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ENGINEERING DESIGN HANDBOOK

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DESIGN GUIDANCE FOR PRODUCIBILITY

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UNITED STATES ARMY MATERIEL COMMAND
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31 August 19[illegible]

ENGINEERING DESIGN HANDBOOK

DESIGN GUIDANCE FOR PRODUCIBILITY

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FOREWORD

As one of the handbooks in the Army Engineering Design Handbook Series, this *Design Guidance for Producibility* was prepared in accordance with the goals of the Series. In general, the Army Engineering Design Handbooks contain basic information and fundamental data essential in the design and development of Army materiel and systems. They are authoritative references for practical and quantitative facts helpful in the design and development of materiel meeting the tactical and technical needs of the Army. They incorporate sound and proven principles of design; at the same time they direct attention to the consideration of production, maintainability, human factors, and related problems during the design and development stages. The handbooks contain much information which is not available in open literature; they are revised periodically to ensure that their contents reflect the latest technologies.

One of the prime objectives of this handbook on producibility is to reemphasize the fact that the design agency developing a commodity has a distinct influence on subsequent production and logistics.

It is also intended to provide guidance to the individual designer through which he may recognize, at the earliest practical point in the design effort, those problems of production and support which, if eliminated from the design, will further the objective of creating a design which can be manufactured using readily available materials, in the shortest possible time, at the lowest cost, by the largest possible segment of the industrial base. It therefore provides a collection of pertinent information to aid in designing for ease of production, including the maintenance of required levels of quality.

The user should recognize, however, that the handbook offers only guidance. Its content is general. It is intended to lead the designer to answers to his specific problems, but not to provide them. For treatment of specific problems refer to the appropriate handbook in the Engineering Design Handbook Series, or to one of the several sources of information listed in the appendices.

This handbook was developed by the John I. Thompson & Company, Washington, D. C., under the general direction of E. F. Deady, Vice President Engineering. Project Manager and principal author was P. H. Bailey. Other contributors included W. Duggan, Lt. Col USA (Ret); E. K. Gratehouse, and D. D. Peterson. Prime contractor to the U.S. Army for this and other handbooks in the Series is the Engineering Handbook Office of Duke University.

The Handbooks are readily available to all elements of AMC including personnel and contractors having a need and/or requirement. 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. Procedures for acquiring these Handbooks follow:

a. Activities within AMC and other DOD agencies should direct their requests on an official form to:

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b. Contractors who have Department of Defense contracts should submit their requests through their contracting officer with proper justification, to the address indicated in paragraph a.

c. Government agencies other than DOD having need for the Handbooks may submit their requests directly to the Letterkenny Army Depot, as indicated in paragraph a, or to:

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U.S. Army Materiel Command
ATTN: AMCAM-ABS
Washington, D.C. 20315

d. Industries not having Government contracts (this includes Universities) must forward their requests to:

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U.S. Army Materiel Command
ATTN: AMCRD-TV
Washington, D.C. 20315

e. All foreign requests must be submitted through the Washington, D. C. Embassy to:

Assistant Chief of Staff for Intelligence
ATTN: Foreign Liaison Office
Department of the Army
Washington, D.C. 20310

All requests, other than those originating within the DOD, must be accompanied by a valid justification.

Comments and suggestions on this handbook are welcome and should be addressed to Army Research Office-Durham, Box CM, Duke Station, Durham, North Carolina 27706.

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PREFACE

In the past, periods of relatively rapid advancement in military hardware have alternated with usually longer periods of relative inactivity, during which time an arsenal inventory has been maintained containing weapons which were largely obsolescent at the time they were needed. For example, little radical change in the military inventory took place between the end of World War I and the beginning of World War II. That change which did occur resulted more from the ability of an advancing commercial technology to offer and supply more effective and sophisticated weaponry than from the demands of the military in the interests of national defense. Indeed, much mothballed inventory from the 1914-18 war, and even earlier eras, was pressed into service in the earlier stages of the 1939-45 conflict.

This was the era in which industry speculated on a new weapon; designed, built, and demonstrated it; and hoped that it would sufficiently impress the intended military customer to initiate procurement.

Under these circumstances, the problems of producibility were almost nonexistent. The term itself was virtually unknown—having found its way into the dictionary only as recently as the mid-1960's. The design was intended to employ the materials of commercial production, the facilities at hand, and the skills which were inherent in everyday operations.

Producibility problems in the form in which they exist today made their appearance in substantial volume with the industrial mobilization occasioned by World War II. Shortages rapidly accumulated in materials, facilities, equipment, and skills. The extension of the production base met repeated delays through the necessity to reengineer one company's design to permit its production by another. Troops placed faith in a weapon if it was produced by company A and shunned it if it was a product of company B. Even more critical was the fact that the parts made by B would not fit into the weapon made by A. Skyrocketing costs attended and were part of the overall problem.

World War II also saw the beginnings of what is now referred to as the "technological explosion"—a rather poor description of the ever increasing rate of development of new basic scientific knowledge, new materials, processes, and products. A large part of today's military arsenal consists of weapons, systems, and equipment which, 20 years ago, would have been beyond technological capabilities of construction even in prototype form. These exist side by side in an inventory which contains devices which are little changed from those of the World War II or the Korean Conflict.

Undoubtedly, to the military designer, the biggest change has been in the radical and continual expansion of types of material from which he may create his design. If a suitable material does not appear to be available and all of the physical, mechanical, metallurgical, chemical, and thermodynamic needs of the product cannot be met, a suitable compound or alloy can frequently be computer-designed in a matter of hours. The months or years of development trial and error can thus be avoided.

On the surface, it may appear that the task of the designer has been considerably simplified. In fact the situation is exactly the opposite. Technological advancement permits the development of vastly more complex and destructive weaponry, while the rate of advancement causes its obsolescence at a hitherto unknown rate.

While stockpiling is inherently necessary to the maintenance of a sound military posture, costs and rate of obsolescence prohibit maintenance of inventories beyond those necessary for immediate response to aggression or for the sustenance of the most

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limited conflict. While basic strategy demands the operational readiness of such immediate retaliatory power that a potential aggressor is dissuaded, the second line of defense relies heavily upon the rapid mobilization of industry and its conversion to production for the military arsenal.

Thus two states of production exist—that which contributes to national preparedness and that which responds to a state of national emergency.

The requirements of producibility are constituent elements of both states. They are not, however, necessarily identical in both situations: nor are they fixed constants. As technology continues to advance, as new materials become available, as old materials change in availability, and as both vary in potential availability in national emergencies, the materials influence on producibility changes. The same state exists with all attendant processes through which the raw material is converted to finished product. Producibility is thus a rather nebulous and everchanging goal which may seldom be fully achieved in a design and which must be frequently reviewed if it is to be retained. The ideally producible design could be made by anybody out of anything at any time—a production engineer's dream. Its antithesis—the production engineer's nightmare of unsatisfactory materials and processes, and inadequate skills—is, however, usually entirely avoidable. Thus negative avoidance is one sure means of positive accomplishment.

While checklist approaches can be developed to spot check the producibility features of a specific design, the development of sound design practices which promote producibility objectives can only be the product of an individual's knowledge, experience, and continual efforts to keep abreast of development in his own field or investigate those in fields in which he is only infrequently involved. To this end the handbook is divided into three parts:

Part One, The Army Design Environment

Part Two, The Production Environment

Part Three, Information Sources

Whether the designer is a part of a military or an industrial organization, in contributing to the development of an item of Army weaponry, he is operating within a clearly identified and closely controlled framework (the design environment) with which he must be thoroughly familiar and with which he must comply if all of the design objectives, not just that of producibility, are to be achieved. This framework is largely administrative in nature and gives the appearance of preventing the designer from giving full vent to his inventive genius. To some extent this is true. Once the designer is aware of the specific objectives, demands, and restrictions of this system and of the selective and decision processes which he may use within it, he is in a position to make an effective contribution. These factors are the subject of Part One, The Army Design Environment.

A clear distinction must be made between producibility and production engineering. Any design, upon being committed to production, involves some degree of production engineering, the development of production plans, schedules, sequences, and tools with which to manufacture the item in the simplest, most economical, and timely manner with the highest degree of repeatability and the lowest level of scrap and rework. No two plants manufacturing the same item will use the same production engineering package (unless the plants themselves are identical twins). The introduction of producibility concepts into the design will usually greatly simplify the production engineering task by the avoidance of frequently encountered manufacturing problems. This avoidance, in turn, will broaden the production base which is capable of contributing to the manufacturing program. However, producibility considerations also involve factors such as materials availability, parts standardization, and other considerations which are not essentially features of production engineering.

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The designer does not normally accomplish the production engineering task. However, if he "thinks production" he will advance the cause of producibility. Part Two, The Production Environment, is designed to provide basic assistance toward this end by reviewing both the readily available as well as the currently unavailable. Since this handbook is not directed toward any specific class of commodity, the designer will find it convenient to supplement this part with information peculiar to his specific interests.

With the almost daily changes in the status of practical technology (and the even faster change of feasible technology), the design engineer is hard put to stay abreast of current status, even within his own discipline. It has been realistically estimated that by 1970 he will have to spend 16 out of every 40 working hours in doing so.

The accumulation, digesting, and dissemination of technical information is an increasingly burdensome problem which has given rise to a rapid increase in the numbers and types of organizations established explicitly, or secondarily, for this purpose. The potential user is faced with two immediate problems. First, he is frequently unaware of the existence of an information source or of its scope of operation. Second, since virtually none of these sources are completely random access, his inquiry must be phrased so as to clearly define the information which he is seeking. Part Three, Information Sources, is designed to assist him in both functions. It provides extensive references to bibliography, data sources, indexing, abstracting and other information sources, broadly categorized by technical subjects which they cover.

Also included, in Appendixes B, C, and D, is a comprehensive series of "generic trees" which provide a graphical presentation of structured thesaurus relationships in most technical areas of interest to the designer. Many data indexing systems are structured on a similar basis. By locating a term descriptor in which he is interested in one of these trees, the user may identify narrower terms which better define his interests and thus prevent an avalanche of superfluous information, or a broader term through which information may be sought if previous efforts have been unsuccessful. The trees are also useful as design effort stimulants since they aid in the creation of a perspective and may automatically suggest alternate approaches.

Indexing terms in the handbook index (with the exception of the few terms identified by an * in front of the entry, which are drawn from the Army materiel life cycle system) are all contained within these trees. Thus the complete text of the handbook is geared to the appendices and to a method for securing additional information on virtually any technical subject of interest.

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PART ONE THE ARMY DESIGN ENVIRONMENT

CHAPTER 1

BASIC CONCEPTS AND CONSIDERATIONS

1-1 INTRODUCTION

To contribute to the development of a new item of military hardware, the design engineer must operate within a controlled environment and conform to a set of prescribed standards. This environment is determined by the life cycle of the product, which consists of the concept, definition, development, production, operational, and disposal phases, as shown in Fig. 1-1. The prescribed standards applicable to each phase of the Army Life Cycle[1]* provide the designer with descriptions of the various required characteristics of the product.

During each stage of development, an organized and systematic pattern of events must take place if a design is to fully meet all of its objectives. Implicit in these objectives is the requirement that a design achieve the highest possible degree of producibility. However, producibility goals are rarely defined in documents describing the end item, such as the Qualitative Materiel Development Objective (QMDO), the Qualitative Materiel Requirement (QMR), or the Small Development Objective (SDO).[2]

Since the design effort has often been conducted to satisfy a description which includes no reference to producibility, the design engineer may easily neglect it as an element of his responsibility or overlook its effects on the total design. This handbook is intended to assist the designer in recognizing producibility implications and to provide guidance in designing to maximize its benefits.

1-2 DEFINITION OF PRODUCIBILITY

For the purposes of this handbook, producibility is defined as the inherent elements of a design by which an object, while meeting all of its performance objectives within the design constraints, may be produced in the shortest total time, at the lowest cost, with the most readily available materials, using the most advantageous processes and assembly methods.

By definition, then, the performance objectives must not be compromised or adversely affected by factors introduced to maximize producibility. The design which meets the performance objectives and yet can be produced in the simplest and most economical manner will have the maximum practical producibility. Producibility is, in reality, cost effectiveness practiced by the design engineer during the concept, definition, development, and production phases of the life cycle.

It may be argued that producibility is the same as value engineering. However, while value engineering studies most certainly contribute to the producibility of an end item, they constitute only one aspect of producibility. Value engineering studies and trade-off analyses normally are conducted when various approaches to fabrication and inspection are known to exist, but decisions concerning the most favorable and appropriate approaches cannot be made without detailed investigation and evaluation. In cont[illegible] of the objectives of producibility can be met b[illegible]n engineer without the need for exhaustive ana[illegible] the use of formal value engineering techniques.

1-3 PRODUCIBILITY IN DESIGN DEVELOPMENT

This handbook assists the design engineer in recognizing the design areas where producibility can be improved. Relatively little space is devoted to the creative aspects of the design process itself. It is not intended, however, to minimize the role of creativity, a fundamental ingredient of the design process. Rather, the

*Superscript numbers refer to the References at the end of each chapter

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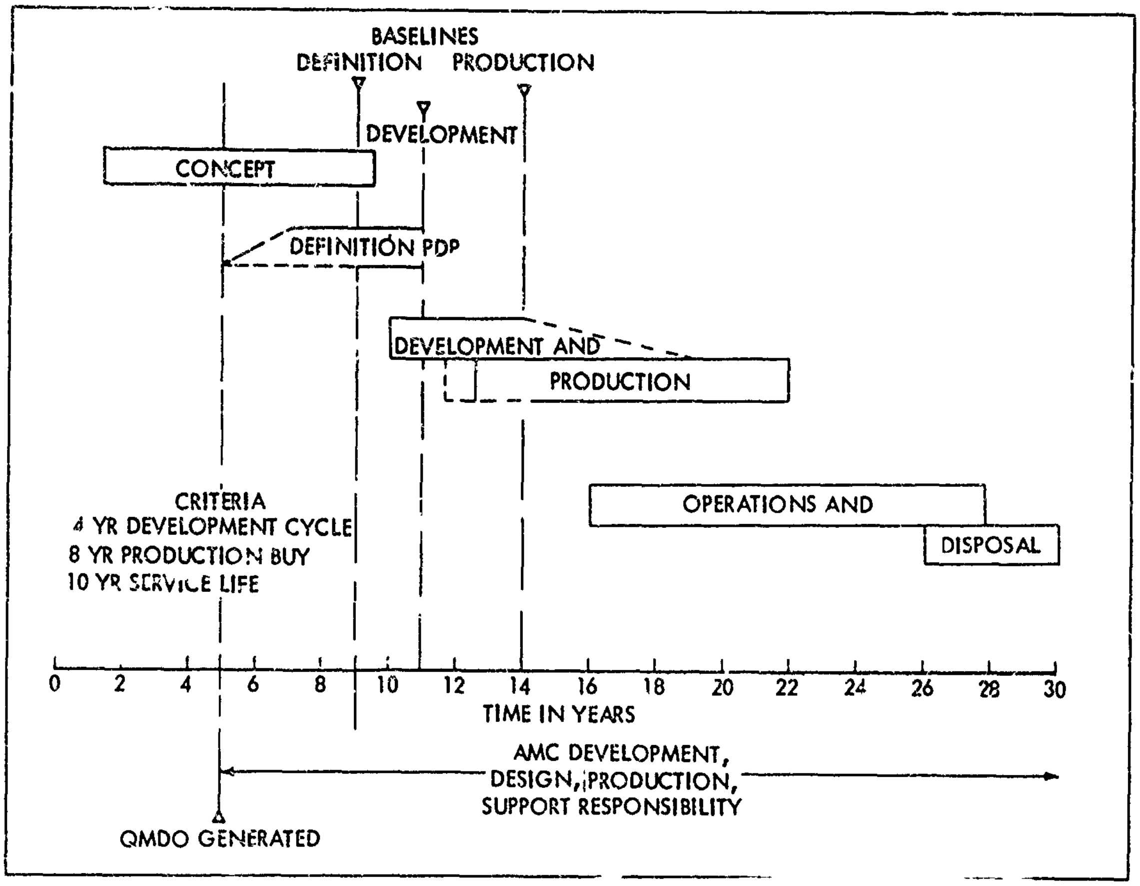

FIGURE 1-1. Life Cycle Spectrum

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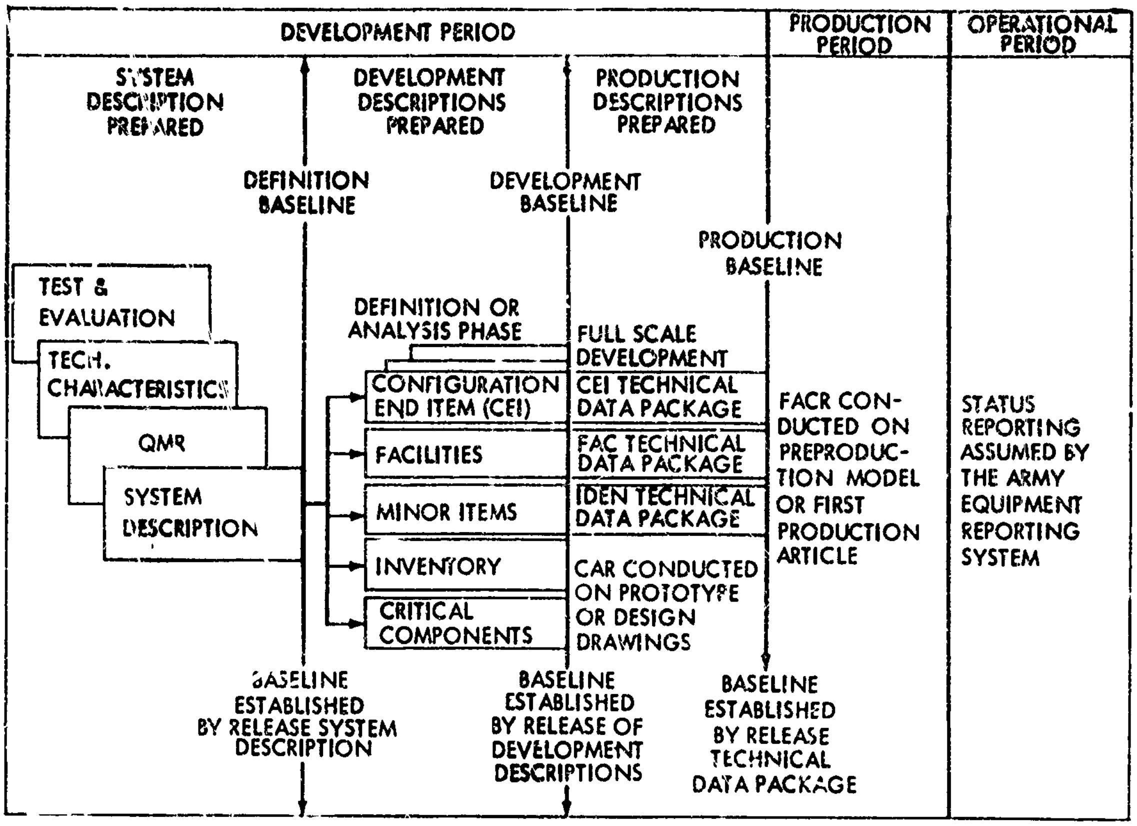

FIGURE 1-2. Life Cycle Baselines

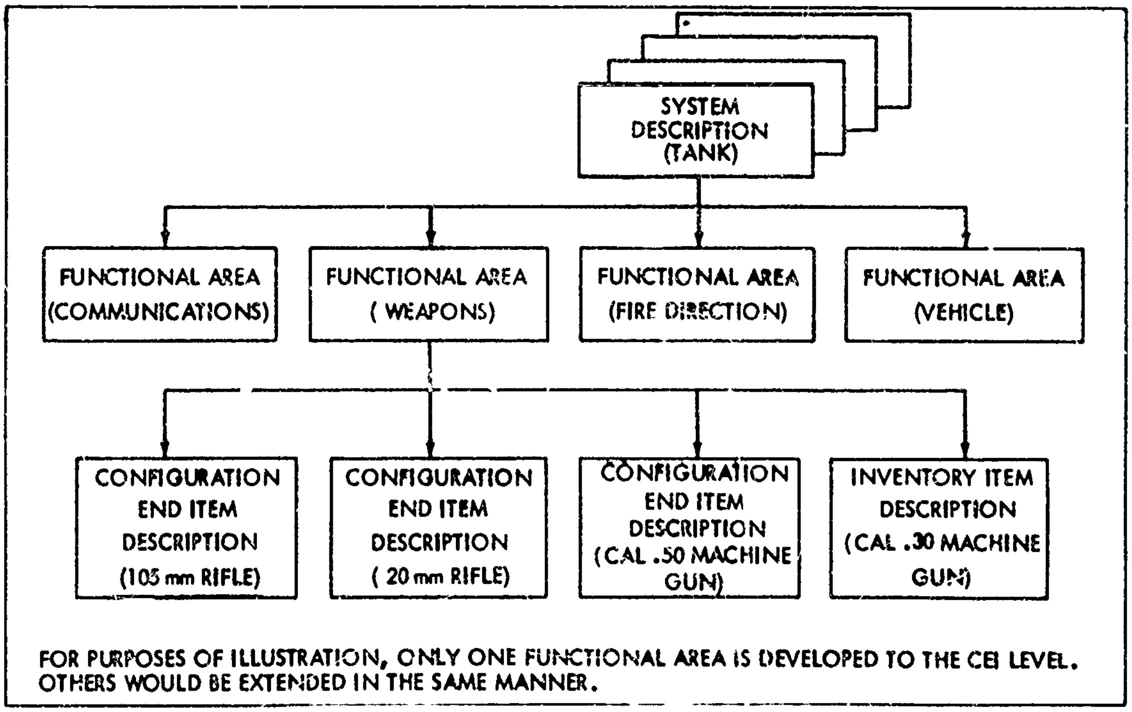

FIGURE 1-3. Specification Tree for Typical System

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intention is to provide guidelines in developing the most producible design attainable that is still compatible with all of the prescribed performance objectives.

1-3.1 CONCEPT FORMULATION PHASE

Concern for producibility must be exercised at the start of the concept formulation phase and must influence the entire design effort. Inherent limitations to producibility must be recognized at each stage in the development and production process. For example, during the concept phase, broad producibility considerations might be choosing materials and processes for major elements. Later considerations and problems are likely to involve specific steps in fabrication and specific features of each element of the product. The engineering efforts expended during the concept and definition phases should be directed to effective and suitable documentation of requirements and recommendations for use in the development phase, e.g., a system description.

Some general decision rules which lead to good designs with intrinsic producibility can be identified. Among these are "simplicity" and "standardization" in design components and manufacturing processes. However, all demands upon the system—such as reliability, maintainability, safety, producibility, etc.—heavily interact with each other, creating the need for trade-offs. These can only be considered in light of all their possible ramifications, and with recognition that the means to producibility cannot permit performance degradation below that level established by the design requirements.

The technical research projects initiated by the QMDO plan are directed largely toward filling technological gaps or deficiencies, to evolving potential concepts, and to identifying and evaluating the risk of failure to attain operational status. The results of this effort mark the end of the concept phase and the commencement of the definition phase.

1-3.2 DEFINITION PHASE

Work during this phase consists entirely of exploration and preliminary development. Preliminary engineering and contract and management planning are accomplished to ensure management decisions are made on a total system/total cost basis, including both realistic cost and schedule estimates, as well as achievable performance specifications. The definition phase affords the developer an opportunity to perform trade-off analyses, cost-effectiveness studies, and system analyses, to establish improvement coefficients, to ensure that the necessary building blocks and components are available; and to select the best technical approach. A principal objective of this phase is to establish total feasibility, including system effectiveness, personnel implications, operational concepts, and logistic support requirements.

A System Development Plan (SDP) is prepared and this, together with the QMR, is submitted to the Department of the Army (DA) for program approval. DA approval results in initiation of the development project. Active consideration must be given throughout this series of events to the basic elements of producibility.

Initiation of the development project represents the establishment of the first configuration baseline, the Definition Baseline (Fig. 1-2), consisting of the QMR's, the Technical Characteristics (TC's) and the Test and Evaluation Requirements (TAER's). This combined documentation forms the System Description. The Definition Baseline also represents the point of transition between investigatory research and development and design engineering. It is at this point in the life cycle that the efforts of the design engineer are introduced and emphasized.

In the case of a major system, a formal contract definition phase may follow. This consists of the initial design work, with any associated developmental hardware fabrication and testing, performed to expand the system description into a complete series of development descriptions for equipment items or major components, minor items, critical components, facilities, and inventory items. This phase does not result in a detailed design, but establishes the detailed parameters and descriptions from which detailed design engineering can proceed.

1-3.3 DEVELOPMENT AND PRODUCTION PHASE

The definition phase culminates in the establishment of the second baseline, the Development Baseline at which point a family of basic descriptions, or specifications, has been developed. Fig 1-2 shows a simplified specification tree of these for a typical system. Less complex systems may not require this step, and, since the design considerations for producibility during the development phase are virtually identical with those of the previous step, the first and second baselines may therefore be considered as one.

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1-4 IDENTIFYING PRODUCIBILITY OBJECTIVES

Regardless of the degree of complexity of a system or item, the objective is to create a design which will satisfy all the specified functional and physical objectives and yet be producible.

