., may waive these requirements, as required, until Department of Defense Standards are formulated.)

(6) Fuel-filler neck dimension should be a minimum of 1.75 in. for fuel tanks of 25 gals. capacity or less, and 2.5 in. for larger fuel tanks. Water and coolant filler necks should have a minimum diameter of 1.5 in. and located so they may be serviced with a 5 gal. can conforming to MIL-C-13984.

(7) The type of fuel to be serviced and the tank capacity should be stenciled or marked on

Cap Function	Color	FED-STD-595 No.
Fuel	Insignia red	11136
Oil	Orange yellow	13538
Coolant	White	17875

16-3.3 DRAINING REQUIREMENTS

The following design recommendations for the draining of tanks should be considered:

(1) The fuel system should be easily drained for storage and cleaning and the interiors of the fuel tanks should be protected against corrosion. Fuel filters should be located so that they can be cleaned and replaced without having to disassemble other parts. Access plates should be provided wherever possible for easy inspection of the fuel system.

(2) Locate fuel tank outlets so that, when the tank is a maximum of 5% full, the outlets are just submerged for the design operating conditions of the equipment in which the tank is installed. Incorporate internal arrangsments to provide full, continuous fuel supply to the equipment until the tank is a maximum of 5% full. Provide each fuel tank with a sump located at the lowest portion of the tank with the equipment in its normal position. The sump, used for collecting sediment and water, may be combined with the fuel tank outlet. Provide a machine-thread opening at its lowest point that contains a drain plug or self-locking drain valve. The sump drain should be made accessible to personnel wearing heavy, winter gloves and should not require the use of special tools.

(3) When it is essential to avoid overfilling, accessible level plugs may be used (see Figure 16-3). External hexagons or internal squares on drain, level, and filler plugs are desirable. Drain cocks that provide a high rate of drainage should be fitted to all air receivers and oil reservoirs. All drain cocks should be designed to be closed when the handle is in the down position to prevent accidental opening.

(4) Drain holes large enough to facilitate cleaning should be provided *wherever* water is likely to collect. Provide drainage facilities in enclosed equipment that might be subject to accumulated moisture resulting from condensation or other causes. (Since one method of avoiding condensation is to keep tanks as full as possible, furnish information to this effect in appropriate maintenance instructions.) Provide adequate drain tubes or channels to carry the liquids to a safe distance outside of the unit. An appropriate drain valve may be selected from Table 16-2.

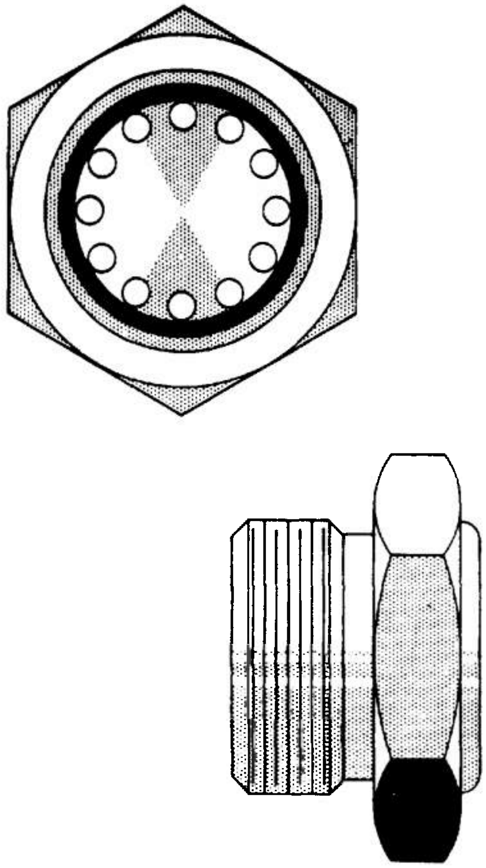


Figure 16-3. Oil Level Sight Plugs

In selecting drain valves, consider the galvanic series of metals to reduce the effects of corrosion between the drain valve and the metal to which it is attached (see Chapter 10, Table 10-4).

(5) Level indicators (Figure 16-3) for fuels, oils, water or other liquids should be located external to the vehicle or tank, when possible, and should be easily viewed without removal of doors or covers. For level indication of infre-

TABLE 16-2. DRAIN VALVES

Dimension (in.)	Material	Army Command Part No.
1.75	Steel	8724469
3	Steel	8742185
3	Aluminum	8742180
5	Steel	8741715

quently checked units (such as gear boxes), dipsticks with integral sealing caps should be provided. The use of threaded plugs for level indication should be confined to such locations as automotive differentials where other types could be torn off by rocks, mud, stumps, etc. When such plugs are used, they should have the wrench projection accurately made to fit standard end socket wrenches and be sufficiently long to obtain full bearing area on a wrench.

16-4 CLEANING AND PRESERVING

The designer should realize that at sometime during their service life, vehicles, weapons, weapon systems, etc. will require some kind of cleaning. Equipment should therefore be designed to require a minimum of manpower, supplies, and equipment for cleaning, preserving, and refinishing. Consideration should be given to the use of preservative materials for protection of surfaces subject to deterioration as follows:

(1) Surfaces subject to rubbing or chipping.

(2) Fastenings and small parts in hidden locations.

(3) Hidden surfaces whose complex shape or inaccessible location make them difficult to prepare and refinish.

Where function is not adversely affected, use a protective finish on parts exposed to the environment and on assembled parts or service parts otherwise requiring protective processing for shipping or storage. Materials should be resistant to or protected against chemical and electrolytic corrosion to the extent that such deterioration will not diminish effectiveness or appreciably increase maintenance requirements for the equipment. See Chapter 10, Table 10-3 for additional guidance in this area. Particular attention should be given to the following:

(1) Surfaces subject to wear and abrasion.

(2) Small, light parts such as those made of sheet metal and other thin gage materials.

Specify ozone resistant compounding for all rubber components that are exposed to atmosphere. Otherwise, these components will have to be specially preserved during storage to prevent deterioration.

Equipment should not require protective processing while in storage any more often than once each six months. Eliminate requirements for special protection or processing for storage by designs featuring built-in corrosion and deterioration protection.

Exposed surfaces should be shaped to avoid recesses that tend to collect and retain dirt, water, servicing fluids (spilled in servicing or lost in operation), cleaning solutions, and other foreign materials. Where such recesses cannot be avoided, suitable deflectors and drains should be provided.

Where feasible in terms of cost and performance reliability, provide ultrasonic cleaning equipment to facilitate cleaning of parts. In addition to speed of operation, ultrasonic equipment has the advantage of eliminating toxic cleaning solutions used in cleaning tanks containing alkaline solutions. For petroleum solvent cleaning, provide tight fitting metal covers for the solvent tanks when they are not in use. These covers reduce fire hazards.

The external parts (or the entire equipment) of all vehicles, weapons, weapon systems, etc. should be capable of being steam cleaned. This applies also to tanks, pumps, valves, filter bodies, accumulators and cylinders used with common fuels, exotic fluids, oils, water, air, and gases. Materials should therefore be used which will be able to withstand steam cleaning. Materials not suitable for steam cleaning, such as upholstery and soft linings of vehicles, should be washable, without damage, with strong detergents and water and, wherever possible, with gasoline or flame inhibiting solvents. Consideration should also be given to the cleaning, and resistance to cleaning required when, for example, a relatively minor hydraulic component bursts and coats everything in a compartment with oil.

16-5 ADJUSTING AND ALIGNING

Design of equipment should be such as to require the minimum number of periodic maintenance adjustments. Maintenance adjustments that cannot feasibly be eliminated should be so simplified as to permit their accomplishment at the lowest practicable maintenance level. The use of built-in, self-adjusting devices should be considered.

If adjustments are to be made manually, provide for them to be accomplished without having to disassemble components. Wherever practicable, the effect of manipulation of the service adjustments on the characteristics of the equipment should be clearly and easily discernible by reference to appropriate displays. Multiple adjustment peaks should, in general, be avoided. Avoid critical adjustments wherein a slight manipulation of the device (or slight variation during normal operation) causes a very large change of the affected parameter. Adjustment devices should have an adequate range of adjustment without being unduly critical or interdependent on other adjustments.

Misadjustments that may occur during a servicing procedure should not result in damage to any parts when the equipment is operated under such conditions for a period of up to 5 min. In general, the range of control of service adjustments should be such as to prevent damage by misadjustment.

Components should be designed with the minimum number of pivots and bearing surfaces that wear and require periodic adjustment. Any alignment or adjustment devices that are susceptible to vibration or shock should have a positive locking device to assure retention of settings. The locking device should be easy to apply and release. The application and release of the lock should not affect the setting of the adjustment. Traveling clamps and locking devices should be designed so as to avoid inadvertent release.

Spindles for adjustments may be slotted, but the head should be strong enough to withstand many manipulations with a screwdriver. A method of locating and holding the adjusting screwdriver while in use is desirable. If screwdriver adjustments must be made blind, the spindles or shafts should be mounted vertically so that the screwdriver will stay in the slot more readily.

Consider the use of locked-nut-and-thread type adjustments instead of shims. Avoid shim-type adjustments that perform the dual function of adjusting bearings and positioning units. Where shim-type adjustments cannot be avoided, design to provide shim removal rather than shim addition as parts wear. Where corrosion of nuts and threads is a factor in the adjustment of large components, consider hydraulic-type adjustments.

Where applicable, use variable-pitch, V-belt drives or high speed applications. Use spring-loaded idler sprockets on chain drives to avoid frequent adjustments. Eliminate adjustment of hose fasteners used in low-pressure applications by using spring-type fasteners that maintain a constant peripheral pressure. When enclosed chain drives require periodic adjustment, automatic adjusters should be provided.

Alignment and adjustment devices should be neither so fine that a number of turns is required to obtain a peak value, nor so coarse that a peak is quickly passed, necessitating very delicate adjustment. Part selection and system design should be such that the alignment procedure can be a straightforward operation. It should be unnecessary to go back and readjust or realign earlier stages after later stage alignments or adjustments are made. It should be possible to make all alignment adjustments without removal of any case, cover, or shield that would affect the accuracy of alignment upon replacement. No special tools should be required for alignment or adjustment.

Alignment and adjustment devices should be so located that they can be readily operated while observing the displays associated with the function being adjusted. It should be possible to check and adjust each unit of a system separately and then connect the units together into a total functioning system with little or no additional adjustment required.

16-6 SERVICING CHECKLIST

Table 16-3 is a checklist summarizing the design recommendations presented in this chapter. The checklist contains several items which were not discussed separately in the text. These items are included here because their necessity in the design is so obvious that they might otherwise be inadvertently overlooked. In using the checklist, if the answer to any question is *no,* the design should be restudied, to ascertain the need for correction.

TABLE 16-3. SERVICING CHECKLIST

1. Are standard lubrication fittings used so that no special extensions or fittings are required?
2. Are standard lubricants that are already in the Federal Supply System specified?
3. Are adequate lubrication instructions provided that identify the frequency and type of lubricants required?
4. Are filler areas for combustible materials located away from sources of heat or sparking and are spark resistant filler caps and nozzles used on such equipment?
5. Are fluid replenishing points located so that there is little chance of spillage during servicing, especially on easily damaged equipment?
6. Are filler openings located where they are readily accessible and do not require special funnels?
7. Are air reservoir safety valves easily accessible, and located where pop-off action will not injure personnel?
8. Are fuel tank filler necks, brake air cocks, flexible lines or cables, pipe runs, fragile components and like items positioned so they are not likely to be used as convenient footholds or handholds, thereby sustaining damage?
9. Where bleeds are required to remove entrapped air or gases from a fuel or hydraulic system, are they located in an easily operable and accessible position ?
10. Are drains provided on all fluid tanks and systems, fiuid filled cases or pans, filter systems, float chambers, and other items designed or likely to contain fluid that would otherwise be difficult to remove?
11. Are drain fittings of few types and sizes used, and are they standardized according to application throughout the system?
12. Are valves or petcocks used in preference to drain plugs? Where drain plugs are used, do they require only common hand tools for operation, and does the design ensure adequate tool and work clearance for operation?
13. Are drain cocks or valves clearly labeled to indicate open and closed positions, and the direction of movement required to open?
14. Do drain cocks always close with clockwise motion and open with counterclockwise motion?
15. When drain cocks are closed, is the handle designed to be in down position?
16. Are drain points placed so that fluid will not drain on the technician or on sensitive equipment?
17. Are drain points located at the lowest point when complete drainage is required or when separation of fluids is desired (as when water is drained out of fuel tanks)?
18. Are drain points located to permit fluid drainage directly into a waste container without the use of adapters or piping?
19. Are drain points placed where they are readily operable by the technician?
20. Are instruction plates provided as necessary to ensure that system is properly prepared prior to draining?
21. Are drain points located so that fuel or other combustible fluids cannot run down to, or collect in, starters, exhausts, or other hazardous areas?
22. Are lubrication requirements reduced to two types, if possible; one for engine lubrication and one for gear lubrication?
23. Are the same fuels and lubricants used in auxiliary or mounted equipment as in prime unit, where practical?
24. Are easily distinguished or different types of fittings used for points or systems requiring different or incompatible lubricants?
25. Are pressure fittings provided for the application of grease to bearings that are shielded from oil?
26. Is ample reservoir space provided for grease to bearings in gear unit?
27. Is provision made for a central lubrication or filler point, or a minimum number of points, to all areas requiring lubrication within a given system or component?
28. Are service points provided, as necessary, to ensure adequate adjustment, lubrication, filling, changing, charging, and other services to all points requiring such servicing?

TABLE 16-3. SERVICING CHECKLIST (cont)

29. Are oil filler caps designed so that they :

a. Snap then remain open or closed?

b. Provide large round opening for oil filling?

c. Permit application of breather vents, dipsticks, and strainers?

d. Use hinges rather than dangerous chains for attaching the lid?

e. Are located external to enclosure, where possible, to eliminate necessity for access doors, plates, or hatches?

CHAPTER 17
SIMPLIFICATION

17-1 THE PROBLEM

There is a general tendency, on the part of many present day designers of equipment, to produce an overly complex product. In many cases the equipment uses too many parts; has too close operating tolerances ; is too expensive to build, and is difficult to maintain. Equipment design should represent the simplest configuration possible consistent with functional requirements, expected service and performance conditions.

Simplification, although the most difficult maintainability factor to achieve, is the most productive. By simplification of otherwise complex equipment, a monstrosity is transformed into a working piece of equipment. *Simplification should be the constant goal of every design engineer.* The paragraphs below analyze one of the factors that tends to produce this type of overly complex equipment.

The first design to satisfy a specified set of functions is often complex. Safety factors are usually low and performance is usually marginal. First-order specification improvements can be achieved by increasing further the number of parts and further pyramiding equipment complexity.

A complex answer to a set of specifications is often easier to develop than a simple answer; six parts can be made to satisfy a group of functions more quickly than a simple equipment with three parts. And it is more costly, initially, to develop a simple equipment than it is to develop a complex equipment. Spending in development, however, may save production and maintenance costs, and more important may increase the effectiveness of the equipment in military applications.

The essential functions of an equipment should be incorporated in the design, using the minimum number of components consistent with good design practices. In electrical and mechanical designs, engineers should try to simplify preventive and corrective maintenance, as well as normal operation. Any reduction in the downtime need for maintenance will increase the efficiency of weapon systems.

17-2 IS SOME COMPLEXITY NECESSARY?

Operating complexity, equipment complexity, and reliability are related factors. In the developmental evolution of equipment during and immediately following World War 11, analysis showed some human limitations. An important decision was made to accept the limitations of the human and to stay within these limitations by complex instruments that accomplished many of the tasks automatically. The aim was to achieve maximum use of the reasoning capability of the human, which cannot be instrumented, by removing the confusion factor caused by overloading him. Equipment complexity and reliability are basic problems facing the equipment designer. A certain amount of equipment complexity is necessary and the designer should try to achieve reliability in spite of complexity.

One of the goals of the designer should be to make the user believe that a complex equipment is really simple. For example, to many persons the telephone seems a simple device—it seldom fails, requires little maintenance, and is easy to operate. To those who designed, tested, redesigned, and retested the telephone to achieve this high reliability, it was hardly a simple task ;

nor is the welter of electronic instruments in the modern automatic telephone exchange simple. The challenge for the designer is to learn how to build reliability and maintainability into complex equipment.

17-3 PRINCIPLES OF DESIGNING EQUIPMENT FOR SIMPLICITY OF MAINTENANCE

Two general principles can be applied to the problem of equipment design and the mechanic's job. First, the design of new equipment is also the design of new jobs. Two job areas are involved — operating the equipment, and maintaining the equipment. The more human factors engineering is considered in the design of new equipment, the better these two jobs of operating and maintaining can be done. In designing equipment, effort should be directed toward simplifying the operator's and maintenance man's job.

Even an equipment that performs complex operations can be designed so it is comparatively easy to operate and maintain: for example, by providing parts that are standard and interchangeable (see Chapter 18), using simple methods of testing, and packaging the equipment to simplify troubleshooting and replacement of defective parts (see Chapter 23, Section I).

Second, reliability and maintainability of a new equipment in realistic field conditions should be considered, i.e., the manpower price should be included in the cost picture.

17-4 COORDINATING EQUIPMENT AND JOB DESIGN

One of the byproducts of research has been the recognition of the importance of integrating job design and equipment design at early stages of equipment development. The comparative simplicity or difficulty of the maintenance job is built into the equipment. Thus, the engineer is unconsciously designing a job when he designs an equipment, and he should be aware of the capabilities and the limitations of the human beings on whom effective maintenance of the equipment depends.

Specialists in human factors engineering and in personnel training should assist in planning the equipment. The design engineers should remember that equipment will be no better than the maintenance of it, and that they cannot count on having engineering college graduates to keep the equipment in operation. They can count, rather, on some, but not all, high-school graduates. These men will probably have a number of weeks of schooling in their job but only a few hours of real practice on actual equipment before they get into the field (see Chapter 8).

CHAPTER 18
STANDARDIZATION

18-1 GENERAL

Standardization should be a primary goal whenever the design configuration of equipment is considered. When standardization is carried out to a maximum degree, the results are substantial savings in cost and supply, and increased maintainability and reliability. The savings in the logistics area alone are noteworthy. Standardization does even more, however, because it achieves a degree of interchangeability heretofore unattained (Ref. 1).

Standardization refers to the establishment of engineering practices to achieve the greatest practical uniformity in equipment design. It denotes any effort to select, design, or manufacture parts, assemblies, equipment, or associated tools, service materials or procedures, so they are identical to or physically and functionally interchangeable with other parts.

The use of nonstandard or newly designed components may result in decreased equipment reliability, and, hence, increased maintenance (Ref. 2). For example, nonstandard fixed-paper capacitors, constituting only 2.0% of the total capacitors in use, caused 49.2% of all fixed paper capacitor failures reported in 29,000 World War II failure reports (Ref. 3).

Some of the factors that contribute to a high failure rate for nonstandard items include the following :

(1) Deterioration during long storage time before use because of low demand.

(2) Misapplication, or faulty handling, installation, or maintenance because of lack of knowledge of the "unusual" component.

(3) Lack of uniformity of manufacture in small quantity production. The use of nonstandard components has the added disadvantages that spare parts might be more difficult to obtain, and adding new parts to the supply system increases the logistical burden.

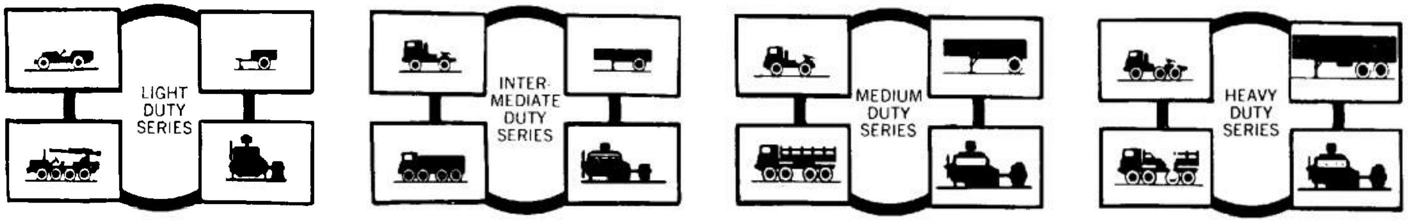
Standardization includes standardization of models or types as well as standardization of assemblies, subassemblies, and parts between or within models or types. DOD Directive No. L1120.3, referring to the Defense Standardization Program, states that "The determination as to the desirability of, and priority of, standardization projects will be made on the basis of resulting identifiable benefits." Before the designer can fully follow this policy, however, he needs some guides. Component reference books or cards and formulas to compute total costs would provide such guides and encourage maximum standardization. For instance, it may be less expensive to use an existing item, which might itself cost more than a newly designed one, than to introduce a new item into the supply system.

Standardization has received more attention and documentation than reliability or maintainability. The results are evident in standardized industrial engines and automotive-type engines, the new light rifle, and in the concept of the family of wheeled tactical vehicles (see Figure 18-1). But, continued coordination and application are necessary as new equipment is conceived. The danger is that standardization rules and regulations will be violated under the guise of expediency, especially during mobilization, when standardization is most important.

Standardization is the key factor in unitization. Without it, maintenance supply and replacement would be an infinite task. Complete standardization leads to the optimum degree of interchangeability. It becomes a vital necessity in times of emergency when the field main-

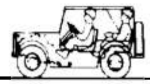
WHEELED TACTICAL VEHICLES

GENERAL PURPOSE TRUCK SERIES



TRUCK, UTILITY, ¼ TON, 4 x 4

M 151



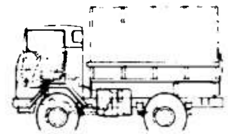
CURB WEIGHT	2,000 LB
PAYLOAD	800 LB
GVW	2,800 LB

TRUCK, CARGO, 1 TON, 4 x 4

XM 435

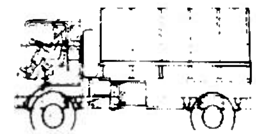
CURB WEIGHT	5,500 LB
PAYLOAD	2,350 LB
GVW	7,850 LB

TRUCK, CARGO, 2 TON, 4 x 4



CURB WEIGHT	8,000 LB
PAYLOAD	4,350 LB
GVW	12,350 LB

TRUCK, CARGO, 5 TON, 4 x 4



CURB WEIGHT	13,000 LB
PAYLOAD	10,350 LB
GVW	23,350 LB

TRUCK, CARGO, ¾ TON, 6 x 6

XM 408

CURB WEIGHT	2,450 LB
PAYLOAD	1,850 LB
GVW	4,300 LB

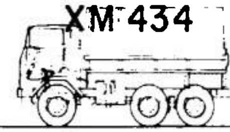
TRUCK, CARGO, 1½ TON, 6 x 6

XM 436

CURB WEIGHT	6,500 LB
PAYLOAD	3,850 LB
GVW	10,350 LB

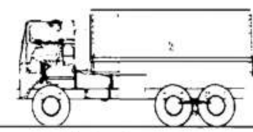
TRUCK, CARGO, 3½ TON, 6 x 6

XM 434



CURB WEIGHT	9,700 LB
PAYLOAD	7,350 LB
GVW	17,050 LB

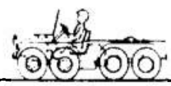
TRUCK, CARGO, 7½ TON, 6 x 6



CURB WEIGHT	16,750 LB
PAYLOAD	15,350 LB
GVW	32,100 LB

TRUCK, CARGO, 1 TON, 8 x 8

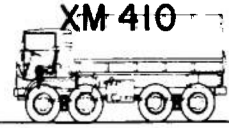
XM 384



CURB WEIGHT	3,250 LB
PAYLOAD	2,350 LB
GVW	5,600 LB

TRUCK, CARGO, 2½ TON, 8 x 8

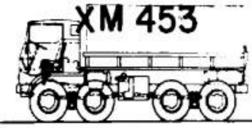
XM 410



CURB WEIGHT	7,500 LB
PAYLOAD	5,350 LB
GVW	12,850 LB

TRUCK, CARGO, 5 TON, 8 x 8

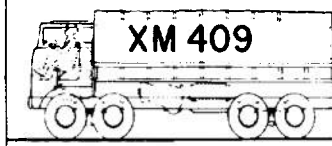
XM 453



CURB WEIGHT	11,500 LB
PAYLOAD	10,350 LB
GVW	21,850 LB

TRUCK, CARGO, 10 TON, 8 x 8

XM 409



CURB WEIGHT	20,500 LB
PAYLOAD	20,350 LB
GVW	40,850 LB

Figure 18-1. General Purpose Truck Series

tenance shop becomes cut off from the main supply depot.

While standardization is highly desirable for maintainability, it must be realized that standardization cannot be permitted to interfere with technical advances. Consequently, standardization is a continuous process rather than a static condition.

18-2 GOALS OF STANDARDIZATION

The primary goals of standardization are to:

(1) Reduce the number of different models and makes of equipment in use.

(2) Maximize the use of common parts in different equipment.

(3) Minimize the number of different types of parts, assemblies, etc.

(4) Use only a few basic types and varieties of parts, assemblies, etc. and to ensure that those parts are readily distinguishable, compatible with existing practices, and used consistently for given applications.

(5) Control, simplify, and reduce part coding, numbering practices, and storage problems.

(6) Maximize the use of standard off-the-shelf items and components.

(7) Maximize the use of interchangeable parts.

Standardization, however, is not intended to inhibit design improvement effects. Before such efforts are undertaken, it should be established that the value of design improvement outweighs the advantages of standardization. Rather than being a matter of initiative or freedom, the lack of Standardization seems largely attributable to poor communication among designers, contractors, users, buying agencies, subcontractors, and their divisions and agencies. It is suggested that the maintainability effort concern itself with this lack of communication and assume responsibility for ensuring and coordinating compatibility and uniformity in design (Ref. 5).

18-3 ADVANTAGES OF STANDARDIZATION

A well planned standardization program will provide the following (Ref. 4):

(1) Avoid requirements for special or close tolerance parts, etc.

(2) Save design time, manufacturing cost, and maintenance time and cost.

(3) Result in more uniform and predictable reliability.

(4) Minimize the danger of misapplication of parts, assemblies, etc.

(5) Prevent accidents which arise from improper or confused procedures.

(6) Facilitate "cannibalizing" maintenance procedures.

(7) Reduce errors in wiring, installation, replacement, etc., due to variations in characteristics of similar equipments.

In addition, procuring, stockipg, training, and downtime problems which were compounded by the use of nonstandard parts and costs of production and maintenance, are considerably decreased. Combat efficiency is also enhanced by the use of the commonly used and satisfactorily tested standard materials and components.

18-4 DEPARTMENT OF DEFENSE STANDARDIZATION PROGRAM

The Department of Defense Standardization Program was authorized by Public Law 436, 82nd Congress and Public Law 1028, 84th Congress and was implemented by DOD Standardization Manual M201 (Ref. 4).

18-4.1 PURPOSES

The purposes of the Defense Standardization Program are to improve the efficiency and effectiveness of logistical support and operational readiness of the Army, Navy, and Air Force, and to conserve money, manpower, time, production facilities, and natural resources by each of the following:

(1) Adopting the minimum of sizes, kinds, and types of items and services essential to military operations.

(2) Providing the greatest practical degree of component interchangeability.

(3) Developing standard terminology, codes, and drawing practices.

(4) Preparing engineering and purchasing documents that provide for the design, purchase, and delivery of items that are consistent

with the objectives of the Department of Defense Standardization Program.

(5) Supplying the military departments with the most reliable equipment possible by adoption of materiel that has been evaluated according to established Government Specifications and Standards.

18-4.2 SCOPE

The scope of the Defense Standardization Program includes the standardization of materials, components, equipment, and processes as well as the standardization of engineering practices and procedures essential to the design, procurement, production, inspection, application, preservation, and preparation for delivery of items of military supply.

The congressional mandate to standardize the Federal Supply System applies to all areas where specific benefits can be anticipated. A vigorous standardization program is of mutual concern to both industry and the Government. Eliminating and/or preventing excessive item variations results in economies in tooling, engineering, manpower, and in the size of both Governmental and industrial inventories.

18-4.3 APPLICATION

Standardization must be applied at all stages of design, as well as to items already in the supply system. Wherever practical, it is required that standard parts, components, and subassemblies be used. The achievement of standardization will decrease the number of unique component items and design prerogatives in weapon-system development and production.

A key factor in reducing the overall and long range costs of logistical support is to design so as to standardize for both physical and functional interchangeability. Due consideration to standardization during the development of a new system will provide for rapid and easy interchange and replacement of parts and subsystems under all conditions. This is the ultimate result of effective standardization. Both Government and industry should see that their efforts are coordinated toward this achievement.

18-5 RECOMMENDATIONS FOR STANDARDIZATION

18-5.1 DESIGN REQUIREMENTS

In order that parts may be quickly exchanged or used in diverse applications, make all items that are subject to removal and replacement standard and uniform. To facilitate supply of replacement parts, base designs on the use of available parts which are of standard, rather than of special manufacture. Do not base designs on the use of parts made by only one manufacturer when equivalent parts are available from several other manufacturers. Insure that all parts having the same manufacturer's part number are designed to be directly and completely interchangeable with respect to installation and performance.

Ensure also that mechanical and electrical interchangeability exists among like assemblies, subassemblies, and replacement parts, regardless of the manufacturer or supplier (see Chapter **14**). Interchangeability and standardization are among the prime factors for consideration in the design of components, parts, assemblies, and equipment and these factors are of paramount importance in effective supply and maintenance support.

Use standard MS, **AN,** or MIL parts wherever they are suitable for the purpose, and identify them on the drawing by their part numbers. Common hardware parts, such as screws, bolts, nuts, and cotter pins, should be replaceable by standard MS, **AN,** or MIL parts without alteration. In applications for which no suitable corresponding MS, **AN,** or MIL part is available, commercial parts may be used if they conform to the other requirements of this guide.

Materials and parts available world wide should be given first consideration. Use of the Federal Cataloging Handbook, the Numerical Index of Descriptive Patterns and Item Name Code H6-1, FED-STD-No. 5, and other specifications and standards should be selected in accordance with **MIL-STD-143. All** screw threads should conform to Screw Threads for Federal Services, H-28.

The Qualified Products List (QPL) is a list of products qualified under the requirements stated in the applicable specification. Use QPL parts wherever they are suitable for the purpose. AR 750-1 provides additional guidance for standardization. Essentially, it specifies the following (Ref. 7):

(1) Developing agencies will provide the design agency or contractor a listing of standard components, parts, handling equipment, tools, and test equipment applicable to the equipment under development.

(2) Design agencies or contractors will provide the development agency with full justification in all cases where a peculiar item is developed for an application formerly utilizing or capable of utilizing a standard item.

(3) Approval for the use of nonstandard items will not be granted unless it is determined that the standard item cannot meet the approved military characteristic or safety requirements, or the state of the art or technological advances requires the acceptance of the new item, or the new item will materially increase the overall effectiveness and modernization of the equipment under development.

In addition to the above requirements, provide the following wherever possible:

(1) Similar component parts for all major items within a system.

(2) Similar component parts between major combinations or systems.

(3) Maximum use of parts already listed in the Army Repair Parts Lists or the Federal Supply Catalog.

(4) Maximum use of commercial, nonproprietary parts.

(5) Maximum use of standard and common tools and general-purpose test equipment.

(6) Maximum use of tools and test equipment already listed in the Army Stock List.

18-5.2 SPECIFIC APPLICATIONS

Standards parts, components, and circuits should be used for the following applications (Ref. 8):

(1) Operating levels, inputs and outputs, or circuits.

(2) Values of regulators, supply voltages, etc.

(3) Routine functions such as RF, IF, studio, video, or computer circuits.

(4) Arrangement and packaging schemes.

(5) Part identification methods and practices.

(6) Labeling and marking practices and methods.

(7) Wiring identification and other coding.

(8) Selection, application, and mounting of covers and cases.

(9) Selection and application of fasteners.

(10) Servicing materials and equipments, particularly oils and fuels.

(11) Items which are interchangeabie from equipment to equipment, such as starting motors, generators, air cleaners, oil and fuel cleaners, batteries, radiators, instruments, controls, lights, etc.

18-5.3 ADMINISTRATIVE RESPONSIBILITY

Parts or equipment manufactured by different contractors should be made uniform by agreement with the procuring activity. Contractors should ensure that standardization requirements are met and satisfied by all subcontractors in a uniform and consistent manner. Each contractor should ensure that his own equipment satisfies the goals of standardization described in Paragraph 18-2.

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CHAPTER 19
UNITIZATION AND MODULARIZATION

19-1 DESIGNING EQUIPMENT FOR EASY REPAIR

Components or subassemblies of equipment can be designed to be fully repairable, partially repairable, or nonmaintainable. In a fully repairable design, all parts should have maximum life expectancy, be easily accessible, and capable of being removed without special tools. In a *partially repairable design,* the replaceable parts should be chosen so that their life expectancies are approximately equal, are removable and replaceable without special tools, and are readily accessible. A nonmaintainable design should have all parts designed for approximately equal life expectancies.

19-2 UNITIZATION OR MODULARIZATION

There is an increasing trend toward partially repairable and nonmaintainable designs in industrial and military equipment. This trend is reflected in the increasing use of unitized or modular construction.

Unitization refers to the separation of equipment into physically and functionally distinct units to facilitate removal and replacement. It denotes any effort to design, package, and manufacture a group of parts and elements in an aggregate which can be considered as an undivided whole. Unitization enables systems, assemblies, and subassemblies to be designed as removable entities.

The modular concept covers the range of complete black-box equipment built on a single structure to the smallest printed circuit insert. The significance of modular construction lies in its degree of use. For example, a module may consist of nothing more than a single operating circuit in a system, i.e., the system reduced to the smallest operating function possible, or it may consist of modules built on modules to form the overall equipment function. The degree to which the concept is applied depends on the particular application of the equipment and its practicality and cost.

Modular construction should be incorporated or designed into the product whenever practical, logistically feasible and combat suitable, or where elimination or reduction of personnel training and other similar advantages will result.

Examples of modules are:

(1) Fireable missiles in their shipping-firing containers requiring no field adjustment or maintenance.

(2) Ammunition rounds and fuzes.

(3) Electronic modules.

(4) Sealed relays.

(5) Electronic tubes.

(6) Missile guidance systems.

(7) Hermetically sealed units.

19-3 ADVANTAGES OF UNITIZATION AND MODULARIZATION

The concept of unitization and modularization creates a divisible configuration more easily maintained. Troubleshooting and repair of unitized assemblies can therefore be performed more rapidly. Utilization of these techniques to the fullest extent improves accessibility, makes possible a high degree of standardization, provides a workable base for simplification, and provides the best approach to maintainability at all maintenance levels.

Another important advantage of unitized or modular construction from a maintenance viewpoint is the division of maintenance responsibility. Modular replacement can be accomplished in the field with relatively low skill levels and few tools. This accomplishes a prime objective of maintainability — the reduction of downtime to a minimum. Defective modules can be discarded (if nonmaintainable), salvaged, or sent to a higher maintenance level for repair.

Modular design cannot be applied to all types of equipment with equal advantage. Its greatest application is in electronic equipment. It has application in complex equipment of other types, but becomes increasingly difficult to exploit in simpler devices. Following are a few additional advantages of modular construction:

(1) New equipment design can be simplified and design time shortened by use of previously developed, standard "building blocks."

(2) Current equipment can be modified with newer and better functional units that replace older assemblies of component parts.

(3) The standard "building blocks" can be manufactured by fully automated methods.

(4) Maintenance responsibilities can be divided among the various maintenance levels best equipped to fulfill them.

(5) The recognition, isolation, and replacement of faulty units is facilitated, permitting rapid maintenance at the user level, with consequent reduction of downtime.

(6) Training of user maintenance personnel will take less time and cost less.

19-4 DISPOSABLE MODULE REQUIREMENTS

A disposable module denotes any module designed to be thrown away rather than repaired after its first failure, assuming that the original diagnosis of failure is validated prior to disposal (Ref. 2.).

All decisions and requirements for disposable modules must be concurred in by the purchasing activity, and should be based on exhaustive and/or clearly decisive analyses which prove that:

(1) Maintenance is either impractical or costs more than replacement (see Chapter 7).

(2) The advantages given in Table 19-1 outweigh the disadvantages.

(3) Significant and favorable differences exist between the values of:

(a) End costs of the disposable versus the maintainable module.

(b) Man-time, materials, tools, etc. necessary to maintain each.

(c) Maintenance and supply programs as they differ in war and peace.

(d) Supply, storage, handling, and procuring costs and problems.

(e) Other costs and problems as determinable and applicable.

TABLE 19-1. ADVANTAGES AND DISADVANTAGES OF A DISPOSAL-AT-FAILURE DESIGN

Advantages	Disadvantages
1. Savings in repair time, tools, facilities, and manpower	1. Increased supply burdens because modules must always be on hand
2. Smaller, lighter, denser, simpler, more durable, and more reliable design	2. Reduction in failure and maintenance data to aid design improvement
3. Fewer types of spares and a one-way supply system, at least for the item	3. Excessive usage rates, through excessive and/or erroneous replacement
4. More concise and less difficult trouble-shooting procedures	4. Redesign problems and costs because such modules cannot be modified
5. Use of sealing and potting techniques which further improve reliability	5. Degraded performance and/or reliability as a result of production efforts to keep modules economical enough to justify disposal
6. Improved standardization and interchangeability of modules and assemblies	

19-5 DISPOSABLE MODULE DESIGN REQUIREMENTS

Disposable modules should be designed, manufactured, and installed so that they meet the following criteria:

(1) Expensive parts are not thrown away for failure of cheap parts.

(2) Long life parts are not thrown away for failure of short life parts.

(3) Low cost and noncritical items are, in general, made disposable.

(4) Throw away modules are encapsulated wherever practical.

(5) All encapsulated modules are designed for disposal-at-failure.

(6) Modules costing $50 or less are disposable wherever practical.

(7) Modules costing more than $50 are encapsulated as necessary to meet the performance and reliability requirements.

(8) The maintenance level of throw away is clearly specified.

(9) Test procedures to be applied before disposal are clearly specified and provide clear and unequivocal results.

(10) The identification plate or marking contains the statement: "DISPOSE AT FAILURE."

19-6 GENERAL MODULARIZATION DESIGN RECOMMENDATIONS

In the design of modular-type equipment, the following principles should be considered:

(1) The equipment should be divided into as many modular units as are electrically and mechanically practicable in keeping with efficient use of space and overall equipment reliability.

(2) An integrated approach should be used, considering simultaneously the problems of materials, component design, and application of the modular concept.

(3) All modules and component parts should be approximately uniform in basic size and shape for the best packaging.

(4) A modular unit should contain components that are optimized for a given function rather than providing multiple, divergent functions.

(5) Modular units or subunits should be designed to permit operational testing when removed from the equipment and little or no calibration after replacement.

(6) The physical separation of equipment into replaceable units should be matched with the functional design of the equipment. This will maximize functional independence of units and minimize interaction between units. A hypothetical example is shown in Figure 19-1.

(7) Where an assembly can be made up of two or more subassemblies, design the major assembly so that it consists of subassemblies which can be removed independently, without removal of the other subassemblies. This uniti-

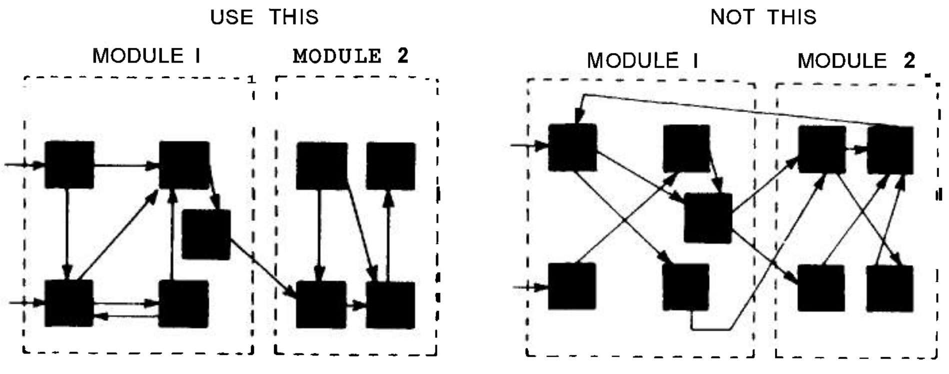


figure 19-1. Design for functional Unitization That Corresponds to Modularization

zation is especially valuable when the various subassemblies have widely varying life expectancies.

(8) Design all equipment so that rapid and easy removal and replacement of malfunctioning components can be accomplished by one technician, unless it is structurally or functionally not feasible (see Chapter 23, Section I).

(9) Where possible, make units small and light enough for one man to handle and carry. The weight of removable units should be held below 45 lb. Units weighing more than 10 lb should have handles.

(10) Where possible, make each module capable of being checked independently. If adjustment is required, design for adjustment separate from other units.

(11) Consider application of modular concepts to major subsystems and components of vehicles so they are replaceable as a unit and capable of being repaired and tested outside the vehicle or parent item.

(12) Design control levers and linkages so they can be easily disconnected from components to permit easy removal and replacement.

(13) Emphasize modularization for forward levels of maintenance to enhance operational capability. Modularization versus parts replacement for shop and depot maintenance can be determined to a considerable extent by cost factors.

(14) If all components of a module except for one or two are reliable, consider unitizing the module with the unreliable components removable from the exterior of the package (see Figure 19-2.)

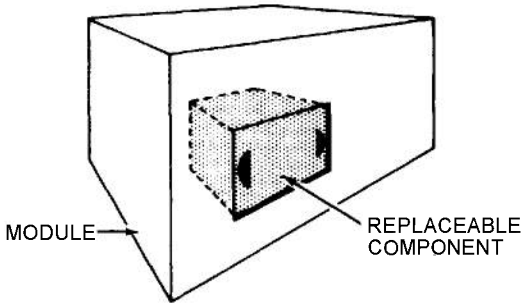


Figure 19-2. Unitization of a Module for Easy Replacement of Low Reliability Components

REFERENCES

1. J. W. Altman, et al., *Guide to Design of Mechanical Equipment for Maintainability*, ASD-TR-61-381, Air Force Systems Command, Wright-Patterson AFB, Ohio, 1961, (DDC No. AD 269 332).
2. *Maintainability Design Factors*, U S Army Missile Command, Redstone Arsenal, Ala., 1963.

CHAPTER 20

REDUNDANCY

20-1 GENERAL

Redundancy is a major factor of maintainability. It can be simply defined as an "excess," or "more than enough." At first glance, redundancy seems to come under the liability column. However, as generally practiced in the engineering world, its definition places it in the asset column so firmly that in many instances it is not just "more than enough," it is *barely* enough.

Redundancy in engineering may have **a** different connotation for each engineering specialist; for example, to the structural engineer, a factor of safety; to the electrical engineer, a generator with the capacity to handle an overload without damage; to the lubricating engineer, a lubricating supply of more than the normal requirements to take care of unforseen eventualities; to the operational design engineer, the capacity to meet the emergency of a minor functional failure to prevent the destruction of the whole product.

When redundancy is designed into an equipment, maintainability is often greatly enhanced, even though the original reason for incorporating redundancy was not to improve the maintainability. Sound judgment must be used when redundancy is utilized purely for maintainability purposes, since in some cases, a decrease in maintainability could occur as a result of the possible increased maintenance due to the redundancy. Redundancy should be considered in those cases where its incorporation will not increase the equipment's maintenance, or excessively increase its cost.

When redundancy is incorporated into an equipment specifically to increase maintainability, the following objectives should be the goal of the maintainability engineer:

(1) Restoring the equipment to a usable operational condition.

(2) Prevention of destruction of the whole equipment so it can be maintained, even on an operational mission.

(3) Prevention of destruction of units of an equipment when an overload or emergency arises.

(4) Substitution of one item of equipment to do the normal function of another.

(5) Increase the reliability of the equipment.

(6) Reduce or eliminate maintenance.

(7) Reduce the maintenance man-hours and costs.

(8) Simplify the inspection process.

20-2 GENERAL DESIGN RECOMMENDATIONS

Whenever practicable, redundancy, and other fail-safe principles should be considered in the design of all weapons, commodities, and systems, so that the failure of a single structural element will neither cause catastrophic failure of the equipment, nor prevent the equipment from being safely transported to its normal place of repair. For this fail-safe requirement, the weapon, commodity, or system is defined as including all of the structural elements of major systems, and all of the structural connecting and supporting elements of the power plant installation, the failure of which will:

(1) Cause uncontrollable motions **of** the equipment within the limits of its structural design.

(2) Reduce the ultimate factor of safety for operational design conditions to a value less than **1.0.**

Examples of the use of redundancy in equipment are as follows:

(1) Structures: capable of withstanding more than their most severe load.

(2) Bearings: capable of withstanding more than their most severe load.

(3) Circuits: capable of withstanding high

stray or surge voltages, or pressures.

(4) Insulation on electrical equipment: continually capable of withstanding higher than normal voltages and temperatures for short periods without failure.

(5) Capacitors: capable of withstanding voltages higher than normal.

(6) Dual electrical power supply: each capable of fulfilling the product's mission.

(7) Electrical plugs on outside of product: to supply product with power normally generated on board.

(8) Dual or multiple prime movers: each, or in combination, capable of sustaining satisfactory motion.

(9) Front and rear drives on land vehicles separately driven from prime mover: each capable of continuing their function in the event the other fails.

(10) Multiple braking systems: each capable of operation should the other fail.

(11) Hand crank on engines with self-starters: to crank engine in the event self-starter fails.

(12) Auxiliary power plants: to substitute for main power source.

(13) Multiple sealed compartments in floats, boat hulls, etc.: each, or in combination, capable of sustaining floatation.

(14) Dual control systems: either of which will serve the intended mission or function. Typical are:

(a) Two identical controls.
(b) Power plus mechanical activation.
(c) Dual cable, wire, or push rod.

(15) Dual electrical or electronic circuits: each able to substitute for the other.

(16) Dual vehicle tires on one axle: each capable of carrying the load in case the other fails.

(17) Multiple fuel tanks: each capable of being valved to serve all engines or a combination thereof.

(18) Dual fuel systems: each capable of supplying an engine in the event the other fails.

(19) Tire tube inside an outer tire tube: capable of carrying the load and fulfilling the mission in the event the outer tube fails.

(20) Two or more fasteners: each, or in combination, capable of carrying the load in the event the other fails.

(21) Multiple fuzes on ordnance items: to further assure satisfactory action in the event the other(s) malfunction or fail.

(22) Local manual fire control: to substitute for automatic fire control on military items (guns, missiles, etc.).

(23) Telescopic rangefinders: to substitute for radar rangefinders.

(24) Multiple bilge pumps: each having its own sources of energy, and capable of performing the function of the other.

(25) Visual or audible warning system: to operate simultaneously with, for example, an automatic fire extinguishing system.

(26) Multiple fire extinguishing systems: each capable of being directed into the other's normal area.

(27) Multiple escape means to afford quick exit from a single compartment in an emergency.

(28) Two or more methods for shutting down an engine burner, etc. in the event the normal method fails.

(29) Military fire control systems for a single weapon or battery: capable of alternate use with gun or missile without delay.

(30) Alternate air intake source to carburetors: to prevent or correct icing or contamination.

(31) Oil tanks of sufficient size to permit continued satisfactory lubrication even though a small leak or seepage exists.

(32) Resettable circuit breakers capable of immediate reuse, and without having to replace a less complicated item, such as a fuse.

(33) Test or calibration equipment: with universal capability, as for example:

(a) Multifunction meters capable of reading volts, ohms, amperes, and watts.
(b) Universal missile checkout device capable also of serving more than one type of missile.

(34) Dual means of communication: such as a telephone intercommunication system, horn, bell, light, etc.

(35) Frequency change equipment in a radio transmitter or receiver to permit two or more radios normally used on two or more channels to be substituted for each other.

(36) Stiffened fuselage bellies: capable of reasonably resisting forced belly landings in the event of landing gear failures.

(37) Manual overrides on power actuated components: such as on retractable aircraft landing gears, power driven hatches, flight controls, ship steerage, etc.

CHAPTER 21
FASTENERS

21-1 GENERAL

This chapter presents recommendations for the design and use of fasteners. Fasteners are available in a wide variety of types and sizes, and new types are always appearing. The application of fasteners should be preceded by a review of the varieties available. Fasteners should be selected and evaluated on the basis of durability, ease of operation, speed, ease of replacement, and other requirements described in this chapter. The design, selection, and application of fasteners should take into account the following considerations :

(1) Stress and environmental factors the fasteners must withstand.

(2) Work space, tool clearance, and wrenching space around the fastener.

(3) Types of tools required for operation of the fastener as a function of fastener type, application, and location.

(4) Types and varieties of fasteners being used elsewhere in the system.

(5) The frequency with which the fasteners will be operated.

(6) The time requirements of tasks involving operation of the fasteners.

21-2 GENERAL FASTENER REQUIREMENTS

The paragraphs which follow give some general requirements which should be considered in the use of fasteners.

21-2.1 STANDARDIZATION OF FASTENERS

(1) Minimize the number of types and sizes of fasteners within the system.

- (a) Use only a few basic types and sizes which can readily be distinguishable from each other.
- (b) Use the same type and size of fastener for a given application (for instance, all mounting bolts for a given type of item).
- (c) Make certain that screws, bolts, and units of different thread size are of clearly different physical sizes, otherwise they may be interchanged.
- (d) Avoid requirements for special or close tolerance fasteners.

(2) Minimize the number of differing torque requirements within the system.

- (a) Use only a few basic values.
- (b) Key these values to clearly differing types, sizes, or coded fasteners.
- (c) Plan for and provide clearance for wrenches or socket tools with variable torque settings, where precise torquing is required.

(3) Minimize the number of tool types and sizes required for fastener operation.

- (a) Avoid requirements for special tools.
- (b) Select fasteners for hand operation by common hand tools (see Chapter 11).

21-2.2 MATERIAL FOR FASTENERS

(1) Fasteners should be of nonferrous (rust resistant) material.

(2) Corrosion resistant steel or nickel-copper alloy may be used where strength is required.

(3) Aluminum alloy should not be threaded into aluminum alloy parts.

(4) Do not use fasteners that can cause galvanic action, e.g., a titanium fastener used with magnesium would cause galvanic corrosion.

(5) Do not use nonmetallic fasteners where high tensile or shear strength is required.

21-2.3. MOUNTING OF FASTENERS

(1) The replaceability of stripped, worn or damaged fasteners should be considered in design. Fasteners (studs) which are a part of the housing should be avoided.

(2) Fastener mounting holes or other tolerances should be large enough to allow "starting" of fasteners without perfect alignment.

(3) Hinges, catches, latches, locks, and other quick disconnect devices should be attached by means of small bolts or screws, not rivets.

(4) Bolts should be mounted with the head up so they will stay in position if the nut falls off.

(5) Nuts and bolts (particularly those which are frequently operated or poorly accessible) should be mounted so they can be operated with one hand or one tool by :

(a) Providing recesses to hold either the nut or bolt.

(b) Semipermanently attaching either the nut or bolt.

(c) Using double nuts on terminal boards and similar applications.

(d) Using nut plates, gang-channeling, or floating nuts.

21-2.4 NUMBER OF FASTENERS

(1) Minimize the number of fastener and fastener parts.

(2) Maximize the use of hinges, catches, latches, and quick disconnect fasteners to reduce the number of fasteners required.

(3) Use a few large fasteners rather than many small ones (except where many are necessary to maintain a fluid or air tight seal).

(4) Use no more than four fasteners to mount a unit. A common fault is use of too many fasteners when a more rigid construction is preferred.

21-2.5 LOCATION OF FASTENERS

Fasteners should be located so that they :

(1) Can be operated without prior removal of other parts or units.

(2) Can be operated with minimum interference from other structures.

(3) Do not interfere with each other or other components.

(4) Do not constitute a hazard to personnel, wires or hoses.

(5) Are surrounded by adequate hand or tool clearance for easy operation. Requirements for two hands or power tools for manipulation, breakaway, or removal of stuck fasteners should be considered.

21-2.6 CODING OF FASTENERS

(1) All external fasteners which are manipulated during normal maintenance should provide strong color contrast with the color of the surface on which they appear.

(2) All other external fasteners and assembly screws should be of the same color as the surface on which they appear.

(3) The heads of "special" bolts and screws should be color or stamp-coded to ensure that they are properly handled and are replaced by identical fasteners.

(4) Only markings which designate the size type, or torque value of the fastener should be used ; omit manufacturers' names or trademarks.

(5) Fastener markings must be etched or embossed to withstand exposure to chemicals, fuels, LOX, weather, or other operational conditions.

(6) One fastener marking code should be used throughout the system. The code must be determined and standardized ahead of time, and should conform to prevailing standard practices.

21-3 TYPES OF FASTENERS

Fasteners are used to join two or more parts, components, or units together. They include devices such as quick disconnects, latches and catches, captive fasteners, combination-head bolts and screws, regular screws, internal wrenching screws and bolts, and rivets. Each type has certain advantages for various applications. The paragraphs which follow give some general recommendations and applications for each type of fastener in order of preference.

21-3.1 QUICK RELEASE FASTENERS

Quick release fasteners, also known as cowl fasteners and panel fasteners, are fast and easy to use, do not always require tools, may be operated with one hand, and are very good for securing plug-in components, small components and covers. However, their holding power is low and they cannot be used where a smooth surface is required. They should be carefully evaluated on the basis of type and application, and used wherever possible for components that must be frequently dismantled or removed. These fasteners should fasten and release easily (maximum of one complete turn) without the use of tools. The female section should be coded as to its color, shape, size, and spline so that only the correct male section may be attached.

Quick release fasteners can be classified according to their method of actuation: rotary operated, lever actuated, slide action, and pushbutton. Rotary operated types depend on a turning or rotary motion, imparted to some actuating member, for opening or closing. Lever actuated types are operated through a release or locking lever arrangement. Slide action types are operated by sliding one member over or through another. Pushbutton types are operated by depressing a button to release the latch (Ref. 1). Figure **21-1** illustrates examples of each type. Specific requirements for quick release fasteners are given in MIL-F-5591.

21-3.2 LATCHES, CATCHES, AND CLAMPS

Latches and catches are very fast and easy to use, require no tools, have good holding power, and are especially good for large units, panels, covers, and cases. They cannot be used where a smooth surface is required. Latches and catches should be located and positioned so that accidental opening is minimized (see Figure **21-2).** Catches should be spring loaded so that they do not require positive locking. If positive locking is necessary to meet structural or stress requirements, a latch loop with locking action should be utilized (see Figure **21-3).** If a handle is used in conjunction with the latch, the latch release should be located on or near the handle so that only one hand is needed for operation.

Clamps of the quick-release type (Figure **21-4)** should be provided for holding wires, tubing, or hoses that must be removed frequently. Hinged clamps (Figure **21-5)** are preferable for mounting tubing or wiring on the face of a panel. Such clamps facilitate maintenance by supporting the weight of the line, thus freeing both hands for the required task. Wherever possible, clamps should be provided that can be fastened with one hand (Figure **21-6).** For large plug-in assemblies, positive locking clamps that may be released easily should be used.

21-3.3 CAPTIVE FASTENERS

Captive fasteners (Figure **21-7)** are slower and more difficultto use and require the use of common hand tools ;however, they stay in place, save the time spent handling and looking for bolts and screws, and require only one handed operation.

Whenever lost screws, bolts, or nuts might cause excessive maintenance time, or could cause damage as a foreign object, captive fasteners should be utilized. Use only the type that can be operated by hand or common tools and can be easily replaced in case of damage. Self-locking, spring loaded action should be provided on the quarter-turn type.

21-3.4 SCREWS

Because machine screws can be readily removed and replaced, they are used more than any other type of mechanical fasteners in some types of equipment. There are, however, more than **30** screw-head styles available. Eight head styles have been standardized by the American Standards Association, but military usage should be generally restricted to two styles— either the pan head or the flat head, according to whether or not a flush assembly is desired (see Figure **21-8).**

To reduce assembly costs, the self-tapping screw is sometimes used as a semipermanent fastening. Its use is usually limited by Military Specifications to applications where removal is not intended. Head styles available for self-tapping screws are similar to those on machine screws.

Captive screws, which are becoming more and more common in field equipment, are particu-

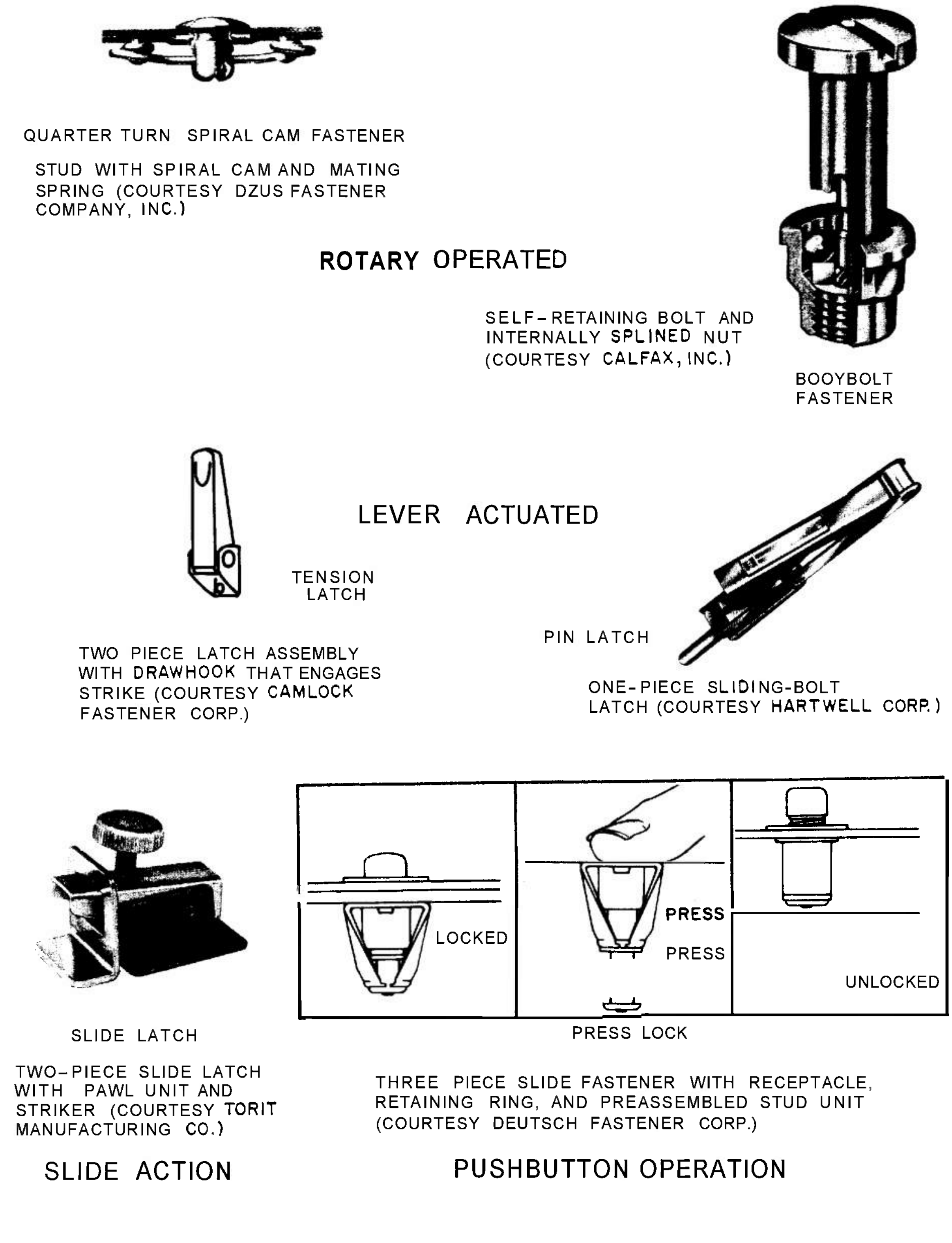


Figure 21-1. Examples of Quick Release Fasteners

larly desirable on panels that require frequent removal. Captive screws cannot easily be detached from the panel, although they generally turn easily for removal of the panel. Also, they can be turned by hand and do not require a tool.

Cost, appearance, field use, tightening torques, etc., must be considered in determining the type of driver recess to specify. Efforts should be made to vary driver recess size as little as possible to hold to a minimum the variety of screwdrivers needed. The most common types of driver recesses are the slotted, cross (Phillips), and hex, with the cross recess currently the most widely used because of its adaptability to power driving during equipment manufacture. This latter characteristic allows quick assembly and lower labor costs, but offers no advantages to the technician once the equipment is in the field.

21-3.4.1 Combination-Head Bolts and Screws

Combination-head bolts and screws (Figure 21-9) should be used in preference to other screws or bolts because they may be operated more rapidly with either a wrench or a screwdriver. This allows use of the more convenient tool and reduces the possibility of slot damage and stuck fasteners. In general, slotted, hexagon heads are preferable to knurled and slotted heads (see Figure 21-10).

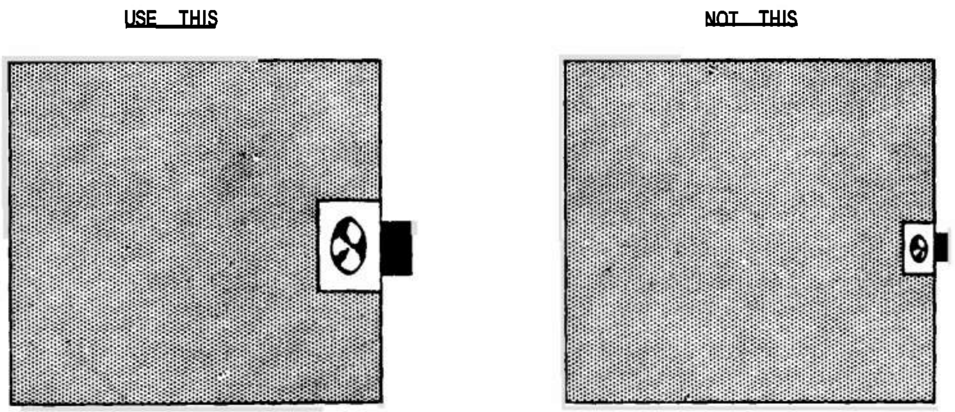


Figure 2J -2. Provide Long Latch Catches to Minimize Accidental Springing fRef.21

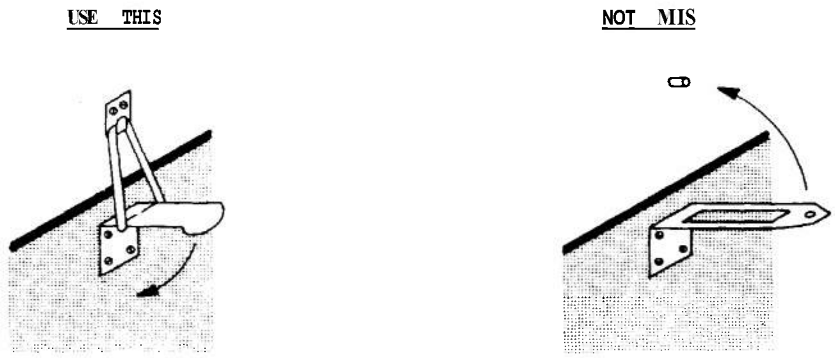


***figure 27* -3. Latch Loops Provide Secure Locking**

21-3.4.2 *Regular Screws*

Regular screws require more time and are more subject to slot damage, stripping, and misapplication than combination-head screws, but they require less wrenching space, only one handed action to operate, and do not involve a number of extra parts. Square head screws are generally preferable to round or flat since they provide better tool contact, are less subject to slot damage, and may be removed with pliers. Some general requirements for using screws are:

(1) The number of turns required to tighten or loosen a screw should be less than 10.

(2) When tightened, the screw must fully engage to a distance at least equal to its diameter.

(3) Deep slots must be provided on screw heads to minimize slot damage (see Figure 21-11).

(4) Screws should be used only when screwdrivers may be used in a straight-in fashion; do not require use of offset screwdrivers.

(5) If a screw must be operated blindly, provide a tool guide in the assembly.

(6) Fine thread screws are recommended for pressurized units.

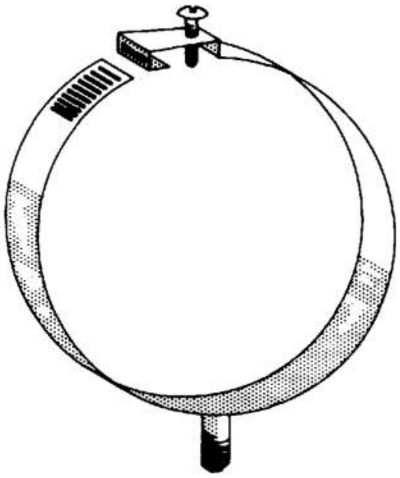


Figure 21-4. Quick Release Clamp

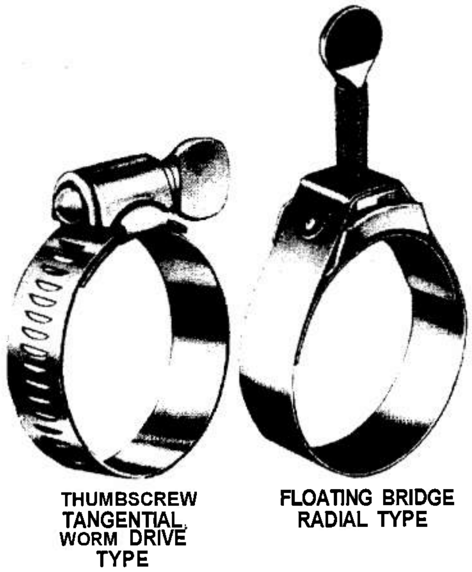


Figure 21-6. Provide Clamps That Can Be Fastened with One Hand

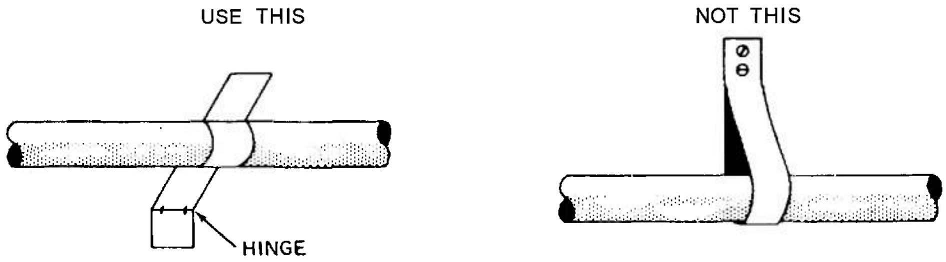


Figure 21-5. Use Hinged Clamps for Panel Mounting Tubes and Wires (Ref. 3)

(7) Countersunk screws should be used only where necessary to provide a smooth surface.

(8) Round head rather than flat head screws should be used on panels less than **0.094** in. thick to prevent screws from ripping through the panel.

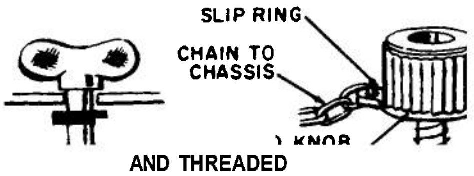


Figure 21-7. Captive Fasteners

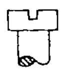
(9) Self-tapping screws should have one type of head and be of one size, where feasible, or **a** minimum number of sizes.

21-3.5 BOLTS

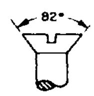
Bolts are usually slow and difficult to use; they require two handed operation, access to both ends of the bolt, and often the use of two tools. They also require precise movements in starting nuts and have many loose parts to handle and lose (nuts, washers, etc.).

Some general requirements for the use of bolts are:

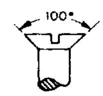
(1) Bolt length should not be more than re-



Flat Fillister
Similar to standard fillister but without oval top. Used in counterbored holes that require a flush screw. Available with slot only for machine screws.



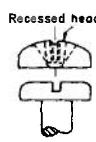
Hat, 82 dog
Use where flush surface is desired. Countersunk section aids centering. Available with slotted, clutch, Phillips, or hexagon-socket driving recess. Also available with no recess for metal drive screws.



Rat, **100 deg**
Larger head than 82-deg design. Use with thin metals, plastics, etc. Available with slotted or Phillips driving recess.

Flat Trim
Similar to **82** deg flat head except depth of countersink has been reduced. Available in Phillips driving recess only.

Flat Undercut
Standard **82** deg flat head with lower **1/3** of countersink removed for Production of short screws. Permits flush assemblies in thin stock. Available with slotted or Phillips driving recess.



Pan
Low large diameter with high outer edges for maximum driving power. Available with slotted or Phillips recess for machine screws and cap screws. Available plain for driving screws. Pan head screws are recommended for use instead of round head screws. They are satisfactory substitutes.

Figure 21-8. Threaded Fastener Styles Recommended for Military Use

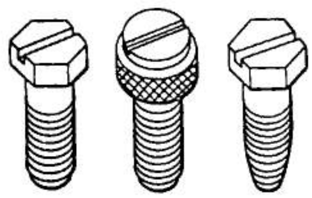


Figure 21-9. Combination-Head Bolts and Screws

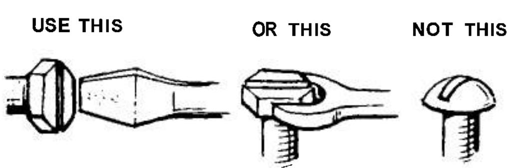


Figure 21-10. Use Slotted Hexagon Heads

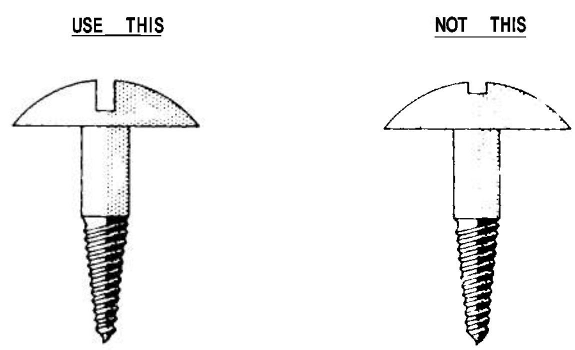


Figure 21-11. Provide Deep Slots in Screw Heads

quired for a given purpose (see Figure **21-12).**

(2) Bolt threads should be no finer than strength requirements dictate.

(3) The number of turns to tighten a bolt should be less than **10.**

(4) When tightened, the bolt should extend a minimum of **2** threads beyond the nut.

(5) Hexagonal head bolts should be used generally and especially for high torque usages.

(6) Left-hand threads should be used only when stress conditions require it ;both bolts and nuts should be clearly identifiable by suitable marking, shape, and color.

(7) Self-locking bolts (in tapped holes) should be used only when one surface must be smooth or is inaccessible and temperatures will be below **250°F.**

(8) Make mounting bolts semipermanently captive. Snap-on collars are good for this purpose, since they permit easy replacement of damaged bolts.

(9) When design trade offs make it desirable, use bolt fasteners which are not part of fixed equipment (see Figure **21-13).** This will provide optimum replaceability for bolts which may be stripped during assembly or disassembly.

(10) Tapped machine threads must have sufficient tensile strength to withstand maximum bolt or screw torque plus a safety margin to allow for wear.

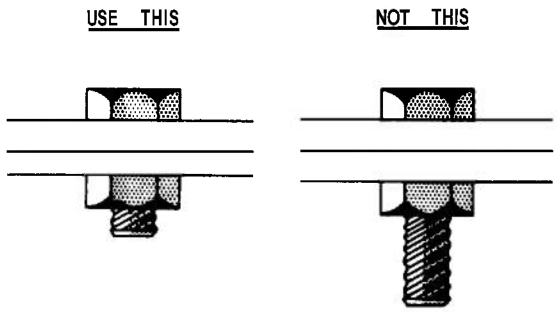


Figure 21- 12. Select Appropriate Bolt Length

21-3.6 NUTS

Nuts can be divided into two general classifications :plain (or nonlocking) and locking, with possibly a subclassification of fixed or nonfixed in each classification.

Self-locking nuts are intended to replace cotter pins, wiring, lock washers, etc., as a means of keeping a nut tight on its bolt. They contain some means of gripping the threaded member so that relative rotation is impeded or prevented. This feature poses some problems if the nut is to be removed frequently during maintenance. Many specifications state that the self-locking nuts should be capable of removal from and replacement on the same threaded member at least fifteen times, but most are removed and replaced far more often.

Fixed nuts are rigidly prefixed to the chassis by welding, riveting, clinching, or staking and are used where the metal is too thin or too soft to tap or where space is limited so that the nut would be inaccessible. They offer advantages in assembly and repair because the bolt can be installed without handling the nut. Trends toward modularization or unitization might increase the use of fixed nuts and reduce the variety of wrenches needed.

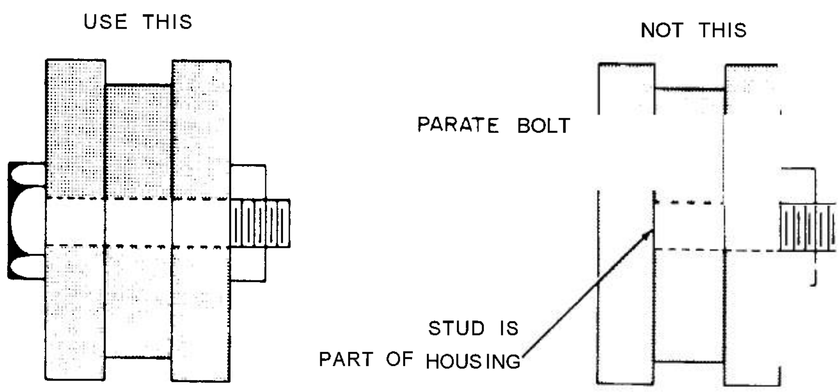


figure 27-13. Use Bolts Which Are* Not *an Integral Part of fixed Equipment

The following recommendations for the use of nuts should be considered:

(1) Self-locking nuts should conform to MIL-N-25027.

(2) Regular hexagonal nuts in a few easily distinguishable sizes are preferred.

(3) Different sizes of nuts should be used for different thread requirements.

(4) Wing or knurled nuts, which require no tools, should be used for low-tension applications. Wing nuts are the easier to use.

(5) Self-sealing nuts should be used for fastening equipment to fluid tanks to prevent leaking around fastener (see Figure 21-14).

(6) Lock nuts may be used for mounting light components, but they must withstand heat requirements and cannot be used where fallen nuts could damage equipment (see Figure 21-15).

(7) Clinch nuts should be incapable of rotating or moving with respect to the surface on which they are mounted (see Figure 21-16).

(8) Floating nuts should have an allowable shift of only plus or minus 0.062 in.

(9) Self-locking nuts of the thread-interference type should be used to resist vibration or other forces that tend to separate the joint. Locking is accomplished in any one of several ways (see Figure 21-17).

(10) When space is very limited, provide nut designs that require less wrenching space. Provide nut recesses which lock the nut and permit tightening of only the bolt (see Figure 21-18).

(11) A self-wrenching nut may be used in areas where there is insufficient wrench clear-

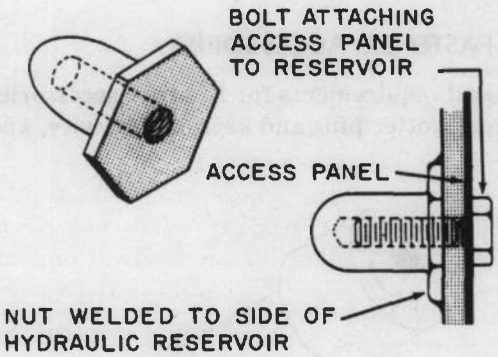


Figure 21-14. Self-Sealing Nut

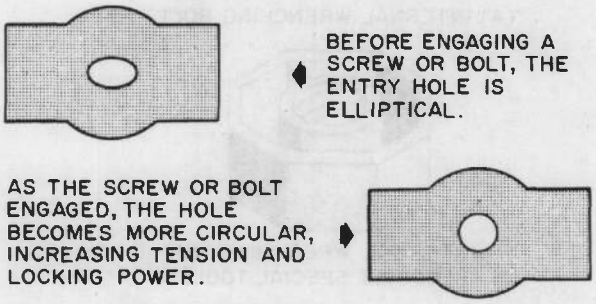


Figure 21-15. Lock Nut

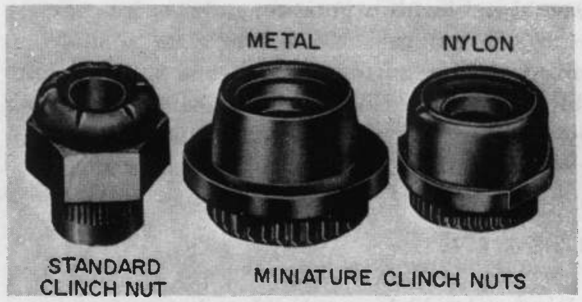


Figure 21-16. Clinch Nuts
(Courtesy of Elastic Stop Nut Corp.)

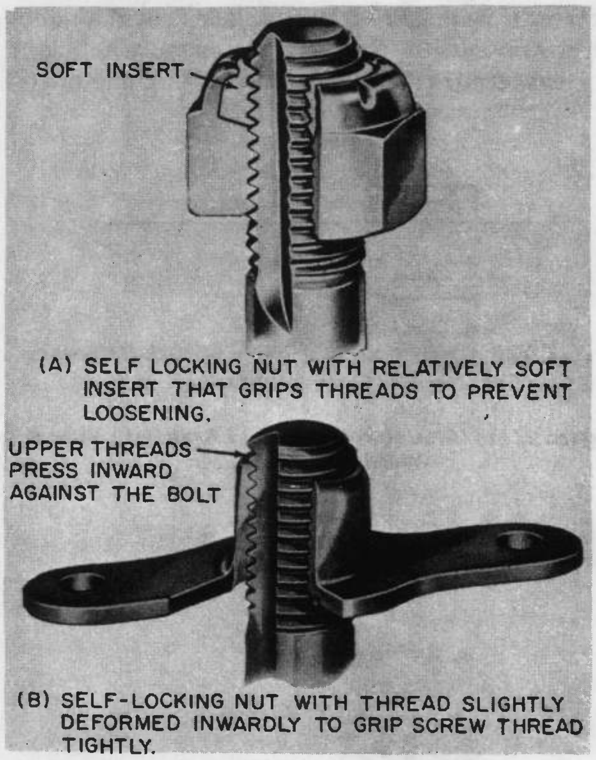


Figure 21-17. Self-Locking Nuts
(Courtesy of Elastic Stop Nut Corp.)

ance, where high torque is not required, where the additional metal will not impose a weight penalty, and where recess locking holes for conventional nuts are undesirable (see Figure 21-19).

21-3.7 INTERNAL WRENCHING SCREWS, NUTS, AND BOLTS

Internal wrenching fasteners (Figure 21-20) allow higher torque, better tool grip, and less wrenching space. However, they are easily damaged, difficult to remove, and require special tools. The number of different sizes should be minimized to require as few special tools as possible. Slots should be deep to minimize damage to the fasteners. Otherwise, the requirements are similar to those for bolts and screws.

21-3.8 RIVETS

Rivets should be used only when a fastener will not require removal or replacement. Although rivets are the most permanent type of fastener, they are not reusable and require greater time and effort for replacement than do screws or bolts. Wire stapling or metal stitching is generally preferable to rivets for maintenance purposes. General requirements **for** rivets are:

(1) Rivets should not be used on latches, hinges, or retainers.

(2) The diameter of the heads of countersunk rivets should be larger than the thinnest of the pieces they fasten to prevent them from ripping through.

(3) When shear rivets are to be used, ensure that the holes are drilled to close tolerances since shear rivets do not expand to fill the holes. Maintenance instructions should specify for allowable tolerances, the proper size reamer to be used for a certain size hole, and the size plug gage that must be used to check the hole size.

(4) For minor maintenance of light components, use rivets which expand by chemical charge rather than those that require peening (see Figure 21-21). Such a rivet contains a chemical charge in its body which expands the rivet upon application of heat. These rivets are especially useful in blind applications.

(5) For noncritical applications, use rivets made of slightly softer metal than the surrounding equipment. This will minimize damage to thin panels or other equipment.

21-4 FASTENER ACCESSORIES

General requirements for fastener accessories (washers, cotter pins and keys, safety wire, and

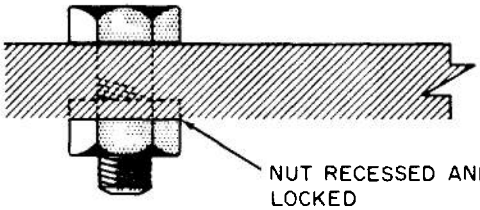


Figure 21-18. Use Nut Recesses in Areas of Limited Wrenching Space

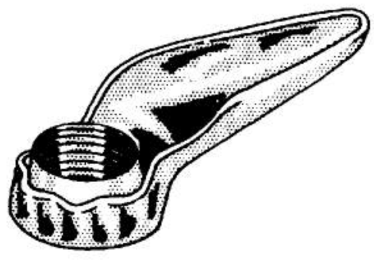


Figure 21-19. Self-wrenching Nut

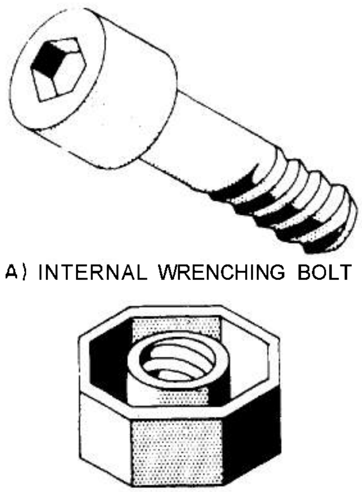


Figure 21-20. Internal Wrenchinn Fasteners

retainer rings and chains) are given below.

(1) Washers should fit tightly against the underside of the fastener head.

(2) Washers should fit the shaft snugly, but should be easy to remove.

(3) Split-ring lock washers should be used with static loads in excess of 2 oz.

(4) Lock washers should be used with lock nuts for maximum locking action.

(5) Metallic inserts and blocks should be so secured that tightening of the screw or bolt will not loosen or move the insert or block.

(6) Gang-channeling of nuts can save time in handling many nuts when they are in a straight line (see Figure 21-22). Only channels should be used in which nuts can be replaced individually.

(7) Nut-plates are heavy and expensive to replace when a hole is stripped ; but they may be used when several bolts are to be fastened on one surface and alignment is no problem.

(8) Cotter pins and keys should fit snugly, but should not require driving in or out. Heads of cotter keys should be large enough to facilitate removal and prevent the keys from slipping through (see Figure 21-23).

(9) Safety wire should be used only where self-locking fasteners or cotter pins are not adequate to withstand the expected vibration or stress.

(10) Safety wire should be attached so it can be easily removed and replaced.

(11) Retaining rings may be used to replace nuts when vibration is not a serious factor. A retainer ring is a satisfactory fastener and is more easily removed and replaced than a nut. Use properly designed bolts when retainers are to be used as the sole means of attachment (see Figure 21-24).

(12) Use retainer rings which may be removed easily. Those which hold with a positive snap action are most desirable.

(13) Use retainer rings or washers to attach bolts or screws semi-permanently to a component which may be frequently removed. This will minimize misplacing bolts.