The definition of producibility given in par. 1-2 may represent this as an easily achieved objective. However, several influences (which the system description will assist in defining) complicate recognition of the specific producibility objectives. These are:

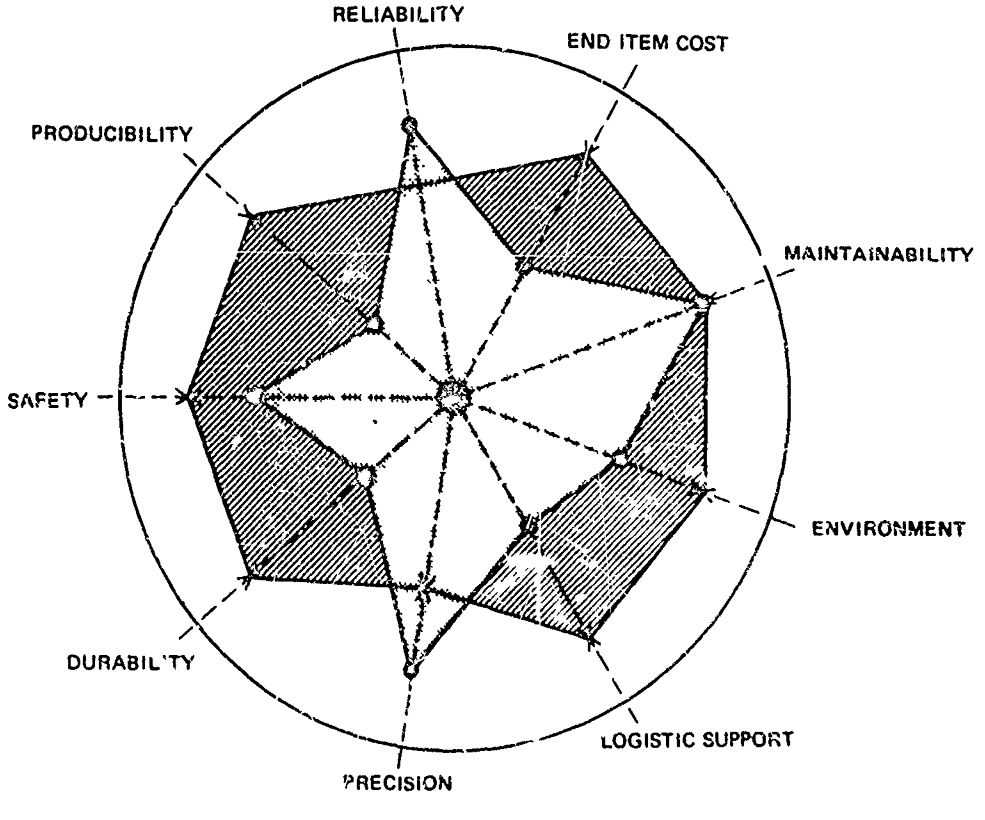
(1) To maximize:
- (a) Simplicity of design
- (b) Standardization of materials and components
- (c) Potential industrial production capability
- (d) Confirmation of design adequacy prior to production
- (e) Process repeatability
- (f) Product inspectability
- (g) Industrial safety in production
- (h) Competitive procurement

(2) To minimize:
- (a) Procurement lead time
- (b) Use of critical (strategic) materials
- (c) Special production tooling
- (d) Special test systems
- (e) Use of critical processes
- (f) Skill levels of production personnel
- (g) Unit costs
- (h) Design changes in production
- (i) Use of limited availability items and processes
- (j) Use of proprietary items without production right releases

Since these "maximize" and "minimize" objectives are not constant, they cannot be properly evaluated and pursued without answers to the following questions:

(1) Is the design for an experimental or production model only, or should the design actively consider production quantities?

(2) If production quantities are to be considered, what is the probable lot size, and what is the relationship of this lot size to potential requirements in a state of mobilization?



EXPAND PARAMETERS AS NECESSARY TO REFLECT PERFORMANCE OBJECTIVES AND DESIGN CONSTRAINTS

FIGURE 1-4. Design Quality Diagram

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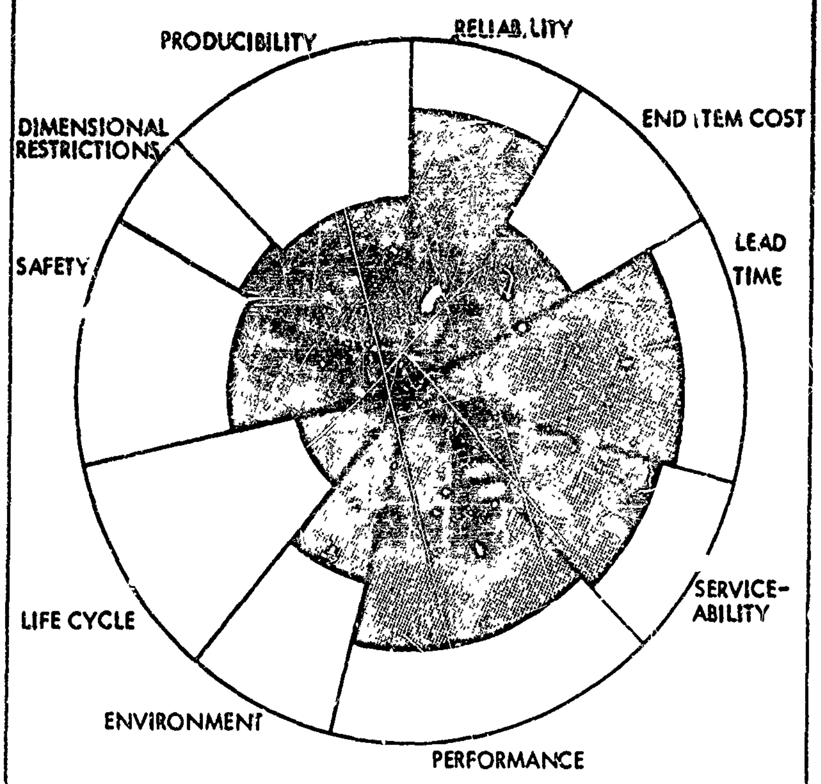

EXPAND PARAMETERS AS NECESSARY TO REFLECT THE PERFORMANCE OBJECTIVES AND DESIGN CONSTRAINTS

FIGURE 1-5. Design Difficulty Diagram

Since any design represents a compromise between the various requirements placed upon it, the design effort is buffeted by conflicting values placed upon various attributes of the design From conception to obsolescence, these attributes undergo time-based changes Thus, in the early stages of the design process, time is often described as of the essence, and there is a push to meet the schedules. In the middle history of a project, more emphasis may be placed upon producibility and value, while near the end of the line, when an item is about to be phased out, concern will often be expressed over excessive spare parts costs.

An attempt to ensure that all relevant factors are adequately considered when initiating a new design and to indicate the way in which their relative values interact has led to the development of the Design Quality Diagram, Fig. 1-4

Terms describing attributes of the design of major importance are placed at various points around the circumference of the circle Radiating lines leading out to each of these terms provide scales for marking in a point that represents the value assigned to each of the design attributes. The center of the circle represents a minimum value on each scale and the circle represents the maximum, which might be called "the highest possible degree of importance, overshadowing everything else".

The design description will usually provide the direction a product design should take to meet all objectives—except producibility The producibility objectives list must be reviewed in terms of the design description, in conjunction with information on intended lot size, in order to properly evaluate and introduce this factor into the design quality diagram. All other requirements should be directly associated with the performance objectives and design constraints of the System Description (see Chapter 3) When agreement is reached, the diagrammer can fill in relative values on an arbitrary scale, such as 0 to 100, and draw connecting lines from point to point, so as to enclose an area The size of the diagram represents money to be

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spent on the design, and the shape of the area indicates where the money will go. If more attention is required by one facet of the design, more man-hours or more highly qualified personnel will be required—with resultant higher costs.

Two diagrams are superimposed on the same set of coordinates in Fig. 1-4. The star-shaped, or more deeply indented, diagram may represent a special equipment, intended to do a precise job for one year, with no repeat production. The ρ (radius) values associated with the various design attributes indicate the opinion of the planning team on factors that are important in such a design. The more nearly rectangular, larger diagram represents the design for a standard equipment which will be used for every conceivable purpose within its range, and which will be in production for several years. The envelope extends beyond that of the special equipment in several areas to improve the general acceptance of the design and falls below it in only a few points. The net result is a design that would be called balanced if the meaning of the word is restricted to "meeting each of the requirements about as well as it needs to". (This does not imply that there is anything wrong with the special machine design, which has less generalized design objectives.)

The area of the diagram represents money, and the total area available is the amount budgeted for the expense of the work. Within the limit thus established, the relative ρ values may be juggled in and out as discussion progresses, always bearing in mind that an increase in one will necessitate a reduction in another, to avoid cost overruns. This is referred to as the "mobility" of the diagram, the term being limited to adjustments made within the limits of the originally established area. Other adjustments possible within the diagram are those of inflation or deflation. Inflation occurs if it is decided that the job warrants more funding to strengthen it in certain areas without sacrificing in others. The operation is performed by pumping dollars into the area to expand it. Deflation is simply the opposite operation—deciding the job is goldplated, opening the valve, and letting the dollars drain out.

Most of the discussion about the diagram ex post facto will concern the phenomenon of mobility, which permits changes in the appearance of the job as it progresses. Mobility will occur with relative ease in the early stages of product development, but the closer the delivery date and the more hardware commitments made, the stiffer the diagram becomes, until at last it has totally congealed. The stiffening rate is variable as a function of the flexibility of the organization. Generally, large and over-organized engineering departments will see their diagrams congeal rather rapidly. Since stiffening is largely an inbuilt characteristic, it is not referred to as one of the permissible adjustments. It is mentioned only as one of the deterrents to unlimited mobility.

In order to represent distribution of dollars among the various attributes more accurately, a modified form of the diagram, Fig. 1-5, is suggested. In this style of diagram, the ρ values indicate the relative importance of the items as before, but the θ (central angle) values represent the relative difficulty of achieving "unit degree" of improvement. For this method, instead of a point along one of the radii, a sector is filled in between two lines, bounded on the outside edge by an arc whose radius indicates the ρ value. The θ value is indicated by the angular width of the sector. Thus it is apparent that unit improvement in a wide sector will require that more area be filled in. This diagram shows graphically how dollars can be expended rapidly in a wide sector without much improvement. Also, as each sector grows in the ρ direction, the dollars per ρ increase. This shows the relative slowing in improvement as the ultimate is approached. If "ultimate" were taken to mean "perfection", this representation would not be valid, because ρ values would have to be asymptotic to the ultimate circle. No pretense is made that ultimate means perfection; it merely means that this particular attribute receives top priority, regardless of resultant lopsidedness of the picture.

The diagram in Fig. 1-5 represents only the special equipment in Fig. 1-4 and some of the attributes have been rearranged around the circle to exaggerate the lopsidedness. It becomes immediately apparent that the diagrammer can make this exaggeration look good or bad according to how he arranges the different items. This manipulation can be partially avoided by adopting a standard distribution of the attributes around a circle, unless there is some unusual condition. Hence, the standard diagram can be made with traditionally important attributes alternated with traditionally less important ones around the circle, so that for the "normal" or "usual" job the first sketch, at least, appears to be in static balance. Then, any unusual condition will give an indication of unbalance and will receive more attention than would be the case where random distribution of the items makes all jobs look lopsided.

A major convenience would result by assigning some sort of scales to the ρ values if quantitative comparisons could be made from one job to another. The difficulty arises from the change in scale implied in the situation of Fig. 1-4 where the actual dollars of the standard design might be ten times as many as for the special machine, but its diagram is only about twice as large. Obviously the two diagrams are not drawn to the same

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scale. The user is thrown back on the generalization that ρ indicates relative values only, which was the original intent. However, there is nothing to prevent drawing the ultimate circles of various sizes to indicate the actual financial range being considered for each job.

REFERENCES

AR 70-37, *Configuration Management*, Suppl. 1.

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CHAPTER 2

DESIGN EVOLUTION

2-1 ROLE OF CONFIGURATION MANAGEMENT

The progression from QMR to production is essentially one guided by configuration management which is a formalized system for documenting established military requirements for materiel. Its purpose is to protect the integrity of the established configuration by a prescribed control method utilizing reference points (or "baselines"). These baselines are defined by documentation:

(a) Definition Baseline—the system description

(b) Development Baseline—the development description

(c) Production Baseline—the production description (also called Technical Data Package (TDP))

Configuration management is a required AMC management discipline. This chapter discusses those facets which are of most concern to producibility. AR 70-37 [1] provides greater detail regarding the formal process of configuration management and delineates the contents and format of both the system and development description.

2-2 PRODUCIBILITY AND THE SYSTEM DESCRIPTION

The degree to which producibility is achievable is largely influenced by the system description. A breakout of its components is illustrated in Appendix B, Fig. B-2.

This paragraph discusses some of the interrelationships and factors which must be considered by the designer. The material is presented in a sequence coincident with that of the six sections of the system description.

2-2.1 SCOPE

The scope section of the system description provides a broad descriptive discussion of the system. It explains, in general terms, what the designer is to create and establishes the framework within which producibility aspects can be considered. The scope section further serves as an introduction to the "Requirements" section of the system description in which the major producibility influences are found.

2-2.2 APPLICABLE DOCUMENTS

The applicable documents section of the system description is an index of the specifications, standards, drawings, bulletins, manuals, etc., referenced in Sections 3 through 5 of the system description and thus incorporated by reference. Some specifications and standards references may be program administrative requirements, however, the information they contain forms a useful guide. This section is an early indication of the producibility requirements and the potential problems.

The applicable documents section also lists any requirements for the selection of MIL-STD materials and parts, specific processes, or special components (particular processes or "building block" components which may have been experimentally developed during the concept stage). This provides an excellent overview of the fixed design and fabrication requirements and constraints, and may be used to review the producibility limitations placed on the design.

2-2.3 REQUIREMENTS

The majority of producibility variables introduced by the system description are found in its requirements

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section. The relative influence of each type of information upon producibility can be roughly tabulated as shown in Fig. 2-1. The requirements of the system are detailed within the requirements section, under nine principal headings. These are discussed in the paragraphs which follow.

2-2.3.1 Performance

The performance statements in the system description provide a detailed description of the intended performance of the system. They will generally include the following:

(a) Performance Characteristics
  (1) Operational
  (2) Employment
  (3) Deployment
(b) Operability
  (1) Reliability
  (2) Maintainability
  (3) Useful Life
  (4) Natural Environment
  (5) Transportability
  (6) Human Performance
  (7) Safety
  (8) Dangerous Materials and Components
  (9) Noise and Vibration
  (10) Life Support

In the performance statements the designer is told what the system must accomplish. These statements are the performance objectives for the system. Subsequent statements in the requirements section describe the physical, functional, and support framework for the system. These subsequent statements are substantially constraints placed on the design. The relationships between the performance objectives and the constraints establish the potential standards of producibility for the design. If the statements giving constraints rigidly specify the system, subsystem, component, materials, and manufacturing or production processes, the producibility level of the design is largely predetermined (even though it may not have been a primary consideration in establishing the specification). As the degree of latitude expressed in the constraint statements increases, the producibility potential of the system becomes greater and the direct influence of the design engineer upon eventual producibility also increases proportionally.

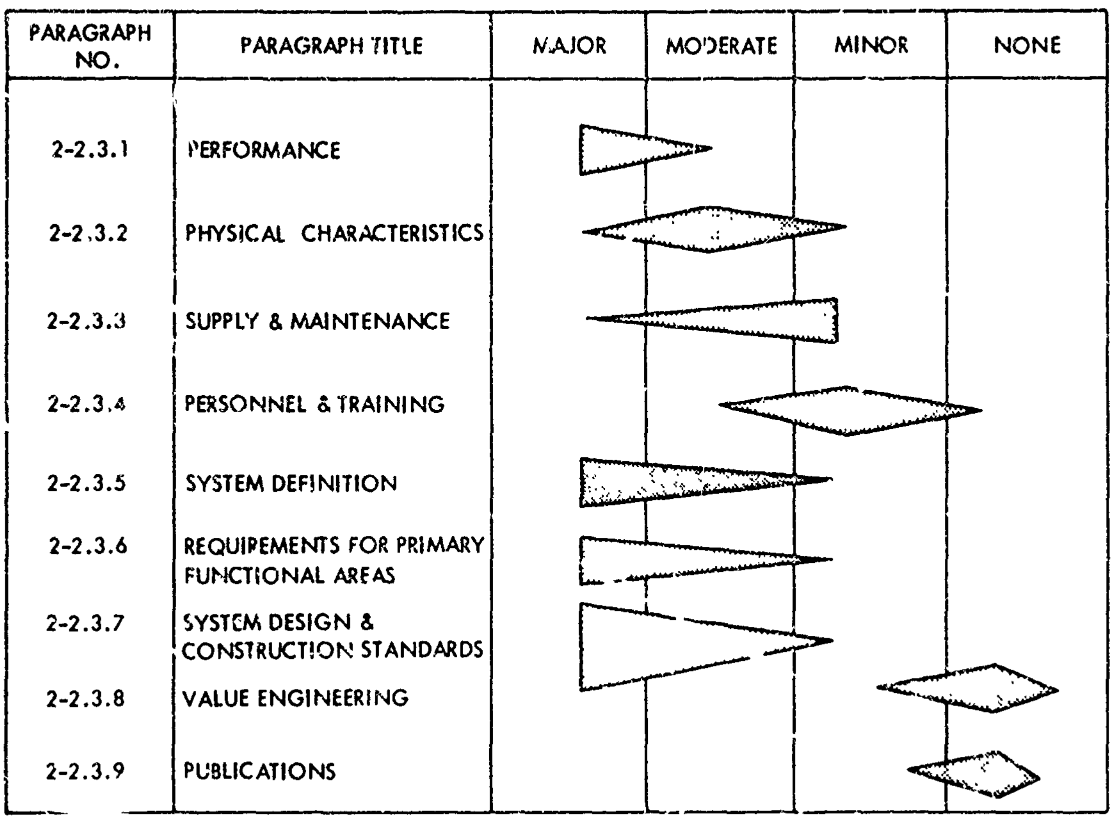

FIGURE 2-1. Influence of Requirements on Producibility

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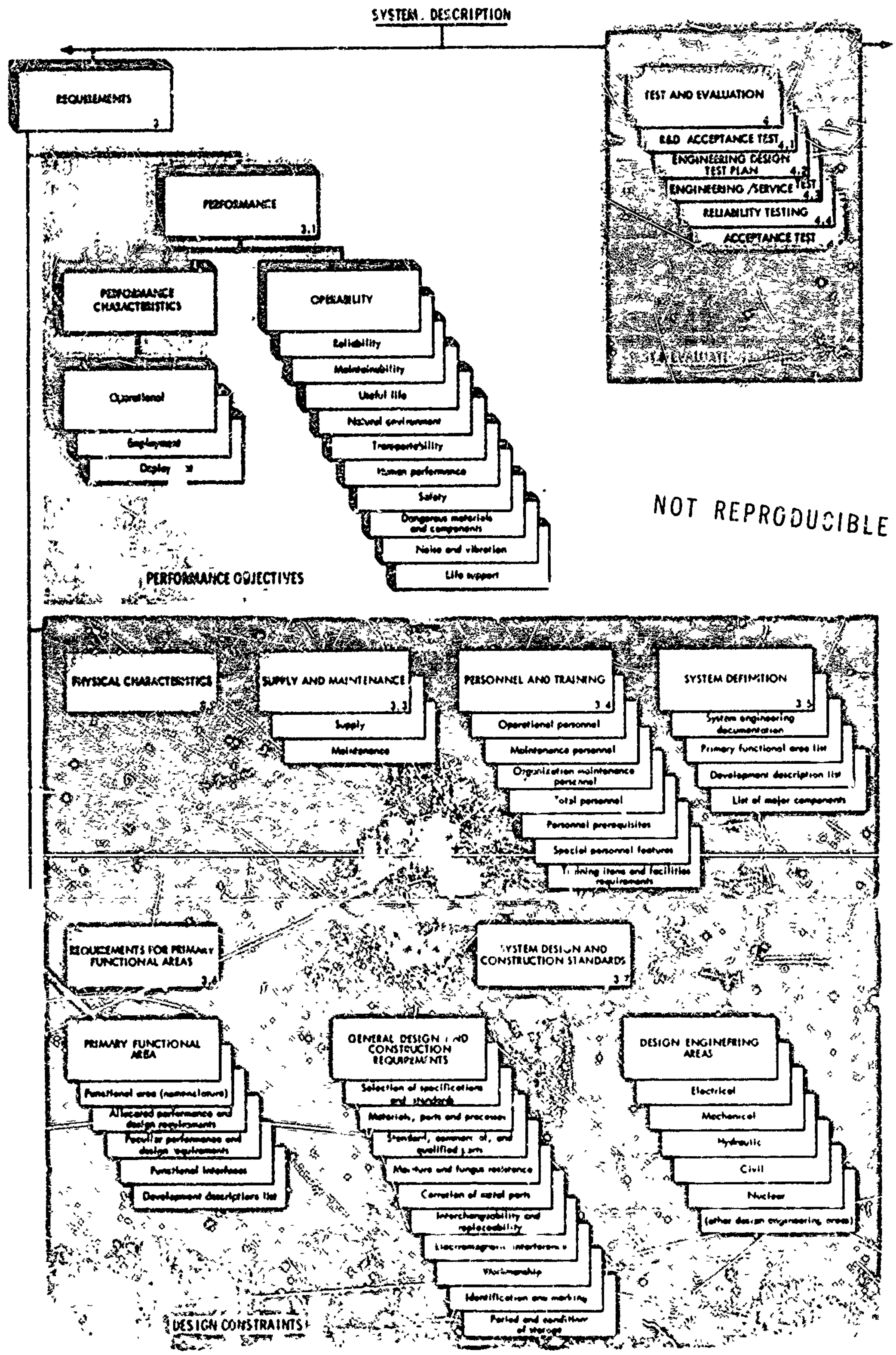

FIGURE 2-2. Performance Objectives, Design Constraints, Test and Evaluation Requirements in the System Description

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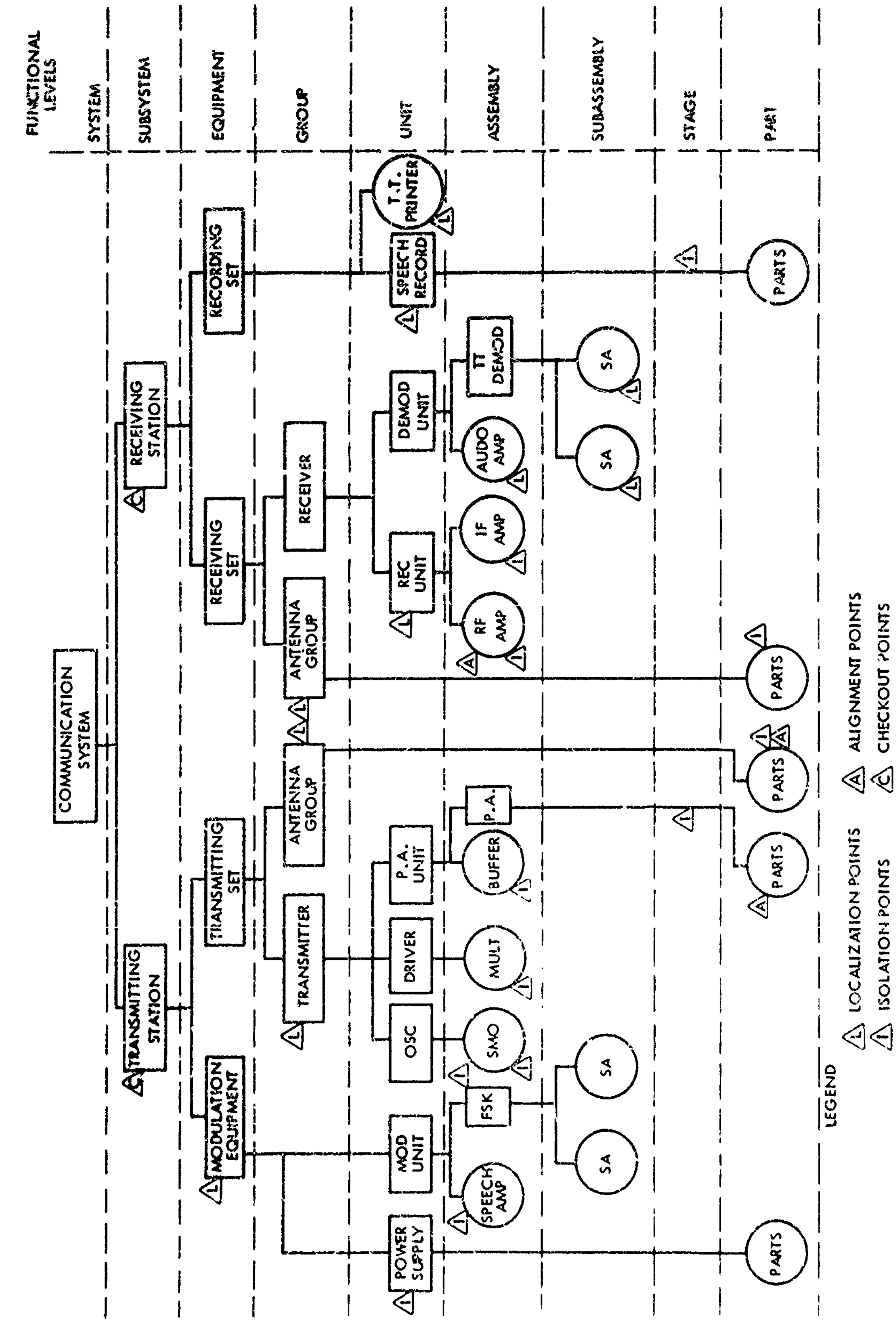

FIGURE 2-3. Typical Functional Breakdown Factors

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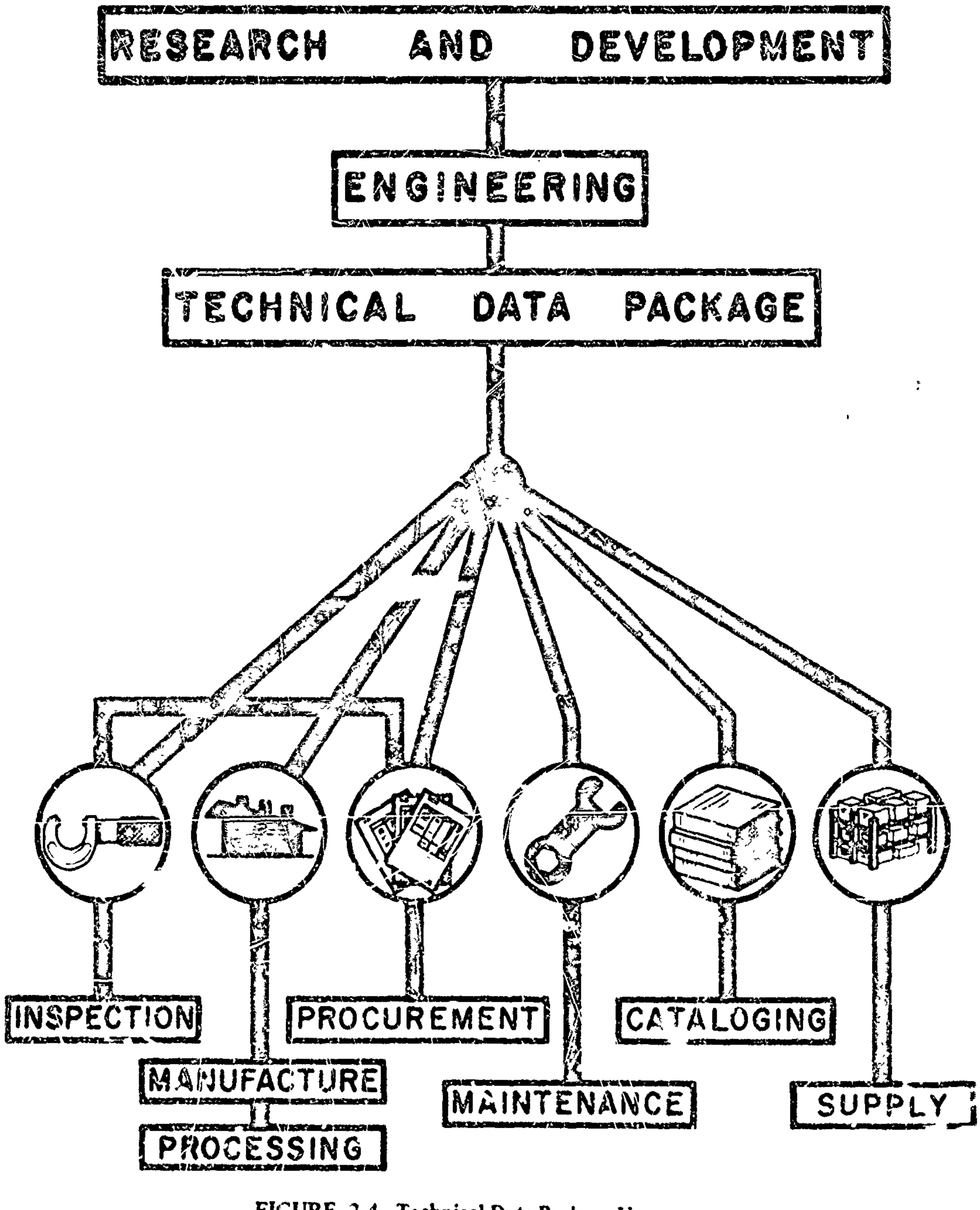

FIGURE 2-4. Technical Data Package Usage

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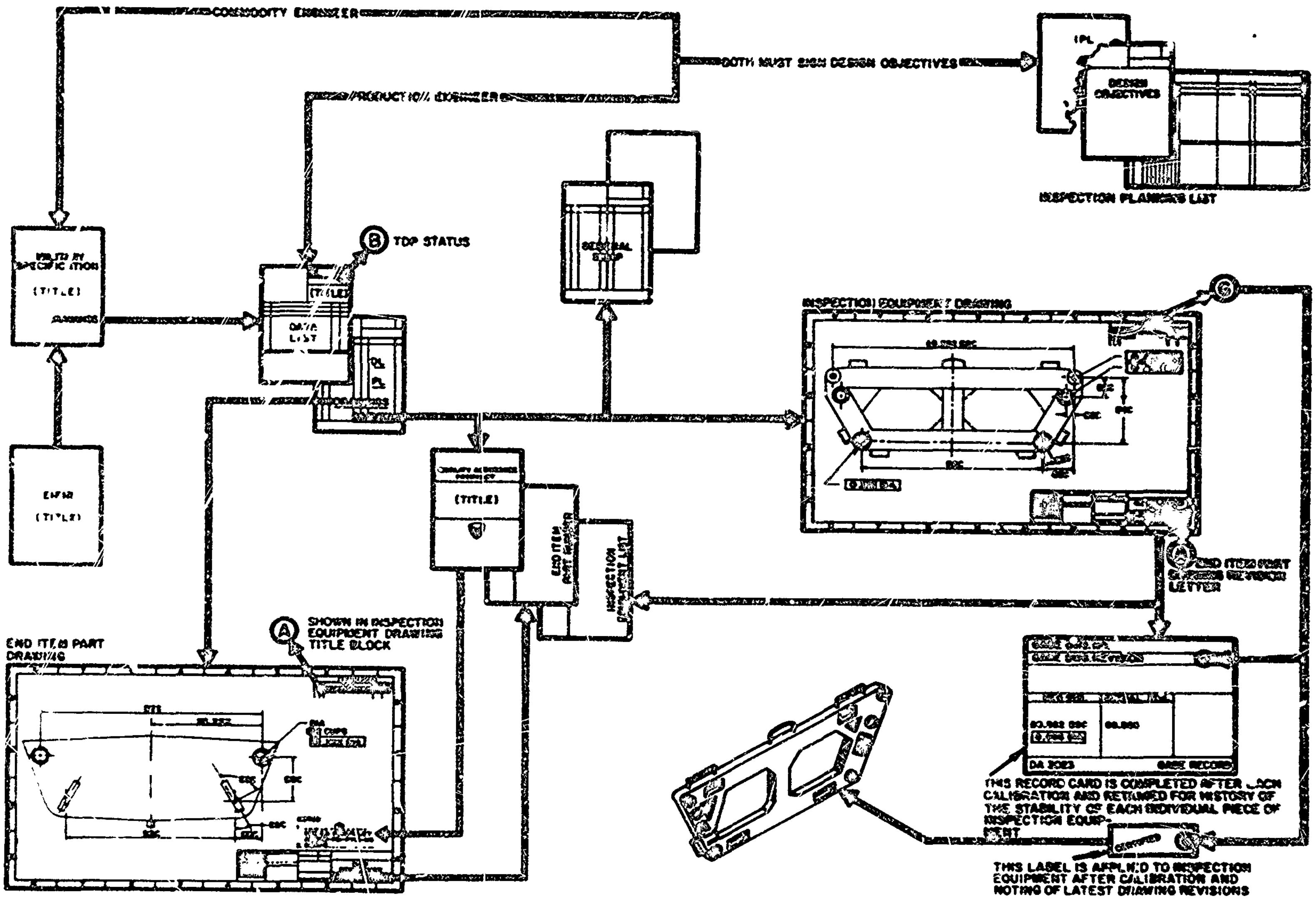

FIGURE 2-5. Technical Data Package (TDP) Document Interrelationship

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2-2.3.2 Physical Characteristics

The statement of physical characteristics for the system reflects the first constraints placed upon the designer. These statements generally include:

(a) Required physical limitations of the proposed system
- (1) Dimensions
- (2) Weight
- (3) Major assemblies

(b) Requirements for operator station layout

(c) Intended means of transport

(d) Degree of ruggedness required
- (1) Storage
- (2) Transportation
- (3) Use

(e) Potential effects of explosives

(f) Hazards
- (1) Biological
- (2) Mechanical
- (3) Radiation
- (4) Other

These statements will place some constraints upon producibility. (The system might, for example, be more simply designed and more cheaply and easily fabricated if the weight limitations could be increased by 5%.) At the same time, the requirements which they impose furnish additional producibility objectives since they describe physical characteristics toward which considerations of producibility can be directed.

2-2.3.3 Supply and Maintenance

The influence of supply and maintenance statements in the system description upon producibility is highly variable. They are meant to identify the potential impact of the proposed commodity on the supply system and, conversely, the considerations which the supply system imposes upon the design and use of the commodity or item. In addition, basic maintenance policy, such as use of multipurpose test equipment and modular replacement approaches, may be stipulated.

The supply and maintenance statements must be reviewed in conjunction with the maintainability objectives given as part of the performance objectives to fully determine their combined influence upon design. Their principal combined influence is in the form of a constraint upon design and, as a result, upon producibility In general, the supply and maintenance statements are the dominant consideration fr a producibility viewpoint since they directly dictate the design approach

The objectives of producibility and those of supply and maintenance are not necessarily compatible, except to the extent that they both ideally aim at cost reduction. Producibility should aid in reducing the cost of acquisition but must avoid increasing the cost of ownership which is usually many times greater.

2-2.3.4 Personnel and Training

The human factor implications that the designer must consider are given as the personnel and training requirements for the system. These are stated as requirements for operational and maintenance personnel: personnel prerequisites, special personnel features (such as an unusually arduous environmental exposure). and necessary training equipment and objectives. Such requirements may place constraints on producibility. They must be judged in this appraisal in conjunction with the human performance objectives given for the system.

2-2.3.5 System Definition

The system definition statements are directed to describing the proposed system from a functional standpoint. They include a general system identification, to the degree that it has been defined during the conceptual stage, system level functional schematics, and a list of all development descriptions. A list of major components may be included in the development description or may be added at some point during the development phase (in which case it becomes a function of the designer to develop and identify them).

The system definition statements provide additional producibility constraints Particularly significant is the listing of Government-Furnished Property (GFP) to be supplied for incorporation into the system. Compatible interfaces for the GFP must be assured This dictates specific features in the system

2-2.3.6 Requirements for Primary Functional Areas

Requirement statements given for primary functional areas are concerned with providing further refinement of the functional description given in the system definition statements The statements are directed to providing a more detailed description of the requirements for each primary functional area The detern

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nation of primary functional areas is stated as being "basic to properly limiting specified systems requirements and to fixing responsibilities for engineering tasks".

Each primary functional area statement is a key constraint upon design, but does not necessarily exert a proportionate influence on producibility. This is because they are functional in character imposing requirements on what the primary area is to perform without imposing limitation or restriction on how it is to be accomplished. This permits the designer to properly exploit trade-off considerations, including producibility, without doing violence to the basic performance intent.

2-2.3.7 System Design and Construction Standards

The design and construction standards applicable to the system are often listed in chart or table form. These statements more directly influence and constrain the producibility aspects of designing than any others given in the system description. They will normally include statement of, or reference to:

(1) General design and construction requirements
(2) Selection of specifications and standards
(3) Materials, parts, and processes
(4) Standard, commercial, and qualified parts
(5) Moisture and fungus resistance
(6) Corrosion of metal parts
(7) Interchangeability and replaceability
(8) Workmanship
(9) Electromagnetic interference
(10) Identification and marking
(11) Period and conditions of storage
(12) Design engineering areas

Each of these requirements identifies applicable documents, or sets of documents, with which the design must comply. There is only limited leeway for deviation from these standards which thus become the guidelines for design and producibility in the areas to which they apply.

Statements giving the system design and construction standards provide the designer with a valuable tool for evaluating potential versatility in applying producibility techniques to the design at all levels of the system. Since the discussion under "Design Engineering Areas" identifies specific requirements by design discipline (electrical, hydraulic, pneumatic, mechanical, civil, nuclear, etc.) it provides to the designer a clear picture of the required engineering and technological policy which must be followed.

A detailed analysis of the influence of the design and construction standards upon each primary functional area is prerequisite to proceeding with the design. Some of the primary influences exerted by the system description and approaches for their recognition and evaluation are discussed in par. 2-3.

2-2.3.8 Value Engineering

Statements relevant to the value engineering policy to be observed in the system design are given in the system description. Value engineering is a formal program intended to reduce cost; in this respect, it serves a basic objective of productibility. The goal of cost avoidance must exist whether or not a value engineering program is formally prescribed. This reasoning dictates that it be shown (in Fig. 2-1) as having no significant influence on producibility.

2-2.3.9 Publications

The requirements for technical manuals, etc., to support the equipment are given in the system description generally by reference to governing style guides and specifications. While these statements have marginal significance from a hardware producibility viewpoint, they are an integral part of the system and accordingly invoke producibility considerations in their own right

2-2.4 TEST AND EVALUATION REQUIREMENTS

The R & D Acceptance Tests, Engineering Design Test Plans, Engineering Service Tests, Reliability Testing, and Final Acceptance Tests applicable to the system are given in the test and evaluation requirements section of the system description. Here the minimum test requirements for the total test plan are stipulated. The test and evaluation requirements are intended to verify, at each step in the program, that the product meets all of the specified performance requirements and constraints.

Failure to set up proper testing and evaluation procedures at an early stage in the development can result in a loss of producibility

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2-2.5 PREPARATION FOR DELIVERY

Specific instructions for delivery of the system, to the degree that they may differ from the normal procedure for the particular type of system or equipment involved, or the requirements for adherence to standard practice are given in the preparation for delivery section of the system description. In some instances, the deviations from the norm may be sufficient to influence design. To this degree, the requirements may contain producibility implications and impose additional constraints.

2-2.6 NOTES

The notes section of the system description is not binding upon design development and does not modify performance characteristics. It furnishes any material which may provide useful background information for the development of the design. It should be reviewed as an aid to producibility since it may contain references to previous studies concerning the suitability of materials or processes, or to design trade-off studies which can serve as a guide to improved design and producibility.

2-2.7 APPENDIX

In the case of highly complex systems, some material pertinent to and forming part of previous sections of the system description may be placed in an appendix. This material must be reviewed in the context of the particular requirements area to which it relates in order to determine its total impact upon the design and producibility.

2-2.8 OBJECTIVES AND CONSTRAINTS

The system description details the intended performance of the system, together with its physical and functional characteristics down to the primary functional level.

In the performance section, the requirements may be classified into two types of influence on design Performance Objectives and Design Constraints Fig. 2-2 shows into which type each of the sections and subsections of a system description falls

The performance objectives define the system or product to be designed The design constraints establish ground rules and a framework within which the designer must work. The formal system of configuration management provides controls which ensure that the performance objectives and design constraints are met. Further controls and checks are provided by the quality assurance program.

The designer must work toward a goal of achieving total system effectiveness. To accomplish this, he must create a design which:

(1) Meets the performance objectives

(2) Complies with the design constraints

(3) Achieves the highest practical level of producibility

(4) Achieves lowest cost of acquisition and ownership

Developing a design which exhibits conformance to the first two goals inherent in system effectiveness is, in itself, a monumental task. However, systems have been developed which do meet both broad classes of criteria, but which could not be produced. As a result, a totally useless project was pursued.

2-2.9 EVALUATING THE SYSTEM DESCRIPTION

All elements of the system description are interactive. Modification of any one element of the description almost inevitably affects others. Their combined influence on producibility is equally interactive. Whether viewed from a total system standpoint or from that of individual primary functional areas, the composite requirements set the limits of producibility.

Prior to start of the design effort, a thorough evaluation of the system description must be made to determine potential problems and complexities in developing the design. This review, while primarily directed toward an evaluation of the design requirements, serves as an indicator of the degree to which producibility aspects may be actively considered in the design. Design problems may vary significantly from one primary functional area to another, as may the influence of the design constraints As a result, separate evaluations must be conducted in each area

The manner in which the review is conducted may differ by commodity class and by individual system. Thus, no standard check sheet is suitable to all applications. Table 2-1 illustrates a fairly typical series of topics against which to evaluate the potential difficulty of a design task. Such an evaluation not only indicates the overall magnitude of the design task but also reveals individual design problems which may present difficulties

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TABLE 2-1. TYPICAL SYSTEM DESCRIPTION EVALUATION FACTORS

PARAGRAPH NUMBER*	PERFORMANCE OBJECTIVE	SIMPLEST DESIGN CONDITION	MOST DIFFICULT DESIGN CONDITION
3.1.2.4	Natural environment	Controlled artificial environment	Wide range, uncontrolled natural environment
3.1.2.5	Transportability	None	Maximum versatility
3.1.2.6	Human performance	Low system complexity with high intelligence and training level	High system complexity with low intelligence and training level
3.1.2.7	Safety	Unattended, remotely located	Highly flammable, toxic, or otherwise dangerous to life or property
3.1.2.8	Dangerous materials and components	No use of liquid or solid propellants, of nuclear components, of explosive ordnance, of toxic, corrosive. or radioactive materials	Wide use of liquid or solid propellants, of nuclear components, of explosive ordnance, of toxic, corrosive, or radioactive materials
3.1.2.9	Noise and vibration	Minimal noise; minimal vibration	Noise exceeding human tolerance; vibration exceeding normal structural stress capabilities
3.1.2.10	Life support	No requirement	Requirement for health factors, for control of atmosphere, for personal sustenance

*Subparagraphs of paragraph 3.1.2, Operability, which are required in all systems descriptions. Description of the contents and numbering of paragraphs in a system description is found in AR 70-37[1]. See also Fig. 2-2.

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TABLE 2-2. COMPARISON OF SYSTEM AND DEVELOPMENT DESCRIPTIONS

COMMON SECTIONS	SYSTEM DESCRIPTION	DEVELOPMENT DESCRIPTION
3. Requirements **3.1 Performance**		
	3.1.1 Performance Characteristics **3.1.1.1 Operational** **3.1.1.1.1 Employment** **3.1.1.1.2**	**3.1.1 Functional Characteristics** **3.1.1.1 Primary Performance Characteristics**
3.1.2 Operability **3.1.2.1 Reliability**		**3.1.1.2 Secondary Performance Characteristics**
	3.1.2.2 Maintainability	**3.1.2.2 Maintenance Requirements** **3.1.2.2.1 Maintainability** **3.1.2.2.2 Maintenance and Repair Cycles** **3.1.2.2.3 Service and Access**
3.1.2.3 Useful Life		
	3.1.2.4 Natural Environment	3.1.2.4 Environmental
3.1.2.5 Transportability 3.1.2.6 Human Performance 3.1.2.7 Safety		
		3.1.2.7.1 Personnel Safety 3.1.2.7.2 Equipment Safety
NOTE: At this point, the numerical sequence of the tables of contents for these two documents becomes notedly inconsistent with respect to each other; however, comparison between the two still is possible	3.1.2.8 Dangerous Materials and Components 3.1.2.9 Noise and Vibration 3.1.2.10 Life Support	
	3.2 Physical Characteristics 3.5 System Definition (breakdown follows) 3.6 Requirement for Primary Functional Areas (breakdown follows)	3.2 CEI Definition 3.2.1 Interface Requirements 3.2.1.1 Schematic Arrangement 3.2.1.2 Detailed Interface Definition 3.2.2 Component Identification 3.2.2.1 Government Furnished Property List 3.2.2.2 Engineering Critical Components List 3.2.2.3 Logistics Critical Components List
--------- NOTE ---------		
	3.7 System Design and Construction Standards 3.7.1 General Design and Construction Requirements	3.3 Design and Construction 3.3.1 General Design Features
3.7.1.1 - 3.3.2 Selection of Specifications and Standards 3.7.1.2 - 3.3.3 Materials, Parts, and Processes		
	3.7.1.3 Standard, Commercial and Qualified Parts	3.3.4 Standard and Commercial Parts
3.7.1.4 - 3.3.5 Moisture and Fungus Resistance 3.7.1.5 - 3.3.6 Corrosion of Metal Parts 3.7.1.6 - 3.3.7 Interchangeability and Replaceability 3.7.1.7 - 3.3.8 Workmanship 3.7.1.8 - 3.3.9 Electromagnetic Interference 3.7.1.9 - 3.3.10 Identification and Marking		
	3.7.1.10 Period and Conditions of Storage	3.3.11 Storage
	3.7.2 Design Engineering Areas (breakdown of areas)	3.3.12 Advanced Production Engineering
	3.4 Personnel and Training (detailed breakdown follows)	3.4 Technical Manuals and POMMS
	3.9 Publications	
	3.8 Value Engineering	---

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To derive the fullest benefit, the review is normally conducted in two stages. In the first step, the performance objectives given in the system description are individually reviewed and scored for design difficulty without consideration of the constraints contained in subsequent sections of the description. This furnishes the basic analysis. It is then rescored by reviewing the constraints contained in the requirements section of the system description. This yields a measure of the degree to which the constraints influence the design. This evaluation also serves to demonstrate the primary functional areas in which producibility characteristics of the design can be actively pursued and those in which the difficulty of achieving the performance objectives within the constraints will dictate the consideration of trade-offs of producibility factors.

The arbitrary nature of such an evaluation must be recognized. It is primarily an expression of opinion, ideally an opinion based on applicable experience. The value of the survey can be improved by conducting and comparing two or more independent analyses. It also can be given a measure of authenticity by using an existing similar system as a reference against which each factor of the requirements can be evaluated for its degree of simplicity or difficulty. Such an analysis is an essential prerequisite to the systematic approach to designing, discussed in Chapter 3, and recommended as an effective procedure through which producibility may be realized.

2-3 DEVELOPMENT DESCRIPTION

Where the system description sets forth the performance requirements, the available design criteria, and the test and evaluation requirements at the system and major component level, the development description provides an expansion of this information in terms of the system elements. It is a more detailed presentation, its release marking the development baseline of the life cycle. The objectives of performance, design, test, and evaluation of the components of a system should combine to equal the objectives of the total system.

The effort leading to the preparation of the development descriptions, as well as the accomplishment of the eventual design, is a responsibility of the design engineer. Starting with the information contained in the system description, the designer must generate the required detailed descriptions in a manner which will indicate just what is entailed in achieving the design—an interpretation of the system description designed to yield the eventual design. Thus it is clear that the development description is an important function of the design effort. It details the individual items of the system. Fig. 2-3 indicates the type of breakdown which might be developed for a typical communications subsystem of the total system down to the parts level.

There are five basic types of development description prescribed for detailing the major system components categories:

(1) *An Equipment Development Description* is prepared for items of equipment or major components to the lowest level at which logistic (hardware and software) support of the item is specifically considered.

(2) *A Minor Item Development Description* is prepared for simple items of issue, support items or components, e.g., items having very few or no repair parts, a low dollar value, or to which few, if any, changes are expected. The information requirements of this development description are basically the same as those for the equipment development description, as is the degree of detail. A minor item is usually considered a Contract End Item (CEI).

(3) *A Critical Component Development Description* is required for components which are considered to be functionally critical, logistically critical, or which are company standard components requiring repair parts.

(4) *A Facility Development Description* is prepared for facilities forming a part of a system, in a manner ensuring interface with the equipment it supports. It has the same significance as the equipment development description.

(5) *An Inventory Item Development Description* is the instrument used to specify existing inventory items necessary to support or to be installed in a system or equipment.

The first three listed descriptions are of principal interest to the designer. The comparison shown in Table 2-2 illustrates the parallelism existing between the system description and the development description. The paragraph numbers given in Table 2-2 refer to the numbering system actually used in the system and development description.

2-4 TECHNICAL DATA PACKAGE

The system description and the development description represent intermediate steps which serve as the basis for the development of the Technical Data Package (TDP). The TDP then becomes the vehicle used by the Army to convey its equipment manufacturing requirements to industry. The importance of the systematic approach to TDP preparation is in creating

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a logical progression of effort leading to precisely detailed requirements for every element of a required product.

The TDP documentation contains all design disclosure data, specifications, quality assurance provisions, and acceptance criteria required for development, production, and acceptance of the item. It provides the Government with an equitable basis for competitive bidding; and it provides industry with the official documentation needed for bidding, make or buy decisions, estimating, vendor item purchasing, specialty house procurement, and production engineering. It is the basis of Government acceptance or rejection.

The uses of the TDP are illustrated by Fig. 2-4. The contents include product specification, data list, parts list, drawings, quality assurance data, Government standards and specifications, industry standards and specifications, and end item final inspection requirements. The interrelationship among the contents of the TDP is illustrated by Fig. 2-5.

2-4.1 PRODUCT SPECIFICATION

The product specification is the basic document of the TDP; it contains general design criteria, performance requisites, and inspection procedures not covered by the drawings.

2-4.2 DATA LIST

The Data List (DL) is an inventory of the total content of the TDP (including those incorporated by reference) and a record of revision status. All specifications and standards (whether military, federal, or industrial) and all standard hardware items are identified. Figs. 2-6 and 2-7 are examples of the DL and the information which it contains.

2-4.3 PARTS LIST

The Parts List (PL) is indentured starting at the top part (the complete system) and gives the total physical content of the end item. A separate PL is prepared for each assembly which does not contain a List of Material (LM) on the drawing depicting it. The LM appears in the drawing only when the item is an inseparable assembly or a detailed drawing. Fig. 2-8 is an example of such a drawing.

The PL is associated with its assembly drawing by use of the same number. The assembly drawing lacks definitive specifications, item quantities, and connecting hardware information. Therefore, the PL serves to complete the data in a manageable and convenient format. Fig. 2-9 is an example of a PL.

2-4.4 DRAWINGS

Drawings are the heart of the TDP since they alone can control and completely delineate shape, form, fit, function, and interchangeability requirements for full competitive procurement. Military design drawings are prepared in accordance with MIL-D-1000, *Drawings, Engineering, and Associated Lists*[*]. This is a mandatory specification, derived from MIL-STD-100, *Engineering Drawing Practices*, which is a document gathering together all the old "how-to-do" standards under one cover. MIL-D-1000 covers format, types of drawings and associated lists, and drafting requirements.

All or part of the TDP received by the industrial user, bidder, or manufacturer may be in the form of 35-mm microfilm aperture cards, as prescribed by MIL-STD-804[*]. This format reduces the storage and shipping bulk of the TDP (or portion thereof) by about 95%. The use of aperture cards enables the user to reproduce as many copies as he may require.