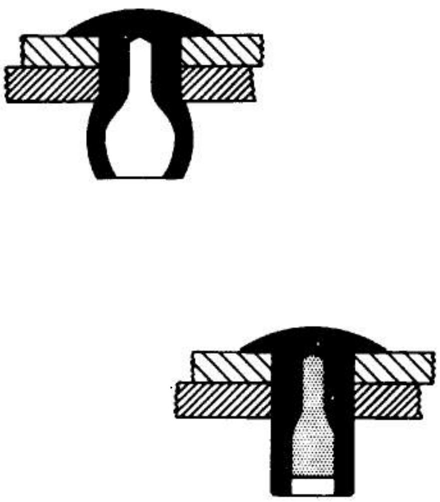


Figure 21-21. Chemical Charge Rivet

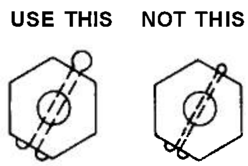


Figure 21-23. Provide Large Heads on Cotter Keys

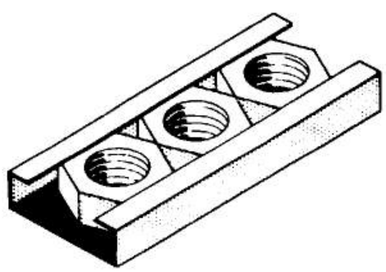


Figure 21-22. Gang-Channeled Nuts

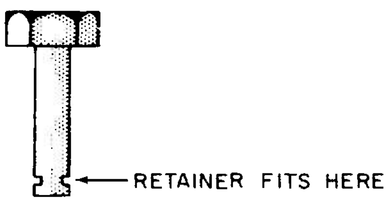


Figure 21-24. Specially Designed Bolts Used With Retainer Rings

(14) Retainer chains and locking bars should be used to:

(a) Keep hatches or doors from opening too far and springing their hinges.

(b) Turn doors or covers into useful shelves for the technician.

(c) Prevent small covers, plates, or caps from being misplaced.

(d) Secure small, special tools to the location in which they will be used.

(e) Secure objects which might otherwise fall and cause personnel injury.

General requirements for retainer chains are:

(1) Link (Figure **21-25**), sash, or woven mesh-type chains are recommended to prevent loss of small removable parts, such as pins, caps, and covers, from the main body of the equipment. Because some retainers tend to break apart, especially when kinked, care should be exercised in the selection of suitable retainers to ensure that they meet performance requirements.

(2) Chains should be attached with screws or bolts. Attachment should be strong and positive, but easily disconnected when required.

(3) Eyelets should be provided at both ends of the chain for the attaching fasteners.

(4) Chains should be no longer than necessary to fulfill their function.

(5) Chains to filler caps should be attached externally rather than internally to facilitate replacement and prevent broken parts from damaging equipment.

Figure 21-25. Use of Chain Prevents Loss of Small Removable Parts

(6) Chains should *not* be used wherever they might interfere with moving parts.

(7) Chain covers, where required to prevent chains from becoming tangled, should be flexible, durable, and easy to bend.

21-5 FASTENER CHECKLIST

Table **21-1** summarizes some of the design requirements to be considered in the use of fasteners. In using the checklist, if the answer to any question is *no*, the design should be restudied to ascertain the need for correction.

TABLE 21-1. FASTENER CHECKLIST

1. Are fasteners for assemblies and subassemblies designed to operate with maximum of one complete turn?
2. If bolts are used, do they require a minimal number of turns (less than 10)?
3. When tool operated fasteners are required, are only those operable with standard tools used?
4. Are combination-head mounting bolts with deep internal slots and hexagonal heads used?
5. When high torque is required, are external hex head bolts used?
6. Are mounting bolts designed to be semipermanently captive (with snap-on collars)?
7. Are mounting bolts or fasteners identified accordingly to disassembly instructions?
8. Is no more than one thread size per bolt size used in a given equipment?
9. Are heads of mounting bolts unobstructed by nearby components or structural members?
10. Are assemblies and units designed to be replaceable by standard tools?
11. Are guide pins on units and assemblies provided for alignment during mounting?
12. Are U-lugs rather than 0-lugs used for

TABLE 21-1. FASTENER CHECKLIST (cont)

clamping purposes?

13. Are self-locking safety catches provided on connector plugs rather than safety wire?
14. Are permanently attached tapped or riveted-in nuts used to avoid losing the nut or forcing the technician to hold the nut in place?
15. When tool-driven screws must be used, are types used which can be driven by several tools (screwdriver, wrench, or pliers, where possible, i.e., a hex head with screwdriver slot)?
16. Are access cover fasteners of the captive type?
17. Are fasteners designed so that close torque tolerances are not required?
18. Are different types and sizes of fasteners held to a minimum?
19. Are fasteners of rust resistant material?
20. Are fastener mounting holes large enough to allow "starting"?
21. Are bolts mounted with heads up?
22. Are special fasteners properly marked or coded?
23. Is maximum use made of quick release fasteners?
24. Have clamps, fasteners, etc. been selected to permit fastening with one hand?
25. Is screw head shape compatible with thickness of panel?
26. If self-locking bolts are used, is operating temperature below 250°F?
27. Is length of bolt adequate (minimum of 2 thread widths showing)?
28. Are rivets restricted to those items which are permanently attached? Are rivets softer than surrounding metal?
29. Have small removable parts been secured by chains to prevent loss?

REFERENCES

1. *Machine Design,* Fasteners Reference Issue, March 11, 1965.
2. J. W. Altman, et al., *Guide to Design of Mechanical Equipment for Maintainability,* ASD-TR-61-381, Air Force Systems, Command, Wright-Patterson AFB, Ohio, 1961, (DDC No. AD 269 332).
3. *Maintenance Engineering Handbook of Maintainability Design Factors,* U S Army Missile Command, Redstone Arsenal, Ala., 1963.

CHAPTER 22
BEARINGS AND SEALS

SECTION I
BEARINGS

22-1 GENERAL

Because bearing maintenance and bearing failures account for the largest percentage of maintenance costs for mechanical products, selection by the design engineer of the proper sizes and types of bearings can be considered one of the most important of all design considerations. The total life span of mechanical items is more often limited to the life of its bearings than from any other cause.

The tendency on the part of the design engineer to neglect bearing design has led to unnecessary waste of machinery and increased maintenance costs. There is no cost saving, however, for the design activity or the U. S. Army when an improper bearing has been selected. Furthermore, an incorrectly selected bearing can be a combat hazard of the first magnitude (Ref. 1).

22-2 BEARING SIZE SELECTION

To reduce or eliminate the need for redesign, the design engineer should specify the largest bearing size practical, taking into consideration its load carrying capacity versus its:

(1) Highest continuous service speed.

(2) Load to be carried.

(3) Safe lubricant film load carrying capacity.

If a smaller size bearing can be utilized, its size should be increased at least 50% above all manufacturers' ratings, except for speed, which should be for its maximum service speed.

22-3 BEARING TYPE SELECTION

In selecting the proper type bearing, the design engineer should consider, at the minimum, the bearing that:

(1) Requires the minimum life cycle cost.

(2) Requires little or no maintenance (lubricating, adjusting, etc.)

(3) Requires little or no periodic inspection.

(4) Permits the most rapid inspection.

(5) Satisfactorily overcomes manufacturing, operating, or aging misalignment problems.

(6) Performs satisfactorily for the life of the product.

22-4 BEARING MISALIGNMENT

Self-aligning bearings or assemblies should be used in critical bearings where even the slightest misalignment can endanger the bearing. A typical bearing of this type is one whose outer side of the outer race is spherical and fitted into a ring whose inner surface is spherically complementary to the outer side of the outer race. Other configurations, also satisfactory when applicable, are spherical roller bearings, rubber-cushioned pillow blocks, housing supported on swivel blocks, and flexible metal straps. Typical applications of self-aligning bearings are jet engine turbine shafts, helicopter tail rotor drive shafts, and tank and truck axles. The use of these type bearings should also be considered for use on shafts in large cast or weldment items to compensate for machining errors, metal growth, temperature variations, and other factors.

22-5 BEARING DESIGN RECOMMENDATIONS

The paragraphs which follow consider the various types of bearings and present design recommendations for each.

22-5.1 OIL-LESS BEARINGS

Bearings requiring no lubrication or maintenance should be used wherever possible. Such bearings are made of synthetic rubber, nylon, Teflon, and fiber. These type bearings should be given first consideration in such applications as instrument bearings, leaf spring ends, pushrod ends, drive shaft universal joints, and fuel valve bearings.

22-5.2 SEMILUBRICATED BEARINGS

In bearing applications where the materials used for oil-less bearings cannot be utilized, the use of oil impregnated sintered bronze, or similar bearings, may be considered. Such bearing assemblies should include contaminant-excluding seals when they are used in locations where destructive contaminants may be present. For ease of servicing, an easily accessible oil service point, sealed with a plug or oil cup and properly marked, should be provided (See also paragraphs 16-2 and 16-3).

22-5.3 SEALED BEARINGS

In applications requiring a high load carrying capacity with minimum space requirements, bearings containing their own supply of lubricants are highly desirable. The lubricant is retained by seals on one or both sides of the bearings. However, even though these type bearings are "sealed for life" they should be provided with some means of external relubrication. Such relubrication may, when necessary, be difficult, e.g., the "oil hole" may be through a synthetic seal pierced with a hypodermic needle, or an entrance may be drilled in the bearing, leading out through the housing to an easily accessible position. Regardless of the method selected, the loss of lubricant back through the "oil hole," or the entrance of contaminants into the lubricant, must be avoided.

22-5.4 SLEEVE BEARINGS

Probably no one factor of past design has contributed more to premature equipment aging or costly maintenance than the widespread use of solid metal sleeve bearings. These bearings, in general, never provide for wear, but progressively grow worse with use and seldom provide any means of compensating for this wear. The use of solid metal, nonporous sleeve bearings in any application should, therefore, be questioned in every case. In applications where sleeve bearings are used, however, high-pressure lubrication should be supplied to the bearing surface wherever possible.

22-5.5 STRAIGHT ROLLER BEARINGS AND BALL BEARINGS

The use of nonadjustable, nonwear, compensating straight roller and ball bearings should be confined to applications where:

(1) The bearing size, the load carrying capacity, and the operating speed is such to guarantee that the bearing will outlive the service life of the product.

(2) Needle bearings operate against shafts of at least **40** Rockwell C scale hardness.

(3) They operate in an enclosure having a constant supply of lubricant.

(4) They conform to Specifications FF-B-185 and FF-B-171, respectively, and other applicable Federal and Military Specifications.

(5) No other type of bearing will perform the task more suitably.

Roller bearing life is determined by the fatigue life of raceways and rollers if proper attention has been given to the details of lubrication, mounting, and to the exclusion of foreign material. Minimum bearing life is defined as that life which **90%** of the bearings in a given group will equal or exceed.

The nomograph shown in Figure **22-1** provides a rapid means for determining the expected minimum life of **a** proposed roller bearing size when the operating speed and applied radial load are known. To use the chart, perform the following steps:

(1) Select a tentative bearing size and obtain the radial capacity at 1000 rpm from the manufacturer's dimensional tables.

(2) Draw a straight line between the point representing the capacity at 1000 rpm (Point No. 1) and a point representing the imposed radial load (Point No. **2**).

(3) Draw a line between a point representing the operating speed in rpm (Point No. **3**) and the intersection of the first line with the central (unnumbered) line.

(4) Project the second line until it intersects the *Service Factor—Minimum Life* scale (Point No. **4**). From the point of intersection the service factor and minimum life can be determined.

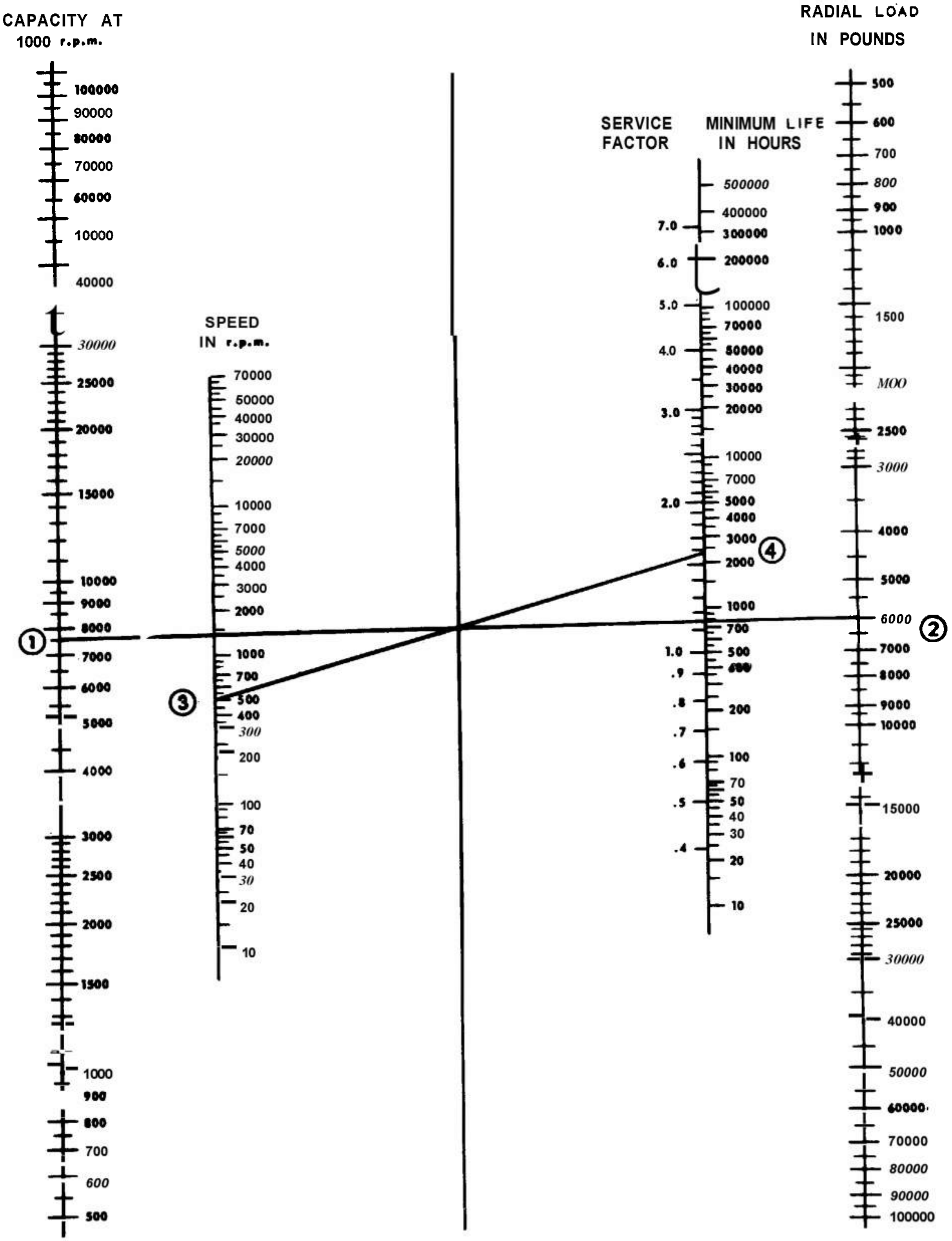


Figure 22-1. Nomograph for Determining Expected Minimum Life of Roller Bearings (Ref. 21

22-5.6 TAPERED ROLLER BEARINGS

Tapered roller bearings, where suitable for design, represent the optimum in bearing maintainability and should, therefore, be given high priority in the selection of bearings. The fact that they are occasionally higher in initial cost should be weighed against the cost of replacement of another type of bearing throughout the life cycle of the product. An arbitrary costing example, presented in Table 22-1, indicates that when the total life cost of another type bearing exceeds that of the adjustable bearing, the adjustable bearing should be used.

Tapered roller bearings may be adjusted by using threaded, lockable components, or by shims. Wherever possible, the threaded adjusting method should be used to eliminate the necessity for stocking shims. Regardless of the method of adjusting, however, bearing housing design should allow the easiest and simplest access to the adjustment.

22-6 BEARING SEALS

Seals used to retain lubricants in bearing housings having protruding, rotating, and sliding shafts and axles should be given specific and special consideration in the design of equipment. Some of these considerations are :

(1) Seals should reflect the highest quality in design and material concurrent with the state of the art for its intended service. A cost analysis similar to that described in Paragraph 22-5.6 should be made prior to bearing seal selection.

(2) Seal housing design should provide the optimum of simplicity for replacement of the seals by inexperienced personnel operating in the field. If possible, no special tools, including wheel pullers, should be required to replace bearing seals.

(3) The use of blind fittings and fasteners should be avoided.

(4) Consideration should be given to the use of multiple lipped seals and double and triple seals, each of which is capable of fulfilling the sealing requirements alone.

(5) When design will permit their use, prime consideration should be given to the use of spring-loaded, positive-contact end seals.

(6) Each design should be examined to ensure that the seal will not be damaged by excessive internal pressure. Where the possibility of excessive pressure exists, due to heat expansion of the lubricant or other causes, a relief valve should be installed on the housing and a return line to a sump should be installed, when appropriate.

TABLE 22-1. BEARING COSTING ANALYSIS

Bearing Factor	Another Type Bearing	Adjustable Bearing
Cost of bearing	$1.00	$5.00
Cost of replacement (man-hours, tools, facilities, overhead, etc.	$20.00	None
Number of replacement bearings required for the life of the product	4	1
Adjustment cost	None	4 times at $2.00 = $8.00
Total manufacturing and maintenance cost for the bearing for the life of product	$84.00	$13.00

22-7 LUBRICANT REQUIREMENTS

Where sealed bearing or semilubricated bearings are used, lubricants selected should have the optimum state-of-the-art characteristics for protection against deterioration with age. This requirement is particularly important to items liable to long inactive storage where deterioration could cause destruction of lubricating properties. Whenever possible, lubricants should also be capable of satisfactory service at ambient temperatures ranging between −67°F and 250°F (see also Chapter 16). To help determine the approximate oil viscosity for all bearing applications refer to the selection chart illustrated in Figure 22-2.

22-8 DERATING

All bearings should be derated to ensure that their capabilities have dynamic factors of safety. This factor of safety is necessary to prevent overload conditions not readily apparent in new applications or due to unexpected service conditions. Derating also provides longer bearing life, with less required maintenance and increased maintainability. As a general rule, bearings should be derated to the maximum extent permitted by cost, performance, weight, or space provisions. Reliability organizations should establish the methods and specifications for derating bearings, based on QMR requirements, specifications, etc.

SECTION II
SEALS

22-9 GENERAL

Prevention of leaks is one of the major problems facing engineers, regardless of field. Proper seal design is critical for all systems and devices, whether sealing a piece of electronic equipment against dust and moisture, preventing leakage in a high pressure hydraulic system, or sealing a missile against the rigors of outer space. This section discusses two types of seals: gaskets and O-rings.

22-10 GASKETS

A gasket creates and maintains a tight seal between separable members of a mechanical assembly in which there is no relative motion between the joined parts. When properly designed and installed, a gasket seal is economical and efficient. It is superior to other forms of sealing, such as machining and grinding the facing surfaces for a perfect mating, because the gasket itself is usually inexpensive, easily replaced, and capable of withstanding complex and variable pressures. The gasket with these characteristics is an ideal seal that also prolongs the life of the parent assembly. Such an ideal seal can be obtained only by selecting the proper material and forms to satisfy the following basic gasket design requirements :

(1) Must be permeable.

(2) Must make complete contact with the joint contact surface.

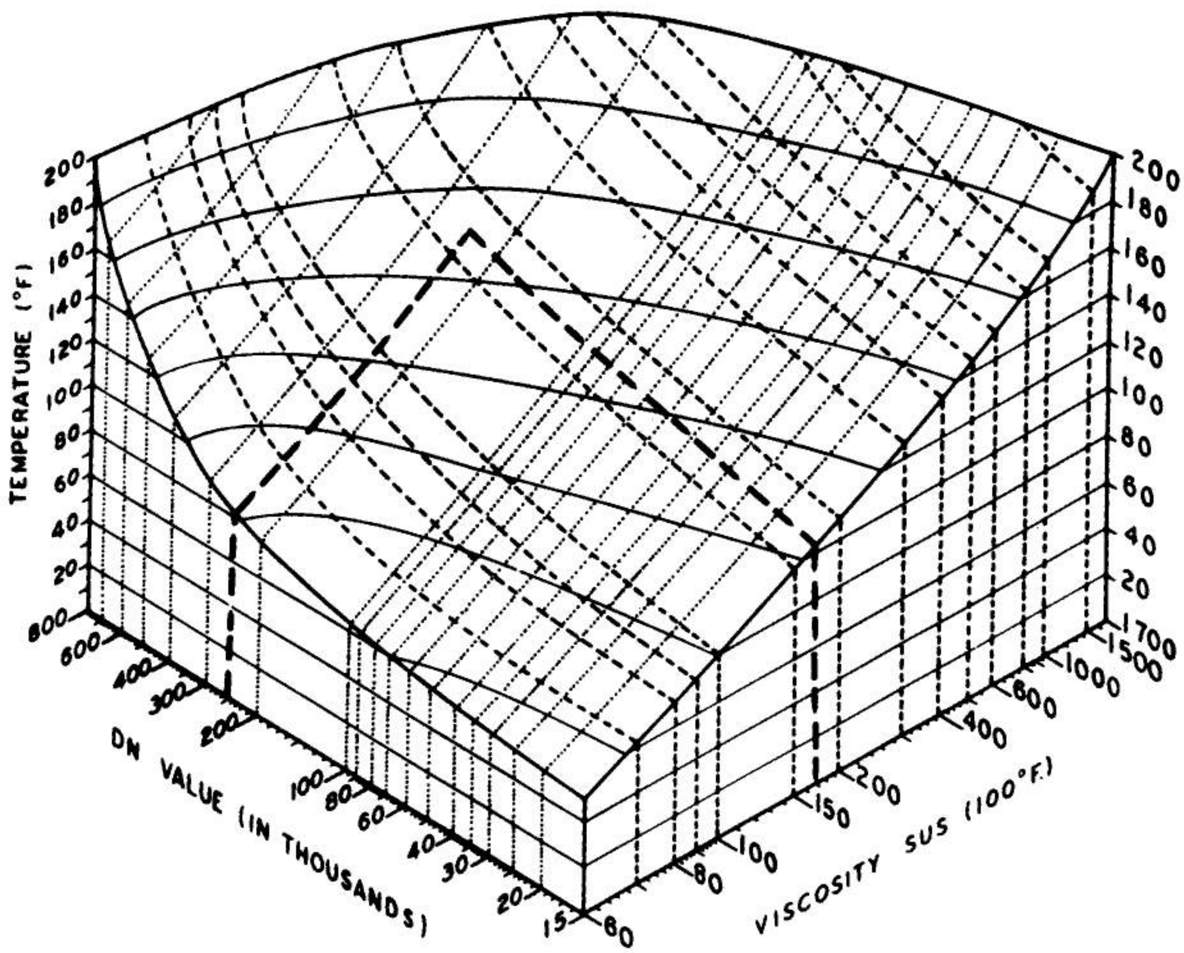
(3) Must maintain this complete contact despite various pressures.

(4) Must be compatible with factors in its immediate environment.

Effectiveseals at lowest cost are best obtained when the flanged joint and the gasket material are considered as a unit in the design stage. These two factors — flange design and gasket material — are interdependent. The best gasket will not seal a poorly designed joint; and a well designed joint usually cannot be sealed with a deficient or improperly selected gasket material.

22-10.1 CLASSIFICATION OF GASKETS

Gaskets are classified according to their function and the type of material used in their manufacture. They may be metallic or nonmetallic and used for specific or general applications. The nonmetallic gaskets are used in a wide variety of applications and are the gaskets



Procedure:

1. Determine the DN value—Multiply the bore diameter of the bearing (in mm) by the speed of the shaft (in rpm).
2. Select the proper temperature—The operating temperature of the bearing may run several degrees higher than the ambient temperature depending upon the application. The temperature scale shown reflects the operating temperature of the bearing.
3. Enter the DN value on the DN scale (250,000 on chart).
4. Follow or parallel the "dotted" line to the point where it intersects the selected "solid" temperature line (150°F on chart).
5. At this point follow or parallel the nearest "dashed" line downward and to the right to the viscosity scale.
6. Read off the approximate viscosity value—expressed in Saybolt Universal Seconds (SUS) at 100°F.

Figure 22-2. Oil Viscosity Selection Chart (Ref. 31 most frequently required by the Army design engineer. Metallic gaskets are usually required in specific high-pressure, high-temperature applications that demand complex technical considerations. Only nonmetallic gaskets are discussed in this chapter.

22-10.2 GASKET MATERIALS

The nonmetallic, general purpose gaskets are composed of asbestos, cork, leather, paper, rubber and several composites and combinations. Molded rubber and plastic parts may function as gaskets while actually satisfying other design requirements. O-rings are a form of packing that may also function as ordinary flat gaskets in many applications.

Government Specifications pertaining to typical gasket materials are given in Table 22-2. The relative resistance of resilient gaskets to common fluids are listed in Table 22-3.

22-10.3 GENERAL DESIGN RECOMMENDATIONS

The following recommendations should be considered in the design and use of gaskets:

(1) Handle gaskets carefully so that they can be applied without cracks, creases, or other damage. Some critical installations require the use of mechanical aids such as torque wrenches. In general, proper installation involves tightening of bolts or fasteners correctly and in the prescribed sequence. A pattern of installation should be developed that will distribute the increasing load on the gasket uniformly. It may be necessary to hand-tighten all screws or nuts and then to proceed with wrenches or other drivers.

(2) For rapid handling, stiff gaskets are preferred to very flexible types that may be easily deformed by any handling. For use in service or maintenance application this feature is not vital, but where a great number of gaskets are to be assembled in units in a moving line, these characteristics merit consideration.

(3) Gaskets which are almost symmetrical in shape should be provided with an index notch or other feature to indicate their proper position. Very large gaskets may be easier to handle if they are brought to the assembly point with interlocking ends rather than in one solid piece. Also, if the bolt holes are made elongated instead of perfectly round, such gaskets can be put into position more rapidly.

(4) Where a precise degree of fit is critical, it may be necessary for the design engineer to provide the user of the gasket with detailed information on the part or parts to which the gaskets are fitted. Because of differences in measuring equipment and techniques, a blueprint alone may not be sufficient to guarantee the desired pattern of fit.

(5) To prevent slipping during installation, the gasket, if possible, should be made of a material that will not slip on oily surfaces and lubricants, and wet adhesives should not be used on any flanges where slipping can occur.

(6) Avoid specifying unnecessary preshaping as a result of transference of fillets, radii, etc., from mating parts to the gasket. Unless the part is molded, such features mean needless extra operations and higher costs. Actually, most gasket stocks will conform to mating parts without preshaping. Any radii, chamfers, etc., designed into the gasket should be functional, not merely copied from metal members.

(7) Avoid the several common gasket design defects and consider their remedies as illustrated in Figure 22-3.

(8) Use the simple flange joint shown in Figure 22-4 (A) for all kinds of flat gaskets and for internal pressures up to 200 psi.

(9) For higher pressures, use the reduced gasket wall section shown in Figure 22-4 (B), which creates higher gasket stress without increasing bolt loads.

(10) For applying extremely high flange pressures and retaining high internal pressures, the tongue and groove variation shown in Figure 22-4 (C) can be utilized.

(11) Where accurate internal clearances or alignments are essential, and where it is necessary to limit the amount of stress on the gasket material, metal-to-metal joints, as shown in Figures 22-4 (D), (E), and (F) can be used. Compressible materials such as cork composition and cork-and-rubber are most suitable in these joints. If rubber gaskets are used, relief must be provided for sideflow or the gasket must be cut so that its volume does not exceed that of the cavity. Also, the initial shape of a rubber gasket must permit 20% deflection when the joint is closed.

TABLE 22-2. GOVERNMENT SPECIFICATIONS FOR GASKET MATERIALS

Item	Government Specification
Packing, Asbestos, Sheet, Compressed	MIL-A-17472
Asbestos Sheet, Compressed, for Fuel, Lubricant, Coolant, Water, and High Temperature Resistant Gaskets	MIL-A-7021
Cork Sheet (Gaskets, Sheets, and Strips)	HH-C-576
Cellular Elastomeric Materials, Fabricated Parts	MIL-C-3133
Chock Padding, Rubber and Cork Composition, Pressure Sensitive	MIL-C-17539
Gaskets. Synthetic Rubber (For Fuel and Lubricant Containers and Accessories)	MIL-G-432
Gaskets and Sheet Gasket Material, Synthetic	MIL-G-6183
Gasket Materials, Nonmetallic	MIL-G-12803
Paper, Gasket, Fiber (Animal or Plant), Sheet	HH-P-0096
Packings and Gaskets, Preformed, Petroleum Hydraulic Fluid Resistant	MIL-P-5516
Rubber Sheets, and Cut, Molded and Extruded Special Shaped Sections - Synthetic, Medium Soft, Low Temperature, Gasket Application	MIL-R-900
Rubber Sheets, Strips, and Gaskets, Solid, Synthetic, Medium and Medium Hard	MIL-R-1149
Rubber, Fabricated Parts	MIL-R-3065
Rubber, Cellular, Chemically Blown	MIL-R-6130
Rubber, Synthetic, Sheet, Molded and Extruded, for Aircraft Applications	MIL-R-6855
Rubber Sheets, and Cut, Molded and Extruded Special Shaped Sections - Synthetic, Medium Soft, Shipboard Gasket Use	MIL-R-15624
Stoppers, Bottle, Cork	MIL-S-731
Tape, Ahdesive, Rubber and Cork Composition	MIL-T-6841
Test Methods, Rubber	Federal Test Method Standard No. 601

TABLE 22-3. RELATIVE RESISTANCE OF RESILIENT GASKETS TO COMMON FLUIDS (Ref. 4)

Liquid or Gas to be Sealed	Cork Compositions	Uniphase Cork*	Cork and Rubber Compositions				Synthetic Rubber Compounds**		Accopac* Fiber Sheet Materials		
	All Types		Chloroprene (CR)	Nitrile (NBR)	Styrene (SBR)	Butyl (IIR)	Chloroprene (CR)	Nitrile (NBR)	Nitrile (NBR)	Styrene (SBR)	Chloroprene (CR)
Acetone	S	F	S	U	S	S	S	U	U	F	S
Acetylene	U	F	S	S	F	S	S	S	S	U	S
Acids (inorganic)	U	U	U	U	U	U	S	F	U	U	U
Air	S	S	S	S	S	S	S	S	S	S	S
Alcohol-Amyl, Butyl, Ethyl, or Methyl	F	F	S	S	S	S	S	S	F	S	S
Alkalis	U	U	U	U	U	U	S	S	U	U	U
Ammonia	U	U	U	U	U	U	S	S	S	S	S
Animal fats and oils	S	S	F	S	S	F	S	F	S	F	S
Benzene (benzol)	S	F	U	F	U	U	U	F	F	U	F
Bunker oil	S	S	F	S	F	U	F	S	S	U	S
Butane	S	F	F	S	F	U	F	S	S	U	F
Butyl acetate	S	F	F	U	U	S	F	U	F	S	F
Carbolic acid (phenol)	F	F	U	U	U	U	F	U	U	U	U
Carbon dioxide	S	S	S	S	S	S	S	S	S	S	S
Carbon tetrachloride	S	F	U	S	U	U	U	S	F	U	F
Chlorinated solvents	S	F	U	U	U	U	U	U	F	U	F
Chlorine	U	U	U	U	U	U	BA	U	U	U	U
Cresol	S	F	U	U	U	U	U	F	U	U	U
Dibutyl phthalate	S	S	U	U	F	S	U	U	F	S	F
Ether	S	F	U	F	U	U	U	F	S	U	F
Ethyl acetate	S	F	F	U	U	S	F	U	F	S	F
Ethylene glycol	S	S	S	S	S	S	S	S	S	S	S
Formaldehyde	S	S	S	S	S	S	S	S	S	S	S
Fuel oil	S	S	F	S	F	U	S	S	S	F	S
Gas, illuminating	S	S	S	S	F	U	S	S	S	U	S
Gasoline	S	S	F	S	U	U	F	S	S	U	F
Glycerine	S	S	S	S	S	S	S	S	S	S	S
Greases	S	S	S	S	F	F	S	S	S	S	S
Hydrochloric acid	U	U	U	U	U	U	F	F	U	U	U
Hydrogen	S	S	S	S	S	S	S	S	S	S	S
Hydrogen peroxide	U	U	U	U	U	U	S	S	U	U	U
Hydrogen sulphide	S	S	F	F	F	S	S	S	S	S	S
Inks	S	S	S	S	S	S	S	S	S	S	S
Kerosene	S	S	F	S	U	U	F	S	S	F	S
Lacquers and thinners	S	F	F-U	F-U	F-U	F-U	F-U	F-U	S	U	F
Lubricating oil	S	S	S	S	U	U	S	S	S	F	S
Naphtha	S	S	U	F	U	U	U	F	S	U	F

TABLE 22-3. RELATIVE RESISTANCE OF RESILIENT GASKETS TO COMMON FLUIDS (Ref. 4) (cont)

Liquid or Gas to be Sealed	Cork Compo-sitions		Cork and Rubber Compositions				Synthetic Rubber Compounds**		Accopac* Fiber Sheet Materials		
	All Types	Uniphase Cork*	Chloro-prene (CR)	Nitrile (NBR)	Styrene (SBR)	Butyl (IIR)	Chloro-prene (CR)	Nitrile (NBR)	Nitrile (NBR)	Styrene (SBR)	Chloro-prene (CR)
Nitric acid (dilute)	U	U	U	U	U	U	BA	BA	U	U	U
Nitro benzene	U	U	U	U	U	U	U	U	U	U	U
Oxygen	S	S	S	S	S	S	S	S	S	S	S
Ozone	S	S	S	U	U	S	F-S	U	S	S	S
Paints and varnishes	S	S	F	S	U	U	F	S	S	F	S
Propane	S	S	S	S	F	F	S	S	S	U	S
Propylene glycol	S	S	S	S	S	S	S	S	S	S	S
Soap	F	F	F	F	F	F	S	S	S	S	S
Sodium silicate	F	F	F	F	F	F	S	S	S	S	S
Steam	U	U	U	U	U	U	F	F	S	S	S
Sulphur Dioxide	F	F	U	U	U	U	F	F	U	U	U
Sulphuric acid (dilute)	U	U	U	U	U	U	BA	BA	U	U	U
Tar	F	S	F	F	U	U	S	S	S	S	S
Toluol	S	F	U	F	U	U	U	F	F	U	F
Trichloroethylene	S	F	U	U	U	U	U	U	F	U	U
Turpentine	S	F	U	S	U	U	U	F	S	U	F
Vegetable oils	S	S	F	S	F	F	F	S	S	S	S
Water	F	F	F	F	F	F	S	S	S	S	S
Water, sea	F	F	F	F	F	F	S	S	S	S	S
Xylol	S	F	U	F	U	U	U	F	S	U	F

Key:
- S - Satisfactory
- F - Fair
- BA - Best material available, though not completely satisfactory
- U - Unsatisfactory
- CR - Asbestos, blend of chloroprene rubber
- NBR - Asbestos, nitrile-butadiene rubber
- SBR - Asbestos, styrene-butadiene rubber
- IIR - Butyl rubber
- * - Armstrong Cork Co. trade name
- ** - Conforms to MIL-C-6183

(12) Use simple, round, square, or flat cross section gaskets whenever possible to eliminate using relatively expensive molded shapes. Figure 22-4(G) illustrates a square section rubber ring deformed in assembling a stamped container and cover. In Figure 22-4(H), a flat rubber gasket is deformed to dish shape and held in place by steps or serrations in the sloping seat. This is a joint between a ceramic insulator and transformer cover.

(13) Design for lowest cost whenever possible. For example, Figures 22-4(I), (J), and (K) illustrate the adaptation from a particular gasket-flange combination to a much less expensive type. In Figure 22-4(I), a cork composition gasket was used which sealed effectively but required broad flanges. To reduce flange size without impairing sealing effectiveness, a cork-and-rubber gasket was used as shown in Figure 22-4(J). Although made from a more expensive

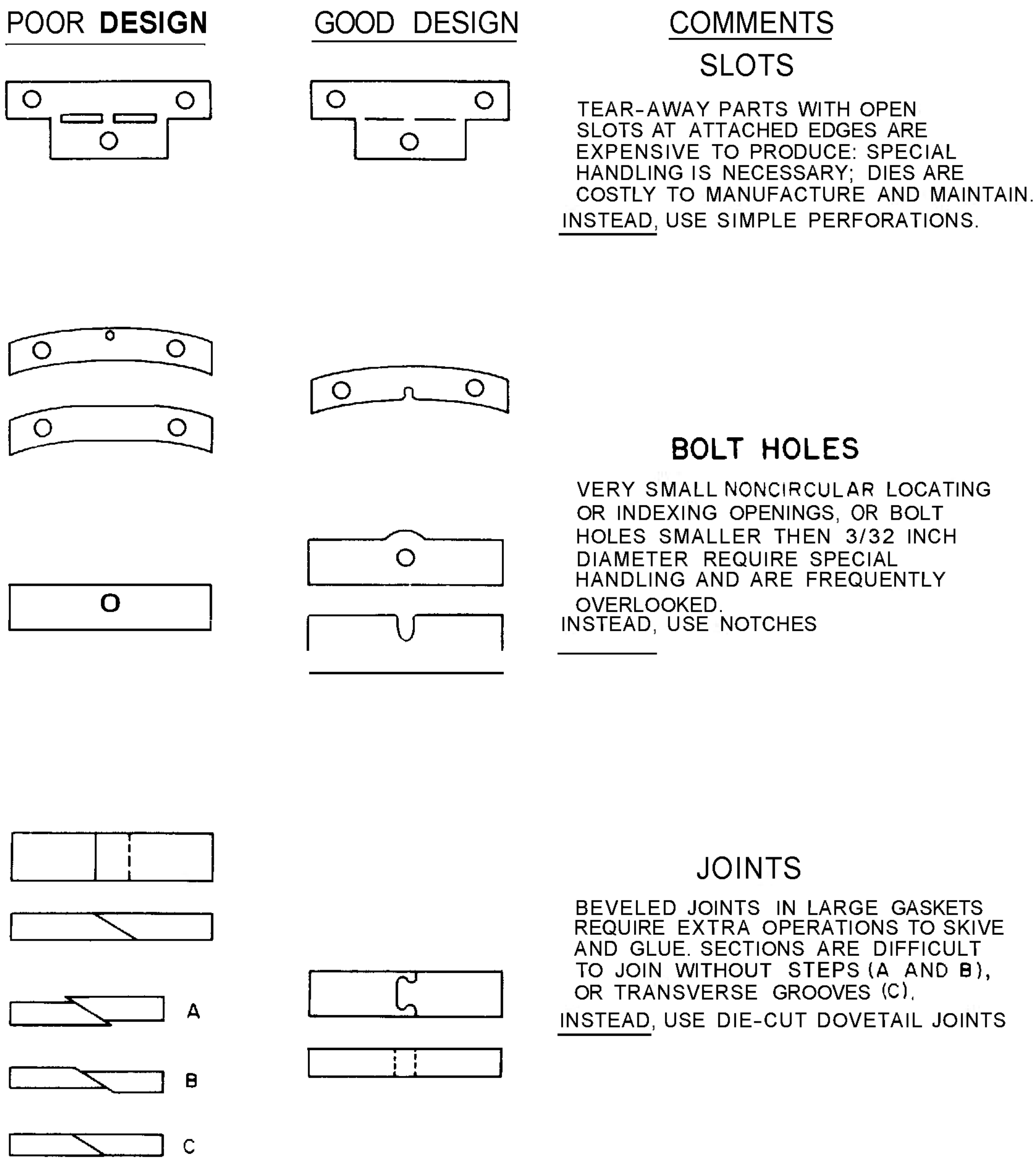


Figure 22-3. Improving Gasket Design (Ref. 5)

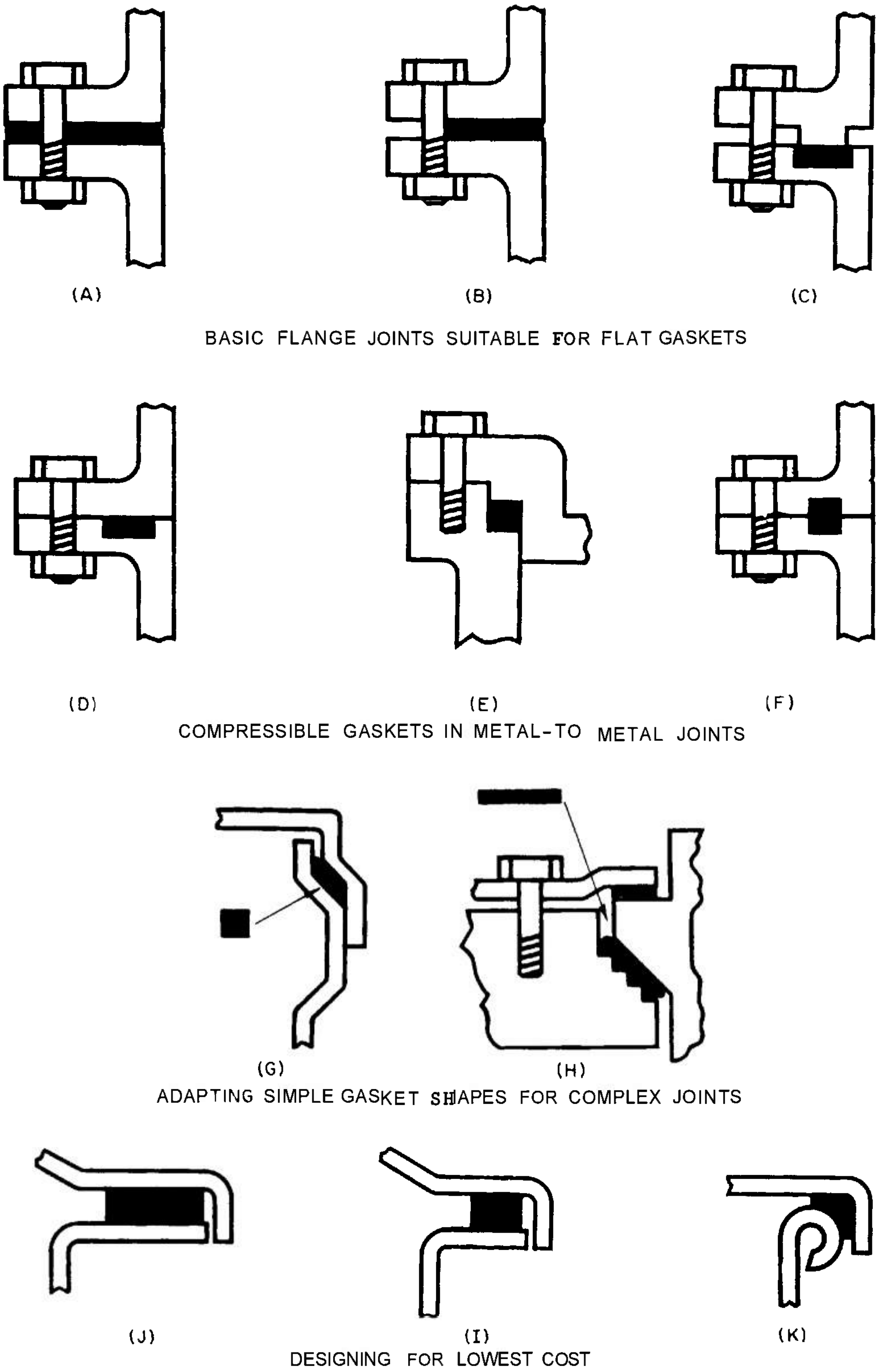


Figure 22-4. Joint and Gasket Design Recommendations (Ref. 6)

material, the new gasket was smaller and total cost was about the same. Later, metal parts again were redesigned and reduced in size as shown in Figure 22-4(K). The gasket adopted this time was a simple square section cork-and-rubber ring. It was lathe cut from a mandrel cured tube and thus was lower in cost than any previous gasket.

(14) Consider the flange surface finish with respect to the sealing characteristic of the gasket to be used. If a soft, resilient material will be satisfactory, it may be economical to leave the flange relatively rough; the gasket will fill any normal irregularities. On the other hand, if close alignment is necessary, a relatively smooth flange and a thin gasket are usually required.

(15) As a general rule, use the thinnest gasket that will seal a joint. In determining this minimum, it should be noted that the total distance a gasket can be compressed must be greater than the cumulative deviations from perfect parallelism of the two flange surfaces. For example, a 0.031-in. cork composition gasket can be compressed about 50% or 0.016-in. in a normal situation. But if the cumulative inaccuracies of the flanges are more than 0.016-in., a thicker material must be used. (It is sometimes possible to change to a more compressible material. In the above example, for instance, a material that would compress more than 50% or 0.016-in.) Since considerable leeway generally exists in the choice of gasket thickness, for economy, a standard or commercial thickness should be specified whenever possible.

(16) Consider the following recommendations to reduce tension losses in flat faced gasketed joints (Ref. 7):

(a) Increase the bolt elongation by longer bolts and/or higher bolt loads. Whatever the bolt load, it should not exceed the elastic limits of the bolt itself.

(b) Increase the initial compressive stresses on the gasket.

(c) Give preference to gaskets with good resistance to extrusion. According to their resistance to extrusion, gaskets can be rated in the following order, the best being: (1) rubber-asbestos, (2) rubber-cellulose, (3) cork composition, (4) cork and rubber, (5) rubber.

(d) Give preference to gasket materials with good torque retaining qualities. Materials can be listed in an order depending on their capacity for holding torque: (1) rubber-asbestos, (2) rubber-cellulose, (3) cork composition, (4) cork and rubber, and (5) rubber.

(e) Design the cantilever projection on a joint design.

(f) Retighten the initial torque setting after the initial tension loss has taken place.

(g) Reduce the thickness of the gasket.

22-11 O-RINGS

The O-ring is a homogenous torus-shaped ring made of natural or synthetic rubber compound and is used as a pneumatic or hydraulic seal. By its inherent characteristic of elastic deformation under pressure, the O-ring seals off the space between two opposing surfaces inhibiting passages of the fluid. The fluid may be liquid or gaseous.

In the majority of applications, the O-ring seal consists of a single O-ring assembled in a proper gland whose dimensions are compatible with those of the O-ring. A proper gland encloses the O-ring and applies on it a predetermined cross sectional squeeze along with allowing sufficient space to permit sliding, rolling, kneading action to take place during operation (see Figure 22-5).

The initial squeeze applied to the O-ring provides a positive sealing action under low operating pressures or vacuum. Perfect sealing action continues as operating pressures become higher.

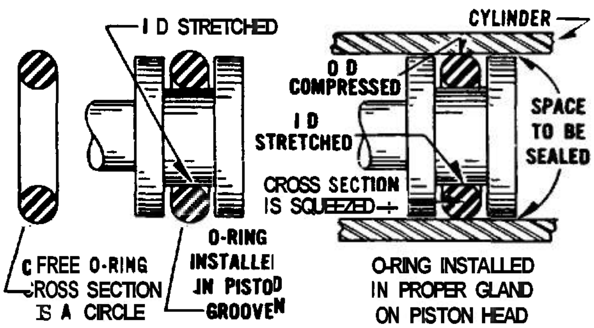


figure 22-5. Typical 0-Ring Installation (Ref.8)

Pressures above **1500** psi generally require the use of antiextrusion rings to prevent O-ring failure by extrusion into the clearance space (see Figure **22-6).**

22-11.1 CLASSIFICATION OF O-RINGS

O-rings are frequently classified, according to the manner in which they are used, as either dynamic or static seals. In dynamic applications, O-rings are described as **a** "packing" and are used to prevent leakage of fluid between two surfaces that have relative motion. The most widespread use is for reciprocating motion. O-rings are also used for oscillating movement, as in valve stems, and to a limited extent, on slow speed rotary applications. Example **of** the use of O-rings as dynamic seals are given in Table **22-4.**

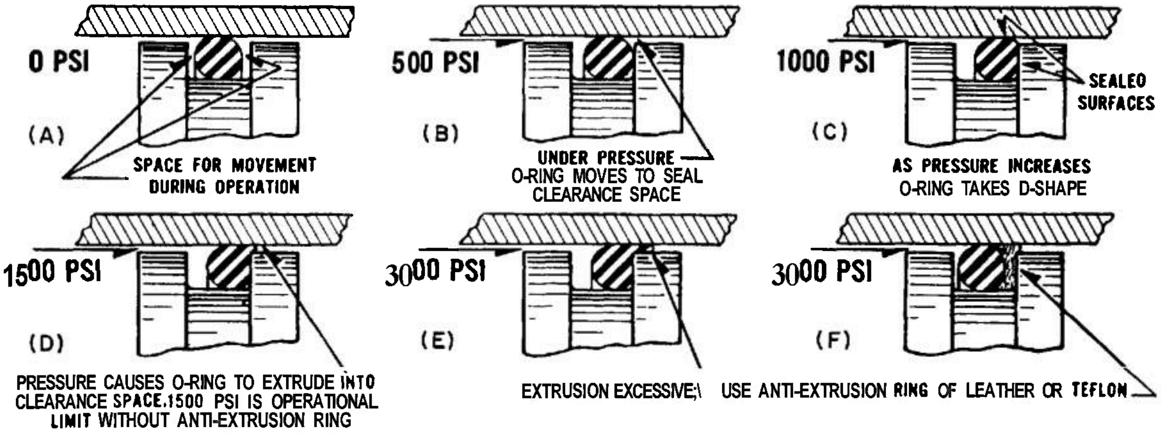


Figure 22-6. Use of Antiextrusion Rings to Prevent O-Ring Failure

TABLE 22-4. EXAMPLES OF O-RING DYNAMIC SEALS

Application	Characteristics of Movement				
	Type	Fast	Slow	Inter-mittent	Con-tinuous
	Recip.		X	X	
Aircraft control	"	X	X	X	
Aircraft shock strut	"	X		X	
Machine tool	"	X	X	X	
Hydraulic press	"		X	X	
Hydraulic booster	"		X	X	X
Hydraulic accumulator	"	X		X	
Power steering	"		X	X	
Hydraulic jack	"		X	X	
Hydraulic elevator	"		X	X	
Shuttle valve	"	X	X	X	X
Pressure switch	"		X	X	
Slide valve	"		X	X	
Door check	"		X	X	
Globe valve stem	Rotary		X	X	
Turbine water pump	"	X			X
Swing joint	"		X	X	
Pneumatic chuck	"		X		X
Field roller bearing oil seal	"		X		X
Hydraulic operating lever	"		X	X	

When used as a static seal, the O-ring is usually described as an O-ring gasket and functions to seal the gap between two closely spaced surfaces that remain stationary with respect to each other. It seals concentric circular parts or flat surfaces. Circular seals may be represented by a plug seal and a cap seal. A face seal may be represented by a flange seal or a bolt seal (see Figure 22-7).

Examples of the application of O-ring static seals are given in Table 22-5. An illustration of both dynamic and static seals is also shown in Figure 22-7.

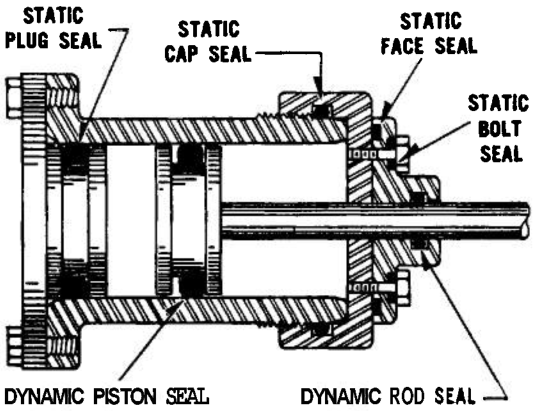


Figure 22-7. Dynamic and Static Seals

22-11.2 GENERAL DESIGN RECOMMENDATIONS

The following general recommendations should be considered in the design and use of O-rings:

(1) Never design dynamic O-ring installations in which the O-ring passes over ports, annular grooves, or slots while under fluid load. Under zero load, such ports, etc., may be passed by the O-ring if the necessary radii or tapers are provided.

(2) Wherever possible, provide some lubrication before assembly—grease is best—and provide lubrication during operation to avoid excessive friction and rapid wear. If the fluid being sealed has inherently low lubricity, provide a lubricant-impregnated felt washer in a separate groove on either side of the O-ring to lubricate the moving surfaces.

TABLE 22-5 EXAMPLES OF O-RING STATIC SEALS

Bolt head
Pipe flange
Flanged valves and fittings
Cylinder head
Hose coupling
Removable parts of valves, carburetors, instruments, etc.
Oil filter cover
Waterproof telephone jack
Gas engine cylinder liner
Packless shaft seal
Pneumatic hose couplers
Tube fittings and connectors

Make provision to replenish the lubricant throughout the operational life of the seal. The lubricant used should not cause shrinking or swelling of the O-ring, soften excessively, or solidify over the anticipated temperature range, break down or leave gritty deposits. The lubricant must be compatible with the fluid being sealed and correct for the mechanical application. Hydraulic oils generally exhibit satisfactory lubricating qualities. Water is a good lubricant and petroleum and vegetable oils are satisfactory.

(3) Ensure that the surface finish of all gland surfaces is as smooth as practicable. In general, the better the finish, the better the seal.

(4) Specify the use of steel for dynamic O-ring glands. When the surface is hardened by heat treatment, chromium plating, hard nickel plating, or case hardening, and then made smooth, the mildly abrasive action of the O-ring tends to maintain and improve the surface finish.

(5) Ensure that the clearance between the moving parts of a dynamic O-ring gland is kept

to a minimum consistent with the fluid pressures involved, the thermal expansion characteristics of the materials, and the cost of machining the parts. Cylindrical static seal glands require the same clearance as dynamic glands; static face seal glands are preferred with a metal-to-metal contact, or zero clearance.

(6) Provide scraper rings, boots, or lip-type rubber wipers in installations where dust or dirt can reach the seal (see Figure 22-8).

(7) In conventional installations avoid using more than one seal per piston. If more is used, a pressure trap may be formed between the seals causing seal failure.

(8) For rotary applications, O-rings should have a minimum cross section and a durometer hardness of 80 to 84. Temperature, shaft speeds, and materials must also be taken into account. Where surface rotational speeds exceed 50 ft per min, frictional heat must be kept at a minimum and then effectively dissipated to prevent early seal failure.

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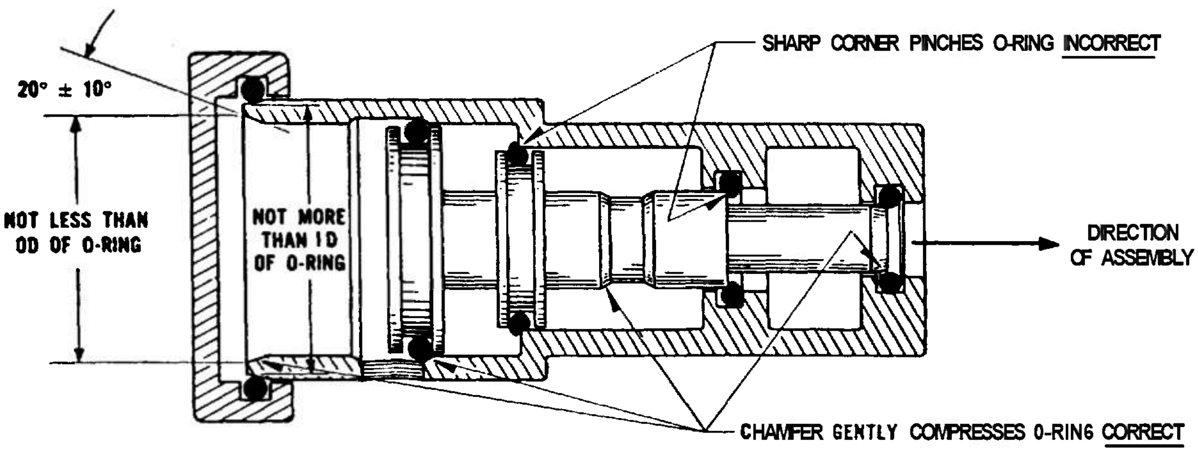


Figure 22-8. Provide Scraper Rings or Boots in Exposed 0-Ring Installations

PART FIVE

CONSIDERATIONS APPLICABLE TO SPECIAL TYPES OF MATERIEL

CHAPTER 23

ELECTRONIC AND ELECTRICAL EQUIPMENT

SECTION I

DESIGNING EQUIPMENT UNITS

23-1 LAYOUT AND PACKAGING REQUIREMENTS

The layout, packaging, and mounting of units, assemblies, components and/or parts should be designed to facilitate the required or expected maintenance operations. General layout should systematically follow one or more of the combinations of methods described in the paragraphs below.

23-1.1 LOGICAL FLOW PACKAGING

Logical flow packaging is based on the following :

(1) Circuits, parts, and components are packaged and located in an arrangement parallel to their functional relationships as established by block diagraming.

(2) Methods and subassemblies are selected so that only single input and output checks are necessary to isolate a fault within an item.

(3) Clear indication is given of the unidirectional signal flow within a given piece of equipment.

23-1.2 CIRCUIT PACKAGING

Circuit packaging uses the following techniques :

(1) All parts of a given circuit, or logically or generally related groups of parts, are located in a common volume.

(2) Each circuit is placed in a separate module. If a tube is associated with the circuit, place it on top of the module.

(3) The circuit should consist of a single terminal board or module of the plug-in type when practicable.

(4) Plug-in printed circuit boards should be structurally rigid and easy to remove and replace.

23-1.3 COMPONENT PACKAGING

Component packaging incorporates the following :

(1) All similar components are found in one place on the equipment.

(2) Relays are located in a single or small number of relay panels.

(3) Resistors, capacitors, tube sockets, etc., are segregated in a minimum number of locations on subassemblies or terminal boards.

(4) Inexpensive components are placed on separate plug-in type boards mounted beneath the chassis to facilitate disposal at failure.

(5) Multiplicities of similar parts (tubes, etc.) that are likely to require replacement at the same time are grouped together.

(6) Components are segregated on the basis of significant variations in the required maintenance tasks. For example, items which are to be cleaned by different methods (steam, gunk, solvent, etc.) are packaged so cleaning is possible with minimum masking.

23-1.4 STANDARD PACKAGING

Standard packaging has no clear cut procedures; it simply works to a final product by balancing a number of factors such as heat loss, component size, unit size, and component weight to arrive at a compromise which varies for each equipment made. Examples of such a compromise are the simple radio receivers available on the civilian market.

23-1.5 EVALUATION OF PACKAGING METHODS

An empirical evaluation of the equipment packaging techniques previously described was performed by technicians of two different skill levels on a simple and complex system (Ref. 1). Based on the performance data used to make the evaluation (troubleshooting time, amount of information gained per unit of time, technician's subjective performance, and engineering criteria), it was found that the logical flow method is superior to the standard method and that its use clearly enhanced the maintainability of equipment. The other packaging methods (i.e., component grouping and circuit grouping) also seemed to be advantageous although their superiority over the standard method was not as clearly shown as was the logical flow method.

23-2 MOUNTING REQUIREMENTS AND GENERAL MOUNTING METHODS

Mounting of components refers to a means of attaching and positioning various items of equipment with the emphasis on accessibility for maintenance personnel. The following factors are important in determining mounting requirements :

(1) The frequency of removal of the component for maintenance or replacement. This is determined by the reliability or estimated mean-time-to-failure of the component. The length of time the system will be down for maintenance is also important.

(2) Accessibility of other components which may be affected.

(3) The size and weight of the component to be mounted.

(4) The amount of space required for access for removal and replacement of the component, or for the use of test probes, tools, and other servicing equipment.

(5) Preventive maintenance required on the component in its installed position. The amount of adjustment required after replacing a component.

General guidance relating to various methods of mounting components is outlined below :

(1) *Mounting fixtures.* Slide rails, rollers, brackets, etc. should be designed so that:

- (a) Only interconnecting wire and structural members are permanently attached to units; all other fixtures should be removable.
- (b) Fixtures which are built-in to the chassis are either strong enough to withstand usage over life of the system or are removable.
- (c) Mounting is compatible with the size and weight of the part to prevent lead breakage or similar damage from fatigue under vibration, handling stress, etc.

(2) *Fold-out construction.* This method of constructing subassemblies should be used whenever feasible (see Figure **23-1**) ; the parts and wiring should be positioned to prevent damage to them when opening and closing the assembly.

(3) ***Braces.*** Braces or similar items should be provided to hold hinged assemblies in the "out" position while they are being worked on (see Figure **23-2**). Rests or stands should be provided to prevent damage to delicate parts. If feasible, the rests or stands should be a part of the basic chassis as shown in Figure **23-3.**

(4) *Straps and brackets.* Use straps and brackets :

- (a) As necessary for tying down large components.
- (b) Particularly to support items mounted on the underside of assemblies.
- (c) Instead of cantilever brackets for mounting parts.
- (d) **As** necessary to prevent the mounted item from sliding or jumping out of the position. "U" straps should only be used to "tie-down" components, not to secure or support them.

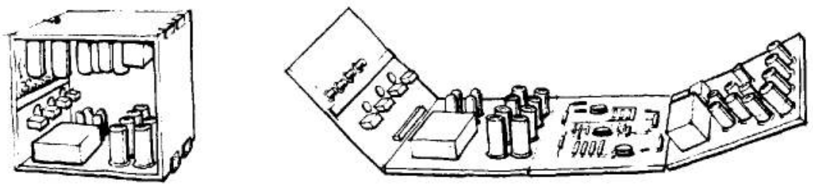


Figure 23-1. fold-Out Construction for Electronic Chassis

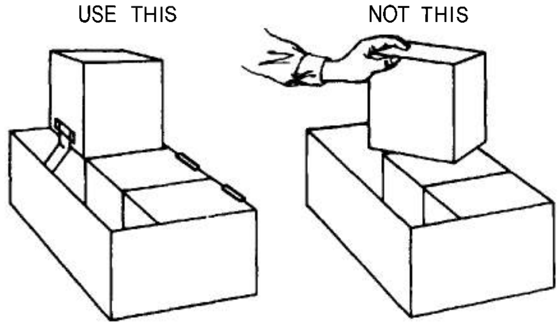


Figure 23-2. Hinged Assemblies Braced in the "Out" Position Leave Both Hands Free

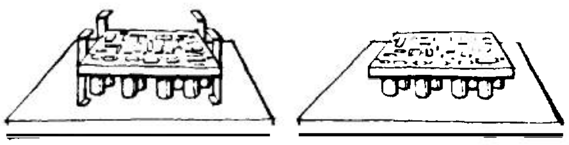


figure 23-3, Stands for Maintenance As a Part of the Chassis Will Prevent Damage to Parts

(e) Which are thick or rounded enough so they have no sharp edges.
(f) Which are shorter than mounted units to provide a clamping action.
(g) Which are twist- or push-to-lock mounting types for small components (see Figure **23-4**). Such brackets should be designed so that locking studs are visible when the component is in place, and locking screws or dimples are provided as necessary to ensure security of mount.

(5) *Shock mounts.* Shock mounts should be used, as necessary, to :

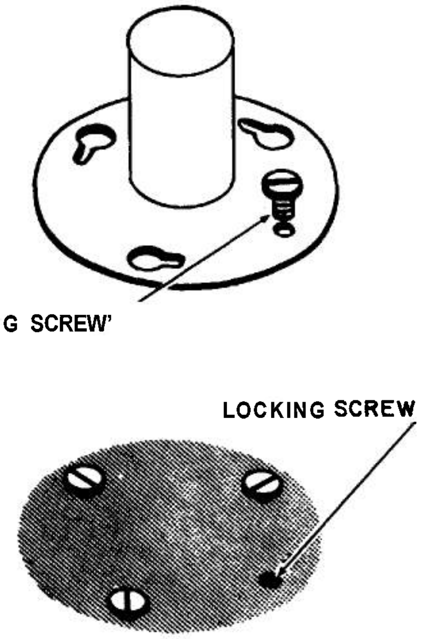


Figure 23-4. Twist-to-Lock Mounting Bracket

(a) Eliminate vibrational fluctuations in displays, markings, etc.
(b) Protect fragile or vibration-sensitive components and instruments.
(c) Control sources of high or dangerous noise and vibration.

Other methods to be considered in the mounting of components are as follows :

(1) Hinged bars are useful for tying down and permitting access to a number of small components at one time. Such bars should be padded or provided with springs as necessary to prevent damage to the items secured.

(2) Where rigid mounting may result in damage to components, use a device which permits some flexibility. For example, a frequent cause of thread-stripping of "T" fittings is the rigid mounting of the fittings.

(3) Where blind mounting is required, secure the inaccessible side with mounts which will allow exceptionally easy mating and do not require access (such as friction lugs, tongue and groove fittings, etc.) .

(4) Use spring clamps to mount tubing, pipes, or wiring which may require frequent removal and replacement (see Figure 23-5). For overhead mounting, use a spring clamp similar to that used for floor mounting, but provide a hinged locking latch over the open side of the clamp to prevent accidents.

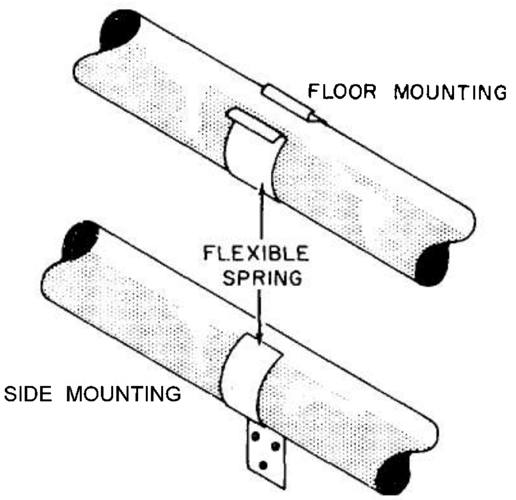


Figure 23-5. Use Spring Clamps for Frequently Removed Components

23-3 REPLACEABLE UNITS

There are two primary reasons for designing electronic equipment with relatively small, removable, or replaceable units. First, constructing electronic equipment with easily removable assemblies, subassemblies, and components permits the division of maintenance responsibility — particularly troubleshooting — among various maintenance levels. This design permits rapid corrective maintenance at the user level, with additional maintenance at other levels, if required. Second, when equipment is built with removable units, it is easier to work on malfunctioning parts (see also Chapter 19).

The following recommendations should be considered in the design of replaceable units :

(1) Replaceable components should be designed so that they cannot be installed in the wrong way. Also, if two parts are physically interchangeable they must also be functionally interchangeable. Designs, mockups, manufacturing processes, etc., should be continually reviewed to identify and correct or compensate for all potential sources of such errors.

(2) Use tapered alignment pins, quick-disconnect fasteners, and other similar devices to facilitate removal and replacement of components.

(3) Design mounting brackets and surfaces so that mounting bolts and fasteners can be placed on a surface adjacent to the technician's work space. Provide guides and guide pins for alignment of units on mountings (see Figure 23-6).

(4) Where possible, design units so they are removable along a straight or slightly curved line rather than through an angle (see Figure 23-7).

(5) Design mounting brackets so that the component can only be installed in the correct position. Where space permits, provide side-alignment brackets which permit installation in only one position (see Figure 23-8).

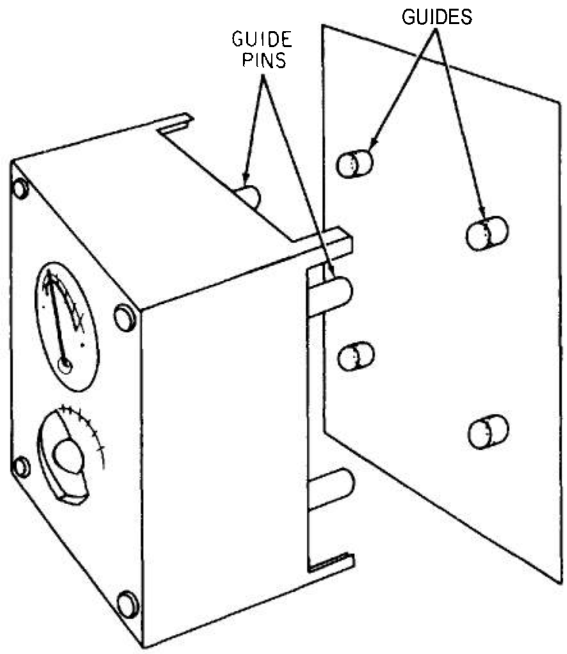


Figure 23-6. Alignment Guides and Guide Pins

(6) Use bottom mounted aligning pins for components which are light enough to be lifted easily. Such aligning pins are not desirable for heavy components because they require a lifting process for aligning the component. Side aligning devices, similar to the one shown in Figure 23-8, are more desirable €or heavy components because the component can be slid into place.

(7) Code, label, or key symmetrical components to indicate the proper orientation for mounting or installation.

(8) Do not require the opening of more than one access panel to remove any single unit.

(9) Position components so that the technician does not have to reach too far out for heavy units.

(10) For components that are heavy or relatively inaccessible, provide slide-out racks. When using roll-out mounting racks, provide limit stops to prevent dropping the components (see paragraph 23-7).

(11) Design units for easy connection to each other and to the housing in which they are installed.

(12) Design electronic and electrical units with plug-in rather than solder connections.

(13) When using AN connectors, specify the quick-disconnect type (see Figure 23-9 and Paragraph 23-12).

(14) Make incorrect assembly impossible by using different sizes or completely different

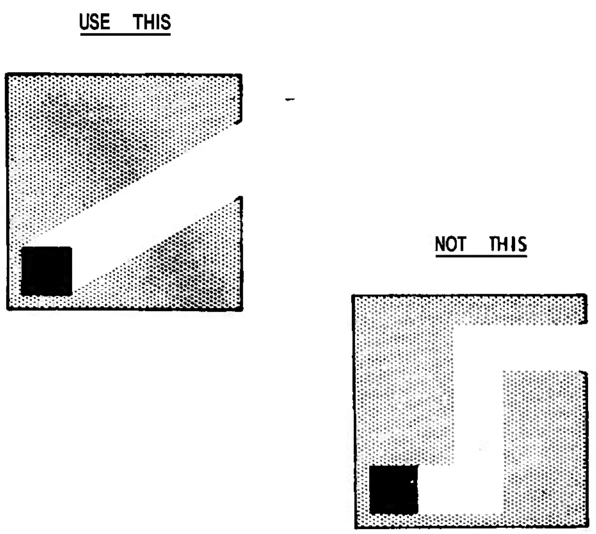


Figure 23-7. Provide for Removal of Equipment in a Straight Line (Ref. 2)

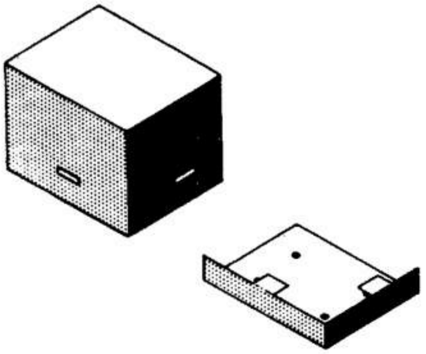


Figure 23-8. Side Alignment Brackets Facilitate Correct Mounting

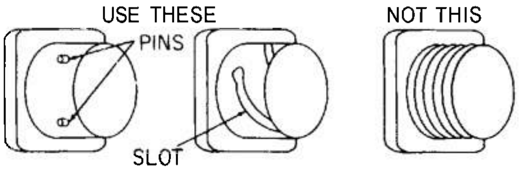


Figure 23-9. Types of AN Connectors

types of connectors. Where it is possible to assemble incorrectly, use coding techniques, e.g., color, size, shape, etc. (see also Paragraph 23-12).

(15) Use connectors requiring no tools (or only common hand tools) and with only a fraction of a turn or quick-snap action being required for connection.

(16) Provide mounting bolts, screws, and fasteners that can be easily removed and replaced with minimum chance for error. Use captive bolts and nuts to prevent the dropping of small items into the equipment (see also Chapter 21).

(17) Attach small removable parts such as pins, caps, and covers, to the main body of the equipment by small chains or other suitable means to prevent their loss (see Chapter 21, Figure 21-25). Because some retainers tend to break apart, especially when kinked, care should be exercised in the selection of suitable retainers to insure that they meet performance requirements.

(18) Use lock washers or other restraining measures to prevent bolts, nuts, etc., from vibrating loose. Safety wire is not generally recommended, but if it must be used, provide for

means of attaching it, and make the means of attaching it simple as possible.

(19) Keep the weight of components under 30 lb if possible.

(20) Provide adequate handles on all units weighing more than 10 lb and on those weighing less than 10 lb if they might otherwise be difficult to grasp, remove, or hold (see Paragraph 23-6).

23-4 LOCATION OF INDIVIDUAL COMPONENTS

Consider the following when locating individual components :

(1) Locate equipment components to minimize the possibility of equipment damage or personnel injury.

(2) Locate delicate components where they will not be damaged while the equipment is being worked on.

(3) Place components in positions where oil, other fluids, and dirt are not likely to fall on them.

(4) Guard high temperature parts or locate so that personnel contact will not occur during operation or maintenance. Arrange and shield heat producing equipment so that discomfort to personnel is avoided.

(5) Enclose high current switching devices to protect personnel. Do not locate internal controls close to dangerous voltages.

(6) Lay out components so that they are accessible to both operating personnel and maintenance technicians.

(7) Group components maintained by the same technician. They should be laid out so that, during system checking, a minimum of moving from position to position is necessary.

(8) Place check points, adjustment points, cable-end connections, and labels in full view of the technician.

(9) Provide that small hinge mounted units, which must have access to the back, are free to open their full distance and remain open without being held (see Figure 23-10).

(10) Make components and systems requiring frequent inspection and maintenance as easily accessible as possible.

(11) Locate units so no other equipment has to be removed to gain access to them.

(12) Do not stack units. If it is necessary because of space limitations, place the unit requiring less frequent access in the back or on the bottom.

(13) Avoid the situation where frames and structural members interfere with maintenance and operational personnel reaching components they must maintain, inspect, or operate (see Figure 23-11).

(14) Install components that require frequent visual inspection in positions where they can be seen easily without removing panels, covers, or other units.

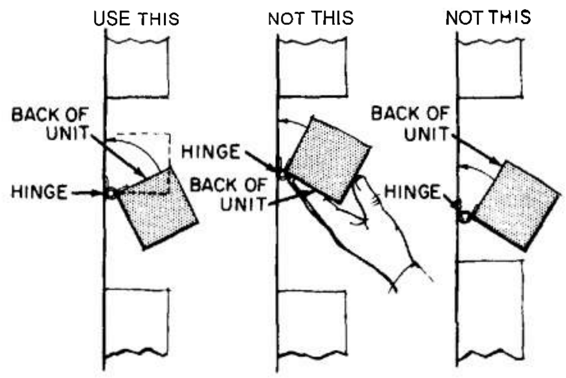


Figure 23-10. Hinged Units

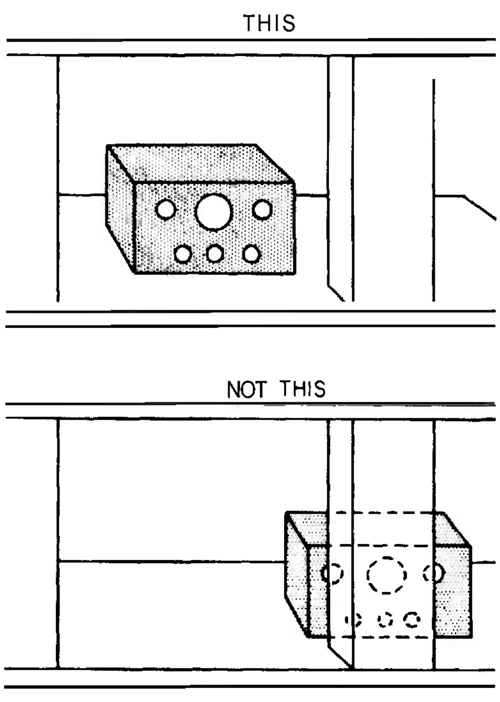


Figure 23-11. Component Placement

23-5 LOCATION OF INDIVIDUAL COMPONENTS WITHIN UNITS

Unit parts should be mounted in an orderly array on a two-dimensional surface and not stacked. Orderly layout is helped by mounting parts on one side of a board and having wiring, including printed or soldered circuits, on the other side, with electrical contacts inserted through the board.

Components within an equipment unit should be placed for easy access for servicing and replacement of parts. Components should be arranged with the following considerations in mind:

(1) Sufficient space should be provided to use test probes, soldering irons, and other required tools.

(2) Tubes should be replaceable without removing assemblies and subassemblies.

(3) Miniature tube sockets should be oriented with the gaps facing in one direction to facilitate replacing tubes (see Figure 23-12). When tubes must be replaced through narrow openings, provide an external indication of the position for pin insertion.

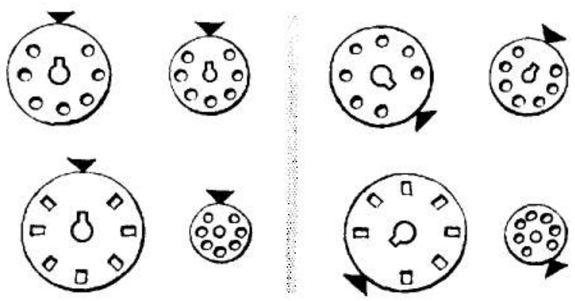


Figure 23-12. Common Orientation of Tube Sockets Will Facilitate Tube Replacement

(4) Resistors, capacitors, wiring, etc. should not interfere with tube replacement.

(5) All assemblies or parts to be serviced or replaced should be accessible without removal of other components.

(6) Delicate components should be located where they will not be damaged while the unit is being worked on.

(7) Fuses should be located so that they can be seen and replaced without removing other parts or subassemblies.

(8) Tools should not be required for replacing fuses.

(9) Internal controls, such as switches and adjustment screws, should not be located close to dangerous voltages.

(10) Components that retain heat or electrical potential after the equipment is turned off should be equipped with bleeder networks or else not be located where technicians are likely to touch them while changing malfunctioning parts.

23-6 HANDLES FOR EQUIPMENT UNITS

Handles should be provided on all packages, units, components, and covers whenever these items are frequently handled, difficult to carry, incorporate fragile components, or weigh over 10 lb. The size, location, and positioning of handles are functions of the following:

(1) Weight and center of gravity of the item or unit.

(2) Number of men, or hands, required to lift or carry the item.

(3) Type of clothing and gloves worn by these men.

(4) Operational position of the item relative to other items.

(5) Manner in which the item is to be handled or positioned.

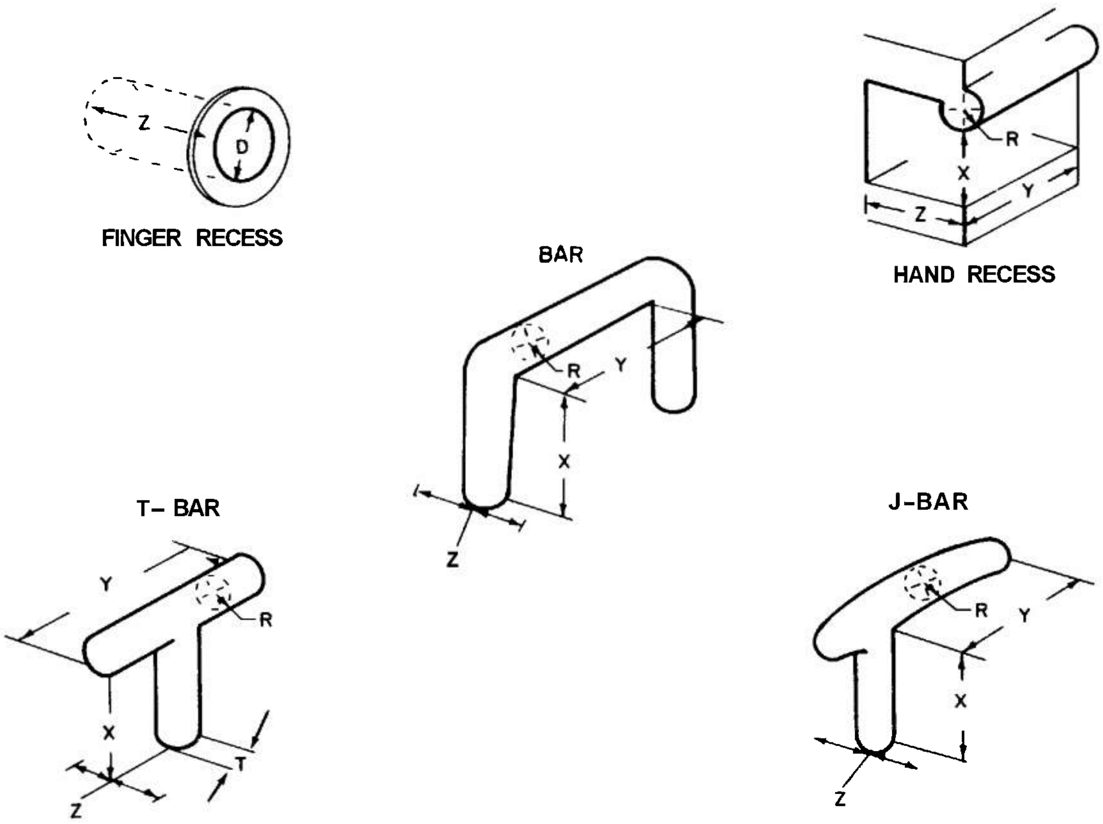
(6) Distance over which the item must be carried.

(7) Frequency with which the item must be handled or carried.

(8) Additional uses the handles could serve.

23-6.1 TYPES OF HANDLES

Some commonly used handles are the finger recess, hand recess, bar, T-bar, and J-bar (see Figure 23-13). The minimum acceptable dimensions of these handles are also illustrated in the figure. The minimum radius of curvature (R) should be 0.25 in. for items weighing up to 15 lb, 0.5 in. for items weighing between 15 and 20 lb, and 0.75 in. for items weighing over 20 lb. Gripping efficiency is best if fingers can curl around the handle at a minimum angle of 120°



Type	Bare Hand (in.)			Gloved Hand (in.)			Arctic Mitten (in.)		
	X	Y	Z	X	Y	Z	X	Y	Z
One-hand bar	2.0	4.25	2.0	2.5	4.75	2.0	3.0	5.5	3.0
Two-hand bar	2.0	8.5	2.0	2.5	9.5	2.0	3.0	11.0	3.0
Two-finger bar	1.25	2.5	1.5	1.5	3.0	1.5	Don't use		
One-hand recess	2.0	4.25	3.5	2.5	4.75	4.0	3.0	5.5	5.0
Two-finger recess	1.25-dia		2.0	1.5-dia		2.0	Don't use		
One-finger recess	1.25-dia		2.0	1.5-dia		2.0	Don't use		
Finger-tip recess	0.75-dia		0.5	1.0-dia		0.75	Don't use		
T-bar	1.5	4.0	1.5	2.0	4.5	2.0	Don't use		
J-bar	2.0	4.0	2.0	2.0	4.5	2.0	3.0	5.0	3.0

Figure 23-13. Types of Handles and Their Dimensions (Ref. 31

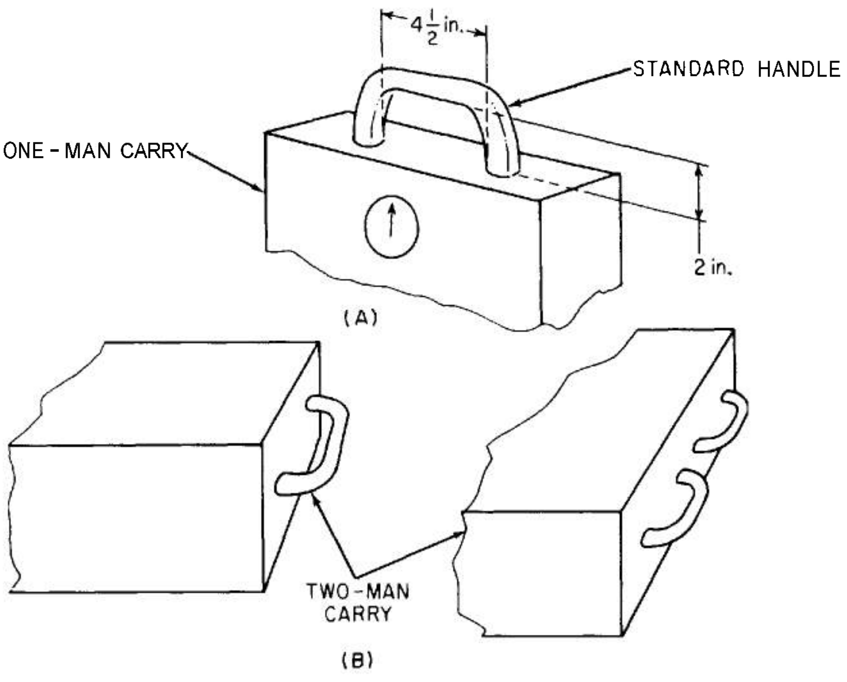


Figure 23-14. Handles for Ease of Carrying

23-6.2 RECOMMENDATIONS FOR THE DESIGN OF HANDLES

The following design recommendations should be observed when providing handles for units:

(1) Handles that must be gripped firmly should be at least **4.5** in. in height and **2** in. in depth (see Figure **23-14).**

(2) When providing a handle for one-man carrying, locate the handle on top of the unit above the center of gravity. When two or four handles are required, place handles at equal distances from the center of gravity (see Figure **23-14).**

(3) Handles should be provided on covers of units to facilitate removing the cover and carrying the unit (see Figure **23-15).**

(4) Handles should meet the lifting criteria given in Table **23-1.**

(5) Units weighing more than about **25** to 40 lb (depending on sine and bulkiness of unit) should be provided with handles for two-man carrying. For units weighing more than 100 to **150** lb (depending on size and bulkiness of unit), suitably labeled lifting eyes should be provided.