TDP drawings are engineering, not production, drawings. DOD Instruction 5010.12[*] states that "End product documentation is defined as a design disclosure package which is sufficient to permit a competent manufacturer to reproduce an item without recourse to the original design activity". An engineering drawing applicable to a part, when supplemented by the referenced specifications and standards, should include all dimensions, tolerances, notes, and other data necessary to fully describe the characteristics of the part after all manufacturing has been completed. Examples of drawings are presented in Figs. 2-8, 2-10, and 2-11

2-4.5 QUALITY ASSURANCE DATA

The quality assurance data included in the TDP consists of the Supplementary Quality Assurance Provisions (SQAP), the inspection equipment drawings, and the appropriate quality assurance pamphlets SQAP's cannot contain elements not cross-referenced to the applicable design requirements on the parent document. The SQAP is an inspection instrument providing quality assurance check points (Fig. 2-12)

Certain end items requiring closely toleranced and geometrically controlled machined surfaces are ac-

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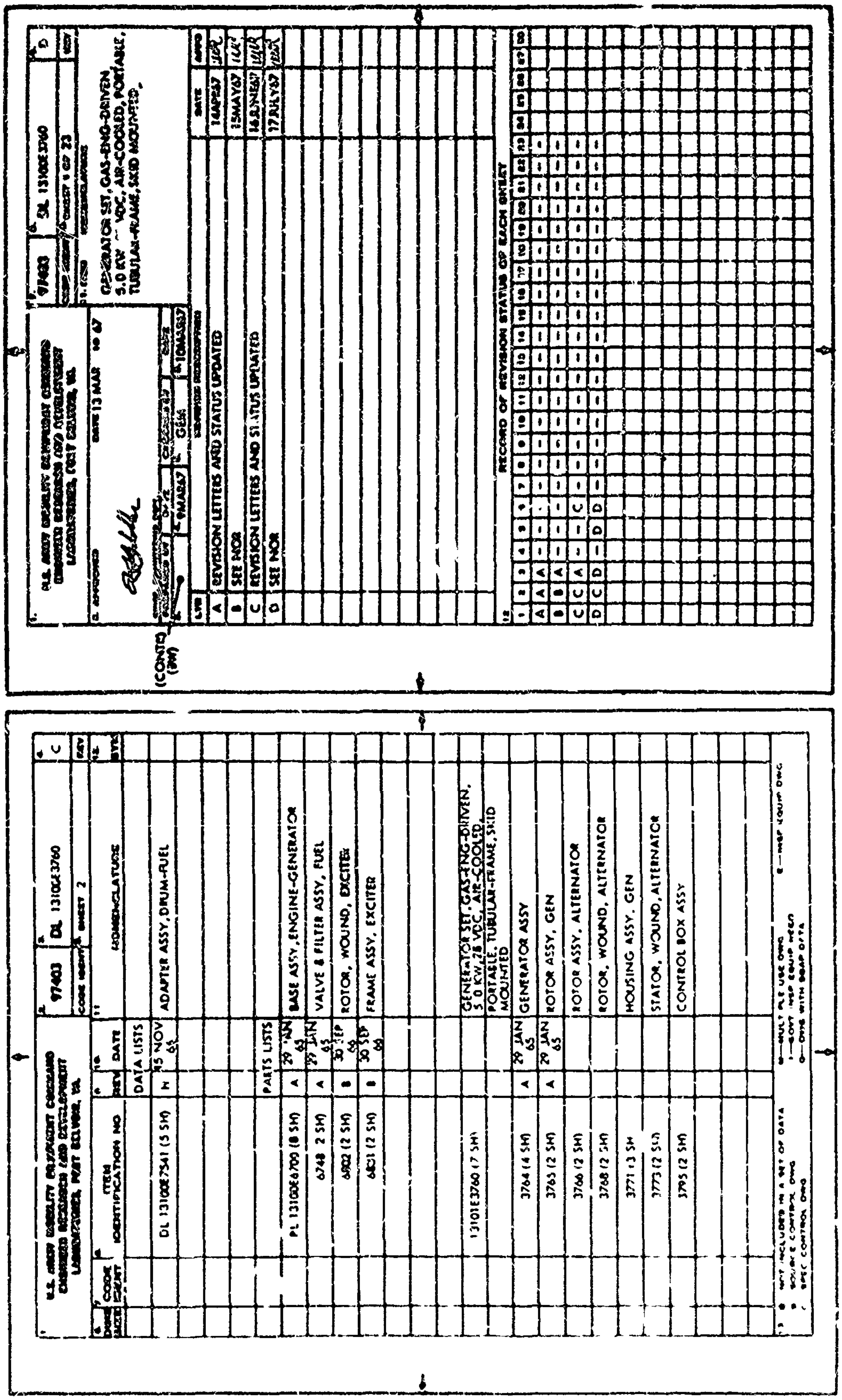

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97403 | DL 13100E3760 | C

CODE IDENT | SHEET 2 | REV

DWG SIZE	CODE IDENT	ITEM IDENTIFICATION NO	REV	DATE	NOMENCLATURE	SYS
				DATA LISTS		
		DL 13100E7541 (5 SH)	N	15 NOV 65	ADAPTER ASSY, DRUM-FUEL	
				PARTS LISTS		
		PL 13100E6700 (8 SH)	A	29 JAN 65	BASE ASSY, ENGINE-GENERATOR	
		6748 (2 SH)	A	29 JAN 65	VALVE & FILTER ASSY, FUEL	
		6802 (2 SH)	B	30 SEP 66	ROTOR, WOUND, EXCITER	
		6831 (2 SH)	B	30 SEP 66	FRAME ASSY, EXCITER	
		13101E3760 (7 SH)			GENERATOR SET, GAS-ENG-DRIVEN, 5.0 KW, 28 VDC, AIR-COOLED, PORTABLE, TUBULAR-FRAME, SKID MOUNTED	
		3764 (4 SH)	A	29 JAN 65	GENERATOR ASSY	
		3765 (2 SH)	A	29 JAN 65	ROTOR ASSY, GEN	
		3766 (2 SH)			ROTOR ASSY, ALTERNATOR	
		3768 (2 SH)			ROTOR, WOUND, ALTERNATOR	
		3771 (3 SH)			HOUSING ASSY, GEN	
		3773 (2 SH)			STATOR, WOUND, ALTERNATOR	
		3795 (2 SH)			CONTROL BOX ASSY	

● NOT INCLUDED IN A SET OF DATA; ● SOURCE CONTROL DWG; / SPEC CONTROL DWG; M—MULTIPLE USE DWG; I—GOVT INSP EQUIP NEED; O—DWG WITH DEAP DATA; E—INSP EQUIP DWG

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CODE IDENT | SHEET 1 OF 23 | REV

APPROVED — DATE 13 MAR 19 67

NOMENCLATURE: GENERATOR SET, GAS-ENG-DRIVEN, 5.0 KW — VDC, AIR-COOLED, PORTABLE, TUBULAR-FRAME, SKID MOUNTED

(CONTD) (3W)

PREPARED BY — DATE 9MAR67 — CHECKED BY GEM — DATE 10MAR67

LTR	REVISION DESCRIPTION	DATE	APPD
A	REVISION LETTERS AND STATUS UPDATED	14APR67	
B	SEE NOR	15MAY67	
C	REVISION LETTERS AND STATUS UPDATED	16JUNE67	
D	SEE NOR	17JULY67	

RECORD OF REVISION STATUS OF EACH SHEET

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
A	A	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B	B	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C	C	A	-	-	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D	C	D	-	D	D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

FIGURE 2-6. Data List Cover Sheet and Data List Continuation Sheet

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U.S. ARMY MOBILITY EQUIPMENT COMMAND ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES, FORT BELVOIR, VA. | 97403 | DL 13100E3760 | SHEET 3 | REV D

DWG SIZE	CODE IDENT	ITEM IDENTIFICATION NO	REV	DATE	NOMENCLATURE	SYM
		US ARMY TANK AUTOMOTIVE CENTER PARTS LISTS				
	00000	PL 10905417 (2 SH)			SHIFTING CONTROL	
				DRAWINGS		
B		9786E59-2	E	15 NOV 65	GASKET MUFFLER	C
C		13200E6140	D	29 JAN 65	LATCH ASSY	C
C		13210E6700 (2 SH)	A	29 JAN 65	BASE ASSY, ENGINE-GENERATOR	Q
C		6701 (4 SH)	A	29 JAN 65	SKID, GEN-BASE	
C		6702	B	30 SEP 66	MOUNT RESILIENT	
C		6703	A	29 JAN 65	CONNECTOR, RECEPTACLE [illegible] SLAVE W/BRACKET, MTG	Q
B		6706	A	29 JAN 65	TERMINAL LUG, INS	C
C		6707	A	29 JAN 65	BRACKET, MTG, RECEPTACLE, [illegible] SLAVE	Q
B		6708	B	30 SEP 66	CABLE, BATTERY, POS	Q
B		6709	A	29 JAN 65	TERMINAL BOARD	C
B		6710	A	29 JAN 65	CLAMP BATTERY, POS	C

* NOT INCLUDED IN A SET OF DATA; S—SOURCE CONTROL DWG; C—SPEC CONTROL DWG; M—MULTIPLE USE DWG; I—GOVT INSP EQUIP REQD; Q—DWG WITH GAP DATA; E—INSP EQUIP DWG

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DWG SIZE	CODE IDENT	ITEM IDENTIFICATION NO	REV	DATE	NOMENCLATURE	SYM
		INDUSTRY STANDARDS AND SPECIFICATIONS				
		AMERICAN IRON AND STEEL INSTITUTE				*
		STL PRODUCTS MANUAL			CARBON STL: SEMIFINISHED FOR FORGING; HOT ROLLED AND COLD FINISHED BARS; HOT ROLLED DEFORMED CONCRETE REINFORCING BARS	
		STL PRODUCTS MANUAL			CARBON STL: PLATES; STRUCTURAL SECTIONS- ROLLED FLOOR PLATES; STL SHEET PILING	
		STL PRODUCTS MANUAL			CARBON STL SHEETS	
		STL PRODUCTS MANUAL			STAINLESS AND HEAT RESISTING STL	
		AMERICAN SOCIETY FOR TESTING AND MATERIALS				*
		ASTM A 107			STL BARS	
		A 108			STL BARS AND SHAFTING	
		A 153			ZINC COATING	
		A 159			GRAY IRON CASTINGS	
		A 228			STL SPRING WIRE	
		A 366			STL SHEETS	
		A 386			ZINC COATING	
		A 415			STL SHEETS	
		A 536			DUCTILE IRON CASTINGS	

* NOT INCLUDED IN A SET OF DATA; S—SOURCE CONTROL DWG; C—SPEC CONTROL DWG; M—MULTIPLE USE DWG; I—GOVT INSP EQUIP REQD; Q—DWG WITH GAP DATA; E—INSP EQUIP DWG

FIGURE 2-7. Data List Continuation Sheets

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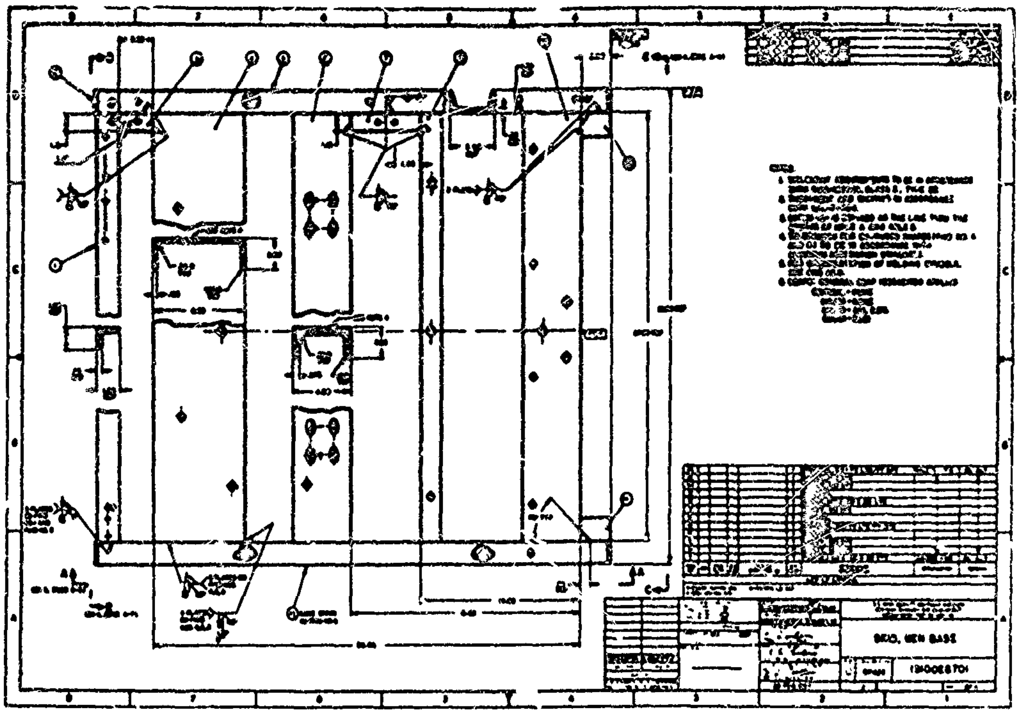

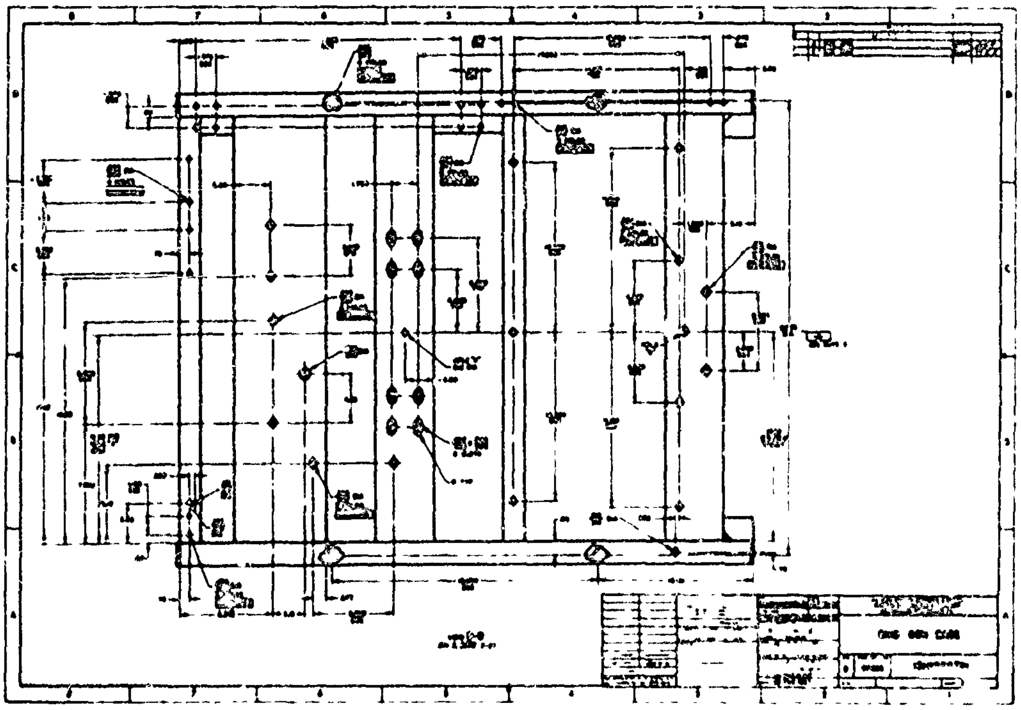

FIGURE 2-8. Inseparable Assembly Drawing

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(CONTRACTOR)

U.S. ARMY MOBILITY EQUIPMENT COMMAND ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES, FORT BELVOIR, VA.	PREPARED BY 7MAR67	97403	PL 13100E3760	C
	CHECKED BY GEM 9MAR67	CODE IDENT	SHEET 1 OF 7	REV
NEXT ASSEMBLY	USED ON	APPROVED DATE 13 MAR 67 CHIEF ENGINEER ... DEPT	ITEM NOMENCLATURE: GENERATOR SET, GAS-ENG-DRIVEN, 5.0 KW, 28 VDC, AIR-COOLED, PORTABLE, TUBULAR-FRAME, SKID MOUNTED	

LTR	REVISION DESCRIPTION	DATE	APPR	LTR	REVISION DESCRIPTION	DATE	APPR
A	FIND NO. 44-1 REQ'D WAS 4	1 APR 67					
B	SEE NOR	3 MAY 67					
C	FIND NO. 49 DELETED	1 JULY 67					

RECORD OF REVISION STATUS OF EACH SHEET

1	2	3	4	5	6	7
A	-	-	-	A	-	-
B	-	-	B	A	B	-
C	-	-	B	A	B	C

U.S. ARMY MOBILITY EQUIPMENT COMMAND ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES, FORT BELVOIR, VA.	97403	PL 13100E3760	
	CODE IDENT	SHEET 2	REV

FIND NO	SYM	CODE IDENT	DWG SIZE	PART OR IDENTIFYING NO	QUAN REQD	NOMENCLATURE OR DESCRIPTION	SPECIFICATION OR NOTE
			D	13100E3760		GENERATOR SET, GAS-ENG-DRIVEN, 5 0 KW, 28 VDC, AIR-COOLED, PORTABLE, TUBULAR-FRAME, SKID MOUNTED	
			D	13100E3761		WIRING DIAGRAM, 5 0 KW, 28 VDC	
			D	13100E3762		SCHEMATIC DIAGRAM, 5 0 KW, 28 VDC	
1			D	13100E3793	1	PLATE, INSTRUCTION, OPERATING	
2				MS 24662-5	6	RIVET, BLIND-UNIV HD, DRIVE TYPE, AL ALY 2117-T4, .125 DIA X .187 LG	
3			C	13100E3792	1	PLATE, IDENTIFICATION, GEN SET	
4				MS 21318-14	4	SCREW, DRIVE, RD HD, TYPE U, CS, CAD PL, #2-8X .19 LG	
5					1	EXTINGUISHER, FIRE, VAPORIZING-LIQUID MONO-BROMOTRIFLUOROMETHANE, 2 75 LB, W/BRACKET	MIL-E-52031
6				MS 90725-3	[illegible]	SCREW, CAP, HEX HD, STD CS, CAD PL, 1/4-20 UNC-2A X .50 LG	
7	F			MS 35338-44	4	WASHER, LOCK-SPRING HELICAL, REG SER, CS .25 NOM SIZE	
8	R			MS 51967-2	4	NUT, PLAIN, HEX, CS, GR 8, CAD PL, 1 4-20 UNC-2B	
9	C		B	13100E6765	1	BOLT, EYE	
10				MS 35691-17	1	NUT, PLAIN, HEX(JAM), CS, GR 8 CAD PL, 3/8-16 UNC-2B	
11			D	13100E3795	1	CONTROL BOX ASSEMBLY	
12				MS 90727-5	4	SCREW, CAP, HEX HD, ALY STL, CAD PL, 1/4-28 UNF-2A X .63 LG	
13				MS 27183-10	4	WASHER, FLAT RD, CS, CAD PL, GEN PURPOSE, .281 ID X .625 OD X .05 THK, NOM SIZE	

SYMBOLS
R—RECURRING ITEM
F—TOTAL QUAN OF RECURRING ITEM
B—BULK MATERIAL
C—SPEC CONTROL DWG
S—SOURCE CONTROL DWG
N—NOT INCLUDED IN A SET OF DATA
M—MULTIPLE USE DWG

FIGURE 2-9 Parts List Cover Sheet and Parts List Continuation Sheet

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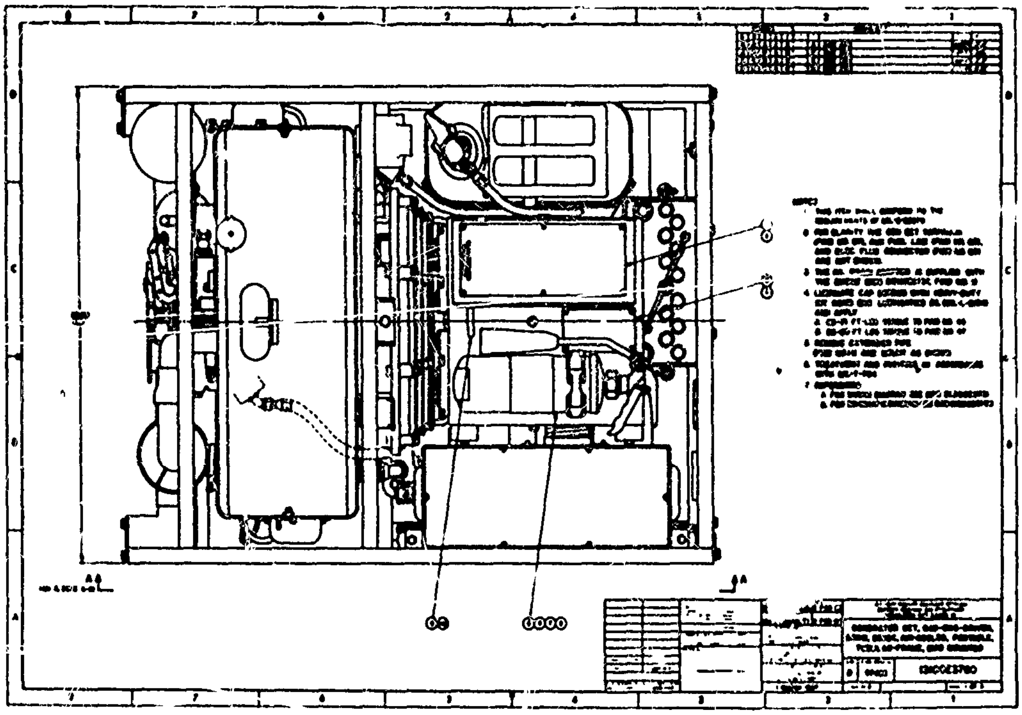

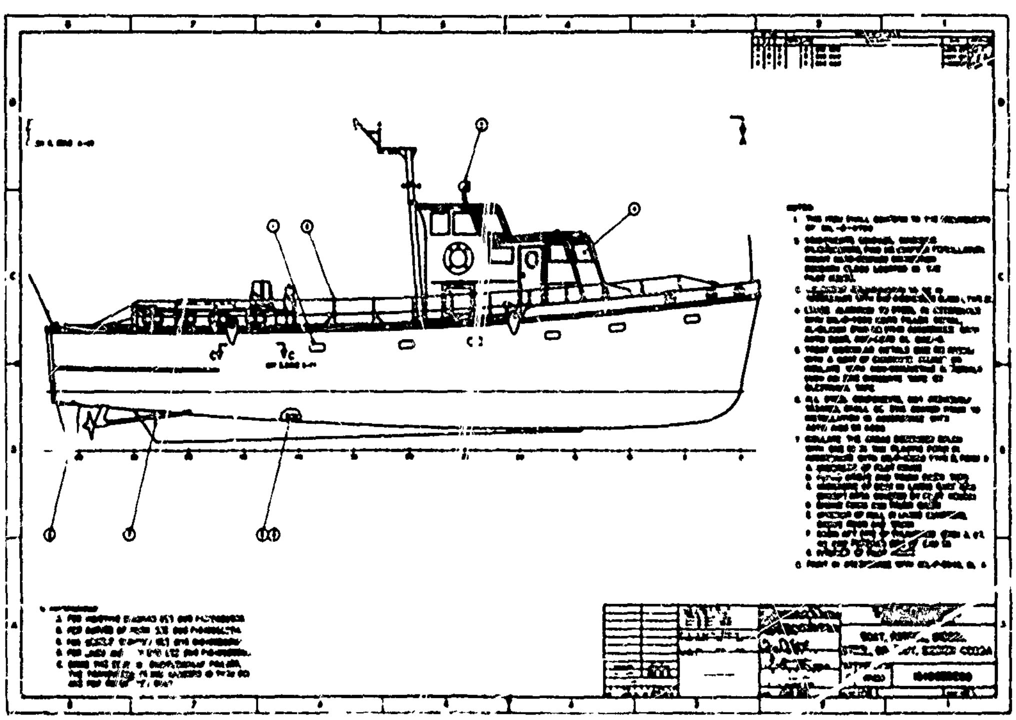

FIGURE 2-10. Principal Assembly Drawings

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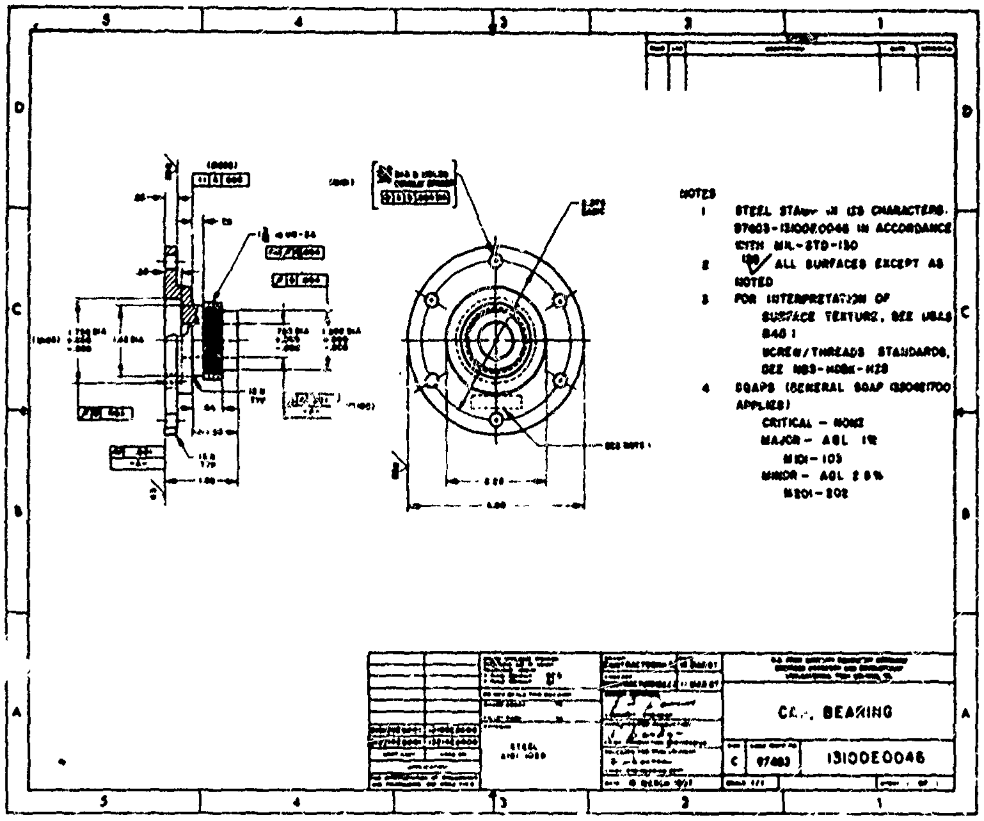

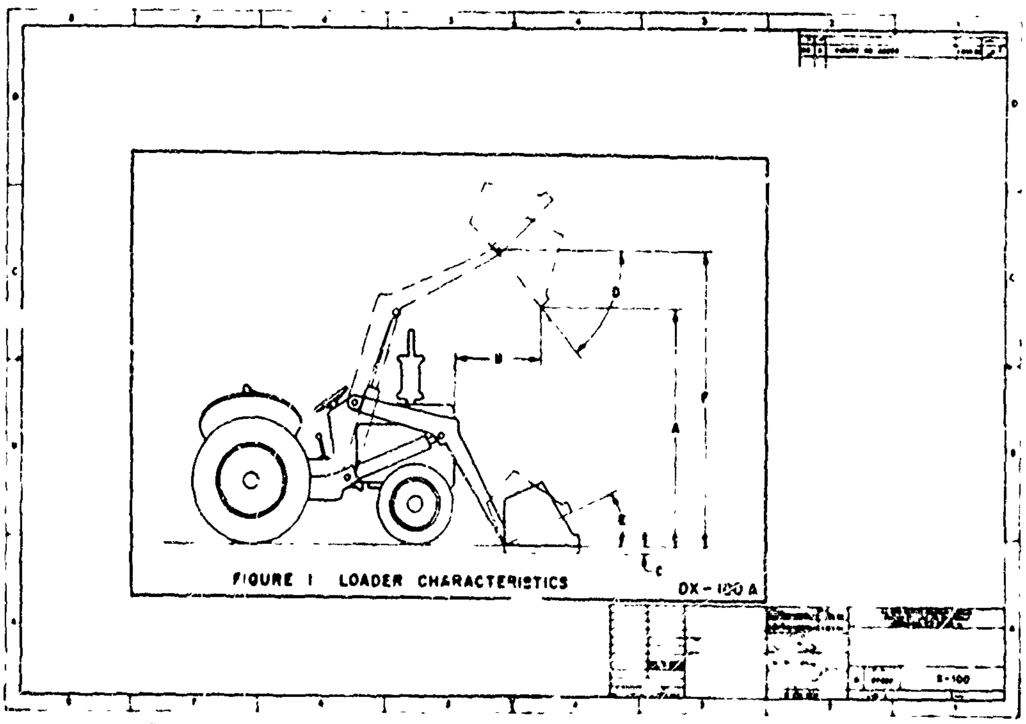

FIGURE 2-11. Monodetail Drawing and Specification Figure Drawing

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1 US ARMY MOBILITY EQUIPMENT COMMAND ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES, FORT BELVOIR, VA.	2 97403 CODE IDENT	3 SQAP 13213E0025 5 SHEET 1 OF 2	4 REV

SUPPLEMENTARY QUALITY ASSURANCE PROVISIONS

6 NOMENCLATURE	7 APPROVED BY DATE
SHAFT, ROTOR	

8 PREPARED BY	9 SUBMITTED BY	10 DRAWING SIZE, NO., REV, AND DAT
		13213E0025 C None 15 June 1965

11 REVISIONS

DWG	SQAP	DATE	APPD	DWG	SQAP	DATE	APPD	DWG	SQAP	DATE	APPD
		-									

INSTRUCTIONS: THE GENERAL SUPPLEMENTARY QUALITY ASSURANCE PROVISIONS (SQAP 13201E5400) ARE APPLICABLE TO THIS SQAP.