(6) Handles should be comfortable and easy to grasp. When units must be frequently carried for long periods of time, use a molded handle to prevent side pressure on the fingers.

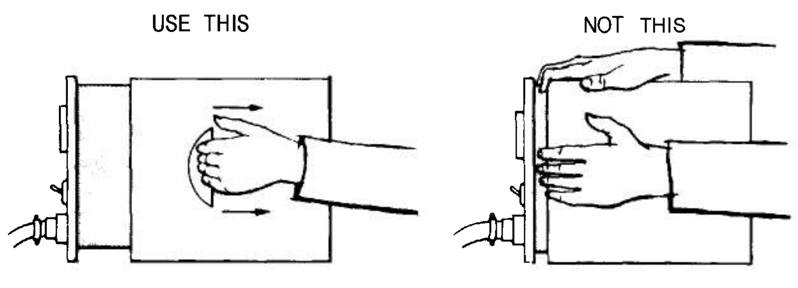


figure 23-15. Handles Facilitate Removal of Covers and Carrying of Units

(7) Provide recessed grips near the back of

concealed, or folding handles may be used to conserve space, but they must be accessible without tools and must remain securely folded when not in use.

(8) Equip handles with quick-release pins to make them easier to insert and remove (see Figure 23-16).

Besides the above function of carrying com-

ure 23-18.

TABLE 23-1. LIFTING CRITERIA FOR HANDLES

Weight To Be Lifted	Handle Diameter (in.)	Finger Clearances (in.)	Handle Width (in.)
Under 25 lb	0.25 - 0.5	2	4.5
Over 25 lb	0.5 - 0.75	2	4.5
Lifted by gloved hand		2.5	5

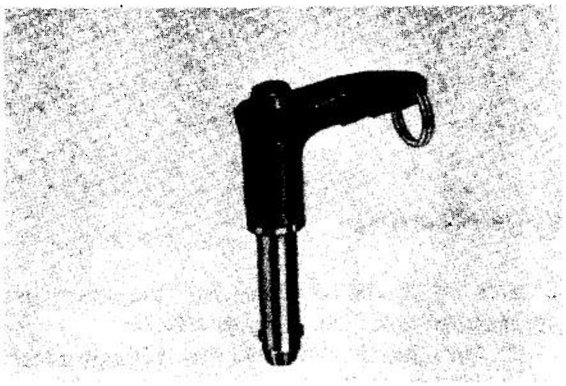


Figure 23-16. Equip Handles With Quick-Release Pins

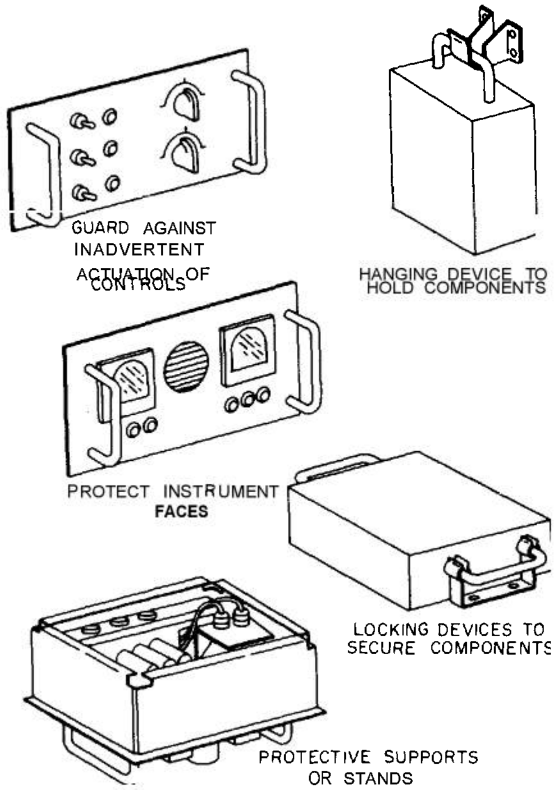


Figure 23-17. Additional Uses of Handles

23-7 DRAWERS AND RACKS FOR EQUIPMENT UNITS

Pull-out, roll-out, or slide-out drawers, shelves, racks or other hinged or sliding assemblies (Figure 23-19) should be provided as necessary and wherever practicable to:

(1) Optimize work space, tool clearance, and accessibility.

(2) Reduce the need for the technician to handle fragile or sensitive items.

(3) Facilitate the handling and/or positioning of heavy or awkward items.

(4) Facilitate maintenance of items which must be frequently moved from the installed position for checking, servicing or repair.

Pull-out, roll-out, or slide-out racks and drawers should be designed so that:

(1) A minimum number of operations are required to open or release them.

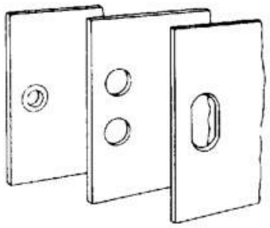
(2) They operate with a force less than 40 lb.

(3) A smooth operating bearing assembly facilitates the operations, as needed.

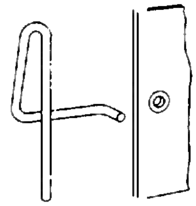
(4) They lock automatically in both the servicing and operating positions.

(5) Handles are provided as necessary to facilitate operation and handling.

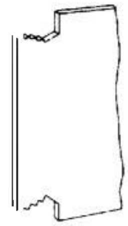
(6) Assemblies may be opened without



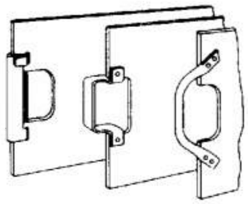
PUNCHED OR DRILLED HOLES can be used if space between boards is sufficient for finger insertion; grommets may be required in some materials.



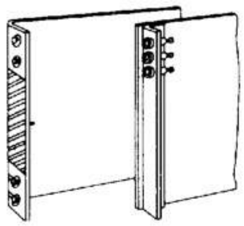
SMALL EYELET and removable extractor when space and weight are at a premium.



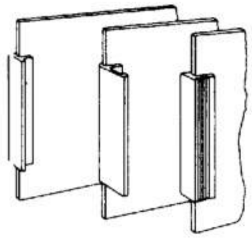
SERRATED FINGER GRIPS when spacing of boards is close.



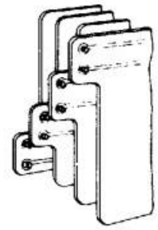
INDIVIDUAL HANDLES tabbed or riveted in place.



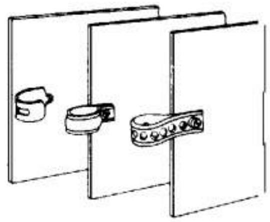
FORMED BOARDS do double duty when test points and jacks are incorporated into handles.



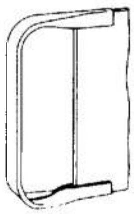
EXTRUSIONS staked, crimped or pinned in place.



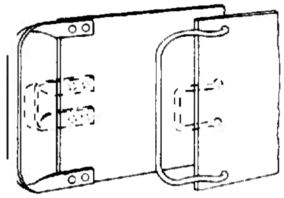
STAGGERED POSITIONS of removal tabs give easy access to test points on closely spaced panels.



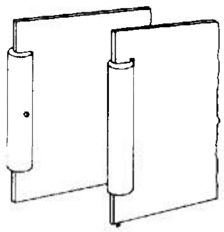
CABLE CLAMPS AND STRAPS; by using solderable materials handles can be assembled during component-soldering operation.



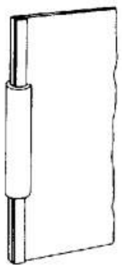
SHEET METAL HANDLE of more complex shape.



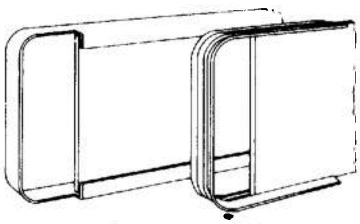
WIRE OR SHEETMETAL parts may be full handles or fingergrips.



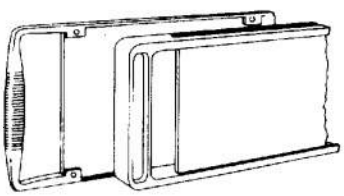
SLOTTED ROD held by either a screw or adhesive is suitable when stronger fastening is required.



SPLIT TUBING can be slipped onto panels and retained by spring effect, or a copper strip can provide a shoulder.



BOARD-STIFFENING FRAMES have integral slide surfaces and handles; suitable for press-forming or extrusion.



DIE-CAST AND MOLDED handles can be provided if needed in quantity large enough to justify added cost of tooling.

figure 23-18. Handles for Printed Circuit Boards (Refs. 4 and 5) breaking internal connections which are necessary for the required maintenance.

(7) Extension cables or hoses are provided as necessary to allow completely removable assemblies to be checked in a convenient location.

(8) Guards and shields are provided as necessary to prevent damage to fragile or sensitive parts during movement of the assembly.

(9) Rests, limit stops, guards and/or retaining devices are provided as part of the basic chassis. These devices should :

(a) Prevent the assembly from being dropped.

(b) Prevent heavy assemblies from tipping the equipment.

(c) Allow complete and convenient removal of the assembly.

(d) Allow the assembly to open its full distance and remain open without being held.

Where internal connection is not required during maintenance, connectors to the drawer, shelf, etc., may be attached to the assembly itself, so that closing the assembly effects connection. This requires that :

(1) Connector parts be mounted on the assembly and rear wall.

(2) Locks be provided to ensure that connectors remain engaged.

(3) Guides be provided to ensure proper orientation of the assembly prior to pin engagement.

(4) Insulation be provided as necessary to ensure safety.

23-8 COVERS, CASES, AND SHIELDS FOR EQUIPMENT UNITS

Covers, cases, and shields refer to all protective and packaging devices which guard equip-

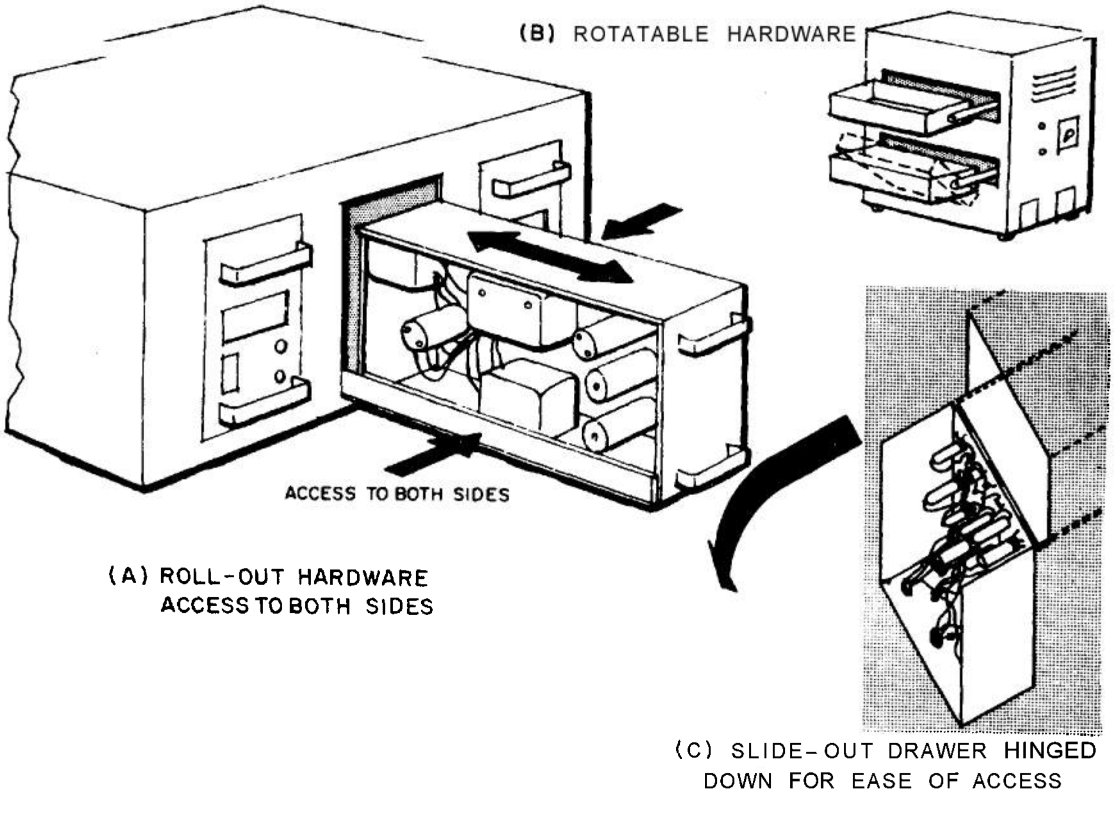


Figure 23-19. Use Pull-Out, Roll-Out, or Slide-Out Drawers for Components Requiring Frequent Checks

ment from damage during shipping or during operation and maintenance on the job site. Design features should provide for adequate protection of the equipment while ensuring its accessibility for maintenance. These design features are dependent on the particular maintenance operations to be performed on the units. The major feature in regard to maintainability that should be designed into covers, cases, and shields is ease of removal and replacement. Also, the number and types of fasteners should be minimized and removal should be possible with the unit in its installed position. Covers, cases, and shields should be provided whenever it is necessary to :

(1) Maintain the degree of enclosure required by structural, operational, or environmental protection or control.

(2) Divide enclosures into sections which differ by virtue of temperature or ventilation control, types of cleaning methods to be used, etc.

(3) Protect personnel from coming into contact with dangerous electrical or mechanical parts.

(4) Protect moving parts, fuels, lubricants, etc., from dust, dirt, moisture, chips, grit or splatter.

(5) Protect delicate or sensitive equipment from damage by movements of personnel, shifting of cargo of loose objects, or actions involved in the installation and maintenance of nearby assemblies.

In addition to these criteria, covers, cases, and shields should be designed and evaluated in terms of the degree to which they contribute to, or detract from, the speed and ease with which required maintenance can be performed. Their value in this respect largely depends on :

(1) The manner in which they are fastened.

(2) Their size, weight, and ease of handling.

(3) Provisions for handles or tool grips.

(4) The work space and clearance around them.

(5) The frequency with which they must be opened or removed in terms of the reliability and maintenance requirements of the enclosed components.

23-8.1 GENERAL DESIGN RECOMMENDATIONS

Design, locate, and mount covers, cases, and shields so they :

(1) Do not bear any part of the structural load—it should not be necessary to support download, or disassemble any equipment to remove the item.

(2) Are completely removable and replaceable in case of damage—irregular extensions and accessories should be readily removable.

(3) Can be opened or removed as necessary when the equipment system is completely assembled and auxiliary equipment has been installed.

(4) Do not cause the equipment to become unbalanced when opened—provide props, retainers, or other support where required to prevent this.

(5) Do not obscure or interfere with controls, displays, test points, or connections related to work within the access or enclosure, when in the open position.

(6) Are provided with adequate stops and retainers to prevent them from swinging into or being dropped on fragile equipment or on personnel.

(7) Are provided with locking devices or retainer bars to lock them in the open position if they might otherwise fall or shut and cause damage, injury or inconvenience—this is particularly necessary for doors, covers, and shields which may be used in high winds.

(8) Can be lifted off of units rather than the units lifted out of them (see Figure 23-20).

(9) Are light in weight, if possible, but are whatever size necessary to accomplish the degree of enclosure and allow the degree of accessibility required.

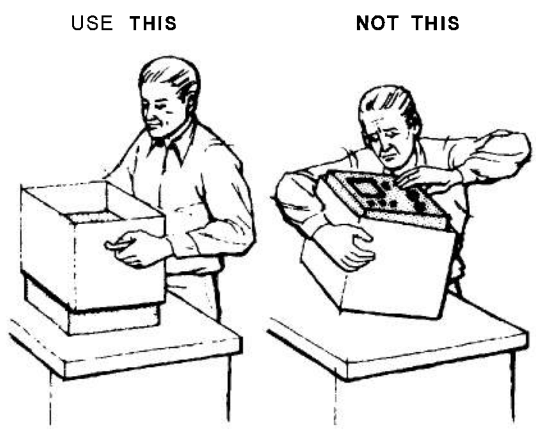


Figure 23-20. Cases Should Lift Off Units

(10) Are openable, removable, and transportable by one hand, one man, or, at most, two men, in that order of preference.

(11) Are provided with lifting eyes and planned for crane handling if more than 100 to 150 lb.

(12) Are provided with handles or tool grips if heavy **or** difficult to open or handle.

(13) Allow sufficient clearance around enclosed components to minimize damage to these components and avoid requirements for extremely fine or careful positioning and handling (see Figure **23-21**).

Select, apply, and mount fasteners for covers, cases, and shields so that :

(1) Maximum use is made of tongue and slot catches to minimize the number of fasteners and requirements for handling and stowing (see Figure **23-22**).

(2) Fasteners for a given item or identical items are interchangeable (i.e., are the same type, size, diameter and pitch of thread).

(3) Fasteners align themselves with their retaining catches, nuts, blocks, or inserts without sticking and without damage to their thread or latches.

(4) The cover or case will not open or loosen accidentally under whatever stress, vibration, or other conditions that are expected.

(5) It is obvious when a cover or case is not in place or securely fastened. Where possible, spring-load fasteners so they stand out or the cover itself stays ajar when not secure.

23-8.2 HINGED DOORS, HOODS, AND CAPS

The use of hinges allows the fastest and easiest access, reduces the number of fasteners required, supports the cover so the technician does not have to handle it, and makes it unnecessary to disconnect wires or components mounted on the cover prior to entering the access. Such covers do, however, require swinging space and may interfere with other operations or components.

The following design features are recommended for hinged doors, hoods, and caps:

(1) If opening space is a problem, utilize double hinged **or** split doors.

(2) Avoid heavy cumbersome back access doors on equipment.

(3) All door and cover plates for a given enclosure should have the same diameter thread and pitch of thread. Means should be provided for retaining all bolts on the door or cover when it is opened or removed. Bolts shall be designed to engage securely when in the closed door or closed cover position.

(4) Place hinges on the bottom, bias the hinges, or provide a prop, catch, or latch so the door will stay open without being held (see Figure **23-23**).

(5) Adjacent hinged doors should open in opposite directions to maximize accessibility ; cabinets should be so arranged that functionally related cabinets are adjacent and open in opposite directions.

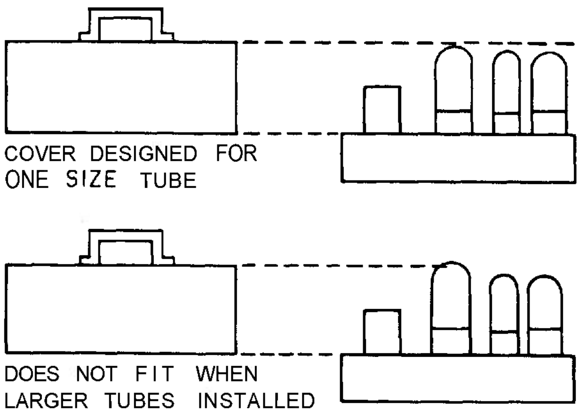


figure 23-21. Good and Poor Cover Tolerances

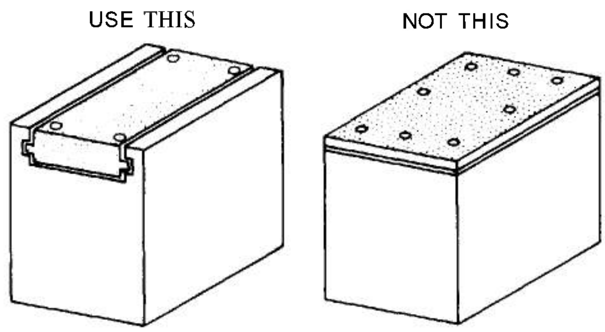


Figure 23-22. Tongue-and-Slot Cover to Minimize Number of Fasteners Required

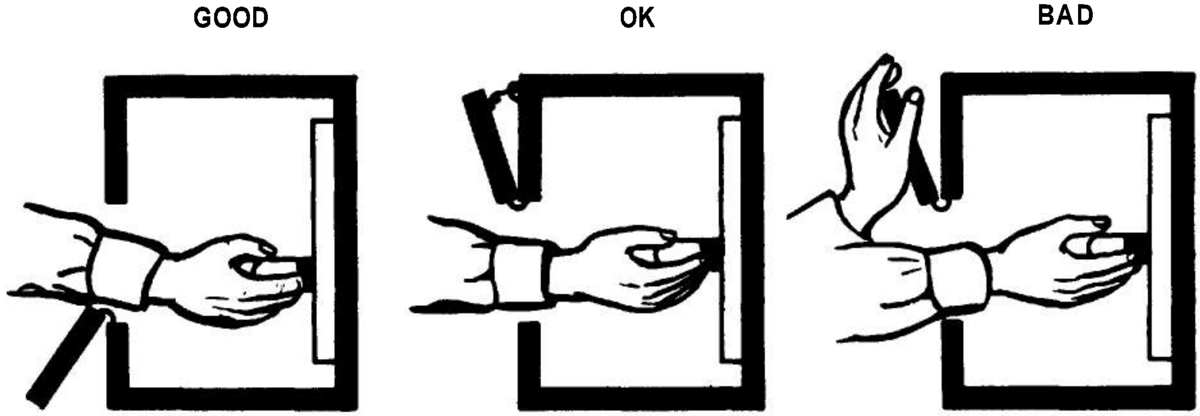


Figure 23-23. Design Covers to Open Down or Have Support to Maintain Them Open

(6) Hinged caps over service or test points must be so designed as not to interfere with the insertion or attachment of service or test equipment.

(7) Provide stops, retainers, etc., as necessary to prevent the door from swinging into adjacent displays, controls or fragile components, and to prevent springing of the hinges.

(8) Doors should be completely removable to facilitate installation and maintenance. If the doors are too heavy to be supported in the open position by hinge bolts, separate hinges with removable pins should be provided.

23-8.3 SLIDING DOORS AND CAPS

Large sliding doors may create structural design problems, but are particularly useful where swinging space is limited. Small sliding caps are particularly useful for small accesses that do not require a close seal. Sliding doors and caps should be designed so they :

(1) Lock positively.

(2) Do not jam or bind.

(3) Are easy to use and require no tools for operation.

(4) Do not interfere with, cause damage to, or provide potentially harmful contact with wires or other equipment items.

23-9 EQUIPMENT UNITS CHECKLIST

Table 23-2 is a checklist which summarizes some of the important features to be considered in the design of equipment units. The checklist contains several items which were not discussed separately in the text. These items are included here because their necessity in the design is so obvious that they might otherwise be inadvertently overlooked. In using the checklist, if the answer to any question is ***no,*** the design should be restudied to ascertain the need for correction.

TABLE 23-2 EQUIPMENT UNITS CHECKLIST

Packaging

1. Are plug-in components used where feasible?
2. Is wrong installation of unit prevented by virtue of size, shape, configuration, etc. ?
3. Are modules and mounting plates labeled?
4. Are guides used for module installation?
5. Are means provided for pulling out drawers and slide-out racks without breaking electrical connections when internal in-service adjustments are required ?
6. Are units and assemblies mounted so that replacing one does not require removal of others?
7. Are parts mounted on a single plane, not stacked one on another?
8. Are parts mounted on one side of a surface with associated wiring on the other side?

TABLE 23-2. EQUIPMENT UNITS CHECKLIST (cont)

9. Are easily damaged components mounted or guarded so they will be protected?
10. Are all replaceable parts accessible by fold-out construction or other special techniques when necessary?
11. When fold-out construction is employed, are parts and wiring positioned so as to prevent damage by opening and closing?
12. Are braces provided to hold hinged assemblies in "out" position while being worked on?
13. Are parts which retain heat or electrical potential after equipment is turned off located so that the technician is not likely to touch them while replacing commonly malfunctioning parts such as tubes?
14. When screwdriver adjustments must be made by touch, are screws mounted vertically so that the screwdriver will not fall out of the slot?
15. When necessary, are internal displays illuminated?
16. Are internal controls (switches, adjustment screws) located away from dangerous voltages?
17. Are screwdriver guides provided on adjustments which must be located near high voltages?
18. Are parts located so that other large parts (such as indicator and magnetron tubes) that are difficult to remove do not block access to them?
19. Are parts, assemblies, and components placed so there is sufficient space to use test probes, soldering irons, and other tools without difficulty?
20. Are parts, assemblies and components placed so that structural members of units do not prevent access to them?
21. Are all throwaway items made accessible without removal of other items?
22. Are units designed so that it is unnecessary to remove an assembly from a major component to troubleshoot that assembly?
23. Is equipment lay-out used that will not require the technician to retrace his movements during checking routines?
24. Are all miniature tube sockets oriented with the gaps facing one direction?
25. When tubes must be replaced through small access openings, is an external indication of the position for pin insertion provided?
26. Are all fuses located so that they can be seen and replaced without removal of any other items?
27. Are fuse assemblies designed and placed so that tools are not required to replace fuses?
28. Are removable units removable along a straight or moderately curved line?

Handles

1. Are handles used on units weighing over 10 lb?
2. Are handles provided on smaller units which are difficult to grasp, remove, or hold without using components or controls as hand holds?
3. Are handles provided on transit cases to facilitate handling and carrying of unit?
4. Are handles placed above the center of gravity and positioned for balanced loads?
5. For handles requiring firm grip, are bale openings provided at least 4.5 in. wide and 2 in. deep.
6. Do handles have a comfortable grip while unit is being removed or replaced?
7. Are handles placed where they will not catch on other units, wiring, or structural members?
8. Are recessed handles located near the back of heavy equipment to facilitate handling?
9. Are handles located to prevent accidental activation of controls?
10. Are handles placed to serve as maintenance stands for equipment?
11. For heavy equipment requiring two men to lift, are four standard size grips or two large size grips provided?
12. Are handles or other suitable means for grasping, handling, or carrying provided on all units designated to be removed or replaced?

Covers, Cases, and Shields

1. Are clearance holes for mounting screws in cover plates and shields oversize to ob-

TABLE 23-2. EQUIPMENT UNITS CHECKLIST (cont)

viate need for perfect alignment?
2. Are cases designed to be lifted off units rather than units lifted out of cases?
3. Are cases made larger than units they cover to preclude damage to wires and components?
4. Are guides or tracks provided to prevent cases cocking to one side?
5. If method of opening a cover is not obvious, is an instruction plate attached to the outside of the cover?
6. When covers are not in place and secure, are means provided to make it obvious?
7. Are no more than six fasteners used to secure the case?
8. Are the same type fasteners used for all covers and cases on a given equipment?
9. Are ventilation holes with screening of small enough mesh provided to prevent entry of probes or conductors that could inadvertently contact high voltages?
10. When the edges of a case must be slid over sealing material (such as rubber stripping) does the sealing material adhere tightly enough to prevent it from buckling or tearing?

SECTION II

SELECTING AND APPLYING WIRING, CABLING, AND CONNECTORS

23-10 WIRE CONNECTIONS

The following design recommendations should be observed when providing for wire connections in units:

(1) For easy maintenance, plug-in contacts are better than screw terminals and screw terminals are better than solder connections.

(2) The end of a wire soldered to a terminal should be left out of the solder so that the wire will be easy to remove (see Figure 23-24).

(3) Use U-lugs rather than 0-lugs whenever practicable (see Figure 23-25).

(4) Separate terminals to which wires are to be soldered far enough apart so that work on one terminal does not damage neighboring ones (see Figure 23-26).

(5) Make terminals or other connections to which wires are to be soldered long enough so that insulation and other materials are not burned by the hot soldering iron (see Figure 23-27).

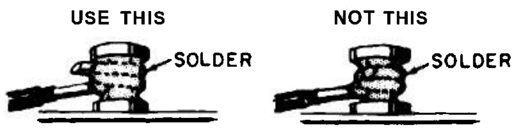


Figure 23-24. Soldering Wire to Terminal To Facilitate Removal

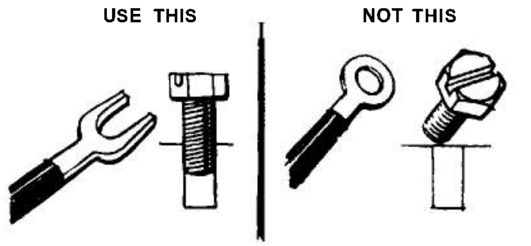


Figure 23-25. U-Type lugs Facilitate Repairs

23-11 CABLES

Because the primary purpose of interconnecting conductors is to transmit power and signals reliably to and from the various parts of the equipment, end connections are usually soldered, tightly screwed, or made permanent or semipermanent in some way. Such design practices make it more difficult for the technician to connect and disconnect the units when this becomes necessary. But reliability need not be sacrificed for ease of maintenance; the recommendations

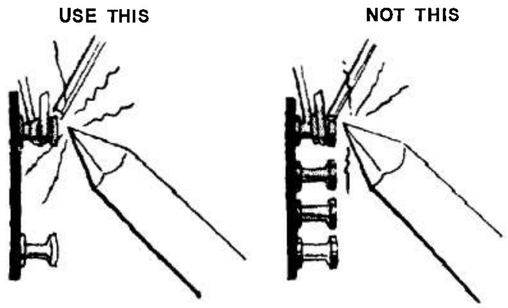


Figure 23-26. Spacing Wire leads Facilitutes Repairs

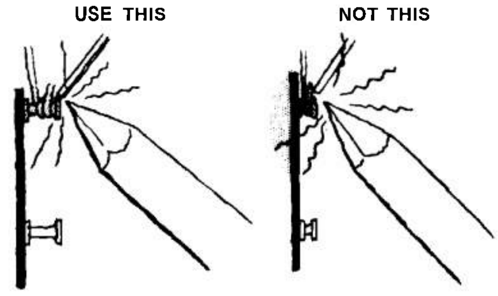


figure 23-27. Terminals Should Be long Enough To Prevent Damage to Insulation During Repairs

that follow can be used to improve maintainability without affecting reliability.

23-11.1 CABLE DESIGN

The following recommendations should be observed when designing and using cables:

(1) Cables should be long enough so that:

(a) Each unit can be checked in a convenient place (extension cables should be provided when necessary).

(b) Units in drawers and slide-out racks can be pulled out to be worked on without breaking electrical connections.

(c) Connectors can be reached easily for replacement or repair.

(d) Units that are difficult to connect where they are mounted can be moved to a more convenient position for connecting and disconnecting.

(2) The length of cables should be the same for each installation of a given type of electronic equipment if the circuit might be affected by differences in the length of the cable. (Even if a unit can be adjusted to compensate for differences in the length of the cable, using different lengths of cable means that adjustments made on the bench might be out of tolerance when the unit is installed.)

(3) Cable harnesses should be designed so that they can be built in a shop or factory and installed as a package.

(4) Cables should "fan out" in junction boxes for easy checking, especially if there are no other test points in the circuits (see Figure 23-28). Each terminal in the junction box should be clearly labeled and easy to reach with test probes.

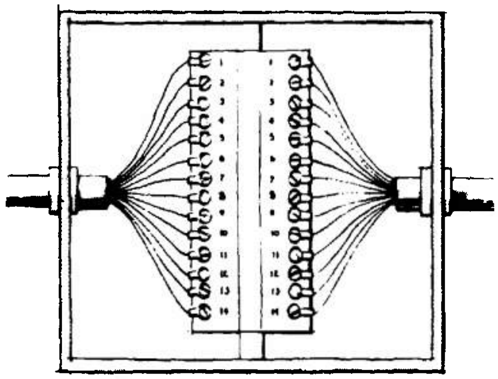


Figure 23-28. Cables Should "Fan-Out" in Junction Box for Easy Checking

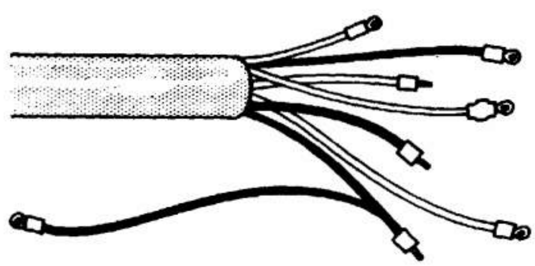


Figure 23-29. Use Preformed Cables When Possible

(5) Use preformed cables when possible (see Figure 23-29). They permit flexible, more efficient assembly methods and minimize the chances of making wiring errors. They also permit testing and coding of the entire cable before installation. Once the cable is placed in position on the chassis, the leads can be connected without the usual interference and confusion caused by stray wires.

(6) Consider the use of a clear plastic covering to insulate leads and cables so that breaks in internal wiring can readily be seen.

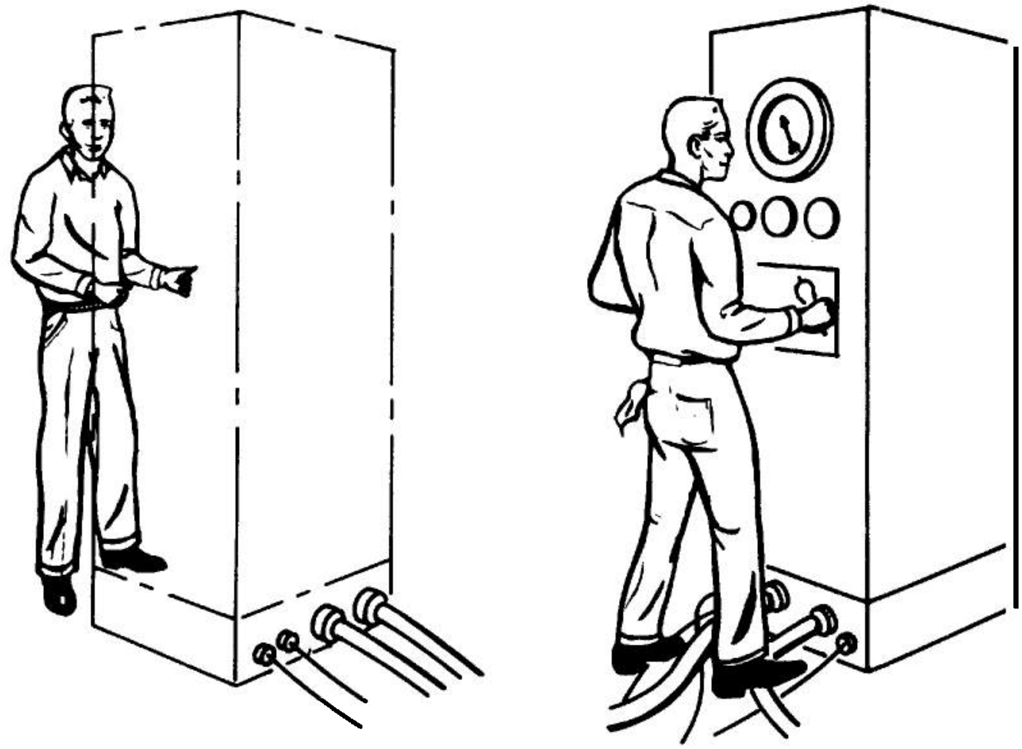


Figure 23-30. Route Cables So That They Are Not Likely To Be Walked On

(7) When polyvinyl wire is used, care should be taken so there will be no cold flow of the insulation due to tightness of lacing or mounting.

(8) Neoprene-covered rather than aluminum-sheathed cable should be used in areas where intense vibration or corrosive substances may cause failures.

(9) High-temperature wire should be used when wires are routed near ducts carrying pressures over 50 psi and/or temperatures above 200°C (392°F).

(10) Metallic shielding unprotected by outer insulation should be secured to prevent the shielding from contacting exposed terminals or conductors.

(11) Color code or number code insulated wire or cable in accordance with MIL-STD-195 and MIL-STD-681.

23-11.2 CABLE ROUTING

The following design recommendations should be observed:

(1) Route cables so that they are not pinched by doors, lids, and slides; are not walked on or used for handholds (Figure 23-30); are accessible to the technician, i.e., are not under floorboards, behind panels or components that are difficult to remove, or routed through congested areas, and need not be bent or unbent sharply when connected or disconnected (see Figure 23-31).

(2) Design cables or lines which must be

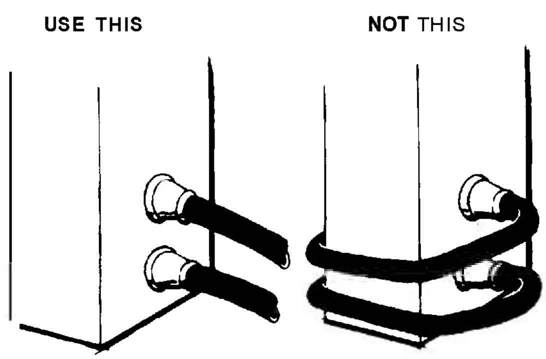


Figure 23-31. Route Cabling So As To Avoid Sharp Bends

routed through walls or bulkheads for easy installation and removal without the necessity for cutting or compromising the integrity of the system.

(3) Cable routing should avoid close contact with tubes, transformers, or rectifiers so that they will not be damaged by overheating.

(4) Provide guards or other protection for easily damaged conductors such as waveguides, high frequency cables, or insulated high voltage cables.

(5) Protect electrical wiring from contact with fluids such as grease, oil, fuel, hydraulic fluid, water, or cleaning solvents. These may damage insulation and result in injury to personnel.

(6) Provide means for keeping cables and lines off the ground. While permanent lines should never be on the ground, this is especially important in areas where ice and snow may cover the lines for long periods, making them inaccessible for maintenance.

(7) Where cable connections are maintained between stationary equipment and sliding chassis or hinged doors, provide service loops to permit movement, such as pulling out a drawer for maintenance, without breaking the electrical connection. The service loop should have a return feature to prevent interference when removable chassis are replaced in the cabinet. Figure 23-32 shows two methods of recoiling the cable.

(8) Provide storage space for long electrical cables which are a part of ground power, service, and test equipment. Often a storage compartment is present but no easy means is provided for coiling the wire into a shape and size which will permit storage. A simple means is a cable winder, a device around which the cable may be wrapped (see Figure 23-33). Use a circular spool as a cable winder to prevent bending radii of less than six times the diameter of the cable.

(9) Precautions should be taken to protect the insulation at the ends of cables from moisture. Moistureproof jacketing, which will withstand the required temperature range and mechanical abuse, should be used.

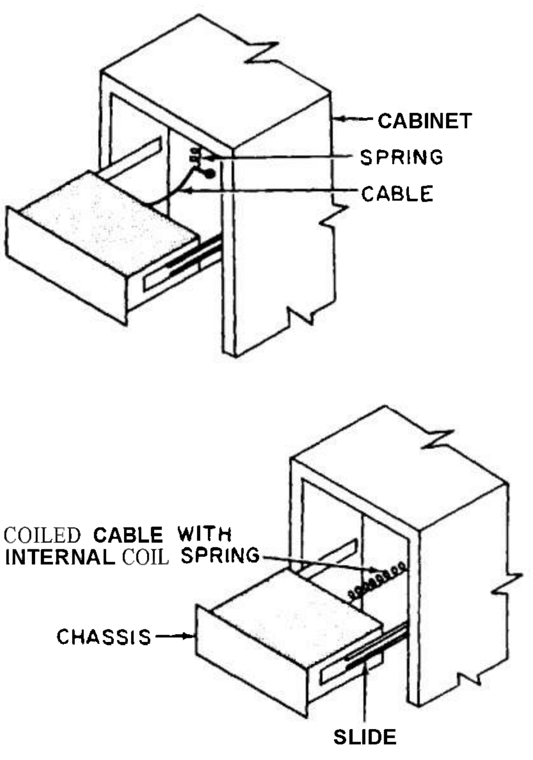


Figure 23-32. Methods for Recoiling Service Loops in Sliding Chassis (Ref. 21

23-12 CONNECTORS

Electrical connectors should be designed and selected so that they accomplish the following:

(1) Maximize the rapidity and ease of maintenance operations.

(2) Facilitate the removal and replacement of components and units.

(3) Minimize set-up time of test and service equipment.

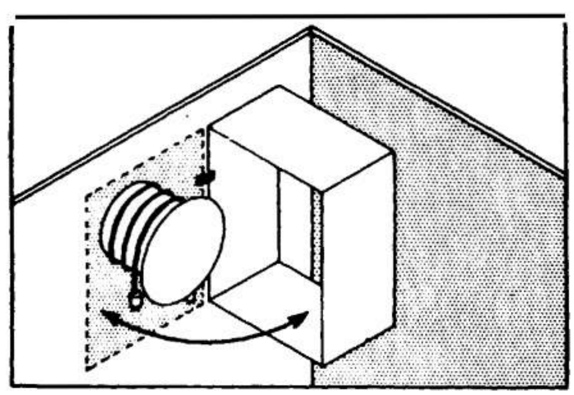


Figure 23-33. Cable Winder and Cover

(4) Insure compatibility between prime and ground support or auxiliary systems.

(5) Minimize dangers to personnel and equipment from voltages of cables or lines during the release of connectors.

(6) Be operated by hand where possible, or with common hand tools.

(7) Are standardized to facilitate corrective maintenance.

23-12.1 GENERAL DESIGN RECOMMENDATIONS

The following recommendations should be observed when providing for the connecting and disconnecting of cables :

(1) Use plugs and matching receptacles that make it impossible to connect the two incorrectly. For example, use different sizes of plugs for nearby connections, use different keys or alignment pins, and/or color code or paint stripes, arrows, or other information on each plug and the receptacle to which it belongs (see Figure 23-34).

(2) Each pin on each plug should be clearly identified, e.g., numbered.

(3) Use quick-disconnect plugs or plugs that can be disconnected with no more than one turn rather than plugs with fine threads that require many turns (see Figure 23-35).

(4) Use plugs in which the aligning pins or keys extend beyond the electrical pins. This arrangement protects the electrical pins from damage through poor alignment or twisting of the plug when it is partially inserted (see Figure 23-36).

(5) Avoid symmetrical arrangements of aligning pins or keys so that plugs cannot be inserted 180" from the correct position (see Figure 23-37).

(6) Locate connectors far enough 'apart so that they can be gripped firmly for connecting and disconnecting. The space needed will depend on the size of the plug, with 2.5 in. between plugs being a minimum separation (see Figure 23-38).

(7) When a part of a machine or system can be removed for maintenance, cables connecting the removable part with the rest of the machine or system should have plugs and receptacles that will disconnect before the cables will break, particularly if nonelectronics personnel do the removing. A jerk-open plug will separate before any damage is done; a screw plug will not.)

(8) Use plugs and receptacles for connecting cables to equipment units rather than "pig-tailing" them ; "pig-tailed" connections are harder to replace (see Figure 23-39).

(9) Use plugs with integral test points for each input and output that cannot be easily checked otherwise. If dust or moisture is a problem, provide an integral sliding cover for the test points on the plug (see Figure 23-40). As an alternative, provide a test point adapter for insertion between plugs and receptacles (see Figure 23-41).

(10) Use fewer plugs with many pins rather than more plugs with fewer pins (see Figure 23-42) ; it takes about the same amount of time to connect a plug with many pins as it does one with a few pins.

(11) Use connectors in which electrical contacts cannot be shorted by external objects.

(12) Receptacles should be "hot" and plugs "cold."

(13) Plugs should have a self-locking safety catch rather than require safety wiring. If safety wiring is a requirement, design holes and slots for most efficient and rapid attachment of the safety wire.

(14) Ensure that plugs and leads do not transmit stored charges when being disconnected.

(15) Lead pins and plugs should be designed so that they are strong enough not to be damaged by rough use. Avoid the use of miniature plugs where pins can be easily bent upon mating, thus causing a short circuit.

(16) On a given weapon system, standardize wiring connectors used in identical types of electrical equipment to reduce errors in wiring during installation or maintenance.

(17) Use individual power disconnects to permit turning the power off in one part of the system without the necessity of disconnecting the entire system.

(18) Label electrical cable connectors with the current and voltage. Include on the label a designation of the source of the current such as line, station, generator, or auxiliary power unit.

(19) Clearly label power receptacles for primary, secondary, or utility systems in order to prevent personnel injury or equipment damage.

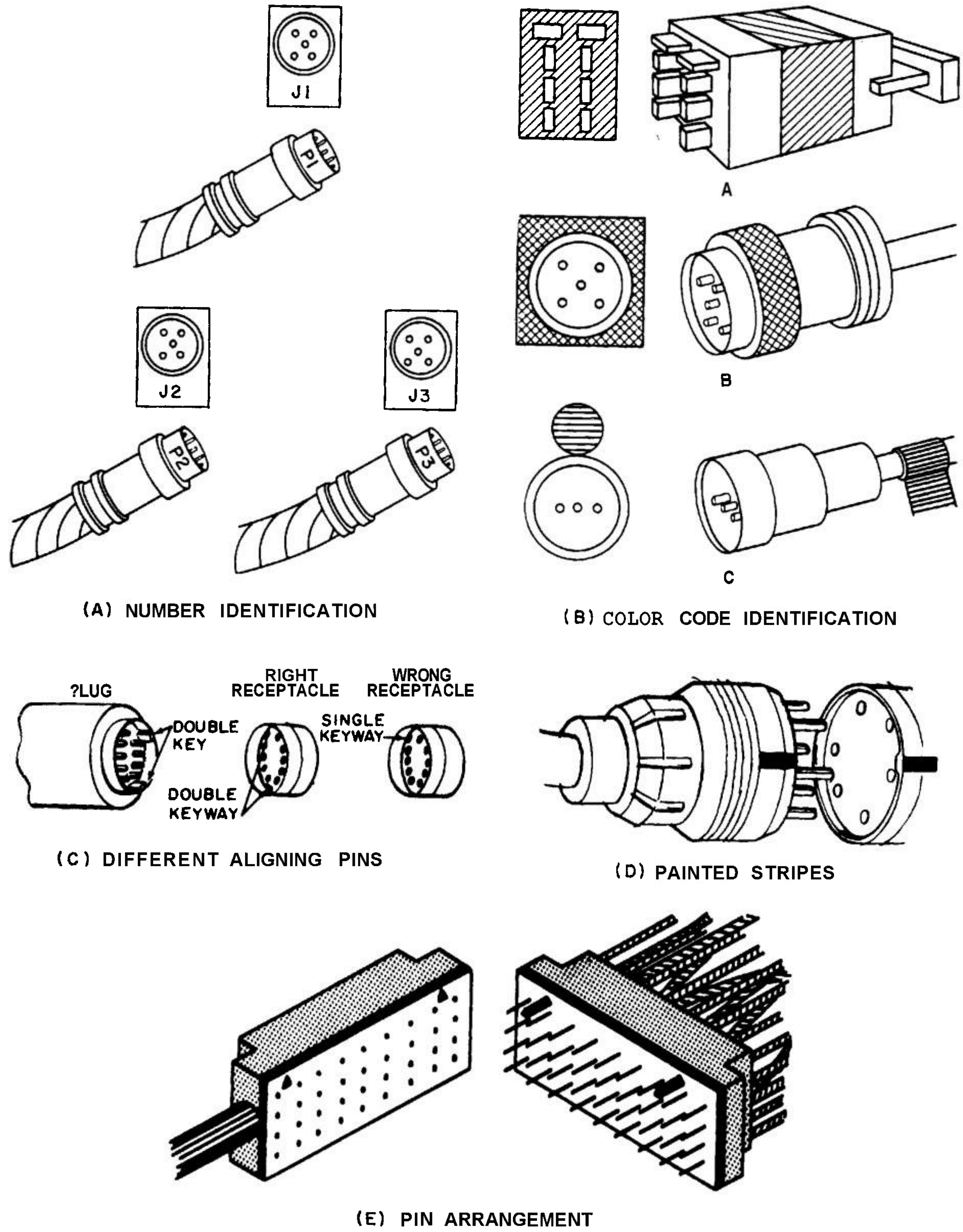


Figure 23-34. Methods of Identifying Plugs and Receptacles To Prevent Mismatching

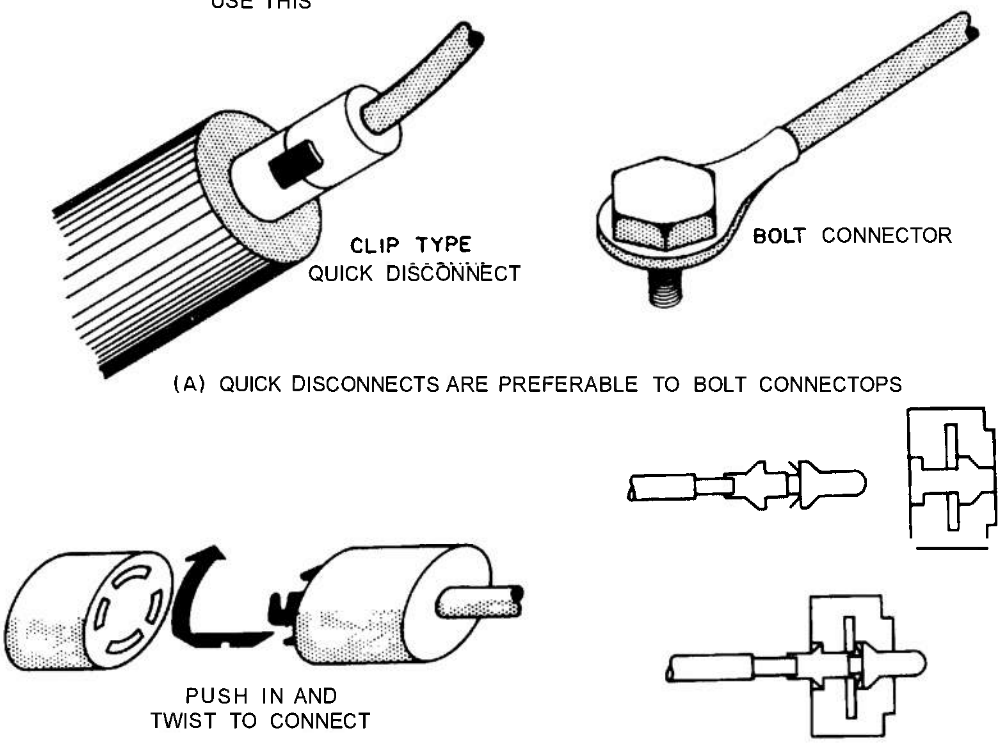


*Figure **23-35.** Use Quick-Disconnect Plugs*

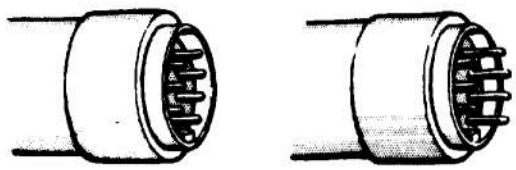
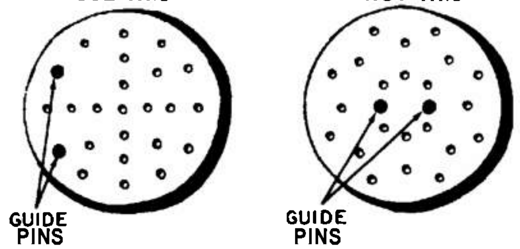


*Figure **23-36.** Extended Alignment Guides Protect Electrical Pins from Damage*



*Figu're **23-37.** Unsymmetrical Arrangement of Pins and Keys Prevents a Plug from Being Inserted 180" Out of Phase*

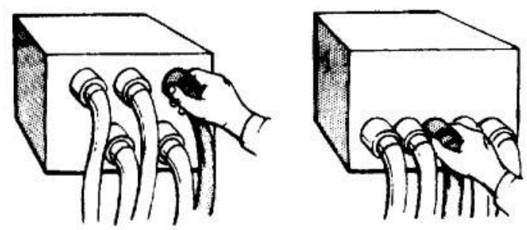


*Figure **23-28.** Connectors Should Be Arranged So That They Can Be Grasped Firmly For Disconnection*

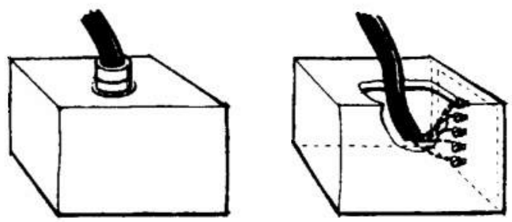


*Figure **23-39.** Use Plugs and Receptacles for Connecting Cables Rather Than "Pig-Tailing" Them*

23-12.2 CONTACT REQUIREMENTS

Inadequate electrical contact is a constant source of intermittent faults. To reduce these effects, the following recommendations should be observed :

(1) Whenever possible, superior insulating materials, corrosion-proof platings and moistureproof connectors should be used. Cables to connectors should be looped to allow moisture runoff. When moistureproof connectors cannot be used, the connector case should contain a drain hole. Do not mount connectors vertically.

(2) To protect against corrosion, all parts and mating surfaces of connectors should be coated with an electrical lubricating compound. Metal parts of all MF, VHF and UHF connectors should be silver plated inside and out.

(3) Insertion forces should be kept low to minimize possibility of damaging contact surfaces on connector parts.

(4) Avoid contacts which depend upon wires, lugs, terminals, etc., clamped between a metallic member and an insulation material. All such contacts should be clamped between metal members.

(5) Ensure that both ends of static discharge lines and ground wires are securely fastened. Alligator clips are preferred for temporary grounding or testing because they are fast and easy to use; they should not be used for permanent grounding where they may be inadvertently detached.

(6) Use spring contacts which are:

(a) Relatively long to avoid concentrating stress and permit contact surfaces to wipe each other clean as contact is made.

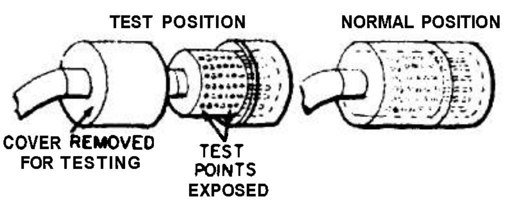


Figure 23-40. Test Points With Built-In Covers as Part of Connector Plug

(b) Made of beryllium copper where contact is to be frequently stressed—copper is adequate for most other purposes.

(c) Not stamped from flat metal—these tend to resume flat shape after a number of flexings.

(7) Plate contact surfaces with nontarnishing materials such as:

(a) Gold—a perfect plating material but very costly.

(b) Cadmium—satisfactory for most purposes.

(c) Silver—may be used wherever its tendency to migrate in humid environments does not interfere with circuit operation.

(d) Other materials acceptable to the user.

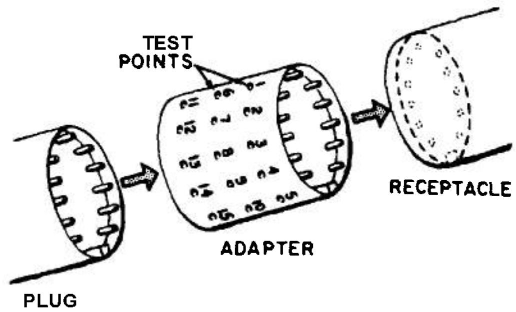


Figure 23-41 Adapter With Test Points for Insertion Between Plug and Receptacle

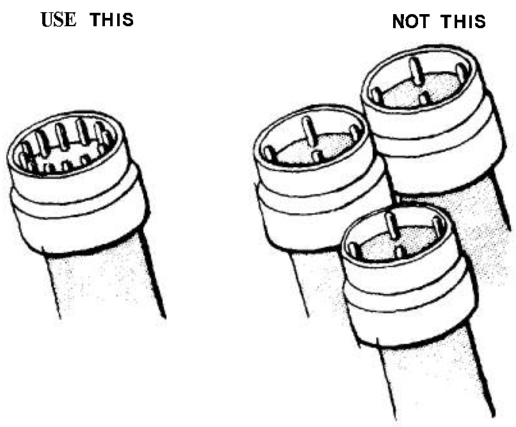


Figure 23-42. Use Fewer Plugs With Many Pins Rather Than More Plugs With less Pins

23-13 CABLING AND CONNECTORS CHECKLIST

A checklist summarizing the important maintainability design features relating to cables and connectors is given in Table 23-3. The checklist contains several items which were not discussed separately in the text. These items are included here because their necessity in the design is so obvious that they might otherwise be inadvertently overlooked. In using the checklist, if the answer to any question is *no*, the design should be restudied to ascertain the need for correction.

TABLE 23-3. CABLING AND CONNECTORS CHECKLIST

Cables

1. Are cables of sufficient length so that each functioning unit can be checked in a convenient place?
2. Is it possible to move units which are difficult to connect when installed in convenient positions for connecting and disconnecting?
3. Are cable harnesses designed for fabrication in shop as a unit?
4. Are all cables color coded and both ends tagged? Are colors selected which cannot be confused because they are too nearly alike or may not be recognized because of poor illumination?
5. Are cables and lines directly accessible to the technician wherever possible (not under panels or floor boards which are difficult to remove)?
6. Are cables routed so they need not be bent or unbent sharply when being connected or disconnected?
7. Are cables routed so they cannot be pinched by doors, lids, etc., or so they will not be stepped on or used as hand holds by maintenance personnel?
8. Are cables or lines attached to units which can be partially removed (chassis on slide racks) and attached so unit can be replaced conveniently without damaging cable or interfering with securing of unit?
9. Is a 3-in. minimum clearance provided wherever possible between control cables and wiring, or physical means provided to prevent chafing? (Designer must anticipate potential chafing hazard.)
10. Is electrical wiring routed away from all lines that carry flammable fluids or oxygen?
11. Is care taken in design of cable conduits to prevent collection of water or debris which could interfere with operation of a control system (freezing or short circuiting)?
12. Is the necessity for removal of connectors or splicing of lines avoided?
13. Is direct routing through congested areas avoided wherever possible?
14. Are cable entrances on the front of cabinets avoided where it is apparent they could be "bumped" by passing equipment or personnel?

Connectors

1. Are adjacent solder connections far enough apart so work on one connection does not compromise integrity of adjacent connections?
2. Are connector plugs designed so that pins cannot be damaged (aligning pins extended beyond electrical pins)?
3. Are self-locking safety catches provided on connector plugs rather than safety wire?
4. Are connectors designed so that it is physically impossible to reverse connections or terminals in the same or adjacent circuits?
5. Is the use of special adapters for sake of standardization avoided since these are often lost?
6. Are electrical connectors protected from possible shorting through contact with external objects? Are adequate covers provided on electrical connectors to prevent foreign matter from shorting out the connector?

TABLE 23-3. CABLING AND CONNECTORS CHECKLIST (cont)

7. Are separate ground connections provided for each voltage regulator so that a single grounding failure does not cause failure of several other systems?
8. Are quick-disconnect devices used wherever possible to save time and minimize human error which could occur in soldering, etc. (fractional-turn, quick-snap action, press-fit, etc.) ?
9. Are unkeyed symmetrical arrangements of aligning pins on connectors avoided?
10. Are electrical terminals plainly marked + (plus) or — (minus) since the caps which are usually marked may be lost?
11. Do markings on plugs, connectors, and receptacles show proper position of keys for aligning pins for proper insertion position ?
12. Is the use of identical fittings avoided by staggering location, varying lengths, size or shape, or by shape, symbol or color coding?
13. On cable connected removable units, will plug and receptacle disconnect before cable breaks ?
14. Are connectors located for easy accessibility for replacement or repair?
15. Are U-lugs (spade) used in lieu of 0-lugs (ring) where frequent removals are anticipated ?
16. Are connectors for auxiliary equipment used that do not require tools for their operation?
17. If tools must be used to operate connectors, are only standard tools required ?
18. Are connectors requiring no more than one full turn to connect test equipment to a test point used?
19. Can wires be unsoldered and removed without damaging lugs?

SECTION III

DESIGN RECOMMENDATIONS FOR TEST POINTS

23-14 GENERAL

A test point provides a convenient and safe access in determining a significant quantity of a circuit in order to facilitate maintenance, repair, calibration, and alignment. Strategically placed test points provide a technician with a practical means of examining the operational status of the equipment.

23-15 CLASSIFICATION OF TEST POINTS

Test points consist, in general, of the following types (Ref. 6) :

(1) *Major.* Test points provided for checking the overall performance of and localizing trouble in groups of major electronic or electromechanical units.

(2) *Intermediate.* Test points provided for checking the performance of and localizing trouble in equipment groups, major units, and subassemblies.

(3) *Minor.* Test points provided for checking performance of and localizing trouble in specific circuits of a major unit or subassemblies.

(4) *Exposed point.* Test point which is readily accessible when the equipment is in normal operating condition and position.

(5) *Accessible point.* Test point which is accessible without the aid of tools, but which is not exposed.

(6) *Special point.* Test point which is accessible only by tools or other special means.

23-16 FUNCTIONAL LOCATION OF TEST POINTS

The specific test points to be employed in an electronic system should depend upon the operational and tactical demand placed on the system design, and the special needs of a particular service. The number and type of test points should be compatible with test instrumentation (built-in or otherwise) that is available at the place of system use, or at the maintenance or repair activity.

The functional location of test points should be fixed by determining from the maintenance procedures what signals must be available to the technician and at what points they must be available. Test points should make available those signals that the procedures indicate the technician must have in order to maintain the system. Their location must be planned into the system for maximum effectiveness.

A test point (which may be nothing more than a bare wise) should be provided at the input and output for each line replaceable unit. One convenient way to provide these test points is to mount components on one side of a board and wiring on the other side with electrical connection through the board. The advantage of having test points alone on a flat surface rather than in among the parts is that full identifying information for each test point can be stamped on the surface without being obscured by the parts.

It should not be necessary to remove any assembly from a major component to troubleshoot that assembly. This may require special test points on the major components or assemblies. But test equipment and bench mockup access to the outputs and inputs of each line replaceable unit should be provided through the normal interconnecting plugs wherever possible.

23-17 PHYSICAL LOCATION OF TEST POINTS

The physical location of test points has a marked effect on the quality of maintenance. Generally, all test points should be located in one place. But previously developed equipment may have to be used, or the nature of a signal may be such that it does not travel well without being altered in the process of transmission. The designer should keep in mind that the technician needs only an indication that reflects an out-of-tolerance condition of the true signal. If these indications are checked and recorded during engineering tests, they should be adequate for field use. This consideration is particularly pertinent in those cases where the wave shape of the signal is critical and will tend to change in transmission to a test point.

Test points should be accessible in the particular installation. Internal test points should be clustered around the portion of the unit that will be most accessible when installed. There should be only one adjustment control associated with each test point and it should be easily and reliably operated.

23-18 GROUPING OF TEST POINTS

Group or arrange test points on a central panel to facilitate checking and troubleshooting. The test points should be grouped in an orderly fashion which is convenient for sequential checking (see Figure **23-43**). When this is not practical, the alternate arrangements suggested here can be used. They are intended to help the designer evaluate the adequacy of his own plans for test point arrangement.

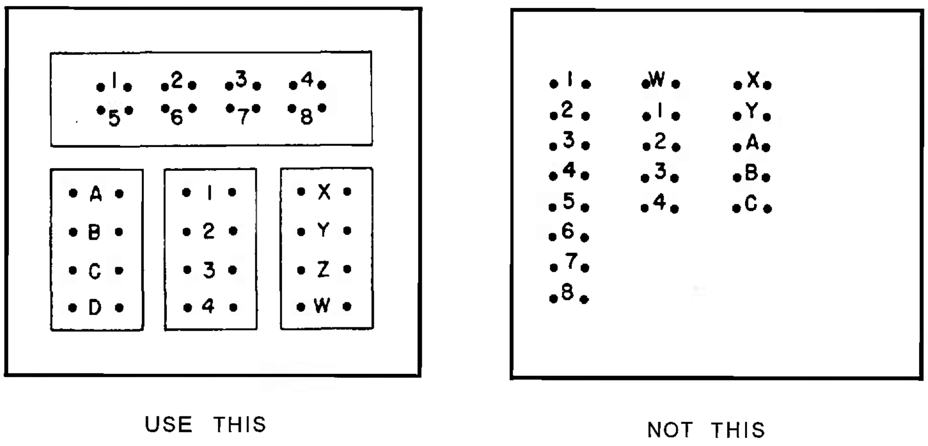


figure 23-43. Grouping of Test Points

(1) *A built-in test unit.* An arrangement built in as part of the installation is most desirable for efficient maintenance and troubleshooting. If voltages and wave shapes must be checked, for example, the test unit might consist of a meter, an oscilloscope, and a rotary switch for selecting circuits, as shown in Figure 23-44(A). The meter and oscilloscope should have fixed, preset circuits so that the meter always reads center scale and the oscilloscope needs no adjustment. Either an in-tolerance meter reading or an in-tolerance waveform on the oscilloscope should be coded for each position of the rotary switch. If more test points are needed than can be handled by a single switch, multiple switches could be used.

(2) *A partially built-in test unit.* Because some oscilloscopes are large, heavy, and expensive, it might not be practical to design a test unit such as that recommended in step (1) for each major component of a system. An acceptable compromise is to mount a center-reading meter on each major component that can be checked by meter and then provide a set of test jacks as an outlet for signals requiring an oscilloscope, as shown in Figure 23-44(B). The selector switch and circuits for this arrangement should be designed as before.

(3) *A portable test unit.* If neither of the two arrangements is practicable because of space or weight limitations, an integrated portable test unit resembling the built-in unit can be designed, as shown in Figure 23-44(C). A single multiprong contact on the end of a cable can be used to attach the test unit.

(4) *A built-in test panel.* If, for some reason, none of the alternatives described above is practicable, a test panel should be provided on the equipment, as shown in Figure 23-44(D). With this arrangement, the outputs of each test point should be designed for checking with standard test equipment, and the points should be planned to provide a miniature block diagram of the system, with each block representing a line replaceable unit. Overlays for the test panel should direct the technician to test points he should check and the order in which he should check them. In-tolerance signals should be shown on the overlays, and test points should be coded on the panel with full instructions provided in the maintenance manual in the event the overlay is lost.

(5) *Test points on replaceable units.* If none of these arrangements is practicable, provide test points for the inputs and outputs on each replaceable unit. If possible, mount components on one side of the board or chassis and wiring on the other side. (See Figure 23-45.) Even if the wiring is mounted on the same side as the parts, test leads should be brought through to the back. An advantage in having test points on the .back is that full identifying information for each test point can be marked on the back without being obscured by parts.

23-19 LABELING OF TEST POINTS

The following design recommendations should observed when labeling test points :

(1) Label each test point with a number, letter, or other symbol that identifies it in the maintenance instructions.

(2) Label each test point with the in-tolerance signal and the tolerance limits of the signal that should be measured there, if possible.

(3) Include the name of the unit in the label, if possible.

(4) Consider color coding test points so that they can be located easily.

(5) Use phosphorescent or chemoluminescent markings on test points, selector switches, and meters that might have to be read in very low ambient illumination.

23-20 TEST POINTS CHECKLIST

Table 23-4 summarizes some of the important features pertaining to the design of test points. The checklist contains several items which were not discussed separately in the text. These items are included here because their necessity in the design is so obvious that they might otherwise be inadvertently overlooked. In using the checklist, if the answer to any question is *no,* the design should be restudied to ascertain the need for correction.

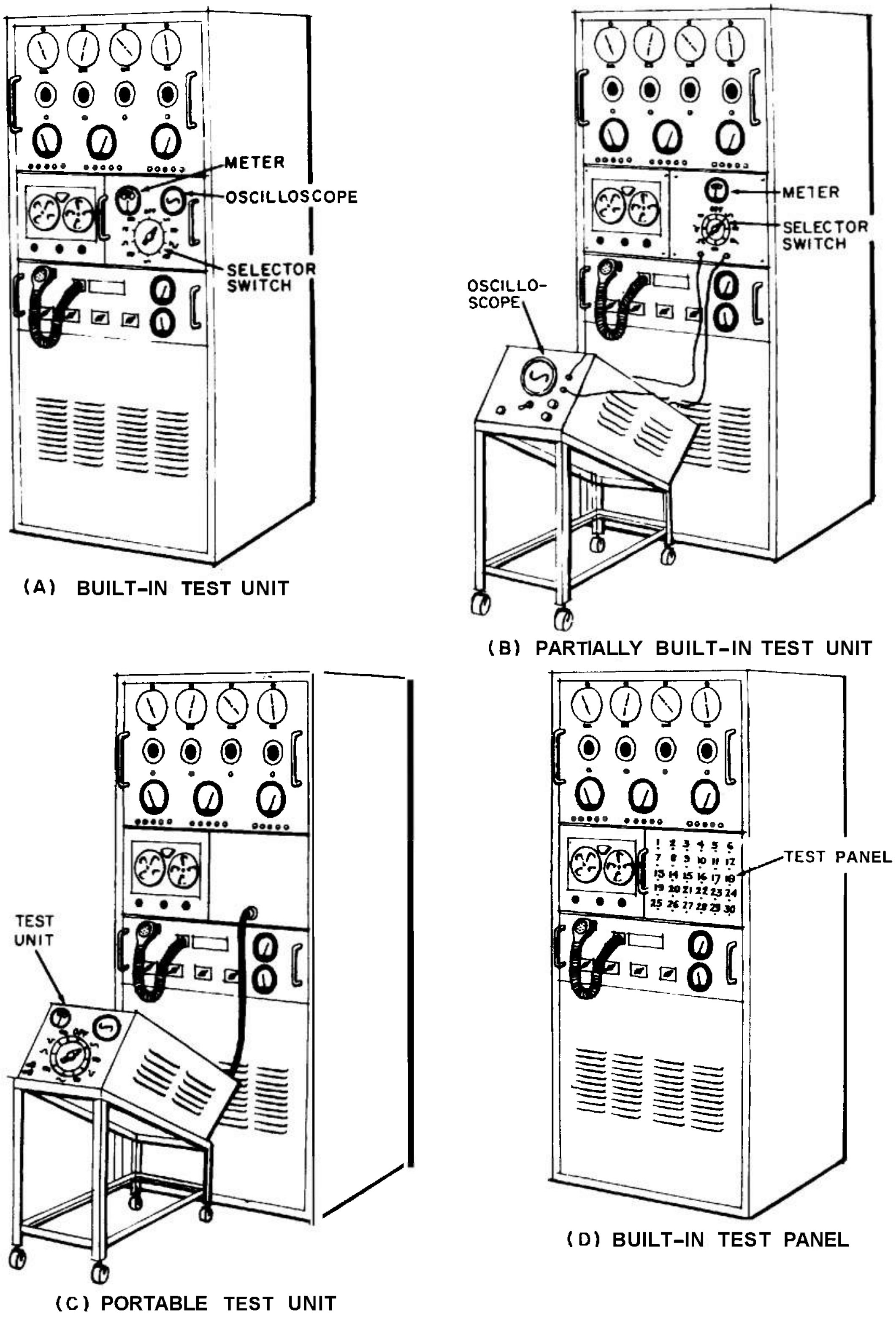


figure 23-44. Alternate Methods for Grouping Test Points

JABLE 23-4. TEST POINTS CHECKLIST

1. Are test points located on front panel wherever possible?
2. Is accessibility of external test points assured under use conditions?
3. Are test points grouped for accessibility and convenient sequential arrangement of testing?
4. Is each test point labeled with name or symbol appropriate to that point?
5. Is each test point labeled with in-tolerance signal or limits which should be measured?
6. Are test points labeled with designation of what output is available?
7. Are all test points color coded with distinctive colors?
8. Are test points provided in accordance with the system test plan?
9. Are test lead connectors used which require no more than a fraction of a turn to connect?
10. Are test points located close to controls and displays with which they are associated?
11. Is test point used in adjustment procedure associated with only one adjustment control?
12. Are means provided for an unambiguous signal indication at test point when associated control has been moved?
13. Are test points located so technician operating associated control can read signal on display?
14. Are test points provided for direct check of all replaceable parts?
15. Are fan-out cables in junction boxes used for checking if standard test points are not provided?
16. Are test points planned for compatibility with the maintenance skill levels involved and not randomly located?
17. Are test points coded or cross referenced with the associated units to indicate location of faulty circuits?
18. Are test points provided to reduce number of steps required: (i.e., split-half isolation of trouble, automatic self check sequencing, minimizing of step retracing or multiple concurrent tests)?
19. Are test points located so as to reduce hunting time (near main access openings, in groups, properly labeled, near primary surface to be observed from working position)?
20. Are test points which require test probe retention provided so that technician will not have to hold the probe?
21. Are built-in test features provided wherever standard portable test equipment cannot be used?
22. Are routine check points provided for the technician without removal from cabinet.
23. Are test points adequately protected, illuminated, and accessible?
24. Are rountine test points provided which are available to the technician without removing the chassis from the cabinet?

SECTION IV
DESIGN OF TESTING AND MONITORING EQUIPMENT

23-21 GENERAL

The trade-off decision factors pertaining to maintenance testing techniques and the selection of types of test equipment (special purpose, general purpose, built-in, and automatic) are discussed in Chapter 5, Section 11. In this section, design recommendations are given for automatic test equipment and three other types of testers: handheld testers, very light, small instruments ordinarily capable of being held and operated by one hand; portable testers, larger and heavier but can be carried from place to place, usually by one man; and console-type testers, large semipermanent fixtures made up of a number of smaller units or subassemblies. The individual units that make up a console are similar in many ways to portable testers. Thus, most of the recommendations for console units are also applicable to portable testers.

The design of test equipment should be in general accordance with MIL-T-21200 **(ASG)**. Test methods should be in accordance with MIL-STD-202.

23-22 AUTOMATIC TEST EQUIPMENT (ATE)

The primary function of ATE is to check the system prior to operation, rather than monitor its function. Thus, **ATE** may be either appended to the prime equipment or independently packaged and connected when needed (in trailers, consoles, etc.). In either case, considerable built-in circuitry is assumed.

The exact nature and character of ATE is so dependent upon the nature of the prime equipment and the circumstances of its use that only the following general design considerations are presented. To be fully effective, ATE should:

(1) Allow connection and "set-up" with minimum time and effort.

(2) Control stimuli to the system undergoing test, e.g., do not allow operating voltage of tester to be impressed on system components.

(3) Be able to evaluate signals from the system against tolerances or standards which can be programmed.

(4) Have fail-safe circuitry throughout both tester and prime equipment.

(5) Self-verify every step in the test procedure.

(6) Automatically sequence test operations.

(7) Automatically verify the proper functioning of the tester.

(8) Automatically localize malfunctions in both tester and prime equipment to the replaceable package or module level.

(9) Be simple to operate and maintain.

(10) Require minimum calibration and support.

(11) Monitor operator displays and provide a permanent record of results.

(12) Provide controls to re-check or by-pass portions of the program.

(13) Provide templates or overlays for use in data reduction.

(14) Impose minimum judgment and interpretation upon the operator.

(15) Allow decisions on a positive, unambiguous, objective basis.

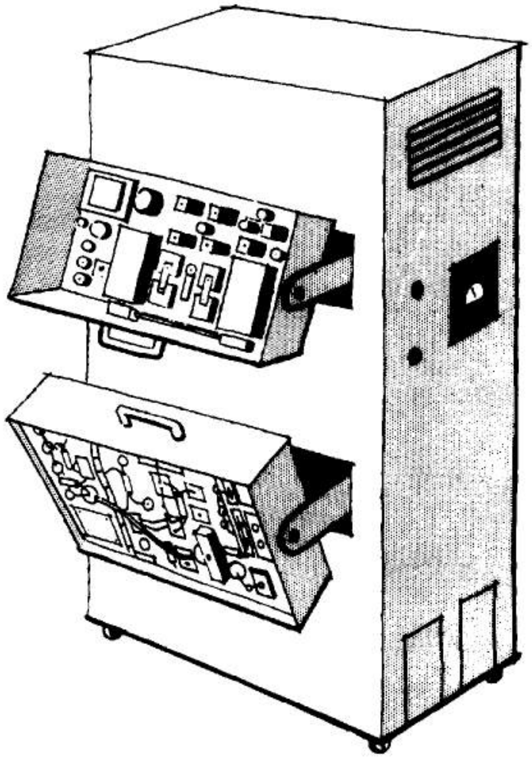


figure 23-45. Test Points on Replaceable Units

23-23 HAND-HELD TESTERS

Specify hand-held testers only for fairly simple testing tasks: when one or, at most, two functions are to be measured; **or** when the operator must make measurements at fairly inaccessible locations. The following design recommendations should be considered :

(1) Hand-held testers should be small, lightweight, and of convenient shape.

(2) Testers should not weigh more than **3** lb and should be capable of being held and operated with the same hand as shown in Figure **23-46**(A).

(3) Provide a grip on the underside of the tester through which the hand can be inserted, as shown in Figure 23-46(B). This will reduce the probability of dropping the tester and will eliminate the necessity of holding the tester with both hands.

(4) Serrate or ridge the underside of the tester to prevent it from slipping out of the operator's hand.

(5) Equip the tester with a string or strap so that the operator can place it around his neck when not in use; the tester can then hang free and permit the use of both hands for other tasks.

(6) Hand-held testers should be as simple, functionally, as possible.

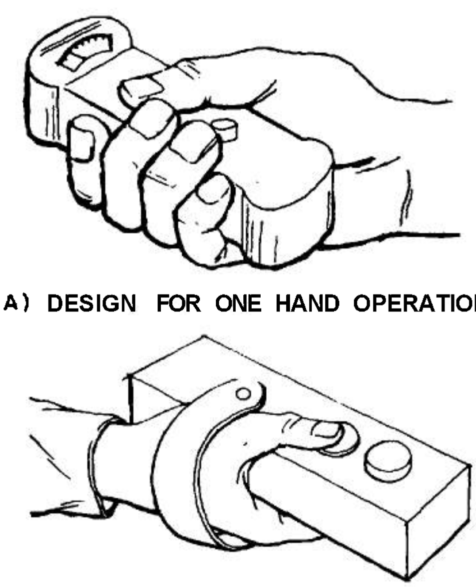
(7) The tester should be self-powered and not require attachment to an electrical outlet. If battery powered, the tester should be designed to give the operator some indication of when to change batteries. For example, have an insert on which is printed "Return tester to maintenance shop before (date) for battery change." The batteries should be sealed, or sealed battery compartments should be provided to prevent equipment damage from corrosion.

(8) The indicator on the tester should be of the simple go/no-go type with a light to indicate out-of-tolerance conditions. If a meter is necessary, tolerance zones should be color coded.

23-24 PORTABLE TESTERS

Specify portable testers when hand-held testers would not be adequate. Consider the following in the design of portable testers:

(1) Use when the number or complexity of functions to be tested would make hand-held testers too heavy or bulky.



(A) DESIGN FOR ONE HAND OPERATION

(B) WITH HAND SUPPORT

Figure 23-46. **Hand-Held** *Testers*

(2) Specify when equipment to be tested will not be located at a permanent testing installation.

(3) Use when **a** number of pieces of equipment have to be tested, and they are separated physically.

(4) Portable testers should be of medium size and weight and approximately cubic in shape.

(5) To facilitate one-man handling, keep the wieght under **14** lb.

(6) If the tester must weigh more than **30** lb, consider providing a stand equipped with wheels or casters.

(7) When the weight is in excess of **100** lb. provide a wheeled base.

(8) For one-man handling, limit the width to 18 in.

(9) Rectangular or square shapes are recommended for ease of storage. If possible, they should be dimensioned to **fit** relay racks for transportation in shop vans in the field.

(10) Design handles of sufficient size and hape to avoid discomfort when carrying, especially the heavier testers (see Paragraph **23-6).**

(11) To conserve storage space consider the use of recessed or hinged handles on portable equipment.

(12) Provide an adjustable harness or sling to facilitate carrying testers.

(13) If the tester has a removable cover, provide handles or grips on the sides of the tester for carrying it when the cover is not attached.

(14) Use rounded corners and edges for safety.

(15) Provide positive latches so that the cover will not open inadvertently when the tester is being carried.

(16) Hinged, permanently attached covers are recommended (see Paragraph 23-8). If the tester must have a removable cover, it should be labeled with the same identification as the tester.

(17) Make warm-up and starting procedures simple and fast.

(18) Provide for go/no-go indications wherever possible.

(19) Print instructions on metal plates and attach them to the tester's panel, cover, or on **a** sliding metal drawer.

(20) Consider the use of a roller type display for presenting instructions.

(21) Clearly label tester connectors with the type of electrical source that should be used.

(22) Provide panel lighting such that the tester can be used under conditions of low illumination or high illumination.

(23) Provide stands on which the tester can be placed while being used.

23-25 CONSOLE-TYPE TESTERS

The following recommendations should be considered in the design of console-type testers :

(1) Use modular design to greatest extent possible (see Chapter 19) and off-the-shelf modular units whenever they are available.

(2) Design equipment so that consoles can be converted from one function to another by the replacement of modules.

(3) Design console units in accordance with the equipment unit design recommendations given in Section I of this chapter.

23-26 OTHER DESIGN CONSIDERATIONS

The general considerations which follow should be observed in the design of test equipment.

23-26.1 ELECTRICAL CONNECTIONS

(1) To perform its function, most test equipment will be connected to a piece of prime equipment or to another tester. Refer to Sections II and III of this chapter for design recommendations concerned with making connections both to receptacles and test points.

(2) Use selector switches on test equipment rather than many plug-in connections (if the effects of switching, i.e., introduction of noise, will not degrade desired information).

(3) Check points, adjustment points, cable-end connections, and labels should be in full view of the technician who will make connections or adjustments at that point.

(4) Do not require the operator to assume an awkward position to make connections. Place receptacles on the side of a tester facing his free work space.

23-26.2 OPERATION AND MAINTENANCE

(1) Make equipment simple to operate and provide self-checking and calibration features.

(2) Design test equipment for one-man operation.

(3) Provide a simple method to calibrate test equipment. Equipment should be equipped with a go/no-go indicator or simple check to determine whether the tester is malfunctioning or needs calibration.

(4) A warm-up indicator should be provided if applicable. Required warm-up time should be indicated clearly near the warm-up switch if no visual signal is provided. Make warm-up procedures explicit.

(5) The tester should incorporate a simple check for testing the accuracy of results.

(6) Attach conversion tables to test equipment when they are needed. Make standards and tolerances explicit.

(7) The purpose of the tester and special caution for its use should be clearly indicated in attached instructions.

(8) Provide set-up procedures on an instruction card attached to the equipment.

(9) Do not require tests necessitating quantitative readings and adjustments by operating personnel. Limit adjustments to those essential and provide for them to be made by means of equipment of the "low-go-high" type. Furnish information by qualitative, positive signaling devices, such as color-code signals and zero-center meters or similar means of indication.

(10) Design equipment either to prevent the operator from making errors or to warn him of his errors.

(11) Clearly label a component or equipment as to whether it is to be used with alternating or direct current.

(12) Provide circuit breakers on all testers to safeguard against damage if the wrong switch or jack position is used.

(13) Incorporate fail-safe features into equipment design to minimize the danger to operator and equipment should failure occur.

(14) Specify regularly stocked standard components and units.

(15) If components are physically interchangeable, make sure that they are also functionally interchangeable.

(16) Test equipment should be built to be as rugged as the conditions of its use will make necessary; that is, equipment to be used in the field should be more rugged than that built for laboratory use.

(17) Design controls, dials, and adjustments to prevent misalignment caused by vibration, service use, or accidental contact.

(18) Provide safeguards against equipment damage from inadvertent human error.

(19) Provide equipment with devices to insure that the equipment is turned off when testing is completed.

(20) Power switches should shut off automatically when the tester lid is closed.

(21) Include on the tester panel a device to indicate that power is on.

(22) Design controls to prevent equipment damage if it is operated at the wrong time or in the wrong manner.

(23) Locate delicate components where they will not be damaged while the unit is being worked on.

23-26.3 SAFETY

(1) Design equipment so that personnel handling it are protected.

(2) Avoid sharp edges, projections, and dangerous hinged devices.

(3) Shield all exposed moving and cutting parts.

(4) Provide covers of rubber or other appropriate material over protrusions, rails and corners with which operators might come in contact.

(5) Heat-producing equipment should be located or shielded to avoid burning the operator.

(6) Design equipment interlock switches that break electrical circuits when removal of a cover or panel exposes high voltage areas.

(7) Do not locate internal controls close to dangerous voltages or other hazards.

(8) Insulate exposed shock sources that must be located near controls. Locate controls so that operator movements do not cause contact with equipment that could cause injury. Insulate or guard high voltage areas and high current switching devices if there is danger of personnel contacting them.

(9) Do not route power cables through switches that personnel in remote locations are likely to switch off or on while the equipment is being checked.

(10) Wherever potential injury exists, provide adequate warning signs. (Refer also to Chapter **15** for additional safety considerations.)

23-27 TEST EQUIPMENT CHECKLIST

A summary of some of the important test equipment design recommendations is presented in Table **23-5.** The checklist contains several items which were not discussed separately in the text. These items are inculded here because their necessity in the design is so obvious that they might otherwise be inadvertently overlooked. In using the checklist, if the answer to any question is no, the design should be restudied to ascertain the need for correction.

TABLE *23-5.* TEST EQUIPMENT CHECKLIST

1. Are the instructions for using test equipment in step-by-step format?
2. Is a signal provided which shows when the test equipment is warmed up?
3. If it is not feasible to present such a signal, is the warm-up time required clearly indicated near the warm-up switch?
4. Is a simple check provided to indicate when the test equipment is out of calibration or is otherwise not functioning?
5. Is appropriate indication of test equipment performance provided so the technician does not attempt to measure with a faulty standard or instrument out of calibration?
6. Do test equipment displays which require transformation of values have conversion tables attached to the equipment with the transform factor by each individual switch position or display scale?
7. Is adequate support provided for test equipment which must be taken into the

TABLE 23-5. TEST EQUIPMENT CHECKLIST (cont)

work area so the technician does not have to hold the test equipment or take separate support devices to the work area for this purpose? 8. Are built-in test features provided wherever standard portable test equipment cannot be used? 9. Does portable test equipment packaging reflect the manner in which the equipment will be carried (i.e., size, shape, e.g., location of hand grips, clearance of technician's leg and of the floor, etc.)? 10. Does portable test equipment weigh under 14 lb. if it is to be carried by one man? 11. Do plugs, jacks and binding posts used for test of test equipment appear on outer casing of equipment so it is not necessary to remove the case? If internal repair requires removal of case, are duplicate jacks, plugs, etc. provided on chassis so jury-rig connections to the case are not necessary?	12. Are display lights, automatic power switches, or printed warnings provided to insure that test equipment is turned off when testing is completed? 13. Is storage for cable and test leads (within test instrument case or lid) designed so loose cable cannot interfere with closure of case? 14. Is purpose of test equipment and special cautions displayed in a conspicuous place on the outer surface of the test equipment? 15. Are units which are not self checking designed to be checked in the operating condition without the aid of special rigs and harnesses wherever possible? 16. Are selector switches provided in lieu of a number of plug-in connectors? 17. Is test equipment designed so as to be capable of connection to prime equipment within two minutes?

SECTION V
ELECTRICAL EQUIPMENT

23-28 GENERAL

This section presents general design recommendations for electrical equipment. Included also are recommendations for some specific electrical-electronic items, such as batteries, fuses, electrical machines, etc.

23-28.1 ELECTRICAL SYSTEMS

Electrical and electronic equipment should be designed in general accordance with MIL-T-21200(ASG), MIL-E-5400, and MIL-STD-202.

23-28.2 ELECTRICAL STANDARDS

Electrical and electronic equipment should be designed in accordance with the following electrical standards:

(1) Electrical systems used in conjunction with commercial power sources should conform to the National Electrical Code, the Joint Industry Conference standards for electrical equipment, and the National Machine Tool Association machine tool electrical standards.

(2) Electrical system components should conform to standards of the National Electrical Manufacturers Association.

(3) Explosion proofing requirements should conform to the standards specified for Aircraft Hangars as a Specific Occupancy in Article 510 of the National Electrical Code.

(4) Vehicle electrical systems should conform to applicable Army Materiel Command standards for tactical vehicles and to SAE standards for commercial vehicles, where applicable.

23-28.3 ELECTRICAL INTERFERENCE AND TRANSIENT VOLTAGES

The operation and servicing of electrical equipment should not be adversely affected by radio interference or stray magnetic fields generated by nearby sources. Similarly, the equipment itself should not adversely affect the operation of other nearby equipment. Field tests should be made by the design activity to ensure that equipment can be operated and maintained without such external interference.

Electrical and electronic equipment should also be designed to resist externally generated surge or stray voltages capable of puncturing insulation or burning out parts or components. Traps or isolation techniques should be incorporated in the circuit design to accomplish this. Typical examples would be a choke coil, or a dynamotor interposed between the equipment and the outside source of energy.

23-28.4 PROTECTION AGAINST HEAT

Do not locate components susceptible to heat damage in close proximity to heat-generating sources. Where possible, shields should be installed to protect heat sensitive components, and ventilation from an ambient air source could be provided to facilitate cooling.

23-29 BATTERIES

(1) Batteries should be installed in locations away from sources of heat and be protected in such a manner as to ensure satisfactory functioning within the maximum and minimum operating ambient air temperature limits.

(2) Battery holders should be rugged and have easily operated clamping devices, not requiring the use of tools, to firmly hold the battery in position against all vibrations, motions, and traveling under gunfire shocks.

(3) Batteries should be capable of rapid and easy removal by one man for servicing and replacement without removing other items of equipment or without requiring special tools.

(4) Complete freedom of access for replenishing the electrolyte, and testing the specific gravity and voltage should be provided. Use of loose filler caps should be avoided whenever possible.

(5) Dust caps should be provided so battery terminals cannot contact metal surfaces during handling, removal, or replacement.

(6) Battery supports, hold-downs, and areas around the installation which could possibly be affected by dripping or seepage of acids should be protected with acid-proof paints or coatings. Battery cases should be drained overboard with acid-proof piping when required.

(7) Batteries should be located in well ventilated areas and have facilities to prevent freezing when necessary.

(8) Batteries should not be charged in a poorly ventilated compartment where explosive mixtures of hydrogen and air may result.

(9) Specify batteries with special filler caps employing a palladium catalyst to reconvert hydrogen and oxygen into water, thus reducing noxious fumes in the battery area.

(10) Only electrical fixtures approved for hazardous locations should be used in battery compartments to prevent gas explosions.

(11) Quick-disconnects should be provided on battery leads for power-off maintenance or emergencies.

(12) Labeling should be provided as necessary to identify the battery as to type, voltage, polarity, and safe rate of charge: i.e., the'rate which will preclude production of dangerous concentrations of hydrogen gas and excessive heat. All related terminals, connectors, contacts, and leads that are part of the battery circuit should also be identified. When practical, a block or pictorial wiring diagram of the battery circuit should also be provided.

(13) Batteries with "dry" electrolytes should be installed in accordance with the preceding requirements, as applicable, except that certain type dry batteries may be installed in sealed containers without ventilation. Dry electrolytic batteries should be mounted in housings which will keep them dry from water, moisture, and contaminants. "Plug-in" designs installed without tools or loose parts should be used wherever possible.

(14) To increase the shelf life of dry batteries, encapsulate the batteries in plastic films or by packaging in water tight metal cases. Batteries should be stored in cool places.

23-30 FUSES AND CIRCUIT BREAKERS

Protective devices should be provided within equipment for primary circuits and such other circuits as required for protection of the equipment from damage due to conditions such as overload and excessive heating. All parts which are likely to carry an overload, due to malfunction of circuits, poor adjustments, antenna or tube casualty, or other deleterious effects, should be designed to care for such an overload. Where this is impractical, circuit breakers, relays, fuses, or other devices should be included to protect the affected parts. The use of secondary protective devices should be held to a minimum consistent with good engineering practice (see also Chapter **15.)**

Additional design considertions are as follows :

(1) Fuses (or circuit breakers) should be provided so that each unit of a system is separately fused and adequately protected from harmful powerline variations or transient voltages.

(2) When fuses are used, they should conform to **MIL-F-15160.**

(3) Fuses should be located on the front panel of the unit where they can be seen and replaced without removing other parts. Fuses should not be located inside the equipment.

(4) Fuses should be grouped in a minimum number of central, readily accessible locations and should be replaceable by the equipment operator whenever possible without the use of tools.

(5) Fuses should be provided which safeguard the circuit if the wrong switch or jack position is used, and overload indicators should be provided on each major component.

(6) Spare fuses should be provided and located near the fuse holder, and labels adjacent to the fuse holder should provide both fuse value and function. (If space is limited, provide fuse value rather than fuse function.)

(7) Fuse holder cups or caps should be of the quick-disconnect rather than screw-in type, and should be knurled and large enough to be easily removed by hand.

(8) To protect the fuse and fuse holder against corrosion, whenever practicable, coat the fuse (including the contact surfaces) and the interior of the fuse holder with a silicone electrical lubricating compound. The exterior of the fuse holder, except contact surfaces, should be coated with fungicidal varnish. If possible, sealed fuses should be used.

(9) Design fuse installations so that only the "cold" terminal of the fuse can be touched by personnel.

(10) Consider the current overload capabilities of one-time standard fuses, as shown in Table 23-6. One-time fuses are used for most applications where circuits are not subject to frequent overloads. These fuses are discarded after they are once called upon to function. One-time standard fuses are designed to carry continuously **110%** of their rated current in open air and to operate instantly in case of a short circuit. Such fuses, however, will carry an overload for a few minutes before opening as shown in the Table **23-6.**

TABLE 23-6. MAXIMUM BLOWING TIME OF STANDARD ENCLOSED FUSES (Ref. 7)

Fuse Rating (Amperes)	Maximum Blowing Time (min.)	
	On 135% Current	On 200% Current
0- 30	60	2
31- 60	60	4
61-100	120	6
101-200	120	8
201-400	120	10
501-600	120	12

(11) When selecting fuses or circuit breakers, consider the suitability of each to perform a particular function, as shown in Table **23-7.** Two types of circuit breakers are listed : thermal air and magnetic air. Thermal air circuit breakers are used primarily for overcurrent circuit protection. They are best adapted to d.c. circuits up to **250** volts, and to a.c. circuits up to 600 volts in capacities up to 600 amperes. Magnetic air circuit breakers may be used to provide protection in event of overcurrent, undercurrent, reverse current, low voltage, reverse phase, etc.

23-31 RELAYS

Essentially, relays are switches which are often used as circuitry protective devices. As a switch, the relay opens or closes a circuit when its contacts are brought together. It is in the contacts that many relay maintenance problems are encountered. As the contacts are opened or closed in the presence of an active gas, such as oxygen, oxidation occurs as a consequence of arcing, resulting in a smaller contact surface, increased arcing, and increased oxidation. Since oxides act as an insulating layer, ultimately the relay will fail to function,

The following recommendations should be observed in the design of relays:

TABLE 23-7. GENERAL COMPARISON OF FUSES AND CIRCUIT BREAKERS (Ref. 7)

Desired Function	Fuse	Circuit Breaker Thermal Air	Circuit Breaker Magnetic Air
Instantaneous action	X		X
Time delay features	X	X	X
Resetting		X	X
Adjustable tripping range for other than maximum setting			X
Automatic resetting			X
Remote con-trol resetting and tripping			X
Overcurrent protection	X	X	X
Low current, reverse cur-rent, reverse phase, and low voltage protection			X

(1) If possible, design circuits so as to avoid the use of relays.

(2) Relay contacts should be the largest size practical and be made of the highest grade of arc resistant material.

(3) Use mercury-type relays whenever possible.

(4) To avoid oxidation of relay contacts, glass enclosed vacuum or gas filled relays should be used. If circuit is extremely critical, consider "out-gassing" of materials after periods of storage even though a vacuum initially prevailed.

(5) Hermetically sealed relays should be used for applications in moist or salty environments.

(6) Natural organic insulators, such as paper or cotton, can contribute to corrosion of windings in the presence of moisture or high direct current potentials. To reduce these effects, synthetic insulating materials should be used in the construction of relays.

(7) Relay operation can cause transients in the power supply if large currents are applied or interrupted by the relay. If operation at minimum current is not possible, decoupling networks and filters may be necessary.

(8) The time delay between application of coil current and the closing of contacts will increase with the life of the relay as spring members fatigue. If close timing is important, it is recommended that external circuits, copper slugs in the relay core, or air dashpots be used to control the delay.

(9) The effects of shock and vibration can be decreased by using relays with contacts that are mounted on short, thick supports. Wiping, or follow-through contacts, such as used in a stepping relay, should be used when subjected to shock and vibration. Relays should be used in the energized position, if possible, as the holding force is greater, and there is less danger of inadvertent opening. Adequate current should be supplied to the coil to obtain the most armature attraction.

23-32 RESISTORS AND CAPACITORS

Electrical and electronic circuits should use resistors and capacitors which have the widest praticable tolerances of value and temperature. Resistors or capacitors in series or parallel connections should not be used in place of a single component having the correct rating. Use series or parallel connections in such applications as attentuators, voltage dividers, and trimmer capacitors.

In addition to derating for ambient temperature conditions, resistors and capacitors should be derated by at least 75% of the normal peak load to increase both component reliability and long life. Derating should be made after the components have been selected according to the nominal values and tolerances given in applicable Government standards. The application of these components in circuit design should take into account the transient voltage requirements discussed in Paragraph 23-28.3.

23-33 ELECTRON TUBES

Electron tubes should be designed in accordance with MIL-E-1- and selected as prescribed in MIL-STD-200. Tube applications should follow the requirements specified in MIL-HDBK-211. The designer should incorporate in electron tube circuit design the highest practical derating that can be achieved consistent with available space and product performance. (see Paragraph 23-35.5). Circuit design should also ensure that replacement of electron tubes does not require recalibration of associated equipment. No new tubes should be developed by the design activity ; however, if circuit design requires the use of new type tubes, the need must first be approved by the pertinent U. S. Army procuring activity *before* use.

23-34 TRANSISTORS

Transistors should be selected in accordance with MIL-STD-701. Adequate and effective provisions should be incorporated in circuit designs to prevent over-voltage damage to the transistor. The design should also reflect the highest practical transistor derating possible consistent with product performance (see Paragraph 23-35.5).

23-35 ELECTRICAL MACHINES

Electrical machines, such as generators, motors, synchros, dynamotors, inverters, alternators, etc., are often a very vital, if not the most vital component of a weapon, commodity or system. They are, however, invariably expensive and difficult to repair. Too much emphasis cannot be given to ensuring that the highest quality of materials and techniques known to the state of art are incorporated in these machines. Although these machines can be built to give many years of total reliability, past deficiencies in good maintainability design has too often resulted in heavy maintenance costs to the U S Army.

The criteria that follows presents design recommendations for four major component areas of electrical machines : windings, bearings, brushes, and commutators.

23-35.1 WINDINGS

Any deficiencies in coil windings, which causes intermittent or short-circuit operation, will destroy the efficiency or operation of the entire electrical machine. The design criteria presented in the paragraphs which follow should therefore be considered to reduce electrical machine malfunctions due to faulty windings.

23-35.1.1 Wires and Connections

Broken or burned-up wires are the usual causes which destroy the efficiency or operation of electrical machines. To prevent these faults the following should be observed:

(1) All terminals of windings of motors, generators, solenoids, coils and similar types of electrical and electronic equipment should terminate inside the winding if the wire is smaller than 0.042 in. diameter.

(2) The ends of windings should be soldered, brazed, or welded to a separate larger wire or metal strip which makes at least one turn around the coil, terminating in a rugged mechanical joint. The end of the large wire or strap should then protrude through the insulation or potting where it may be suitably attached to its outside service wire or terminal. In service applications, where damaging vibration may be present either by the self-induced vibration of the unit or transient vibration from

external sources, the large wire or metal strip should be made of a fatigue resistant material such as beryllium, alloyed copper, or bronzes. The larger wire of metal strip should be suitably treated to prevent the entrance of moisture into the windings either directly by wick action, or by leakage of the potting compound.

(3) Service leads to field coils, etc., should be of braided wire to absorb vibrations and combat fatigue unless the machine design employs leads of heavy bar stock capable of resisting all vibrations.

23-35.1.2 Internal Maintenance Deficiencies

Internal maintenance deficiencies of windings result mainly from insulation breakdown which are primarily due to:

(1) Poor grade of insulation.

(2) Insulation incapable of resisting normal heating.

(3) Vibration which causes mechanical breakdown of insulation.

(4) Entrance of moisture causing local or general breakdown.

(5) Insufficient cooling.

(6) Aging.

(7) Continuous pressure of one wire against another, causing thinning of insulation and reduction of its dielectric strength.

To reduce these maintainability deficiencies, the following recommendations should be observed :

(1) Select wire insulation which will withstand high temperature, e.g., silicones, phenolics, melemine, etc., and continue development of superior materials. Do not use insulation which will permit wicking of moisture.

(2) Select wire insulation having little or no plasticizers or age-producing characteristics.

(3) Inspect wiring on an "inch by inch" basis to insure that there are no local holes or reduction of dielectric strength.

(4) Vacuum impregnate or pot and seal all windings and coils wherever possible (see Paragraph **23-35.1.3).** The baking process, which imparts good mechanical strength, should be given careful attention in design. When the wire is surrounded with the impregnating material, it imparts mechanical strength to support the wire. The normal insulation on the wire does not then have to entirely support the mechanical loads of one wire as it passes over another wire. This embedding action aids in increasing the dielectric strength of the wire, supports the wire while it normally expands and contracts, reduces damage from vibration, excludes moisture, and often helps in "piping" the heat out of the center of the coil.

(5) Perforate poles, when necessary, to aid in cooling windings.

(6) Provide a built-in fan (and external fins when possible) to supply a flow of cool air through or around the windings of continuously operating machines. Consider cooling fins in the design of housings of noncontinuous operating machines.

(7) Use high purity metals to retard corrosion of windings in open-type constructions. Chlorides, sulfides, and other soluble salts should be avoided. Where temperature permits, the use of a highly resistant material, such as Mylar, is recommended. **A** coating with a moisture resistant fungicidal varnish will also be beneficial.

23-35.1.3 Techniques for Prevention of Insulation Breakdown

Two manufacturing techniques can be used to prevent inuslation breakdown : vacuum impregnation and potting and sealing.

23-35.1.3.1 Vacuum *Impregnation* All coils and windings of electrical or electronic equipment, except, if satisfactory, those contained in hermetically sealed cases, should be thoroughly dried and then vacuum impregnated with varnish conforming to MIL-V-1137, or better. The varnish should completely cover the wires so that it will *support* and *additionally insulate* each wire from the other. Wherever possible (or practical), varnished coils and windings should be baked to set the varnish and drive out the solvents.

23-35.1.3.2 *Potting and Sealing* The practice of potting, filling, and sealing coils and electrical and electronic assemblies should be considered, when applicable. Electrical and electronic assemblies, potted or embedded, are those which are classified as modules and not subject to repair, and should be considered accordingly.

Care should be given to the selection of materials which are as nonhydroscopic as practical. Filling, potting, or sealing compounds, liquid or solid, should enclose all voids and air spaces, and should preferably be vacuum impregnated. Prior to filling, potting, or sealing, the coils should be pre-treated to remove all moisture. If there is any danger of moisture entering the coil, durable sealing compounds should be used instead of impregnated coils. Embedding compounds should conform to MIL-I-16923 Type D, or better.

23-35.2 ELECTRICAL BEARINGS

Bearings for electrical machines should be adjustable for wear to ensure that armatures can be kept centered in the field poles. This will prevent the armature from rubbing the field poles, causing excessive friction heat which often burns up electrical machines. Housing designs should permit easy and rapid replacement of bearings. (see also Chapter 22).

23-35.3 BRUSHES

Consider the following criteria in the design of brushes :

(1) Brushes on electrical machines should be easily and rapidly replaced without removing more than a dust cover.

(2) Use "bayonet type" brush holders wherever possible to permit the replacement of brushes from outside the housing without the need of removing or replacing covers.

(3) Where brush holder cages are required, an easily removed cover, exposing the cage to obtain good access, should be used. Where pigtails are required, the attaching screws should be readily accessible and should not require full removal to replace the brush. All parts of the brush holder cage should be captive with a minimum of loose parts.

(4) Electrical machines should not incorporate split-line design outside housings where the split-line parts over the field poles, and where the bearings or brushes are mounted in these housings.

(5) Provision should be made for brushes to be periodically cleaned, and a means of positive lubrication should be provided.

23-35.4 COMMUTATORS

Commutators for electrical machines should be made of the best wear- and arc-resistant materials commensurate with the state of the art. Segments should be designed with deep "undercuts" to prolong the service time between maintenance.

23-35.5 DERATING

All components of electrical and electronic equipment should be *derated* to ensure that its output capability or size has a *dynamic* factor of safety. This factor of safety is necessary to prevent overloads not readily apparent in new items, or due to unexpected service conditions. Derating also provides longer equipment life with less required maintenance and increased maintainability. As a general rule, equipment should be derated to the maximum extent permitted by cost, performance, weight, or space provisions. Reliability organizations should establish the methods and specifications for derating all components of electrical equipment based on the QMR (Qualitative Materiel Requirement) specifications, etc.

Derating percentages should be specified on all vital components. Two examples of derating are given here.

(1) *Electrical machine derating.* Electrical machines should be derated to ensure against overload. This can be accomplished by specifying machines having a capability of supplying the maximum service load horsepower demand within 75% of the full continuous capability and rating of the machine.

(2) *Power pack derating.* Power packs for electronic equipment, generally consisting of transformers and rectifying tubes or vibrators, should be capable of supplying the maximum wattage demand of the equipment, with no more than 75% of the proven continuous capability of the power pack (derated).

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CHAPTER 24
FIRE CONTROL MATERIEL

24-1 GENERAL

The guidelines presented here are offered to designers for their consideration and incorporation into new fire control equipment. They are grouped into the following characteristic equipment categories: optical, mechanical, hydraulic, and combinations of these.

24-2 OPTICAL EQUIPMENT

General design guidance in the field of optical equipment is as follows:

(1) Avoid the use of injection sealing if it is possible to obtain a satisfactory seal with gaskets; injection sealing may be used in non-maintained items.

(2) Whenever practicable, a metal-to-metal sealing technique, which uses an insert of rubber or similar material, should be adopted. This technique is preferable to luting or the use of sealing compounds.

(3) Means of pressure testing and desiccating sealed instruments or assemblies without having to readjust or reset them afterward should be provided.

(4) Carrying cases for optical instruments should incorporate a desiccant container which seals off the desiccant material when an instrument case is open; when such an arrangement is impractical, cases should be fitted with replaceable screw-type desiccators.

(5) Provide humidity indicators on sealed instruments to permit proper cycling of purging operations.

(6) Optical equipment should be made moisture-proof and fungus-proof wherever practicable.

(7) Use standard types of seals wherever practicable.

(8) Whenever possible, design optical instruments with built-in features for collimation.

(9) Provide shock mountings for optical equipment. Also, provide shock mounting or cushioning in stowage and shipping containers.

(10) Use quick-release methods of removing optical instruments from mounts wherever practical.

(11) Design mounts for coated or bloomed optical components so when recoating is necessary they are easy to remove from their respective cells or mounts.

(12) Provide built-in aligning devices and other aids wherever possible to increase the ease of positioning optical elements.

(13) Provide built-in lighting features in optical equipment wherever practical. Use miniature-type batteries and consider the use of a sealed battery compartment to protect equipment in case of battery leakage.

(14) Reduce the number of adjustments required.

(15) Provide a means of purging and charging optical instruments where feasible.

(16) Provide an instruction plate or waterproof decal indicating the time interval and pressure requirements where instruments are periodically purged and charged.

(17) Provide access to purging and charging fittings.

(18) Do not apply reflecting coatings to optics such as reticles, field lenses, and collective lenses that lie in or very near the fecal point of the eyepiece assembly.

(19) Use the metric system when designing ballistic reticles for optical instruments.

(20) Provide windows for all exposed optical surfaces.

(21) Avoid the use of slotted lens retainers. Wrenches used with slotted lens retainers raise burrs and damage mating threads. Provide holes for pin-type wrenches to eliminate raising burrs.

(22) Avoid the use of long, uninterrupted threads for lens retainers. Unnecessarily long threads cause excessive wear on retainer thread finishes and allow dirt to fall on the optics.

(23) Avoid silvered surfaces whenever possible.

(24) Design optical equipment so as to provide interchangeability of optical assemblies within an instrument.

(25) Specify realistic dimensions for optical components. This will minimize the adjustments required after replacing components or assemblies.

(26) Use either noncorroding material or material treated with a preservative finish for all components, including nuts, grub screws, bolts, and springs.

(27) Engrave to a reasonable depth all legends and marks on components to avoid the need to re-engrave them after repair.

(28) Choose materials to minimize any electrolytic action between dissimilar metals (see Chapter **10,** Table **10-4).**

(29) Design reticles to provide for:

(a) The reticle to be etched or, where this is not practicable, protected by a cover glass.

(b) Positive location for the reticle in its cell.

(c) Easy access for cleaning.

(d) Access openings to facilitate replacement, adjustment, and cleaning. Instruments are often rendered unserviceable because of dirt and condensate formations on the reticle, and extensive disassembly is often necessary to correct these conditions when adequate accessibility is not provided.

24-3 MECHANICAL EQUIPMENT

General guidance for the design of mechanical equipment is as follows:

(1) Design small part mountings to support a static load of **50** times the weight of the part. Avoid the use of cantilever brackets for equipment that is to be shock tested.

(2) Minimize backlash and torquelash. The effects of backlash and lost motion should be taken into consideration in the selection or design of movable parts.

(3) Use same type socket on all socket set screws.

(4) Use screws, studs, nuts, etc., made of nonferrous material where practicable.

(5) Avoid using dowel pins for the final positioning of mounts on support surfaces provided on the weapon; fixed locating points present a problem when mounts are interchanged. Consider key and keyway, eccentric and keyway, or single dowel pins for the final positioning of mounts.

(6) Eliminate dual doweling. Instead use eccentric dowels, dowels with stopscrews, with slots, with edge-locating shoulders, with keys, etc.

(7) Avoid, where possible, the use of split pins; taper pins are more desirable.

(8) Use split clamp couplings instead of pinned sleeves to facilitate the replacement of parts and adjustments.

(9) Cadmium plate (using the Cronak or an equivalent inhibiting process) ferrous parts that are susceptible to corrosion and are used internally in instruments: phosphate finishes (especially where not oiled) do not protect.

(10) Make mounting bolts easily accessible.

(11) Avoid through bolts having nuts that are inaccessible except through extensive disassembly of adjacent parts.

(12) Do not use socket-head screws where relative inaccessibility would require special or modified hexagonal wrenches.

(13) Use interchangeable fastening devices, and keep to a minimum the number of types and sizes of bolts, nuts, and screws. Where practicable, have lock washers attached to the bolts and screws.

(14) Use fast-acting fastening devices for covers, cover plates, etc., that are of the captive type and do not require special tools (see Chapter **21).**

(15) Study list of available Army tools before designing special rings, retainer nuts, cells, etc. Wherever possible, make design compatible with existing tool, common or special (see Chapter **11).**

(16) Use corrosion resistant, sealed bearings in all fire control materiel except where the sleeve type has a logical application (see Chapter 22).

(17) Use, wherever possible, self-aligning bearings instead of ball caps and sockets in worm gear mechanisms.

(18) Avoid securing bearings by staking; stakes have a tendency to break when in use for prolonged periods of time.

(19) Standardize types and sizes of bearings where practical.

(20) Use oil-impregnated bearings where practical.

(21) Group related subassemblies together as much as possible.

(22) Provide a manual means for the engagement, disengagement, and locking of elevating and traversing mechanisms to facilitate maintenance.

(23) Design doors or hinged covers so they are rounded at the corners, and provide slip hinges and stops to hold them open (see Chapter 23, Section I).

(24) Provide access openings for instrument adjustment (see Chapter 12).

(25) Provide external access to internal adjusting devices.

(26) Provide, in mounting fire control components, access to both sides of the equipment, and leave sufficient hand room for the technicians to remove and replace parts.

(27) Locate high-mortality parts near access openings.

(28) Make lubrication points easily accessible and clearly mark them (see Chapter 16).

(29) Standardize knob set screws so that a stanaard diameter and thread are used for a given shaft diameter.

(30) Standardize tolerances on similar parts for interchangeability.

(31) Standardize the method of pinning gears; use set screws where keyways or splines are used.

(32) Specify, in high-speed applications, mating gears to be of materials having dissimilar wear characteristics.

(33) Provide personnel with protection from moving mechanical parts by the use of guards, safety covers, warning plates, etc (see Chapter 15).

(34) Provide covers or boots for exposed couplings, universal joints, etc.

24-4 HYDRAULIC EQUIPMENT

Consider the following recommendations in the design of hydraulic equipment:

(1) The design of hydraulic systems should conform to MIL-H-5540; design of hydraulic reservoirs should conform to MIL-R-5520.

(2) Use elbows and adapters to ensure compact installations for quick inspection and maintenance. Such adapters also reduce weight by requiring shorter lines (see Figure 24-1).

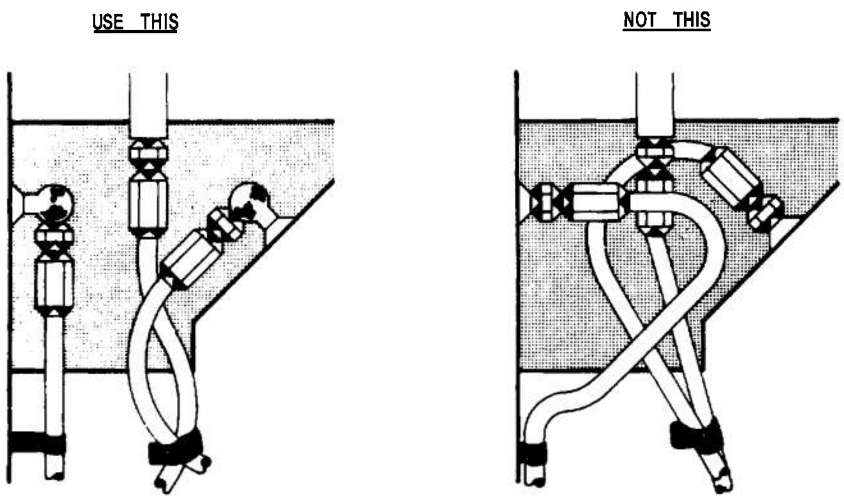


Figure 24-1. Use Elbows and Adapters on Hydraulic Lines

(3) Use adapters, couplings, and hose assemblies that do not require special tools, wherever practicable.

(4) Standardize, where practical, valves and cylinders, hose assemblies, coupling, fittings, and filters.

(5) Use quick-release fastening devices on connections that require frequent disconnection. Provide self-sealing features to prevent leakage of fluid when disconnect is made.

(6) Use shock-proof pressure gages on all mobile equipment.

(7) Select gages that have an external pointer adjustment for ease of adjustment and calibration.

(8) Place meters, gages, and control valves in a centralized position.

(9) Use valves with integral limit switches where practicable.

(10) Use permanent or cartridge-type filters.

(11) Use straight-thread O-ring boss connections for high-pressure applications.

(12) Use molded-type clamps, and consider mold materials such as asbestos impregnated with Teflon and materials impervious to oil, corrosive solvents, etc.

(13) Provide, in case of electrical failure, a means for manually operating hydraulic systems.

(14) Use color coding for hydraulic lines, valves, etc.

(15) Provide permanent identification and instruction markings (see Chapter 13), and indicate periodic inspection and drain schedules on them.

(16) Provide mechanical stops for valve handles to prevent the valves opening because of vibration.

(17) Provide for the positive locking of A-end pumps when in the traveling position.

(18) Consider Teflon or equivalent for all hydraulic seals and wipers.

(19) Use seals which are visible externally after they are installed since costly accidents result when seals are left out during assembly or repair (see Figure 24-2).

(20) Use gaskets and seals which do not protrude or extrude beyond the coupling. Protruding seals are chipped and shredded by vibration or contact and the damage spreads internally to destroy sealing power and deposit pieces in the line.

(21) Specify couplings which utilize replaceable seals rather than those which must be removed and replaced when the seal wears out.

(22) Consider the use of armor-covered flexible hose for hydraulic lines to facilitate replacement in the field from bulk stock.

(23) Use aircraft-type safety fittings with built-in check valves in hydraulic lines to limit fluid loss in the event of a line rupture.

(24) Design for automatic bleeding of hydraulic systems wherever possible.

(25) Use relief valves in hydraulic lines to prevent their bursting and injuring personnel.

(26) Provide easily accessible removable fitlers or strainers where possible.

(27) Permanently identify high- and low-pressure lines.

(28) Use standard hardware for mounting hydraulic components.

(29) Ensure that all connectors are standardized by content of lines and that the number of different sizes are held to a minimum. If there is danger of mismating connectors for adjacent lines carrying different fluids, specify physically incompatible connectors for the two lines.

(30) Consider the connector recommendations shown in Figure 24-3.

(31) To prevent fluid spraying or draining on the technician or nearby objects when fluid lines are disconnected during maintenance, utilize the following design recommendations :

(a) Provide line drains at low level access points.

(b) Reposition line disconnects from sensitive components or shield the component.

(c) Provide high visibility warning signs at disconnect areas which are especially critical.

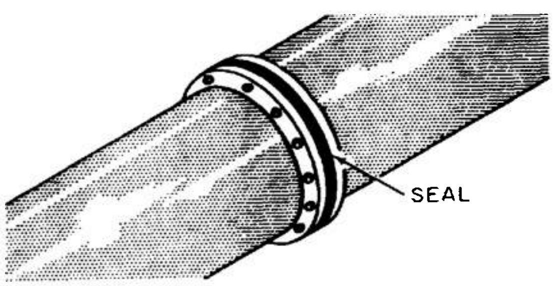


Figure 24-2. Use Seals ***Which Are Visible After Installation***

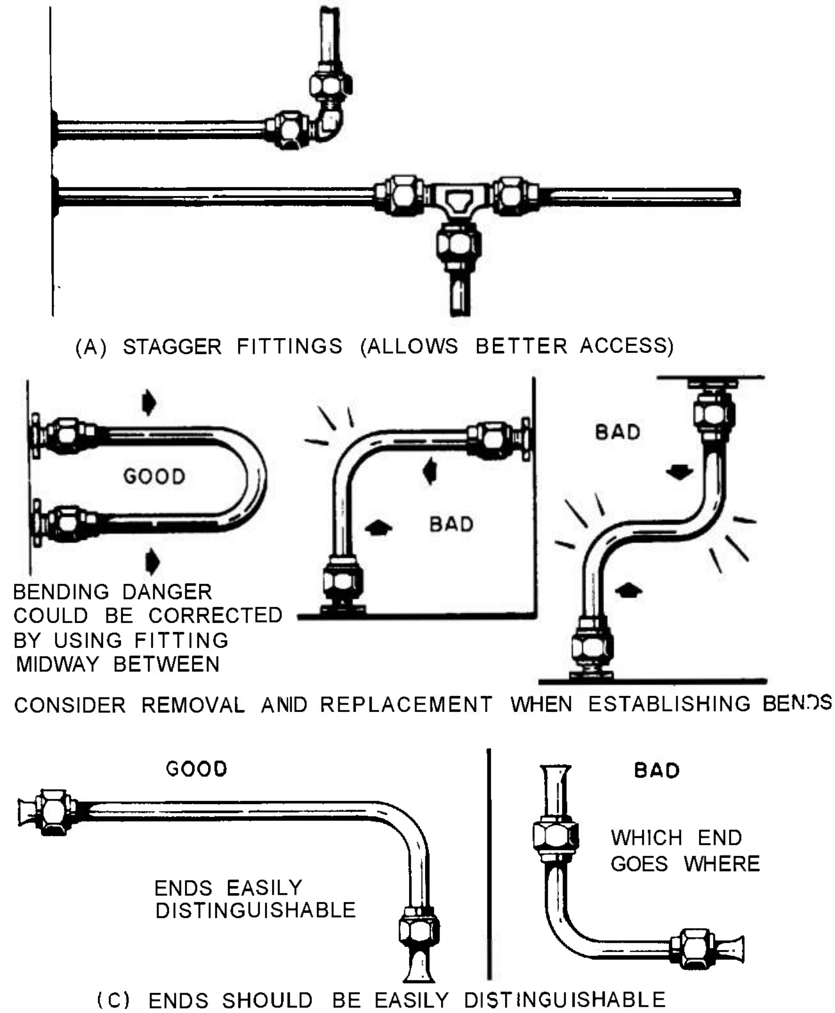


Figure 24-3. Connectors for Fluid Lines

24-5 COMBINATIONS OF EQUIPMENT

24-5.1 GENERAL

Monitoring devices should be provided for checking the following:

(1) Overall static and dynamic accuracy.

(2) Any critical d.c. or a.c. supplies.

(3) Other critical parameters related to electrical, mechanical, or hydraulic components.

(4) The overall fire control system.

24-5.2 COMPUTERS

Monitoring devices should be provided for rapid and frequent checking of the following:

(1) Overall accuracy, with and without corrections.

(2) Accuracy of rate measuring circuits and the efficiency of smoothing circuits.

(3) Any critical d.c. or a.c. supplies.

(4) The speed of rotating parts where these are critical.

24-5.3 RADAR EQUIPMENT

(1) Monitoring devices should be provided for frequent checks of overall equipment performance (the device should be able to detect a change of 5% in range performance) and servomechanism performance. Built-in facilities should be provided for rapid checking by maintenance personnel of the following :

(a) Transmitter power output.
(b) Transmitter frequency.
(c) Transmitter spectrum.
(d) Waveguide SWR.
(e) TR-cell operation.
(f) Mixer performance (crystal).
(g) Receiver noise factor.
(h) Voltage, currents, and waveforms at various stages.

(2) Fire control radar equipment should be designated so that the following are easy to check in their original position :

(a) That the motion of the aerial array in elevation lies in planes parallel to the bearing axis.
(b) That the optical axis is perpendicular with respect to the elevation axis.
(c) That the electrical and optical axes are parallel.

(3) Means should be provided to check periodically the mechanical backlash in the main motor drives and gear trains of positional controlling devices and the data transmission elements.

(4) The use of preloaded gear wheels to reduce backlash in gear trains should be avoided wherever possible.

REFERENCES

1. *Maintenance Engineering Handbook,* Vol. 1, Frankford Arsenal, Philadelphia, Pa.
2. *Maintenance Enginering Handbook,* Vol. *2,* Frankford Arsenal, Philadelphia, Pa., 1959

CHAPTER 25
MISSILE AND ROCKET MATERIEL

SECTION I
MISSILES AND ROCKETS

25-1 DESIGNING MAINTAINABILITY INTO THE MISSILE SYSTEM — GENERAL

Good missile maintainability requires the following:

(1) Self-checking features, or test points for external checking, that permit quick and effective troubleshooting down to the last replaceable or repairable unit in the missile.

(2) Ease of access to test points and to units that are to be replaced, repaired, adjusted, or serviced.

The general maintainability requirements for missile systems design are specified in MIL-M-45765 (MI), MIS- 10017, and RCR-870 (see Table 3-3). Chapter 23 provides valuable information relating to wiring electrical connectors, test equipment and related items.

25-2 MISSILE SHELL DESIGN REQUIREMENTS

25-2.1 SECTIONALIZATION

To facilitate handling, transportation and storage, the designer should provide sectionalized construction adaptable to rapid field assembly. He should, in general, allow separate storage of explosives and other hazardous materials. Whenever practicable, the designer should incorporate all operating systems within a single section to facilitate storage, assembly, handling, maintenance and periodic testing.

25-2.2 INSPECTION AND ACCESS

The designer should provide suitable access doors or removable covers for servicing operations such as inspection, test, lubrication, drainage, adjustment, and for replacement of parts. The access openings should be of sufficient size to furnish an adequate view of the parts to be inspected, serviced, or lubricated, and to allow ample access for a man wearing arctic gloves. The access doors should be made externally flush, to be opened easily, and held securely closed by approved fasteners. The doors should be designed so that the action of the slipstream will tend to keep the doors closed in flight (see also Chapter 12).

25-2.3 REPLACEABILITY AND INTERCHANGEABILITY

The designer should provide for ease of replaceability of items subject to rapid deterioration, such as seals and connectors. Whenever possible, corresponding assemblies, components, and parts of a missile shell should be interchangeable in accordance with the requirements of MIL-I-8500.

25-2.4 HANDLING

The missile shell and its subsections should be designed for ease of handling; however, if handles are used they should be made retractable or easily detachable to prevent adversely affecting missile aerodynamics. The missile should be clearly marked to show the proper location of supports when the missile is placed in such handling devices as dollies or slings. Provisions should be made for towing missiles that are supported on dollies with wheels. Particular attention should be paid to the center of gravity for ease of hoisting and handling missile sections or the complete missile.

25-2.5 DRAINAGE REQUIREMENTS

The design should provide for drainage of the missile shell and its nonpressurized subsections in order to prevent the collection of rain or condensation within them. These provisions should consist of drain and limber holes (holes or notches close to the lower skin of surfaces or bodies provided in bulkheads or stiffeners). Such holes permit the water to run to low points when the missile is resting in a normal position.

Fuel tanks should be sealed off from other portions of the shell. Adequate drains should be provided so that leaking fuel and fumes will be carried overboard during fueling, minimizing the fire hazard. Particular attention should be paid to the areas around engine exhaust systems and electrical equipment to avoid fuel drainage into or around these items.

25-2.6 ENVIRONMENTAL REQUIREMENTS

The effects of environment on missile maintainability will vary with temperature, geography, pressure and altitude (see Chapter 10, Section II). Unless ice formation would definitely make the missile inoperable, as in the case of an infrared seeker, designing against failure or damage from icing might be economical. Each case should be considered separately depending on the probability of occurrence, performance demanded of the missile, and the required maintenance.

The damaging effects of sand and dust can be prevented by compartment pressurization or by keeping the missile in a sealed envelope or package until ready for operation. Sand and dust can have a detrimental effect on both maintenance personnel and on the missile shell.

25-3 LIQUID PROPELLANT SYSTEMS

The term "propellant system" as used here, includes all lines and equipment from the propellant tank to, but not including, the engine. In this area of design, consideration should be given to the following :

(1) Use bends in all lines where practicable to prevent breakage caused by expansion and vibration.

(2) Do not use pipe threads for connections — they intensify the sealing problem.

(3) Consider the use of surge chambers. If this is not feasible, provide for dumping propellants overboard at shutdown to prevent "water hammer" from bursting lines and creating fire hazards. Also, some propellants might "diesel" (ignite) when subject to rapid valve closures, pressurization, flow through sharp bends, etc.

(4) Provide that all lines will be kept free of foreign materials. Grease, oil, or water may cause explosions when contacted by some liquid propellants. Dirt of any form will mar valve seats and prevent complete shutoff of the propellant, thus creating a fire hazard. Dirt or ice might also delay regulator valve operation and cause dangerously long starts.

(5) Route piping as directly as practicable to minimize its vulnerability to failure and maximize its accessibility in the compartments. Keep the piping free from sharp bends and restrictions, and route it so that there is a minimum of interference during removal or adjustment of engine accessories. Also, lines should not be close to sources of heat or cold. Special consideration should be given to the position of combustible fluid lines with respect to sources of heat to reduce the fire hazard in the event of leakage.

25-3.1 TANKS

The missile propellant tanks, whether fixed or removable, should be equipped with drains and made adaptable to purging systems so that tanks can be depressurized and propellants drained in case of failure to fire at launching. The designer should provide for rapid and safe filling with a minimum of extra or special equipment. The filler lines should be large enough to keep servicing time down to a minimum. The nozzles should be so designed that they will not fit in the wrong tank. Avoid the use of screw-type ports whenever possible, but if they are used, the tank should contain the female thread to prevent handling damage. Extended ports should be avoided.

Provision should be made for positive retention of packings or gaskets against pressure. Fill and vent ports should be designed to accommodate standard fill and vent fittings. When dangerous propellants are used, provision should be made for vapor return lines from the propellant tanks to the tanks from which the propellants are being transferred. Special precautions should be taken when loading unstable propellants to ensure that no moisture comes in contact with the propellants. Automatic disconnect couplings should be provided on tanks that are pressurized prior to the completion of loading. Maintenance personnel should be able to ensure that no moisture is in the propellant tanks. Moisture can cause ice formation, corrosion, or explosion during filling, or rough burning during operation.

25-3.2 TUBING

Install metal tubing so that vibration, deflection, or expansion will not cause failure of the tube or any of its connections. This usually can be accomplished by putting bends or expansion bellows in the lines.

(1) The size of propellant lines is determined by the rate-of-flow requirements. Metal tube outside diameter dimensions, however, should be, as far as possible, of the following sizes: 0.187, 0.25, 0.375, 0.5, 0.625, 0.75, 1, 1.25, 1.5, 1.75, 2, 2.25, 2.5, 2.75, 3, 3.5, 4, 4.5, 5, 5.5, 6, and 7 in. or larger. Tubing that is necked down to smaller diameters at the ends can be used, but the reduced ends should conform to the tubing diameters given above.

(2) Tube wall thickness depends on the type of propulsion system used and the required pressures. The normal wall thickness of stainless steel and aluminum tubing, however, should not be less than those shown in Table 25-1.

(3) Flexible hoses for main propellant lines to engines should be avoided whenever possible; their use can result in unstable combustion because of their susceptibility to pressure pulses, which can result in missile failure. The hose inside diameter should be of the following sizes: schedule-4, -5, -6, -8, -10, -16, -20, -24, -32, -40, -48, -64, -80, or larger, if required.

(4) The minimum bend radius for hoses conforming to MIL-H-5511 (see Appendix) should be eight times the outside diameter of the hose for sizes up to and including 6 in. The minimum bend radius for larger sizes should be five times the outside diameter. In addition, the minimum bend radius for hose conforming to MIL-H-6000 should be twelve times the outside diameter.

(5) Suitable drains should be provided around all couplings, fittings, etc., to prevent leaking propellants from damaging the missile.

(6) In selecting seals, packing and gaskets, the chemical reaction between the propellants and the sealing material must be considered as well as the aging characteristics of the sealing material. Table 25-2 gives suggested material-propellant combinations.

25-4 GUIDANCE, CONTROL, AND TELEMETERING SYSTEMS

The designer should simplify the complex electronic circuitry in the guidance, control, and telemetering systems and package them in such a way that they are reliable and maintainable. These systems should be packaged in a controlled environment transportation kit that will maintain pressure, humidity, and temperature at acceptable limits under all ambient conditions.

Care should be taken to design for easy functional checking and easy replacement of defective assemblies in the field. Avoid batteries that leak, freeze, and require charging ; hydraulic systems with problems of leakage, dirt, close valve tolerances, and pressurization ; relays and other kinds of mechanical switches ; vacuum tubes and high-pressure gas bottles that are difficult to replace or reach.

The designer should consider the areas below when designing the missile's guidance, control, and telemetering systems (see also Chapter 23).

25-4.1 WIRING ASSEMBLIES

Wires should be numbered in accordance with MIL-W-8160 (see Appendix). Wire numbering for missiles is preferred because it provides ease of circuit tracing and troubleshooting, is easily identified, reduces the possibility of error in repair, and reduces the logistic and storage requirements in tactical units.

25-4.2 ELECTRICAL CONNECTORS

All electrical connectors should be of the quick-disconnect type and should be limited to a maximum of six or eight sizes. This will simplify the logistical problem and expedite the replacement of components.

TABLE 25-1. RECOMMENDED NORMAL WALL THICKNESS OF STAINLESS STEEL AND ALUMINUM TUBING

Tube Outside Diameter (in.)	Wall Thickness (in.)	
	Stainless Steel	Aluminum
0.25	0.020	0.022
0.375	0.028	0.028
0.5-2	0.035	0.049
2.5-3	0.049	0.065

TABLE 25-2. SUGGESTED PROPELLANT AND OTHER MATERIAL COMBINATIONS

Propellant	Packings and Gaskets	Lubricants	Metals
Ammonia	Neoprene, Teflon, Kel-F, asbestos	Silicones, graphite	Any except copper-base alloys, nickel, or monel
Aviation gasoline 100/130	Nylon, Kel-F, Trithene, Fluorothene A, polyvinyl alcohol, Teflon, Buna N (linear compound MJ-70), Parker PS-10-13N, plastic rubber compound N209-70, butyl rubber, Vinylite polyethylene	Molykote, Fluorolubes, Nordcoseal 147-S, AN-G-14, electrofilm graphite coating	Stainless steel, carbon steels, aluminum, magnesium alloys
Dimethyl hydrazine	Teflon, Fluorothene A	Fluorolube-F, Fluorolube-S	Stainless steel, aluminum alloys AISI 4130 low alloy steel
Hydrozine hydrate	Polyethylene, Buna N (MJ-70, Parker PS-10-13N, plastic rubber 209-70), Kel-F, Teflon, Trithene A, Nylon, Trithene-Fiberglas laminate	Graphitar No. 2	Stainless steel, aluminum alloys
Hydrogen peroxide (up to 90% concentration)	Polyethylene, Teflon, tin (treated with HCL and rinsed with H_2O), Koroseal, Kel-F, Trithene, 2S Aluminum, degreased Fiberglas, Saran, Vinylite, glass cloth impregnated with Teflon or Kel-F	Fluorolube 10214, Fluorolube 10213, Kel-Flo, Perfluorolube oils	Aluminum, certain recommended aluminum alloys
JP-4	Nylon, Kel-F, Trithene, Fluorothene A, Vinylite, Teflon, Buna N (linear compound MJ-70), polyethylene	Molykote, Fluorolubes, AN-G-14, electrofilm graphite coating	Carbon steels, stainless steels, aluminum, magnesium alloys
Liquid fluorine	Packless valves, copper gasket and seats	None	Nickel, 18-8 SS, stainless steel, copper
Liquid oxygen	Kel-F, Trithene, Fluorothene A, Teflon, asbestos, soft copper, aluminum and Johns-Manville No. 61-S bonded asbestos sheet, Ulner leather	Molykote, electrofilm graphite coating, Parker Oxyseal	Stainless steel, aluminum, monel, nickel, Inconel and copper base alloys
Nitromethane	Neoprene, Teflon, Kel-F, Trithene, Fluorothene A, Nylon, Saran, polyethylene, Vinylite VE 5901, Perbunan	Silicones, graphite	Stainless steel, or mild steel
Propyl nitrate	Nylon, Dacron, Bakelite, polyethylene, Kel-F, Teflon	Graphite	Stainless steel, aluminum, wrought or cast magnesium
Water alcohol	Nylon, polyethylene, neoprene, asbestos, Graphitar, Kel-F, Teflon, Johns-Manville No. 61-S bonded asbestos sheet, Tygon, cork, Saran, Vinylite	Molykote, silicone greases, Nordcoseal No. 234-S, Parker's Alcolube	Stainless steel, aluminum, wrought or cast magnesium
WFNA and RFNA	Teflon, Kel-F, Trithene, Carbide & Carbon's CF-3, Fluorothene A, Norbide, polyethylene	Kel-Flo, Fluorolubes, Desco lubricant, halocarbon oils of series 13-21 and 8-25 HV	Stainless steel, Haynes alloy No. 25, aluminum, gold, platinum, rhodium

25-4.3 POTTING OF COMPONENTS

The potting of components and the use of extended jackets for cables and harness assemblies decrease maintainability. But the question of reliability versus maintainability should be carefully studied and weighed. In many instances, the design can be slightly changed to eliminate the necessity for potting or extruded cable jackets.

25-4.4 MODULAR CONSTRUCTION

Modular construction will minimize the time element in the fault isolation, repair, and return to service of defective components (see Chapter 19). Also, logistical suport will be lessened because the number of line items required to be stocked in the tactical unit will be decreased.

25-4.5 TEST POINTS

Modular construction lends itself easily to a logical series of built-in test points. These test points can be used for voltage or current measurements and, with the aid of an oscilloscope, for analyzing the various waveforms.

25-4.6 STANDARD TEST EQUIPMENT

The insertion of test points in the missile will permit the use of standard test equipment rather than specially designed test equipment having limited application. Fault isolation can be accomplished by a systematic point-to-point measurement of the faulty circuitry.

25-4.7 CHECK-OUT EQUIPMENT

Check-out equipment determines that the system, or a major portion of the system, is functioning properly. This is often referred to as the "go/no-go" method of checking. It is only when a "no-go" indication is present that troubleshooting or fault isolation of equipment is required. To incorporate both fault isolation and check-out in one instrument would result in a highly complex instrument having little versatility.

The "go/no-go" type of check-out equipment should be designed to operate rapidly and automatically. It should be able to check all major circuits and should incorporate a method of readout that indicates the condition of the circuit under test. This test equipment, as well as any other specialized test equipment required for missile maintenance, should be designed concurrently with the design and development of the missile itself and its associated ground support equipment.

25-4.8 ACCESSIBILITY

Consideration should be given the following factors during the design studies (see also Chapter 12):

(1) Components should be hinge mounted to open to their full position and remain in that position during maintenance.

(2) Components should be installed so that bulkheads, brackets, etc. do not interfere with the removal of covers or other components.

(3) Components should be installed to exclude the possibility of the technician having to work in awkward positions.

SECTION II
SPECIAL WEAPONS ADAPTION KITS

25-5 GENERAL

The adaption kit for special weapons provides safing-arming and the fire signal to the warhead and holds the warhead in position within the body of the missile. It might include power supplies, timer mechanisms, barometric sensing devices, radar intertial devices, or various combinations of these. If the adaption kit includes the ballistic case of the missile, design considerations for the ballistic case must follow those for the missile itself.

25-6 DESIGN REQUIREMENTS

The adaption kit should require a minimum of maintenance and inspection in a tactical situation because of the absence of highly skilled technicians required to maintain complex end items. Other design requirements are presented here.

25-6.1 SECTIONALIZATION

The end item should be sectionalized for easy disassembly, replacement of defective sections, and simple reassembly. Sectionalization is also necessary for ease of transportation.

25-6.2 MODULARIZATION

Each section should be composed of modules that are easily removed and replaced by simple mechanical operations. Circuits should be completed by using accessible plugs that can be mated only in the proper position and cannot be physically interchanged with any other plug on the same item. Components should slide easily into position and lock into place by sliding the whole assembly into the ballistic case. 'If bolts and screws are necessary, they should be accessible, require standard tools, and, if possible, be quick acting and self-locking. Avoid large diameter threaded components because they are difficult to maintain, particularly if the mating metals are dissimilar. Under repeated assembly and disassembly, dissimilar metals will bind and seize, and, when left assembled for any period of time, the metals will corrode, and the joint will be effectively frozen.

25-6.3 STANDARDIZATION

Components that have been successfully applied to weapons already deployed should be used in subsesquent designs, unless newly developed items will materially increase the overall effectiveness and modernization of weapons under development (see Chapter 18).

25-6.4 SIMPLIFICATION

If electronic fuses are required in the safing-arming, fuzing, and fire-signal sequence, they must be in the adaption kit circuitry. If, on the other hand, fuses are required only to protect components during electrical tests and monitoring, they should be in the testers. Unnecessary parts in circuits reduce the reliability of the circuit out of proportion to their convenience (see Chapter 17).

25-7 INSPECTION AND TEST REQUIREMENTS

If they are absolutely necessary, inspections and tests in the field should be limited to simple go/no-go tests (green-red light). It is desirable to limit test inspections to simple readings that can be obtained without opening the warhead section, and, even more desirable, without even opening the container which houses the warhead section.

25-8 PRESSURIZATION AND DESICCATION REQUIREMENTS

Pressurized components offer some benefits ; arcing is better controlled under pressure than in a near vacuum, and inert gases tend to inhibit corrosion. But pressurization is almost intolerable under field conditions, adding to the logistic and maintenance burden.

The designer should consider "controlled leakage," a practice that permits a component to function properly in an environment of a fraction of one atmosphere of pressure. The system is designed so as to control the leakage of gas to ensure that, during the time of flight under near vacuum conditions, no less than the acceptable fraction of pressure will exist. A system so sealed will not be completely free of the breathing effect caused by repeated temperature changes, but the circulation of air will be inhibited by the sealing itself and, in storage, can be further inhibited by the container, which can be desiccated.

Desiccation must be carefully considered in all phases of packaging. The designer should consider the capabilities of each type of environment control, compare the logistics problems to support them, and examine what is already available in the field for packaging.

CHAPTER 26
GROUND SUPPORT MATERIEL

26-1 GENERAL

This chapter includes ground support materiel used for transporting, handling, lifting, and positioning tasks in the maintenance support of a weapon system. Included are considerations for overall equipment configuration, transporting vehicles and components, lifting equipment, auxiliary equipment, etc. The emphasis is on major structures and sub-units common to more than one type of equipment.

26-2 OVERALL SYSTEM CONFIGURATION

Any piece of transporting, positioning, or lifting equipment is designed to carry, position, or lift some type of equipment or component. In some cases one piece of equipment will combine all three of these functions. In other cases, equipment will be designed for one specific function. The designer must consider such things as general appearance of the equipment, size and weight of the complete structure as well as its individual components, and the placement of individual components within the structure.

26-3 GENERAL REQUIREMENTS

Operating or structural characteristics of the various types of ground support materiel cannot always be specified because they must relate to the specfic purpose for which the equipment is designed. However, where special or newly designed ground support equipment is required, the equipment should be selected and designed so that it meets the following general requirements:

(1) Is maintainable.

(2) Is compatible with the maintainability features built into related equipment, and with maintenance environment in which it will be used.

(3) Is maximally useful to the technicians who must use it, in terms of the exact tasks and functions they are to perform.

(4) Satisfies standardization and interchangeability requirements.

(5) Provides maximum protection for components and working parts to minimize the need for repair.

(6) Requires minimal servicing, adjusting, or other maintenance to remain usable throughout its service life.

(7) Is flexible and able to fulfill as many required maintenance functions as practicable.

(8) Is as simple as possible to operate; use, and maintain.

(9) Minimizes overall size so that maneuverability under or around the prime vehicle, equipment, or structure is not impaired.

(10) Satisfies real needs and requirements in such a manner as to maximally contribute to the overall rapidity, ease, economy, accuracy, and safety of system maintenance, in accordance with:

- (a) Functional requirements of the vehicle it is to support.
- (b) Service conditions under which it is to be used.
- (c) Frequency with which it is to be used.
- (d) Duration of such use and expected or required service life.
- (e) Number and capability of personnel available to operate and maintain the equipment.
- (f) Other operations which will be performed concurrently with use of the equipment.

(11) Equipment requirements are combined, where possible, into a minimum number of types and varieties of equipment.

The paragraphs which follow give design recommendations for some specific types of ground support materiel.

26-4 FRAMES AND STRUCTURAL MEMBERS

(1) Design frames so that visibility among men is not impaired.

(2) Make use of openings in frames where possible so that the man at each operating position can see all four corners of the equipment (see Figure 26-1).

(3) Keep the height of frames to a minimum so that standing personnel can see over the frames.

(4) Consider the use of mirrors to give all men optimum visibility of otherwise hidden equipment.

(5) Design moving structural elements to avoid hazard and hindrance to personnel.

(6) Eliminate (or guard) sharp edges where two moving elements come together.

(7) Incorporate design features to prevent personnel from placing any part of their bodies where moving parts,come together.

(8) Place operating controls for moving elements so that personnel can see all parts of the moving structure while it is being manipulated.

figure 26-1. Open Frames for Maximum Visibility

(9) Place other controls, adjustments, and connections so that the operation of the moving element does not interfere with the control manipulation.

(10) Provide sufficient clearances between moving structural elements to allow for environmental conditions. Binding and sticking caused by changes in temperature and humidity may delay operations or require time-consuming retrofit.

(11) Incorporate fail-safe features into all moving elements so that if hydraulic or electrical power is lost, for instance, gravity will not cause a structural member to fall. Fail-safe features should not be an inconvenience to personnel. Where possible, fail-safe features should be designed so that they are not removable and cannot by by-passed.

(12) Avoid projecting edges, protrusions, rails, or corners on which personnel might injure themselves. Where such protrusions are unavoidable, provide bumper guards and covers (see Figure 26-2). Bumper guards and covers should be of a material that is not susceptible to climatic damage and should be firmly attached to last the lifetime of the equipment.

(13) Place moving parts, such as belts, chains, gears and linkages, where operating and maintenance personnel are least likely to come in contact with them. If there is any danger of personnel contact, guards should be provided (see Figure 26-3).

(14) Insulate or place guards around high-voltage areas.

(15) Provide protection against personnel coming in contact with components that generate high temperatures. Protection can be provided by careful placement of the component or by designing appropriate guards.

(16) Where hinged devices are attached to the structure, and there are not overriding reasons for hinging at the bottom, place hinges at the top to prevent the device from injuring personnel in case it accidentally unlatches.

(17) Design realistic proper tolerances into equipment.

(18) Allow wide ranges of tolerances for items subject to extremes of environmental conditions.

(19) Make tolerances sufficient to accomodate all the various sizes and characteristics of

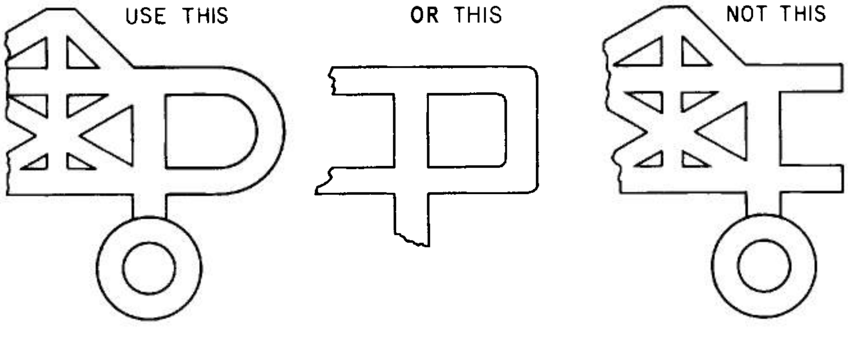


Figure 26-2. Bumper Guards for Frames

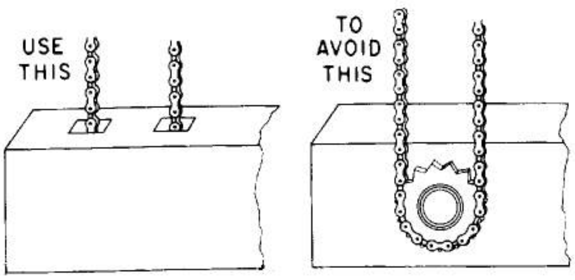


Figure 26-3. Guards for Protection Against Moving Parts

any one type of article. The battery tray (Figure 26-4), for instance, can be used with batteries of several different sizes.

(20) Label equipment designed for several different purposes. For instance, when one unit can be adjusted to fit a number of situations, clearly label each adjustment. As an example, a hoist beam might be used with several different weapons, each having a different center of gravity. If there is a scale on the beam that must be adjusted to different positions for each weapon, the weapon designation (MK1, MK2, etc.) should be marked at the appropriate positions on the scale (see Figure 26-5).

(21) Design for convenient removal of those major items of equipment which must be frequently removed.

(22) Design enclosures, or major portions thereof, so that they are readily removable for maintenance.

(23) Provide hoisting equipment for all removable components that cannot be readily handled by one man.

(24) Make size, weight, and general appearance consistent with the functional requirements specified for the equipment.

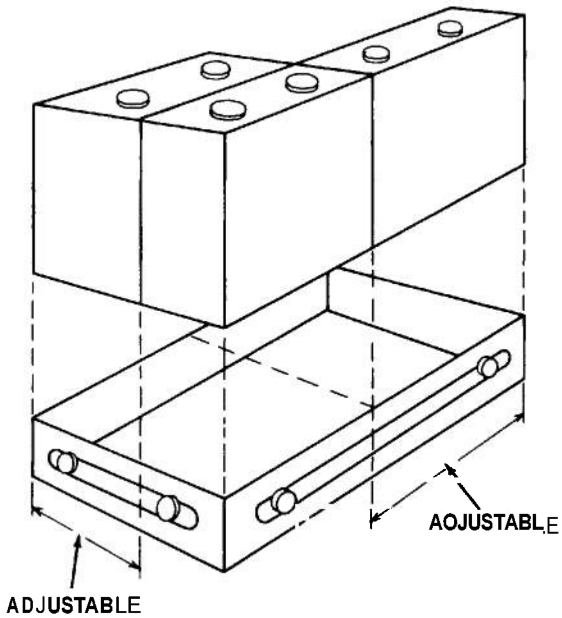


Figure 26-4. Adjustable Battery Tray

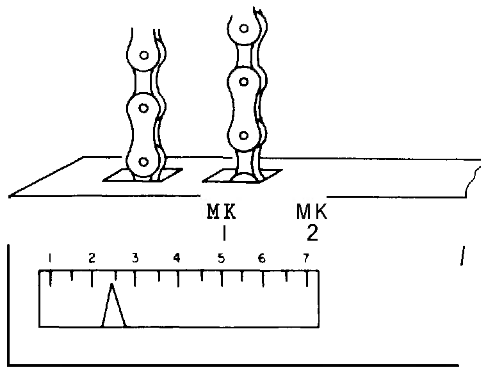


Figure 26-5. Hoist Beam Showing Scale Adjustments for Different Lifting Arrangements

(25) Avoid weight that does not contribute to the performance of the equipment; especially in trailers, bolsters, and other equipment that occasionally require manual positioning.

(26) Avoid nonfunctional embellishments. Such additions to equipment complicate maintenance and, in some cases, actually create hazards.

26-5 TRANSPORTING VEHICLE COMPONENTS

Included in this paragraph are recommendations on stores, component and van trailers, and major components of these vehicles such as wheels and casters. Stores trailers carry an entire weapon, such as a missile, and might include transporters and combination transport-launching vehicles. Component trailers carry only a part of the weapon, such as a fuze or warhead. These trailers are used both as stands on which to mount the component for servicing and as vehicles to position the component for mating to the main part of the weapon.

26-5.1 STORES TRAILERS

(1) Provide an extension light with plug-ins at appropriate positions when the trailer will be used at night.

(2) Equip tie-downs with quick-disconnect features.

(3) Design tie-downs so that if tools are required for their installation or removal, common hand tools will suffice.

(4) Avoid time-consuming turnbuckles.

(5) Provide dummy connectors on the trailer to permit securing air hoses, electrical cables, etc., when they are not attached to the prime mover.

26-5.2 COMPONENT TRAILERS

(1) Design component trailers with precise positioning controls when they are used to mate parts. Do not require personnel to manually push or lift the mating components to bring them together.

(2) Make the component trailer of sufficient height and configuration so that when it is moved close to the component—a missile, for example—the mating surface of the component on the trailer is directly in line with the mating surface of the missile (see Figure 26-6).

(3) Equip the trailer with brakes so that, when coarse positioning movements have been made by moving the trailer, it can be immobilized for precise positioning with cradle controls. Locate brake controls so that personnel can reach them while restraining the trailer manually.

(4) Design into component trailers the capability for individual swiveling all four wheels to reduce positioning time.

(5) Design into component trailer independent controls (such as roll, pitch, or yaw) which will allow the technician to position components properly for required maintenance if the trailer is to be used as a maintenance stand.

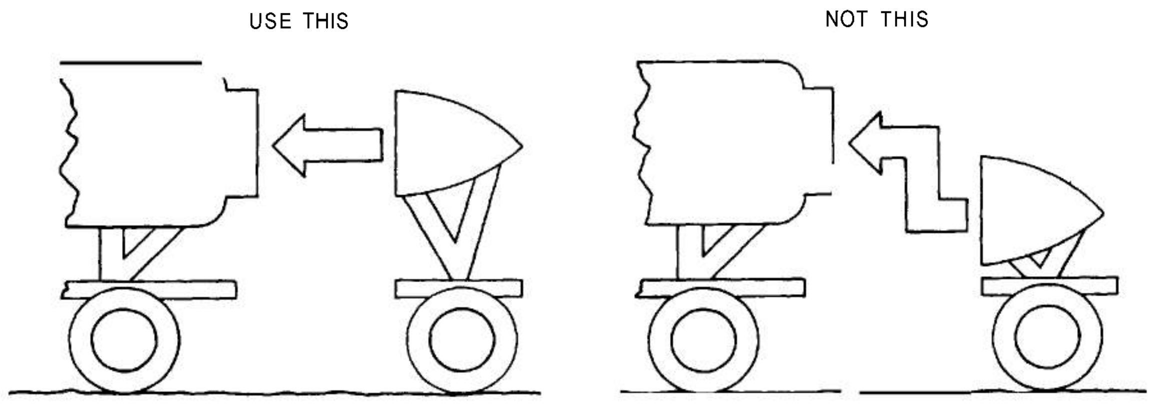


Figure 26-6. Mating Surface of Component Trailers

26-5.3 VAN TRAILERS

(1) Equip trailer beds with safety tread-type steel or aluminum plate. If beds will be exposed to ice and snow, consider the use of expanded metal for floors.

(2) Standardize trailer hitches to facilitate rapid moving of equipment by any towing equipment.

(3) Design connections between tractors and trailers for quick attachment and release, and make provisions for tying up connecting lines when the trailer is disconnected.

(4) Provide landing gear for large trailers that are to be attached to tractors so that the trailer can be parked after the tractor has been disengaged.

(5) Place the landing gear handle at the right side of the trailer, and design the handle so that it folds when not in use (see Figure 26-7). Do not require excessive force to operate the landing gear handle.

(6) Ensure that jacks for leveling the trailer (as well as lifting it for tire changes) are made an integral part of the vehicle and have swivel-type landing pads (see Figure 26-8).

(7) Make the operating levers, if the trailer is to be equipped with individual hand-operated brakes for each of the four wheels, integral parts of the vehicle, placing them so as to preveni injury to the operator.

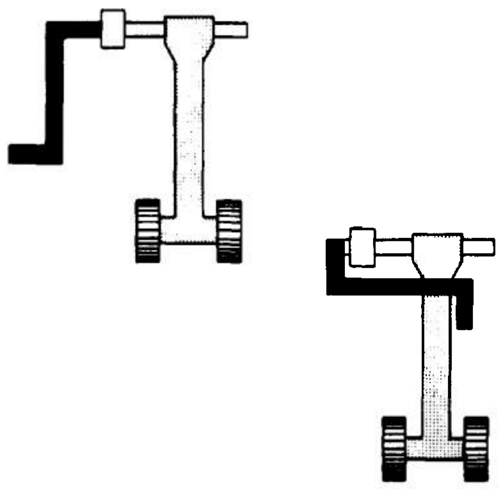


Figure 26-7. Design Folding Handles on Trailer Landing Gear (Ref. 1)

(8) Use handles rather than round knobs on heavy trailer doors. The latter increase the likelihood of the technician's hand slipping.

(9) Provide a device to slow the closing action of doors, such as pneumatic checks or other retarding mechanisms. This is especially important where a heavy door may close quickly as in a high wind or when a trailer is parked on a hill.

(10) Provide a platform upon which the technician may stand while opening the door if a door must be reached by steps or a ladder (see Figure 26-9). The steps should be lightweight and either retractable or removable. Provide nonskid treads and, if necessary, handrails. These should be 32 in. in height, and 1.75 to 2 in. in diameter.

(11) Provide latches that will not become unfastened under conditions of severe vibration.

26-5.4 WHEELS AND CASTERS

(1) Design wheels and tires for efficient operation and ease of maintenance.

(2) Do not require wheels to be removed for minor periodic maintenance, such as lubrication.

(3) Design wheel mounting so that wheels can be removed easily and quickly. Avoid the use of guards or panels that might interfere with the removal of wheels.

(4) Design storage for spare wheels and tires so that they are accessible regardless of the load condition of the vehicle.

(5) Use casters only on shop equipment for ease of operation and maintenance.

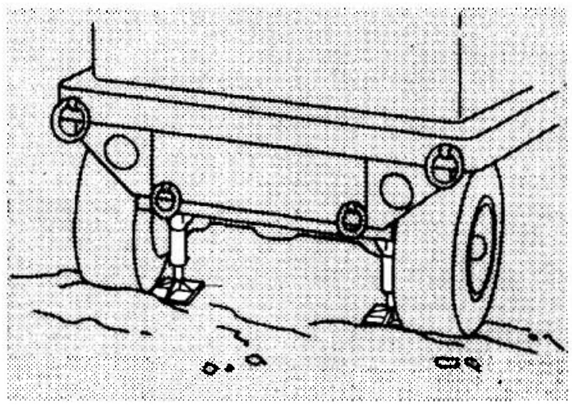


Figure 26-8. landing Pad Should Be an Integral Part of Trailer

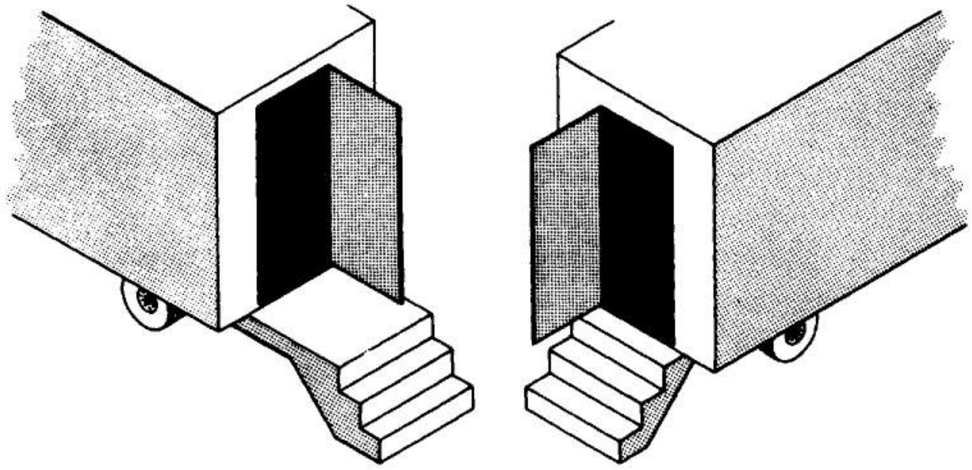


Figure 26-9. Provide a Platform To Be Used While Opening and Closing Van Doors (Ref. 1)

(6) Design casters so they are capable of individual swiveling, locking, and braking and passing easily over a 0.75-in. obstruction.

(7) Do not require special tools for locking and unlocking of swivels or that personnel crawl under the vehicle.

(8) Ensure that brakes can be operated by the foot and are an integral part of each caster.

(9) Use standard, off-the-shelf casters wherever possible.

26-6 LIFTING EQUIPMENT

26-6.1 EQUIPMENT HOISTS

(1) Incorporate controls into a portable, lightweight, hand-held control box because, ordinarily, hoist operators must move to different positions as the weapon is raised.

(2) Provide two spring-loaded, recessed pushbuttons on the control box, one above the other.

(3) Place the UP button above the DOWN button.

(4) Use green for the **UP** button and red for the DOWN button if buttons are to be colored coded.

(5) Identify the control buttons with the words **"UP"** and "DOWN" above the appropriate button.

(6) Design the pushbuttons with flat (or slightly concave) surfaces and large enough to be repeatedly pushed without discomfort.

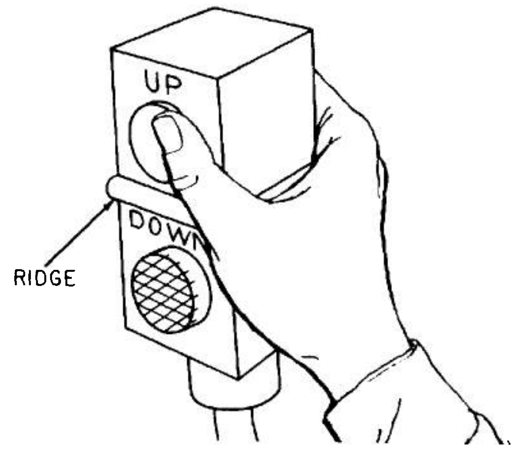


figure 26-10. Control Box Design

(7) Pressure for pushbutton activation should be 10 to **40** oz.

(8) Allow 2 in. between the UP and DOWN buttons. To further prevent inadvertent activation **of** the wrong button, provide ridging between the buttons (see Figure 26-10).

(9) Texture the surface **of** the top button differently to further differentiate the two buttons for blind operations.

(10) Make the control box small enough so that the operator can reach both control buttons while holding the box securely and comfortably **in** one hand.

(11) Design the control box so that cables enter at the bottom.

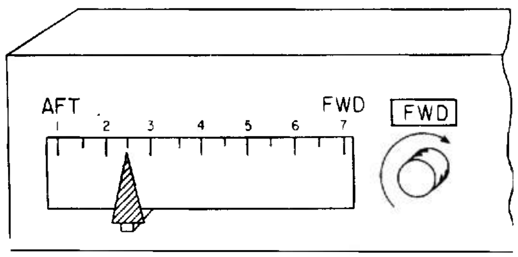


Figure 26-11. Clockwise Rotation to Move Beam Forward

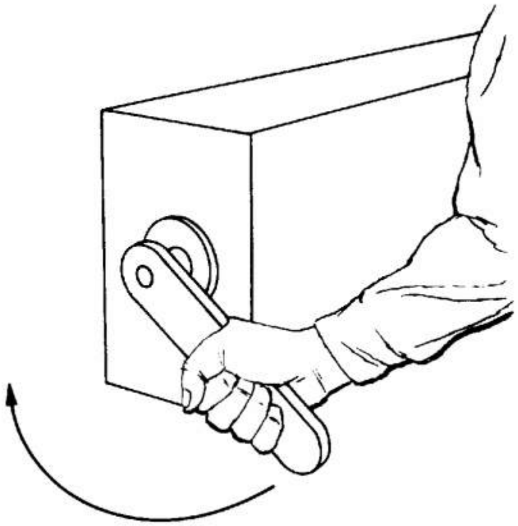


Figure 26-12. Labels Indicating Direction of Movement

(12) Consider attaching a strap to the control box for placement around the neck to prevent its being dropped, and to permit the operator the use of both hands for other tasks. The strap can also be used for hanging up the control box when it is not in use.

(13) Make scales for indicating the fore-and-aft position of beams readable and easily set.

(14) Use only as many scale divisions as are necessary in designing scales (see Chapter 9, Section 11).

(15) Space scale divisions far enough apart to be distinguishable from a distance of at least 28 in. The minimum separation is 0.05 in. but this should be at least doubled if conditions permit.

(16) Number scale divisions to increase from

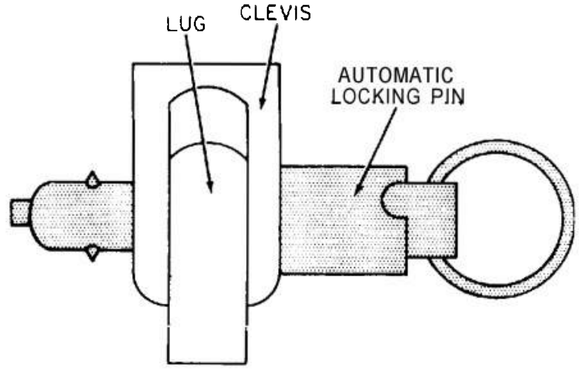


Figure 26-13. Lugs and Pins for Lifting

aft to forward; movement of the scale forward should indicate beam movement in the same direction.

(17) Place control settings for scales in the same plane as the scales if controls are mounted on the hoist beam.

(18) Provide that clockwise rotation will move the beam forward and counterclockwise rotation will move it aft if the scale control must be placed on the end of a beam (see Figure 26-11).

(19) Place a label above the control indicating the direction of movement and its relationship to the scales (see Figure 26-12).

(20) Consider placing controls for scales on a separate control box. If the controls are mounted on a separate control box, place the controls for forward movement above and the controls for aft movement below.

(21) Specify a ratio of control-to-pointer or beam movement such that the operator will be able to determine immediately if he is moving the control in the wrong direction.

(22) Provide sufficient clearance for lugs that are used for attaching hoist beams to the equipment structure so that attachment can be made easily and quickly. Use pins that have automatic locking features and do not require the insertion of cotter pins for locking (see Figure 26-13). The pins should be attached to the hoist by a wire or chain. For attaching the hoist beam to the weapon or cradle, design matching lugs so that the beam will not have to be held in place while pins are being inserted.

(23) Design junction boxes for hoists to be weatherproof and watertight.

(24) Design circuit breakers with recessed pushbuttons, and provide an indicator light that is on when the circuit breaker is in the line.

(25) Design systems requiring two junction boxes so that both boxes are enclosed in same case.

(26) Indicate hoist capacity on the side of the hoist that will be toward the operator to prevent overloading.

(27) Make hoist beams as light as is consistent with strength requirements.

(28) Provide positive locking devices to hold hoist beams in the raised position in case of power failure.

26-6.2 JACKS, ELEVATORS, AND LIFTS

(1) Design jacks so they can be transported, handled, and stored easily.

(2) Design small jacks that are to be lifted and carried by one man so as not to exceed **40** lb.

(3) Equip wheeled carts with locking wheels for mounting of larger assemblies. A cart with swivel wheels will permit local repositioning and accurate centering under the jacking points.

(4) Design large hydraulic jacks so that the wheels may be retracted or folded into the base of the cart, thus allowing the ram base to touch the ground for greater stability.

(5) Provide removable or folding jack handles. If a jack handle is left protruding during maintenance, there is a possibility that personnel or equipment may strike against the handle, knocking the jack from under the load.

(6) Provide one or more access plates at least 6 in. in diameter on hydraulic jacks to permit inspection and cleaning of the hydraulic fluid reservoir.

(7) Specify level type controls for lifting components. Upward or forward movement of the control should raise the lifting mechanism and backward or downward movement should lower it.

(8) Design controls which are of the rotating type so that clockwise rotation raises the jack head and counterclockwise rotation lowers it.

(9) Do not use foot controls for lifting mechanisms because the feet are relatively limited in their ability to select and manipulate controls, and is difficult to make delicate adjustments with foot controls.

(10) Label all controls used with elevators and lifts with their direction of movement and their function.

(11) If the lifting mechanism associated with a particular control must move in **a** direction opposite to that expected, the gear ratio should be such that a slight movement of the control produces large movements in the lifting mechanism consistent with sensitivity of control for fine positioning. This will give the operator immediate information that he is or is not moving the control in the proper direction.

(12) Avoid duplicate controls at the base of the lift and at the lift head. If duplicate controls are absolutely necessary, design them so that they are identical in position and orientation.

(13) Permit the operator of the lifting mechanism to see the load and the area under the lift or elevator platform at all times.

(14) Locate controls to eliminate the need for excessive moving about and so as to especially avoid requiring the operator to move into hazardous positions, i.e., under the lift head or under the elevator platform.

(15) Provide one master control panel that contains all controls and instruments necessary for lifting operations. Group all maintenance controls and gages on a separate panel, preferably at a different location.

(16) Design the lines between the hydraulic pump and cylinder to be located internally. Lifting should be continuously and smoothly controlled from the fully-lowered to the fully-raised position.

(17) Provide two guard rails around elevator or lift platform; one 1.5 ft and one **3** ft above the platform. Where the railing is broken for an entrance, place a detachable chain across the opening (see Figure **26-14).**

(18) Design elevator platforms with protec-

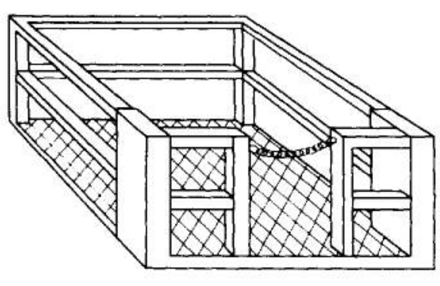


Figure 26-14. Elevator Plafform

tive covers (and sides) when they are likely to be used in extreme climates.