NOTES

A. THIS SQAP COVERS ONLY THOSE DEFECTS WHICH AFFECT SAFETY, FUNCTION, PERFORMANCE AND INTERCHANGEABILITY.
B. CHARACTERISTIC NUMBERS FOLLOWED BY THE SUFFIX "S" (SPECIAL) UNLESS COVERED BY A SPECIFIED SAMPLING PLAN, SHALL BE VERIFIED TO THE SATISFACTION OF THE CONTRACTING OFFICER.
C. ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED.

1. LOT-BY-LOT INSPECTION:
1.1 VISUAL, DIMENSIONAL, AND PRIMARY FUNCTIONAL INSPECTION:
1.1.1 CLASSIFICATION OF DEFECTS AND DEFECTIVES:

CHAR. NO	ZONE	CHARACTERISTICS	METHOD OF INSPECTION
		CRITICAL - NONE	
		MAJOR AQL 1.0%	
101	1-B	.999-1.000 DIA (2 PLACES)	MICROMETER
102	3-D	.7550-.7555 DIA	INSIDE MICROMETER

(JULY 1965)

FIGURE 2-12. Supplementary Quality Assurance Provisions

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cepted by the Government inspectors after scrutiny in conjunction with use of a Government-supplied gage, an item normally not commercially available. Since it is supplied to the producer, certain limitations and restrictions are enforced. For each Government gage, there is an associated quality assurance pamphlet detailing its operations and maintenance. More often, however, the production contractor is expected to supply his own gages and inspection equipment to meet specified detail or general requirements. Fig. 2-12 is illustrative of the types of documents included in the TDP as quality assurance data.

2-4.6 GOVERNMENT STANDARDS AND SPECIFICATIONS

This TDP section includes the pertinent Military Standards, Air Force-Navy Aeronautical Standards, Military Specifications, Federal Standards and Specifications, and applicable Government handbooks and documents.

2-4.7 INDUSTRY STANDARDS AND SPECIFICATIONS

Appropriate industry standards and specifications, as well as those published by societies, associations, or committees and appropriate to a particular TDP are included in this section.

2-4.8 END ITEM FINAL INSPECTION REQUIREMENTS (EIFIR)

This section of the TDP is a controlling factor in the final Government acceptance of an end item The EIFIR specifies a record requirement and a chronological sequence listing relative to quality characteristics which must be verified for functional performance and completeness by the producer. Defects and the resultant corrective actions are listed to establish a permanent record of the final inspection of the item The EIFIR is used in conjunction with the Quality Assurance Provisions section of the specification, the SQAP's, and any special contract requirements affecting quality characteristics

2-5 REVISION SYSTEM

If the need for TDP revision develops, it is imperative that care be exercised in so doing. For instance, changes made to any drawing which affects the interchangeability of repair parts for an equipment in the supply system must reflect a change in the affected part number. All revisions made to drawings and/or parts lists necessitate follow-through revisions updating all drawing lists in which the revised drawing and/or parts lists are mentioned. Fig. 2-5 shows the manner in which one revision to any TDP document affects the revision status of all related documentation.

2-5.1 ENGINEERING CHANGE PROPOSALS (ECP's)

An ECP must be initiated and approved before any changes can be made to any TDP documents. Inasmuch as changes are detrimental to producibility, the designer must strive to avoid them. Many changes are the result of poor or careless initial design.

2-5.2 CLASS OF REVISION

ECP's are categorized as either Class I or Class II, depending on the type of change necessitated by a particular situation. The criteria used to determine Class I and Class II ECP's follow

Class I changes cover alterations in form, fit, or function which involve one or more of the following.

(1) Contract price or fee, contract weight, contract guarantee, contract delivery, contract schedules, Government-furnished inspection equipment, or other contract requirements

(2) Reliability

(3) Maintainability

(4) Safety

(5) Electromagnetic interference to electronic equipment or electromagnetic radiation hazards

(6) Government-furnished property (GFP)

(7) Retrofit

(8) Interchangeability

(9) Repair part requirements

(10) Support equipment, trainers, and training devices

(11) Operating limits or performance

(12) Interface compatibility

Any engineering change not falling within the criteria for Class I changes is designated as a Class II

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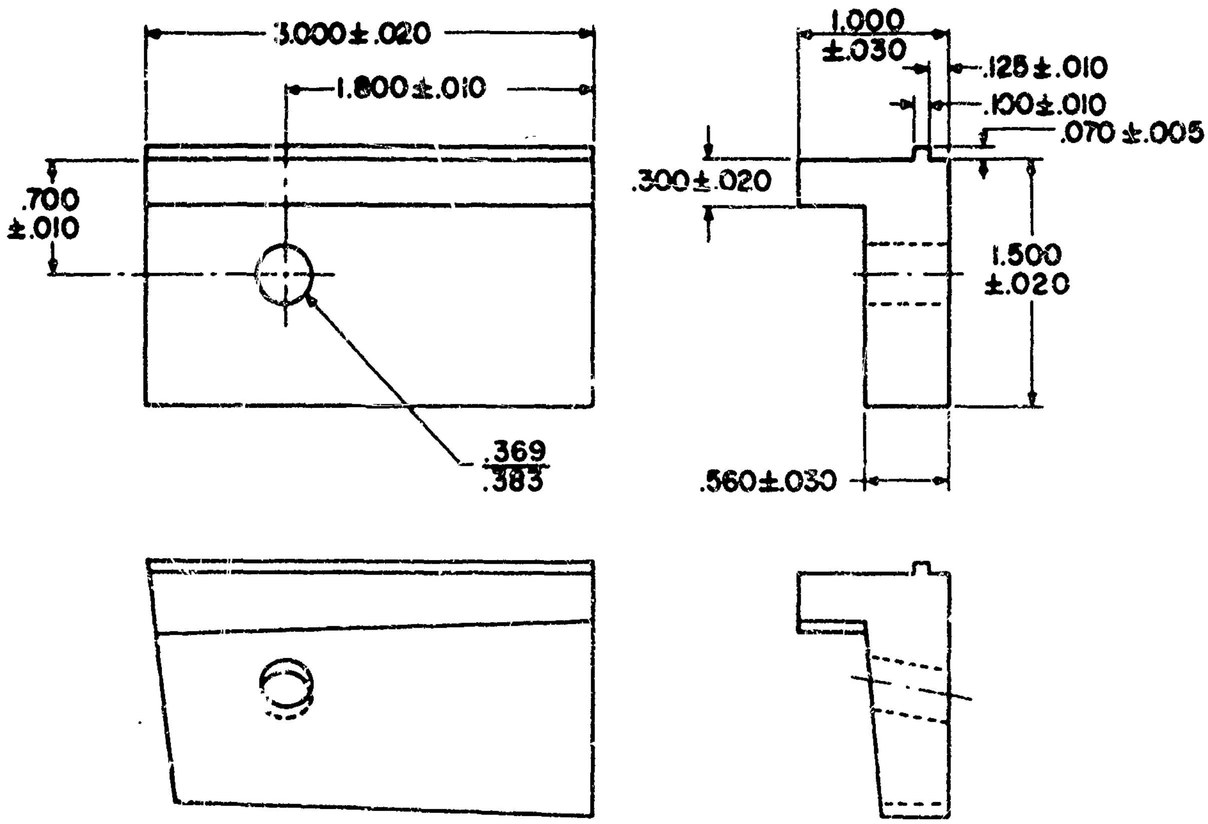

FIGURE 2-13. Possible Results of Failing to Provide Positioning Tolerance (Provide Datum Points)

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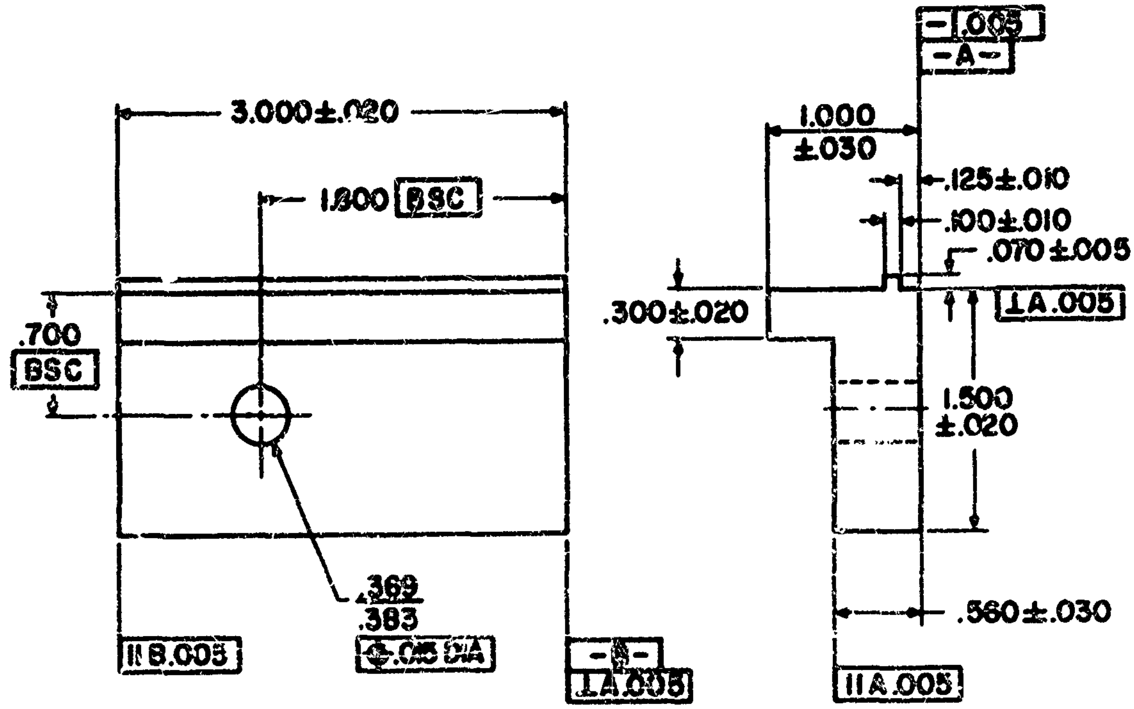

FIGURE 2-14. Application of Geometric and Linear Controls

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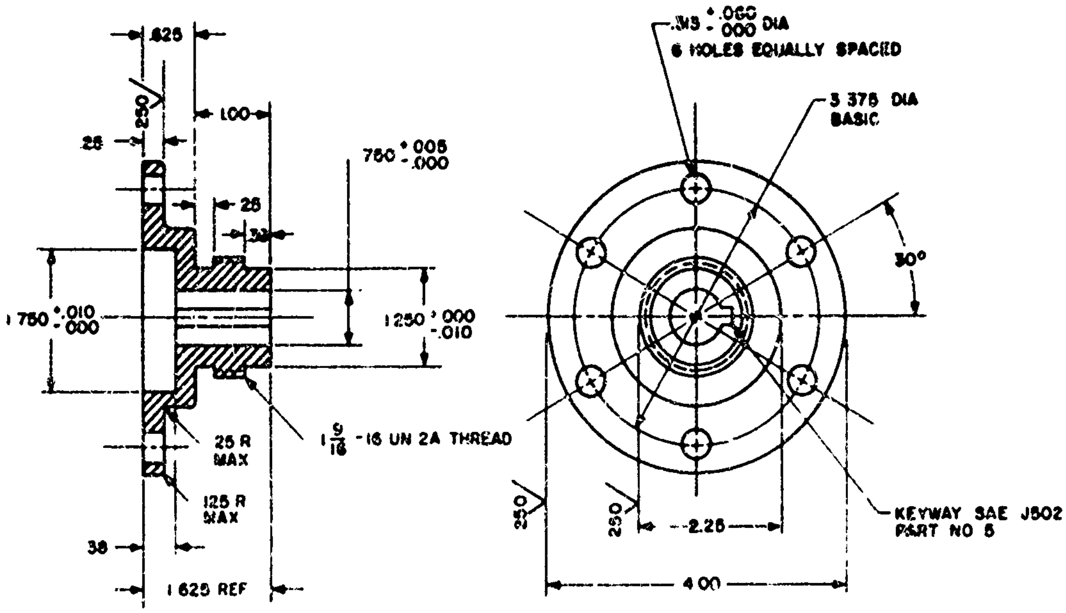

NOTES

1 UNLESS OTHERWISE SPECIFIED SURFACE ROUGHNESS 125

2 OPTIONAL MATERIALS:
   A AISI 1111 -1113
   B ASTM A27, GRADE 65-35

3 FOR INTERPRETATION OF
   DIMENSIONING AND TOLERANCING, SEE USASI Y14.5
   AND DWG NO 13----E----.
   SURFACE ROUGHNESS, SEE ASA B 46.1

MATERIAL	TOLERANCES
STEEL	XX ± 03
AISI 1010-1020	XXX ± 010
(SEE NOTE 2)	

FIGURE 2-15 Drawing Without Positioning Controls

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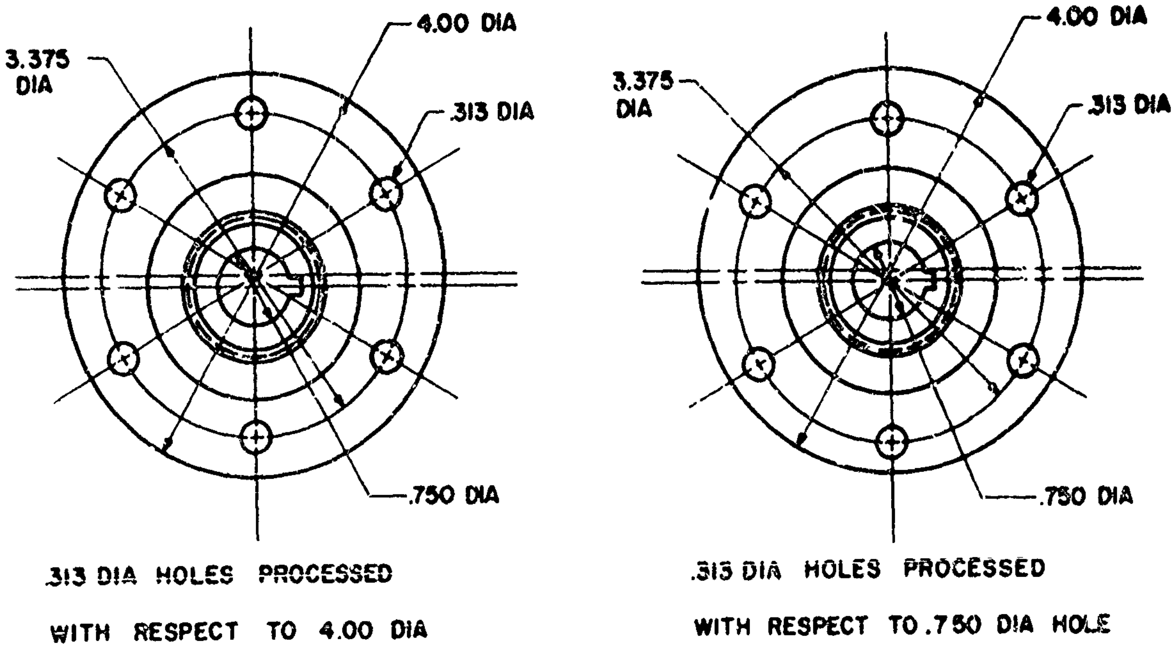

FIGURE 2-16. Possible Results of Failing to Provide Positioning Controls

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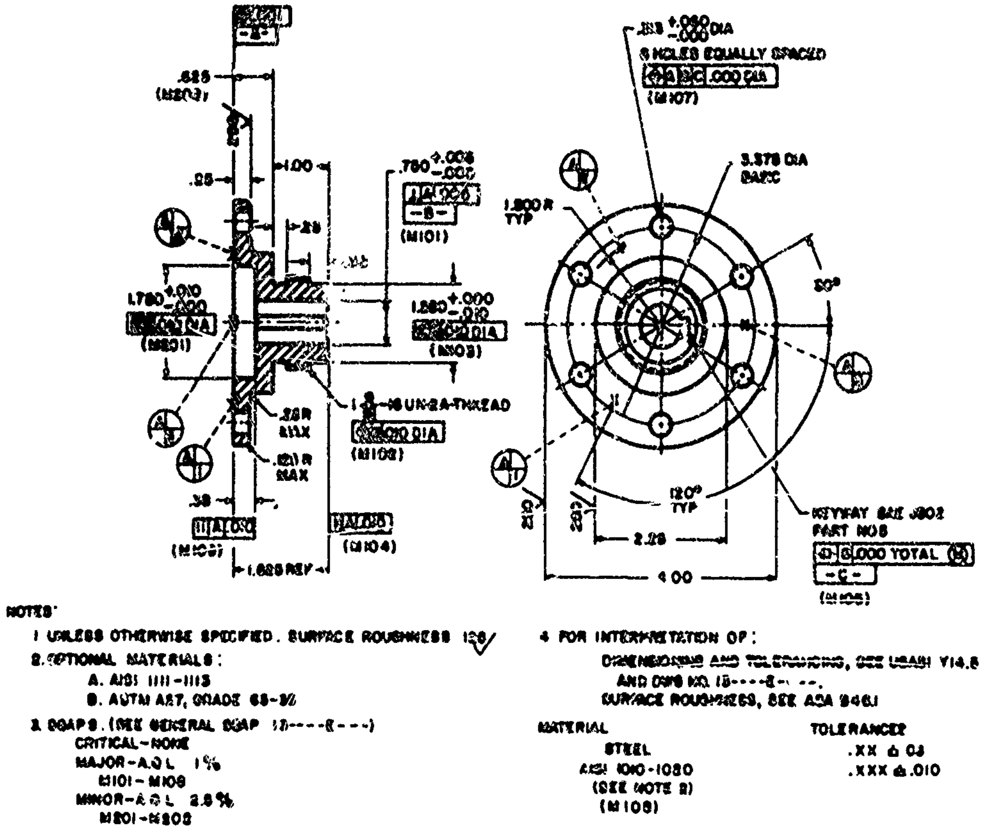

FIGURE 2-17. Illustration of Proper Positioning Controls

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change, which is any change to the TDP encompassing correction or documentation maintenance. Such corrections cannot affect form, fit, function, and interchangeability of the end item or its components. Space is provided on DD Form 1692, *Engineering Change Proposal*, to indicate whether the change in Class I or Class II.

2-5.3 NOTICE OF REVISION (NOR) AND ENGINEERING REVISION NOTICE (ERN)

The NOR is a multiuse change document that is used to effect changes to the authenticated drawings of a TDP. A NOR is prepared:

(1) To support an ECP for either Class I or Class II changes

(2) To support a producibility study or a production review performed after drawing authentication

(3) To effect the changes to drawings upon approval of the NOR and the ECP

(4) To serve as the official record of all revisions to the drawings.

Under certain predetermined conditions, an Engineering Revision Notice (ERN) supplements a NOR, and may temporarily be made a part of a TDP, but an ERN is never an element of a contract. Normally, its use is limited to that of providing advance warning of an impending change to a TDP. The TDP to be changed would remain the basis for bidding until such time as the formal NOR is issued and incorporated in the contractual document. The ERN indicates by drawing zone location the exact change to be made Thus, it is an aid to the bidder in determining the extent of the change and its effect on planning and estimating

2-6 THE TDP AND THE PRODUCTION ENVIRONMENT

The TDP is the vehicle for communicating requirements for a specific product between Government and industry. Effective competitive procurement needs clear, concise, and unambiguous definition of all Government requirements for the product to be delivered The TDP contains design disclosure data, specifications, quality assurance provisions, and acceptance criteria necessary for full and complete description, procurement, manufacture, and acceptance

2-6.1 GOALS OF TDP PREPARATION

The objective of the TDP is to provide documentation to industry that is both complete and accurate In addition, the Government expects that the procurement base will be broadened because of the ability of more potential suppliers to bid. This is one objective of producibility.

2-6.2 TDP DRAWINGS AND PRODUCTION

It must be borne in mind that each shop or manufacturer has a set of shop practices for in-house drawings and information dissemination. These are based on internal practices and thus allow for less cumbersome internal operations. However, these practices, though helpful and efficient internally, may be useless or actually harmful and misleading if other organizations try to follow them. Consequently, the military end product drawings which embody any practices peculiar to any manufacturer should identify them as "optional"

2-6.3 SOME PROBLEMS OF COMMUNICATION

If it is realized that the end product drawing is the communication medium among the design engineer, the bidder, the producer, and any other user, it will also be apparent that there must be a universal understanding of the procedures for attaining quality control This provides interchangeability for repair parts it is form, fit, function, and interchangeability on a mass-production basis.

MIL-D-1000 permits three forms of drawings. drawings to military standards, drawings with partial military control, and drawings with minimum military control The intent is to procure a minimum of new data and to use existing commercial data at lower cost This implies a minimum of Government drawing file maintenance and a minimum of drawing file space Uncontrolled sizes are a problem, which is somewhat alleviated by the microfilm aperture card system The preparation of military drawings, therefore, is faced with opposing pressures, i e, standardization versus the use of existing data (in other words, redraw to standard format), and delineation and controls versus use of available data regardless of format (delineation and controls as long as they are basically adequate)

However, the language of drawings tends sometimes to be incomplete For example, the top half of Fig 2-13

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shows a simple application of tolerancing on all dimensions. The lower half shows some of the possible variations that may occur during manufacture. Not all variations possible would occur during any one production run, but any variation could be introduced as a result of the method of manufacture. However, all the variations shown meet the requirements listed in the top half of the drawing.

Fig. 2-14 shows the application of geometric and linear controls. While variation still exists, it is a more controlled and allowable variation. For example, the 3.000 dimension may vary 0.020, but whatever it is, within that limit, the right side of the item is perpendicular to the top within 0.005, and the left side is parallel to the right side within 0.005. Thus, there is an allowable variation of 0.020, permitting machine flexibility, but a control of the resultant surface to within 0.005. The variations are within limits that assure interchangeability, form, fit, and function are not violated.

The possibility of variation in production exists within a single shop as well as between different contractors' shops where production techniques and production line equipment are different. Illustrating this case is Fig. 2-15 showing a fairly complete drawing. All dimensions are toleranced, surface roughness requirements are noted, and materials are specified. The drawing appears complete, but the controls are missing Fig 2-16 shows two production possibilities If the piece is chucked on the 4.00-in. diameter (left hand view), the six 0.313-in. diameter holes may be concentric with the 4.00-in. diameter, however, the other bores, the diametral bosses, and the keyway may be off center, depending on the process used. If the piece is held in an expanding arbor, everything may be concentric and symmetrical, but the six 0.313-in. diameter holes may be off (as shown in the right hand view).

Fig. 2-17 eliminates all of these possibilities by control. Data are established, geometric requirements are specified, quality assurance is invoked, and all items produced and accepted will meet the form, fit, function, and interchangeability requirements. As a result, the repair parts from any producer will fit.

2-6.4 CONCLUSION

The many related effects inherent in TDP package contents and the degree to which each detail contributes as a procurement tool must be highly respected and thoroughly understood. Only under such ideal circumstances can the TDP expect to be fully effective.

REFERENCES

1. AR 70-37, *Configuration Management*, Suppl 1
2. MIL-D-1000, *Drawings, Engineering, and Associated Lists.*
3. MIL-STD-100, *Engineering Drawing Practices.*
4. MIL-STD-804, *Format and Coding of Tabulating and Aperture Cards for EDMS.*
5. DOD Instruction 5010.12, *Technical Data and Information, Determination of Requirements and Procurement of.*

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CHAPTER 3

THE SYSTEMATIC APPROACH TO DESIGN

3-1 WHY BE SYSTEMATIC?

It has been stated that: "The engineer talks of himself as a professional man and draws analogies to the medical doctor and lawyer, while almost every move of the engineering fraternity is in the opposite direction . . .

"In short, the engineer, who at one time was the educated and elite leader in matching science to society, is fast becoming just another member of the industrial labor pool.

"The old-line definitions of professionalism all accent high individualism. The engineer should be an independent individual who stands alone in his professional identity. This is now an unrealistic view because the complexities of today's society require team effort. There may be room for individual leadership qualities but these must be displayed and practiced in a team environment. The idea of professionalism needs a sharp revision, a redefinition that accents the best of human endeavor but which is considered in the context of our present, highly integrated society."

The Army designer is operating as a member of a team which is, in turn, part of a bigger team.

The implications of individual actions and their relationship to those of all other team members must be recognized and the systematic approach to design must parallel that used by others in order to achieve a complete, comparable, and, therefore, producible design.

The systematic approach must be applied to both plans and schedules. A systematic and cyclical flow process is a prerequisite to develop a final design which meets all performance requirements while still exhibiting maximum producibility within the imposed design constraints. The approach is vital, whether it is for design of a simple component or for a complex system. The process must give careful and iterative consideration, review, and analysis to all the requirements and constraints, as well as to the interacting influences of proposed design concepts upon the requirements.

Basic to developing a systematic approach is the consideration of producibility objectives (Chapter 1). One design area can have producibility objectives which mesh perfectly with design requirements, while in another area they may conflict. Conflicts can usually be resolved, but the first responsibility is to meet the performance requirements within the design constraints. The more difficult this becomes, the more limited is the application and the realization of producibility.

The systematic approach to design is the effective method of accomplishing the producibility objectives as well as the basic design requirements (including those of reliability, maintainability, safety, human engineering, and value engineering).

No fixed pattern of activity applicable to all design programs exists. The sequence and nature of events must be governed by factors such as system complexity, the extent to which new processes and techniques are employed, the structure of the design organization, program schedule, and other variables. Even with an effective approach, the design effort must remain an iterative process in which all the principal steps shown in Fig. 3-1 must be followed if an optimized design is to be achieved.