(19) Specify floors on elevator platforms to be made of expanded metal if there is possibility of ice and snow accumulating on them.

(20) Indicate capacity on jacks, elevators, and lifts to avoid overloading.

(21) Incorporate self-locking, foolproof devices to prevent accidental or inadvertent collapse of jacks, elevators, and lifts. If the possibility of collapse still exists, design jacks, elevators, and lifts to drop slowly in the event of failure.

(22) Design lifting mechanisms with safety features which cannot be bypassed or eliminated from the system.

26-6.3 CRANES AND SLINGS

(1) Use "through" type bolts with conventional nuts and lock washers or with lock nuts for assembling structural members.

(2) Provide hook eyes on boom sections at the centers of gravity for easy boom assembly and disassembly.

(3) Where feasible, include provisions for adjusting the boom length to accommodate operational requirements and to make the equipment more versatile.

(4) Wherever possible, employ two identical and interchangeable winch assemblies to operate the cables of the crane, one for hoisting the load, and the other for control of the boom height.

(5) Mount heavy ground support equipment, such as portable electric winches and cranes, on wheels for ease of movement. These should incorporate locking features for safety.

(6) Specify an operator's cab which will rotate with the crane to allow continuous surveillance of the operation. Locate the operator's seat so the technician will have an optimum view of the load, the ground, and equipment in the vicinity, and at the same time can manipulate crane controls easily.

(7) Mount lights so that movement of the load carried by a crane can be followed at all times during night operations.

(8) Label attaching points on slings if surface space allows.

(9) Enclose sling cables in some form of wrapping to prevent injury to personnel and damage to the equipment.

26-6.4 PNEUMATIC BAGS

Design pneumatic bags so that:

(1) Handles will withstand a steady pull of 200 lb.

(2) Coating compounds used do not contain ingredients known to promote skin irritation or fabric deterioration.

(3) The following labels are stenciled in yellow paint where appropriate:

(a) INLET or OUTLET (over these openings).

(b) "Do not use this bag in excess of ____ lb."

(c) "CAUTION — All traces of oil or grease shall be removed with gasoline immediately upon detection." (CAUTION letters should be 2 in. high; all other letters 1 in. high.)

26-7 CRADLES, BOLSTERS, AND STORAGE PALLETS

Cradles support a weapon while it is being lifted, positioned, or stored. They can be separate pieces of equipment or integral with transporting, positioning, and lifting equipment. Positioning is usually accomplished by manipulating the vehicle upon which a weapon is loaded. Some equipment, however, is designed specifically for weapon positioning. The following recommendations should be considered by the design engineer:

(1) Design cradles so that weapons can be quickly, effectively, and safely positioned on them.

(2) When a cradle is designed to carry a particular weapon, mark guidelines on the cradle so that, when the weapon is loaded onto the cradle, perfect positioning will be obtained by merely matching the guidelines (see Figure 26-15). For visual inspection of proper positioning, place the guidelines on the cradle so that they will be visible after the weapon is loaded on the cradle.

(3) Equip retaining straps with quick-disconnect, easily accessible fasteners.

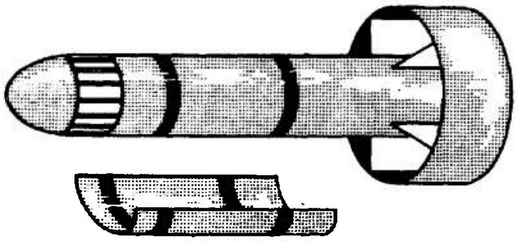


Figure 26-15. Guidelines for Positioning Weapons on Cradles (Ref. 21

(4) Provide the basic equipment with controls for positioning the cradle when cradles are designed as integral parts of other equipment.

(5) Do not require the operator to reach inside the trailer frame to operate cradle controls.

(6) Design for sufficient cradle travel so that, even if the basic vehicle is not perfectly positioned, it will still be possible to position the missile by means of the cradle controls.

(7) Specify that matching guide marks be placed on the basic vehicle and on the cradle on which the weapon is to be loaded to assure better initial positioning of the basic vehicle.

(8) In designing movable cradles, make the ratio of control-to-cradle movement such that the operator can tell immediately whether he is moving the control in the proper direction.

(9) For separate cradles that must be attached to a trailer or other piece of equipment, design mating fittings with sufficient tolerance so that attachment will be facilitated.

(10) Secure attaching pins to the cradle with small chains.

(11) Color code the matching attaching lugs on the cradle and trailer if there is a possibility of attaching the cradle to the wrong trailer lugs.

(12) If different weapons are to be used with the same cradle and lifting or hoist points are different, these points should be indentified for each anticipated weapon.

(13) When practical, attach a platform to the lift cradle to permit a technician standing on the platform to directly observe positioning of the component.

(14) Provide mechanical safety devices to prevent inadvertent dropping of the load because of hydraulic failure. Two acceptable safety provisions are either check valves or ratchet devices.

(15) Provide bumper guards on projecting edges of cradles and bolsters. Use rubber or other suitable material to cover protrusions, rails, and corners that personnel might come into contact with.

(16) Label all lift or hoist-attaching points on bolsters and cradles.

(17) Design storage pallets so that they can be lifted by fork-lift trucks from all four sides (see Figure 26-16).

(18) Design pallets so that skids are at least 3 in. high.

26-8 EQUIPMENT COLOR REQUIREMENTS

Table 26-1 gives the colors maintenance equipment should be painted unless otherwise specified by the procuring agency.

26-9 AUXILIARY EQUIPMENT

Auxiliary equipment includes cables, stands, platforms and ladders, towbars, and spare wheels and tires as well as storage provisions for these items. Both auxiliary and emergency equipment should be readily available, easily recognizable, and easy to use, but should not interfere with normal operations when not in

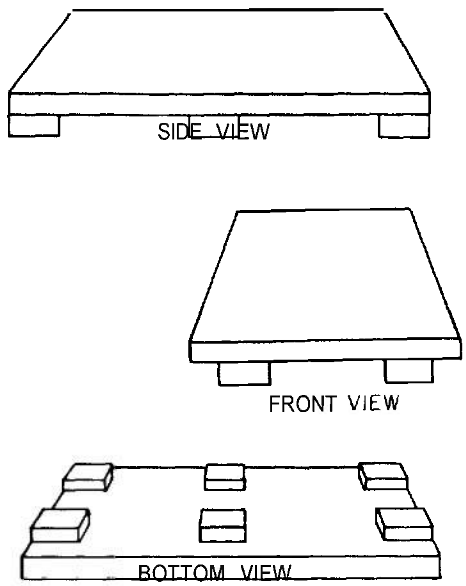


Figure 26-16. Pallets Designed for Four-Sided Lifting

use. The designer should consider auxiliary equipment in the early phases of prime equipment design.

26-9.1 GENERAL DESIGN RECOMMENDATIONS

(1) Storage space for auxiliary equipment should be accessible under all conditions of equipment use.

(2) Do not require the removal of a trailer's load to gain access to auxiliary equipment.

(3) Label storage space that has auxiliary equipment stored there.

TABLE 26-1. MAINTENANCE EQUIPMENT COLOR REQUIREMENTS (Ref. 2)

Equipment	Color	Fed-Std 595 Code No.
Operational or maintenance equipment:		
Console panels	Gray	36492
Panel lettering	Black	37038
Console exterior	Green	24300
Console interior	Gray[1]	26622
Vans and trailers:		
Floor	Gray	36440
Walls	Green	34670
Ceilings	White	37866
Storage cabinets and equipment racks	Green	34300
Pipes, conduits, etc.	Same color as surface to which they are attachedunless color coding is required.	
Major ground support equipment:		
Shop equipment	Aircraft gray	16473
GSE interior	Aircraft gray	16473
General purpose vehicles	Olive drab	24087
Other equipment not used on flight lines, in hangars, or shops	Olive drab	24087

Note 1. Use only where maintenance and trouble-shooting are required within console. Otherwise, standard requirements for an economical internal protective finish apply.

(4) Do not permit auxiliary equipment when not in use to interfere with normal operations.

(5) Attach auxiliary equipment to main equipment where possible by sash or regular link chains (see Figure 21-25). Where attaching by chains is not feasible, clamp auxiliary items to the prime equipment. Do not require excessive force to remove them, and do not require special tools.

(6) Label auxiliary equipment to identify the prime equipment with which it is associated.

(7) Use off-the-shelf items for auxiliary equipment whenever possible. Do not require special tools in using auxiliary equipment.

(8) Provide spares for items such as pins, spark plugs, and batteries that can be replaced by operators.

(9) Consider making every piece of auxiliary equipment an integral part of the prime equipment.

26-9.2 CABLES

(1) Provide storage space for removable cables. If cables are not removable, design equipment so that cables are out 'of the way when not in use.

(2) Specify cable connectors that require no tools and which can be connected with a fraction of a turn or a quick snap action.

(3) Provide cables with caps to prevent the entrance of dirt and moisture.

(4) Provide reel carts for the removal, replacement, and handling of large, heavy cables when a system must operate in rough terrain.

(5) Use automatic tensioning and rewinding reels whenever necessary to prevent kinking and damage to cables and lines.

(6) Attach casters to heavy servicing cables or hoses to facilitate their use by technicians (see Figure 26-17).

(7) Provide storage space for critical spare parts on the chassis of cranes, lifts, etc. to ensure readiness of the equipment at all times.

26-9.3 STANDS

(1) Design maintenance stands so that they can be used on inclined surfaces of up to 15° without danger of tipping when the weight of

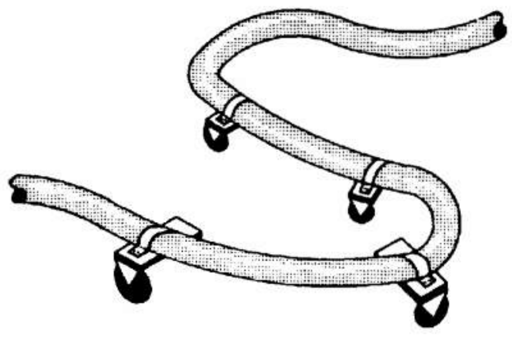


Figure 26-17. Casters for Heavy Cables and Hoses (Ref. 1)

personnel and components is applied to one side (see Figure 26-18).

(2) Use anchors or outriggers for stands which have high centers of gravity and can be overturned by winds.

(3) If stands are an integral part of the equipment, be sure that personnel can reach all items they must manipulate without falling off.

(4) Provide brakes for auxiliary stands equipped with wheels.

(5) Design the walking surfaces on stands and platforms to afford good traction under all weather conditions.

(6) Specify the use of engine stands which are slightly larger than the engine diameters to prevent damage from forklifts and other handling vehicles.

(7) Use properly balanced and supported fuselage stands with low centers of gravity so that the stands will not tip under unevenly distributed weights.

(8) Where consistent with aerodynamic and weight requirements, incorporate rails in the power plant shell structure in order to roll the engine in and out of the shell. The rails should be matched to the height and size of the engine transporter dolly (see Figure 26-19).

26-9.4 PLATFORMS AND LADDERS

(1) Design work platforms to allow maximum work space and to provide complete safety protection for the technician.

(2) Provide a minimum of six square feet of work space per technician.

(3) The platform should have a one-ton capacity. This capacity should always be in excess of the heaviest component to be supported by the platform.

(4) The platform must permit the technician to have both hands free for work.

(5) Incorporate the following features when designing maintenance ladders:

(a) Light weight construction.
(b) Nonconductive materials.
(c) Nonslip rungs.
(d) Splinter proof materials.
(e) Waterproof and humidity resistant materials.
(f) Materials resistant to chemical action.

(6) Design ladders and steps so they may be deiced when necessary by use of hot water or steam.

(7) Provide adequate protection against slipping for ladders ends when these ladders must be used in snow or ice. Rubber cleated, pivoted feet work well in dry or even rainy

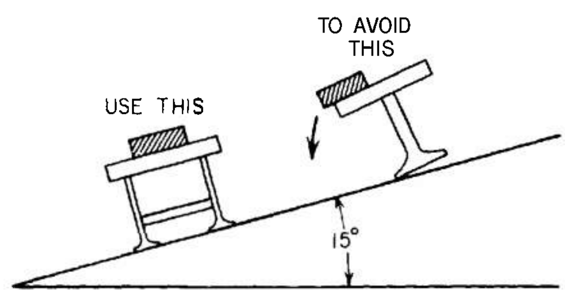


Figure 26-18. Physical Stability for Maintenance Stands (Ref. 3)

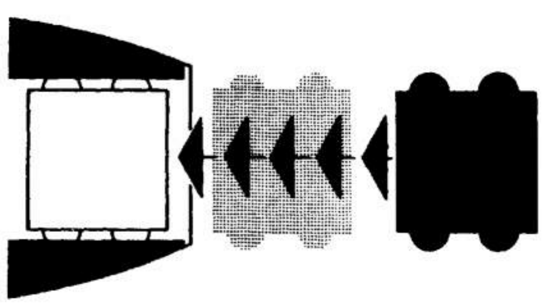


Figure 26-19. Incorporate Rails in Power Plant Shell Structure for Engine Removal and Installation (Ref. 1)

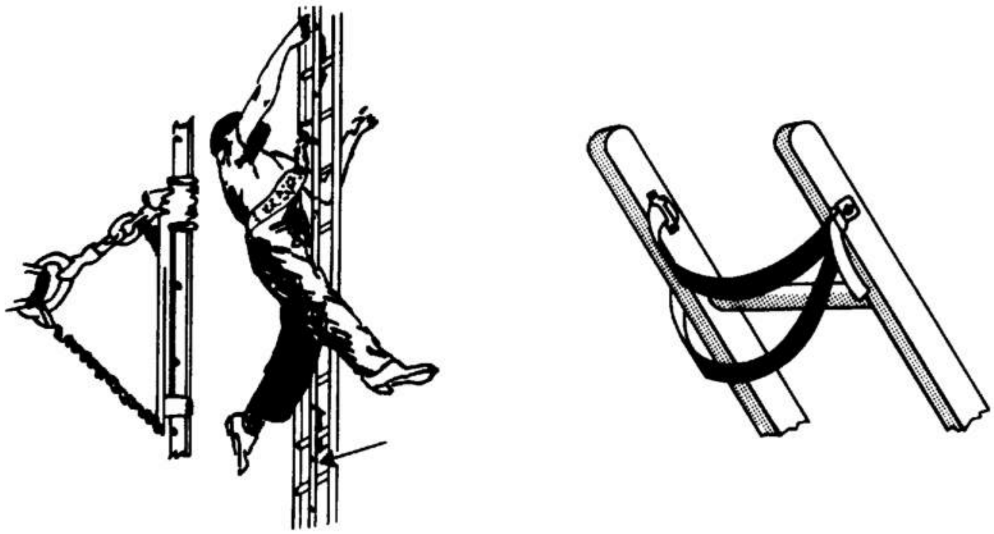


figure 26-20. Ladder Safety Devices (*Ref.* 21

weather, but are even worse than the conventional ladder end when used in snow and ice. For these conditions, provide ladders with steel cleats.

(8) Use safety devices on either fixed or portable ladders whenever necessary. Two such devices are illustrated in Figure 26-20.

(9) If metal ladders must be used, mark ladders with signs or waterproof decals warning against the danger of shock. Place these decals prominently on the outside of the side rails where they are clearly visible (see Figure 26-21).

(10) Use permanent-type hinges and locks in preference to bolts and nuts for assembling two-section extension ladders (see Figure 26-22).

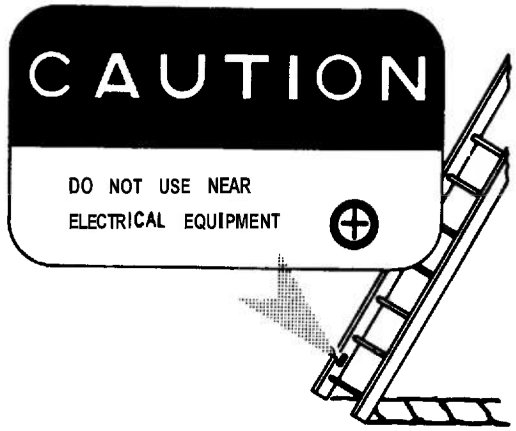


figure 26-27. Labeling *To Warn* of Danger from *Electrical* Shock (Ref. *1)*

26-9.5 TOWBARS, SPARE WHEELS, AND TIRES

(1) Design towbars and trailer tongues to be easily stowed when not in use.

(2) Provide storage space on vehicles for towbars and detachable tongues. If tongues are not detachable, provide means for stowing them out of the way.

(3) Make provisions for quick attachment of towbars and tongues. The presence of a load on the vehicle should not unduly hinder attachment.

(4) Use quick-disconnect pins rather than nuts and bolts for attachment.

(5) Keep towbars and tongues as lightweight as possible consistent with stress requirements. If the towbar is necessarily heavy because of the weight of the trailer plus the weapon, special design features (extra length, multiple handles) should be incorporated to allow handling by the minimum number of extra personnel.

(6) Equip towbars and tongues with clamps for securing air, electric, and hydraulic interconnecting hoses that must be attached to a prime mover.

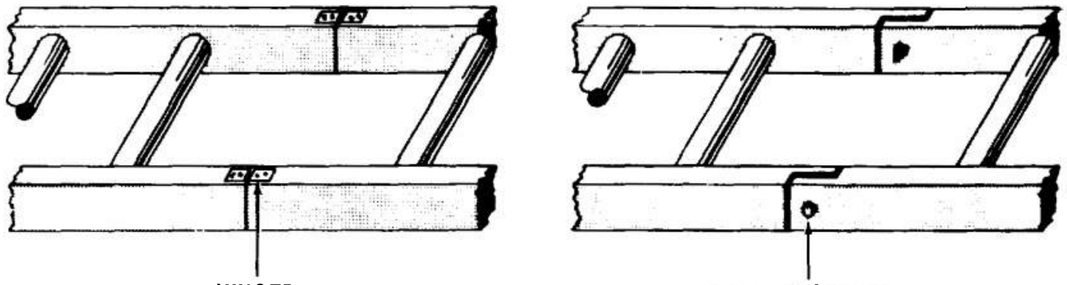


Figure 26-22. Assembling Two-Section Extension Ladders (Ref. 1)

(7) When a towbar is to be used for steering, provide a tongue extension to facilitate precise positioning if that is necessary.

(8) Locate storage for spare wheels and tires so that they will be accessible whether the vehicle is loaded or not.

(9) Ensure that the location of the spare wheel and tire stowage will not interfere with the performance of trailer maintenance.

(10) Position spare wheels and tires so that personnel will have no difficulty checking tire pressure or performing other periodic preventive maintenance.

REFERENCES

1. J. W. Altman, et al., *Guide to Design of Mechanical Equipment for Maintainability.* Air Force Systems Command, Wright-Patterson AFB, Ohio, 1961.
2. *Maintenance Engineering Handbook of Maintainability Design,* U S Army Missile Command, Redstone Arsenal, Ala., 1963.
3. P. H. Newman and G. L. Murphy, *Human Factors Handbook, Volume 111, For Design of Protective and Storage Ground Support Equipment,* AFSWC-TR-59-13, Air Force Special Weapons Center, Kirtand AFB, New Mexico, 1959.

CHAPTER 27
TANK-AUTOMOTIVE MATERIEL

27-1 GENERAL

The maintenance goals and criteria are described in the paragraphs which follow.

27-1.1 MAINTENANCE GOALS

The maintenance goals of the design engineer concerned with tank-automotive materiel should be:

(1) That ground vehicles will accomplish the following in a military environment, unless otherwise directed:

(a) *Wheeled, tactical vehicles. 25,000* miles without field or depot maintenance.

(b) *Tracked vehicles.* 5,000 miles without field or depot maintenance.

(2) That the total scheduled and unscheduled maintenance man-hours shall be a constant percentage and not exceed the following, within the requirements of (1) above:

(a) *Self-propelled wheeled vehicles.* Seven percent of the operational hours. The average distance negotiated by the vehicle shall be considered to be twenty miles for each hour of operation.

(b) *Self-propelled tracked vehicles.* Twenty percent of the operational hours. The average distance negotiated by the vehicle shall be considered to be ten miles for each hour of operation.

27-1.2 MAINTENANCE DESIGN CRITERIA

To help develop tank-automotive materiel that can meet these maintenance goals, the design engineer should consider incorporating the following maintenance design criteria into the development items:

(1) Use of modular or throwaway components, assemblies, and parts.

(2) Reduction in weight and quantity of components, assemblies, and parts.

(3) Simplification of vehicular operational requirements (operator and maintenance functions).

(4) Culmination of component design prior to application.

(5) Increased use of standardized, pre-tested components (see Figure 27-1).

(6) Wear-out limits should be defined to a degree that answers a clear margin of performance over the maintenance objective.

(7) Use of self-lubricating principles where practicable.

(8) Use of sealed and lubricated components and assemblies where feasible.

(9) Use of built-in testing and calibration for major components.

(10) Use of self-adjusting mechanisms wherever feasible.

(11) Use of gear drive accessories to eliminate belts and pulleys.

(12) Minimum number and complexity of maintenance tasks (i.e., calibration, adjustments, inspections, etc.),

(13) Maximum use of simple design.

(14) Design for rapid and positive recognition of malfunction or marginal performance.

(15) Design for rapid and positive identification of the replaceable defective component,

assembly, or part.

(16) Design to eliminate torque specifications at organizational maintenance level and minimize need for all other torque specifications.

(17) Design to minimize maintenance personnel skills and training requirements.

(18) Design to minimize the numbers and types of tools and test equipment (special and standard) required to perform maintenance.

(19) Design for optimum accessibility in all systems, equipments, and components requiring maintenance, inspections, removal or replacement.

(20) Design for maximum safety and protection for both equipment and personnel involved in the performance of maintenance.

(21) Design to minimize the net mean time required to accomplish scheduled and unscheduled maintenance to assure operational availability.

General problem areas and other design considerations are given in the paragraphs which follow.

27-2 FOUR GENERAL PROBLEM AREAS

Four general problem areas pertaining to tank-automotive materiel are discussed here.

First, the military vehicle continues operating as long as possible, therefore an unexpected element of the environment, such as mud, can become a problem. If a tank is operated over muddy ground without fenders, the amount of mud thrown on the deck may completely stop the flow of engine cooling air within a short time.

Second, a tank or tactical truck is also a home and work shop for the crew, who live in their vehicle and operate and maintain it. The designer should not overlook living and working requirements.

Third, military vehicles travel over rough terrain at high speeds. The shock loads applied under the punishment of high-speed, cross-country operation may cause the failure of many designs accepted as conventional practices in other applications (see Figure 27-2). Thus, snap-rings, spring loaded fasteners, press-fit retentions, and similar designs should be considered with caution.

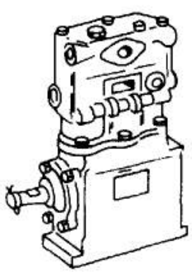
COMPRESSORS

RECOMMENDATION FOR M35AI MULTIFUEL 21/2 TON - 6 X 6

USE OF AIR COOLED COMPRESSOR IN PLACE OF WATER COOLED COMPRESSOR

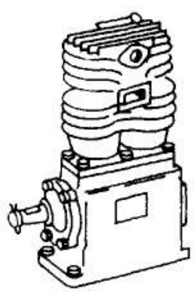
ADVANTAGES
LOWER COST
LESS WEIGHT
LOWER SUPPORT COSTS
TOTAL SAVINGS....$ 98.20

WATER COOLED



COST $ 83.20
REQUIRES COPPER TUBING & FITTINGS
COST $ 15.00
21 LINE ITEMS REQUIRED TO SUPPORT AT A COST OF $ 45.00
TOTAL COST $ 143.20

AIR COOLED



COST $45.00
ELIMINATES TUBING & FITTINGS
30% REDUCTION IN WEIGHT
THROW-A-WAY ITEM
NO SUPPORT REQUIRED
TOTAL COST $45.00

Figure 27-7. Use Standard Reliable Components (Ref. 1)

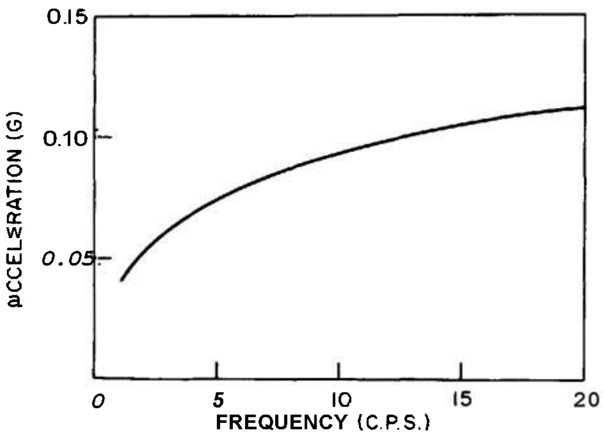


Figure 27-2. Vibration Limits for Wheeled Vehicles (Ref. 2)

Fourth, the designer must consider the problems created by arctic clothing. It is not sufficient to design a vehicle for the average man. The designer must realize that men are much larger in arctic clothes, with bulking bodies that become wedged in narrow hatches, ponderous feet that fumble with small closely-spaced foot pedals, and awkward hands unable to operate intricate hand controls (Ref. 3).

The designer must also consider the following maintainability factors to reduce the maintenance effort under arctic conditions (see also Refs. 4, 5, 6, and 7):

(1) Quick-disconnects in fuel and coolant lines.

(2) Increased size of fuel lines.

(3) Drain facilities in battery boxes.

(4) Easily accessible drains on fuel tanks.

(5) Hinged radiator louvers to facilitate cleaning.

(6) Consideration of low temperature flexible materials.

(7) Greater use of vibration absorption mountings.

27-3 OTHER DESIGN CONSIDERATIONS

To provide maximum reliability and minimum maintenance, it is essential that components be balanced as to their fatigue life, with performance levels designed to achieve a logistically known lifetime. Field testing, involving many hours of field evaluation, may be necessary. The designer must also consider preproduction testing and engineering reports before he can choose the components he eventually will incorporate into the vehicle's design.

Accessibility to vehicle components for removal, adjustments, repair, inspection, etc., is of major importance for both organizational and field maintenance. This factor is of particular importance for parts known to require frequent replacement, e.g., spark plugs, and particularly if the work will be done in combat or forward areas. Figure 27-3 is an example of how ease of maintenance can be improved by designing for accessibility.

An effective solution to replacing parts is by simplified packages of modular assemblies. In some diesel engines the fuel injection equipment is factory-timed and calibrated and requires no field service adjustments. The designer should consider simplified assemblies that permit removal and replacement by similar assemblies, much as one would handle a spark plug. Similar techniques can be applied to turbo-chargers and other essential accessories. An example of how downtime can be reduced by designing for rapid removal of parts is shown in Figure 27-4.

To keep the dust out and the fluid in, the designer must consider the rigidity of contact points, the use of gaskets, the shape of joints, and the stress applied to various parts of the vehicle. The environment in which a military vehicle operates calls for special efforts to provide adequate sealing. For example, the necessity for military vehicles to be submerged in water places added emphasis on adequate seals for rotating shafts.

All instruments should provide simple and visual means by which maintenance personnel can understand exactly the status of the operating mechanism. With simplified instrumentation, satisfactory operation can be achieved and maintenance downtime can be kept to a minimum, even with inadequately trained maintenance personnel (Ref. 4).

The need for a variety of lubricants is a constant burden on logistics. Designers should aim for a single multipurpose lubricant for all lubrication requirements.

Another way to maintain adequate vehicle performance and reduce the need for maintenance is to minimize the number of field adjustments by maintenance personnel. By proper design, the designer can reduce the temptation for field adjustments and field disassembly. The problem of readjusting proper clearances and tolerances and the introduction of dirt and foreign materials in the process shortens the life of the equipment.

The adequacy of vehicle design should be determined by extensive tests during premanufacturing evaluation. The manufacturer should be initially responsible for sufficient test hours on a large group of prototype vehicles to establish life factors and maintenance schedules. Such practices will go far in establishing efficient preventive maintenance schedules and will contribute to the designer's knowledge of fatigue factors influencing the life of components.

27-4 DESIGN RECOMMENDATIONS

27-4.1 THE OVERALL VEHICLE

Easy access to adjustment points, and filling, and draining locations should be provided, namely :

(1) Controls should be grouped together where practicable.

(2) Filler caps should be accessible and easy to remove in daylight or darkness without auxiliary light sources.

(3) Anti-splash or drip trays should be fitted when it is necessary to prevent fuel dripping.

(4) Access doors for engine and transmission compartments should be designed so that they car, be opened by one man.

(5) Doors should be able to remain in the open position by their own weight without being an obstruction.

(6) Access doors should be operable without traversing the turret.

Vehicles and equipment should be designed so as to facilitate and simplify waterproofing, namely :

(1) When waterproofing is provided as an integral part of the design, it should not interfere with ease-of-maintenance requirements.

(2) Built-in waterproofing should remain effective for long periods of storage.

All working parts require protection against the effects of mud, sand, dust, moisture, ice, snow, etc. The protective measures adopted will vary from complete sealing to removable covers or protective finishes, namely :

(1) Parts that would deteriorate from oil or

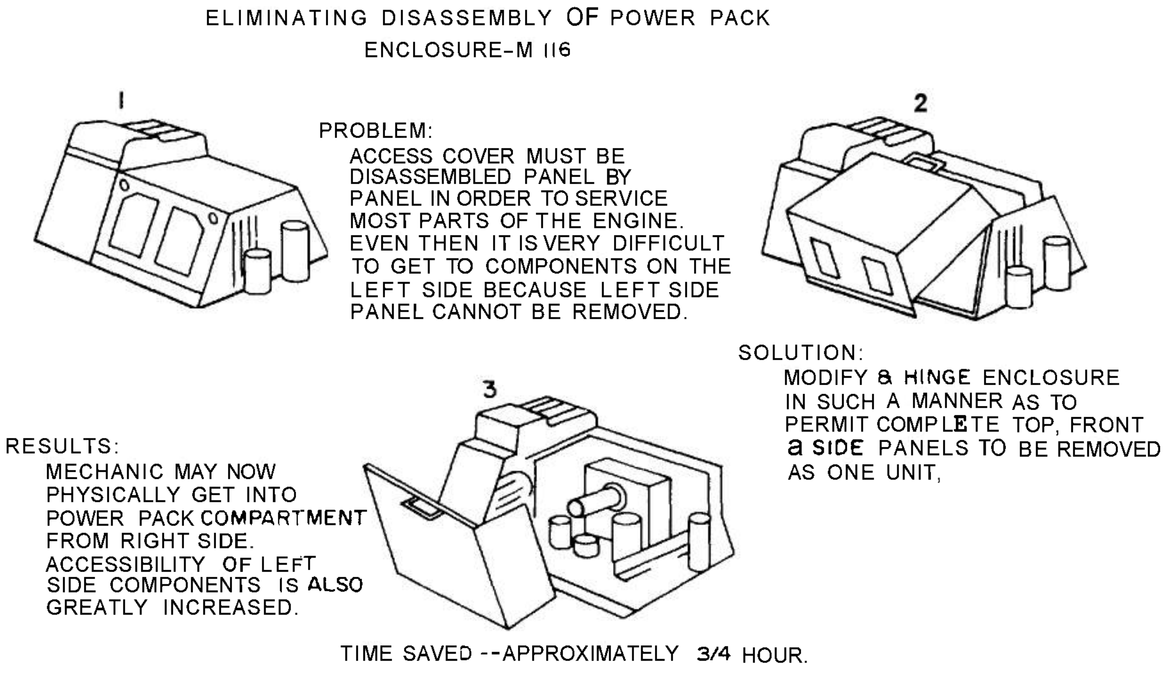


Figure 27-3. Increasing Ease of Maintenance by Improving Accessibility (Ref. 1)

salt-water contamination should be suitably protected.

(2) All vital parts should be protected from grit entering them during fording.

(3) Control rods, pipes, cables, flexible drives, etc., should be accessible and arranged to avoid corrosion or the effects of ice formation on them.

(4) It should be possible to dismantle and reassemble sealed parts without difficulty or damage to the sealing facers and without the use of any special tools.

(5) All areas and parts that become inaccessible after assembly should be treated beforehand to provide protection from corrosion.

(6) Equipment should require only a minimum of preservation to protect it against deterioration when in storage or transit. Unskilled personnel should be able to carry out the preservation work.

(7) Deep corners, recesses and other configurations that tend to harbor corrosive deposits should be avoided.

(8) The shelf life of packaged components should be at least 5 yr.

(9) Any protective measures adopted should not interfere with ease-of-maintenance requirements.

27-4.2 VEHICLE COMPONENTS AND SYSTEMS

The following design recommendations should be considered to facilitate the maintainability of specific vehicle components and systems. Automotive diagnostic test equipment criteria are discussed in par. 27-5.

27-4.2.1 *Engines*

Modern developments that reduce the rate of engine wear should be incorporated in the

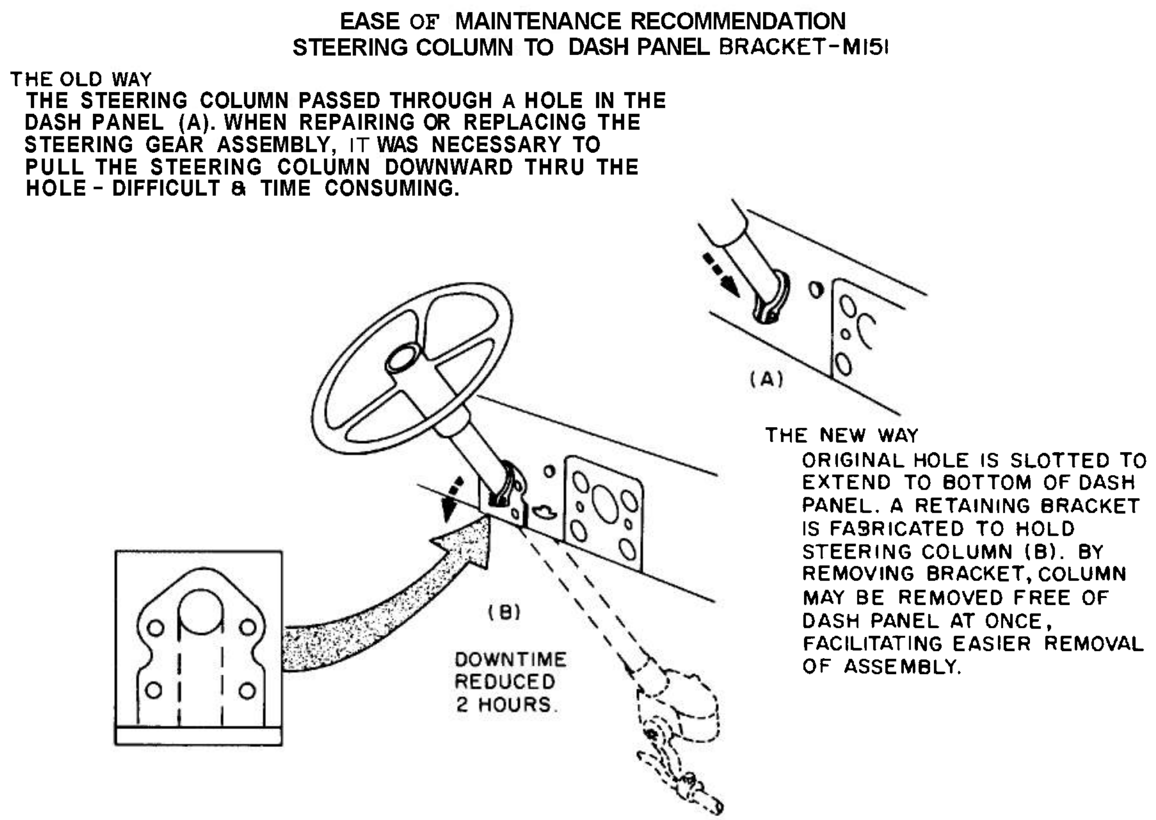


Figure 27-4. Reducing Downtime by Designing for Rapid Removal (Ref. 1)

design of internal combustion engines. The designer should provide special surface treatments, such as plating, aluminizing, and hardening, or use of antiscuff agents. Additional guidelines to be considered are as follows:

(1) For internal combustion engines of 20 hp or more, consideration should be given to either replaceable liners, or making allowances for reboring the cylinders to at least two standard oversizes. Whichever procedure makes for easier maintenance should be adopted. Hydraulic cylinders of 1 in. diameter or larger should have replaceable liners or cylinder bodies.

(2) Crankshaft bearings of the precision type should be provided.

(3) Crankcase sumps should be easy to remove.

(4) Adequate air cleaners should be accessible and easy to clean.

(5) Easy access to fan and other drive belts should be provided to simplify their adjustment or replacement. Consider the use of spring-loaded idler pulleys in these type installations.

27-4.2.2 Exhausts

Exhaust pipes and mufflers should not be placed where their heat is likely to affect other components. They should also be protected to avoid damage when the vehicle is moving over rough ground. Consider also the following:

(1) Exhaust pipes and mufflers should be made of heavy gage material suitably coated to resist corrosion and burning, particularly under adverse climatic conditions.

(2) Stainless-steel nuts and bolts should be used for exhaust-manifold pipe-flange joints.

(3) Flanges should be designed so that the bolt head cannot turn with the nut.

(4) Provide gravity draining of the exhaust system, when the equipment is on level ground.

27-4.2.3 Fuel and Hydraulic Systems

Fuel systems should be easy to drain, and fuel taps should not contain perishable seals. Vent pipes of adequate size should be provided to ensure speedy filling of fuel tanks. The following features should also be considered:

(1) Fuel feed pumps should be as easy to replace as any roadside repair. If this is not possible, an alternate fuel supply system should be considered.

(2) Adequate fuel filters that are accessible and easy to clean should be provided.

(3) The carburetor air intake pipe should be easy to remove.

(4) The interior of fuel and water tanks should be treated to resist corrosion. However, in deciding upon the coating for fuel tanks, expert advice should be sought since the fuel may dissolve the coating and aggravate the contamination problem.

(5) Drain cocks that provide a high rate of drainage should be fitted to all air receivers and oil reservoirs.

(6) All drain cocks should be closed when the handle is in the down position.

(7) Self-sealing couplings should be provided for hydraulic systems where frequent disconnection is necessary.

(8) A color or number code should be provided on complex hydraulic and pneumatic systems to simplify identification.

(9) Whenever possible, design the fuel system to have all piping constantly rising from the fuel tank to the using unit; e.g., carburetor, burner, etc., to avoid sumps in the piping which may collect water and freeze, and thus immobilize the equipment. Down-drained fuel lines accomplish the same purpose, but a suitable drain should be installed in installations of this type.

27-4.2.4 Brakes

Brakes should be designed as simply as possible to accomplish the vehicle's operational requirements. Consider also the following design features:

(1) All parts of a brake assembly-drums, discs, shoes, cylinders, support plates and housing, mechanisms, etc—should be readily and easily removable, replaceable, renewable, and reasonably repairable.

(2) Brakes should be adjustable without the need for removal of any part.

(3) No special tools, including wheel pullers, should be required to adjust or maintain brakes.

(4) Adjustments required to tighten brakes should be clearly marked as to proper rotation or action when operation is not obvious.

(5) Provide an inspection hole, protected by an attachable cover or window, for examining the condition of brake linings.

(6) Design brake drums or discs thick enough so they can be remachined at least twice.

(7) Provide rapid accessibility to such brake operations as filling, bleeding, adjusting, etc. Do not require maintenance personnel to work blindly.

(8) The use of self-adjusting brakes is desirable provided characteristics are not incorporated which will permit the brake adjustment to be accidentally tightened or loosened. However, before self-adjusting brakes are decided upon, the design activity's maintainability organization should require conclusive test data from reliability personnel as to their effectiveness.

27-4.2.5 Clutches

The general design recommendations for clutches are the same as those given for brakes. Additional features which should be considered however are as follows:

(1) Whenever possible, utilize split-line clutch element design, or other appropriate methods, so that clutch linings, plates, or discs can be rapidly removed or replaced without removal of the prime mover, e.g., engine, associated gear box, etc.

(2) Clutch adjustment devices should indicate the remaining life of the clutch lining.

(3) Clutch design, when of the dry type, should provide generous positive slingers designed to prevent oil leakage from the prime mover or gear box from coming in contact with the friction surface of the clutch. Well guarded drain holes and baffles should be provided to lead away this oil.

(4) Thrust bearings should be replaceable, without removal of any major part of the equipment, by use of split-line design or other appropriate method.

27-4.2.6 Wiring and Cable

Consider the following recommendations:

(1) Provide standardized connectors for intervehicle connection.

(2) Bonding points should be accessible, and their securing screws should have vibration-proof washers.

(3) Test points should be provided for checking components when their terminals are not accessible.

(4) Electrical shielding should be easy to remove.

(5) All ground return connections should be brought to a common, grounded bus bar.

(6) All wiring should be positioned away from sharp corners.

(7) Wiring passing through unprotected holes in metal parts should be protected by grommets.

(8) All electrical cables should be oil proof unless their location provides adequate protection against contact with oil.

(9) Exposed cables should be protected from mechanical damage. Consider the use of armored cables in such installations.

(10) Avoid long unsupported lengths of cable or wire.

(11) Cables may be run inside frame members providing they are accessible and not exposed to heat or oil.

(12) Electrical cables should be color coded or tagged for ease in identification. They should also be the quick-disconnect type wherever possible (see Figure 27-5).

27-4.2.7 Ignition Equipment

Ignition equipment for internal combustion engines should be designed to have the following maintainability characteristics:

(1) Spark plugs should be of the highest quality and reflect the most advanced technology in the state of the art. Materials selected should provide maximum life, ease of adjustment, and maintenance. Self-cleaning types should be used wherever possible.

(2) Distributors should be located to permit rapid and easy access to all maintenance points, close line-of-sight inspection, and rapid total removal and assembly. Flywheels used for timing should be clearly and adequately marked by engraving or deep stamping, and be provided with an accurate rigid pointer.

(3) Ignition points should be designed and located for rapid removal, adjustment, and assembly. The contact diameters of ignition points should not be less than 0.1875 in. and the contacts should be made of the highest quality material.

(4) Ignition timing advance mechanisms should be rapidly and easily replaceable, and capable of inspection.

(5) Ignition coils should be completely embedded or potted and should be tested by immersion and other means to ensure permanent exclusion of moisture. Coils should be mounted away from heat damaging environments.

(6) Ignition systems shall be radio suppressed in accordance with Spec. MIL-S-10379.

27-4.2.8 Dynamotors

Consider the following design recommendations:

(1) Dynamotors should be designed to allow for the use of commutator dressing and burnishing stones and should be mounted so they do not have to be removed to dress and burnish the commutator.

(2) Slip ring assemblies should be provided with extra slip rings, where practicable, for emergency repairs.

(3) Slip rings should be protected from the entrance of dust and moisture and should be self-cleaning and accessible for servicing.

27-4.2.9 Chassis

Parts that might have to be replaced should be bolted, not riveted or welded, to the frame. Consider also the following:

(1) Standard devices for checking chassis alignment should be provided at accessible positions and should be suitably marked.

(2) Cabs and bodies should be easy to remove, and heavy cabs should be provided with lifting points.

(3) Bumpers should be rugged, of standard proportions, and placed at a standard height within the vehicle class. Provide towing attachments on the bumper.

(4) The skirting plates, track guards, mud flaps, etc., of combat vehicle suspension systems should be easy to remove.

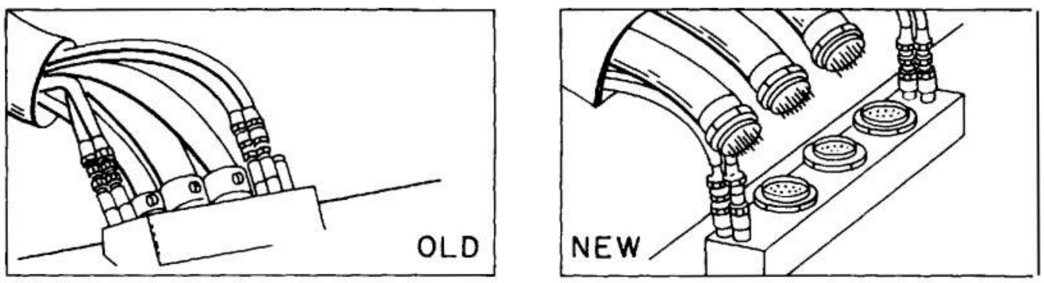
(5) The installation and adjustment of tracks should not require the use of special jacks or special tensioners to pull out slack in the track.

(6) Suspension units and final drives should be removable under field conditions.

27-4.2.10 Batteries

The maintainability criteria presented in Chapter 23, Paragraph 23-29 should be followed in the design and location of batteries.

XM437EI, XM438E2 VEHICLES



FAULT:

TIME REQUIRED FOR REMOVAL OF CABLES WAS APPROXIMATELY (2) HOURS.

REMOVAL OF IO OR 15 INDIVIDUAL BOLT-ON CONNECTIONS AND DRAWING HARNESSES OUT OF BOXES AND THROUGH CONDUIT WILL RESULT IN HIGHER MORTALITY RATE ON WIRING AND UNNECESSARY DOWNTIME FOR VEHICLES.

CORRECTIVE ACTION REQUIRED:

RECOMMEND THAT WIRING HARNESSES RUNNING FROM THE PRIME MOVER TO EITHER THE FUEL TANKER OR THE CARGO CARRIER BE EQUIPPED WITH QUICK DISCONNECT FITTINGS. PIN AND SOCKET TYPE QUICK DISCONNECT FITTINGS CAN BESEPARATEO IN NO MORE THAN (3) MINUTES FOR ALL THREE CABLES

Figure 27-5. Use Quick-Disconnects for Electrical Wiring Harnesses (Ref. 7)

27-4.2.11 Other Items

For maintainability criteria relating to other vehicular items, such as canvasses and accessories, radiators, intervehicular connectors, and tires, refer to the checklist at the end of this chapter.

27-5 AUTOMOTIVE DIAGNOSTIC TEST EQUIPMENT CRITERIA

The purpose of these guidelines is to assist planners, designers, and developers of Intemal Combustion Engine Powered Materiel (JCEPM). These guidelines will enhance ICEPM maintainability and availability through the use of Automatic Test Equipment (ATE) and state-of-the-art Automatic Test Measurement and Diagnostic Equipment (ATMDE). The application of these guidelines and the use of ATE/ATMDE also will reduce the life cycle cost of all ICEPM to which they are applied.

These general guidelines embrace all ICEPM including principal subsystems such as engine, fuel, electrical, cooling, exhaust, lubrication, and drive/transmissions. Specific applications, however, depend upon the life cycle milestone of the particular ICEPM.

27-5.1 Automatic Test Equipment for ICEPM

Three levels of automatic diagnostic sets are in development, i.e., organizational, light field, and medium field sets. ATE generally is used for Organizational (ORGL), Direct Support (DS), and General Support (GS) functions.

The principal function of ATE/ICEPM (ORGL) is to diagnose automatically, at the organizational level, malfunctions in the fuel, electrical, cooling, oil, and engine components of combat vehicles and transport-type vehicles. Limited testing of combat-type vehicle transmissions will be provided.

The principal function of ATE/ICEPM (DS/GS) is to diagnose automatically, at the DS/GS level, malfunctions in the electronic, electrical, electromechanical, hydraulic, pneumatic, hydropneumatic, and electro-optical components of standard "A" tactical and transport-type vehicles.

A direct benefit of a good diagnostic process is that maintenance effort is applied exactly where it is needed—no more, no less. Thus, the maintenance support positive (MS+) concept is efficiently promoted.

27-5.2 ICEPM Adaptability for Automatic Test

The ICEPM design should provide accessible measurement points to enable attachment of instrumentation and controls for ATE/ICEPM. Until such time that built-in instrumentation, terminating in a common connector, becomes cost effective, maximum consideration should be given to existing instrumentation. The instrumentation will be selected from the Standard Transducer Kits of the ATE/ICEPM. Placement of the standard and new transducers should be such that data from them will provide (either uniquely or in combination) the necessary information to permit diagnosis of a malfunction.

To assist the ICEPM designers, Table 27-1 lists the measurements desired to be made on two types of engines—spark ignition (SI) and compression ignition (CI)—with the approximate location and method of sensor attachment indicated. Each individual test access point should be identified separately in proposal or design studies. The final design should designate the location of the test points to be incorporated in the ICEPM. To assist in the interpretation of Table 27-1, the following information is provided:

(1) Pipe plugs are to be standard **3/8** in. NPT (National Pipe Taper) removable by one man without requiring removal of any interfering element. Clearance shall be provided to allow the insertion of a fitting and/or hose and/or transducer. Access to the test points should be from the **upper** point of the ICEPM end item. The design goal for plug removal time should be 1 man-minute or less.

(2) Either a protrusion (desired) or a line depression on an element rotating at camshaft speed should be provided. Such protrusion or depression should be indexed to the timing mark indicating top dead center on the power stroke of the No. 1 cylinder. A bracket or threaded hole (5/16 in. - 24 U. S. Standard) should be provided to hold and

position an Electro Products Laboratory Model 3016 magnetic pickup, or equivalent, such that the pickup to protrusion distance can be set to 0.003 to 0.005 in. If a line depression is used, it must be of sufficient depth to produce a discernible pulse above those produced by surface discontinuities. The design goal for installation at the referenced pickup should be 2 man-minutes or less.

TABLE 27-1. TEST POINTS

MEASUREMENT	TYPES OF ENGINE SI	CI	TYPE AND ACCESSORIES
1. Intake Manifold Pressure	X		Pipe Plug- see par. (1) *
2. Engine Speed/Camshaft Ignition	X	X	See par. (2)
3. Fuel Rate	X	X	See par. (3)
4. Ignition Waveform	X		See par. (4)
5. Engine Torque	X	X	See par. (5)
6. Air Flow	X	X	See par. (6)
7. Exhaust Analysis		X	See par. (6)
8. Injector Pump Pressure	X	X	See par. (7)
9. Exhaust Blowby	X	X	See par. (8)
10. Oil Consumption	X	X	Dip Stick
11. Cylinder Power Drop	X		see par. (4)
12. Oil Pressure (Engine)	X	X	Pipe Plug- see par. (1)
13. Oil Temperature	X	X	Dip Stick
14. Battery Voltage & Charging Current	X	X	See par. (9)
15. Starter Drain	X	X	Normal Cable
16. Lower Crankcase Vibration	X	X	See par. (10)
17. Coolant Temperature Inlet/Outlet	X	X	Pipe Plug- see Par. (1)
18. Transfer Vibration	X	X	See par. (11)
19. Differential Vibration	X	X	See par. (11)

*Subparagraphs of par. 27-5.2.

(3) The fuel line between the fuel pump and carburetor must be capable of being disconnected and displaced enough, approximately 5 in., to allow the insertion of appropriate connections to transducers. Disconnection must be accomplished by access from the upper portion of the engine within a design goal of 1.5 man-minutes or less.

(4) A suitably protected access point should be provided in the distributor/coil assembly such that the secondary reflected waveform can be sensed in the coil primary. The access point should be capable of accepting an Adapter, Engine Electrical' Test, FSN 4910-356-7492, drawing number 7540877. The design goal for the installation of the adapter should be 1 man-minute or less.

(5) Provision should be made for removal of the propeller shaft and insertion of a replacement shaft with an inline torquemeter attached. A section of the drive line with a minimum longitudinal dimension of 10 in. and minimum radial clearance of 3 in. is required to permit insertion. A design goal is that the section of propeller shaft to be removed be capable of being handled by one man.

(6) Air flow and exhaust analysis measurements require no special provisions except that of easy removal of the air cleaner connecting tubing to the carburetor/air intake in order to permit insertion of flow and temperature measuring transducers.

(7) In compression-ignition engines access to a common point of the injection system must be provided. In distributor systems a cap screw is normally provided in the common point and is satisfactory. In other type injection systems, pipe plug access is required at an accessible location in the pump-injection system. For unit injector systems, consideration should be given to incorporation of load cells in the mechanical activation mechanism. Outputs to a connector, or mounting means, for an externally supplied accelerometer, or access for measurement of exhaust manifold temperature should be provided.

(8) The crankcase ventilation line must be capable of being disconnected and displaced for insertion of appropriate connections to transducers (approximately 5 in.). Disconnection must be accomplished by access from the upper portion of the engine within a design goal of 1.5 man-minutes or less.

(9) An electrical subsystem harness should be provided to permit isolation of electrical subsystem malfunctions. Circuit design should permit desired measurements to be obtained from one conveniently located waterproof receptacle,. The electrical test points listed in Table 27-2 should be provided.

(10) Four bosses, with threaded holes (3/8 in. - 24 U. S. Standard) into which,

accelerometers may be mounted, are required on the block just above the oil pan. A minimum of four thread engagement is required. The holes (two on each side of the block) must be parallel and in the same plane within normal manufacturing tolerances. Approximately equal spacing is required but this requirement may be waived to enhance accessibility. The design goal for the removal of protective cover and installation of a stud should be a total of 2 min or less. Access may be provided from either above or below.

(11) Threaded bosses as specified in par. (10) should be provided in the differentials and transfer case(s) with the longitudinal axis of the hole in an approximately vertical position and accessible from undemeath the vehicle.

27-5.3 Diagnostic Analysis

The ATE/ICEPM equipment is used to perform inspection and diagnosis on the engine, fuel, electrical, cooling, exhaust, and transmission subsystems of the ICEPM to which it is applied. In performing its function as diagnostic equipment, it is capable of testing those items of the appropriate ICEPM subsystems which are specified in the Maintenance Allocation Chart (MAC) contained in the appropriate Maintenance Manual for the ICEPM.

TABLE 27-2. ELECTRICAL TEST POINTS

SYSTEM CHECK	VEHICLE CIRCUIT CONNECTION
1. Battery Amperage	Battery Terminals
2. Generator Voltage	Generator Regulator
3. Generator Current	Shunt in Vehicle
4. Starter Voltage	Starter Terminals
5. Starter Solenoid Voltage	Solenoid Terminals
6. Lighting Breaker Voltage	Lighting Breaker
7. Instrument Panel Gage Calibration connections to instrument panel gage sending unit terminal and to terminal of corresponding sending unit brought out separately with a means built into the vehicle circuit to provide connection between gage and sending unit for normal operation.	
8. Instrument Panel Gage Breaker	Voltage Gage Breaker
9. Starter Current	Shunt in Starter Cable

The diagnostic requirements for the ATE/ICEPM must be defined for the ICEPM in terms of the specific me'thod of diagnosis required. These specific diagnostic methods are defined:

(1) Diagnosis (D). Automatic measurement and evaluation of the performance of the "item" and indication of the maintenance action required.

(2) Assembly Diagnosis (AD). Automatic measurement and diagnosis are performed on the assembly of which the listed item is a component. Automatic measurement, evaluation of the performance of the assembly, and indication of the maintenance action required are revealed.

(3) Inspection and Diagnosis (ID). Automatic measurement and evaluation indicate possible sources of malfunction. The equipment is assisted by the operator in determining the source of the malfunction by performing directed tests and recording the results.

(4) Inspection Test, Malfunction (IT[M]). Upon detection of a malfunction as a result of an automatic, semi-automatic, or manual test, the operator is directed to perform manual or inspection tests on the indicated item and record the result.

(5) Inspection Test, Routine (IT[R]). As part of the normal test procedure, the operator is directed to perform visual/manual inspection tests on the indicated item and record the results.

The diagnostic capability is provided by a detailed analysis of function, criteria, and accessibility performed on the ICEPM in order to meet (as a minimum) the diagnostic requirements authorized in the MAC. This Unit Under Test (UUT) diagnostic analysis should include, but not be limited to, the following UUT engineering data:

(1) Diagnostic Criteria: qualitative and quantitative pass/fail indicators and/or including marginal good/bad bands

(2) Transducer Selection: accuracy and, if not in the standard Transducer Kit (TK) or a standard ATE/ICEPM Transducer, reasons for selection

(3) Transducer Placement and Mounting

(4) Test Point Selection and Adapter Design

(5) Test Procedures

(6) Software/Hardware/Operator Function Allocation
(7) Malfunction Diagnosis Rationale (Truth Table).

The analysis must be sufficiently detailed and complete to prove the validity of each UUT malfunction diagnosis. The analysis must show that each malfunction can be uniquely defined in terms of the selected UUT parameters (may be more than one).

27-5.4 Transducer Kit (TK) (if required)

27-5.4.1 General

A detailed analysis must be prepared which furnishes the engineering data for the detailed design of the appropriate TK for the UUT class covered. The required data include:

(1) Physical Parameters
(2) TK Contents
(3) Components
(4) Circuits
(5) Wiring Diagram
(6) Rough Draft of Technical Manual (TM).

The TK must contain the components which are required to connect the transducer(s) to the UUT in order to derive the signals which are indicators of physical parameters related to UUT performance. The TK must also contain the hardware necessary to adapt the Programmable Diagnostic Unit (PDU) for the specific ICEPM class. Each TK must include, but not be limited to, the following contents:

(1) Transducers, Mounting Adapters, and Special Tools
(2) Junction Box (w/approximate signal conditioning if required)
(3) Cables/Harnesses
(4) UUT Program and TM.

The carrying case should meet the provisions of the ATE/ICEPM requirements for the housing and safe transport of the contents. Emphasis must be placed on the human factor engineering aspects of the arrangement of the TK contents to insure that the components (to be affixed to the UUT) are readily accessible and easily identified, and promote the use by the operator. In its transport condition, the TK must be portable by one (1) man (at ORGL). The maximum degree of standardization of TK components among various TK's is desired; however, the design must be such as to minimize probability of erroneous diagnosis as well as erroneous TK employment.

27-5.4.2 Transducers, Mounting Adapters, and Special Tools

Each TK should contain transducers which, when coupled to the UUT by their proper adapters, generate electrical signals that provide data representation of performance parameters of the subsystems to be tested and diagnosed by the ATE/ICEPM equipment. The number, type, and accuracy of the transducers that are included in each TK are determined by the data that must be obtained to provide the required degree of UUT malfunction diagnosis. The individual transducer-UUT interfaces are determined by the accessible locations for obtaining the data required, without modification or major disassembly of the UUT and within the time constraints imposed. Such actions as disconnecting a lead or no-pressure fuel line, for example, are not construed as major disassembly in this context.

Placement of the transducers and adapters on the UUT should be performed using either of the following standard organizational maintenance tool kits:

(1) Tool Kit, Automotive Mechanics, Lightweight, W33004, reference SC 5180-97-CL-E50
(2) Tool Kit, Mechanical Repairman, w/case, W45128, reference SC 4940-95-CL-A69
(3) Special Tools. If special tools are required that are not included in these organizational tool kits, they must be provided in the TK. The use of special tools requires HQ, USAMC, approval.

The TK must be designed so that the operator can instrument the TK, using the tools defined, as indicated:

(1) Transport Vehicles—20 min
(2) Tactical Vehicles—40 min exclusive of protective armor removal
(3) Special Purpose Equipment—30 min
(4) Special Equipment Vehicles—40 min.

27-5.4.3 Junction Box

A junction box must be provided to facilitate transmission of the electrical signals from the UUT to the PDU. A single connector should be provided on the junction box to mate with the PDU cable. Necessary transducers, transducer excitation, and unique signal conditioning, not UUT affixed, are to be included in the junction box. In addition, internal test connectors are to be provided in the junction box exclusively for depot maintenance of the junction box itself.

27-5.4.4 Cables/Harnesses

Each TK should include required electrical, hydraulic, and pneumatic cabling necessary to connect the junction box to the transducers and adapters that are affixed to the UUT. Each cable termination should be designed so as to minimize the probability of erroneous connection. All electrical connections to the UUT should be combined in a cable which terminates in a single connector for attachment to the junction box.

27-5.4.5 UUT Program and Technical Manual

The TK should contain the UUT Program which relates the PDU to the UUT type. The means for entering the program into the PDU is provided in the PDU. In addition, the TK should include a Technical Manual that provides instructions for operation and maintenance of the TK.

Programs for the PDU-UUT diagnosis should be written in the Abbreviated Test Language for Army Systems—Expandable (ATLAS-X). ATLAS-X user manuals are available.

Consideration must be given to the need for updating and revising the TK as changes are made to the UUT and/or test procedure. The TK contents should be so configured as to facilitate replacement of the Technical Manual and UUT Program.

The Technical Manual shall be structured to direct the operator to the appropriate sections of the UUT Organizational Maintenance Technical Manual, i.e., "-20" or "-12" TM, to accomplish the maintenance action indicated by the PDU.

27-5.5 Technical Assistance

Additional information and technical assistance relating to these guidelines may be obtained from the Fire Direction and Diagnostic Equipment Laboratory, Frankford Arsenal. Written requests for information should be addressed to: Commanding Officer, Frankford Arsenal, Philadelphia, Pa. 19137. Telephone requests for information should be directed to Autovon 348-1800.

27-6 DESIGN HINTS FOR AVOIDING SPECIAL TOOLS

Keep to a minimum the number of special tools needed to maintain or repair any type of tracked vehicle. Sample expedients to accomplish this goal are:

(1) *Torsion bars and anchors.* Puller hole should be ½-20 UNF.

(2) *Recoil mechanism piston rod.* End hole for the compressor should be ⅝-11 UNF.

(3) *Road-wheel arms.* Provide ways to lift the road wheel, such as by extending the spindle.

(4) *Engine turning.* Provide means for turning the engine mechanically, such as by an access cover to the power takeoff or by hexagonal or flat parts of the fan drive shaft.

(5) *Puller holes in gears.* Use an even-number, ⅝-19 UNF threaded hole to fit the puller.

(6) *Shock-absorber bearings.* Do not crimp or stake the bearing in place, and provide an easy method for locking it.

(7) *Oil seals.* Press them in flush with the housing. Provide a lead on shafts to slip the seal over it. Threaded shaft ends must clear the seals.

(8) *Bearing locknuts.* Do not use slotted- or serrated-type bearing locknuts; use hex type locknuts.

(9) *Miscellaneous locknuts.* Never use slotted face-pin, or radial-pin types; use hex types. Provide flat parts for an open-end wrench instead of holes or slots for a spanner wrench.

(10) *Access or drain plugs.* A machined 0.25-, 0.5-, or 0.75-in. square hole to fit the drive tang of common tools is preferable. Cast or forged holes with a taper are unsuitable for this purpose.

(11) *Bearings.* Do not seat the bearing with the inner or outer race completely against a shoulder so that there is no room behind to pull from. Do not shrink fit bearings that will have to be removed for servicing (see also Chapter 22).

(12) *Main and connecting rod bearings.* Main and connecting rod bearings and crankshaft seals on internal combustion engines should be replaceable without having to remove the engine, crankshaft, or connecting rods from the vehicle. It should be possible to "drop" the crankshaft sufficiently to easily rotate the bearing into the upper position. A short locating pin should be fixed in the crankshaft bed to indicate and locate, without tools, the correct position of this bearing half. Crankshaft end seals should be of split-line design and incorporated in their own rigid housing which fits tightly into a groove in the engine bed. Unsupported "wick type" seals are prohibited. Main and connecting rod bearings should be of sufficient length, with each having a clearance of 0.006 in. total diametral difference (for bearings up to 2.5 in. diameter), and 0.010 in. (for bearings up to 5.0 in. diameter), so that the normal oil, pressure for the engine when running hot with summer grade oil should not drop more than one half the new engine normal oil pressure at one fifth maximum engine speed.

(13) *Power plants.* All power plants must be capable of being testrun away from the vehicle without requiring extensive adaptation. The existing electrical and fuel lines are to be used to the maximum extent possible.

(14) *Sprockets.* To eliminate the need for special gages, indicate on the sprocket itself the wear pattern and degree of wear permissible.

(15) *Transmission shock mounts.* Bolted- or screwed-type transmission shock mounts are preferable. Pressed-in types are extremely difficult to remove and replace, and require a number of special tools.

(16) *Road wheels.* Design the flange that contacts the center guides so that the amount of permissible wear can be easily determined without the use of special tools.

(17) *Counterbores.* Make counterbores around bolt heads large enough to permit the use of maximum size outside diameter sockets in standard tool sets.

(18) *Truck tension.* Design the track-tension adjusting device so that it can be turned by common tools. Make sure the turning device is free of excessive space restrictions, and accessible.

(19) *Threaded jacking holes.* The holes should be ¼-20 UNC, ½-13 UNC, or ¾-10 UNC. In-between sizes are not desirable. If possible, use attaching bolts long enough to do the jacking job.

(20) *Final-drive assemblies.* These assemblies are to be removable by lifting directly from above. For lifting the final drive case, provide eyebolts or threaded holes (see Table 27-3).

(21) *Engine-deck-grille work.* Grilles should be designed so that they can be removed in one

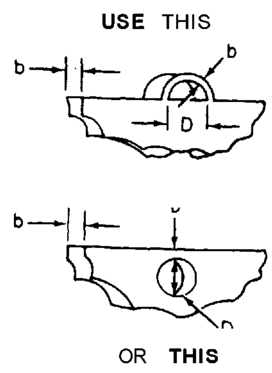
TABLE 27-3. LIFTING EYES

Provide lifting eye attachment threads (or lifting loops) for all parts weighing more than 100 lb.

Load	Thread Size	No. of Holes
1000 lb	1/2 - 13UNCx1-1/4	1
2000 lb	1/2 - 13UNCx1-1/4	2
4000 lb	1 - 8UNCx2-1/2	1
8000 lb	1 - 8UNCx2-1/2	2

Use the following integral lift loops if cost savings will result:

Load	Loop Opening D	Bar Size (Steel)b
1000 lb	1.5	1.5
2000 lb	1.812	0.75
4000 lb	1.062	1
8000 lb	3	1.5



complete assembly to eliminate piecemeal removal. Lifting eyes for this purpose should be permanently attached (see Table 27-3).

(22) *Engine and transmission lifting points.* Design lifting points so they are up high and easily accessible. If they are low and hidden, lifting slings must have spreader bars, stiff beams, etc. Make lifting points strong enough to be lifted by a spread-leg type sling without requiring beams or spreaders.

(23) *Valve seats.* Make sure that room is left behind valve seats so that a puller tool can be used to remove them.

(24) *Nitrogen recoil mechanisms and accumulator.* Uses the standard charging valve, Army Command Part No. **799261,** which will eliminate any need for special charging equipment.

(25) *Starters and generators.* Use quick-disconnect devices for mounting starters and generators. Studs, nuts, and bolts take a great deal of time to remove. Mounting nuts, when used without enough head clearance, require special open-end, crowfoot, or half-moon wrenches because they are hidden and inaccessible to standard tools.

(26) *Fasteners.* Keep to a minimum the number of fastener types and sizes used. Whenever possible, use only one size of fastener to attach a component (see Chapter 21).

27-7 CHECKLIST

Table 27-4 summarizes the recommendations which should be considered in the design of tank-automotive materiel (Ref. **2**). The checklist contains several items which were not discussed separately in the text. In using the checklist, if the answer to any question is ***no,*** the design should be restudied to ascertain the need for correction.

TABLE 27-4. TANK-AUTOMOTIVE MATERIEL CHECKLIST

Engines

1. Are means provided for manually cranking the engine?
2. Are engine timing marks visibly accessible?
3. Do engine timing marks have a reference point on the engine to permit a timing check when the engine is installed in the vehicle?
4. Are breathers easy to remove and replace?
5. Are engine governors provided where practical?
6. Are governors made tamperproof?
7. Are fan belts and other drives requiring adjustment simple and readily accessible?
8. Does the oil drain plug drain the pan completely without requiring the operator to move the vehicle?
9. Is the distributor or fuel injector located in an accessible and unobstructed location?
10. Are fuel and oil filters located so they can be cleaned and replaced without disassembly of other parts of the vehicle?

Drains and Vents

1. Is the vehicle designed to require few drain valves with simple, accessible, and dependable operating mechanisms?
2. Are vents and drains designed to prevent clogging from mud, ice, or other contamination?
3. Are drain plugs and valves designed to resist seizing, either in the open or closed position?
4. Are all drain plugs a minimum number of sizes (preferably of the same size) and do they have a socket (recess) to permit removal by a common hand tool?
5. Are drains provided and designed to empty components completely of lubricants and hydraulic fluids?
6. Do drained fluids drain unobstructed to the outside of the vehicle without special equipment and without splashing onto vehicle components?
7. Are pneumatic system reservoir purging drains readily available to the operator

TABLE 27-4. TANK-AUTOMOTIVE MATERIEL CHECKLIST (cont)

and do they drain the tanks completely?

8. Are means provided to remove water from cab and cargo body with vehicle either under way or at rest?
9. Are drains and vents located where they can be cleaned and checked easily by crew members?
10. Are drains and vents capable of easy identification and located to allow closing and checking prior to operation of floating or swimming vehicle?
11. Are instruction plates provided showing procedure and location for drains and vents on floating or swimming vehicles?
12. Are drain operating handles designed to be down when in closed position?

Batteries

1. Are storage batteries capable of being exchanged by one man in no more than ten minutes, using on-vehicle equipment only?
2. Are batteries and their compartments capable of being cleaned and serviced without removal of other compartments?
3. Are positive and negative battery terminals different sizes to prevent incorrect assembly?
4. Are battery retaining devices secured with fasteners that can be removed without hand tools or provided with the same bolt or nut size as the battery terminal clamps?
5. Are batteries mounted on roll-out racks, slides, or hinges and is it covenient to extend these components without disconnecting them?
6. Are battery access covers fastened with quick-release fasteners and is the mounted position of the access cover obvious? Where a hinged cover is used, is sufficient clearance allowed for opening the door?

Canvas and Accessories

1. Are tarpaulins and bows covering the bed of cargo vehicles capable of providing a 75-in. clearance from the cargo floor to provide head clearance for men working inside the vehicle?
2. Is one man able to gain access to the cargo compartment from front or rear with a tarpaulin and curtains in place within three minutes?
3. Are tarpaulin bows, ropes, and snaps easy to unfasten? Are bows easy to remove from sockets under wet, muddy, and/or freezing operation conditions by personnel wearing gloves?
4. Are tarpaulin bows (especially wooden ones) designed to resist seizing in their sockets because of moisture, rust, or dirt?
5. Are tarpaulins and cab tops shaped and supported to shed waste, and preclude formation of water or ice pockets, whether the vehicle is parked or in operation?
6. Are cab tops, tarpaulins, and curtains protected from chafing and flapping?
7. Are tarpaulin and cab-top bow sockets provided with adequate drain apertures?
8. Is the cab capable of conversion from open to closed type, and vice versa, by one man in ten minutes or less?
9. Are tarpaulin, and curtains, and bows capable of being removed or installed by two men in no more than ten minutes?
10. Are tarpaulins and end curtains inherently fire resistant or treated to be fire retardant?
11. Are pins and other retaining devices provided with the largest working clearances which will still permit them to be retained properly?
12. Are pins and other retaining devices removable and replaceable by men wearing arctic gloves?
13. Are retaining chains provided to prevent the loss of retaining pins and small removable items?

Radiators

1. Is filler neck size compatible with existing fillers for efficiency of filling?
2. Is a drain provided in lower tank of the

TABLE 27-4. TANK-AUTOMOTIVE MATERIEL CHECKLIST (cont)

radiator to allow for complete drainage?

3. Does the drain have sufficient clearance and provide sufficient grip to allow for opening and closing with a gloved hand?
4. Is the drain readily accessible to the 5th through the 95th percentile man?
5. Is the filler neck positioned so that the operator can see the fluid level inside the tank? Is the necessity to add fluid to determine fluid level eliminated?
6. Are upper and lower hose connectors located to provide sufficient hand clearances for removal and replacement of hoses?
7. If lower echelon of maintenance is intended (through direct support level), is silver solder avoided in the construction of the radiator to facilitate repair?

Intervehicular Connections

1. Are intervehicular cables of adequate length so as not to restrict maneuverability of towing vehicle when vehicles are coupled together under any applicable conditions?
2. Are suitable provisions made to prevent damage to intervehicular cables in use?
3. For vehicles equipped with air-over-hydraulic or air brakes, are suitable provisions provided for connecting to the brake system of another vehicle at the front and rear, and for controlling brakes of a vehicle being towed by another truck during emergency operation?
4. Are brake hoses or cables long enough to permit unrestricted maneuverability of the prime mover or a towed vehicle when coupled together, under any applicable conditions?
5. Are suitable provisions made to prevent kinking, entanglement, dragging, abrasion, or pinching of the brake lines?
6. Wherever practicable, are the wheels of a towed vehicle designed to be interchangeable with those of its normal prime mover?

Tires

1. Are spare tires and servicing tools readily available and capable of being removed and stowed by one man using only OVE (on vehicle equipment) ?
2. Is a pneumatic outlet and OVE pressure gage provided to inflate and reduce pressure in vehicle tires on any vehicle employing air-over-hydraulic brake system?
3. Is the air hose of sufficient length to reach tires, including the spare tire?
4. Is the spare tire capable of being inflated and checked in the mounted position by a standard air gage?
5. Are dual tires designed to allow the inflating and checking of air in both the outer and inner tire, and does this valve location enable the tires to be inflated and checked when tires are interchanged?
6. Is equipment used to stow and unstow spare tires simple to operate and pose no possibility of injury to personnel?
7. Is the spare wheel capable of being removed and replaced with vehicle fully loaded?

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CHAPTER 28

MUNITIONS MATERIEL*

SECTION I

INTRODUCTION

28-1 GENERAL

This chapter provides design and maintainability data and guidelines for engineering consideration during the development phase of new ammunition and military explosives. Consideration and application of these data will help produce munitions having optimum properties of handling, storage, shelf life, and serviceability. The importance of better, more maintainable ammunition and explosive products is particularly significant due to the large quantities of items involved and the hazards associated with these commodities when not afforded adequate maintenance considerations.

28-2 MAINTAINABILITY DESIGN REQUIREMENTS

Design for maintainability requires incorporation of at least the following maintenance principles :

(1) Design to minimize maintenance and supply requirements through attainment of optimum durability and service life of materiel.

(2) Recognition of field maintenance problems encountered in earlier designed items.

(3) Design for ease of maintenance by assuring accessibility to facilitate inspection, repair, and replacement.

(4) Consideration of field maintenance based on geographical locations and climatic conditions.

(5) Design for maximum utilization of interchangeable components.

(6) Detection of conditions which will adversely affect the conduct of maintenance operations or generate excessive maintenance and supply requirements.

(7) Design to effect maximum compatibility of maintenance operations with contemporary common tools.

(8) Evaluation for ease of packaging, carloading, and shipment.

(9) Design to enable removal of major components as individual units.

(10) Assurance that proper materials and special treatment are used for maximum resistance to deterioration.

(11) Consideration of long term storage with a minimum of periodic checks and maintenance in storage.

28-3 'MAINTAINABILITY DESIGN FACTORS

Six major aspects of designing for maintainability are discussed in separate sections and include the following:

(1) *Surveillance.* Includes the observation, inspection, test, study, and classification of ammunition and explosives in movement, storage, and use, with respect to rate of deterioration and degree of serviceability.

(2) *Safety.* Describes ammunition safety hazards including fire, flash, explosion, blast, shock, fragmentation, and radiological and chemical contamination ; pertaining also to the safe care and handling of ammunition.

(3) *Handling (Transportation).*. Discusses the wide range in the sensitivity, stability, and hygroscopicity characteristics of explosives and propellants that requires development of many varied types of packing arid handling techniques. Marking containers for explosives and propellants must comply with regulations of the

*This chapter is based on material supplied by *Picatinny Arsenal, Dover, N. J.*

Interstate Commerce Commission and other governmental regulatory agencies.

(4) *Storage.* Describes explosives, propellants, and ammunition in storage as representing varying degrees of hazard with respect to fire and explosion. This has led to their being divided into a number of classes, establishing storage compatibility lists, and setting up separate quantity-distance requirements for each class.

(5) *Malfunction.* Is the failure of an item to function in accordance with the design, intent, and expected performance when tactically deployed or subjected to nonfunctional tests. Design for maintainability must include recognition of field use problems encountered in earlier designed items, and evaluation for malfunction potential of new designs.

(6) *Serviceability.* The capability of an ammunition item to perform in accordance with the design characteristics when subjected to various conditions (age, environment, handling, and use).

The last section of this chapter is devoted to maintainability design philosophy pertaining to nuclear warheads.

SECTION II

SURVEILLANCE

28-4 GENERAL

Surveillance includes the observation, inspection, investigation, test, study, and classification of ammunition components and explosives, with respect to their serviceability, hazard, and rate of deterioration. The function of the surveillance program in the logistics of ammunition is shown in Figure **28-1.**

28-5 CLASSIFICATON OF AMMUNITION GRADES

In order to intelligently interpret Figure **28-1,** the classification of ammunition grades must be understood. Grades are assigned to ammunition on the basis of surveillance tests and reports from the field and to indicate serviceability and priority. The definition of the various grades follow :

(1) *Grade I.* Serviceable.

(2) *Grade II.* Serviceable but not suitable for long term storage in reserve. First priority for annual allowances will be given stocks of this grade, whenever practicable.

(3) *Grade III.* Unserviceable and to be destroyed or disassembled.

(4) *Grade* D. Dangerous ; immediate steps must be taken to suspend all stocks affected.

28-6 SIGNIFICANCE OF SURVEILLANCE PROGRAM

Smce the designer keeps the use of new and novel components to a minimum in his design, it is important that complete knowledge be developed of the reliability of standard items. The surveillance program gives the engineer a source of data on the reliability of standard items and components after various storage periods. This information can be used for many applications in design, maintenance, quality control, and supply. Analysis of the data made available by the surveillance program can indicate improvements to be made in design of the product, acceptance criteria, packaging of the item, or its storage. The information developed by the program is one of the most important factors in determining the direction of future developments of ammunition.

On the other hand, the designer could contribute to the effectiveness of the surveillance program by introducing features into the design of the item that would facilitate determination of serviceability, hazard, and rate of deterioration. A serious limitation to the program is that, in most cases, these determinations involve costly ballistic tests. As a result, the bulk of the items regularly included in the program consist mainly of signals and simulators. Artillery items and rockets are rarely included. In some cases, serviceability, hazard,

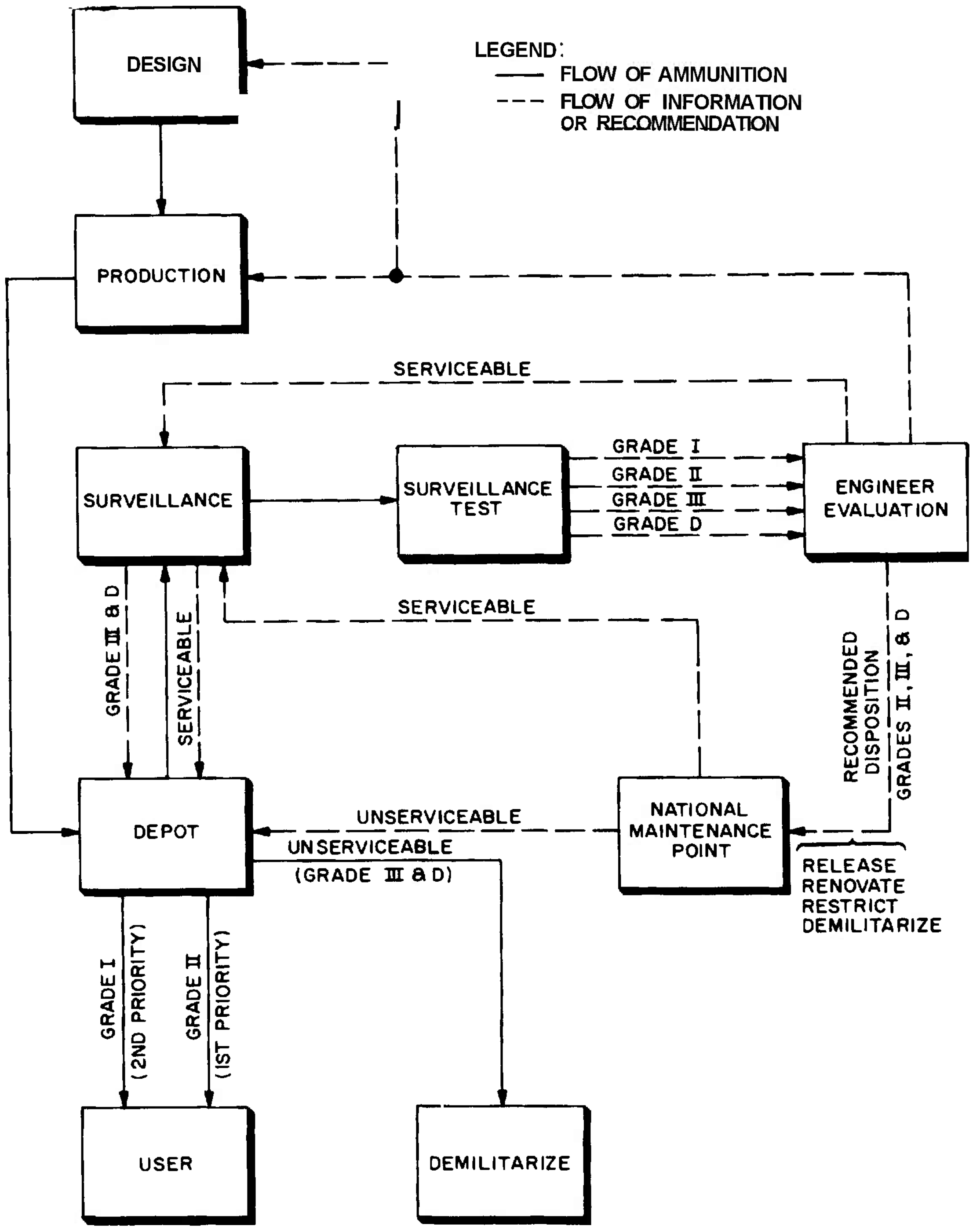


Figure 28-1. Functions of the Surveillance Program in the Logistics of Ammunition

and rate of deterioration of critical components could be indicated by a change in pressure, temperature, color of chemical indicator, or the emission of a particular gas. The designer could help to extend coverage of the surveillance program and reduce its cost by considering these possibilities during the design of the item (see Figure 28-2).

SURVEILLANCE PROGRAM'S INPUT TO DESIGNER	DESIGNERS' INPUT TO SURVEILLANCE PROGRAM
A SOURCE OF DATA ON THE RELIABILITY OF STANDARD ITEMS AND COMPONENTS AFTER VARIOUS STORAGE PERIODS. INDICATES WHERE IMPROVEMENTS CAN BE MADE IN FUTURE DESIGN, ACCEPTANCE CRITERIA, AND PACKAGING. HELPS DETERMINE DIRECTION OF FUTURE AMMUNITION DEVELOPMENT.	INTRODUCES FEATURES INTO DESIGN THAT WOULD FACILITATE DETERMINATION OF SERVICEABILITY, HAZARD, AND/OR RATE OF DETERIORATION.

Figure 28-2. Input Exchange Between Surveillance Program and Designer

SECTION III
SAFETY

28-7 GENERAL

Ammunition can be safely handled provided that safety precautions are rigidly observed. The publications listed in References **1**, **2**, **3**, and **4** at the end of this chapter cover the majority of situations in which munitions may be involved. Specific safety considerations are covered in the applicable sections of this chapter. Examples of how added safety requirements are constantly being developed based on knowledge gained from various projects are the typical cases shown in Table **28-1.**

SECTION IV
HANDLING DURING SHIPPING AND STORAGE

28-8 GENERAL

An effectively conceived ammunition item must not only perform the function for which it was designed when it is made, but must function after prolonged periods of storage in various environments. In addition, maintenance procedures, such as surveillance and renovation, may require remarking and resealing the item. Consequently, design consideration must be given to packaging, marking, and shipping the item. The design must provide a readily transportable item, packed in a manner that ensures arrival in good condition at the storage or use areas, and which functions reliably after prolonged storage.

28-9 PACKING

A necessary prerequisite for sustaining a good ammunition item lies in the design of packaging. Adequate packing provides the protection necessary for handling during shipping and storage. The following basic requirements should be observed:

(1) Make the design economical in material, labor, and space.