As conditions depart from ideal, the increasing consultation among the various specialists contributing to the design is needed. Regardless of the design structure, it is imperative that all of its special aspects be considered simultaneously throughout the entire design cycle. Only with such recurring attention can optimum results be achieved.

3-2 THE ITERATIVE PROCESS

The baselines discussed in Chapter 1 are integral elements of the configuration management system. They would be equally essential even if the formal requirements for configuration management did not ex-

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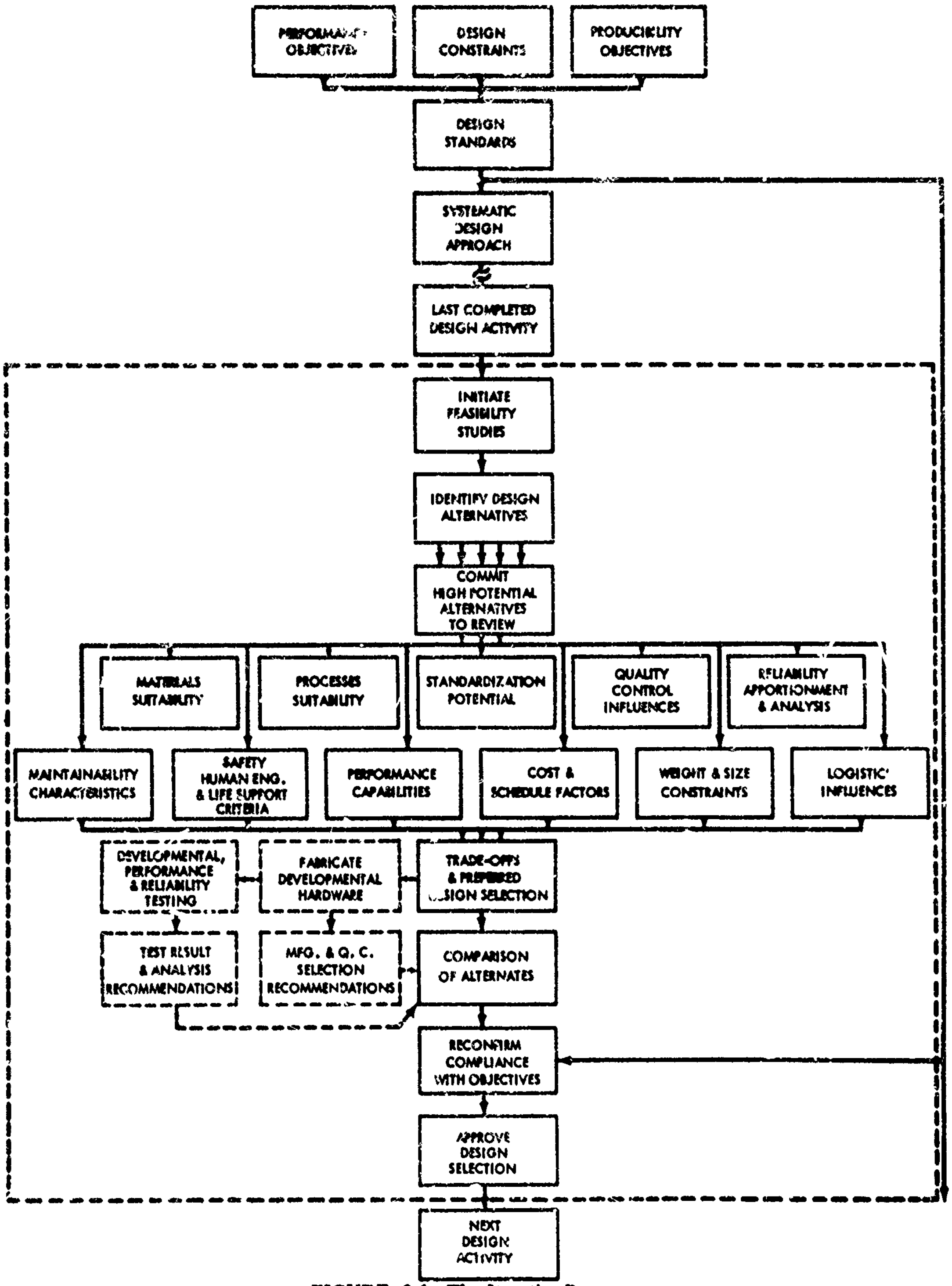

FIGURE 3-1. The Iterative Process

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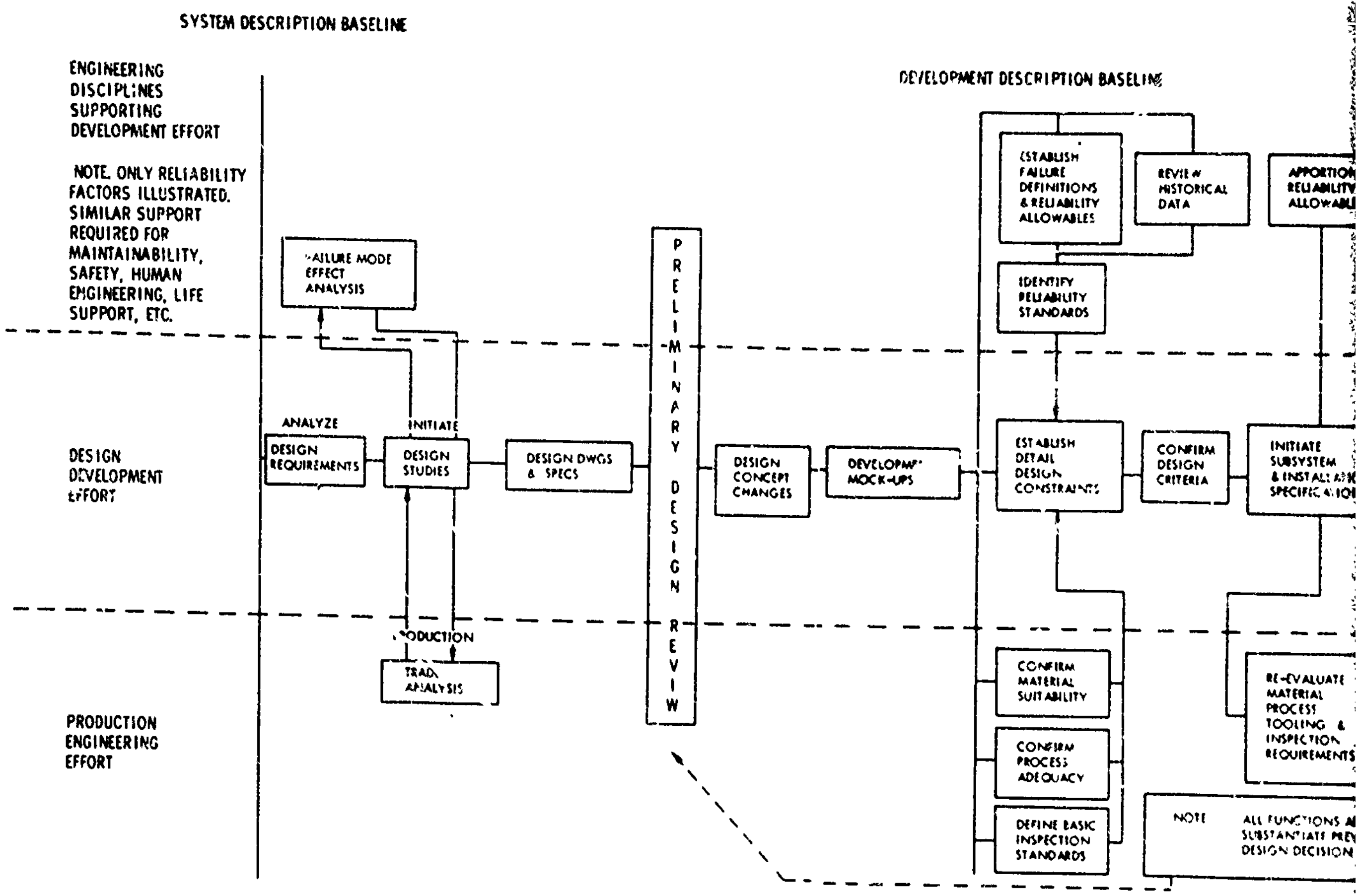

FIGURE 3-2. Basic Iterative Process

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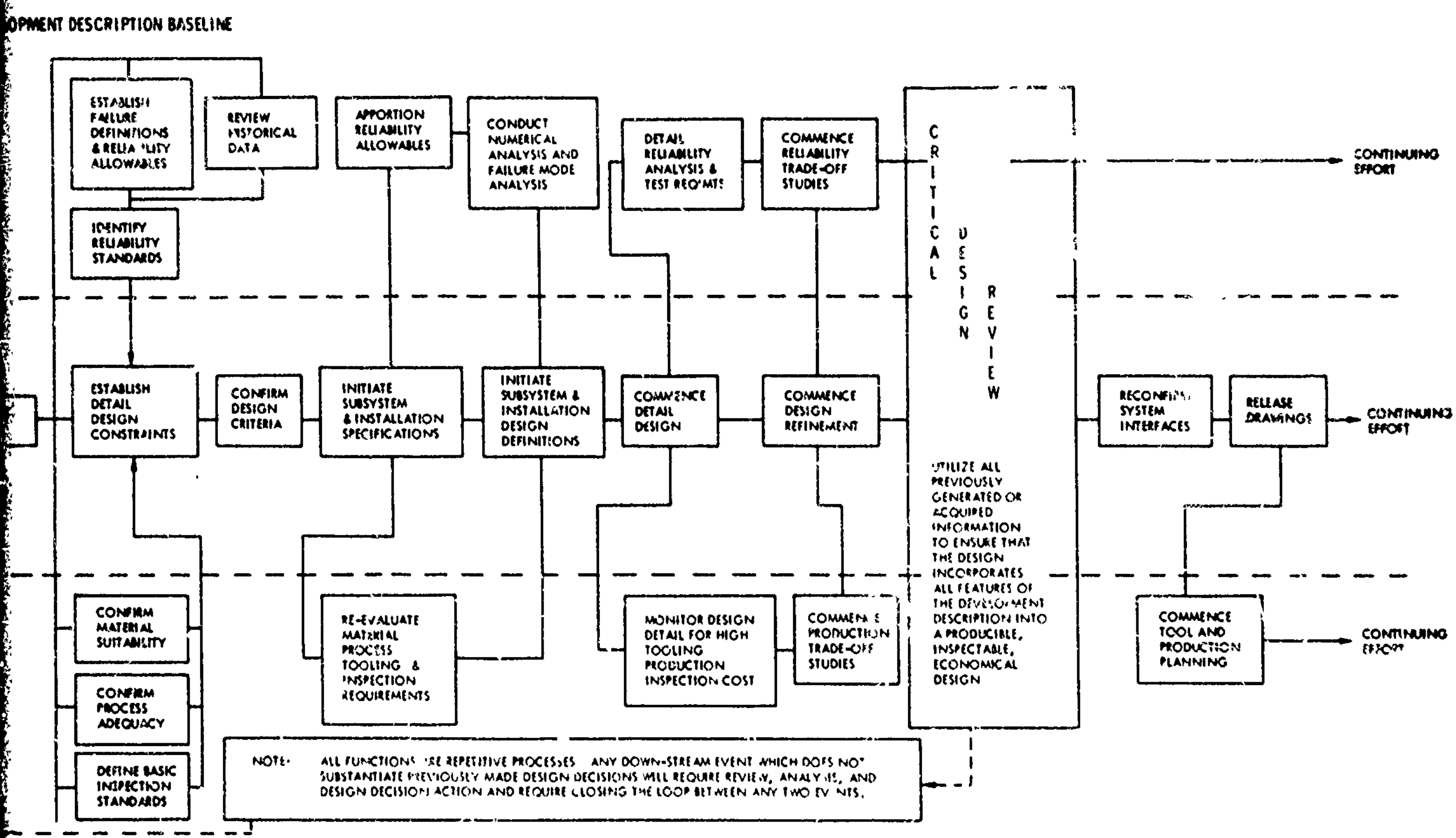

ic Iterative Process

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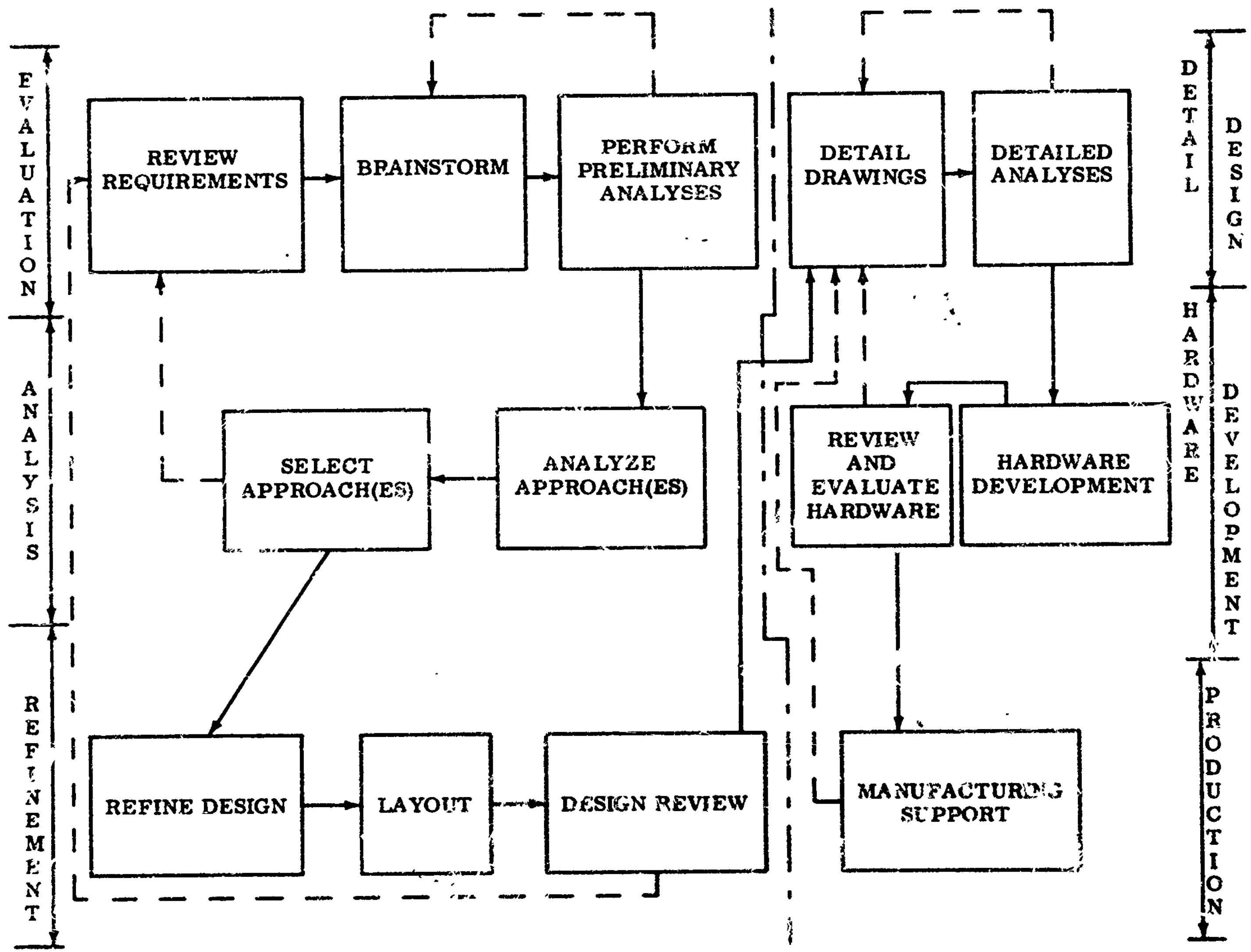

FIGURE 3-3. The Design Process

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ist. Each baseline represents a datum line, or reference point, from which the design effort must progress. The system description (or the QMR or SDR in less complex systems) is the first formally established baseline and the point at which a system design effort begins. Each step in the design effort represents an evaluation through which the system is converted from a raw outline to a detailed, producible description. Thus, each step also represents another internal baseline which can be evaluated and measured for conformity to the system description.

All or part of the basic iterative process (Fig. 3-1) must be undertaken at each step of the design effort if all factors are to be properly analyzed and then appropriately influence the design. Certain elements will be unnecessary at specific steps in the systematic approach. However, all appropriate elements must be used to ensure the requirements and constraints are met and that design producibility is guaranteed.

3-3 THE SYSTEMATIC APPROACH

Fig. 3-2 illustrates a partially developed (hypothetical) flow of activities in the design development sequence as well as the necessary interfaces between the basic design function and the supporting engineering disciplines, such as reliability and production engineering. Each step of the figure requires the application of appropriate elements of the iterative process. Before beginning the general or detailed design effort, a design function flow model should be constructed to ensure that all steps necessary to the design effort are included. This flow chart normally uses the primary design activities as a functional reference. Supporting flow charts must be developed to ensure adequate interfacing of all design supporting activities.

At this point the basic and interfacing functions to be performed have been defined and must be fitted into a program schedule to ensure adequate interfacing of all design supporting activities (Chapter 4). This includes identifying and scheduling major program milestones, as well as developing completely integrated schedules so that schedule allowables, program slack times, and overall schedule impact can be properly analyzed and apportioned.

The comprehensive nature of the systematic approach includes schedule planning for supporting engineering disciplines as shown in Fig. 3-2. A PERT/TIME network, by which the influence of schedule changes in interfacing activities supporting the design development may be recognized and evaluated, will prove of value. In more complex systems, it is necessary to furnish independent, but correlated, functional flow and schedule development for each primary functional area of the total system. Without the development of a systematic approach, consisting of a logical sequence of design events and a realistic schedule for their accomplishment, a successful design which meets the total design objectives (including those of producibility) is not likely.

3-4 APPLICATION TO THE DESIGN FUNCTION

It is frequently claimed that the "systematic approach" is too methodical; and that great ideas are more often arrived at by a combination of intuition and a judicious si[illegible] eties, than by a systematic and logical development of explicitly formulated premises. Carnot, for example, in his astonishing memoirs[1] arrived at many correct conclusions, having started with the incorrect caloric theory of heat. Very few product designs, however, result from such flashes of inspiration; they require planning and thought. Unfortunately many modern design attempts are ruined by a combination of faulty intuition and injudicious disregard of niceties.

In assimilating the rationale behind the systematic design process and in using it in the design process, the reader will find his intuition surer, his "disregard of niceties" more judicious, and his designs characterized by producibility. This discussion presents a method of analyzing the design process, not only from the administrative viewpoint but also as it involves the creativity exhibited in Army designs. By a thorough utilization of the tools presented, design environment can be found where design constraints are limited only to those necessary, performance objectives are couched in terms of the widest possible latitude, and producibility objectives are fully defined.

The design process can be shown in sequential series (Fig. 3-3). This sequence is not a one-pass operation but is, by necessity, a chain of iterative loops. The process may be broken down into six subdivisions:

(1) Approach
(2) Analysis
(3) Refinement
(4) Detail design
(5) Hardware development
(6) Production

Only a systematic approach to the accomplishment of each step will ensure that producibility is properly taken into account.

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3-4.1 EVALUATION

As can be seen from Fig. 3-3, the first step of the evaluation is a review of the requirements. The importance of this step cannot be over-emphasized. It has been said that a problem properly defined is virtually solved. While this may be optimistic, the fact remains that an improperly defined problem resists solution.

The system description should define the performance objectives, design constraints, and producibility objectives. However, performance objectives and design constraints often appear to be contradictory, and the producibility objectives are not mentioned. The Army designer must describe an end product that can be made by many companies, at some time in the future. For this reason, it is especially important that the design requirements be complete and that the trade-offs among the three inputs (see Fig. 3-1) be accomplished in order to design a system that can be procured and reprocured through competitive bidding without recourse to the original design agency.

It is essential to review all design requirements for completeness and clarity and to seek clarification from the responsible activity when these qualities are lacking. If this is not feasible, best judgment must be applied to set up parameters that give the designer the greatest number of options.

The second step of evaluation is brainstorming. While this technique is not new, it is only in recent years that it has been formally defined and procedures developed for maximizing its effect. It is an indispensible part of any design process. Four tips for brainstorming are:

(1) Be prolific. Look for many diverse ideas. Do not concentrate on petty design details.

(2) Do not avoid wild ideas. Even if an idea is patently impossible, its statement may trigger a related idea that is entirely feasible.

(3) Explore new concepts. The tendency to repeat old approaches and methods results in design stagnation.

(4) Avoid limiting generalizations. "It is not practical to use die-casting for lots of less than 5000" may have once been true, but recent developments unknown to the designer may have changed the picture.

The golden rule for brainstorming is to be open minded. Design is a creative process and it cannot take place in an atmosphere of needless restrictions, closed mindedness, and reliance on old concepts. The end product of such an atmosphere is imitation, not creation.

The third step of evaluation is a preliminary analysis of the concepts generated during brainstorming. Here, producibility rejoins the design criteria to be evaluated for cost-effectiveness and production ease versus the degree of compliance with the requirements defined in the first step. These two criteria cannot be applied independently at this stage. Each must be evaluated for producibility within the framework of performance objectives and design constraints. Preliminary analyses must be made to tentatively select components, materials, processes, etc., without locking the design into any tentative selection. This selection merely allows the designer to facilitate its evaluation. In fact, if an approach seems to be confined to only one material, process, etc., it should serve to notify the designer that another approach doing less violence to producibility objectives may be a more cost-saving means of achieving the performance objectives.

As shown in Fig. 3-3, this third step is part of an iterative loop. The approaches are analyzed and either rejected or tentatively accepted. Further brainstorming should consider two possibilities: (1) the feasible approaches may be very few, suggesting that brainstorming may yield more ideas; and (2) the analysis of the approaches may have triggered several new ideas which may prove more feasible. This loop may be travelled a number of times and the user should be alert for signs that the brainstorming is becoming concerned with details rather than the overall concept. If this happens, the value of the feedback process is exhausted, and the effort should proceed to the analysis stage.

3-4.2 THE ANALYSIS

With a number of possibilities in hand, the analysis phase is used to choose the approach that shows the greatest promise. The nature of the particular problem may dictate that several approaches be developed in parallel; however, the steps remain the same. This phase requires, as a minimum, the analysis of the following three items:

(1) Function vs cost

(2) Schedule vs cost

(3) Components vs manufacturing capability

Scheduling is very much a producibility factor. An end item that must go into production in six months cannot use a manufacturing technique that will not be available for a year.

In analyzing components vs manufacturing capability, factors such as the following must be considered:

(1) Will the item be manufactured in the United States or overseas?

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(2) Will a component be available several years from now, or does the design specification greatly limit future off-the-shelf procurement, thus reducing its cost-effectiveness?

(3) Is the component material on the critical list?

(4) Are special tools needed?

(5) Are unnecessary functions and costs eliminated?

When these analyses have been made and the approaches given a relative cost-effectiveness rating, the approach to be developed can be selected. Relative ratings and the peculiarities of the specific problem, schedule, funds, etc., will determine whether one or more approaches will proceed into the refinement phase.

3-4.3 REFINEMENT

The design approach must evolve into a working functional assemblage of detail parts and must move from the concept to the specific. Sketches of detail parts and areas of design should be roughed out to provide a temporary record. Size, weight, possibility of modular construction, reliability, and maintainability objectives should all be examined to see if further investigation is warranted. A refined analysis of loads, pressure drops, flows, heating rates, deflections, stresses, fit, etc., should also be made.

Next, the design bridges the gap between the conceptual and the physical development of the product. It serves to define the result of the myriad analyses, investigations, iterations, and refinements that have gone before. It is the vehicle of communication among the designer and management (to whom the approach must be sold), the draftsman (to whom it must be clearly defined), and the host of other groups (who are responsible for quality control, prototype production, etc.). It is the working paper used to provide preliminary cost estimates for material, labor, and manufacturing. Sufficient information must be given to provide an understanding of the intent. The responsibility to make ideas clearly understood cannot be overemphasized.

Orderliness of presentation will facilitate the systematic review for producibility. Descriptive notes may be [illegible] to more fully explain processes, materials, functions, alternates, etc. The combined package must communicate the reasoning behind this approach, its conformance with objectives and constraints, and its relative cost-effectiveness to the approving agency Layout clarity will greatly influence the acceptance of the design.

REFERENCES

1. *Reflections on the Motive Power of Heat and on Machines Fitted to Develop That Power,* from the original French of Nicholas Leonard Sadi Carnot, ed. by R. H. Thurston, New York, J. Wiley & Sons, 1890.

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CHAPTER 4

PLANNING FOR PRODUCIBILITY

4-1 THE NEED FOR PLANNING

A design can be created which is complete and adequate in all respects—except that there is no way of producing it. It is an unfortunate truism that there is rarely specific evidence of planning for producibility, yet it is applicable to all Army designs.

If its objectives are to be met, they must be quantitatively defined in terms of specific program objectives and must be valid at the system, subsystem, assembly, subassembly, and component level. Once defined, it is unlikely that the objectives will be achieved unless a plan is developed for accomplishment. They are still not likely to be realized unless they are related to all the other activities which they influence and which influence them, and unless sufficient time (schedule) and money (engineering man-hours) are allotted. The producibility plan becomes an added element to the system description, performance objectives, and design constraints to which to apply creative talents. A good starting point is to return to the listing of producibility objectives (maximize and minimize) given in par. 1-4 and to recognize how much more simple this task becomes to the individual creating the design if the design agency and the manufacturing agency are part of the same organization. However, the Army design engineer is usually located in the least favorable producibility situation, i.e., one in which the design activities and manufacturing activities will be different. To achieve producibility under these circumstances, the objectives must first be defined, and a plan for their accomplishment must be developed.

Since producibility requirements are not identified in the system or development descriptions, it would first appear that there is a complete lack of direction as to objectives. This is not entirely true, AR 70-37[1] may provide some guidance. If par. 3.7, Supply and Maintenance, of the System Description stipulates that the system is intended for off-shore procurement, it is incumbent upon the designer to ascertain that adequate facilities are potentially available to the prospective producers to meet process specification requirements. Pars. 3.7.1.6, Interchangeability and Replaceability, and 3.7.1.7, Workmanship, of the System Description may also provide some guidance. The list of logistics critical components (par. 3.2.2.3 of the Development Description) will identify those items with known long procurement leadtime, high dollar value, or other logistical critical characteristics. This furnishes the start of a list of items to which a high rating should be assigned in the design quality diagrams (see Figs. 1-4 and 1-5) Previous history and experience as well as the frequently available checklists also are useful guides.