(2) Use readily available materials, processes, and equipment.

(3) Where possible, make the design suitable for mass production techniques and automatic operations, using noncritical materials.

(4) Limit the weight and size to practical dimensions to facilitate handling and shipping:

(a) **50** to 70 lb per package for ammunition to be handled by the individual soldier.

(b) Limit artillery ammunition of the fixed or semi-fixed type to **150** lb per package (1500 lb gross for projectiles on skids).

(c) Boxes of belted cartridges of small arms ammunition are usually 80 lb gross weight.

(d) Design package not to exceed 8 ft high, 8 ft wide, **32** ft long, and **11,200** lb; special authorization is required to make packaging in excess of these limits.

(e) Pack all types of anti-aircraft ammunition in end-opening type containers; all other ammunition should be packed in top-opening containers.

(5) Packaging must withstand shipping and handling stresses, such as vibration, jolts, parachute delivery, temperature, and humidity. In addition, it must be waterproofed where required. Table **28-2** lists some Military Specifications and standards for typical ammunition packaging and packing materials (see also Ref. 5).

(6) Packaging must conform to U.S. Army, ICC, and other applicable regulations.

(7) Packaging should be sealed against the environment where required: Levels **A,** B, **C—AR 700-15** (Ref. **6).**

(8) Packaging should be reusable where possible.

(9) Types of packaging in use:

(a) Wood boxes. Use boxes and crates where possible. Wire-bound boxes and crates should be used where reuse is not a factor.

TABLE 28-1. MUNITIONS SAFETY CONSIDERATIONS

Area	Typical Example
Design participation and analysis	When reviewing the proposed design of hand-held signals, it was noted that the delay column was unsupported. This has been a source of premature functioning in past designs, and was brought to the attention of the designer.
Post production renovation procedures	It was found that some lots of early manufacture HEAT ammunition for the M-68, 105MM gun had Comp. B under the obturating band. This condition was considered hazardous, and procedures to screen this ammunition for defects were developed.
Technical publications	A problem of fin separation was being reported with the 81MM, M43A1 cartridge. Instructions concerning proper placement of the increments of the propelling charge around the fins to eliminate this problem have been included in technical publications.
Firing line position spacing (training ranges)	A firing line distance study is being conducted on ammunition to provide minimum distance safety requirements to assure minimum casualities if a malfunction or accident occurs at a firing point.

(b) Crates (wood or steel).
(c) Metal containers :
  (i) Metal boxes.
  (ii) Steel packing boxes.
  (iii) Metal lined, wood packing boxes.
  (iv) Metal drums.
  (v) Hermetically sealed can, cylindrical and rectangular.
(d) Fiber containers. Telescopic fiber containers are used for packing complete rounds, hand grenades, some types of fuzes except **proximity** fuzes, and mortar ammunition.
(e) High impact polystyrene materials.

28-10 SHIPPING AND TRANSPORT

Item design and packaging must provide protection during air, motor truck, or board transport to storage and use areas. For all methods of shipment, the design should provide :

(1) Packaging that can be handled with

TABLE 28-2. MILITARY SPECIFICATIONS AND STANDARDS FOR TYPICAL AMMUNITION PACKAGING AND PACKING MATERIALS (Refs. 2, 6, and 7)

Item	Military Specification or Standard
Adhesive, dextrin (spiral tube winding for ammuntion containers)	MIL-A-13374
Adhesive, water resistant, for sealing fiberboard boxes	MIL-A-101
Bags, interior packaging	MIGB-117
Barrier material, greaseproofed, flexible (waterproofed)	MIL-E121
Barrier material, waterproof, vaporproof, flexible	MIL-B-131
Barrier material, waterproofed, flexible, all temperature	MIL-B-13239
Board, composition, water resistant, solid (for filler or cushion pads)	MIL-B-3106
Boxes, ammunition packing; wood, nailed	MIL-B-2427
Boxes, fiber	PPP-B-636
Boxes, ammunition packing, wood, wirebound	MIL-B-46506
Cans, hermetic sealing, metal, light gage, tear strip type	MIL-C-10464
Chipboard; plain	UU-C-282
Containers, fiber, spirally wound for ammunition	MIL-C-2439
Crates, open, wood; maximum capacity, 2500 pounds	MIL-C-132
Crates, wood; lumber and plywood sheathed, nailed and bolted	MIGC-104
Cushioning material, bound fiber	MIL-C-7769
Cushioning material, cellulosic	PPP-C-843
Drums: metal, with removable head, reusable interior shipping	MIL-D-6055
Fiberboard, corrugated, single face (flexible)	PPP-P-291
Liners, case, waterproof	MIL-L-10547
Marking for shipment and storage	MIL-STD-129
Packaging, packing and marking for inter-plant shipment of inert ammunition components: general specifications for pallet units for overseas shipments of WP or PWP projectile	PA-PD-546
Pallet, units, wood, for shipment of projectile metal parts, and projectile ammunition	MIL-P-45440
Paperboard, wrapping, cushioning	PPP-P-291
Plastic foam, molded polystyrene (expanded bead type)	MIL-P-19644
Shrouds, waterproof barrier material	UU-P-271
Steel strapping, round (bare and zinc coated)	QQ-S-790
Strapping, flat; steel	QQ-S-781
Tape, gummed, paper, reinforced (sealing and securing)	PPP-T-45
Tape, pressure-sensitive, adhesive, plastic film, filament reinforced (for sealing of ammunition fiber containers and cans)	MIL-T-43036

standard equipment and carriers and that minimizes development of special equipment.

(2) Safety features.

(3) Hazards classification.

(4) Packaging and relief valves for packaging which will withstand effects of depressurization when shipped by air.

(5) Conformance to regulations and instructions established by the U.S. Army, other military services, ICC, and other applicable government agencies, and to state and municipal laws and codes (see also Ref. 5).

28-11 MARKING

For proper identification, handling, and shipping, the following data are required :

(1) Explosive hazards classification.

(2) Storage compatibility group.

(3) ICC bill of lading.

(4) ICC container marking.

(5) Weight.

(6) Volume.

(7) Color coding.

28-12 DRAWINGS

To ensure that ammunition is packaged, loaded, and marked in a uniform and reliable manner, drawings must be prepared which detail this type information. Table 28-3 lists examples of the types of drawings required.

SECTION V
AMMUNITION STORAGE

28-13 GENERAL

Ammunition is stored unpackaged and packaged, unpalletized and palletized, and in NODEX containers (Ref. 2). It is stored both in the continental United States and overseas worldwide including arctic, temperate and tropical zones (Refs. 2, 8, and 9).

Ammunition is protected in storage by magazine storage, i.e., in above-ground magazines, and by igloo-type storage (Ref. 2). Other than in magazines, ammunition may be stored in

TABLE 28-3. TYPICAL DRAWINGS FOR MARKING, LOADING, AND SEALING AMMUNITION PACKAGING

Drawing Title	Drawing No.
Marking Diagram for Pallets for Filled Projectiles 75 MM—120 MM	8861520
Marking Diagram and Sealing of Metal Lined Wooden Packing Boxes for Shipment of Propellants	8858848
Marking Diagram and Sealing of Container, Metal Universal, M25, for Shipment of Propellants	8858577
Marking Diagram and Sealing for Metal Containers for Conventional Ammunition	8846763
Marking and Sealing Diagram for Cylindrical Shipping Containers (Except Fiber Containers)	8806652
Marking Diagram and Sealing for Interplant Shipment of Ammunition Fiberboard Containers	8799112
Marking Diagram and Sealing for Wood Packing Boxes	8796522
Marking and Sealing for Ammunition Fiber Containers	8796521
Marking on Box, Ammunition, T46 for Cartridges, 20 MM	7258928
Packing and Marking of Metal Containers for Propelling Charges, Assembly and Details	7548187

temporary frame and canvas shelters, in culverts, railroad cars and trucks, caves, and open, unprotected sites where it is stacked and covered with a tarpaulin (see Table 28-4).

The design of ammunition package and packing to improve storageability for long or short term storage should include the following considerations :

(1) Package ruggedness (wooden, fiber, metal, plastic, Fiberglas).

(2) Resistance to fungi, corrosion, rusting and decay.

(3) Stability, when stored horizontally (or vertically when required), palletized or unpalletized.

(4) Modular package for nesting characteristics.

(5) Stability in storage.

(6) Ease in handling (weight, size, and shape). Cleats and/or handles for carrying during storage, shipping, etc.

(7) Waterproof or moisture proof, airtight or moisture resistant as needed.

(8) Easily opened for inspection in storage, easily resealable, and easily opened for use.

(9) Ability to withstand storage under the conditions outlined in References 2, 8, 9, and 10).

TABLE 28-4. AMMUNITION STORAGE FACTORS

Storage Method	Type	Design Factor Affecting Storageability
Magazine (Igloo)	Permanent	Stacking
Frame and canvas	Temporary	Inspection
Culvert (unprotected)	Temporary	Handling
Caves	Permanent	Moisture protection
Railcars and trucks	Temporary	Fungus protection
Open (covered with tarpaulin)	Temporary	Humidity Protective coating

28-14 UNPACKAGED AMMUNITION ITEMS

Ammunition items that may be stored unpackaged include :

(1) Projectiles without external protection other than grommets and eye bolts and paint.

(2) Bombs without external protection other than shipping bands, nose and base plugs.

Design of protective devices for unpackaged items to improve storageability for short or long term storage should consider :

(1) Grommets for projectiles must provide adequate mechanical protection and be easily removable.

(2) Eye bolt lifting plugs must be sealed to prevent entry of moisture and be removable for inspection of cavity while in storage.

(3) Shipping bands for bombs must provide adequate protection for suspension lugs. Nose plugs and base plates must be sealed to prevent entry of moisture and be removable for inspection in storage.

28-15 AMMUNITION PACKAGING MARKING

The ammunition item and container is coated for protection and marked for identification by :

(1) Paints applied to exterior as normal protective coatings.

(2) Annodized exterior as normal protective coating. (Unpainted items such as brass, plastic, or aluminum, are not necessarily given protective coatings in several applications.)

(3) Markings that must give complete identification (see Refs. 11 and 12).

Design of protective coating for ammunition item and container, and marking materials should consider :

(1) Paints, varnishes, anodized coatings must be stable in short and long term storage under all conditions (Ref. 11).

(2) Coatings should be resistant to abrasion, corrosion, fading, peeling and checking.

(3) Ease of application and short drying time for use in depot maintenance storage or at covered or open ammunition supply points.

(4) Marking must be with approved colors of marking paints. Resistance to abrasion and fading is important to avoid improper identification of ammunition types or cause loss of identity while in storage or during handling.

28-16 STABILITY IN LONG TERM STORAGE

The following points must be considered in designing ammunition which may be subject to long term storage:

(1) Ammunition item must be chemically stable in storage.

(2) Explosive fillers should be free from exudation in storage (e.g., exudation of TNT and Comp. B fillers) and free from filler growth. Evidence of exudation requires cleanup and restorage, thus increasing maintenance costs and introducing a safety hazard. Stable fillers require less surveillance and subsequent restorage.

(3) Chemical agent-filled ammunition must be stable in storage. The chemical and physical state must not change significantly where items are kept in long term storage since the usage factors are very low for these types of ammunition.

(4) Chemical agent reactivity with container, projectile, warhead, etc. must be extremely low to prevent leakage in storage. Chemical leakage is extremely difficult to handle and decontaminate. Nerve agent leakage presents difficult problems in long term storage. The required surveillance and restorage as a result of leakage must be kept to a minimum.

(5) Seals (O-rings, solder, etc.) must remain impermeable under varying conditions of storage and must also be capable of withstanding internal pressure developed by chemical agents.

28-17 PYROTECHNICS STORAGE AND STORAGEABILITY DESIGN CONSIDERATIONS

Pyrotechnic ammunition items are stored generally in the same manner as other ammunition items. Every effort, however, should be made to store these items in well ventilated places out of the direct rays of the sun and protected against excessive and variable temperature and humidity. These items are usually not stored with other items due to the fire hazards they present. Although most ingredients in a pyrotechnic composition mixture are sensitive, they are relatively stable. However, reaction between ingredients may cause deterioration and concomitant hazards in storage. Moisture hastens deteriorations and in some cases may cause elements to become more sensitive.

Pyrotechnic items must be handled with extreme care to prevent damage to containers and to the items themselves. Damaged bodies or containers result in shortened storage life and degradation of functioning.

Design of pyrotechnic items to prevent degradation in storage should include the following considerations:

(1) Water- and moisture-proofing of the item and packaging to withstand long term storage.

(2) Stability in long term storage.

(3) Safety in storage (minimum reaction between ingredients).

(4) Selection of materials, containers, and internal components of known capabilities under long term storage.

(5) Selection of compositions that present the least hazard and have the greatest stability in storage.

(6) Packaging and containers that provide the required degree of protection for the particular item if the item itself cannot be designed sufficiently airtight and corrosion resistant to withstand long term storage.

SECTION VI
MALFUNCTIONS

28-18 GENERAL

A malfunction is the failure of an ammunition item to function in accordance with the design, intent, and expected performance when fired, launched, tactically deployed, or subjected to nonfunctional tests. For purposes of clarity, malfunctions do not include accidents and incidents resulting from negligence, malpractice, or implications in other situations such as vehicle accidents, fires, etc. However, malfunctions do include abnormal or premature function of ammunition item incident to normal handling, maintenance, storage, transportation, and tactical deployment.

Some of the factors affecting malfunction rates are:

(1) Weapon condition.
(2) Crew experience.
(3) Propellant charge utilized.
(4) Target impact area.
(5) Rate of fire.
(6) Storage conditions.
(7) Climatic conditions (temperature, humidity, etc.)
(8) Handling prior to use.
(9) Packing and packaging.

28-19 DEFINITION OF TERMS

The following paragraphs define several terms commonly used in ammunition malfunction terminology :

Unserviceable ammunition. Ammunition items considered unsatisfactory for use or items that become unserviceable because of age, deterioration, obsolescence, or damage. Items falling into this condition are evaluated based on surveillance, functional tests, visual inspection, or records.

Serious defect. A defect which, as a result of improper design, manufacture, handling, or storage, provides the opportunity of a malfunction when ammunition is handled or fired.

Misfire. A complete failure to fire which may be due to a faulty firing mechanism, or faulty element in the propelling charge explosive train.

Hangfire. A delay in the functioning of a propelling charge explosive train at the time of firing.

Cook-off. A functioning of any or all of the explosive or propellant components of a round chambered in a very hot weapon due to heat from the weapon.

28-20 TYPES OF DEFICIENCIES AND MALFUNCTIONS

Good ammunition design should eliminate critical defects and minimize noncritical defects. Typical deficiencies and malfunctions that should be eliminated or minimized by the design engineer, as much as is practical, are listed here, (Typical deficiencies encountered for some specific ammunition types together with their probable cause and typical dispositions for field stocks are given in Table 28-5.)

Class A — Endangering life or materiel:

(1) Prematures (in-bore, dose-in, down-range).
(2) Short rounds (less than 60% of expected range, 60%-90% of expected range).
(3) Propellant detonation in weapon.
(4) Primer blowback or gas leakage.
(5) Excessive chamber pressure.
(6) Projectile filler leakage (gas, WP, or HE).
(7) Propellant burning after rocket leaves launcher.
(8) Cook-offs (auto-ignition caused by heat from weapon).
(9) Cartridge case rupture.
(10) Projectile stuck in weapon tube.
(11) Projectile breakup (e.g., windshield separation, loose rotating bands, broken fins, other parts).
(12) Insufficient propellant charge.
(13) Excessive propellant charge.
(14) Defects permitting item or its components to become armed prematurely.
(15) Metal parts in weapon tube after firing.
(16) Erratic projectile flight endangers weapon crew of friendly troops in area between weapon and target.

Class *B—Deficiencies causing failure of ammunition to accomplish its mission:*

(1) Misfires.
(2) Hangfires (ignition delay in functioning).
(3) Failure to eject projectile contents.
(4) Short tracer times.
(5) Ignition failures (includes pyrotechnic items).
(6) Short burning time (including detonation of pyrotechnic composition).
(7) Low order functioning.
(8) Breakup of signal stars.
(9) Late fuze functioning or short delay time (not endangering friendly troops or equipment).
(10) Early fuze functioning or short delay time (not endangering friendly troops or equipment).
(11) Excessive duds'.
(12) Failure to function on proper impact.

TABLE 28-5. TYPICAL DEFICIENCIES FOR SPECIFIC AMMUNITION TYPES

Item	Deficiency Reported	Probable Cause	Typical Dispositions for Field Stocks
Ctg, 81 MM: HE, M43A1 Smk, WP M57A1 Illum, M301A1	Short round	Insufficient propellant increments (human error).	Technical manual revised to include information on correct procedure.
		Deteriorated propellant increments.	Replace increments.
		Fin separation (manufacturing defect).	Assure adequate inspection.
		Fin separation (unsymmetrical placement of increments).	Locate propellant on round in a symmetrical pattern.
		Fin breakup—small cracks in fin assemblies that propagate on firing and cause fin breakup.	Screening or release subject to restriction from overhead fire.
		Instability of round.	Redesign required.
	Prematures	Projectile case cracked on firing due to setback forces and exposed some WP to air which caused it to burn. The burning WP apparently reaches the burster charge which then initiates the round.	Determine suitable in-inspection technique for detection of faulty metal parts.
Ctg, 90MM: HE, M71	Split and ruptured cartridge cases	Reworked cases	Release or replace cartridge cases
Ctg, 90MM: HEAT, M371	Fin separated upon firing	Ignition cartridge cavity in fin excessively drilled permitting metal parts failure	Fluoroscopic screening for incorrectly machined fins
Ctg, 90MM: HVAP-T, M332A1	Projectile breakup	Base shield and bourrelet band breakup during firings	Release—recommended safety precautions
Ctg, 105MM: HE, M1	Premature (in-bore)	Cavitation in filler	Demilitarize
		Improper procedure (human error)	Release
Ctg, 105MM: Smoke, M84	Premature	Propelling gases enter projectile around base plug	Release—not hazardous
Ctg, 105MM: Illum, M314A1	Failure to eject canister	Voids occurring in cloth-bound ejection charges	Redesign of ejection charges

TABLE 28-5. TYPICAL DEFICIENCIES FOR SPECIFIC AMMUNITION TYPES (cont)

Item	Deficiency Reported	Probable Cause	Typical Dispositions for Field Stocks
Ctg, 4.2 in: HE, M329	Prematures	Fuze failure	Rebooster fuze
	Short rounds	Cartridge container extension not removed at below 25-1/2 increments (human error)	Release
Ctg, 4.2 in: HE, M3	Short rounds	Deteriorated propellant	Replace propellant
		Incorrect quantity of propellant (human error)	Release
Ctg, 4.2 in: Illum, M335	Ejection failures	Voids occurring in cloth-bound ejection charges	Replace with new type ejection charge
	Ignition failures	Cartridge components deteriorated	Replace components
Proj, 120MM: AP-T, M358 w/Propelling Charge, M46	Misfires and hangfires	Firing mechanism failure	Release ammunition items
Proj, 155MM: Smk, M116	Duds	Moisture contamination	Base seal improvement. Expelling charge container improvement (plastic enclosed).
		Voiding of expelling charge due to spin	New type expelling charge container to preclude voiding
Proj, 155MM: Gas, Non-Persistent, GB, M121	Premature (in-bore)	Burster charge defects	New type burster charge case to preclude malfunction
Fuze, MTSQ, M500 Series	Premature	Fuze failure	Rebooster
	Duds	Metal parts or explosive components deterioration	Replace fuzes
Fuze, MTSQ, M520 Series	Premature (down-range)	Breakup of mechanical train	Release with restriction
Fuze, MTSQ, M501 Series	Premature	Breakup of mechanical train	Release—not hazardous
	Duds	Metal parts or explosive components deterioration	Replace fuzes

TABLE 28-5. TYPICAL DEFICIENCIES FOR SPECIFIC AMMUNITION TYPES (cont)

Item	Deficiency Reported	Probable Cause	Typical Dispositions for Field Stocks
Fuze, PD, M525A1	Duds	Bent firing pins Excessive pettman cement in head assembly Metal parts deterioration (corrosion)	Replace fuzes
Fuze, PD, M51A5	Duds (delay option)	Delay element deteriorated	Restrict to superquick (SQ) option
Rkt, 3.5 in: Prac, M29A2 and HEAT, M28A2	Motor body split	Motor body defects—low rate	Release
	Misfires	Deteriorated squib in igniter	Replace igniters
	Prematures	Failure of fuze setback sleeve to lock	Renovation recommended
Grenade, Hand, M26 w/Fuze	Prematures	Omission of delay column; or porosity in fuze body and leaking or cracked detonator cups	Inspect and renovate
		Human error	Release
	Duds	Deteriorated fuze	Replace fuze
Flare Surface Trip, M49	Prematures and blown covers	Vent hole seals heavily coated with lacquer (prevents combustion gases from venting through holes in cover	Remove old heavy coat of lacquer and replace seals. Future design - specify alternate material or thickness of coating
Ctg, Photoflash, M123	Short range	Insufficient propelling charge introduced during manufacture Caked propelling charge	Vibration of item (to level out propelling charge) and x-ray to determine quantity satisfactory (comparison with standard)
Signal, Aircraft: Illum Double Star Single Star Tracer, Double Star	Maximum altitude less than 50 feet	Manufacturing defects	Release
	One star failure	Moisture contamination	Renovate
	Exploded in pistol	Lack of sealant at closing cap	Demilitarize

TABLE 28-5. TYPICAL DEFICIENCIES FOR SPECIFIC AMMUNITION TYPES (cont)

Item	Deficiency Reported	Probable Cause	Typical Dispositions for Field Stocks
Simulator, Booby Trap, M116	Premature Leaking photoflash powder Functioned in packing box	Manufacturing defects	Release after screening
Signal Flash, M117; Illum, M118; and Whistling, M119	Functioning failures	Greater force required on pull wire	Improved wire and new procedures provided
Signal, Grd, Smk, M62 (Ctg, Rifle Grenade, Cal. 30, M3)	Stabilizer separated on launcher	Stabilizer sheared off at shoulder (where threaded to fuze housing)	Only if disengaged at least 3-1/2 revolutions from body assembly. If excessive propellant, reload with proper weight
Firing Device, Pull-Release Type, M3	Functioned upon removal of positive safety pin	Dimensional deficiencies	Release after screening
Firing Device, (demolition, M1, Delay type)	Premature firing pin release	Ampoule broken prior to function test (no outward indication). An isolated case	Release
Cutter, Powder-Actuated, Reefing Line	Broken pull wire; failure to activate; misfires	Unsatisfactory materials or deteriorated compounds	Demilitarize
Fuze, Mine, M605 (for Fuze, M15)	Duds	Inadequate waterproofing	Develop greasing procedure check test to assure satisfactory procedure
Fuze, M606 (for mine, NM, AT, M19)	Load greater than specified required to function items	Interference fit due to excessive tolerance allowance in initial design	Extension of function limits of items in field (change in drawing requirements permitting correction in new production items)

(13) Failure of round to chamber.

(14) Weapon stoppage (e.g. failure to extract, feed or fire).

(15) Metal parts separation affecting flight and accuracy (not endangering friendly troops or equipment).

(16) Penetration failures.

(17) Cartridge case fails to extract or eject.

(18) Low trajectory peak (pyrotechnic items and antipersonnel mines).

(19) Parachute failures.

Class C—Deficiencies of a nonserious nature that affect neither safety nor mission:

(1) Excessive recoil.

(2) High chamber pressures or internal pressure in pyrotechnic items.

(3) Loose, displaced, pierced primers.

(4) Minor flash, spark, or smoke at breech or muzzle.

(5) Duds (not excessive).

(6) Rusted or corroded components.

(7) Cartridge case fails to eject in hand-loaded weapon.

(8) Poor or no obturation.

(9) Projectile striking muzzle brake.

(10) Excessive coppering or bore fouling.

(11) Detached metal parts not affecting safety or flight.

(12) Split cartridge case (nonbase rupture).

(13) Fluted cartridge cases.

28-21 SAFETY FEATURES

Features the design engineer should consider incorporating in ammunition design to preclude malfunctions are:

(1) Delay alignment of explosive train to maximum time which will meet tactical requirements, e.g., as a minimum, bore-safe features; close-in safe features desirable to afford maximum protection to weapon crew.

(2) Multiple safety mechanisms preventing unsafe firings where one mechanism fails, e.g., mechanical delay trains, setback devices, spring-actuated slider containing detonator, etc.

(3) Packaging to protect ammunition from all degrees of moisture for extended storage periods, thus reducing possibility of deterioration of components (explosive, metal parts, etc.) and therefore, of malfunctions. For example, the deterioration of propellant increment charge because cloth bag permitted entrance of moisture.

(4) Adequate test program with carefully considered experiments to prove out the design will result in ammunition with an extremely low critical malfunction rate, e.g., prematures-1 per 1,000,000 firings, and a high functioning reliability with a high degree of confidence.

(5) Eliminate, so far as is possible, elements inherent in design which could permit, if circumstances allowed, a critical malfunction.

(6) Consideration of susceptibility to compromise by enemy action, e.g., proximity fuzes.

(7) Consideration of effect of outside influences such as lightning, radio, radar, television, transmission equipment, energized power lines, electrical disturbances, and static electricity.

28-22 MISCELLANEOUS CONSIDERATIONS IN AMMUNITION ITEM PERFORMANCE

The following additional considerations should be taken into account by the munitions design engineer.

(1) Establishment of minimum arming distances (ascertain for all weapons in which ammunition is to be used, and determine for both maximum and minimum propellant charge allowances).

(2) Determination that components and parts likely to deteriorate or that require maintenance are easily accessible (if they are replaceable); components that may deteriorate or that require maintenance may be included, provided the design is optimum in all other respects.

(3) Assurance of maximum reliability possible without adversely affecting safety aspects.

(4) Maximization of service life and shelf life.

(5) Design for ease of use and minimum skill; complicated procedures may result in omission of some safety check.

28-23 TYPICAL RESTRICTIONS IMPOSED ON USE OF AMMUNITION ITEMS

Restrictions are imposed on the use of ammunition to which any of the following conditions apply:

(1) Design limitations of component or item.

(2) Ammunition accepted on waiver.

(3) Normal deterioration in storage.

(4) As a result of deficiency or malfunction investigations.

(5) Review of inspection or test performance.

28-24 GUIDE FOR DESIRABLE MAXIMUM DEFICIENCY FREQUENCY RATES

A design guide for desirable maximum deficiency frequency rates is given in Table 28-6. The indicated rates shown in the table are only general in nature. Existing specifications for like end items should be reviewed for more specific information on acceptable performance.

28-25 FEEDBACK

To ensure that all aspects of a malfunction are considered, and that the information obtained is fed back to the interested designers and maintainability engineers, an investigative and reporting procedure is required. Such a procedure, now in use, is illustrated in Figure 28-3.

TABLE 28-6. DESIRABLE MAXIMUM DEFICIENCY FREQUENCY RATES

Item	Type of Deficiency	Desirable Maximum Deficiency Frequency Rate
High explosive rounds with fuze set for:		
SQ option	Duds	0.05%
Delay option		0.50%
Time (mechanical) option		1.00%
Time (proximity)		3.00%
Illumination rounds Smoke rounds	Functioning failures—includes expelling failures, parachute failures, and illuminant or smoke charge ignition failures.	2.5%
Complete round	Misfires	See Primer
	Hangfires	None
	Cook-offs	None—limitation on sustained firing rates should be indicated
	Short rounds	2% less than 90% of anticipated range and none less than 60% of anticipated range.
Primer, percussion	Misfires	0.1%
Primer, electric and percussion	Misfires	0.2%
Mines, antitank	Duds	2.0%
Mines, antipersonnel	Duds	1.0%
Pyrotechnic items	Functioning failures	2.0%

NOTE: Assure that design incorporates a bore-safe fuze — i.e., one in which the explosive train is so interrupted that while the projectile is still in the bore of the cannon premature action of the bursting charge is prevented if any of the more sensitive fuze elements, e. g., primer or detonator, malfunction.

SECTION VII

SERVICEABILITY

28-26 GENERAL

Serviceability is the capability of an ammunition item to perform under various conditions in accordance with its design characteristics. The conditions which affect serviceability are :

(1) ***Age.*** Time in storage.

(2) Environment. Condition or type of storage (see Table 28-7).

(3) Handling. Routine, rough, or air **drop** (see Table 28-8).

(4) *Use.* Dependent on item. (Serviceability of land mine, for example, is affected when in use ; i.e., when emplaced.)

Designing serviceability into an item, to the extent economically feasible, is one of the func-

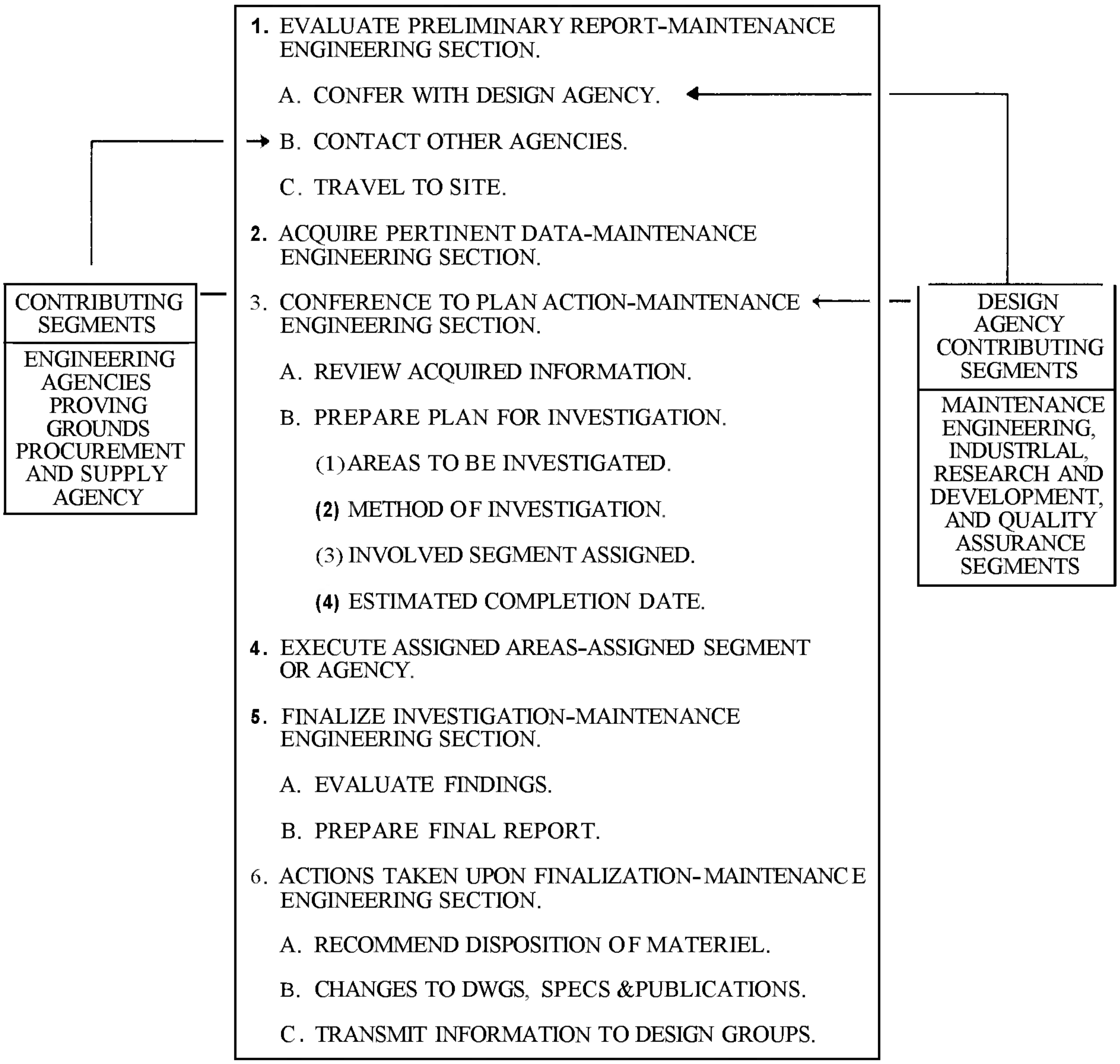


Figure 28-3. Deficiency and Malfunction Investigations Procedure

TABLE 28-7. ENVIRONMENTAL CONDITIONS AFFECTING SERVICEABILITY*

Environment	Type of Storage
Tropics	Igloo
Temperate	Temporary–roof with open sides
Arctic	Tarpaulin Unprotected – exposed to elements

*See also Section V

TABLE 28-8. HANDLING CONDITIONS AFFECTING SERVICEABILITY*

Handling	Occurrence
Routine	In connection with shipping and storage
Rough	Transportation over rough terrain
	Transportation by air or ship (vibration)
Air drop	Severe impact, as a result of slipped parachute (malfunctioning drop)

* See also Section IV

tions of the design engineer. Maintaining ammunition in a serviceable condition for as long as possible is one of the functions of the maintenance engineer. Other functions of the maintenance engineer are to :

(1) Determine when ammunition becomes unserviceable.

(2) Determine disposition of unserviceable ammunition, such as :

(a) Renovate.

(b) Demilitarize and destroy.

(c) Use for practice or training if user's safety is not jeopardized

(d) Use with restrictions.

(3) Plan and conduct maintenance evaluation studies.

28-27 MAINTENANCE EVALUATION STUDIES

There are four basic phases in a maintenance evaluation study: program plan, test plan, test evaluation, and corrective action (see Figure **28-4).** In addition, maintenance evaluation studies are divided into the two following classes :

(1) *Shelf and storage* life. Includes storage under ideal conditions (ammunition depots) and adverse conditions, as might prevail at an ammunition supply point during combat).

(2) *Service life*. Operations under tactical readiness conditions. Examples of several maintenance evaluation studies are shown in Table **28-9.**

Shelf- or storage-life studies are undertaken on newly developed items only if the items, or some of their components, are new **or** novel in design. Since shelf-life study programs are included in the initial production buy, the program must be planned as early in the development phase as is feasible to assure the quantities required. Ideally, items should be first-production items; the theory being that the remainder of the first production will be consumed in tests and training. Therefore, items placed in storage for the shelf life program would be one or two years old at the time production items are placed in field service stocks. Thus, when ammunition begins to deteriorate due to age, the type and degree of deterioration can be detected before field stocks reach that condition.

Generally, in shelf and storage programs, ammunition is stored indoors and outdoors under tropic, temperate and arctic environments. **A** quantity of ammunition, as determined by the test plan, is removed from storage and periodically tested, physically, chemically, statically, and ballistically as required to ascertain whether a change has taken place since previous tests were conducted.

TABLE 28-9. EXAMPLES OF MAINTENANCE EVALUATION STUDIES

Item	Program	Description
Light antitank weapon	Shelf life, Storage	500 units to be stored in arctic, ambient and tropical environments. Static and flight tests will be performed at intervals. Effects of age, storage and environment to be determined.
Y - 155 Power Pack and XM43 Safety and Arming Device for T39E4 Warhead (Honest John)	Shelf life	75 of each item stored (10 mos) under various conditions. Effects of age and environment on terminal voltage and arming time being determined.
Honest John, XM66 Motor, XM58 Igniter XM37 Spin Rocket Thermal Battery	Shelf life	Program recommended. Implementation dependent upon approval and availability of items.
XM38 and XM39 Explosive Harness (Nike)	Sensitivity, Handling, Functioning, Shelf life	Program for determination of safety level. Includes shelf life evaluation. Development of safe handling procedures and investigation of less sensitive explosives.

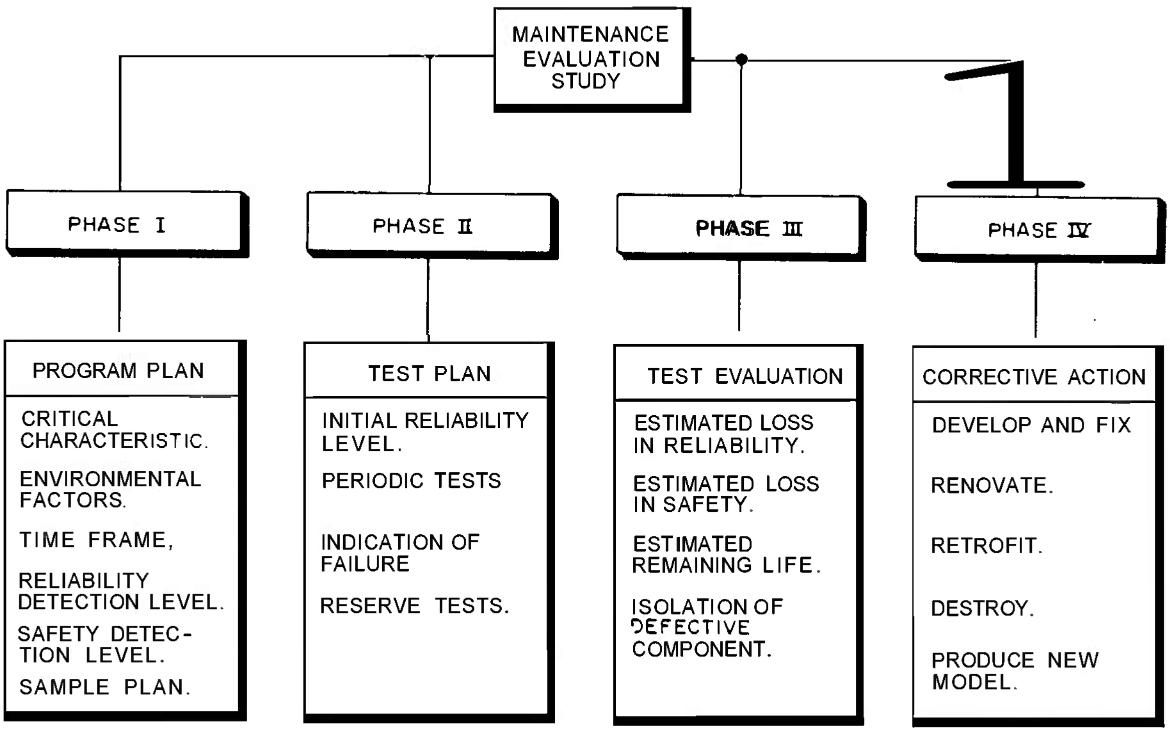


Figure 28-4. Maintenance Evaluation Study Program

SECTION VIII
TRAINING AMMUNITION

28-28 GENERAL

Training ammunition covers a wide range of items and a varying degree of complexity. It ranges from the Training Hand Grenade MK 1A1, an inert cast iron item to the training nuclear warhead section of training guided missiles, which is much more sophisticated in nature. Items such as the MK 1A1 need only simulate the service item and, therefore, can be less complex, less precise, and can be produced with inert compounds and noncritical materials which simplify their production and reduce their cost.

By contrast, however, items such as the training warhead sections offer the troops the maximum in realistic training. These items enable military personnel to perform the necessary prefire checks — interrogating the system and monitoring the responses — and allow them to take appropriate action based on the nature of the response. Since training warhead sections, commonly known as Type X warheads, best exemplify this new type of sophisticated training item, this category is used as an example for the development of the maintainability theory to be applied to such items.

It is important to remember that all training items will be used for training in repeated operations and will be abused in the learning process. Accordingly, training items must be ruggedly constructed as well as designed to simulate the service item.

28-29 TYPE X WARHEAD SECTION TRAINER—MAINTENANCE DESIGN CONCEPTS

The Type X Warhead Section Trainer enables personnel to obtain training on the proper employment of the War Reserve Item. The following design concepts and parameters have been developed for the Type X Trainers to assure that nuclear weapon warhead sections will afford the best in equipment design. It is to be realized that the design concepts represent optimum requirements and that "trading off" one requirement for another, e.g., more reliability for maintenance, performance needs for cost or time, etc., could result in reduced requirements to meet certain conditions.

28-29.1 RUGGEDNESS

To meet the demands of rugged usage, the Type X Trainer should incorporate the following design concepts:

(1) Materials should be suitable to withstand the stresses of continued use. If determined that for a particular application stainless steel is required to assure ruggedness, a substitute material should not be implemented in order to reduce costs (see Figure 28-5).

(2) Parts subject to continual use should utilize designs which, in themselves, are better suited for high usage and low maintenance costs, e.g., use of bolt and nut assemblies in place of blind holes, inserts, etc. (see Figure 28-5(B)).

(3) Use of sensitive components such as timers, relays, microswitches, etc., required to duplicate the functions of the War Reserve item should be avoided. Simple circuitry and mechanisms should be used, e.g., continuity loops and on-off switches should be utilized (see Figure 28-5(C)).

(4) Functional circuitry and components, particularly sensitive items, should be placed in a unit separate from the Type X Trainer (Figure 28-5(D)), and a single cable should be utilized for connecting purposes. An alternate design, but less preferable, would be to house all circuitry and components in one box in an easily accessible position inside the Type X Trainer (see Figure 28-5(E)). Functional circuitry and components should not be positioned throughout the trainer (Figure 28-5(F)) as this introduces more downtime and, generally, the complete loss of trainer while it is being repaired.

28-29.2 EASE OF REPLACEMENT AND REPAIR

To reduce downtime of the Type X Trainer,

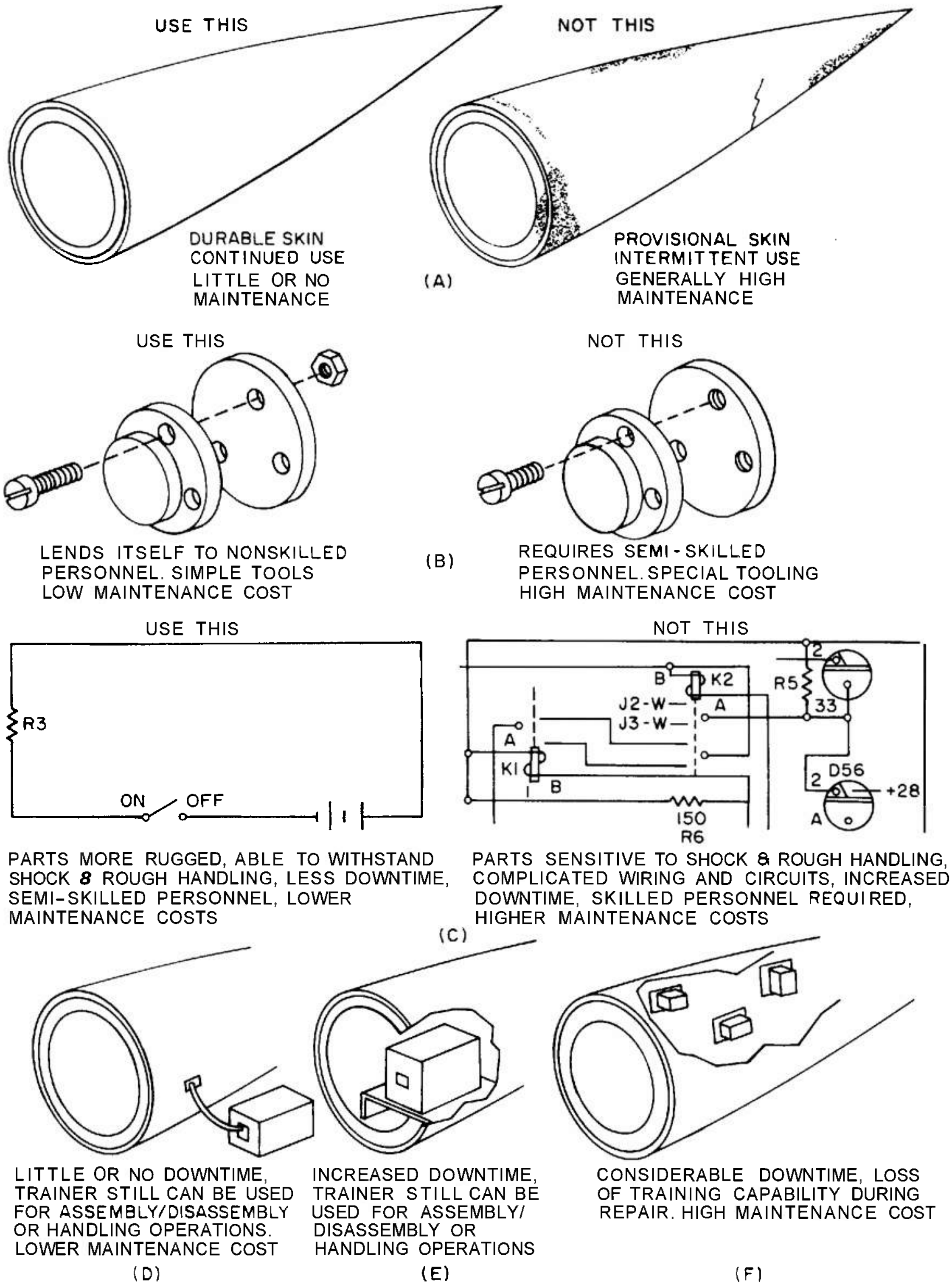


Figure 28-5. Type X Trainer Ruggedness Considerations

replacement and repair should be designed to allow the lower echelons to accomplish the task. Parts to be replaced should be designed to be readily accessible (Figure **28-6(A)**) and capable of removal without special tools. Assemblies should be designed so that assembly/disassembly procedures are simple and no special alignment or connections are required. Parts that cannot be replaced but must be repaired should be designed so that the repair is within the maintenance skills of personnel trained to handle screwdrivers and wrenches. Drilling, machining, and complicated assembly/disassembly procedures should be avoided.

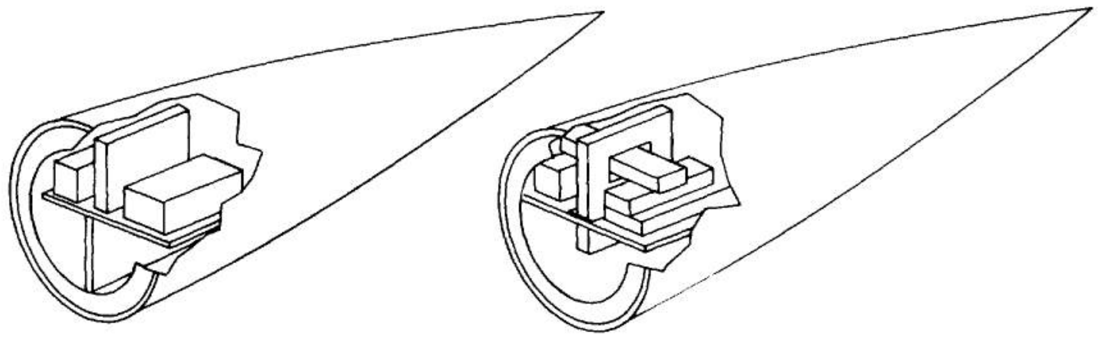
28-29.3 MODULARIZATION

Further reduction of downtime for the Type X Trainer can be accomplished by use of unitized or modular construction (see Figure **28-6** (B)). The replacement of modular units can be accomplished in the field because of the relatively low skills and few simple tools required. In the design of modular units, the following concepts should be considered:

(1) Modules and component parts should be approximately uniform in basic size and shape for the best packaging.

(2) Modular units should be designed to contain components that are optimized for a certain function rather than providing multiple, divergent functions.

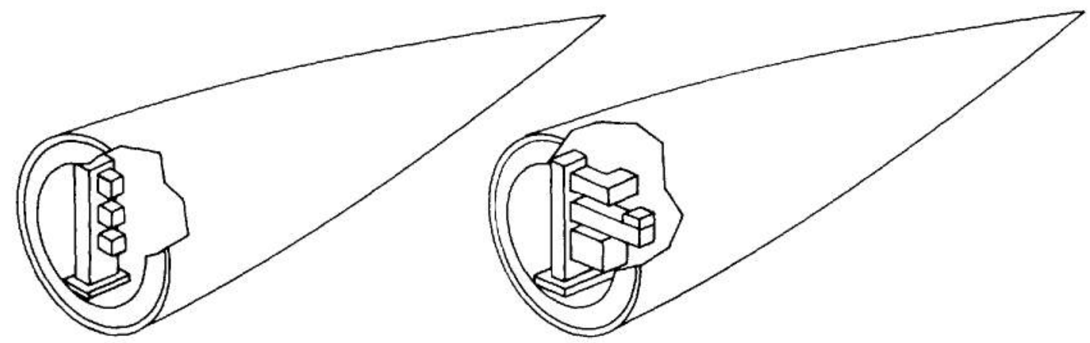
(3) Equipment should be divided into as many modular units as is electrically and mechanically practicable.



NO UNNECESSARY ASSEMBLY/DISASSEMBLY OPERATIONS, LESS DOWNTIME, LOWER MAINTENANCE COSTS

INCREASED DOWNTIME DUE TO INCREASED ASSEMBLY/DISASSEMBLY OPERATIONS. HIGHER MAINTENANCE COSTS.

(A)



EASIER PACKAGING, FEWER DIFFERENT PARTS, FEWER MOUNTING PROBLEMS

MORE INVOLVED PACKAGING PROCEDURES. INVOLVED MOUNTING PROBLEMS.

(B)

Figure 28-6. Ease **of** *Replacement* **and** *Repair*

28-30 MAINTENANCE DESIGN PARAMETERS

The following design parameters represent the desired maintainability characteristics of the Type X Trainer developed as a result of past experience :

(1) External characteristics (weight, size, shape, center of gravity, etc.) of the War Reserve Item should be duplicated in order to assure compatibility with handling equipment and realistic training (see Figure 28-7(A)). However, exact duplication of its dimensional and weight configuration is not required.

(2) Material used for skin of the Type X Trainer should be at least as rugged as the War Reserve Item. If use of a substitute material, such as plastics, is desired to allow repair of the skin for dents, gouges, etc., critical loading points should be reinforced to avoid material failures (see Figure 28-7(B)).

(3) Warhead weight simulation, generally, should be obtained by use of concrete ballast or steel plates. Ballast should be firmly secured to eliminate any movements (see Figure 28-7(C)).

(4) Where repeated operations must be conducted, such as assembly/disassembly of a Type X Warhead Section to another section, reduction of the number of defects that will occur from repeated use can be accomplished by utilizing the following designs considerations:

(a) Mating hardware such as a mating bolt should be less durable than the item into which it is inserted. The bolt will wear rather than the item and can be discarded easily and replaced without any downtime to the trainer.

(b) Where design of the mating hardware does not result in wear to the mating item, e.g., swing bolts, the bolts should have sufficient tensile strength to withstand continued use.

(c) Inserts should be used in lieu of threaded holes. Engineering studies have determined that "Heli-coil" inserts should be used for the first four replacements, and Kelox inserts should be used for an additional three replacements for a maximum of seven replacements. Where threaded holes are required, inserts should be housed in removable support blocks. Thus, when inserts have been replaced, removable support blocks (securing of blocks can be accomplished by utilizing bolts) can be replaced and replacement of inserts can be accomplished (see Figure 28-7 (D)).

(5) Electrical cables should be designed having the following characteristics :

(a) For training purposes, should connect in the same manner as the War Reserve cable.

(b) Should be replaceable, if possible, to assure ease of maintenance.

(c) Should be hot-stamped to assure that cable markings will be able to withstand excessive handling.

(d) Should be designed to withstand continuous use and connector insert material should be more flexible than materials used in War Reserve connectors to prevent damage to connector when mismating occurs.

(e) Dust cover retainer chains should be of sturdy material, i.e., nylon cord.

(6) Units requiring pressurizing or pressure checks should utilize mechanical equipment, such as spring-loaded valves and ball checks, to reduce system maintenance.

REFERENCES

1. AMCR 385-100, *Safety Manual.*
3. TM 9-1905, *Ammunition Renovation.*
4. TM 9-1900, *Ammunition, General.*
5. AMCP 706-121, Engineering Design Handbook, *Packaging and Pack Engineering.*
6. AR 700-15, *Preservation, Packaging and Packing.*
7. MIL-STD-129, *Marking for Shipment and Storage.*
8. FM 9-5, *Ordnance Ammunition Service.*
9. SB 9-156, *Publications for Packaging Ordnance General Supplies.*
10. FM 9-1, *Ordnance Service in the Field.*
11. MIL-STD-709, *Ammunition Color Coding.*

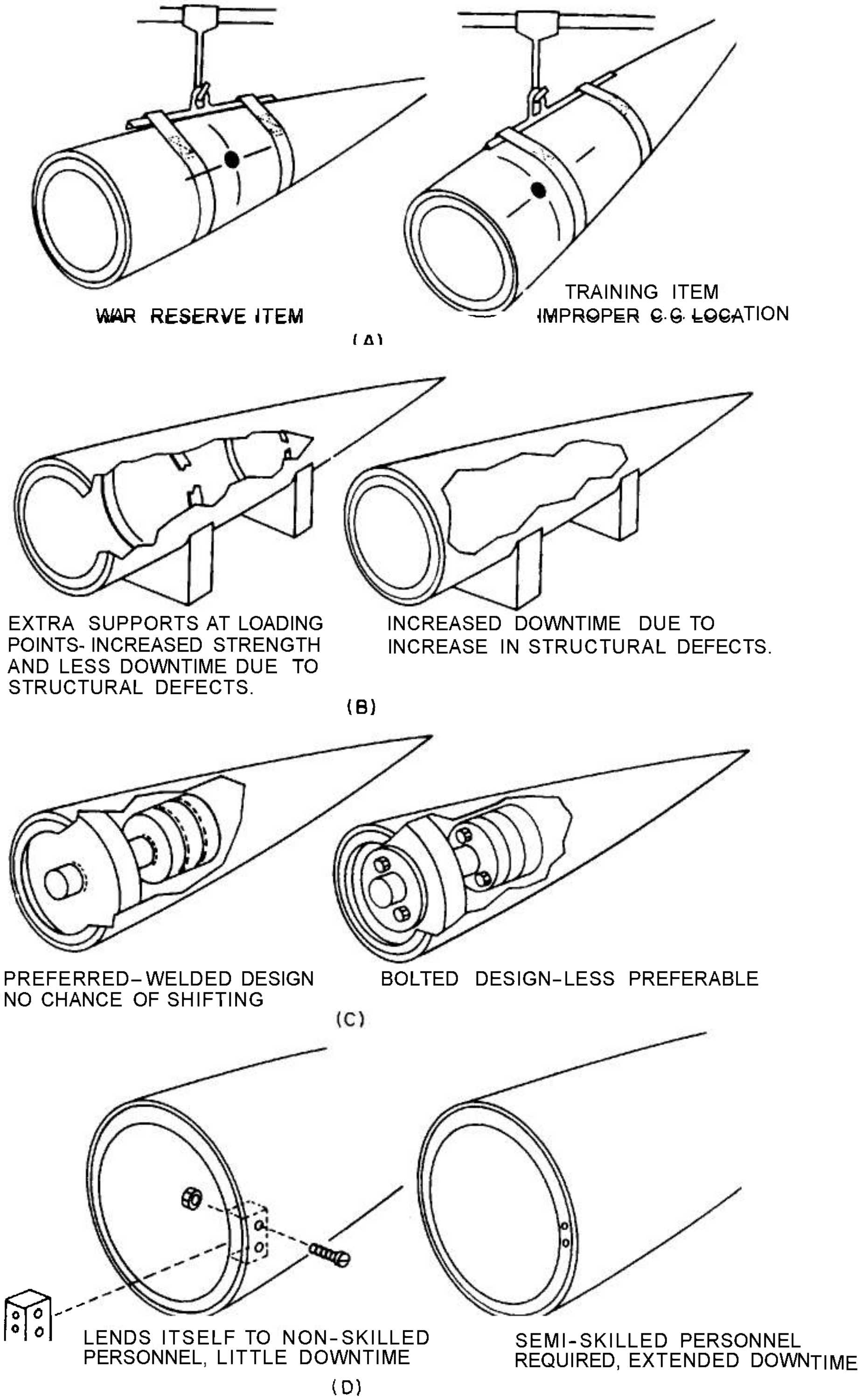


figure 28-7. Type X Trainer Maintainability Design Parameters

CHAPTER 29
WEAPON MATERIEL

29-1 GENERAL

The maintainability design criteria presented throughout this handbook applies also, as appropriate, to weapon materiel. However, the engineer concerned with the design of Army weapons materiel must also seriously consider what effects maintenance will have in regard to the "built-in" safety aspects of the weapon. The paragraphs which follow briefly discuss this all important consideration.

29-2 WEAPONS AND END PRODUCTS SAFETY

Safety *must be,* and *is* considered in the life cycle of weapons, weapon systems, and end products. The safety aspects involved must provide an assurance of safety to the user as well as fulfill the military characteristics which established the need.

Through professional and progressive safety management, the broad concept of safety begins with basic weapon research in the laboratory, and is particularly emphasized during the research and development phase. The safety of each weapon is proven by specialized development, and functional and engineering testing. During the manufacture of these end products and in the packaging and delivery to the user, this safety consciousness is never forgotten. This consideration in the early stages of design reduces the number of modifications required to correct deficiencies, facilitates production, improves operational effectiveness, and/or assures the safety of the weapon to the user. The safety of a weapon system, therefore, must first be initiated in a well conceived design and followed throughout the detail design stages to assure that the safety of the system is "designed-in."

Maintenance work, so vital to the successful operation of *any* piece of equipment, is of greater import when weapons and weapon systems are involved. During routine, scheduled and special maintenance, the "designed-in" safety of the system must not be jeopardized. Each operation must be questioned as to whether the work, the change, the redesign and/or the work order, when accomplished, will not in any way reflect adversely on the capability, reliability, and safety of the system. In addition, continued hazard evaluation, based on engineering data and scientific observation, together with actions designed to minimize, control or protect against these hazards, is necessary. Maintenance work, therefore, must consider and maintain the integrity of weapon and end product safety.

CHAPTER 30

ARMY MARINE EQUIPMENT*

30-1 GENERAL

The maintainability data presented in this handbook can also be applied to the design of Army marine equipment. Another aspect of maintainability which should be considered, however, is the effects of marine fouling on the proper functioning of marine structures and devices. This chapter discusses the effects of fouling on marine equipment and its prevention.

30-2 MARINE FOULING AND ITS PREVENTION

The fouling of ships results in a reduction of speed, an increased cost in fuel, and losses in time and money in applying the necessary remedial measures.

Fouling results from the growth of animals and plants on the surface of submerged objects. Its most widely known effect is on the efficiency of propulsion of ships, but fouling also gives serious trouble when it occurs in pipes and conduits used to conduct water in ships. The growth may have undesirable effects as the result of destruction of the protective coatings intended to reduce corrosion and may increase the corrosion of unprotected metal itself. In other cases, fouling affects the weight or bouyancy of installations, plugs up orifices which should remain open, or interferes mechanically with moving devices. Special problems arise from the effects on sound transmission, the destructive action on paints, and the influence on corrosion.

The tendency of ships to foul is related to the type of service in which they are used, and, particularly, to the resulting time spent in port where they are subject to severe fouling. Any improvement in the technology of protecting ships from fouling which permits the extension of the period between dockings will lead to important savings in time and expense.

The time required for ships to foul depends on the efficacy of the protective coating, which is sooner or later destroyed either by the solvent action of sea water, the physical breakdown of the paint film, or by corrosion. After the paint is damaged, fouling may develop rapidly and cover the unprotected surface completely within a few weeks. It is estimated that as much as 200 tons of fouling may be removed from a large ship's bottom at a single docking.

The tendency to foul varies greatly with the waters in which ships ply. Fouling can attach only at such times as the organisms are infesting the water. Its growth varies with the temperature of the water. It is generally considered that fouling is most severe in tropical waters, where growth is rapid and where there is little seasonal interruption of the reproductive processes. In temperate latitudes, heavy fouling may occur in summer, but during the cold winter period little growth develops.

In fresh water few fouling organisms occur and these are chiefly plants which attach close to the water line. Consequently, ships which can be moored in fresh water are partially immune. (It is sometimes suggested that vessels should be taken into fresh water to kill off the fouling. This is only a partial measure, since the shells of barnacles and some other fouling organisms are firmly attached and adhere to the bottom even though their occupants are dead.)

* This chapter is based on *Marine Fouling and its Prevention*, United States Naval Institute, Annapolis, Maryland, 1952.

30-2.1 PREVENTION OF FOULING WITH TOXICS

The common antifouling paints contain copper, mercury, or arsenic compounds in various combinations which are poisonous in concentrations of about one milligram per liter (one part per million). It is the toxicity of these materials which prevents fouling. Toxic action implies that some ingredient of the paint is poisonous to the organisms and must either repel their larvae at the time of attachment or kill them before they can attach permanently and grow. It has been recognized that the toxic must be free to dissolve from the paint in order to be absorbed by the attaching organism. The toxicity of various organic poisons is summarized in Table **30-1.**

30-2.2 PREVENTION OF FOULING WITH PAINTS

The only method of preventing fouling which is successful with modern ships is the use of toxic paints. Because of biological considerations the demands put on such paints differ from time to time and from place to place, and different coatings have sometimes been proposed for ships in various services. Vessels used in temperate waters, subject to fouling for only a part of each year, may be protected adequately with a relatively poor paint, effective for only six or eight months, provided they are docked annually and start the fouling season with a fresh coating. Little is to be gained by such economies, however, since the cost of the coating is only a small part of the expense of docking and repainting. Effective paints are not necessarily expensive paints. A paint which is effective under the most severe conditions of fouling will be effective in preventing growth under any condition. The superior underwater coatings now used by the Navy have been developed in response to a demand for paints which would completely prevent the growth of fouling under the most severe conditions and for the greatest possible period.

Experiments with paints designed to prevent fouling by the toxicity of an ingredient show that the toxic must be dissolved from the paint by the sea water to be effective. The difficulty in making satisfactory antifouling paints has been in devising formulations which release the toxic

TABLE 30-1. TOXICITY OF VARIOUS ORGANIC POISONS

Organic Poison	Toxic Concentration* ($-\log_{10}$)
2:4 Di-isobutyl phenol	8.2
Chlorophenarsazine	8.0
Ethyl bromoacetate	8.0
Phenyl mercury nitrate	8.0
Diphenyl arsenic acid	6.8
4-nitroso 1:naphthol	6.8
Trichlorovinyl arsine	6.7
Phenyl mercury acetate	6.7
Pentachlorophenol	6.2
Derris extract	6.1
Ferric dimethyl dithiocarbamate	6.0
10-Ethyl 5:10 dihydrophenarsazine	5.0
Arsenobenzene	5.0
4:Amino 1:2 azonaphthalene	4.8
Phenyl arsenious oxide	4.7
p-Bromo acetanilide	4.6
o-Nitrophenyl arsenic acid	4.0

* Toxicity is expressed as a negative logarithm to the base 10 of the concentration required to kill 50% of the test organisms used in 24 hours. (Scale is similar to that used for the expression of hydrogen ion concentrations as the pH.) A toxicity index of 6 means that 10^{-6} grams per ml. (1.0 mg/1) were toxic in the test

at a rate sufficient to provide a lethal concentration at the surface but still slow enough to prevent the rapid and complete exhaustion of the toxic reserve.

30-2.3 CHARACTERISTICS OF ANTIFOULING COATINGS

30.2.3.1 General Requirement

The ideal surface for prolonged protection would presumably be one which could act without consumption of the coating. No such paint, however, has been designed. Any effect due to toxicity of the ingredients requires the gradual wasting of the paint because, to be effective, the poison must dissolve from the coating. The life of a toxic paint is determined by the thickness of the coating, its reserve store of toxics, and its rate of dissolution or wearing away. The effective coatings appear to act by poisoning the organisms at the time of attachment or shortly thereafter.

Shipbottom paints prevent fouling for only a limited time. The aim of antifouling paint research should be to develop coatings which are effective for longer periods. The usual commercial paints have an average effectiveness of three to six months under subtropical fouling conditions. Very few are effective for periods as long as one year. The plastic type of antifouling paint developed by the Navy resists fouling for a much longer period and has permitted the extension of the interdocking interval from six to eighteen months. Many ships coated with these paints have been in operation in the Pacific for more than two years without fouling.

30-2.3.2 Durability

The durability of the coating depends upon its resistance to mechanical damage, the erosive effects of water movement, and the softening or solution of the components of the paint. Since the paint must disintegrate slowly to permit the liberation of the toxic, a compromise must be made between toxicity and durability.

Resistance to the erosive effects of water movement is a particular problem in connection with high speed vessels, such as motor torpedo boats and hydroplants. It is probable that special paints which may sacrifice certain other properties to the development of a hard, tough surface will always be necessary for such craft.

The loss of durability of a paint film is generally most obvious at the water line. Mechanical damage resulting from floating debris or chafing on booms, and the repeated wetting and drying, combined with direct exposure to the sun, undoubtedly accelerate the breakdown of the paint system in this region. As yet, no compositions have been designed for the water line area which give the service life attained by paints applied to the underwater sections of the hull.

30-2.3.3 Adhesion

The coating must adhere to the wood or steel of the ship's bottom. It is not sufficient that adhesion be satisfactory when the paint is applied tinder favorable circumstances. The coating should adhere well when applied under the far-from ideal conditions of dampness and temperature under which much painting is done, particularly during winter in temperate latitudes. The frequently observed variations in the performance of the same paint on different occasions may be due largely to the variable conditions under which it is applied.

30-2.3.4 Effect on Corrosion

It is essential that the shipbottom paint system used on a steel vessel should protect the hull from corrosion. If the coatings do not prevent rusting, the continuity of the paint will be destroyed and fouling of the bared areas will result. At least one coat of primer or anticorrosive paints is applied before the antifouling coating. The effectiveness of this anticorrosive paint may determine, to a large extent, the success of the antifouling material.

The antifouling paint may contribute materially to the protection of the hull from corrosion. This contribution depends primarily on the thickness of the coating and its resistance to the penetration of sea water. Experiments with Navy paints show that the anticorrosive coating alone (about 2 mils) will prevent corrosion for only a few months. The addition of a coat of the cold plastic antifouling paint (about 5 mils) extends the protection to at least fifteen months, and the use of a 30-mil coat of the hot plastic antifouling paint will prevent serious corrosion for at least thirty months. Thick paint films thus aid in preventing corrosion in addition to providing the necessary toxic reserve for prolonged prevention of fouling.

The ingredients of the antifouling paint should not accelerate the corrosion of steel. The common toxic pigments, metallic copper, and salts of copper and mercury, tend to accelerate corrosion if they are not adequately separated from the steel hull. For this reason it is very desirable that toxics other than these be developed for antifouling coatings.

30-2.3.5 Smoothness

The antifouling coating should have a smooth surface to keep the frictional resistance of the vessel at a minimum. The smoothness of the coating will depend upon the behavior of the paint film during drying.

Smoothness is a quality which acquires increased importance where speed is essential. Small racing yachts commonly employ paints which sacrifice most of their antifouling virtue for the sake of a hard, smooth finish.

The thick coatings required to provide prolonged protection against fouling must be carefully formulated to permit easy application, freedom from sagging, and good leveling. If drying is inadequate, a thick coating may tend to flow when the ship gets under way, and thus become rough. On the other hand, the viscous paints necessary to give thick coatings have sufficient body to fill up minor irregularities of the ship's surface.

30-2.3.6 Ease of Application

The antifouling paint should be designed to permit its application by either brush or spray equipment, so that vessels may be painted wherever it is convenient to dock them, and by whatever labor is available. The use of modern spray equipment results in great economies of time and in superior applications. Many commercial paints can be sprayed with standard equipment; the Navy has developed methods for spraying both the hot and cold plastic paints. Paints which can be applied by only one of these methods, such as the hot plastic which must be sprayed, are of necessity limited to those drydocks using the appropriate method of application.

Wide variations in temperature should not seriously alter those properties of the paint, which determine the ease of application, since vessels must be painted in all seasons and climates. Many formulations become undesirably thick in cold weather. The paint should be formulated so that readily available solvents are suitable for thinning. It should not cake in the container or body excessively in storage.

30-2.3.7 Drying Time

Because the time available for painting is usually limited by practical considerations, it is essential that the paint dry rapidly. If the time in drydock is limited, adequate painting is impossible unless the paints dry rapidly. If the time in dock is not too limited, multiple coats may be applied and thus provide the thick coating necessary for prolonged antifouling life.

If the paint film does not harden before the ship gets under way, the erosive action of the water may cause it to flow, thus impairing the serviceability of the coating. It has been found that many paints harden under water, so that a stationary period after undocking may aid in preventing excessive erosion or flow of the paint surface.

It has been traditional to float vessels as soon as possible after the application of the final antifouling coat. Tests on several proprietary paints which recommend this indicate that it either has no effect on the fouling resistance of the paint, or actually impairs it.

The introduction of the tinting pigments commonly impairs the antifouling effectiveness of the paint. A similar problem is introduced in flying-boat hulls, where the need for a pale color has precluded the use of cuprous oxide, the toxic most approved in antifouling paints for ships.

30-2.3.8 Expense and Availability

The cost of the paint normally constitutes only a small proportion of the total expense encountered in docking a vessel. An inefficient paint, no matter how cheap, does not represent a good investment. However, far too often price rather than performance is the dominant factor in the formulation and purchase of antifouling paints.

For strategic reasons, the Navy uses domestic materials as much as possible in order to avoid the curtailment of supplies which might result during wartime. This consideration led the Navy to develop paints using rosin as the binder in place of the gum shellac employed prior to 1926. More recently it has been possible to make satisfactory antifouling paints which do not contain mercury as the toxic. The elimination of this material, which is both expensive and scarce, has saved many thousands of dollars each year.

Many of the synthetic resins which are being developed are more expensive than the common natural resins. Their use may be restricted to paints intended for purposes which justify the extra expense. They may be added in small quantity to improve the qualities which use cheaper materials as the main film-forming ingredient.

During wartime many materials which are normally available in adequate amounts may become scarce. It is frequently necessary under these conditions to modify formulations by the substitution of similar but more available materials. Since small changes in formulations may have a profound effect on the serviceability of the paint, it is essential to understand the properties of alternative ingredients so that substitutions may be made without detriment.

30-3 THE FOULING OF METALLIC SURFACES

The relative tendencies of metallic surfaces to foul are listed in Table 30-2.

Table 30-3 itemizes some common metals and alloys in three groups listed in the order of the probability that they will foul when exposed in the sea. The table indicates that only copper (and its alloys), silver, and zinc appear to resist fouling to a degree greater than that of other hard smooth surfaces. The metals listed as least likely to foul all contain copper in excess of 64%. Among those with a variable tendency to foul, the only pure metals are zinc and silver.

30-3.1 GALVANIC ACTION

The occasional or ultimate fouling of copper sheathing has been attributed to the presence of impurities giving rise to electrolytic effects. In many cases the failure of copper to protect is due to the presence of dissimilar metals in contact with the copper sheathing.

In a study of the potentials existing between a variety of metals and sea water results showed that, in a general way, the potentials observed under this condition follow the same order as the potentials of metals in equilibrium with solutions of their own salts. The values of the potentials observed, however, were somewhat different and showed a striking change with time. In general, the potentials became more positive during the first month and then returned to their original values, and in some cases became even more negative. Different metals varied in the intensity and regularity of these effects, as illustrated in Figure 30-1. In spite of this difficulty, the commoner metals have been grouped in a series of increasing potentials as shown in Table 30-4. Within each group the members may change places depending on conditions of exposure. The range of variation in potential as commonly observed is shown in Figure 30-2. From these results it may be seen that the various alloys of copper do not differ greatly in the ranges of their potentials, and it is probable that these alloys may be coupled without inducing serious corrosion. This fact is commonly taken into account in the construction of vessels and equipment to be

TABLE 30-2. RELATIVE TENDENCIES OF METALLIC SURFACES TO FOUL

Metal	Rating
Aluminum	10
Iron	10
Lead	10
Tin	6
Zinc	0.2
Copper	0

TABLE 30-3. SOME COMMON METALS AND ALLOYS IN THE ORDER OF PROBABILITY THAT THEY WILL FOUL

Metals and Alloys Least Likely to Foul	
Admiralty brass	Commercial bronze
with As	Copper
with Sb	Copper nickel alloys less than 30%Ni & less than 0.15% Fe
with P	German silver (nickel silver)
Adnic	Government bronze
Arsenical copper	Gun metal
Beryllium copper	Low brass
Brasses, more than 65%Cu	Olympic bronze
Brasses—tin with more than 80%Cu	Silicon bronze
Bronzes—tin	P. M.G. bronze
Bronze—comp. G	Red brass, cast
Bronze—comp. M	Red brass, wrought
Bronze—nickel	
Cartridge brass	

Metals and Alloys Variable in Fouling Tendency	
Brasses with less than 65%Cu	Leaded high brass
Common brass	Manganese bronze
Copper nickel alloys, less than 30% Ni & more than 0.15% Fe	Muntz metal
Copper nickel alloys, 30 to 40% Ni	Naval brass (tobin bronze)
High brass (yellow brass)	Silver
	Sterling silver
	Zinc

Metals and Alloys Likely to Foul	
Aluminum	Lead tin alloys
Aluminum alloys	Magnesium
Aluminum brass with or without dezincification inhibitors	Magnesium alloys
Aluminum bronze	Manganese steel
Antimonial lead	Nichrome
Cast iron	Nickel
Cast steel	Nickel aluminum bronze
Chemical lead	Nickel chromium alloys
Copper steel	Nickel chromium iron alloys
Copper nickel alloys more than 40% Ni	Nitrided steel
Galvanized steel	Platinum
Gold	Silver solder
Ingot iron	Stainless steels
Iron	Tin
Lead	Tin lead alloys
	Wiping solder
	Wrought iron

TABLE 30-4. GALVANIC SERIES IN SEA WATER

Magnesium, magnesium alloys
Zinc, galvanized steel, galvanized wrought iron
Aluminum 52SH, 4S, 3S, 2S, 53S-T, alclad
Cadmium
Aluminum A17S-T, 17S-T, 24S-T
Mild steel, wrought iron, cast iron
Ni-Resist
13% chromium stainless steel type 410 (active)
Lead tin solder 50-50
Stainless steel 18-8 type 304, 18-8-3 type 316 (active)
Lead, tin
Muntz metal, manganese bronze, Naval brass
Nickel (active), inconel (active)
Yellow brass, Admiralty brass, aluminum bronze, red brass, copper, silicon bronze, ambrac, copper nickel 70-30, comp. G-bronze, comp. M-bronze
Nickel (passive), inconel (passive)
Monel
Stainless steel 18-8 type 304, 18-8-3 type 316 (passive)

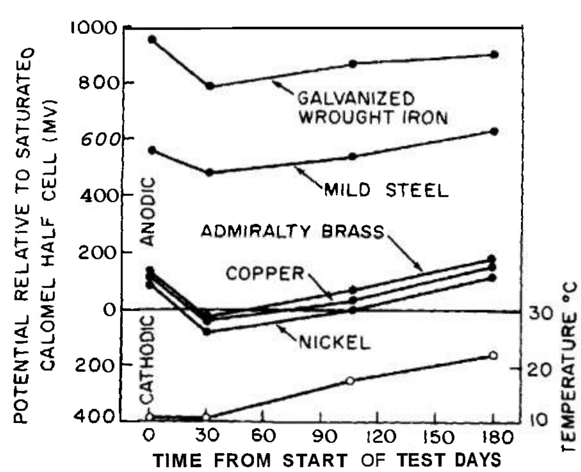


Figure 30-7. Potential of Metals in Flowing Sea Water

exposed to salt water. On the other hand, it is quite evident that small differences in potential can exist between these metals, provided the state of activity of the coupled members does not vary in the same way. At present there appear to be no measurements to show the potentials which actually exist with such permanent couples in sea water.

30-3.2 THE USE OF PAINT TO PROTECT GALVANICALLY COUPLED METALS

When it is necessary to expose dissimilar metals in contact under sea water, the corrosive effects of the resulting galvanic couples may be reduced by the use of protective coatings. When either or both members of a couple consisting of steel and copper are painted the following was found to be the order of preference in the application of the paint:

1st choice—Paint both the copper and the steel.

2nd choice—Paint the copper and leave the steel bare.

3rd choice—Leave both metals bare.

4th choice—Paint the steel and leave the copper bare.

The reason for not painting the steel, if the copper is not painted, is that imperfections in the paint coating may lead to severe localized attack which, on the whole, is more harmful than the uniformly distributed corrosion which occurs on bare steel. Additional experiments also showed that if the steel member of a copper/steel couple was painted with an adequate anticorrosive system, the antifouling action of the copper was no longer inactivated, and the copper remained free of fouling. It was also possible to prevent fouling on the copper member of a couple by painting it with an adequate barrier coat topped off with a metallic copper paint. That is to say, the inactivating action of the steel on the copper member did not extend through the barrier coat to influence the overlying metallic copper paint.

30-3.3 BLISTERING OF PAINT FILMS BY ELECTROLYTIC REACTIONS

The importance of local electrolytic processes resulting from interaction between copper paints and the underlying steel when adequate barrier coats are not present should also be em-

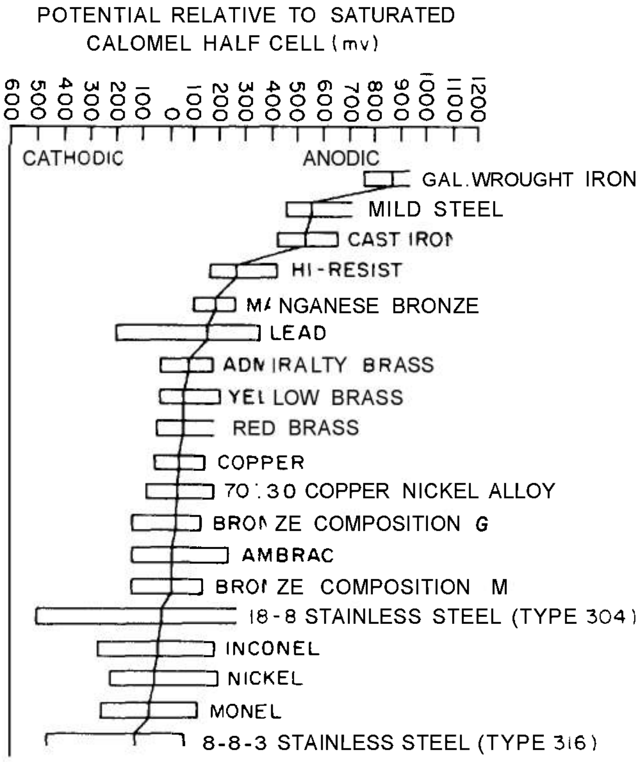


Figure 30-2. Range of Variation in Potentials of Metals and Alloys in Flowing Sea Water

phasized. Blistering can be induced by coupling a painted steel panel with either copper or zinc. With a zinc coupling, the steel is cathodic and becomes the site of hydrogen liberation accompanied by increased hydroxyl ion concentration. The steel beneath the blisters is found to be bright and clean. With a copper coupling, the steel is anodic and severe corrosion occurs in isolated imperfections in the paint film. Blisters are not formed as readily, but when present they are filled with rust. On several uncoupled panels, both types of blisters were observed to be present as little as 0.125 in. apart. This illustrates the effects produced by local electrolytic cells, and shows that greater activity may exist at small, isolated points.

Since blistering, arising from electrolytic processes, is thought to be a frequent cause of paint failure, especial attention should be given to developing anticorrosive coatings which discourage such effects. The use of steel panels to which small pieces of zinc or copper are coupled is recommended to test the resistance of barrier coats to conditions which produce electrolytic blistering.

30-4 SUMMARY

30-4.1 GENERAL

Essentially, the remedy for fouling is to prevent the growth of the organisms, unless the simple procedure of removing them mechanically is practical. At present this can be accomplished most effectively by the application of toxic paints or greases, or by the use of metals which give off toxic ions as they corrode. Success with toxics should not preclude, however, the possibility of finding other, more effective devices. Improvements in paint coatings are needed to ensure longer effective life, and particularly to develop systems less likely to be destroyed by the corrosion of the underlying steel. Coatings which may be applied successfully under the unfavorable conditions of weather frequently encountered in docking are greatly needed, as are special coatings adapted to various uses other than shipbottom application. Up to the present, almost no effort has been expended in developing special alloys particularly adapted to resist fouling; such metals as are available are merely selected from among alloys devised for other purposes. Even the elementary facts regarding galvanic action in relation to its effects on both corrosion and fouling are frequently poorly understood by those responsible for the construction and maintenance of ships and other marine structures.

While interest in the biological aspects of fouling may appear to end with the discovery of toxic coatings capable of preventing the growth, new protective devices cannot very well be developed without a fundamental understanding of the fouling populations. New paint formulations cannot be tested intelligently without this information. Finally, knowledge of the times and places where fouling is to be expected is necessary whenever there is any question of whether protective measures need be taken, how to practice such measures with the greatest economy, or how long structures will remain unfouled when protective measures cannot be applied.

30-4.2 STEEL CONSTRUCTION

On steel construction, accelerated corrosion may be expected if paints containing either copper metal or cuprous oxide are applied unless adequate barrier coats are employed. If the coating contains metallic copper as a pigment, and the barrier coat is inadequate, more serious pitting may result at holidays or breaks in the paint surface. The protection afforded by the paint against fouling will be decreased whenever the conditions lead to increased corrosion, and this may be a more serious consequence than the damage to the steel or the destruction of the paint film by corrosive action.

The corrosive action is probably dependent upon the formation of either gross or localized galvanic couples. The gross couples depend upon contact between particles in the paint and with the underlying steel, and are limited to highly loaded metallic paints. More generally, the effects appear to be explained by the diffusion of dissolved copper through the barrier coat where it is deposited to form local galvanic couples.

The logical method of overcoming corrosive effects of the latter sort appears to lie in the use of barrier coats which, through their impermeability and electrical insulating properties, will interfere with the formation and operation of localized galvanic couples beneath the paint. On the one hand, they should prevent dissolved copper from reaching the metallic surface, and on the other, should insulate the surface from sea water so as to prevent the completion of local circuits through that medium. These findings confirm best shipyard practice, namely, the use of multiple barrier coats or of very heavy undercoats beneath antifouling paints. They further suggest that relatively impermeable barrier coats, topped by medium coats of antifouling paints, should give better corrosion protection, combined with efficient antifouling action, than can be had with light priming coats and a heavy antifouling layer.

The possibility of decreasing corrosive attack by proper formulation of the antifouling composition itself should not be overlooked. Evidence indicates that the plastic paints currently used by the Navy are attacked by sea water largely at the outer surface, and that relatively little solution of cuprous oxide occurs in the deeper layers of the paint. That such an impermeable paint does, indeed, cause less severe corrosive attack at holidays has been indicated by experimentation.

It is also probable that by correct formulation the corrosive effects of metallic copper paints may be reduced and perhaps kept as small as those of cuprous oxide paints. It is not clear that this can be done and still retain the advantage of an ample reserve toxicity. Only two commercial metallic copper paints examined have shown no excessive corrosive tendencies, and these are not very satisfactory antifouling paints when compared to the best Navy coatings now available. On the whole, in view of the demonstrated tendency of metallic copper paints to form gross galvanic couples with steel, and of the attendant corrosion and loss of protection against fouling, their use on steel construction should not be encouraged until compensating advantages have been demonstrated.

30-4.3 WOOD CONSTRUCTION

On wood construction, the danger of corrosion and inactivation are much less serious. Accidental contact of chain, rudder posts, and similar ironware with the antifouling paint on a wood hull would have very little deteriorating effect on antifouling efficiency, unless the contact area were large. However, experiments show that heavily loaded metallic copper paints may result in severe corrosion of galvanized iron fittings and fastenings which they contact. Fouling of the paint in the neighborhood of metallic contacts may also result.

If the fittings and fastenings are of bronze or brass, or if they are protected by a coat of cuprous oxide paint applied so that contact between the fittings and the metallic paint is avoided, these effects will not occur. The disadvantages of attempting such protection must be weighed against the suppressed advantage of using the metallic pigment.