4-2 PERSPECTIVE

4-2.1 GETTING THE PERSPECTIVE

Producibility is rarely, if at all, mentioned in work requirements, statements of work, job descriptions, and other documentation. Any references to this term probably conflict in application or definition, and almost certainly have a more narrow interpretation than that which this handbook presents. Just what, then, is producibility, and why does it need consideration, definition, planning, and attention?

First, it is appropriate to review some of the associated design support disciplines to try to determine exactly where they fit into the scheme of things and how they came into existence. These support disciplines all have one common purpose—improvement. They also have one common origin—confusion. This is not basically the fault of the individual engineering support discipline or its practitioners, but rather primarily a lack of cohesion and communication, both between them and the designer and among themselves. To the designer, each of these design support disciplines is a "cult" or a new "-ility", a nuisance which takes up his time and complicates his job.

Producibility is not a new discipline, not a cult, and

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not an "-ility"; it is an inherent characteristic of the design. To advance this concept, the existing disciplines must first be explored and evaluated. They must conform to several disciplinary requirements. These requirements and their origins should be briefly considered. They are (any program may omit some and add others):

(1) Reliability
(2) Maintainability
(3) Safety
(4) Human Engineering
(5) Life Support
(6) Value Engineering
(7) Standardization
(8) Configuration Management
(9) Interface Management
(10) Logistics Management
(11) Quality Assurance

The first step is consideration of the overall objectives, perspective, and planning.

Oversimplifying is one way to gain perspective. The oversimplified statements may not be entirely accurate, but the perspective which they create frequently will be. Oversimplifying the related disciplines produces the comments which follow.

4-2.1.1 Reliability

Reliability as a discipline was born in the late 1940's from concern that hardware being delivered was not performing as it should for as long as it should. Reliability engineering thus developed as a tool not only of design but of prediction, i.e., "the probability that an item will perform its intended function for a specified interval under 'stated' conditions".

4-2.1.2 Maintainability

Maintainability engineering inherently recognizes that complete reliability all the time is an impossible goal and thus addresses itself to "the probability that an item will be retained in or restored to a specified condition within a given period of time, when the maintenance is performed in accordance with prescribed procedures and resources". Again, here is a predictive "-ility", but one which is concerned with the design from a different standpoint. For example, if a fuel tank has a built-in pump or valve which is subject to failure, does the tank have an access port through which it can be reached and can the pump be repaired (or replaced) readily through the port?

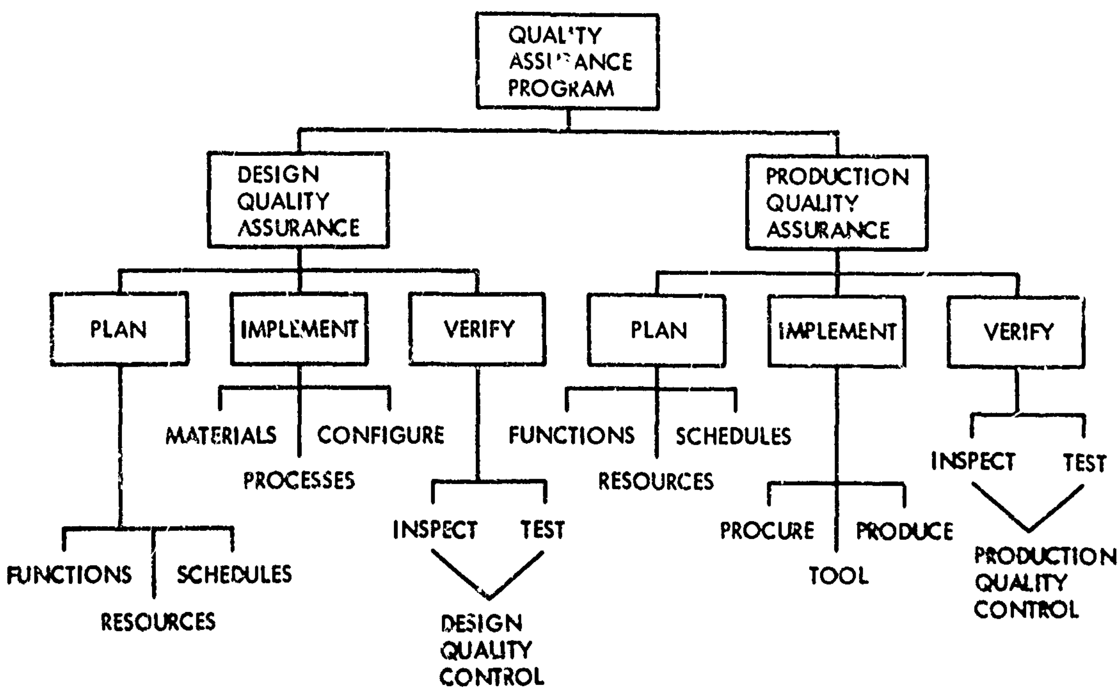

FIGURE 4-1. Elements of a Quality Assurance Program

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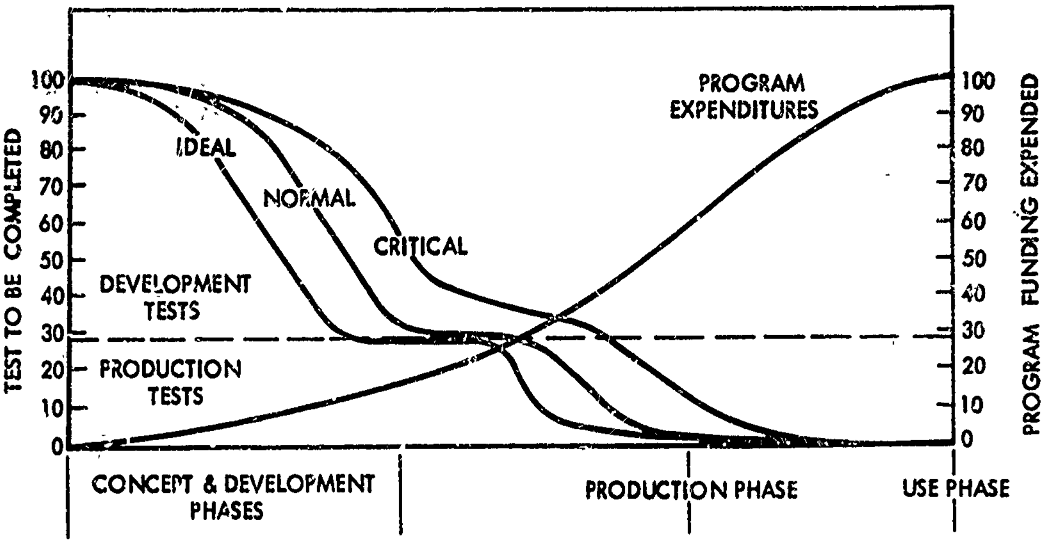

FIGURE 4-2. Effect of Test Status on Program

4-2.1.3 Safety

Safety engineering is concerned with "the conservation of human life and its effectiveness, and the prevention of damage to items, consistent with mission requirements". Thus, it is obvious that reliability, maintainability, and safety engineering are all concerned with failure, but from different standpoints:

(1) Reliability—to prevent failures
(2) Maintainability—to correct failures
(3) Safety—to minimize the effects of failures

4-2.1.4 Human Factors Engineering

Human factors engineering applies "a body of scientific facts about human characteristics . . . to the design of items to achieve effective man-machine integration and utilization". The interest of human factors engineering in failure, and thus in reliability, maintainability, and safety, is readily apparent, particularly that which may be human induced.

4-2.1.5 Life Support

Closely related to human factors engineering is life support engineering in which "scientific knowledge is applied to items which require special attention or provisions for health promotion, biomedical aspects of safety, protection, sustenance, escape, survival, and recovery of personnel". Here, then, considerations have become more specialized, but again are influenced by the preceding factors. In this case harsh or foreign environments which may endanger life could be examined. The objectives of human factors and life support engineering can be added to those previously stated for the first three disciplines as follows:

(1) Human Factors Engineering—to make the item most readily usable
(2) Life Support Engineering—to take all necessary precautions against environment

It now becomes apparent that all the foregoing engineering support disciplines have one common objective: performance effectiveness. It is also evident that they are heavily interactive. They are all small, but significant cogs in the bigger wheel of system performance effectiveness.

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4-2.1.6 Value Engineering

Value engineering must be conducted to achieve results which do not detract from any of the foregoing objectives. As noted in Chapter 7, good value engineering frequently will improve other aspects of the design. It is an element of cost-effectiveness, but is still meshed with the gears in the performance effectiveness wheel.

4-2.1.7 Standardization

Standardization (extensively discussed in Chapter 6) is defined as the "adaptation and use of engineering criteria to:

"(1) Improve operational readiness of the military services by increasing efficiency of design, development, materiel acquisition, and logistic support.

"(2) Conserve money, manpower, time, facilities, and natural resources.

"(3) Minimize the variety of items, processes, and practices which are associated with the design, development, production, and logistic support of equipment and supplies.

"(4) Enhance interchangeability, reliability, and maintainability of military equipment and supplies."

Standardization is thus both a tool and an objective of all the preceding elements, and is a cog in both the cost and the performance effectiveness wheels.

All these factors mentioned may be viewed as tools for job accomplishment. They are aids to the designer faced with an extremely difficult undertaking.

4-2.1.8 Configuration Management

Configuration management represents the transition from design support activities to management controls. The objectives of Army configuration management are to:

(1) Provide the level of identification, control, and status reporting for systems and equipment necessary to assist management in achieving logistic support, weapon readiness, visibility, and traceability.

(2) Provide managers at all levels with sufficient information for making appropriate and timely decisions during the development, production, and operational periods.

(3) Attain maximum economical consistency in configuration management data, forms, and reports within the Army Materiel Command (AMC) and at all interfaces with other Department of Defense elements and industry.

(4) Provide a system for use in the control of project design and engineering that will support optimum competitive procurement and breakout, make contract administration more uniform, increase the effectiveness of standardization and item-entry control, and support project definition.

(5) Assure that a proposed configuration change is timely and includes a thorough consideration of its total impact on cost, operational capability, and support to both hardware and documentation.

(6) Assure the efficient and timely implementation of all aspects of approved changes.

In fact, unless the configuration is effectively controlled, it is likely that one or all of the other objectives of the system description may be lost. Because of this, application of configuration management to systems or equipment is mandatory "continuously during all applicable life cycle periods", and must be applied to all "materials, parts, components, subassemblies, equipments, accessories, and attachments".

4-2.1.9 Interface Management

Interface management is closely related to configuration management and is, in fact, one of its elements. The need for it results from the ever-increasing interdependency of weapon systems and their components. If a configuration management system is complete and stems from the top echelon of the system, interface management, as a part of it, is concerned with the compatibility of form, fit, and function of every item which goes to make up the system. If there is interaction with other systems, then it must concern itself with the compatibility among systems.

4-2.1.10 Logistic Management

Logistic management might be more readily thought of as product support, and includes maintenance support planning. It involves the complete spectrum of getting the system into service, keeping it in service, and eventually removing it from service.

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4-2.1.11 Quality Assurance

Quality assurance is "a planned and systematic pattern of all actions necessary to provide adequate confidence that the product will perform satisfactorily in service". An obvious inherent element of quality assurance is quality control, which is "a management function whereby control of material is exercised for the purpose of preventing production of defective material". Design, development, and production elements in the preceding disciplines are also part of quality assurance. They are not ipso facto functions of a quality assurance department, nor is such a department even proposed. There must be recognition, however, that an integrated plan and evidence of accomplishment are necessary.

4-2.2 THE ROLE OF QUALITY ASSURANCE

The preceding paragraph defines both quality assurance and quality control. There exists a substantial amount of confusion concerning their nature and role. Despite the stated definitions, disagreement exists among and within the services. This paragraph attempts to remove some of the confusion, thereby enhancing program perspective.

A brief examination of the definitions of "assure" and "ensure" shows that these words are closely related:

Assure	*Ensure*
To give confidence; to guarantee	Always implies a making certain and inevitable; to make sure

"Assurance" is the act of assuring, a state of feeling (not being) certain, and the definition of quality assurance should be viewed in this light.

Quality control may be viewed as quality ensurance—the making certain by means of inspection. In fact this "making certain" is one of the objectives. Since 100% inspection is cost prohibitive, statistically acceptable probability can be determined through the use of sampling plans.

An examination of the definition of quality shows that it is "a characteristic mark or trait of a thing; quality is the widest of similar terms and implies any characteristic".

Quality control, therefore, verifies that the required standards of quality have been achieved. A total quality assurance program is illustrated by Fig. 4-1.

Quality control is normally thought of as a function of the production program, but not always as an element of the design and development program. However, since the production contractor has built the article to conform to the TDP and it has been inspected for conformance to drawing, the likelihood of having achieved the prescribed standards of quality are slim unless there has been some form of quality control imposed upon the development of the TDP.

The likelihood of achieving any standard of producibility is even slimmer if its standards have not been defined, planned for, implemented, and verified through inspection and testing. The need for an integrated test program is readily apparent. Any test has as its purpose some element of verification, from the earliest stages of a program (when it may be a feasibility verification) to the production stage (when it may be a conformance verification and is an element of quality control). Under the most favorable circumstances, the pattern of test completions and result verifications would create roughly the pattern shown in the "ideal" curve (Fig. 4-2). Schedule compression rarely permits this and a more normal distribution may be as shown. However, if slippages are permitted and the test picture assumes the "critical" curve, the potential impact on producibility becomes virtually unmanageable. There are two possible courses of action:

(1) Slip the whole program (extend the lead time); or

(2) Risk the hazard of subsequent test failures which cause extensive rework, increased costs, and schedule delays (perhaps as long as in the first alternative).

4-2.3 ENGINEERING DESIGN AND MOCKUP REVIEWS

Formal design and mockup reviews benefit the design engineer with written comments and recommendations resulting from evaluation by independent design management, engineering, and logistic support representatives. These reviews ensure that fewer engineering changes will be required at a later date and also provide a record for technical control of the progressive stages of design. Written comments are solicited for evaluation and incorporation, as appropriate, into the final design solution. Any one of four actions can result from the comments: incorporate, reject, study, or defer. Study items must be followed up periodically until they are resolved. Deferred items must have a date for reconsideration.

Fig. 4-3 shows the flow for a typical Design Review (DR). Preliminary Design Reviews (PDR's) are conducted formally to ascertain that the proposed design concept set forth by layout drawings and the preliminary design data will satisfy the functional and technical requirements and that interfaces are adequately defined. For practical purposes, the components of a system element may be combined for review as a group of functionally related parts.

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Mockup reviews are periodically conducted on developmental (engineering) mockups as they reflect additional increments of the detailed design effort. These mockups show mating and operational features of the design and permit evaluation prior to Critical Design Reviews (CDR's).

When the detail design is essentially complete, CDR's are conducted as formal technical reviews in order to determine the acceptability of the detail design for the purpose intended. All necessary actions are systematically recorded by formal minutes of each CDR. Minutes of CDR's provide the documented basis upon which signoffs of engineering releases (or corrections, if required) may be accomplished.

Each participating organization should have specific review responsibilities. Suggested tasks for engineering, production, quality assurance, and logistic groups follow:

(1) The engineering group should:
   (a) Include requirements for design reviews in engineering work statements and cost estimates.
   (b) Identify items and provision of schedules for reviews at appropriate phases of the design development.
   (c) Transmit preliminary copies of agenda, drawings, and related data to appropriate organizations sufficiently in advance of each review to facilitate their prior evaluation and preliminary comments in preparation for each review.
   (d) Coordinate (or provide) the documentation, drawings, and data incident to each review (including block diagrams, layouts, sketches, and schematics; interface data and drawings; drawings; weight analyses; flip charts; view graphs; appropriate system or item specifications; and failure mode and effect analyses).
   (e) Develop plans and present the design review. (All reviews should include the system or end item requirements; configuration description, and discussion of the manner employed to ensure that the proposed design meets all of its requirements; installation considerations; system or item interfaces with other systems, GFE (if applicable), and so on.)
   (f) Present criteria on at least the following aspects of the design: anticipated development schedule, reliability, maintainability, system safety, human factors, value engineering, producibility considerations (including costs, special tools, and facilities requirements), trade-off studies, test requirements and plans, electrical characteristics, (including power input, output, tolerances, and electromagnetic interference).
   (g) Evaluate comments resulting from reviews, and classification of the comments as incorporate, reject, study, or defer.
   (h) Initiate configuration changes, as warranted.
   (i) Initiate and/or coordinate followup actions as appropriate for all review comments which require further study or are deferred for further evaluation; upon completion of each item, provide appropriate information to the originator.
   (j) Provide accountability for all comments relating to each critical design review.
   (k) Revise configuration definition documentation when warranted by review proceedings.

(2) The production engineering groups, if separate from the design engineering groups, should:
   (a) Provide technical coordinating support (such as manufacturing research data).
   (b) Review technical data, layouts, drawings, and documentation attendant to reviews.
   (c) Participate actively in design and mockup reviews, and make recommendations as appropriate.
   (d) Apply review recommendations to refinement of production planning, procurement planning, and inspection techniques.
   (e) Resolve problems as they affect production, and coordinate or revise schedules as appropriate.
   (f) Conduct, when necessary, a review of a supplier's facility.

(3) The quality assurance group should:
   (a) Review technical data and documentation.
   (b) Provide quality assurance data, reports, and analyses.
   (c) Determine constraints, qualification acceptance, and test requirements as they apply to the quality assurance program.
   (d) Use review recommendations to refine quality, and inspection planning and techniques.

(4) The logistics group should:
   (a) Provide logistic data pertinent to each review.
   (b) Participate in design and mockup reviews, and provide recommendations as appropriate.
   (c) Use recommendations of design and mockup reviews to refine the provisioning program.

It is obvious that design reviews must be held at the earliest practical stages of development if the recommendations are to be effectively utilized. It is equally

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obvious that the first step is to decide whether 100 percent design reviews will be employed or whether some sectors of the design are sufficiently stable and problem-free that they need not be reviewed. In such cases, it is usually wise to take a small sampling of these "easy" jobs and subject them to full review. Frequently, they will not prove as perfect as first believed to be. This may indicate re-evaluation of other "easy" areas.

The design review, then, if it is to serve a useful purpose, requires perspective and planning. Again, it requires recognition of what a design review is, as well as of what it is not. It is a creative step in the design process which permits (and invites) brainstorming as a means of securing problem resolution. It invites the application of combined talents to design problems and is intended to improve the design by creating greater awareness of its potential deficiencies. The design organization must review, evaluate, and incorporate or reject the recommendations which it presents.

4-3 CHECKLISTS

Checklists are of major significance to any program planning. The checklist is simply an accumulation of previous plans, combined with a method for indicating its execution. However, unless the checklists are constantly reviewed and monitored, they can be damaging to the program. Updating to adapt them to an individual program is necessary, even though the majority of the check points and parameters will be unchanged. They can be applied informally by the designer, or formally through a drawing-check system, in which case they become part of the control system. The obvious disadvantage of the informal (do-it-yourself) system is that while it affords some improvement over no checking, it is a form of self-control and relies upon the individual's ability to catch his own errors.

The term "checklist" is frequently misinterpreted. In the general fashion in which it is used, the checklist serves one of three functions. It is either directive, advisory, or reporting, as follows:

(1) The directive checklist contains a series of instructions which may be repetitively applied by the user.

(2) The advisory checklist is essentially a thought promoter, as evidenced by the value engineering checklist illustrated in Chapter 7.

(3) The reporting checklist is intended to serve one purpose—to accept or reject. Do the drawings conform to the standards prescribed, or do they not? If not, why not?

Having distinguished among the three types of checklists, several previously established points may be reiterated:

(1) If objectives are not defined, documented, and planned for, there is little hope of their accomplishment.

(2) If parallel planning is not undertaken, with clearly defined objectives, there will be both duplication and omission.

(3) If time is really of the essence, a little more time might be spent on planning and a little less on implementation.

(4) If controls and checks are not exercised, there will be no evidence and, thus no assurance that the objectives have been met.

(5) Lastly, if checklists are employed, they will create confusion unless they are first properly recognized as directive, advisory or reporting.

It must be emphasized that the objectives of producibility are definable. They can be expressed, and their accomplishment can be planned and measured. The problem can be addressed in generalities, but can be solved only in specifics which must be defined in terms of objectives, plans, and evidence of accomplishment. The last tables in Chapters 5, 9, 10, 11, 12, and 13 present a series of producibility problems pertinent to their individual topics. From these, a series of checklists can be developed.

REFERENCE

1. AR 70-37, *Configuration Management*, Suppl. 1.

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CHAPTER 5

COMMON DEFICIENCIES IN DESIGN

5-1 THE NATURE OF THE PROBLEM

To place this chapter in its proper perspective, a restatement of the objectives of the handbook is in order. It provides guidance for the design of hardware which can be made with the minimum expenditure of time and money, by the largest number of competent suppliers, while retaining the level of quality necessary to meet the performance requirements.

In pursuing this objective, the designer occupies a unique and commanding position since he alone is responsible for the original design. He is intimately knowledgeable of the special requirements of the design, whether it be a piece part, an assembly, a subsystem, or the complete system, and it is he who plans for the orderly incorporation of his design into the overall system. He conducts his activities within a time frame and uses all available resources which permit him to fully consider all aspects of the design. He weighs and judges them, and incorporates all the most desirable features. If, perhaps, he is not knowledgeable or did not plan, or is not provided with sufficient time and resources, errors will occur. Designs will be completed which detract from producibility.

In this chapter, the nature of such deficiencies and how they relate to design, and thus to producibility, are broadly approached. Any deficiency in design, if detected, becomes the subject of effort to correct it, and the corrective action itself becomes essential. This may lead to a long-term improvement in producibility; or it may not influence producibility at all. But, without question, any design deficiency certainly reduces the prospects of attaining producibility to its fullest measure.

5-2 CAUSES OF DEFICIENCIES

There are two basic causes of deficiencies in design, both ultimately traceable to the designer. They are inexperience and inattention. A lack of knowledge—inexperience—may render the designer incapable of optimizing a solution. Inexperience is not a sin; it is a fact of life for all designers whose field of endeavor is broad and dynamic. It becomes a sin only when steps are not taken to rectify it.

Inattention, however, cannot always be attributed to boredom. Design effort is frequently compressed by a schedule which does not allow adequate time for each design element. In some instances, improper planning on the designer's part may have been the determining factor. The deficiency may have occurred before the design stage, when some program planning function failed, again through inexperience or inattention.

5-3 ERRORS OF COMMISSION AND OMISSION

Any design deficiency can be classified as being one of either commission or omission. Errors of commission may include such elements as excessive complexity, production restrictiveness, conflicting directions, or simply Darn Fool (DF) error. Omission deficiencies include inadequate planning and direction, inadequate specification, and insufficient detail. Some deficiencies may result from a combination of causes.

5-3.1 EXCESSIVE COMPLEXITY

Few designs frequently achieve the maximum in reliability, maintainability, useful life, producibility, or any other aspect of theoretical perfection because the designs are overly complex. The more complex the de-

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sign, the more opportunity there is to incur design error. The design may be stronger than actually required, or heavier than desired. It may call for an expensive material when a less costly one would suffice. It may require complex cams that could have been replaced by simple linkages.

Simplifying a given design generally reduces the production cost and produces fringe benefits in its reliability, maintainability, quality, performance, and producibility.

5-3.2 PRODUCTION RESTRICTIVENESS

Designers often dictate the method by which their designs are to be produced. Dictating the production method restricts the freedom of potential producers, reduces the number of competitive producers who might otherwise bid, and often increases production costs.

Consider an industrial complex that conducts its own research and engineering, prepares its own drawings, and does its own manufacturing. In-house drafting and engineering standards are used to facilitate these processes. Designs are predicated on in-house production facilities and capabilities, and take advantage of shortcuts inherent in those capabilities. The designs produced in this set of circumstances, then, would not restrict production for that industrial complex. However, consider the restrictiveness imposed if the same drawings were presented to another manufacturer with his own standards, procedures, production facilities, and capabilities.

The Army designs are expressly for competitive procurement. They must provide as much flexibility in the production processes as possible without degrading performance in order to be as producible as possible.

5-3.3 CONFLICTING DIRECTION

Failure to clearly define project objectives jeopardizes the validity of the design. Management occasionally does not provide a clear, concise, and unambiguous statement of the project objective; in addition, the necessary design reviews and other directions may be incomplete.

It is imperative that the design organization share the responsibility of ensuring that clear project direction information is given to permit a clear understanding of the problem. Failure to do so causes "false starts", lost time, and wasted effort. Vast amounts of time, money, materials, and effort are wasted when end objectives are poorly defined. The design itself must also be devoid of conflicting information.

5-3.4 DARN FOOL (DF) ERROR

The selection of a material with strength limitations inadequate for the intended application, specifying the drilling of blind holes for a subsequent tapping operation when holes could have been through drilled, and selecting a material whose location in the galvanic series would preclude its use constitute but a few of the examples of DF errors. They may be attributed to oversight or ignorance. Any honest designer will usually admit to some DF boners. Some boners rank as classics, as the fabled newly christened ship that slips down the ways—straight to the bottom of the channel.

The majority of DF errors, however, include simpler offenses such as inconsistent double dimensioning or specifying a particular material which is incompatible with a specified process. Such errors invariably confuse the production department, waste manhours and material, and cause distressing delays; and often a cumulative effect is created. Holdups of critical components, which occur while isolating and correcting DF errors, can also cause delays in the delivery of a complete system, increases in cost, and degradation of producibility.

5-3.5 INADEQUATE PLANNING

During the course of a project and upon its completion, proper project control should provide for measurement, comparison, and evaluation of the actual performance of the design against the initial plan. The individual designer as well as the project manager must estimate progress and cost, then measure these parameters against the plan as the work proceeds. Failure to do so adversely affects optimum management at all levels. Schedules must provide for tasks such as patent liaison, lead time for fabrication of prototypes, tooling, tests, or specification of the associated test procedures. One of the most common planning errors is failure to allow sufficient time for redesign (often traceable to overconfidence). Inadequate planning causes scrimping in the final stages, thus jeopardizing the design and its producibility.

5-3.6 INADEQUATE SPECIFICATION AND INSUFFICIENT DETAIL

Drawings and specifications are the principal means of communication among the design engineer, the production engineer, the bidder, and the producer. Inadequate specifications or insufficient detail in design

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drawings serve only to reduce the effectiveness of that mode of communication. While keeping in mind the desire for unrestrictiveness (par. 5-3.2), it is also desirable and prudent to ensure that the end item is explained fully in the specifications and drawings, or detrimental ambiguities will result.