CHAPTER 31
AIRCRAFT MATERIEL

31-1 INTRODUCTION

This chapter deals with all aircraft — fixed wing aircraft, rotary wing aircraft, drones, jet belts, ground reaction machines, parachutes, airborne equipment (designed for use in or around aircraft), paradrop palleting, aircraft ordnance, avionics, and other similar materiel specifically designed to operate above ground level.

The rules applying generally to all types of equipment apply also to aircraft — in fact more so due to hazards from malfunction. For convenience, this chapter repeats some of the design concepts applicable to pieces of equipment which are discussed in other portions of the handbook. To conserve space, however, references are made in many instances to applicable material in other parts of the book. Although specifics, as applied to aircraft only are covered, they are not complete. The designer must visualize the nature of possible problems, and, in many cases, be guided by his common sense.

31-2 GENERAL MAINTAINABILITY DESIGN CRITERIA

U S Army aircraft should be designed for maximum maintainability, reliability, and serviceability. The designer should select simple and flexible equipment which will provide the maximum for self-sufficiency in servicing and maintenance under conditions of varying climatic and environmental extremes. During the *fundamental design stages* the designer should keep in mind the importance of producing a practical, serviceable aircraft, a maximum number of which can be maintained operational in the field with a minimum of maintenance facilities and crew. Consideration should also be given by the designer that all aircraft equipment, with the exception of modules and throwaway items, may need maintenance at some time, even if this maintenance merely entails inspection for wear, cleaning, painting, etc.

Aircraft design should reflect a maximum of self-sufficiency in servicing and maintaining. The aircraft should be designed to permit rapid, simple servicing and repairing and means should be provided for inspection which does not entail disassembly or removal of components. These factors will help minimize ground handling equipment requirements. The ability to put an effective aircraft into the air is no more important than the ability to maintain and support it. The designer should realize also that *maintainability features are also safety features.* (See Paragraphs **31-10** and **31-11.**)

Some general maintainability design features which should be considered for incorporation into aircraft are:

(1) Maximum accessibility, with special emphasis placed on preflight and postflight inspection accomplishment in minimum man minutes (see also Paragraph **31-9**).

(2) Equipment installations such that components are readily maintained without tools by the using agency. Special tools and test equipment should be justified with the U S Army procuring activity in each case (see also Chapter **11**).

(3) Approved quick-disconnect features (see also Chapter **23,** Section 11).

(4) Quick engine installation features (see also Paragraphs **31-7,** -8, and **-9**).

(5) Large, quick opening engine access doors for engine accessory section servicing and ample space in engine accessory area for replacement of components (see also Paragraph 31-9).

(6) All communication and fire control system components which require pressurization to have self-contained pressurized compartments readily detachable from the aircraft, such as detachable nose segment or capsule. High altitude aircraft components requiring inflight inspection or adjustment should be so located as to provide ready inflight accessibility of the pressurized compartment.

(7) Troubleshooting and detection principles and quick-disconnect features to permit the most rapid localization of malfunctions, and subsequent calibration, adjustment, and/or repair (see also Chapter 5, Section I, and Chapter 23, Sections 11, 111, and IV).

(8) Utility systems that can be serviced without the use of external maintenance stands or special equipment, preferably from ground level.

(9) Where required by the procurement contract, a flyaway support kit readily stored in a cavity or wing bomb rack of the aircraft except during combat missions. This kit will normally consist of an auxiliary power unit for engine starting and other equipment required for system checkout.

(10) Quick refueling and arming of the aircraft to minimize ground time.

(11) Incorporation of simple and foolproof aircraft systems and components to prevent maintenance personnel from inadvertently reversing or mismating fittings and couplings (see also Paragraph 31-30).

31-3 ARMY SERVICE CONDITIONS

The aircraft designer should keep in mind the fact that at some time, and particularly in combat, the aircraft will be subject to thick mud, ice, deep snows, dew, tropical salt air, desert dryness, intense desert heat, high altitudes, vigorous dust storms, prolonged inactivity in warehouses and/or outside storage, and continuous, cleaning processes. Unless specifically exempted in the contract or task, the aircraft should be designed, so far as practical, to resist all of these conditions, unless it is positively known that the aircraft will never be subjected to these conditions.

An example of equipment design in which malfunctions resulted from cold weather operation is shown in Figure 31-1. In this installation, the engine breather tubes were designed so that

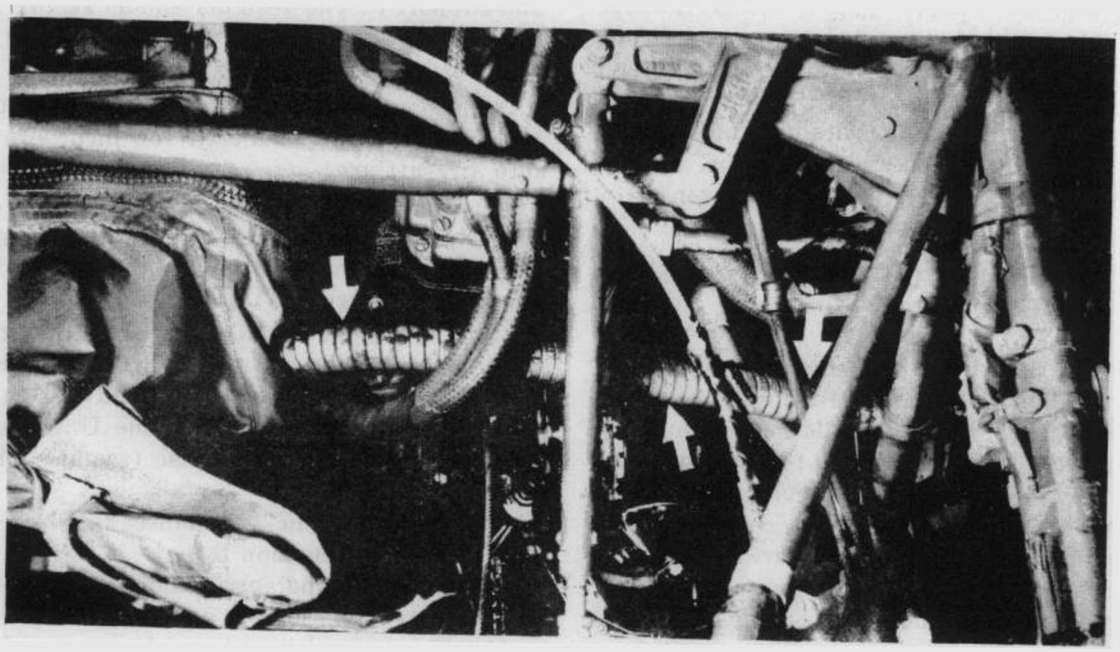


figure 31-1. Engine Breather Tube Not Designed for Winter Operation Had To Be Modified (Ref. 1)

ice was able to form and clog these tubes, allowing a pressure buildup, rupturing seals and gaskets and forcing all of the oil from the engine. As a result of this design inadequacy, the helicopters had to be modified with breather tube heaters for winter operations.

31-4 STANDARDIZATION

The aircraft designer should select AN or Mil Standard parts or components or those covered by applicable specifications, and which are currently being manufactured in sufficient quantity to be readily available at appropriate maintenance levels. Standard designs and parts should be used in preference to special parts or designs serving the same function. Modified parts should be manufactured in accordance with applicable specifications and documents pertaining to threads, materials, processes, equivalent tolerances and sizes using standard tools and tooling in fabrication (see also Chapter 18).

31-5 SIMPLIFICATION

The aircraft designer should analyze the details of his design from the viewpoint of the effort required for maintenance. Close cooperation with the field maintenance specialists during the preliminary design phase enables the designer to realize substantial maintenance and production savings through simplicity of configuration, elimination of nonessential design features, maximum manufacturing tolerances, multiple usage of parts, field service conditions and requirements, and similar features.

Design features should be incorporated which will minimize the complexity of routine and periodic maintenance tasks, such as inspection, servicing, identification and localization of malfunctions, removal and replacement of components, adjustment, calibration, cleaning, simplicity of replacement procurement, etc. (see also Chapter 17).

31-6 SECTIONALIZATION, UNITIZATION, AND MAJOR CLEAVAGE UNITS

Whenever it is possible or practical, all aircraft components should be designed as a unit. Sectionalizing and unitization will make possible the replacement of complete pretested aircraft subassemblies, thereby assisting and expediting field repairs that are difficult to perform because of limited tools and handling equipment. Proper sectionalizing will also limit the logistical problem associated with storing, shipping, and handling of spares. In considering sectionalization and unitization, provide in the basic design as much assistance as possible to make accurate assembly easy.

Typical units should include engines, engines with transmissions, guidance systems, complete warheads, radios, radar components, nutators with drives, stable gyro platforms, telescopes, rangefinders, instrument panels, valves, pumps, hydraulic units, control units, personnel seats, and similar items. Circuit functions — either mechanical, fluid, or electrical — should be designed as replaceable units capable of being bench tested. Wherever practical, components should be grouped on the basis of fuction, mutual compatibility, complexity of circuit, and life expectancy. Some other design recommendations which should also be considered follow (see also Chapters 14 and 19).

(1) In general, it is a requisite that an engine and all its closely associated auxiliary equipment be readily removable from the aircraft as a single unit. The entire engine nacelle unit should be held in place with a minimum number of principal fasteners, e.g., 3 or 4, and should be removable along a line of major cleavage. For all other type nacelle disconnections, easily accessible quick-disconnects are to be utilized. It is then desirable to have the various components easily dismountable for further maintenance.

(2) Provide only minimum connections between the power plant and the airframe, such as fuel and electrical lines. Avoid mounting items such as oil reservoirs on the vehicle frame.

(3) Arrange the power plant, wherever possible, to permit removal or replacement without requiring drainage of coolant, fluids, or lubricants.

(4) Design complex subsystems of the engine, such as turbines and compressors, as complete assemblies so they can be removed and replaced as units. By stocking assemblies as complete units, the aircraft can be returned quickly to operational readiness and the re-

moved item can be repaired at the optimum facility.

(5) Minimize the number of spark plug types. Ensure that the types are standardized where more than one engine is employed on the vehicle. In multiengine aircraft ensure that the shielded spark plug harness ferrules are compatible with the other spark plug harness.

(6) Locate spark plugs so that they are easily accessible for removal and replacement, using standard tools, without removal of engine components other than weather proofing or radio-interference suppression components.

(7) Specify spark plug wires of proper length to prevent incorrect assembly.

(8) Provide hoisting lugs or hand points on motors, gear boxes, and similar units exceeding 45 lb to assist handling when they are removed or replaced.

(9) Design the instrument panel installation so that it is removable as a unit. Bundled wiring and quick-disconnects should be used to the maximum extent possible.

In providing for sectionalization, the aircraft designer should consider sectionalizing subassemblies into major assemblies which may be called "major cleavage units." These units could be manufactured, shipped, warehoused, combat salvaged, and cannibalized as total usable units requiring no alteration for interchangeability. The following is a typical general breakdown of an aircraft into major cleavage units:

nose fuselage units ;
center fuselage unit (s) ;
rear fuselage unit (s) ;
engine nacelles ;
wing panel unit (s) ;
tail surface units ;
landing gears.

The major line of cleavage should be fastened with a minimum number of simple, easily accessible fasteners. All electrical wiring, control rods, cables, and hydraulic lines along this major line of cleavage should be readily partible and located for maximum accessibility, even under emergency combat conditions. Quick-disconnect fittings should be used, and permanent lifting eyes or jack pads should be permanently installed where possible. The total weight of each of these units should be kept under 10,000 lb if possible.

31-7 INTERCHANGEABILITY

The aircraft designer should provide for rapid and easy interchangeability and replaceability of components, assemblies, parts and equipment under field conditions. Parts should be designed which will permit use of maximum tolerances. These features should be considered in the initial stages of design. Military Specification MIL-I-8500 should be referred to for interchangeability provisions applicable to all production contracts for specific aircraft or components.

The availability of large numbers of aircraft for combat use depends to a large extent upon the ease and speed with which engines and engine nacelle assemblies can be removed and replaced. As stated previously in Paragraph 31-6 it is normal practice, particularly in multiengine aircraft, to design many power plant components, such as the lubrication system, so as to be removable from the airframe as a unit with the engine. In this manner, replacement power plant units can be used that have been readied for immediate use and require a minimum of attachments to the airframe. Quick-change characteristics of such units are not difficult to achieve if they are considered early in the design.

Additional interchangeability objectives are presented below (see also Chapter 14) :

(1) Engines tend to have similar parts such as bearings, turbine stators, and rotor blades. These similar parts should be made interchangeable whenever possible.

(2) Design the power plant installations of multiengine aircraft identically, permitting complete interchangeability left to right and position to position. The engine cowl and the accessories forming a part of the engine equipment.

(3) Construct cowling, which is necessarily removed to permit power plant change, to allow complete interchangeability between aircraft of the same model. The advantage of interchangeability of power plants is that a standard pretested power plant can be used to serve any power plant position. In instances where two or more contractors are manufacturing the same model aircraft, maintain complete interchangeability of engine installations between the products of the different manufacturers.

(4) Installations detachable as a unit should fit any power plant position on the aircraft with minimum variations, thus permitting interchangeability. The only points of variance anticipated are those installations employing engines which serve the aircraft with different functions, such as supplying cabin heat from inboard engines and wing deicing heat from outboard engines.

(5) Wherever practicable, all similar aircraft that have the same or equivalent engines should have standard and interchangeable power plant installations. Equivalent engines are engines of the same size, having the same general configuration and approximately the same horsepower ratings and center of gravity location. Similar aircraft are those having approximately the same performance, general configuration, and engine arrangement,

(6) In any multiengine aircraft the engine units should be so constructed as to provide for a maximum number of interchangeable parts. Quickly detachable connectors should be provided for wiring, piping, and controls, as should adequate space for each power plant component as specified in the applicable specification. In utilizing quick-disconnects, however, the designer should be careful to avoid installations in which hazardous conditions could be created as a result of a possible faulty connection.

31-8 ACCESSIBILITY

Components of aircraft that require maintenance should be easily accessible. Ease of maintenance depends, in part, on the difficulty encountered in getting to an item. The designer should consider the frequency of maintenance to determine the degree of accessibility and should be sure that the effort expended to provide accessibility is warranted by the *need* for accessibility.

The paragraphs which follow present general accessibility design recommendations (see also Chapter 12).

31-8.1 GENERAL INSPECTION AND ACCESS REQUIREMENTS

The aircraft designer should provide every possible convenience for performing periodic inspections and replacements of functional components in a minimum period of time. Some of the design recommendations which should be considered here :

(1) Do not use permanent-type accesses (riveted or welded access doors or panels) on aircraft or accesses requiring the removal of permanently attached structures.

(2) Provide doors or access panels in the fuselage, airfoils, nacelles, control surfaces, and any location not otherwise accessible from the interior for the inspection and servicing of actuators, controls, jack screws, pulleys, cables, guides, electric junction boxes, pitot static system, fuel tanks and system, boost pumps, and similar items.

(3) Mark all removable inspection and access doors, or otherwise identify as to location, in order to expedite reinstallation. If hinged doors are used, locate the hinges so that the airstream tends to keep them closed (see also Chapter 12).

(4) Provide for a door opening of at least 150" and preferably 180°. Piano hinges, Drawing AN257, may be used as hinges and are desirable as locking devices for inspection and access doors.

(5) Do not locate inspection or access doors on the engine air intake duct or near enough to the opening so as to be pulled into the engine in the event they become unfastened.

(6) Use flush-type quick-opening fasteners conforming to MIL-F-5591 on inspection doors. Do not use screw-retained doors when frequent inspection, servicing, or maintenance is required.

(7) Design access doors, cowling, etc., so that when they are closed the fasteners do not appear to be fastened when they are not. Figure 31-2 shows the transmission cowling on an aircraft which can be installed so that it appears the fasteners are latched when they are in fact unfastened. The subsequent loss of cowlings in flight with resultant aircraft damage, has been the result of this design inadequacy.

(8) Make size and location of all inspection and access panels such that a mechanic dressed in bulky arctic clothing, including gloves, may accomplish the work (see also Chapter 9, Section I).

(9) Provide each fuel cell with its own access door from the exterior of the aircraft (see

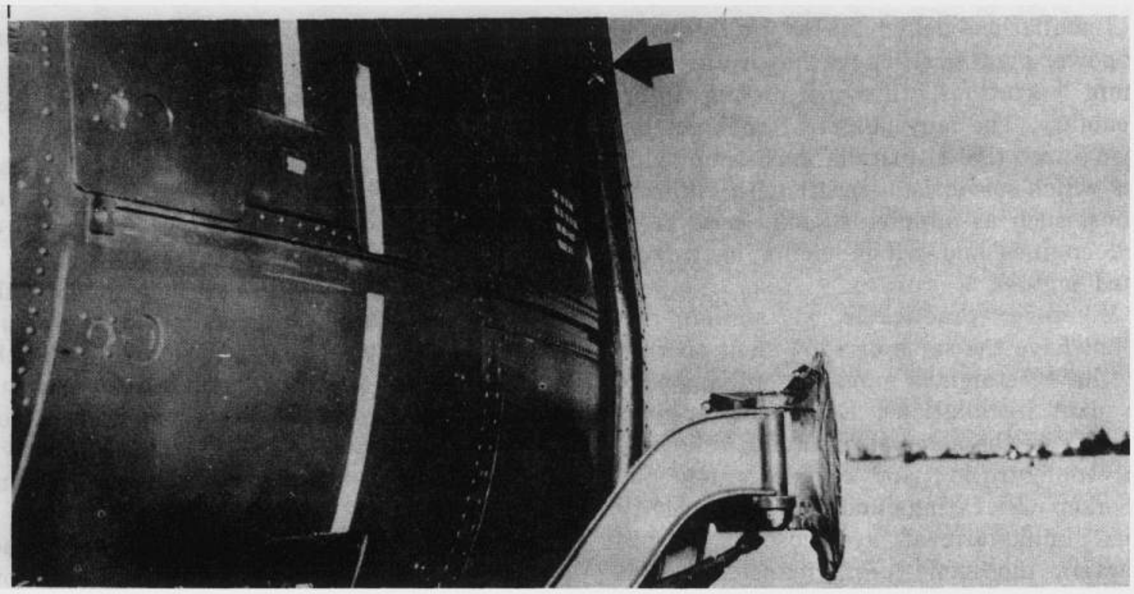


figure 31-2. In This Installation, Cowling fasteners Appear To Be Latched When They Are Not (Ref. 1)

Figure 31-3). Access to fuel cells in large aircraft presents special problems because of the number of separate fuel cells, and the complexity of the interconnecting and regulating hardware located in and around the cells. In a large aircraft there may be hundreds of valves, float switches, circuit breakers, fuel manifolds, or clamps; accordingly, inspection, troubleshooting, replacing, and repairing becomes a formidable task. Where possible, the complexity of the subsystem should be reduced. Reduction of the number of parts of the subsystem will in itself improve access for maintenance.

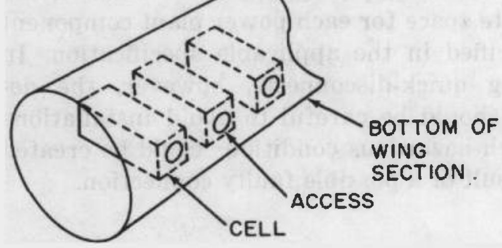


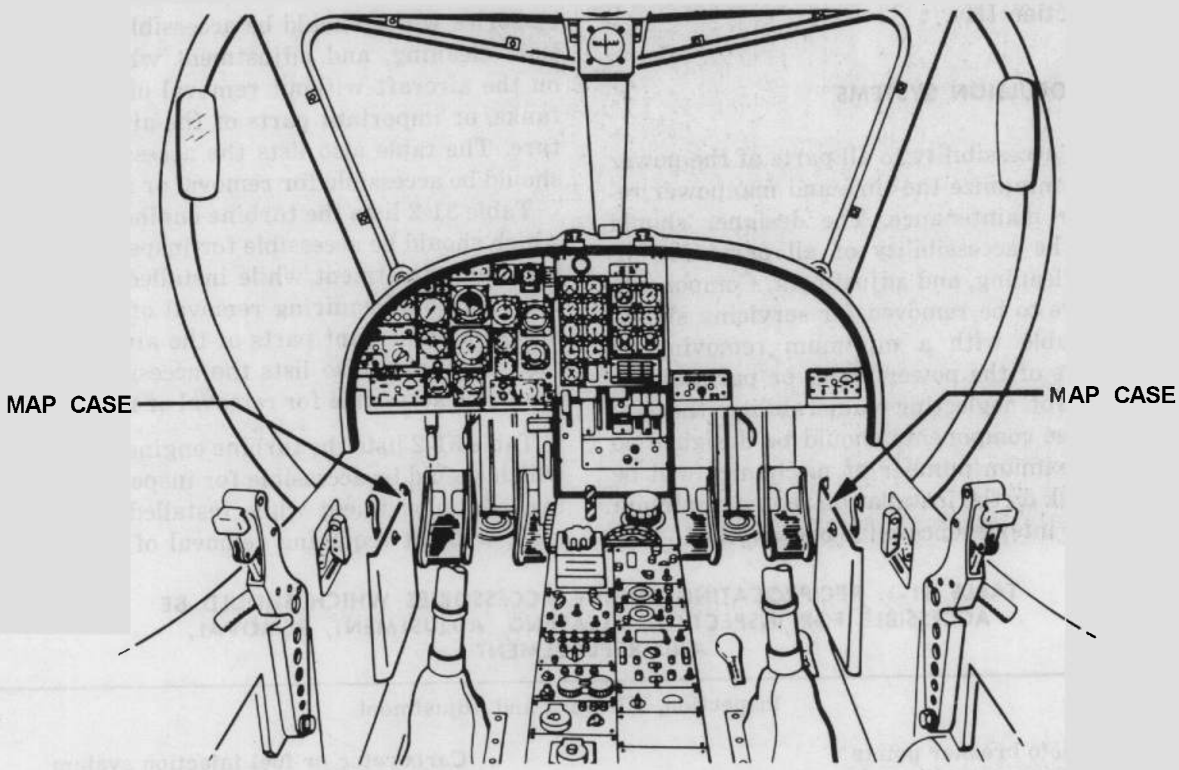
figure 31-3. Provide Individual Access Doors for fuel Cells

(10) Where possible, make equipment accessible for inflight maintenance and operation. Place equipment requiring access, operation, or adjustment during flight within easy reach of the operator. Examples of not designing equipment to be easily accessible during flight are shown in Figure 31-4. Figure 31-4(A) shows the map case location in an aircraft. During flight, with crew members. properly restrained (shoulder harness and seat belts fastened), the map cases are not accessible and crew members are required to release themselves from the ejection seat in order to obtain maps from their cases.

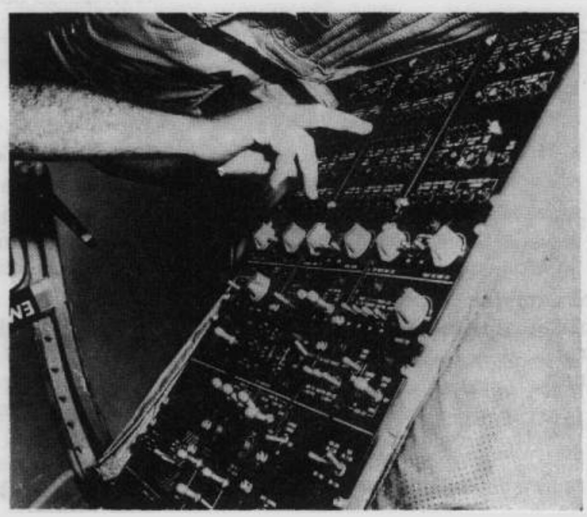
In Figure 31-4(B), the arm of an average size pilot is shown fully extended toward an overhead panel installation. As shown, he still cannot reach the switches.

Design inadequacies of this nature tend to create safety-of-flight hazards but could be avoided by the designer if he considered more carefully human engineering factors (see Chapter 9).

(11) Make control components accessible for inspection and maintenance. Make actuators accessible for stroke adjustment and replacement of motor brushes. Temperature setting adjustments on thermostatic controls should be readily accessible and test points required for checking waveforms, voltages, hydraulic and gas pressures, etc., should be readily available and iden-



(A) MAP CASE INSTALLATION IS NOT ACCESSIBLE DURING FLIGHT



(B) OVERHEAD PANEL MOUNTING IN THIS AIRCRAFT IS BEYOND REACH OF AVERAGE SIZE PILOT.

Figure 31-4. Safety-of-Flight Hazards Are Created By These Inaccessible Equipment Installations (Ref. 1)

tified (see also Chapter 9, Section 11, and Chapter 23, Section 111).

31-8.2 PROPULSION SYSTEMS

Ease of accessibility to all parts of the power plant will minimize the time and manpower required for maintenance. The designer should consider the accessibility of all parts for inspection, cleaning, and adjustment. Components which have to be removed for servicing should be removable with a minimum removing of other parts of the power plant, or parts of the aircraft. Not neglecting vulnerability, the layout of these components should be designed so that a maximum number of mechanics will be able to work on the installation with a minimum amount of interference with one another.

Table 31-1 lists the reciprocating engine accessories which should be accessible for inspection, cleaning, and adjustment while installed on the aircraft without removal of the engine, tanks, or important parts of the aircraft structure. The table also lists the accessories which should be accessible for removal or replacement.

Table 31-2 lists the turbine engine accessories which should be accessible for inspection, cleaning, and adjustment while installed on the aircraft without requiring removal of the engine, tanks, or important parts of the aircraft structure. The table also lists the accessories which should be accessible for removal or replacement.

Table 31-2 lists the turbine engine accessories which should be accessible for inspection, cleaning, and adjustment while installed on the aircraft without requiring removal of the engine,

TABLE 31-1. RECIPROCATING ENGINE ACCESSORIES WHICH SHOULD BE ACCESSIBLE FOR INSPECTION, CLEANING, ADJUSTMENT, REMOVAL, AND REPLACEMENT

Inspection, Cleaning and Adjustment	
Magneto breaker points	Carburetor or fuel injection system
Oil pressure relief valve	Carburetor air filters
Oil tank	Suction relief valve
Oil cleaner or strainer	Feathering pump
Fuel tank	Propeller governor
Fuel pressure relief valve	Turbosupercharger
Fuel strainer	Turbosupercharger regulator
Drain valves	Automatic controls
Removal and Replacement	
Spark plugs	Water injection pump
Magneto	Exhaust stacks and collector
Starter	Flame damper
Generator	Exhaust gas heat exchanger
Tachometer generator	Turbosupercharger
High tension wiring	Turbosupercharger regulator
Radio shielding	Intercooler
Temperature control actuator	Automatic engine controls
Temperature control actuator motor brushes	Suction relief valve
Oil tanks, not integral	Vacuum pump
Oil cleaner or strainer	Hydraulic pump
Oil pump	Deicing pump
Oil pressure relief valve	Accessory gear drive
Oil booster pump	Cabin supercharger (mechanical)
Fuel pump	Fuel injection pumps
Fuel booster pump	Fluid shutoff valves
Fuel strainer	Oil cooler
Carburetor fuel strainer	Oil cooler control valve
Carburetor or fuel injection system	Fuel injection control
Carburetor air filter	

TABLE 31-2. TURBINE ENGINE ACCESSORIES WHICH SHOULD BE ACCESSIBLE FOR INSPECTION, CLEANING, ADJUSTMENT, REMOVAL, AND REPLACEMENT

Inspection, Cleaning, and Adjustment	
Main fuel control	Variable nozzle area unit and control
Starting fuel control	Oil pressure relief valves
Emergency fuel control	Oil tank
Governor (speed)	Oil cleaner or strainer
Suction relief valve	Fuel filter
Actuator motor brushes	Fuel pressure relief valve
Automatic controls	Fuel nozzle
Sump plugs and drain valves	Barometric unit (fuel control)
Spark plugs	Control valve (idling speed)
Removal and Replacement	
Oil cleaner or strainer	Spark plugs
Oil pump	Ignition coil
Oil pressure relief valve	Starter
Oil cooler	Generator
Oil temperature control valve	Tachometer generator
Booster pump	High tension wiring
Fuel pump	Radio shielding
Fuel strainer	Temperature control actuator
Fuel regulator unit or control unit	Temperature control actuator motor brushes
Fuel nozzle	Oil tanks (not integral)
Drip valve	Suction relief valve
Flow divider (fuel system)	Vacuum pump
Pressure bypass valve (fuel system)	Hydraulic pump
Main fuel control	Accessory gear drive
Starting fuel control	Air filter (bearing cooling)
Emergency fuel control	Air filter (vents)
Thermal unit (fuel system)	Tailpipe (extension)
Barometric unit (fuel control)	Reducer (variable nozzle area)
Water tank or thrust augmentation fluid tank	Governor (RPM)
Automatic engine controls	Oil shutoff valve
	Drain valves

tanks, or important parts of the aircraft structure. The accessories which should be readily removable and replaceable without removing the engine, tanks, or important parts of the aircraft structure are also given. The accessories listed in Tables 31-1 and 31-2 should be designed or arranged so that only tools normally found in the mechanic's tool kit are necessary for performing the required work.

Additional accessibility design recommendations for propulsion systems are as follows:

(1) Provide access to engine parts and accessories without necessitating the removal of the ring cowling.

(2) Provide large, quick-opening access doors and sufficient space in the engine accessory area for servicing and replacement of components.

(3) Hinge aircraft skin, where possible, for ease of access to engine maintenance tasks.

(4) Use split-line design whenever possible for maximum accessibility to engine components. For example, split the compressor and combustion chamber housings for easy inspection, servicing, or removal of blades and cannular chambers.

(5) Design engine rail brackets as a part of the main chassis to facilitate removal of the engine.

(6) Design engine mounting in normal installations, e.g., when the engine is installed in the nose or in the nacelle, so that the mount,

complete with cowling, is readily detachable.

(7) To facilitate quick power plant change, use self-aligning mounting bolts employing ball-and-socket or tapered ends. However, this type of fastener should be used only where stress requirements permit.

(8) For maximum access, mount the accessory gear drives and their related accessories in the bottom or 6-o'clock engine position along the compressor section. Present aircraft design makes this the most generally accessible position.

(9) Mount engine accessories so they are accessible for inspection, cleaning, adjustment, or removal without removal of the engine or other important power plant structures.

(10) Design the power plant installation so that all daily and preflight inspections can be made in cold weather when the operator is wearing heavy gloves and body clothing. In particular, provide proper accessibility to fuel and oil drains.

(11) Provide an opening in the engine cowling for ground heaters, with either an accessory door having a minimum diameter of 12 in., or an easily removable section of cowling of equivalent size. Locate the door or opening so that it may be used for conveniently servicing oil and fuel drains. Consider the grouping of the drains, especially the main oil and oil tank sump drains, with respect to the accessory door opening. Stencil the accessory door or cowling section "OPEN FOR GROUND HEATER DUCT."

(12) In turbine powered aircraft, adequate provisions should be incorporated in the aircraft's cooling system and structure for the rapid inspection, repair, and replacement of the tailpipe, flexible coupling, and all components of the system, such as ejector shroud, insulation blanket, cooling air shutters, diverters, and controls. If the system design incorporates an ejector shroud, it should be fabricated or assembled on the tailpipe so that it is removable with this unit.

(13) Design the turbine with removable housing so that the rotor blades are visible, making inspection of every blade possible by rotation of the turbine wheel.

(14) Mount turbine stator and rotor blades so they can be removed and installed individually by hand (see Figure 31-5). If it is necessary to change a blade, the retaining plate is unscrewed and blades are slipped out by hand until the damaged blade is reached. A new blade is slid in, the undamaged blades are reinserted, and the retaining plate is replaced.

31-8.3 LANDING GEARS

Consider the following accessibility recommendations in the design of landing gears:

(1) Design all units of the alighting gear to be accessible for lubrication, servicing, inspection, and replacements.

(2) Design all hydraulic mechanisms so that their filler plugs, bleeder plugs, and air valves may be readily serviced with air and fluid.

(3) Provide sufficient clearance between the shock absorber packing gland nut and adjacent parts of the aircraft when the shock absorber is fully deflated, so that the nut may be readily adjusted with a wrench.

(4) Design so that it is possible to determine the extent of inflation of all shock absorber struts without removal of the cowling, or the use of any measuring device other than a scale.

31-8.4 MECHANICAL ITEMS

Consider the following accessibility recommendations in the design of mechanical items:

(1) In view of the possible necessity of bear-

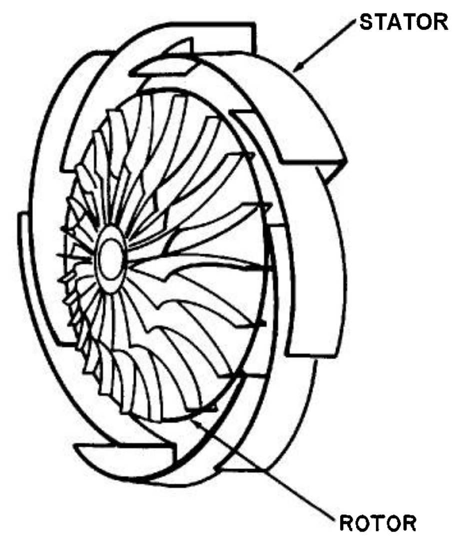


Figure 31-5. Mount Stator and Rotor Blades To Facilitate Removal of Individual Blades (Ref. 21

ing replacement and changing the lubricant to suit widely varying temperatures and conditions at which certain aircraft may operate, provide the greatest possible accessibility to facilitate either removal of the bearing for bench relubrication or purging and relubrication in the aircraft (see also Chapter **22).**

(2) In using split bearings, optimize accessibility by making the plane of the split of the bearing correspond with access ports. For example, split the crankshaft bearing on an engine connecting rod to permit bearing removal through an external access without necessity of removing the crankcase cover.

(3) To permit bearing change without disassembly of the entire component, mount two bearings in tandem rather than a single bearing of larger size. This will permit changing one bearing at a time while the other bearing supports the load.

(4) Where accesses are located over dangerous mechanical components which can cause serious injury, design the access door so that it turns on an internal light automatically when opened. Also provide a high visibility warning label on the access door.

31-8.4.1 Drawer-Type Housings

The accessibility of such assemblies as instrument panels and electrical and hydraulic units can be facilitated by the use of drawer-type housings. Basically, a whole unit is made up of a housing consisting of many cavities. Each cavity contains a component of the whole unit, with each component serving, so far as practical, a separate portion of the overall system. The overall unit should be mounted on a rugged frame, with the front cover serving also as the control panel for the enclosed components. The frame should be supported by hinges which readily came apart to permit withdrawal of the whole component. Rests, limit stops, guards, and/or retaining devices should be provided as part of the basic chassis to prevent the unit from falling from the aircraft. No special tools should be required to withdraw the component. The front panel of the component should have at least a dust seal to prevent contaminents from entering the cavity in the housing. When ventilation is required to cool the cavity, suitable filters should be installed in the ventilating intake and exhaust ducts. Components test points, if required, should terminate at an easily accessible terminal board or strip.

The design of drawer-type housings offers the following desirable maintainability features:

(1) The component may be withdrawn and rapidly calibrated, serviced, inspected, repaired, etc.

(2) The component may be removed completely from the housing, placed on a bench in front of the housing, and with the use of an adapter cable(s), be serviced and maintained with full access to the component.

(3) The component may be taken to a test area and repaired, calibrated, tested, and inspected under ideal conditions.

(4) The component may be replaced with an identical unit from stock, thus facilitating the rapid return of the overall system to an availability status (see also Chapter **23,** Section I).

31-8.4.2 Major Unit Housings

Major unit housings, such as engine nacelles, should have hinged or removable housings which can be opened and closed rapidly to facilitate inspection and repair. The fasteners required to secure the housings should be kept to a minimum and should be adaptable to speed tools, such as speed wrenches and screwdrivers. In addition, an engine nacelle must be a major cleavage unit (see also Paragraph **31-6).**

31-9 HUMAN FACTORS

In Chapter **3,** Paragraph **3-7,** the designer is reminded of his responsibility to try to eliminate design inadequacies which tend toward creating future maintenance problems caused by the familiar Murphy's Law : *"If it is possible to do it wrong, someone will surely do it."* From the maintainability aspect, this means that if an aircraft part can be installed incorrectly, someone will. surely install it that way. Carried one step further, Murphy's Law might **also** state that if an aircraft control is subject to inadvertent and unintentional operation, someone will operate it that way. Due to hazards from malfunction, and in aircraft particularly, the results from doing it wrong are a cause factor in Army aircraft accident frequency and severity (Ref. 1).

31-9.1 SAFETY ENGINEERING

Maintainability features are also safety features. Safety engineering, with its emphasis on human factors, must be introduced in the design stage and not on the flight line after production has been initiated. Expensive retrofit with its subsequent loss of mission capability must be avoided whenever possible, and compromises or trade-offs on design must be carefully considered.

To avoid design inadequacies of this type, it is considered essential that engineers and designers become completely familiar with the functions an aircraft is to perform in its operational environment before the design stage is started. It is also considered essential that "go right or no go" and "work right or no work" concepts be adopted as the uncompromising policy in the design of aircraft components and controls.

The correction of design inadequacies, or Murphies, in present aircraft and the prevention of design inadequacies in future aircraft will require the cooperative efforts of designers, engineers, manufacturers, the military and all who fly or maintain Army aircraft.

31-9.2 EXAMPLES OF MURPHY'S LAW

The following paragraphs present some actual Murphies compiled by the U. S. Army Board for Aviation Accident Research (USABAAR), Fort Rucker, Alabama (Ref. 1). Two categories are depicted: one due to inadvertent installation, the other due to inadvertent and unintentional operation. From these examples, it is clearly evident that the designer can be the real culprit if he ignores his responsibility of designing his equipment to be effectively maintained.

31-9.2.1 Inadvertent Installation

The paragraphs which follow illustrate examples of inadequate designs in current U. S. Army aircraft which are subject to or have resulted in, inadvertent installation by maintenance personnel.

(1) An example of aircraft design subject to reverse installation is the tail rotor pitch change drum cable shown in Figure 31-6. Here, the cable has been wound backwards around the drum, causing reversal of the tail rotor control. Though the cables are color coded to prevent maintenance personnel from reversing the winding, the colors soon wear away. Installations of this nature require more permanent

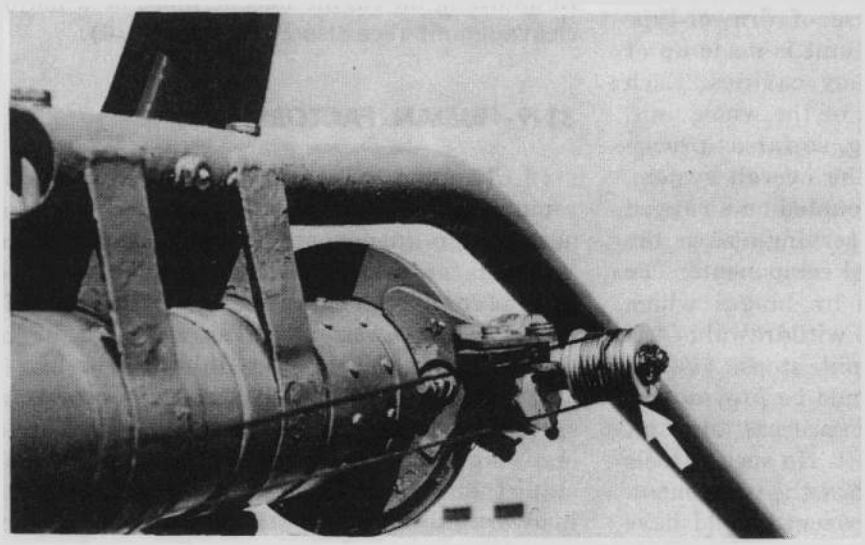


Figure 31-6. Wearing Away of the Color Code Was Responsible for Reverse Winding of This Tail Rofor Pitch Change Drum Cable

types of identification (see also Chapter 13).

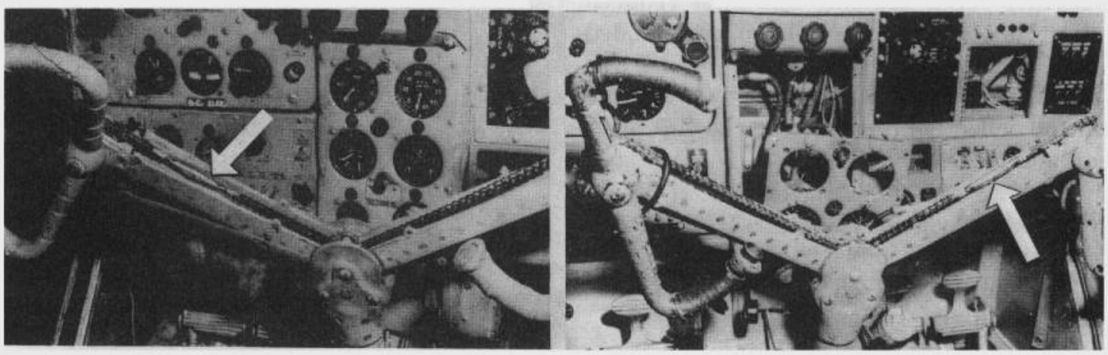
(2) An accident resulting from the reversed installation of the aileron control chains in the control column yoke of an aircraft is shown in Figure 31-7. Color coding the turnbuckles to the correct portion of the yoke could have prevented this accident. This is a good example of the type of design inadequacy which could be corrected by the designer if he used a "go right or no go" design concept.

The aileron control rigging should also be designed so that it is impossible to install it in reverse. Correct and incorrect rigging is shown in Figure 31-8. It is possible to incorrectly rig the cables after maintenance of the control column because the pulley must be removed. This leaves the cables hanging free from the sprockets within the control column. Since the fittings are interchangeable and there is not adequate visual access, the cables can easily be twisted. Twists are not detectable by feel or friction. Suggested design improvements are to provide visual access for aileron control rigging and to provide fairleads for cable guidance.

(3) Another installation which has been subject to reverse installation is the tail rotor whip antenna shown in Figure 31-9. Several helicopters have been damaged as a result of this design inadequacy.

(4) The investigation of a major aircraft accident in which five lives were lost brought out another Murphy-type design inadequacy in the main rotor head assembly (see Figure 31-10). When locking the rotor blade grip horn, the grip horn locking pin can be tightened and safetied, and yet not be completely inserted through the blade grip. In addition, it was found that the blade grip locking pin on this aircraft turned in an opposite direction to lock than that of the bladegrip locking pin on another aircraft. This design inadequacy could have been prevented had the rotor blade grip locking pin ends on both aircraft been painted. Visual inspection would then have indicated if the pin was in the proper position.

(5) This last example describes a mishap to a helicopter which was traced to reverse installation.



CROSSED AILERON FLIGHT CONTROL CABLES

TURNBUCKLE AT LEFT OF YOKE SHOWS REVERSE INSTALLATION

TURNBUCKLE AT RIGHT OF YOKE SHOWS CORRECT INSTALLATION

Figure 31-7. Failure to Color Code Aileron Control Chains Caused This Accident

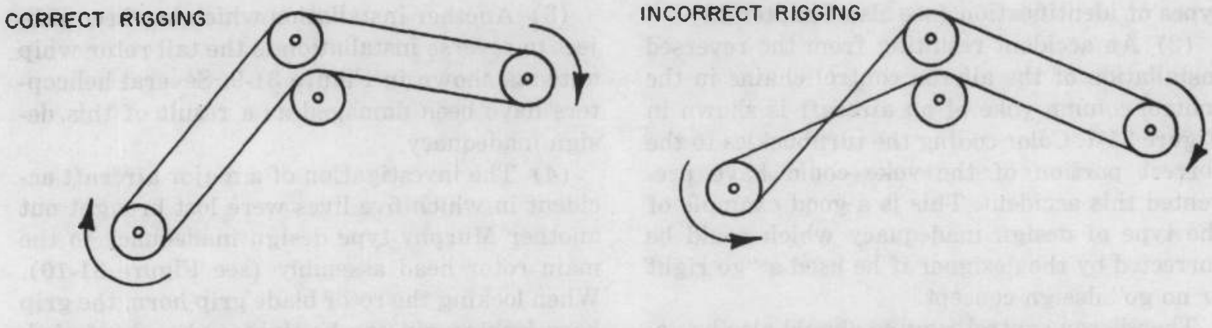


Figure 31-8. Design Aileron Control Rigging So That It Is Impossible To Install It In Reverse (Ref. 2)

A pilot had just landed from a hovering check during a test flight when the collective pitch rose to a full pitch position. His aircraft took off and climbed out of control to 1,200 feet. He turned the hydraulic system off, but it had no apparent effect on the collective. He felt normal feedback through the cyclic.

With three others helping (one standing on the copilot's collective pitch control), the pilot was able to reduce pitch enough to stop the climb and regain partial control. But their combined strength was not enough to reduce the pitch further for a descent. The pilot reduced the power to 6,000 rpm, descended, and landed with power at flight idle. After the engine was shut down, they released the downward pressure on the collective. It moved to the full pitch position and locked.

Only due to the pilot's exceptional flying ability, his knowledge of the aircraft, and quick action on the part of himself and crew, was a $194,000.00 aircraft saved and a catastrophic accident prevented.

The cause of this mishap was due to a Murphy. When the collective boost (hydraulic servo) cylinder assembly was removed from the aircraft, approximately half of the pilot control valve spool end was found broken off. Both ears of the cylinder assembly pivot were also broken and the pivot had slipped out of its normal position. This caused the valve spool to be 0.065 in. higher (thickness of pivot) than normal in the down position. Since normal full travel of the valve spool is approximately 0.080 in., pressure was still ported to move the piston to full up. With boost pressure off, the piston could not be moved down because the valve spool could not be lowered enough to open the return port and allow the fluid below the piston to escape. All down force on the collective pitch stick was re-

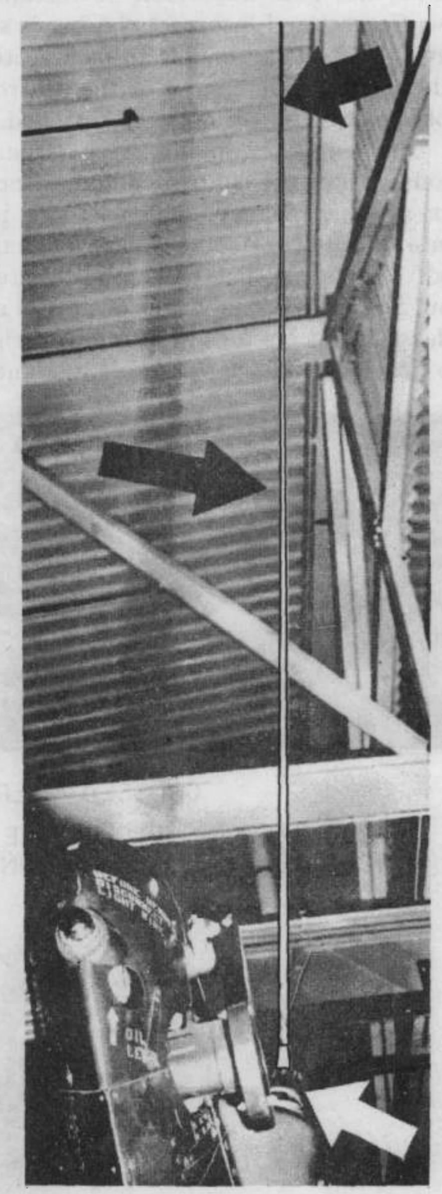


Figure 31-9. Tail Whip Antenna Installation Is Subject to Murphy's Law

sisted by the hydraulic lock of the fluid trapped below the piston.

This condition was caused by a Murphy installation of the cylinder assembly pivot *upside down* (see Figure **31-11**). The function of this pivot is to allow the valve spool to move linearly while the actuating lever moves through an arc. With the pivot upside down, the valve spool will bind in the housing. The drawings show the location of the hydraulic servo cylinder and correct and incorrect installation of the pivot.

31-9.2.2 Inadvertent and Unintentional Operation

In Chapter **9,** Section 11, design recommendations for controls and displays are presented. Some of those recommendations are repeated again here to illustrate more vividly the results of actual designs to the contrary.

(1) *Place identical controls in the same location on all models of the same aircraft.* Figure **31-12** shows the propeller control and throttle levers of different models of the same aircraft placed in opposite positions. These controls are therefore subjected to inadvertent operation by pilots who fly both models. This is a safety-of-flight hazard which could have been eliminated by more careful design consideration.

(2) *Design controls so that their direction of movement is consistent with the controlled object or display.* Figure **31-13** illustrates an aircraft fuel selector switch on an aircraft designed to be turned left for operation from the right tank, and turned right for operation from the left tank. A safety-of-flight hazard can be created by this type of installation. To correct this design inadequacy, the switch panel has to be modified so that the switch turns in the direction of the fuel tank desired.

(3) *Provide detents or catches at discrete control positions to prevent inadvertent movement of controls.* Figure **31-14** shows two examples to the contrary. In Figure 31-14(A), the mixture control levers were originally designed with no detent or catch to prevent inadvertent movement of the levers to the IDLE CUT-OFF position. This design inadequacy had to be corrected by fabricating a detent at the AUTO-LEAN position. In Figure **31-14**(B), design of the power levers made it possible for a pilot to inadvertently move the power levers from the FLIGHT IDLE position through a GROUND IDLE, into propeller reverse.

This has been the suspected cause of several accidents and was considered a contributing factor in at least one fatal accident. The lower portion of the figure illustrates what happened to this aircraft when the power levers were inadvertently moved to the REVERSE position. Incorporation of a more positive "lock" or "indention" on the power lever pedestal would prevent accidental propeller reversals.

(4) *Shape code any controls that are in close proximity so that they can be readily identified.* In one type of aircraft, the hydraulic boost con-

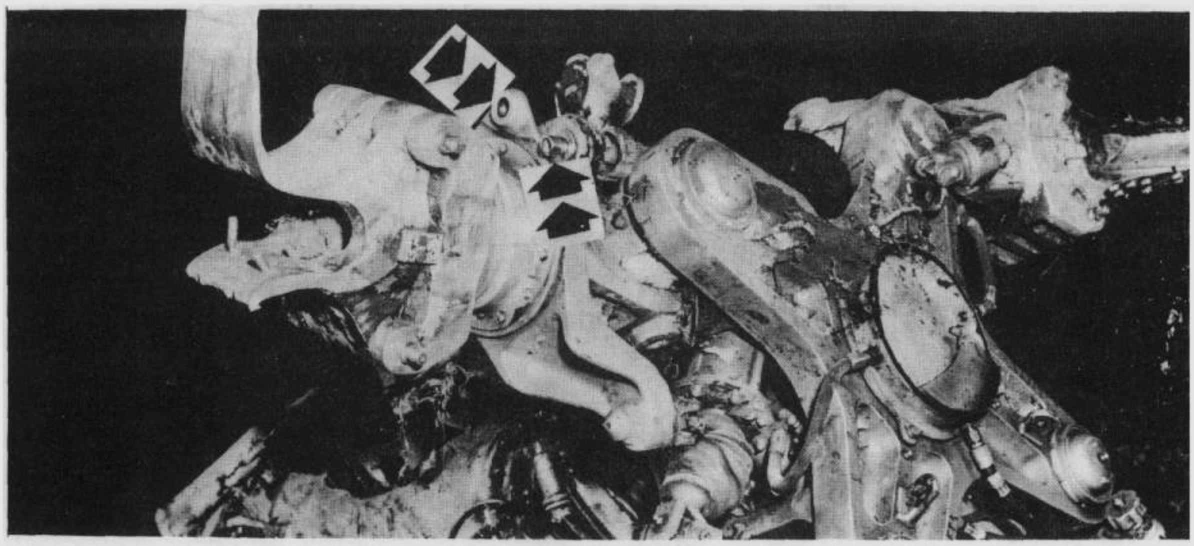


Figure 31-10. Improper Locking Design Caused This Accident

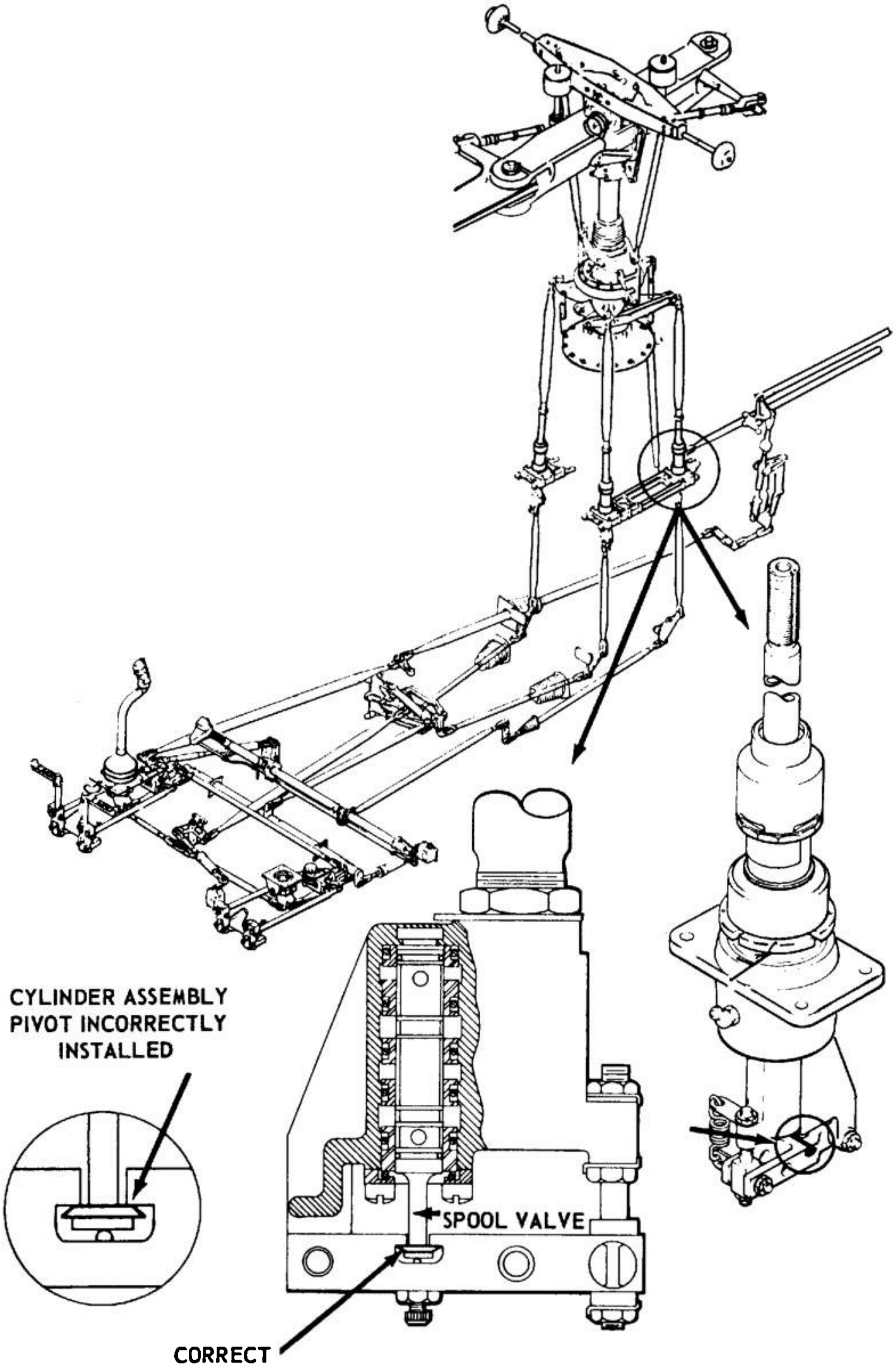


Figure 31-11. Illustration of Murphy Installation in the Hydraulic System of a Helicopter

trol and fuel control switches were originally designed in like shape and placed in very close proximity. This led a pilot to inadvertently switch the fuel control switch to EMERGENCY during takeoff when he attempted to operate the hydraulic boost control. This caused the N2 turbine to exceed **7400** rpm. Figure 31-15 shows the shape of the fuel control switch after modification.

31-10 SAFETY

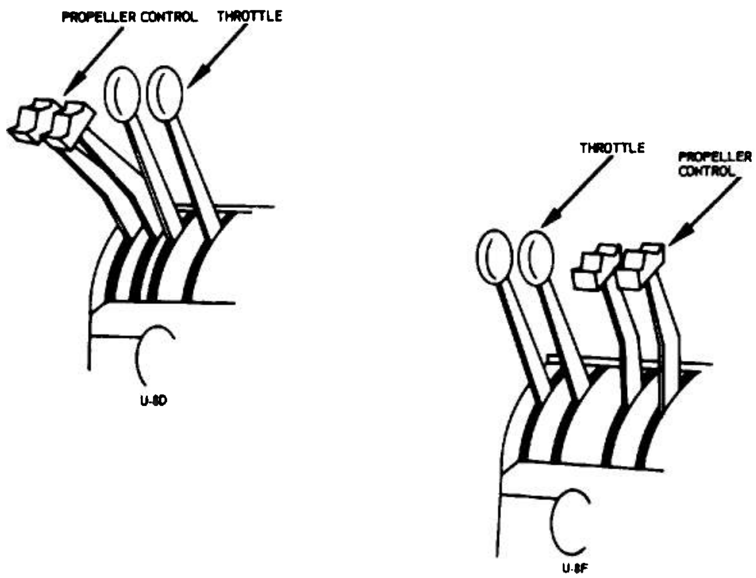
Safety enginering, with special emphasis on human factors, was discussed in Paragraph 31-, 9.1. The design engineer should also incorporate the safety engineering principles pertaining to aircraft systems, associated subsystems, and equipment as specified in MIL-S-58077 (NO). The design of aircraft should incorporate to the maximum extent possible all characteristics and features necessary to protect personnel and equipment from possible harm or damage. Every reasonable effort should be made during the early stages of design to obtain a high degree of inherent safety through the selection of appropriate design features, proven qualified components, and operating principles. Some general safety design recommendations that should be considered are given in the following paragraphs (see also Chapter 15).

31-10.1 SAFETY MARKINGS

Precautionary markings should be provided as necessary to warn personnel of hazardous conditions. Electrical equipment should be marked as required in accordance with Article 510 of the National Electrical Code (see also Chapter **13).**

31-10.2 SAFETY COLOR

The predominant color of equipment attached to aircraft for safety, protective, or emergency purposes should be Insignia Red, Color No. 11136 of FED-STD-595. Safety and protective equipment attached to aircraft on the ground should have streamers conforming to Air Force Drawing 52C1543 securely attached. Streamers must be removed from aircraft before flight.



U-8 THROTTLE QUADRANT

Figure 31-12. Identical Controls in Opposite Locations for Different Models of the Same Aircraft

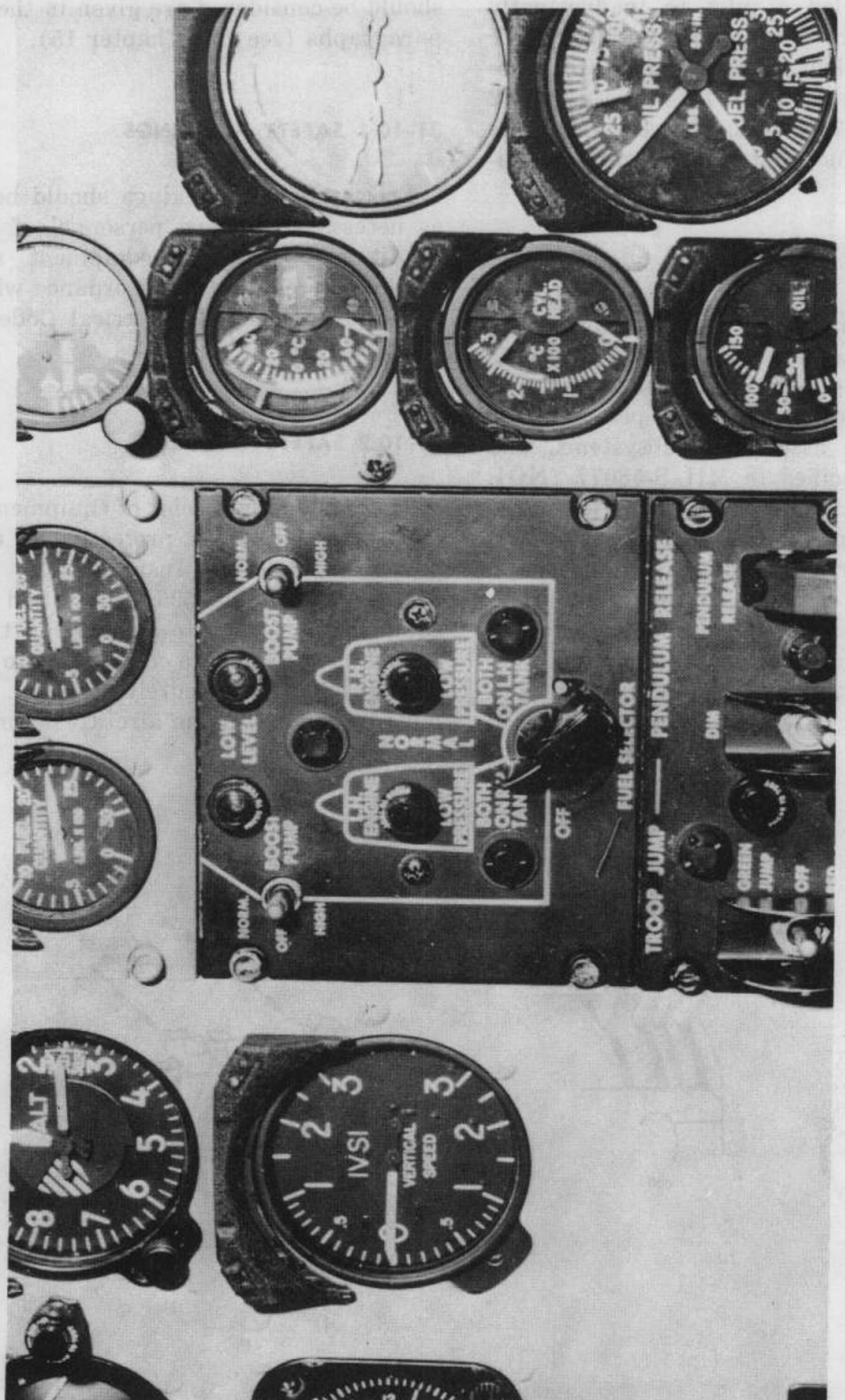
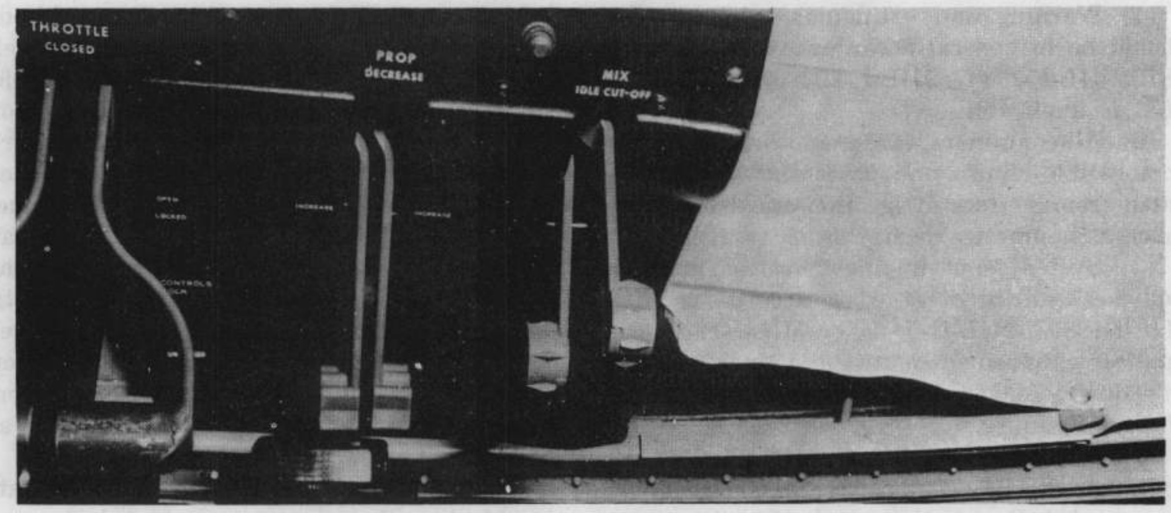


Figure 31-13. Fuel Selector Switch Not Designed To Turn in Direction of Desired Fuel Tank

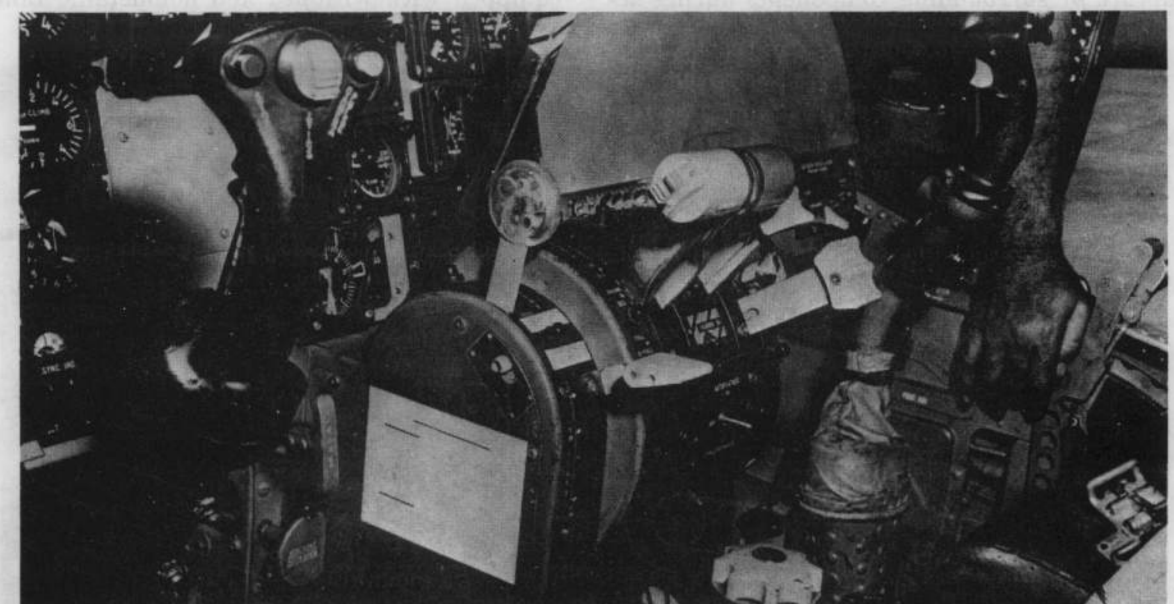
31-10.3 SMOKE, FUMES, AND TOXIC MATERIALS

Equipment should not produce undesirable or dangerous smoke or fumes. If smoke or fumes are unavoidable, proper ventilation must be provided (see also Paragraph 31-17).

Materials which by construction or usage produce toxic effects under any conditions of service or maintenance should not be used without specific written approval from the Procuring Command.



(A) MIXTURE CONTROL LEVERS



(B) PROPELLER REVERSAL

Figure 31-14. Illustrations of Controls Not Designed With Detents or Catches to Prevent Inadvertent Operation

31-10.4 FIRE PREVENTION

The danger to personnel from fire and explosion should be avoided by insuring that hazardous substances are separated or isolated from heat sources. Spark arresters, suitable vents and drains, and other fire prevention methods should be used where necessary. Some design recommendations to be considered in this area are as follows:

(1) Warning and extinguishing equipment should be in general accordance with MIL-F-7872, MILF-23447, MIL-E-22285, and MIL-E-5627, as applicable.

(2) All containers, tanks, and lines carrying combustible liquids and gases should be separated from sources of ignition and isolated as much as is practicable from such sources.

(3) Systems containing combustible gases or liquids should be designed in accordance with MIL-1-18802, MIL-H-5440, or MIL-1-19326, as applicable, to provide minimum vulnerability to fires during flight or ground operation, or to the effects of gunfire.

(4) Adequate structural protection for all containers holding combustible materials should be provided. Design the installations to ensure that the containers will not be susceptible to rupture by surrounding components during accidents, Consider the use of wrapped tanks **or** nonmetallic tanks, where feasible. Wrapped tanks are standard tanks which are wrapped with layers of continuous weave synthetic resin cloth and impregnated with synthetic rubber. Nonmetallic tanks are constructed from layers of synthetic resin impregnated with a suitable resin. This shell is covered with several layers of fiberglass and a synthetic bladder is installed in the shell.

As an example of the seriousness of this design inadequacy fires from ruptured fuel cells occurred in 29 major aircraft accidents in which there were fatalities and burn injuries to more than 40% of the occupants involved. These fires occurred even though the impact forces in these accidents were well within human tolerance. This fire hazard stems from the fact that certain saddle tanks were designed with inadequate protection by the aircraft structure, and the tanks are extremely fragile. Completely exposed, they are susceptible to rupture by various aircraft components (dynamic main rotor components, mounts, fuel line fittings) during accidents.

To devise crash resistant fuel cells, static drop and crash tests were conducted. **As a** result of these tests, it was found that aircraft equipped with wrapped and nonmetallic tanks

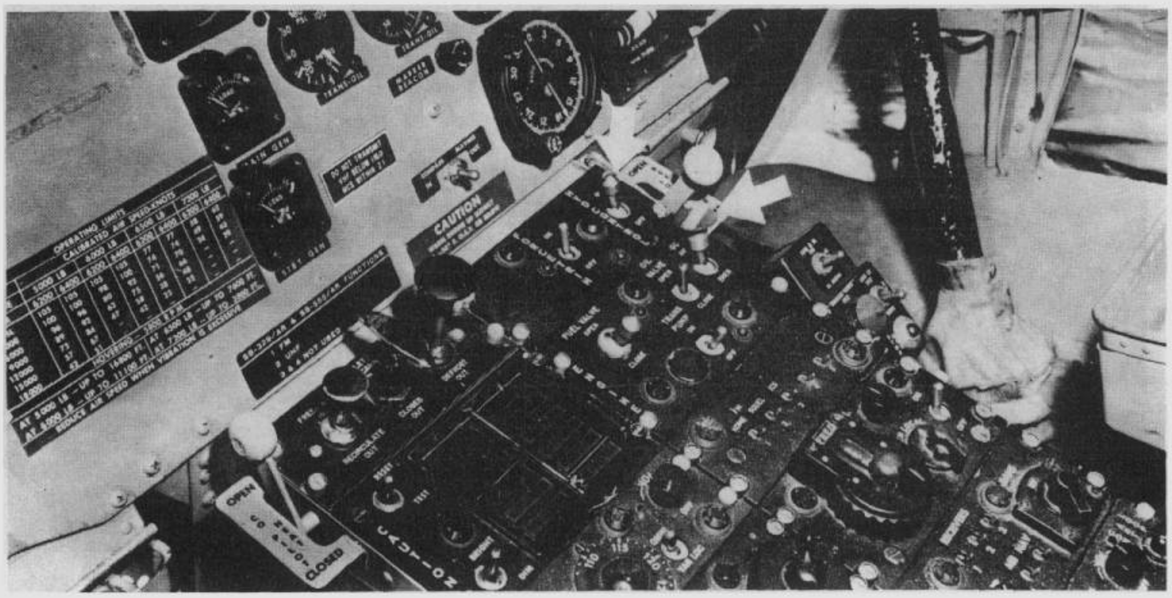


Figure 31-75. Arrow Points to Control That Has Been Shape Coded To Distinguish It from Nearby Control

had much improved crash worthiness over standard tanks (Ref. 5).

(5) The accumulation of combustible liquids and gases in compartments should be prevented. The overboard discharge of combustible liquids and gases, including fuel dumping while in flight, should not, so far as is practicable, result in impingement on any part of the aircraft, or entry of the discharge into the engine intakes. Discharged combustible liquids or gases should not come into contact with exhaust gases while the aircraft undergoes normal maneuvering.

(6) Avoid routing fuel lines through or near areas where potential fire hazards exist. For example, in a certain aircraft the main fuel lines were designed to be routed from the fuel cells, through the rear wheel wells, into the cabins, and to the engines. The lines are rigid aluminum. If major damage should occur to either the rear wheels or wheel assembly, the fuel lines would be broken or ruptured, allowing fuel and fumes to escape. This area is directly below the engines on either side and creates a potential fire hazard (Ref. 1).

(7) Within power plant compartments and other compartments where fires are likely to occur as a result of flammable fluid leakage, all lines and connections carrying combustible fluids should be capable of withstanding 2,000°F flame for a period of five minutes without leakage.

(8) Each propulsion unit, auxiliary power plant, fuel-burning heater, or other combustion equipment installation should be isolated from the crew, combustibles, vital controls, and critical structural parts.

(9) Electrical equipment installed in an environment having explosive vapors should meet the explosion-proof tests (aeronautical) of MIL-E-5272. Wiring should be located in accordance with MIL-W-5088.

(10) Design the location of exhaust outlets so exhaust gases do not come in contact with readily combustible terrain. As an example, Figure 31-16 shows an aircraft which was destroyed by fire resulting from tall grass being ignited by the cabin heater exhaust. This heater exhaust outlet was designed so that it extends from the bottom of the fuselage and directs the exhaust downward. It is also located in close proximity to the fuel cell of the line. The heater exhaust outlet had to be relocated to correct this design inadequacy.

For additional guidance in the protection of aircraft against fires, the following publications should be referred to:

Aircraft Fire Prevention Handbook, NAVAER 00-105E-501.

Mechanism of Start and Development of Aircraft Crash Fires, NACA Report 1133.

Design Manual on Aircraft Fire Prevention for Reciprocating and Gas Turbine Engine Installations, Aircraft Industries Association.

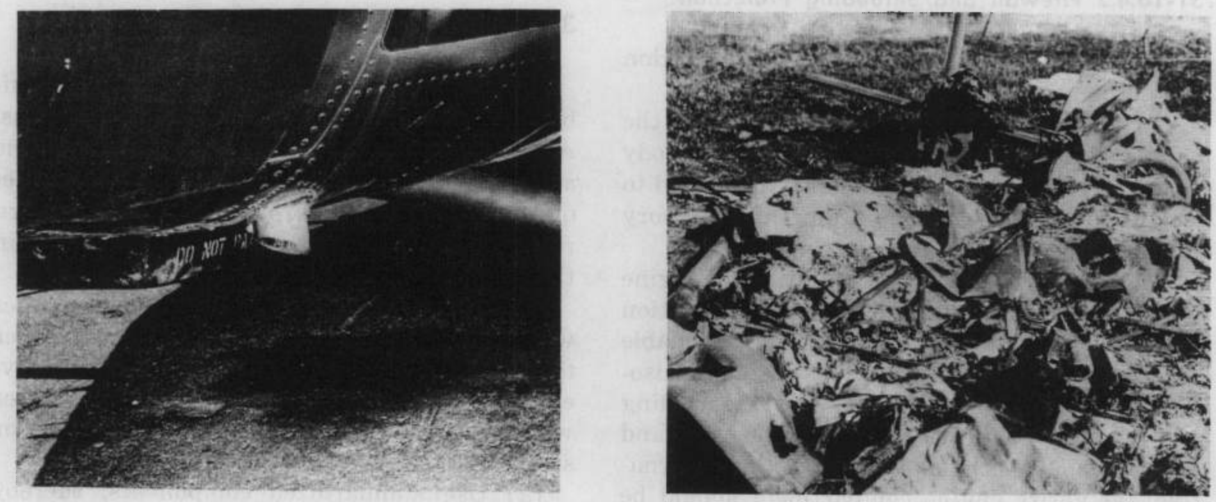


Figure 31-16. Locate Exhaust Outlets To Prevent Potential Combustion of Terrain Features

31-10.4.1 Flammable Fluid Shut-Off

Provision should be made within the aircraft for shutting off or otherwise preventing hazardous quantities of fuel, oil, anti-icing, or other flammable fluids from flowing into, within, or through any power plant, electrical or electronic compartment where ignition sources are normally present. The fluid shut-off should be operable from the cockpit and located outside these compartments unless an otherwise equally high degree of protection is provided. After fluid shut-off has been accomplished, no hazardous quantity of flammable fluid should be able to drain into any of the compartments. Where fluids lines form an integral part of an engine, fluid shut-off need not be provided.

31-10.4.2 Fire Isolation

Spaces or compartments in which leakage of flammables is possible, in which drainage and ventilation of such leakage cannot be practicably obtained, and in which ignition sources cannot be practicably isolated, should be isolated by a firewall or shrouding construction and insulated as necessary to prevent the spread of fire. Such protection should be provided for the crew, the systems containing combustible liquids or gases, vital controls, and critical structural parts.

31-10.4.3 Firewall and Shrouding Protection

In general, firewall and shrouding protection should be provided as follows:

(1) In reciprocating engine installations, the engine should be isolated from the main body of the aircraft, and shrouding should be used to isolate the power sections from the accessory sections.

(2) In turboengine installations, engine parts that are hot enough to become ignition sources should be located away from flammable sources whenever practical. This method of isolation, however, necessitates separate cooling and draining facilities on the combustible and ignition sides of the shrouding. As an alternative, the entire engine compartment should be shrouded to provide, essentially, a cylindrical firewall. In this case, shut-off valves should be provided to isolate all flammable fluids having a source outside the engine compartment.

(3) In multiengine installations, the engines should be isolated from each other. For multiple power section engines, however, isolation between power sections is not required.

(4) Isolate the exhaust system from all combustible fluids and vapors by means of a stainless steel shroud. Locate engine breathers, drains, vents, and similar items so that they will not discharge into or near any part of the exhaust system or turbos. Where possible, keep them at least five feet from an exhaust outlet. Never locate them in or upstream of the exhaust wash.

(5) In installations where exhaust gas is piped to areas remote from the engine, locate the piping inside the aircraft in a liquidtight shroud which is ventilated by a source of ram air, one surface of this shroud being the skin of the aircraft. If an exhaust gas outlet must run in the bottom of a nacelle, cover it with a liquid-tight shroud in such a manner that traps will not form between the shroud and the lower skin. Simple drains in this area will not suffice, as trapped flammable fluids might drain directly on or near the exhaust outlet. Examples of good and bad drains near shrouds are shown in Figure 31-17. Turbos located in the top or sides of a nacelle or power plant compartment present fewer fire hazards than those located in the bottom.

31-11 STRUCTURAL DESIGN

The aircraft designer should avoid inaccessible, flexible, and complex structural designs. Avoiding these tends to minimize repair time and reduces the number of jigging points required for repair operations. General design recommendations which should be considered in this area are as follows:

(1) Provide bolts for attaching assemblies which are subject to frequent removal rather than semipermanent attachments utilizing rivets or multiple screws, except in those cases where excessive weight, structural integrity, or stiffness are overriding factors.

(2) Use standardized components, thereby reducing the logistics problem.

(3) Make design studies, during the early

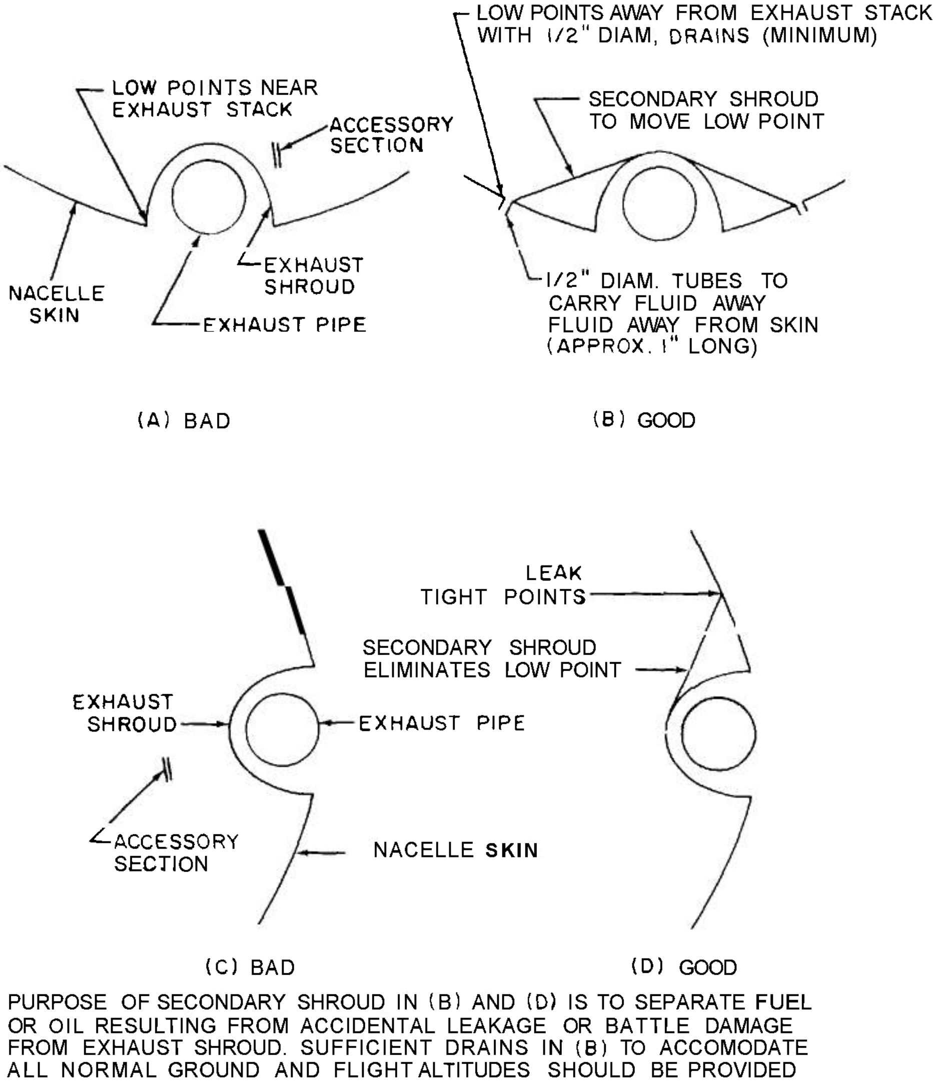


figure 37-17. Shroud Design **(Ref. 6.)**

design stages, of the repair capabilities when new types of structures, such as double skins or sandwich construction, are used.

31-12 MATERIALS AND PROCESSESS

The aircraft designer must give careful consideration to the choice of materials, and should process and fabricate materials by the best methods known. The designer must also consider the maintenance requirements when selecting a material or process to perform a specific function. Procedures should be used which afford the simplest maintenance, after considering the limitations on the use of various materials and processes for primary and other specifically defined structures. The factors which determine the suitability of materials for use in aircraft structures are listed in order of importance in the following paragraphs.

Homogeneity. Select materials that are consistent and uniform with regard to their physical and chemical properties.

Weight. Materials for aircraft construction vary considerably in density, and in the relation of mechanical properties to density. Materials should be selected which have the highest feasible strength-to-weight ratio, after considering such factors as cost, procurability, ease of fabrication, maintainability, and structural characteristics, such as stiffness and hardness.

Stability. Select materials that are resistant to the effects of environment (corrosion, fungi, moisture, operational temperature extremes, sunlight, ozone, dust, and other atmospheric phenomena) without depending upon protective coatings (see also Chapter 10).

Availability. Select materials whose sources of supply are not readily jeapordized during wartime or other national emergencies.

Heat resistance. Use materials which are stable at the expected operating temperature due to aerodynamic and engine heating. Consider losses due to corrosion resistance and strength which may occur with time. Select the best possible material to meet the requirements imposed.

Fire resistance. Select materials that do not support combustion under normal conditions.

Ease of fabrication and repair. Use materials that are easily fabricated and repairable with a minimum of time and equipment. Select materials which are easily formed or machined, or welded in strong and reliable seams and joints.

Standardization. Standardize materials, sizes, gages, and processes so that inventories and processing of raw materials may be minimized. This is an important factor for expediting field maintenance.

Heat treatment of large assemblies. Do not require heat treatment of large assemblies since facilities for heat treating repaired structures are usually not available in the field.

31-12.1 MATERIAL AND PROCESS SPECIFICATIONS

Materials and processes should be selected from the Department of Defense Index of Specifications and Standards (see Appendix). Materials that must be obtained from sources not listed in the Index of Specifications and Standards should be selected from ANA Bulletin 143 in order of preference. Select the part, assembly, or material specified in **AN,** MS, or **AND** listings or drawings in preference to other materials or processes. Exceptions shall be made only if the use of the specified materials or processes will *seriously* degrade the performance of the commodity. Exceptions should be made only after receiving approval from the pertinent U. S. Army procuring activity.

31-12.2 DISSIMILAR METALS IN CONTACT

The use of dissimilar metals in contact, as defined in MS33586, should be avoided to prevent electrolytic corrosion. The relative location of metals on the electroactivity chart is shown on Table 10-4. When two dissimilar metals are in contact, the metal nearer the top of the chart will act as the anode in the presence of an electrolyte, The material listed below it on the table will be protected. The further apart two metals are on the table, the greater is the electric potential between them, and the faster will be the rate of corrosion, other factors being equal. Certain metals form a closely adhering, impervious layer of oxide which slows and finally stops oxidation. Pure aluminum, certain aluminum alloys, stainless steels, and titanium display this phenomenon. Cadmium or zinc plate on brass, copper, and steel reduce the voltage of the couple formed with aluminum and magnesium alloys, thus reducing the tendency for corrosion. Certain aluminum alloys perform better than the more common ones when in contact with the magnesium alloys such as 52S, 53S, 56S, and 61S. Use these alloys when forming a couple with other aluminum alloys, steel, etc. (see also Chapter 10, Section 11).

31-12.2.1 Metallic Parts

Make all metal parts of corrosion resistant material or protect them from corrosion by suitable coatings. Metal parts of their coatings must satisfactorily pass the corrosion tests provided in Specification QQ-M-151. Do not use protective coatings and finishes which will chip, crack, scale, or adversely affect the fatigue resistant properties of the part under operating conditions.

31-12.2.2 Nonmetallic Parts

Suitably protect all parts subject to deterioration as a result of contamination by oil, grease, or gasoline which may be encountered in the normal operation.

31-12.3 MOISTURE, FUNGUS, AND CORROSION RESISTANCE

Materials should be selected for their noncorrosive and nonhygroscopic characteristics, and their ability to resist the effects of corrosion, moisture and fungus. Preference should be given to materials which inhibit fungus growth rather than to materials which include a fungicide, or have received surface fungistatic or fungicidal treatment. Listings of acceptable moisture, fungus, and corrosion resistant materials are contained in MIL-E-5400 and MIL-E-16400 (see also Chapter 10, Section II).

31-12.4 FLEXIBLE MATERIALS

Materials having rubberlike characteristics used for window seals, vibration joint parts, etc., should be made of suitable synthetic materials. All materials used for these purposes should be resistant to at least water, oil, gasoline, steam (from hose), saltwater, sun check, and drying. Specifically, the material selected should be suitable for any environmental or operational service conditions required of the aircraft as specified in the Qualitative Materiel Requirement.

31-12.5 STRENGTH FACTORS

In the design of aircraft, strength factors should be incorporated which are generous and which will meet *unusual* or *extreme* conditions. For example: Can the aircraft wing withstand the violent turbulence of a cold front? Are aircraft structural members designed to withstand survivable impact loads? Will materials selected stand up under excessive wear?

Illustrations of the last two tenets are shown in Figures 31-18 and 31-19. In Figure 31-18, the roof of an aircraft is shown collapsed after a survivable impact load. Here, a design deficiency exists in the cabin roof support column. as the metal gage of the support is inadequate to prevent roof collapse during all survivable impact loads. To correct design inadequacies of this nature, additional support should be given to the roof structures to prevent collapse. Consideration should also be given to incorporating a "roll bar," and to extend the crew seat backs to support any roof collapse and prevent impingement of occupants. In Figure 31-19, the landing gear retraction lever shown was originally designed from an aluminum alloy material Three cases were reported in which these levers failed in flight from excessive wear. The aluminum alloy landing gear levers had to be replaced with steel levers to correct this design deficiency. The figure shows the failed aluminum alloy lever and replacement steel lever.

In answer to these questions, the problems and answers are without end, but the principle remains unchanged.

Whenever possible, factors of safety should be *high* enough to obtain the lowest *normal* practical stress loading, consistent with the performance, efficiency, and expected type of service. This does not mean, however, that over-

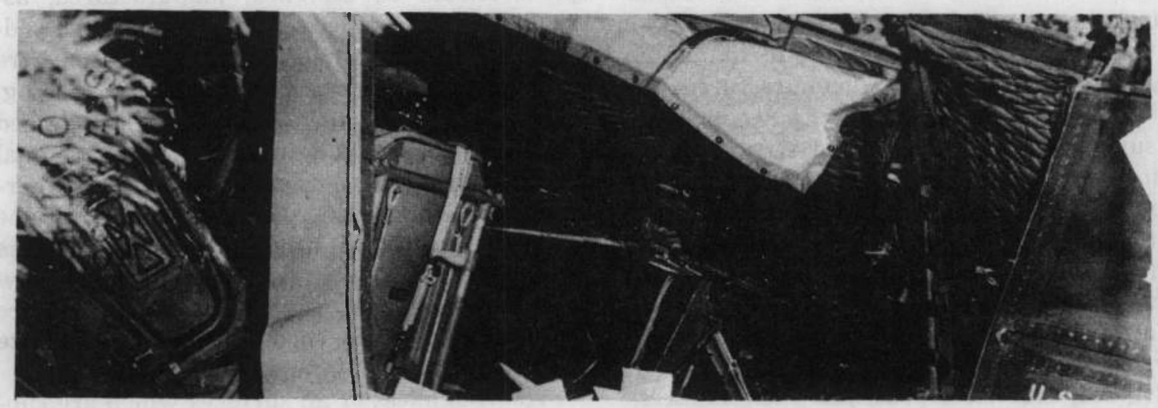
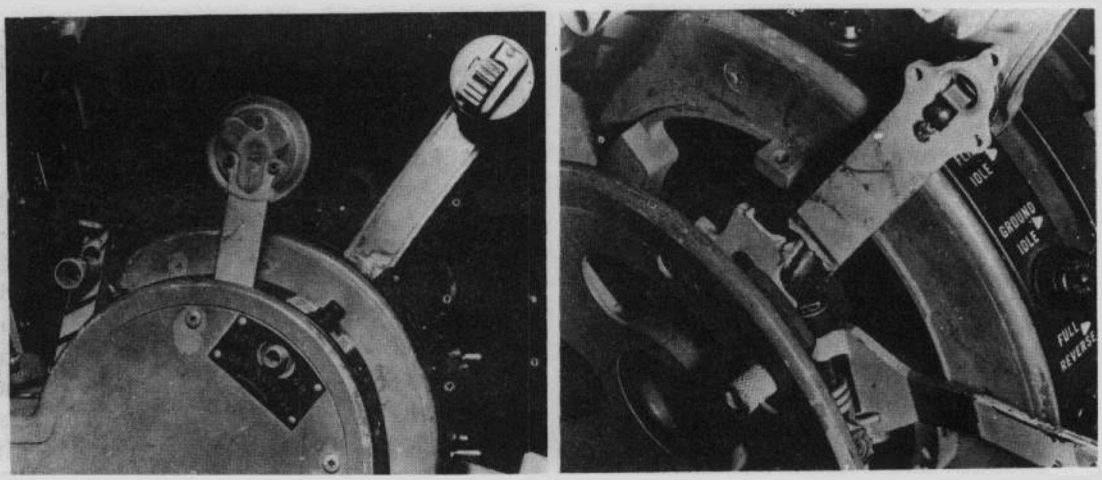


Figure 31-18. Provide Sufficient Support To Prevent Structural Failure During Survivable Impact Loads (Ref. 1)



LANDING GEAR LEVER FAILED IN FLIGHT DUE TO EXCESSIVE WEAR

Figure 31-19. Select Materials To Resist Excessive Wear (Ref. 1)

design should be required to the extent that materials would be wasted or extra weight added. As a guide in this area, the strength properties of metals given in MIL-HDBK-5 (Ref. 7) and ANC-5 (Ref. 8) should be used to the maximum extent possible.

31-12.6 STRESS CORROSION FACTORS

Particular attention should be given to the requirements of optimum heat treatment procedures, corrosion protection , and finish to minimize the hazard of stress corrosion and hydrogen embrittlement damage. To prevent premature structural failures caused by stress corrosion and hydrogen embrittlement, all aircraft parts and components, constructed either of steels heat-treated to tensile strengths above 220,000 psi, or bare high strength aluminum alloys, should be designed, manufactured, assembled and installed so that sustained or residual surface tensile stresses and stress concentrations are minimized. The use of press or shrink fits, taper pins, clevis joints in which the tightening of the bolt imposes a bending load on the female lugs, and straightening or assembly operations which result in sustained or residual surface tensile stresses should be avoided wherever practicable. Where such practices cannot be avoided, corrective practices, such as stress relief heat treatments, optimum grain flow orientation, shot peening, or similar surface working should be used to minimize the hazard of stress corrosion or hydrogen embrittlement damage. In no case should sustained or residual surface tensile stresses in these materials exceed the following:

(1) 50% of the material specification yield strength in the longitudinal grain flow direction.

(2) 35% of the minimum yield strength in long transverse direction.

(3) 25% of the minimum yield strength in the short transverse direction.

31-12.7 FATIGUS FACTORS

To prevent premature structural failures caused by repeated loads, all critical aircraft parts should be designed, manufactured, assembled, and installed so that sustained or residual tensile stresses and stress concentrations are minimized. Practices such as cold straightening, cold forming, and the assembly of mismatched surfaces which result in sustained or residual surface tensile stresses should be avoided wherever practical. Where such practices cannot be avoided, corrective practices, such as stress stress relief heat treatment, optimum grain-flow orientation, shot peening, or similar surface working techniques, should be used to minimize premature fatigue failure.

The roughness of all surfaces which are subject to repeated stresses, the tension component of which is 50% or higher of the material speci-

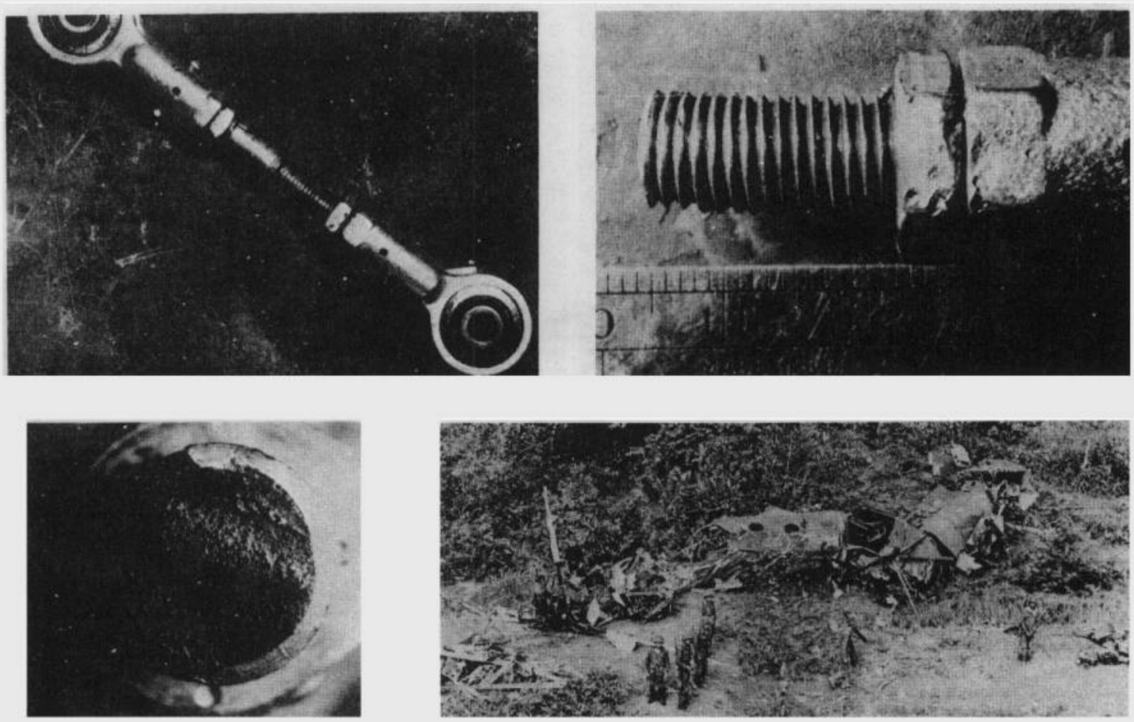


Figure 31-20. Design and Location of This Link Assembly Made It Susceptible to Side Loads and Bending During Maintenance (Ref. 1)

fication minimum yield strength using applicable stress concentration factors, should not exceed 63 rms, as defined in MIL-STD-10. In addition, there should be no flaws, such as tool marks, deeper than 0.0001 in. if the lay of the tool marks is normal to the direction of the principal tension stress. If the lay of the tool marks is parallel to the direction of the principal tension stress, the maximum surface roughness should not exceed 125 rms.

The following two recommendations are presented to point up some design inadequacies in this area.

(1) Avoid component or equipment designs that may be susceptible to adverse strain or load during maintenance operations. For example, Figure 31-20 shows an aircraft which failed, killing seven ocupants as a result of fatigue failure of a flight control push-pull link assembly. Inspection of other aircraft revealed more than 20 such links were also defective. The design of this link assembly and its location made it susceptible to side loads and bending during maintenance. Corrective action for this design inadequacy was a newly designed link assembly of greater strength.

(2) Do not require the drilling of holes in shafts, rods, tubes, etc., which could cause eventual weakening or failure of the component. It should not be necessary, for example, to drill and weaken control rods. The results of just such a failure are shown in Figure 31-21. This accident was caused by a control rod that was designed with a cotter pin hole in addition to a jam nut. This weakened the rod and caused its failure. To correct this design inadequacy, it was recommended that the rod be safetied with only a safety lock (jam nut).

31-13 PROPELLERS AND SPINNERS

The aircraft designer should incorporate quick-disconnect features in the propeller control harness to reduce to a minimum propeller removal and installation time. In turboprop applications, these maintainability features should be designed so that propeller removal and installation will allow a complete power plant (engine and propeller) change in not more than 30 minutes.

Figure 31-21. Drilled Hole Weakened Control Rod and Caused This Accident (Ref. 1)

Where propeller spinners are used, they must meet the requirements of MIL-P-5450. Design features should also be incorporated which will enable a sufficient portion of the spinner to be removed in not more than one minute to allow the propeller to be removed from the engine. In turboprop applications, ensure that the fasteners used to attach the spinner to the propeller cannot be inadvertently lost into the engine induction systems during maintenance work.

31-14 HANDGRIPS AND STEPS

Handgrips and steps should be provided wherever necessary for the use of pilot, crew, and servicing personnel. Grips may consist of folding or telescoping elements which are normally secured and concealed in, or are flush with, the surfaces of wings and bodies when not in use. Make them available for use without recourse to tools, and design them so they do not present a possible hazard during emergency parachute jumps. For those aircraft surfaces subject to damage from the weight of personnel, provide prominent warning labels, such as "WARNING—NO STEP."

31-15 GROUND HANDLING

The designer should consider all possible provisions, consistent with required flight characteristics, to facilitate ground handling, servicing, and general maintenance. Adequate facilities should be provided for towing, jacking, hoisting, and mooring in conformity with applicable specifications (see also Chapter 26).

31-16 CHAFING PROTECTION

At points where chafing protection is required, such as structures rubbed by moving doors, between cowling pieces, and similar applications, the designer should consider the use of waterproof fabric, canvas webbing, synthetic rubber, or suitable plastic materials. Do not use rawhide, leather, and other materials that may promote corrosion when in contact with cable or metallic surfaces. Where tie rods or cables make contact at a crossing, separate them by nonhygroscopic and noncorroding material. If tape is used, attach it to only one of the members in order to permit the initial tension to be tested.

31-17 VENTILATION

The designer should provide adequate ventilation for the following areas:

(1) All enclosed engine, fuel, and fuel line compartments to prevent the accumulation of poisonous gases and explosive mixtures.

(2) All bomb bays where, due to battle damage or other reasons, vapors may accumulate. Preferably use a controllable ventilator.

(3) Enclosed portions of the aircraft, such as floats, wings, control surfaces, and unpressurized tanks, to ensure rapid equalization of pressure between the interior and the exterior during normally rapid changes of altitude.

(4) Crew compartments.

Sufficient ventilation should also be provided to equipment which, when operating continuously at full power and at the maximum specified operating ambient temperature, will not reach temperatures that will tend to damage the equipment or reduce its useful life. No exposed equipment should, under any operating conditions, be allowed to reach temperatures hazardous to personnel, and no personnel should be subjected to the direct drafts of ventilation exhausts. The use of forced air is permitted through renewable, replaceable, or cleanable dust filters.

31-18 CLEANING

The exterior surface of aircraft parts, components, assemblies, etc., subject to direct contact of contaminants such as dirt, oil, salt water, sand, nonvolatile fuels, etc. should be capable of being steam cleaned whenever possible. The housings of delicate equipment, particularly, should be designed to close tightly to ensure that steam cleaning of the housing will not damage the interior components (see also Chapter 16).

31-19 WEIGHT OF EQUIPMENT

Equipment should be designed to have the minimum weight possible, compatible with the economics, performance, operation, life, reliability, serviceability, and strength requirements specified in applicable specifications. Items subject to salvage or movement by helicopter should be limited to 10 tons maximum weight per maximum major cleavage unit (see Paragraph 31-6).

31-20 MECHANICAL PARTS AND COMPONENTS

The paragraphs which follow present some maintainability design criteria for mechanical features.

31-20.1 BEARINGS

Refer to Chapter 22 for general maintainability design recommendations relating to bearings.

31-20.2 BEARING SEALS

Seals used to retain lubricants in bearing housings having protruding, rotating, and sliding shafts and axles should be given specific and special consideration in the design of equipment. Some of these considerations are:

(1) Seals should reflect the highest quality in design and material concurrent with the state of the art for its intended service. **A** cost analysis similar to that described in Chapter **22,** Paragraph **22-5.6,** should be made prior to bearing seal selection.

(2) Seal housing design should provide the optimum of simplicity for replacement of the seals by inexperienced personnel operating in the field. If possible, no special tools, including wheel pullers, should be required to replace bearing seals.

(3) The use of blind fittings and fasteners should be avoided.

(4) Consideration should be given to the use of multiple lipped seals and double and triple seals, each of which is capable of fulfilling the sealing requirements alone.

(5) When design will permit their use, prime consideration should be given to the use of spring-loaded, positive-contact end seals.

(6) Each design should be examined to ensure that the seal will not be damaged by excessive internal pressure. Where the possibility of excessive pressure exists, due to heat expansion of the lubricant or other causes, a relief valve should be installed on the housing and a return line to a sump should be installed, when appropriate.

31-20.3 GEARS

The general design considerations given for bearings (Chapter 22), as regards performance, size, and selection, apply also to gears. Since each gear application is widely affected by such factors as resonance, lubricant temperature, misalignment, tight and loose spots, backlash, face width, etc., test stand or ground tests to determine these factors should be as conclusive as possible prior to release Of the product **for** production. In general, to provide for possible future corrections, every consideration should be given during the basic engineering layout stage to allow for at least a **50%** increase in tooth width over the calculated and tested dimension.

All gear assemblies should be tested and proved satisfactory under simulated service test conditions. The gears should be designed to have a factor of *twice the expected service life* at *twice the maximum expected power loading* (excepting speed) throughout the tests, e.g., 100% increased service life at 100% increased load factor. **As** a general guide line on tooth form, use 20° involute, or greater, to gain tooth strength for protection against heavy, unexpected shocks or overloads.

The use of helical gears (single or double), hypoid, and other relatively resonant free gears is highly encouraged to prevent resonant vibrations from being transmitted to other components, thus creating secondary destruction or other maintenance problems. Helical gears should also be considered in preference to spur-type gears where possible. This is borne out by twenty-two confirmed in-flight failures of spur-type reduction gears in a certain aircraft. Figure 31-22(A) shows the teeth wear pattern just prior to complete failure of the sun gear. Figure 31-22(B) illustrates the complete reduction gear assembly, and Figure' **31-22**(C) indicates what happened to an aircraft when this type of re-

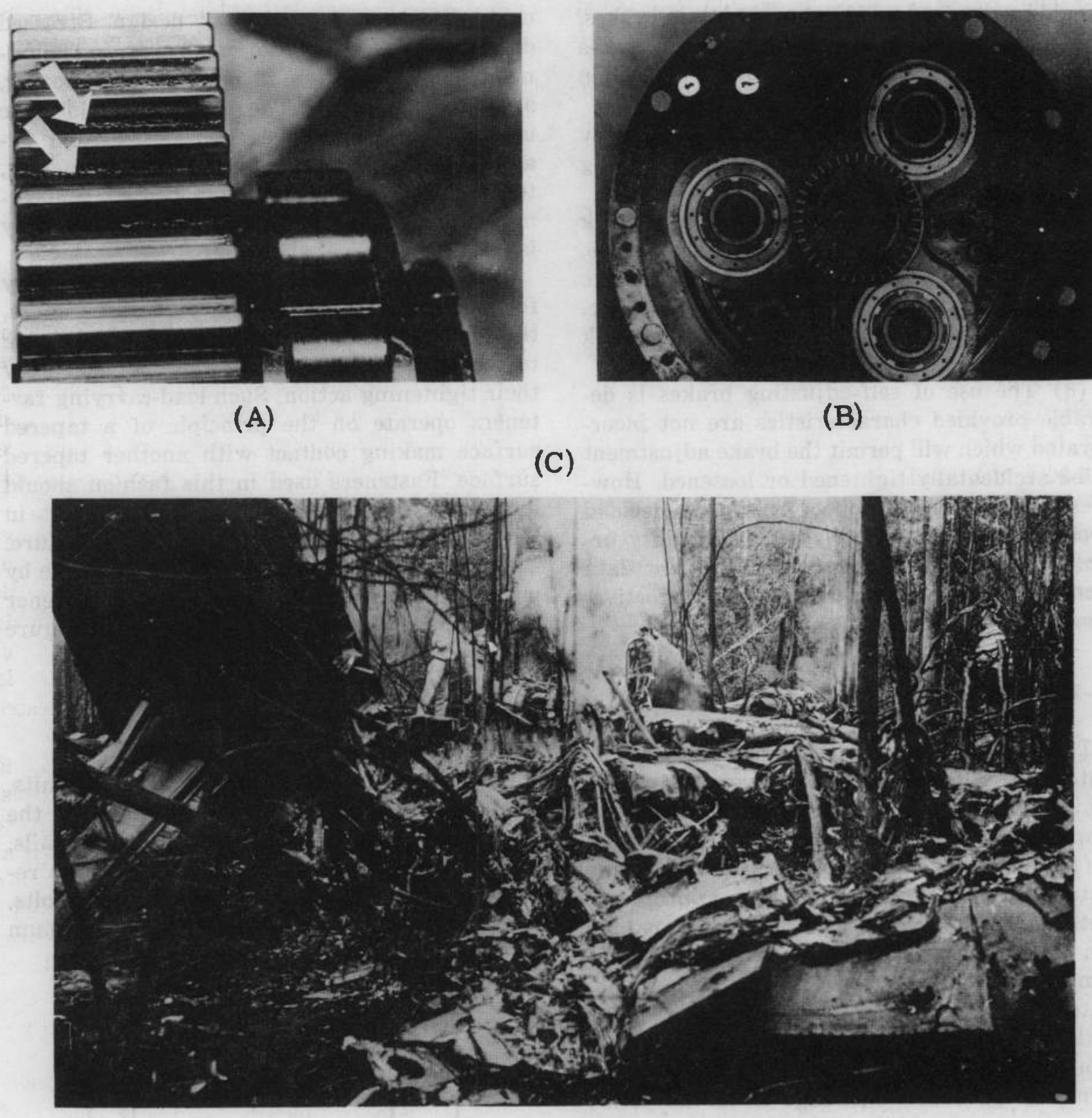


Figure 31-22. Spur-Type Reduction Gear Failure Caused This Accident (Ref. 1)

duction gear failed. It was recognized that the reduction gear had marginal capability and required correction. As a result, the spur-type reduction gear is being replaced with an improved helical gear.

31-20.4 BRAKES

Brakes should be designed as simply as possible to meet the aircraft's operational requirements. Some design features which should be considered are as follows:

(1) All parts of a brake assembly (drums, discs, shoes, cylinders, support plates and housing, mechanisms, etc.) should be readily and easily removable, replaceable, renewable, and reasonably repairable.

(2) Brakes should be adjustable without the need for removal of any part.

(3) No special tools, including wheel pullers,

should be required to adjust or maintain brakes.

(4) Adjustments required to tighten brakes should be clearly marked as to proper rotation or action when operation is not obvious.

(5) Provide an inspection hole, protected by an attachable cover or window, for examining the condition of brake linings.

(6) Design brake drums or discs thick enough so they can be remachined at least twice.

(7) Provide rapid accessibility to such brake operations as filling, bleeding, adjusting, etc. Do not require maintenance personnel to work blindly.

(8) The use of self-adjusting brakes is desirable provided characteristics are not incorporated which will permit the brake adjustment to be accidentally tightened or loosened. However, before self-adjusting brakes are decided upon, the design activity's maintainability organization should require conclusive test data from reliability personnel as to their effectiveness.

31-20.5 CLUTCHES

The general design recommendations for clutches are the same as those given for brakes. Additional features which should be considered however are as follows :

(1) Whenever possible, utilize split-line clutch element design, or other appropriate methods, so that clutch linings, plates, or discs can be rapidly removed or replaced without removal of the prime mover, e.g., engine, associated gear box, etc.

(2) Clutch design, when of the dry type, should provide generous positive slingers designed to prevent oil leakage from the prime mover or gear box from coming in contact with the friction surfaces of the clutch. Well guarded drain holes and baffles should be provided to lead away this oil.

(3) Thrust bearings should be replaceable, without removal of any major part of the equipment, by use of split-line design or other appropriate method.

31-20.6 STRESSED DOORS

The use of stressed access doors, often desired in high performance equipment, is vigorously discouraged in aircraft design. Stressed doors are susceptible to misfitting, misalignment, slow operation in opening and closing, aging, and overloads. The designer should make use of other time-proven methods, as, for example, designs utilizing stiff-corner gusseting, tension or compression diagonal bracing, internal primary structures in which the skin only is used for external shape, etc.

However, when a stressed door is mandatory for performance, or for other pertinent factors, the fasteners used in the design should be able to force the realignment of the door solely by their tightening action. Such load-carrying fasteners operate on the principle of a tapered surface making contact with another tapered surface. Fasteners used in this fashion should have only the captive part of the fasteners in the removable panel or primary structure. These type fasteners should also be operable by power driven tools. An example of a fastener designed for stressed doors is shown in Figure 31-23.

31-20.7 FASTENERS

Fasteners for access doors, panels, units, components, accessories, etc., should be of the quick-release type where possible, e.g., bails, twist-lock type, over-center type, etc. Units requiring non-quick-release fasteners, e.g., bolts, screws, clamps, etc. should have the minimum

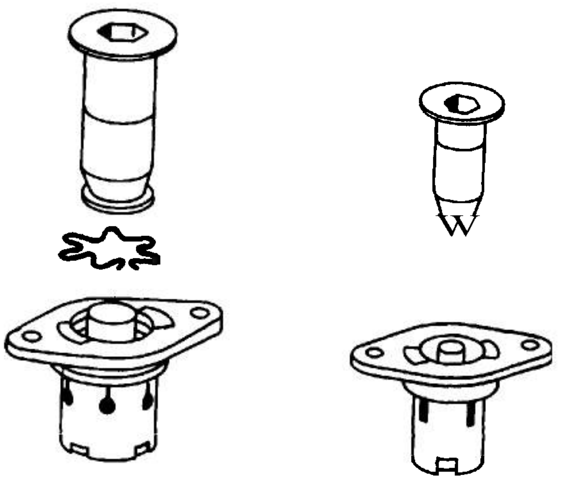


Figure 31-23. Stressed Door Fastener (Courtesy of Camloc Fastener Corp.)

number necessary, be readily accessible and provided with sufficient tool and hand clearance. Military Specification MIL-F-5591 should be used for selecting internal or external panel fasteners (see also Chapter **21**).

31-20.8 LUBRICANTS

The lubrication of aircraft equipment is most important. The best designed equipment, from the standpoint of combat efficiency, performance, maintainability, and reliability, can and does fail completely due to inadequate lubrication. The aircraft designer should therefore follow the following recommendations in this area (see also Chapter **16**) :

(1) Conform to MIL-STD-838 for the lubrication of aircraft, including airframes, engines, accessories, equipment, and components.

(2) Keep the number of different lubricants used on a given aircraft and its components to a minimum consistent with adequate performance. Select aircraft lubricants covered by Federal, Military, or Air Force-Navy Aeronautical Specifications from the list in ANA Bulletin **275.** Table 31-3 lists lubricant specifications, as well as some corrosion preventive compounds, which are applicable to U.S. Army aircraft.

(3) Select lubricants for a specific application on the basis of the following:

(a) Performance or other test requirements of specification covering aircraft, including the airframe, engine accessory, equipment or other components to be lubricated.

(b) Current practice that has been verified by satisfactory operation in the field. Select and apply lubricants in a manner to allow the aircraft, including airframe, engine, accessories, equipment, and other components to meet all requirements of the detail specification affected by lubrication. Give particular attention to whether the part lubricated will be expected to function without further lubrication during its normal overhaul life. If not, make provision for periodic relubrication in the field.

(4) Where a part is to be self lubricated, ensure that satisfactory lubrication is obtained under all climatic and operational conditions which may be encountered. Where the part requires periodic relubrication, select the lubricant and method of application so that the lubrication interval will coincide with regular aircraft preventive maintenance and inspection periods as applicable for preflight, after flight, daily, and specified overhaul periods.

(5) Make the lubricated part readily accessible for lubrication by normal methods.

(6) Specify fittings required for pressure lubrication in accordance with Drawings MS-15001 and **MS15002.**

(7) Design all lubricating oil system parts and all equipment utilizing the oil to function satisfactorily with oil conforming to TB-**AVN-2.**

(8) The use of external lubricating oil lines is discouraged. Use internal oil lines located where they are quickly accessible. When possible, design equipment to use drilled or cast passages instead of oil lines.

(9) In sealed and semilubricated bearings, lubricants should be selected which have optimum state-of-the-art characteristics for protection against deterioration with age. This requirement is particularly important to items liable to long, inactive storage. Whenever possible, the lubricant should be capable of satisfactory service through an ambient temperature range of −67°F to 250°F.

31-21 FUEL, HYDRAULIC, AND PNEUMATIC SYSTEMS

31-21.1 GENERAL DESIGN RECOMMENDATIONS

The following general recommendations should be considered in the design of fuel, hydraulic and pneumatic systems :

(1) Hydraulic systems should conform to **MIL-H-5440,** and hydraulic reservoirs should conform to **MIL-R-5520.** Pneumatic systems should conform to MIL-P-5518. General design criteria in these areas are discussed in Chapter 16 and in Chapter **24,** Paragraph **24-4.**

(2) Mount hydraulic components directly on hydraulic panels and doors to provide optimum access. Locate major components in one or two accessible areas rather than throughout the system.

(3) Mount drain valves on hydraulic reservoirs or tanks so that they may be replaced from outside the tank, eliminating the necessity of reaching inside the tank for valve maintenance (see also Paragraph 31-21.3).

(4) Place hydraulic reservoirs at the highest point in the hydraulic system. This is especially important when bottled air is used for emergency operations of the landing gear in case of hydraulic system failure. It requires considerable maintenance time to purge the air out of the hydraulic lines when the reservoirs are not at the highest point. When they are at the highest point, the aircraft can purge itself by its own operation without requiring the use of test equipment or jacking of the aircraft.

(5) Provide self-sealing fuel, water-alcohol, and oil tanks with an access door of such size that the entire interior of the tank is available for inspection, cleaning, or other maintenance without removing the tank.

(6) Locate the hydraulic reservoir so that it is visually accessible for refilling. If the technician cannot see the fluid level, the hydraulic fluid may overflow and damage nearby components (see also Chapter 16).

(7) Locate tank and reservoir drain valves so that they may be removed from the outside, eliminating the necessity for entering the tank or reservoir to remove or maintain valves (see also Chapter 16).

(8) Design filters to preclude the need for disconnecting pipe fittings in order to drain or replace the filter element. Assure that the filter housing may be easily withdrawn without interference with, or removal of, other components.

(9) Design pumps to be easily and rapidly removable and replaceable with the minimum number of fasteners and piping. Design pump installation so the pump can be removed or replaced without removal of other components.

(10) Design valves to permit the rapid and easy replacement of all internal seats, seals, and packings without removal of the valve body from the system and without removal of the piping to the valve.

(11) Make tanks accessible and easily removable. It should be possible to remove tanks without removing any other part of the aircraft, except cowling or access panels. Disassembly of structural parts should not be required.

(12) Design tank installation so that it should definitely not be necessary to remove the engine or any of its parts prior to removal of the tank.

(13) Provide ample clearance for the removal of sumps or inspection doors or plates.

(14) Provide oil tanks with means to gain access to all corners and sections of the interior when installed in the aircraft so that the inside may be completely cleaned, inspected, and maintained.

(15) Provide self-sealing fuel and water-alcohol tanks with a handhold on top of the tank or cell. Provide covered openings coinciding with the top tank handhold in the aircraft surface so that inspection through the handhold can be accomplished without removing the tank.

(16) Pumps, filters, valves, and similar equipment mounted in and within the envelope of a tank should be readily removable from outside the tank without removing the tank from the aircraft.

31-21.2 TANKS

The design of tanks that are a structural part of the aircraft, such as a wing or fuselage tank, is to be avoided. However, if these structures contain a synthetic rubber bladder liner tank specially designed to fit the cavity, this practice is encouraged. Self-sealing, bullet-proof tanks are also included in this category. When the bladder or self-sealing configuration is used, reasonably rapid means should be provided to repair, remove, or replace these cells when and if they become leaky.

Tanks and reservoirs should not be supported by fittings which are welded, riveted, bolted, or otherwise attached through the liquid barrier (skin, tank, body, etc.). Consideration should be given to the use of chafing strips on all cradles and straps to minimize the vibration transmitted to the tank proper and its internal equipment. The use of tanks for other purposes, such as air ducts, etc., should be discouraged, and flat sides on tanks should be avoided to prevent fatigue cracks. Consider the use of wrapped tanks or metallic tanks as previously discussed in Paragraph 31-10.4.

In the design of fuel tank vent systems, all vent lines should traverse all directions of the fuel tank to minimize the likelihood of post-

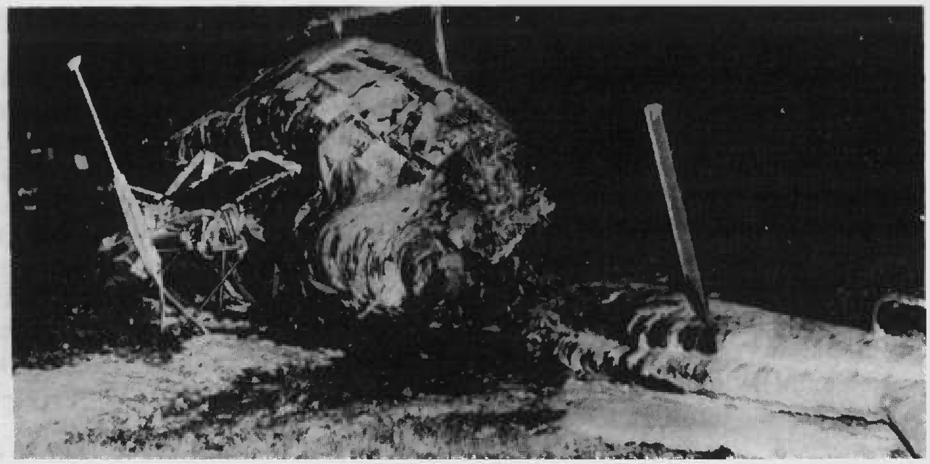


Figure 37-24. Design Vent Lines To Traverse All Directions of a Fuel Tank To Minimize Post-Crash Fires (Ref. 1)

crash fires. In a certain aircraft, for example, the design of the fuel tank vent system is such that when the helicopter comes to rest during an accident on its left side, the fuel in the right fuel tank will drain from the tank. This situation occurred during an accident and resulted in the fire shown in Figure 31-24.

31-21.3 DRAINAGE

Drainage should be provided in wings, bodies, and control surfaces to prevent the collection of unwanted fluids, including water as a result of condensation within the aircraft. The following design recommendations should be considered :

(1) Use drain holes in the skin and limber-holes in bulkheads or stiffeners to permit the unwanted fluids to run to low points when the aircraft is resting in normal position.

(2) Locate drain holes judiciously so that a minimum number is required and a scavenging suction is produced in flight.

(3) Where fabric covering is used, install grommets used for drainage purposes in accordance with MIL-C-5654. Provide all V-type metal trailing edges on wings and control surfaces with drain holes drilled in the tip of the V, in addition to the grommets on lower fabric surfaces.

(4) Seal and dam fuel tank compartments from other portions of the aircraft. In addition, provide adequate drains so that leaking fuel and fumes will be carried overboard at points so as to prevent-a fire hazard. Particularly avoid fuel drainage into or around the engine exhaust system, turbos, bomb bays, and electrical equipment.

(5) Terminate all vent and drain lines at a point outside the aircraft, passing them through resilient grommets in the engine cowling where necessary to prevent chafing. Locate or design them so that drainage cannot be returned to any part of the aircraft structure or enter the exhaust wash from either upstream or downstream.

(6) Make drain lines easily accessible for drainage from the outside of the aircraft. It is sometimes desirable to group a number of drain lines into a common outlet in order to alleviate congestion in the engine compartment and to obtain the most direct and efficient routing of lines. Experience indicates, however, that improper grouping of drain lines may result in fire hazards and increased number of accessory failures. To reduce these hazards the following requirements should be adhered to :

(a) Do not interconnect drain lines for electrical accessories with lines draining fuel, oil, hydraulic fluid, water-alcohol, etc.

(b) Interconnection of two or more electrical accessory drains is permitted.

(c) Other accessory drains may be interconnected provided line sizes are made adequate to insure proper drainage, except where return of one fluid may damage any of the components whose drains are so interconnected.

(d) Routing of a number of drain outlets through a single hole in the aircraft skin is permitted.

(e) Provide adequate ventilation and drainage of all interior areas to prevent the accumulation of toxic or irritating gases, liquids, and explosive mixtures.

(f) Consider the use of chordwise drip fences. These will prevent spanwise gravity fuel flow from crash-ruptured tanks to engine nacelles by wetting conduction on the lower surface of wings.

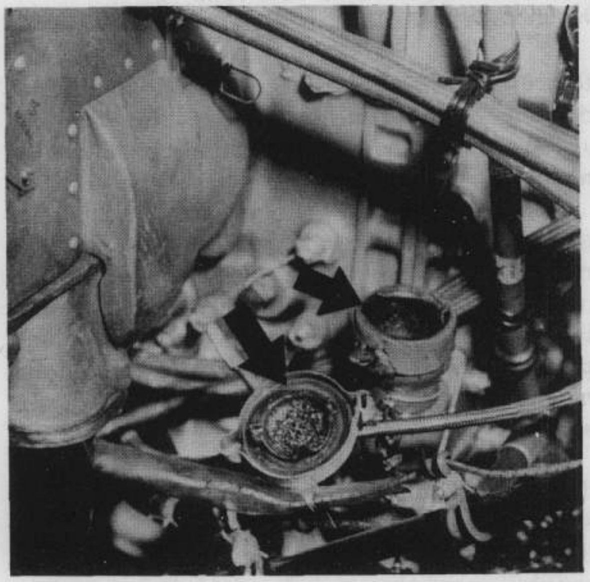


Figure 31-25. Design Oil Filler Cap To Prevent Loss in Flight (Ref. 1)

31-21.4 FILLER CAPS

Design fuel and oil tank filler caps so they cannot be improperly secured to filler necks and cannot come off in flight. Figure 31-25 shows an oil filler cap on an aircraft which requires a safety pin installation to prevent loss in flight. Several major accidents and at least four forced landings have resulted from broken and missing safety pins. When this happens, the oil cap comes off and the engine oil is siphoned overboard. This design inadequacy could be corrected by the installation of a spring-loaded lock type oil cap or the installation of a one-way flow valve in the filler neck below the oil filler cap.

An improperly secured fuel tank filler cap caused a helicopter to catch fire and burn due to fuel spillage (see Figure 31-26). The cap was designed so that it appears to be properly seated when it is not. Alignment marks should have been painted on the cap and filler neck to insure proper seating (see also Chapters 13 and 16).

31-21.5 FLUID, AIR, OR GAS FILTERS

Filters should be selected which not only filter out dirt and similar contaminents, but also trap water, since water often corrodes vital valves, pumps, etc. When filter drain lines are required, use flexible piping which does not require disconnection from the housing when the filter element has to be serviced or replaced.

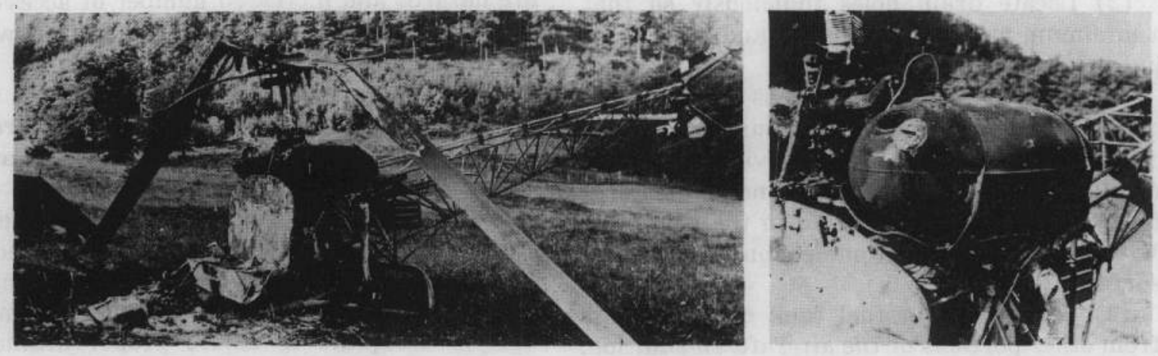


Figure 31-26. Fuel Spillage from Improperly Secured Filler Cap Caused This Accident (Ref. 1)

31-21.6 UPHEADING FUEL LINES

Whenever possible, design fuel systems to have all piping constantly rising from the fuel tank to the using unit; e.g., carburetor, burner, etc., to avoid sumps in the piping which may collect water and freeze, and thus immobilize the equipment. Down-drained fuel lines accomplish the same purpose, but a suitable drain should be installed in installations of this type.

31-21.7 SENSING CHECK FITTINGS

When pressure and temperature checking points are required to inspect, calibrate, adjust, or otherwise service or maintain the equipment, the necessary fitting, with plug or valve, should be made a part of the system. It should not be necessary to disconnect piping, components, or fittings to attach the test line or sensor when performing this operation. This fitting should be placed in an accessible location; if the installation is confined, a separate line, well supported, should be brought out to an accessible location.

31-21.8 BLEEDS

Bleeds are required to remove entrapped air or gas from fuel or hydraulic systems. Bleeds should be located in an easily operable and accessible location. If bleed location does not permit this, a well secured bleed line to an easily accessible location should be provided.

31-21.9 MAGNETIC CHIP DETECTORS

Magnetic chip detector warning lights are to be installed in all engines and gear boxes in the basic power train. Magnetic plugs should conform MS 35844 and should be used as practical throughout all fluid handling systems. Specify magnetic plugs of the same size throughout the end item, if practical. Particular attention should be given to sumps of crankcases, gear boxes, positive displacement pump inlets, and wherever iron or steel chips may endanger the life or operation of equipment. Specify the installation of magnetic chip detector systems on all gearboxes that are critical to the safety of the equipment, e.g., engines, drive gears, etc.

Piston engine aircraft in particular should be equipped with magnetic chip detector systems. Three years of experience with warning lights installed in a particular piston engine aircraft have proven this system to be a very reliable warning of impending engine failure. The designer should therefore make every effort to include this warning system in his design (Ref. 4).

The designer should also ensure that the light is located so as to be clearly visible to flying personnel. In a certain aircraft, for example, the magnetic chip detector warning light for the engine gearbox is mounted in a "blind" location in the aft pylon section of the aircraft; accordingly, the light is not visible to the pilot or copilot while the aircraft is in flight, thus creating a safety-of-flight hazard (Ref. 1).

31-21.10 HYDRAULIC CYLINDERS

Design hydraulic actuating cylinders or liners to be replaceable whenever possible or practical to lower maintenance costs.

31-21.11 VALVES

Design valve installations to prevent outside contaminants from entering vent port openings. Figure 31-27 show a flight control servo valve in an aircraft in which no provision was made to prevent water from entering vent port openings. This caused flight controls to become inoperative in several cases due to ice in the flight control servo valves. This design inadequacy had to be corrected by installing protective covers over the vent.

31-21.12 MARKING OF PIPELINES AND CYLINDERS

All pipelines and cylinders should be color-coded in accordance with MIL-STD-101. On complex systems, pipelines and cylinders should be labeled to speed identification and maintenance.

31-21.3 INADVERTENT ASSEMBLY

Clearly mark or identify piping and components to prevent inadvertent assembly or mis-

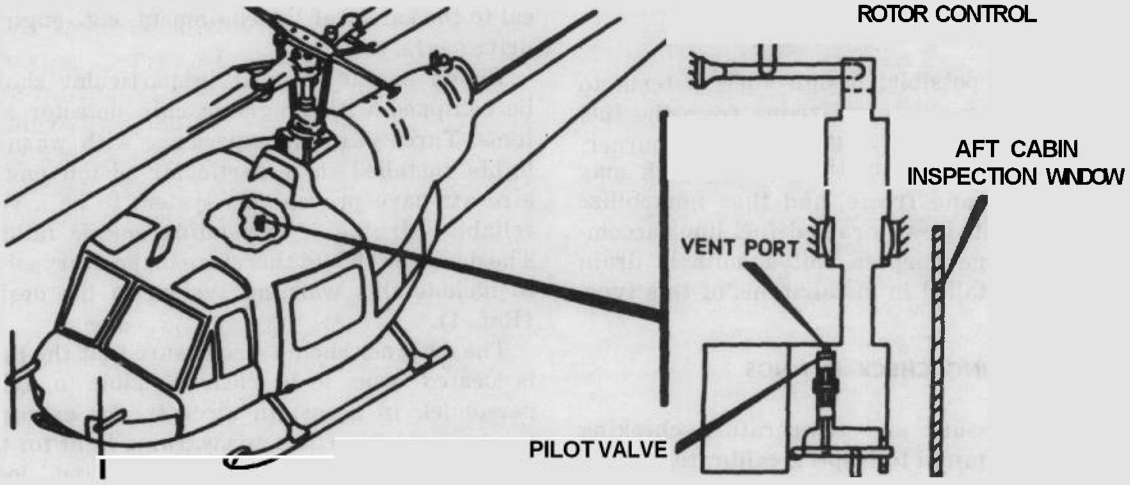


figure 31-27. Prevent Outside Contaminants from Entering Vent Port Openings

mating. This is particularly true on such components as oxygen lines where inadvertent assembly can cause serious danger to personnel and equipment. On installations of this nature, specify nonstandard or industry standardized fittings and threads to physically prevent incorrect assembly (see also Paragraph 31-9.2).

31-21.14 ROUTING OF LINES

The designer should avoid locating and routing normal and emergency lines of compatible systems side-by-side. ,This is pointed up by Figure 31-28 which shows the proximity of the normal and emergency landing gear operating lines of a particular aircraft. As a result of this installation, an aircraft of this type was lost in Vietnam due to one round of ground fire, which severed both the hydraulic pressure line and the emergency air line to the right main gear door. This dual loss prevented extension of the main landing gear. Greater physical separation of the two systems could have prevented this accident.

31-21.15 CLEARANCE BETWEEN PIPE FITTINGS

When a group of pipes are attached side-by-side, sufficient clearance should be provided so that each pipe can be removed individually.

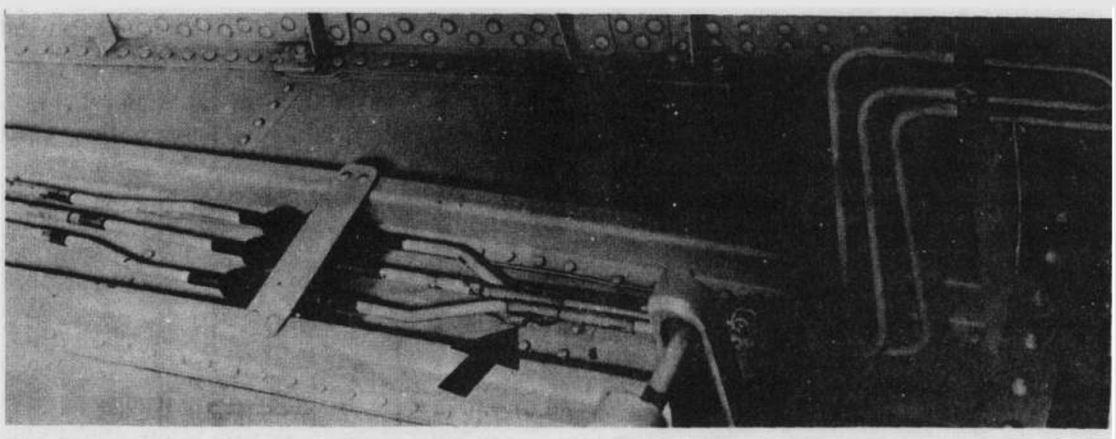


figure 31-28. Physically Separate Adjacent Lines to Simplify Inspection, Replucement, and Service.

Scfficient hand clearance should be provided enabling personnel to manipulate a standard wrench a minimum of 60".

31-21.16 PIPE ASSEMBLY

In cases where rigid pipes, having diameters of 3/8 in. or larger, are used, the fittings can be designed so that the pipes can be bent slightly for mating. In no case, however, should it be required to bend the pipe beyond the material's yield point.

31-21.17 PIPING SUPPORT

Design piping installations so that pipes do not chafe adjacent structures, components, or other piping. In cases where pipes do make contact with other items, provide suitable rigid support to the pipe in the area of contact to prevent unnecessary chafing. Unsupported rigid pipes should not be subjected to continuous resonant vibration between fittings. Clamps and/or braces should be provided where necessary to prevent fatigue failure.

31-21.18 CHARGING PORTS

Fittings on tires, accumulators, air and gas cylinders, purging systems, and similar items should be placed in the most accessible location possible. When practical, the fitting should be externally located, and when necessary, pocketed for protection against accidental damage. These fittings should be permanently piped to the component and appropriately identified as to pressure units, pounds, cu. ft., etc., as well as to the type of gas or air. When practical, no tools should be required to attach service lines to the fittings and no loose parts should be permitted.

31-21.19 PRESSURE RELIEVING DEVICES

Pressure relieving valves or fuses should be installed as necessary to relieve possible excessive internal pressures caused by system malfunction or by the effects of environmental heating, e.g., solar heating.

The cases of all gages, meters, and instruments used for pressure measurements should contain a safety device to protect personnel against possible injury due to accidental overpressures within the measuring instrument. The protective device should be a safety blowout plug, disc, or mechanical fuse which will blow out and relieve the overpressure before the glass on the gage blows out.

31-22 ELECTRONIC AND ELECTRICAL EQUIPMENT

Detailed maintainability criteria for electronic and electrical equipment are presented in Chapter 23. Some of this data plus new recommendations are discussed in the paragraphs which follow.

31-22.1 ELECTRICAL SYSTEMS

Voltage	Phase
28 d.c.	1
115 a.c., 400 cps	1
230 a.c., 400 cps	1
230 a.c., 400 cps	3
440 a.c.	3

Electrical and electronic equipment should be designed in general accordance with MIL-T-21200(ASG), MIL-E-5400, and MIL-STD-202.

31-22.2 ELECTRICAL STANDARDS

Electronic and electrical equipment should be designed in accordance with the following electrical standards:

(1) Electrical systems used in conjunction with commercial power sources should conform to the National Electrical Code, the Joint Industry Conference Standards for Electrical Equipment, and the National Machine Tool Association Machine Tool Electrical Standards.

(2) Electrical system components should conform to standards of the National Electrical Manufacturers Association.

(3) Explosion proofing requirements should conform to the standards specified for Aircraft Hangars as a Specific Occupancy in Article 510 of the National Electrical Code.

(4) Vehicle electrical systems should conform to applicable Army Materiel Command standards for tactical vehicles and to SAE standards for commercial vehicles, where applicable.

31-22.3 AUXILIARIES

Starting and ignition systems should be equipped with an external power receptacle conforming to AN2552 for engine starting. Electrical systems connected to aircraft electrical systems should meet the general applicable requirements of MIL-E-25499 and MIL-W-5088. To facilitate maintenance, standard-type slave battery or interequipment connections should be incorporated in engines normally started by electrical means.

31-22.4 ANCHOR WIRING

All wiring between aircraft components should be suitably anchored. Anchoring may be accomplished by the use of conduits, or clamped or clipped open bundles. Open bundles should be used whenever applicable, and where safety or service requirements permit. Open bundles are groups of individual wires connected together between units, but not completely covered by wrappings. The bundles are tied together at frequent intervals and ordinarily terminate in disconnect plugs having built-in clamps. The bundles should be anchored by clamps which have an insulated lining, such as synthetic rubber, to prevent chafing of the wires in the clamp. Bare metal clamps should not be used. Open bundles facilitate the identification of burned or otherwise defective wires and permit rapid access for repair and maintenance.

31-22.5 IGNITON EQUIPMENT

Ignition equipment for internal combustion engines should be designed to have the following maintainability characteristics:

(1) Spark plugs should be of the highest quality and reflect the most advanced technology in the state of the art. Materials selected should provide maximum life and ease of adjustment and maintenance. Self-cleaning types should be used wherever possible.

(2) Distributors should be located to permit rapid and easy access to all maintenance points, close line-of-sight inspection, and rapid total removal and assembly. Flywheels used for timing should be clearly and adequately marked by engraving or deep stamping and be provided with an accurate rigid pointer.

(3) Ignition points should be designed and located for rapid removal, adjustment, and assembly. The contact diameters of ignition points should not be less than 0.187 in., and the contacts should be made of the highest quality material.

(4) Ignition timing advance mechanisms should be rapidly and easily replaceable and capable of inspection.

(5) Ignition coils should be completely embedded or potted and should be tested by immersion and other means to ensure permanent exclusion of moisture. Coils should be mounted away from heat-damaging environments.

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7. MIL-HDBK-5, *Metallic Materials and Elements for Flight Vehicle Structures.*
8. ANC-5, *Strength of Aircraft Materials.*

GLOSSARY

accessibility.* A design feature which affects the ease of admission to an area for the performance of visual and manipulative maintenance.

active maintenance time.* The time during which preventive and corrective maintenance work is actually being done on the item.

active repair time.* The time during which one or more technicians are working on the item to effect a repair.

active technician time.* That time expended by the technician (s) in active performance of a maintenance task. Expressed in man-hours, not calendar time.

adjustment and calibration time.* That element of active maintenance time required to make the adjustment and/or calibrations necessary to place the item in a specified condition.

administrative time.* That portion of nonactive maintenance time that is not included in supply time.

alert time.* That time when an item is available to perform a mission. Cf. **ready time.**

automatic test equipment (ATE).* Equipment which carries out a predetermined program of testing for possible malfunction without reliance upon human intervention. Also called automatic check-out equipment.

* Terms identified by an asterisk, taken from MIL-STD-778, *Maintainability Terms a[illegible]*

automatic testing? The process by which the localization of faults, possible prediction of failure, or validation that the equipment is operating satisfactorily is determined by a device that is programmed to perform a series of self-sequencing test measurements without the necessity of human direction after its operations have been initiated.

availability (achieved).* The probability that a system or equipment when used under stated conditions in an ideal support environment (i.e., available tools, parts, manpower, manuals, etc.) shall operate satisfactorily at any given time. A_a excludes supply downtime and waiting or administrative downtime. It may be expressed as:

$$A_a = \frac{MTBM}{MTBM + M}$$

where

$MTBM$ = Mean-time-between-maintenance;

M = Mean active maintenance downtime resulting from both preventive and corrective maintenance actions.

availability (inherent).* The probability that a system or equipment when used under stated conditions, without consideration for any scheduled or preventive maintenance, in an ideal support environment (i.e., available tools, parts, manpower, manuals, etc.), shall operate satisfactorily at any given time. A_i excludes ready time, preventive maintenance downtime, supply downtime, and waiting or administrative downtime. It may be expressed as:

$$A_i = \frac{MTBF}{MTBF + MTTR}$$

where

$MTBF$ = Mean-time-between-failure ;

$MTTR$ = Mean-time-to-repair.

availability (operational).* The probability that a system or equipment when used under stated conditions and in an actual supply environment shall operate satisfactorily at any given time. It may be expressed as:

$$A_o = \frac{MTBM}{MTBM + MDT}$$

where

$MTBM$ = Mean-time-between-maintenance and ready time during the same time interval, and

MDT = Mean downtime including supply downtime and administrative downtime during the same time interval. When preventive maintenance downtime is zero or not considered, MTBM becomes MTBF.

calendar time.':' The total number of calendar days or hours in a designated period of observation.

circuit malfunction analysis.': The logical, systematic examination of circuits and their diagrams to identify and analyze the probability and consequence of potential malfunctions for determining related maintenance or maintainability design requirements.

corrective maintenance? That maintenance performed to restore an item to a satisfactory condition by providing correction of a malfunction which has caused degradation of the item below the specified performance.

corrective maintenance time.': The time that begins with the observance of a malfunction of an item and ends when the item is restored to a satisfactory operating condition. It may be subdivided into active maintenance time and nonactive maintenance time. It does not necessarily contribute to equipment or system downtime in cases of alternate modes of operation or redundancy.

criticality.* The effect of a malfunction of an item on the performance of a system.

demand usage time.* The total number of calendar days per month, hours per day, etc. that an equipment is required to be operational.

design adequacy. The probability that a system or equipment will successfully accomplish its mission, given that the system is operating within design specifications.

direct maintenance resources.* The time in man-hours and material in dollars expended directly on the item being maintained during the period of active maintenance.

downtime.:: That portion of calendar time when the item is not in condition to perform its intended function.

ease of maintenance. The degree of facility with which equipment can be retained in, or restored to, operation. It is a function of the rapidity with which maintenance operations can be performed to avert malfunctions or correct them if they occur. Ease of maintenance is enhanced by any consideration that will reduce the time and effort necessary to maintain equipment at peak operating efficiency.

failure. A detected cessation of ability to perform a specified function or functions, within previously established limits, in the area of interest. It is a malfunction that is beyond adjustment by the operator by means of controls normally accessible to him during the routine operation of the device.

failure, catastrophic. A sudden change in the operating characteristics of some part or parameter resulting in a complete failure of the item, e.g., circuit opens or shorts, structural failure, etc.

failure, random. Any catastrophic failure whose probability of occurrence is invariant with time and whose occurrence within any given interval of time is, consequently, unpredictable, e.g., O-ring leakage, shorted electron tubes, wire breakage, etc.

failure, wear out. A failure that occurs as a result of deterioration processes or mechanical wear and whose probability of occurrence increases with time. Wear out failures are those failures that occur generally near the end of life of an item and are usually characterized by chemical or mechanical changes, i.e., those failures that could have been prevented by a replacement policy based on the known wear out characteristics of the item, e.g., motor brush wear out.

fault correction time.': That element of active repair time required under a specified maintenance philosophy to correct the malfunction. It may consist of correcting the malfunction with the faulty item in place, removing and replacing the item with a like serviceable item, or removing the item for corrective maintenance and re-installing the same item.

fault location time.': That element of active repair time required for testing and analyzing an item to isolate a malfunction.

final test time.* That element of active repair time required after completion of maintenance, adjustments, and calibration to verify by measurement of performance that the item is in a condition to perform its function satisfactorily.

free time. Time during which operational use of a system or equipment is not required; may or may not be downtime, depending on whether or not the system is in operable condition.

frequency-of-use-principle (equipment design).* The principle of positioning the most frequently maintained items in preferred locations.

function analysis for maintainability.* The analytical basis for allocating tasks to personnel and equipment so as to achieve optimum system maintainability.

functional principle (equipment design).* The principle of arrangement that provides for the grouping of hardware items according to their functions.

geometric mean-time-to-repair (MTTR).* A measure of central tendency for repair time based on observations which show repair times to be log-normally distributed. See **mean-time-to-repair.**

go/no-go display.': A display that indicates the operable or nonoperable condition of equipment.

human factors.': Human psychological characteristics relative to complex systems and the development and application of principles and procedures for accomplishing optimum man-machine integration and utilization. The term is used in a broad sense to cover all biomedical and psychosocial considerations pertaining to man in the system.

inactive time.': The period of time when the item is available, but is neither needed nor operating for its intended use.

indirect maintenance resources.':: That time in man-hours and material in dollars which, while not directly expended in active maintenance tasks, contributes to the overall maintenance mission, through the support of overhead operations, administration, accumulation of facility records and statistics, supervision, and facilities upkeep.

interchangeability. When two or more parts are physically and functionally interchangeable in all possible applications, i.e., when both parts are capable of full, mutual substitution in all directions.

item procurement time.':: That element of active repair time required to obtain the needed item or items from base supply stock rooms, etc.

life, average. The mean value for a normal distribution of lives. Generally applied to mechanical failures resulting from wear.

life, service. That acceptable period of time when an item can remain in storage and in tactical readiness with authorized organizational and field maintenance being performed that does not affect its operability for the intended tactical use.

life, shelf. That acceptable period of time during which an item can remain in storage without affecting its operability for the intended tactical use.

life, useful. The total operating time between issuing and wear out.

logistic resources.': The support personnel and materiel required by an item to assure its mission performance. It includes such things as tools, test equipment, spare parts facilities, technical manuals, and administrative and supply procedures necessary to assure the availability of these resources when needed.

logistical support. Maintenance and supply support to be provided at organizational, field, and depot levels. Logistical support is influenced by the degree of unitization or modularization, ruggedness, cost and test points, test equipment, tactical employment, and transportation requirements.

logistic time. That portion of downtime during which repair is delayed solely because of the necessity for waiting for a replacement part or other subdivision of the system.

maintainability.':' Maintainability is a characteristic of design and installation which is expressed as the probability that an item will conform to specified conditions within a given period of time when maintenance action is performed in accordance with prescribed procedures and resources.

maintainability index.'::A quantitative figure of merit which relates the maintainability of an item to a standard reference.

maintainability parameters.* A group of factors (environmental, human, hardware) which establishes limits to the performance of maintenance on an item.

maintainability requirement.* A comprehensive statement of required maintenance characteristics, expressed in qualitative and quantitative terms, to be satisfied by the design of an item.

maintenance.': All actions necessary **for** retaining an item in, or restoring **it** to a serviceable condition. Maintenance includes servicing, repair, modification, modernization, overhaul, inspection, and condition determination.

maintenance ability." A figure of merit **for** a crew of a using organization defined as the ratio of the maintenance man-hours established on specific item by a trained and expert maintenance crew to the maintenance man-hours figure established by the crew of the using organization on the same item and under similar maintenance conditions.

maintenance analysis.* The process of identifying required maintenance functions through analysis of a fixed or assumed design and determining the most effective means of accomplishing these functions.

maintenance category. Division of maintenance of materiel, based on difficulty and requisite technical skill, in which jobs are allocated to organizations in accordance with the availability of personnel, tools, supplies, and time within the organization. Maintenance categories include depot, field, and organizational.

maintenance, corrective. *See* **corrective maintenance.**

maintenance cost ratio.':' The ratio of the cost of maintenance for a given unit of time to the initial item cost.

maintenance, depot. That maintenance required for major overhaul or complete rebuild of parts, subassemblies, assemblies, or end items. Such maintenance is intended to augment stocks of serviceable equipment or to support lower levels of maintenance by use of more extensive shop equipment and personnel of higher technical skill than available in organizational or field maintenance activities.

maintenance element? A discrete portion of a maintenance task which can be described **or** measured.

maintenance engineering. The application of techniques, engineering skills, and effort organized to ensure that the design and development of weapons, systems, and equipment provide adequately for effective and economical maintenance.

maintenance evaluation. A process for determining that the design of an item of materiel is compatible with the maintenance required to be performed on it.

maintenance, field. That maintenance authorized and performed by designated maintenance activities in direct support of using organizations. This category will normally be limited to maintenance consisting of replacement of unserviceable parts, subassemblies, or assemblies.

maintenance, organizational. That maintenance which a using organization performs on its own equipment. This includes inspection, cleaning, servicing, preservation, lubrication, adjustment, minor repair not requiring detailed disassembly, and replacement not requiring high technical skill.

maintenance, periodic. Maintenance performed on equipment on the basis of hours of operation or calendar time elapsed since last inspection.

maintenance, preventive. The systematic care, servicing, and inspection of equipment and facilities for the purpose of maintaining them in serviceable condition and detecting and correcting incipient failures.

maintenance procedures.* Established methods for periodic checking and servicing items to prevent failure or to effect a repair.

maintenance proficiency.* The ability **of** maintenance personnel to apply job skills in the maintenance of an item.

maintenance resources.* Facilities, ground support equipment, manpower, spares, consumables, and funds available to maintain and support an item in its operational environment.

maintenance support index.* The total number of direct maintenance man-hours for preventive and corrective maintenance required to support each hour of operation.

maintenance task.* Any action or actions required to preclude the occurrence of a malfunction or restore an equipment to satisfactory operating condition.

malfunction. A general term used to denote the failure of a product to give satisfactory performance. It need not constitute a failure if readjustment of operator controls can restore an acceptable operating condition.

mean. A quantity representing the average of two or more other quantities, arrived at by adding the quantities together and dividing by their number. Also called "arithmetic mean." The "geometric mean" of two quantities is the square root of the product of the quantities.

mean-time-to-correct-failure. The expected value of the time required to restore an equipment or system to a condition of satisfactory operation, measured from the moment when it is judged unsatisfactory for normal use.

mean-time-to-repair (MTTR).* The statistical mean of the distribution of times-to-repair. The summation of active repair times during a given period of time divided by the total number of malfunctions during the same time interval.

mission reliability. The probability that, under stated conditions, a system or equipment will operate in the mode for which it was designed (i.e., with no malfunctions) for the duration of a mission, given that it was operating in this mode at the beginning of the mission.

mission time.* The period of time in which an item must perform a specified mission.

model, developmental. A model designed to meet performance requirements of the specification or to establish technical requirements for production equipment. This model need not have the required final form or necessarily contain parts of final design. It may be used to demonstrate the reproducibility of the equipment.

model, preproduction. *See* **prototype model.**

model, production. A model in its final mechanical and electrical form of final production design made by production tools, jigs, fixtures, and methods.

modification. A major or minor change in the design of an item of materiel, performed to correct a deficiency, to facilitate production, or to improve operational effectiveness.

module. An assembly, forming part of a larger assemblage, which is designed for complete replacement as a unit. Hence, the terms modular unit, modular construction, modular maintenance, modular design, etc. See *also* **unitization.**

nonactive maintenance time.': The time during which no maintenance is being accomplished on the item because of either supply or administrative reasons, considered as not productive towards maintenance task accomplishment.

operational factors.': Various factors, generated by the operational concept, which enter into or affect the mission accomplishment. Among these factors are the number of vehicles, the in-and-out-of-commission rates, availability requirements, the combat readiness, and training requirements.

operational maintenance.* Maintenance that is performed without interrupting the satisfactory operation of the item.

operational phase.* The period in the system life cycle which starts with the delivery of the first inventory unit or installation to the unit command and terminates with disposition of the system from the inventory.

operation profile.* Various equipment status phases, i.e., calendar time, inactive time, demand usage time, operating time and downtime,

operational readiness. The probability that, at any point in time, a system or equipment is either operating satisfactorily or ready to be placed in operation on demand when used under stated conditions, including stated allowable warning time. Thus, total calendar time is the basis for computation of operational readiness.

operating time. The time during which a system or equipment is operating in a manner acceptable to the operator, although unsatisfactory operation (or failure) is sometimes the result of the judgment of the maintenance man.

preparation time? That element of active repair time required to obtain necessary test equipment and maintenance manuals and to set up the necessary equipment in preparation for fault location.

preventive maintenance.* That maintenance performed to retain an item in satisfactory operational condition by providing systematic inspection, detection, and prevention of incipient failures.

preventive maintenance time.':' That portion of calendar time used in accomplishing preventive maintenance. It comprises time spent in performance measurement ; care of mechanical wear out items ; front panel adjustment, calibration, and alignment ; cleaning ; etc.

proficiency test." A test which measures an individual's skill level within a given speciality.

prototype model. A model suitable for complete evaluation of mechanical and electrical form, design, and performance. It is in final mechanical and electrical form, uses approved parts and is completely representative of final equipment.

qualitative maintainability requirement.* A maintainability requirement expressed in qualitative terms, e.g., minimize complexity, design for minimum number of tools and test equipment, design for optimum accessibility.

quantitative maintainability requirement.* A requirement expressed in quantitative terms, **i.e.,** a figure of merit or in measurable units of time or resources required to accomplish a specific maintenance task, or group of tasks, in relation to the applicable performance requirements (reaction time, availabilities, downtime, repair time, turn around time, etc.) .

reaction time.* The time required to initiate a mission measured from the time the command is received.

ready time.* The period of time during a mission that the item is available for operation, but is not required. Cf. alert time.

rebuild. To restore to a condition comparable to new by disassembling the item to determine the conditidn of each of its component parts, and reassembling it, using serviceable, rebuilt, or new assemblies, subassemblies, and parts.

redundancy. The existence of more than one means for accomplishing a given task, where all means must fail before there is an overall failure to the system. Parallel redundancy applies to systems where both means are working at the same time to accomplish the task and either of the systems is capable of handling the job itself in case of failure of the other system. Series of standby redundancy applies to a system where there is an alternate means of accomplishing the task that is switched in by a malfunction sensing device when the primary system fails.

reliability. The probability of a device performing its purpose adequately for the period of time intended under the operating conditions encountered. For a system with independent components, the overall reliability is based on the product of the individual reliabilities; e.g., three independent components with a 90% reliability each will have an overall reliability of 0.9 **X** 0.9 **X** 0.9 or **72.9%.** Similarly, 100 components with a 99% reliability each will have an overall reliability of only **36.5%.**

repair.* The process of returning an item to a specified condition including preparation, fault location, item procurement, fault correction, adjustment and calibration, and final test.

repairability.': The capability of an item to be repaired.

repair time.* ***See*** active repair time.

replacement schedule.* The specified periods when items of operating equipment are to be replaced. Replacement means removal of items approaching the end of their maximum useful life, or the time interval specified for item overhaul or rework, and installation of a serviceable item in its place.

replacing. Substituting one unit for another identical unit. Usually done to substitute a properly functioning unit for a malfunctioning unit.

serviceability. The design, configuration, and installation features that will minimize periodic or preventive maintenance requirements, including the use of special tools, support equipment, skills, and manpower, and enhance the ease of performance of such maintenance, including inspection and servicing, with a minimum expenditure of time and material in its planned environment.

servicing.': The performance of any act (other than preventive or corrective maintenance) required to keep an item of equipment in operating condition, such as lubricating, fueling, oiling, cleaning, etc. This does not include periodic replacement of parts or any corrective maintenance tasks.

skill level.* The classification system used to rate personnel as to their relative abilities to perform their assigned jobs.

special tools.': Tools peculiar to a specific end product.

standardization. The process of establishing by common agreement engineering criteria, terms, principles, practices, materials, items, processes, equipments, parts, subassemblies, and assemblies to achieve the greatest practicable uniformity of items of supply and engineering practices ; to ensure the minimum feasible variety of such items and practices ; and to effect optimum interchangeability of equipment parts and components.

storage time. Time during which a system or equipment is presumed to be in operable condition, but is being held for emergency (i.e., as a spare).

supply time.': That portion of nonactive maintenance time during which maintenance is delayed because a needed item is not immediately available.

support cost.': The total cost of ownership, excluding operating crews and using personnel, of an item during its operational life including the total impact of requirements for skill levels, technical data, test equipment, spares, spare parts, special tools, operational and maintenance equipment, facilities, levels and location of maintenance facilities, manpower, training, and training equipment.

support equipment.':' Items necessary for the maintenance or operation of the system which are not physically part of the system.

system effectiveness. The probability that a system can successfully meet an operational demand within a given time when operated under specified conditions.

system, weapon. An instrument of combat with all related equipment, operating skills, and direct supporting facilities and services required to enable the instrument of combat to operate as a single unit of striking power. *Note:* Singular spelling of "weapon" and "system." Weapon systems is the plural form.

task analysis.':' An analytical process employed to determine the specific behaviors required of human components in a man-machine system. It involves determining, on a time base, the detailed performance required of a man and machine, the nature and extent of their interactions, and the effects of environmental conditions and malfunctions. Within each task, behaviorial steps are isolated in terms of perceptions, decisions, memory storage, and motor outputs required, as well as the errors which may be expected. The data are used to establish equipment design criteria, personnel, training requirements, etc.

technician delay time.* The number of maintenance man-hours expended on a maintenance task while no maintenance is performed because of supply or administrative reasons.

total downtime. That portion of calendar time during which a system is not in condition to perform its intended function : includes active maintenance (preventive and corrective), supply downtime due to unavailability of needed items, and waiting and administrative time.

total technician time." The total man-hour expenditure required to complete a maintenance task : includes active technician time and delay technician time.

trade-off. The process by which a designer could evaluate one or more proposed maintainability design considerations in terms of possible effects in other areas and make an intelligent decision based upon these evaluations.

troubleshooting.': Locating and diagnosing malfunctions or breakdowns in equipment by means of systematic checking or analysis.

unitization. A series of plug-in units or similar subassemblies, each of which contains all parts necessary to make up a complete functioning circuit or stage. Each circuit or stage can be independently removed and replaced with a like unit or subassembly. ***See also* module.**

weapon system. *See* system, weapon.

wear out. The point at which further operation is uneconomical.

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Document	Title
Military Specifications	
ANA BULLETIN 275	Guide for the Use of Lubricants, Compounds, and Fluids in Aircraft
FF-B-171	Bearings, Ball, Annular (General Purpose)
FF-B-185	Bearings, Roller, Cylindrical ; Bearings, Roller, Self-Aligning
MIL-A-7021	Asbestos Sheet, Compressed for Fuel, Lubricant, Coolant, Water, and High Temperature Resistant Gaskets
MIL-A-8421	Air Transportability Requirements, General Specifications for
MIL-A-17472A	Asbestos Sheet, Compressed Gasket Material
MIL-A-19531	Aircraft, Maintenance and Engineering Inspection Requirements
MIL-C-5654	Cloth, Process for Application of Aircraft Surface
MIL-C-13984	Can, Water, Military, 5-Gallon
MIL-D-70327	Drawings, Engineering and Associated Lists
MIL-D-19531 (AER)	Aircraft, Maintenance and Engineering Inspection of
MIL-E-I	Electron Tubes and Crystal Rectifiers
MIL-E-5272	Environmental Testing, Aeronautical and Associated Equipment
MIL-E-5400	Electronic Equipment, Aircraft, General Specifications for
MIL-E-5627A	Extinguishers, Fire, Carbon Dioxide, Portable
MIL-E-7729	Enamel, Gloss, Aircraft, Application
MIL-E-11991	Electrical-Electronic Equipment, Surface Guided, Missile Weapon Systems, General Specifications for
MIL-E-16400	Electronic Equipment, Naval Ship and Shore, General Specifications for
MIL-E-22285	Extinguishing System, Fire, Aircraft, High-Rate Discharge Type, Installation and Test of
MIL-E-25499	Electrical Systems, Aircraft, Design of, General Specifications for
MIL-F-3541	Fittings, Lubrication, Hydraulic
MIL-F-5591	Fasteners, Panel
MIL-F-7872	Fire Warning Systems, Continuous, Aircraft, Test and Installation of
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Military Specs. (Cont.)	
MIL-G-6183	Gaskets and Sheet Gasket Material, Synthetic Rubber and Cork Composition
MIL-H-5440	Hydraulic Systems, Design, Installation and Tests in Aircraft, General Specifications for
MIL-H-6000	Hose ; Rubber (Fuel, Oil, Coolant, Water and Alcohol)
MIL-H-8794	Hose, Rubber, Hydraulic, Pneumatic, Fuel, and Oil Resistant
MIL-H-8795	Hose Assemblies, Rubber, Hydraulic, Pneumatic, Fuel and Oil Resistant
MIL-H-008794	Hose, Rubber, Hydraulic, Fuel, and Oil Resistant
MIL-1-8500	Interchangeability and Replaceability of Component Parts for Aircraft and Missiles
MIL-1-16923	Insulating Compound, Electrical, Bedding
MIL-1-19326	Installation and Tests of Liquid Oxygen Systems in Aircraft
MIL-L-7312	Lubricator, High Pressure, Portable, Type A-2A
MIL-L-7808	Lubricating Oil, Aircraft Turbine Engine, Synthetic Base
MIL-M-79 11	Marking, Identification of Aeronautical Equipment Assemblies, and Parts
MIL-M-8090	Mobility Requirements, Ground Support Equipment, General Specifications for
MIL-M-9933	Maintainability and Reliability Program, Quick Reaction Capability Electronic Equipment
MIL-M-17191	Mounts, Resilient, Portsmouth Bonded, Spool Type
MIL-M-23313	Maintainability Requirements for Shipboard and Shore Electronic Equipment and Systems
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MIL-N-4180	Nozzles, Fuel and Oil Servicing
MIL-N-7284	Nozzles, Oil Servicing, Pistol Grip, Nondrip, Type A-24
MIL-N-25027	Nut, Self-Locking, 250 Deg. F, 450 Deg. F, and 800 Deg. F, 125 KSI FTU, 60 KSI FTU, and 30 KSI FTU
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MIL-P-6906	Plates, Identification and Information
MIL-P-11268	Parts, Materials and Processes Used in Electronic Communication Equipment
MIL-R-5520	Reservoirs, Hydraulic
MIL-R-22732	Reliability Requirements for Shipboard and Ground Electronic Equipment
MIL-S-901	Shockproof Equipment, Class HI (High Impact), Shipboard Application, Tests for
MIL-S-3787	Safety Glass, Laminated, Flat
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MIL-S-5502	Surface Treatments (except Priming and Painting) for Metal and Metal Parts in Aircraft
MIL-T-152	Treatment, Moisture- and Fungus-Resistant, of Communications, Electronic and Associated Electrical Equipment
MIL-T-12664	Treatment, Fungus Resistant, Paranitrophenol for Cork Products
MIL-T-21200	Test Equipment for Use with Electronic and Fire Control Systems, General Specifications for
MIL-V-1137	Varnish, Electrical-Insulating (for electromotive equipment)
MIL-W-5088	Wiring, Aircraft, Installation of
MIL-W-8160	Wiring, Guided Missile, Installation of, General Specifications for
MIL-W-9411	Weapon Systems, Aeronautical, General Specifications for
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MS15001	Fitting, Lubrication Hydraulic Surface Check, 1/4-28 Taper Threads, Steel, Type I
MS15002	Fittings, Lubrication Hydraulic Surface Check, Straight Threads, Steel, Type II
MS33586	Metals, Definition of, Dissimilar
MS35844	Plug, Machine Thread, Magnetic (Drain)
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MIL-STD-202	Test Methods for Electronic and Electrical Component Parts
MIL-STD-210	Climatic Extremes for Military Equipment
MIL-STD-415	Test Points and Test Facilities for Electronic Systems and Associated Equipment
MIL-STD-441	Reliability of Military Electronic Equipment
MIL-STD-681 .	Identification Coding and Application of Hook-up Wire
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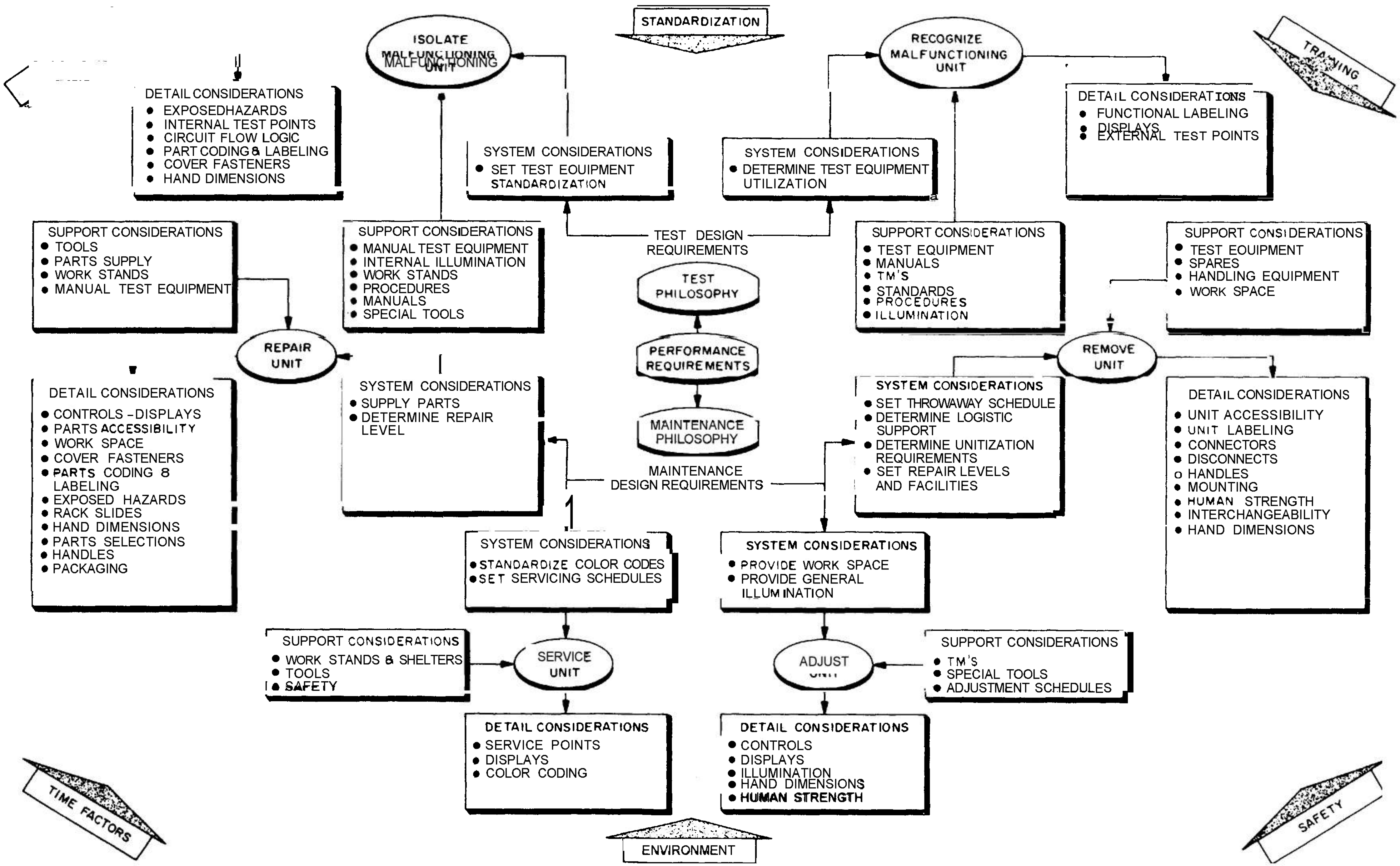

Figure 3-4. Maintainability Decision Structure (Ref. 4)

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347	Traversing Mechanisms
350	Wheeled Amphibians
355	The Automotive Assembly
356	Automotive Suspensions
357	Automotive Bodies and Hulls
360	*Military Vehicle Electrical Systems
445	*Sabot Technology Engineering

*UNDER PREPARATION--not available
+OBSOLETE--out of stock
**REVISION UNDER PREPARATION
#NOT AVAILABLE FROM NTIS