Details are frequently slighted. Chamfers are indicated but not dimensioned, or perhaps desired but never shown. Sections of complicated items with extensive internal coring required are not shown or are shown improperly. The finish desired is omitted, etc. When such detail discrepancies are not recognized and corrected prior to production, the production organization must either guess at the missing or erroneous details, or the designer's real intent must be determined.

Table 5-1 consists of design errors that pertain to the broader aspects of producibility covered by this handbook. Table format permits the user to supplement the handbook with his own experience and expand these lists for his own use. At the conclusion of Chapters 9 through 13 is a tabulation addressed to "Common Problems". Part A is illustrative of Common Designer-Created Problems in the particular subject of that chapter. Part B recognizes Common Production Problems noted in Army materiel production. These tables were inserted at the end of the chapters to extend their content to reflect problems encountered in each area. Since the B section of each table is a summary of outstanding production problems, they represent areas in which production technique research appears necessary. However, techniques in frequent use in one segment of industry are not always known to another, thus some workable solution to the problem may often be available and would serve a broader base if more generally known. Suggested solutions may be directed, through appropriate channels when necessary, to:

Commanding General
U. S. Army Materiel Command
ATTN: AMCRP
Washington, D. C. 20315

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TABLE 5-1. COMMON DESIGN PROBLEMS

Problem: CRITICAL SURFACES FOR GAGING NOT ESTABLISHED.

Cause and Effect:

Designers avoid basing tight dimensions on "as-cast" or "as-forged" surfaces, but they do base them on extruded, rolled, or sheet metal surfaces. These surfaces are not true because of the liberal fabrication tolerances for flatness, waviness, or twist.

Potential Solution:

Avoid using rolled, extruded, or sheet metal surfaces for accurate measurements unless they have been machined to a true surface or otherwise qualified.

Problem: DESIGN AND PERFORMANCE SPECIFICATIONS ARE NOT COMPATIBLE.

Cause and Effect:

The design may fully delineate all details of the item it defines, then spell out (in a performance specification) performance in excess of the capabilities of the design. Confusion, conflict, delayed production, legal problems, and similar problems will arise until all discrepancies are resolved.

Potential Solution:

Review drawings thoroughly to eliminate all areas of conflict prior to their release.

Problem: DESIGN EXCEEDS MANUFACTURING STATE-OF-THE-ART.

Cause and Effect:

Particularly difficult design problems often are avoided by passing the burden on to the manufacturing group in the form of a design that cannot be made. Examples include designing large castings with no draft, designing weldments that cannot warp, designing machine surfaces that cannot be reached, etc. Manufacturing often accepts the challenge and makes every effort to prove their capability; in the long run, however, a costly manufacturing process results or the design comes back for resolution after the expenditure of much time and money.

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TABLE 5-1. COMMON DESIGN PROBLEMS (CONT'D)

Potential Solution:

Early conferences with manufacturing personnel will go a long way toward resolving these problems.

Problem: DESIGN NOT CONDUCIVE TO APPLICATION OF ECONOMIC PROCESSING.

Cause and Effect:

Presents a greater challenge, takes more time, and is more difficult to create a simple design meeting the requirements than it is to produce one which meets the requirements through the use of complicated mechanisms. Being overly restrictive in prescribing fabrication sequence, assembly or machining processes, and preparing specifications leads to further complication of the design.

Potential Solution:

Soliciting advice early in the design process from manufacturing personnel regarding possible appropriate production techniques.

Problem: DESIGNER CREATES A NEW DESIGN FOR AN EXISTING ITEM.

Cause and Effect:

Through oversight, or failure to conduct adequate research, new items are created in cases wherein existing items adequate for the purpose already are in the logistic system. Such duplication not only wastes time and talent, but adds burdens to procurement, inspection, stock control, storage, and other elements of the logistic system.

Potential Solution:

Use standard or other proven existing items, rather than initiate a design for something new. Conduct a systematic research for items that could meet the requirements by consulting Miltary Standards, DoD Index of Specifications and Standards, existing item drawings generated by a familiar design group and germane to a familiar field of endeavor, other Army or military design control drawings, commercial literature, and related sources. Commerical items, if suitable, require specifications or source control drawings, as applicable.

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TABLE 5-1. COMMON DESIGN PROBLEMS (CONT'D)

Problem: DESIGN SPECIFIES USE OF PROPRIETARY ITEMS OR PROCESSES.

Cause and Effect:

Using items or processes which are not in the public domain should be avoided. Such practices as using proprietary items or rights restricts the procurement base, may be costly, and may delay or stop production, in addition it tends to make the Government dependent on some one item or process.

Potential Solution:

Avoid use of proprietary items and processes.

Problem: DRAWING QUOTES INCORRECT OR INCOMPLETE SPECIFICATIONS.

Cause and Effect:

Results from failure of the designer to utilize latest publications, both military and commercial. The burden may fall on the producer to apply the latest specifications; however, production delays, legal difficulties, rejected material, or a combination of all three problems will arise.

Potential Solution:

Review drawings for validity and completeness of all specifications.

Problem: DRAWINGS CONTAIN "CATCH-ALL" SPECIFICATIONS SUCH AS "BEST DESIGN PRACTICE", "GOOD WORKMANSHIP", "HIGH POLISH", "SQUARE AT THE CORNERS", "SOUND WILL BE FAITHFULLY REPRODUCED", ETC.

Cause and Effect:

Manufacturing personnel are put in a difficult position trying to determine the meaning intended by the designer providing the above specifications. Competitive contractors also must know the level of performance they must attain in order to comply with the terms of the contract. With specifications such as those listed above, establishing performance levels is impossible Contractual or production delays are created as is the possibility that the item fabricated is not what the designer intended.

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TABLE 5-1. COMMON DESIGN PROBLEMS (CONT'D)

Potential Solution:

Exercise care and be thoroughly familiar with the requirements of any specifications stated or referenced in the design description; avoiding such vague and meaningless specifications as those cited above will conserve time, effort, materials, and money in both the design and the production phases.

Problem: NO CONSIDERATION GIVEN TO MEASUREMENT PROBLEMS.

Cause and Effect:

For convenience, the design was dimensioned from a centerline, the center of a radius, or possibly the intersection of two planes in space. This may have been convenient for the designer, but may necessitate the construction of difficult and time consuming inspection setups.

Potential Solution:

Review the drawings with care, and attempt to base all dimensions on fixed surfaces.

Problem: OVERDESIGN.

Cause and Effect:

Overdesign usually is caused by lack of sufficient knowledge. This lack may be relative to the true requirements for the component or to the matching of the design with the requirements.

Parts are made too strong, too heavy, too resistant, too smooth, etc. Some parts are made so durable that they long outlive the remainder of the equipment. The components exceed their intended individual performance objectives. The net result is increased component cost without necessarily realizing improved performance of the system as a whole.

Potential Solution:

The obvious solution is to expand the designer's knowledge of the problem and to instill in him an appreciation of the expense of overdesign. (The same comment applies to any one of the large categories of similar problems.) Subjecting the design to value engineering and production engineering personnel

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TABLE 5-1. COMMON DESIGN PROBLEMS (CONT'D)

is a good starting point for soliciting appropriate suggestions leading to the avoidance of overdesign.

Constant critical review by the designer himself, subjecting his design to the criteria of producibility in as objective a manner as possible, is an important aid to the solution of overdesign situations.

Problem: TOLERANCES TIGHTER THAN REQUIRED FOR THE PART TO SERVE ITS INTENDED FUNCTION.

Cause and Effect:

Tight tolerances are necessary on many parts and assemblies; more often than not, specified tolerances are tighter than they need be for proper functioning, assembly, interchangeability, or replaceability.

Tolerances tighter than they need be arise from tradition; drawing notes that specify a blanket tolerance on all dimensions that are not individually toleranced; possible lack of information regarding tolerances of mating parts, e.g., at an interface at which the mating part is designed by some other design group, and resulting in fear that designs produced by the two groups will not go together; or lack of guidance or appreciation relative to the production costs and problems created by tight tolerances.

Potential Solution:

Overall review of standard practice regarding tolerancing, combined with the publication of some guidelines covering various design situations.

Careful review of designs to which tolerances can be relaxed without affecting function; complete information regarding tolerancing requirements at interfaces prior to initiating a design project.

Problem: UNDERDESIGN.

Cause and Effect:

The design is inadequate for its intended use through failure of the designer to properly assess the requirements of the part, or from his lack of knowledge of good design practice. At best, the design effort is wasted if the error is discovered early, but conceivably, the inadequacy might not be discovered until the hardware is produced, inspected, tested, and issued to the field.

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TABLE 5-1. COMMON DESIGN PROBLEMS (CONT'D)

Potential Solution:

The project must plan and schedule adequate design reviews, as well as the adequacy of test plans and programs.

Problem: QUALITY ASSURANCE PROVISIONS TOO RIGOROUS FOR DESIGN OR FUNCTION.

Cause and Effect:

As a safety factor and to assure himself that the design is adequate, the designer specifies inspection and test requirements which exceed those which he intended the design to meet.

Potential Solution:

Approach the specification of quality assurance provisions in a realistic manner, being sure that such requirements contribute profitably to the design program, and not in a manner designed (purposely or unintentionally) to defeat the basic purpose of quality assurance provisions.

Problem: SPECIAL INSPECTION EQUIPMENT SPECIFIED TO MEASURE NONCRITICAL DIMENSIONS.

Cause and Effect:

This over-cautious approach may be caused by a designer's lack of knowledge of capabilities with respect to standard inspection procedures.

Potential Solution:

Before requiring special inspection equipment, solicit the advice of knowledgeable inspection personnel to ensure that such is in fact necessary to the proof of the quality of the product.

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CHAPTER 6

SPECIFICATIONS AND STANDARDS

6-1 "MIL-SPECS" PRO AND CON

Every system can be subdivided into subsystems, equipments, assemblies, and components. These, in turn, can be reduced to their basic constituents of parts and materials. If any defects or deficiencies exist in the parts, materials, and processes being used to create a system, it will exhibit undesirable characteristics of performance, reliability, maintainability, effectiveness, producibility, supportability, and availability. Corrective action may require excessive funds and cause schedule delays during the design and development of a system.

Most advocates of systems engineering recognize technology, economics, and communications as the integral elements influencing systems engineering decisions. These factors may be related to the "MIL-Spec" system as discussed in the paragraphs which follow.

6-1.1 TECHNOLOGY

If a military systems design engineer understands and uses the "MIL-Spec" system, he should be able to develop a greater technical understanding of the design requirements for end-items and have a factual understanding of the available state-of-the-art. He should also be capable of identifying high-risk areas, in the early stages of design evolution, which may adversely affect the desired level of system effectiveness.

6-1.2 ECONOMICS

The use of the "MIL-Spec" system tends to develop a factual body of cost data. It aids in reducing the cost of procurement items, through standardization. In addition, it develops a firm technical basis for value engineering efforts. Carefully documenting the technical requirements of commodities provides a clear relationship among parts requirements tests, and inspections can be established relative to their costs and technical importance.

6-1.3 COMMUNICATIONS

Since the "MIL-Spec" system and methods are known throughout industry and are well documented, they have a significant bearing on communications. Use of the system can provide for an orderly and, normally, well-understood system for the interchange of contractual and technical requirements between the procuring agency and the contractor, among the various technical disciplines in a contractor's activities, and between contractor and commodity vendors. The system is flexible and adaptable; however, it is still subject to control while providing for its own self-improvement.

Selection by the design engineer of parts, materials, and processes is the critical step in determining the ultimate success or failure of a system. Prudently, he recognizes that when evaluating the state-of-the-art available for an end item he also must assess the likelihood that appropriate parts, materials, and processes can be readily used in the design and fabrication of that end item. Such an assessment will provide for greater understanding of probable equipment performance. Of equal importance, it will lead to better understanding of the equipment's reliability, maintainability, producibility, and supportability characteristics. In addition, it will assist in identifying high risk and potential lead-time problems, and making realistic cost estimates.

Fig. 6-1 depicts three general program categories from a reliability and quality point of view. It is a "result" depiction rather than a "designer's dream", although it is readily admitted that one can cite examples of certain commercial parts which may be ranked higher or lower than indicated. Nevertheless, the general ordering and distribution are correct from a relative standpoint.

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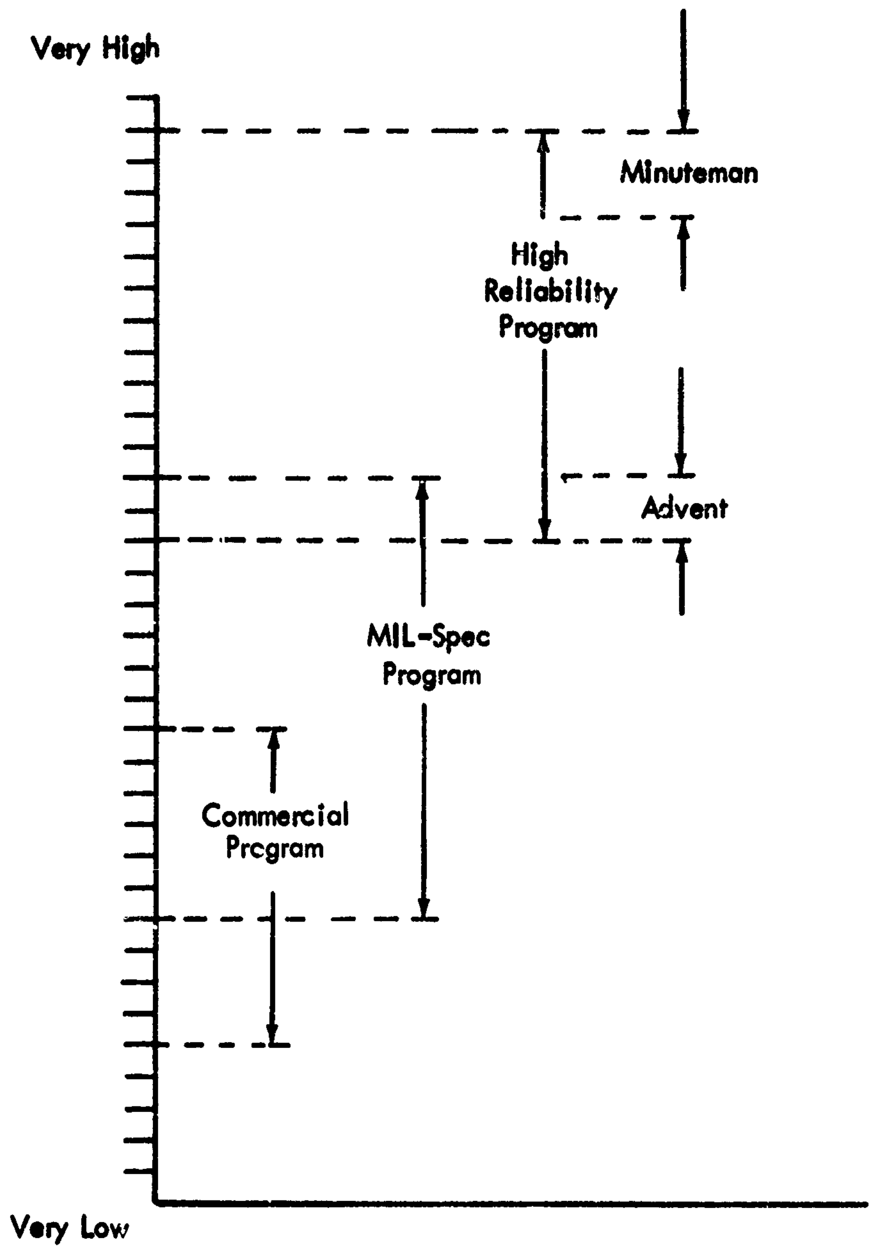

FIGURE 6-1. Relative Reliability and Quality Index

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The commercial parts industry originates almost exclusively the commodities that eventually emerge as "MIL-Spec" or high reliability types. The generic evolution of a large number of parts can be traced from commercial to "MIL-Spec's" into the high reliability area is progressing rapidly. Differences are the degree of inspection, test, and control over the parts.

The design engineer, therefore, has at his disposal at least three general levels of technology, each of which has its own state-of-the-art to offer. A specific methodology is available to the military design engineers whose requirements are for information in depth rather than shallow consideration of the selection of parts, materials, and processes which may suffice for much commercial system planning.

Since the Army engineer, to perform his tasks, must be well versed in the Department of Defense (DOD) system of standards and specifications, a general discussion of the "MIL-Spec" system follows. The system is established and described in DOD Manual 4120.3-M, *Standardization Policies, Procedures, and Instructions*[1]. This document, which includes the DOD Directives governing the system as well as the congressional acts authorizing it, may not be entirely familiar to the reader and inadvertently he may be violating the directives.

Most specifications written today meet the format requirements contained in DOD Manual 4120.3-M. It regulates the preparation and revision of all of the Military Specifications, Standards, Specification Bulletins, and Handbooks. DOD agencies attempt to select and standardize items for their use which meet their minimum essential requirements, which are often the best that the commercial industry of this country is able to produce. In the course of this selection and standardization, certain inspections, tests, and controls of the commodities and their producers became necessary. The end item procurement specification (the TDP) is the medium for stating these requirements explicitly in qualitative and quantitative terms. An example is MIL-R-10509, *Resistors, Fixed Film, High Stability, General Specification for*[2], which controls familiar type numbers such as the RN65 carbon film resistor. Another, MIL-S-19500, *Semiconductor Devices, General Specification for*[3]. These specifications, together with manufacturers' parts, have met the minimum qualification requirements, and the referenced components are readily available.

The method for ensuring contractual implementation of the "MIL-Spec" system is to state appropriate requirements in the contracts (using DD Form 1423, Contract Data Requirements List, or a statement attached to the contract) between the military procurement activity and the contractor for engineering designs or cite specific applicable documents for supply contracts.

The system of standardized commodities is not infallible and will contain cases in which commodities will not be defined and controlled in such a manner as to make them directly applicable in some instances. Examples of some of the factors that might preclude the direct use of some parts are:

(1) Part parametric limits and distributions.

(2) Environmental test requirements not fully covered.

(3) Lack of sampling testing on certain key parameters.

(4) Lack of coverage for a specific important parameter.

(5) Lack of appropriate test to detect or preclude a known failure mode or mechanism.

(6) Failure rate demonstrations are not required.

It has become fashionable to use the preceding factors, or others, to downgrade the "MIL-Spec" system. Similarly, they are used to justify abandoning the "MIL-Spec" system in favor of some other approach for the benefit of a program when actually all that is needed is to prepare new "MIL-Spec's" for the new requirements. A detailed and objective evaluation of the system shows that the "MIL-Spec" system provides ample authorization and a controlled procedure which will accommodate the unique technical requirements of almost any program. One such specification is MIL-D-1000, *Drawings, Engineering, and Associated Lists*[4]. Among other things, this specification authorizes design activities to prepare specifications and specification source control drawings "as necessary" to ensure the procurement of the commodities required to achieve the requirests levied on their equipment. By creating these documents and the engineering tasks necessary to determine their content, the design activities have recognized basis and technical justification for altering, selecting, or modifying parts as necessary. The design activity also may include on specification or source control drawings special inspections as justified and warranted on a technical basis.

The development of the total TDP, which is itself nothing more nor less than a specification must be conducted in conjunction with MIL-STD-143, *Specifications and Standards, Order of Precedence for the Selection of*[5]. This standard sets forth the criteria and order of precedence for the selection of specifications and standards to be used by design activities in the design and construction of military equipment for the Department of Defense. These specifications and

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standards control and define the commodities necessary to the design and fabrication of any conceivable system or equipment.

The "MIL-Spec" system provides an orderly, controlled, and highly practical method of allowing the design requirements of any system to be met. For the procurement activity, it provides assurance that an acceptable level of technology is being utilized in the design and fabrication of the equipment. The system has built into it assessment, monitoring, and control elements essential for its successful contractual implementation and control.

Use of the approach proposed in par. 6-2 will substantially assist in ensuring that the available specification systems are most effectively utilized. Without such an approach it is perfectly possible to demand a course of action in one specification and prohibit it in another.

Despite the inherent problems for the design activity, the system provides a contractual basis allowing the application of a controlled system which demonstrates accomplishment of manufacturing standards. Since it draws from an industry-wide system, the cost and leadtime requirements for purchasing are usually practical.

As described in DOD Manual 4120.3-M, the procuring agency has the additional responsibility of providing an orderly feedback to the "MIL-Spec" system if the technological data and improvements developed during the course of its procurement activities become candidates for incorporation into the "MIL-Spec" system. The best in inspection and test techniques resulting from experience can also be incorporated. Demonstrated deficiencies or weaknesses in "MIL-Spec" documents can be identified and remedied. This data feedback becomes practical if the design activities are required to participate in the "MIL-Spec" system and to document this technology.

In recent years, there has been criticism of the defects and shortcomings of the "MIL-Spec" system primarily because some did not understand it. Some of these criticisms were warranted and constructive. The principal weakness of the system is that the time lag between change in the state-of-the-art and specification coverage appears excessive.

Programs fall into two distinct types. The most typical example is a program in which a mixture of commercial and "MIL-Spec" parts is used to fabricate the equipment. In some cases, commercial quality parts predominate. Other types of programs are those in which extensive efforts are undertaken to obtain the best possible parts offered by the parts industry. In the case of the "high reliability" programs, assessment of the procurement specification invariably discloses that the procurement documents are heavily dependent upon the "MIL-Spec" system. These high reliability specifications either reference their "MIL-Spec" counterpart or literally repeat the technical content thereof. In some cases these high reliability procurement documents are found to be technically inferior to their "MIL-Spec" equivalents. In other cases, it has been determined that real and valuable technical supplementation of the "MIL-Spec" system is achieved. (These are Group V, as defined by MIL-STD-143[3].) If these criteria are created and controlled by an equipment manufacturer (rather than the Army Design Agency), and are divorced from the "MIL-Spec" system, it is extremely difficult from either a technical or a management point of view to incorporate them into the "MIL-Spec" system. They also will frequently detract from producibility in that they will be geared to the production facilities of one company and not to those of the general industrial base. It is, therefore, essential that design contracts should include requirements for development of draft military specifications for new requirements to be added to the "MIL-Spec" system.

In the event that a contract does not require compliance with the "MIL-Spec" system, the parts that ultimately find their way into the equipment delivered will tend to be of a commercial quality level or a mixture of commercial and "MIL-Spec" quality level. In many cases, this will be an acceptable level. If there is doubt, then contractor compliance with the "MIL-Spec" system will usually result in an improvement, but may lead to costs and leadtime penalties.

The "MIL-Spec" system is not static. Improved endtime with improved quality assurance provisions, such as more comprehensive test requirements and tightened sampling plans, are now in the "MIL-Spec" system. Most critics of the "MIL-Spec" system, while being very vocal in their complaints, generally lose sight of the fact that it is a well established and generally widely understood system, and that abandoning the "MIL-Spec" system would produce unacceptable alternatives, i.e., either to fund separately a so-called "high reliability" activity or to use essentially a commercial level technology. The latter is technically undesirable and the former is seemingly financially out of the question. It is more appropriate to use the "MIL-Spec" system, implementing it and referencing it contractually, utilizing its built-in procedures and methodology for enforcing and accomplishing the orderly feedback of data and experience to improve it.

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6-2 APPLICATION OF STANDARDS AND SPECIFICATION TREES

A priori is a favorite term of methematicians, particularly those who deal in statistics of probabilities (predictive techniques). The term is defined as:

(1) Logic. Characterizing the kind of reasoning deducing consequences from definitions or principles regarded as self-evident; deductive; deductively; as an *a priori* argument; hence designating that which can be known by reason alone and not through experience.

(2) Presumptive presumptively; without examination. In the mathematical application there are some well-founded laws which someone else has exhaustively proved and which the user may readily accept (Weibull or Bayesian distributions, for example) in justifying the approach being taken.

Unfortunately, the application of "MIL-Spec's" to a program too often suffers from application of the second definition without benefiting from the qualities of the first. This results in the "shovel them in, somebody's used them before, they must be all right" approach, and in much of the previously mentioned criticism of the system.

Military systems require the generation of many specifications to define the system under contract and, as described in the first part of this chapter, can be an invaluable aid to avoid "reinventing the wheel".

Functional people, other than those directly responsible for preparing specifications, sometimes become alarmed when they determine their work load as represented by technical and documentary references. Often, their related tasks appear confusing amid the many Government, customer, and in-house specifications, standards, procedures, etc., for hardware and software. The most expeditious way to convey these requirements to functional, staff, and project personnel is to generate a specification tree.

Specification trees in the past were usually generated for a select few in the specifications and standards group who wanted to study or monitor the interrelationship of system, subsystem, and component requirements. Today, however, the specification tree has become a very important tool in managing any design, development, or production activity.

Most new contracts for major military and aerospace systems now require that a specification tree be provided as a separate "line item" of the contract. Since major emphasis is placed upon this function in the "design and produce" type contract, it may be reasonably assumed that it is equally important to the in-house design effort within an AMC commodity command. In fact, it is the key to the effective and useful application of the "MIL-Spec" system to the specific product. This provides insight and control for the number of reference and supporting documentation items. The quantity often runs into the hundreds when quality control, reliability, maintainability, safety, human factors, design, and documentation requirements are included.

In general, a specification tree, in the context to be discussed, is a pictorial presentation of the interrelationship of specifications and other requirements on documents and standards applicable to a particular program. As a management tool, it:

(1) Provides a basis for technical and management hardware and software control.

(2) Forms a part of the program work package structure for the earned value administration and control.

(3) Serves as a ready reference document for procuring agency and contractor personnel, particularly engineering, quality control, and reliability groups.

(4) Displays the effect of decisions on the configuration and data agreements for Contract End Items (CEI's).

(5) Provides the simple way to inform in-plant personnel of changes in revision, amendments, etc., to specifications on the program.

A specification tree is necessary because it is the basis for proper management of hardware and related software. The tree informs the various operations of the support they must provide, such as apportioning reliability numerics; conducting design reviews; preparing qualification test plans; quality control testing instructions; manufacturing plans; subcontractor work statements for "buy" items; reliability figure of merit reviews; and many more related software items. In other words, a specification tree is a control point for related projects and provides time to plan and implement the necessary functions on a timely basis.

The timeliness of a specification tree is important. The earlier it is released, the better acceptance it will have, the more useful it will be, and the more effectively its contents can be analyzed and refined. At the inception of a design, the specification tree may indicate only basic identification to the subsystem levels. However, it must include system engineering, program managers, reliability, quality control, and design groups.

Specification trees for standards (Fig. 6-2, for example) are equally important since, combined, the whole family of trees is a ready reference tool for design engineers, reliability engineers, and manufacturing and quality control groups.

The following are a few of the functions which can be significantly assisted by use of a specification tree:

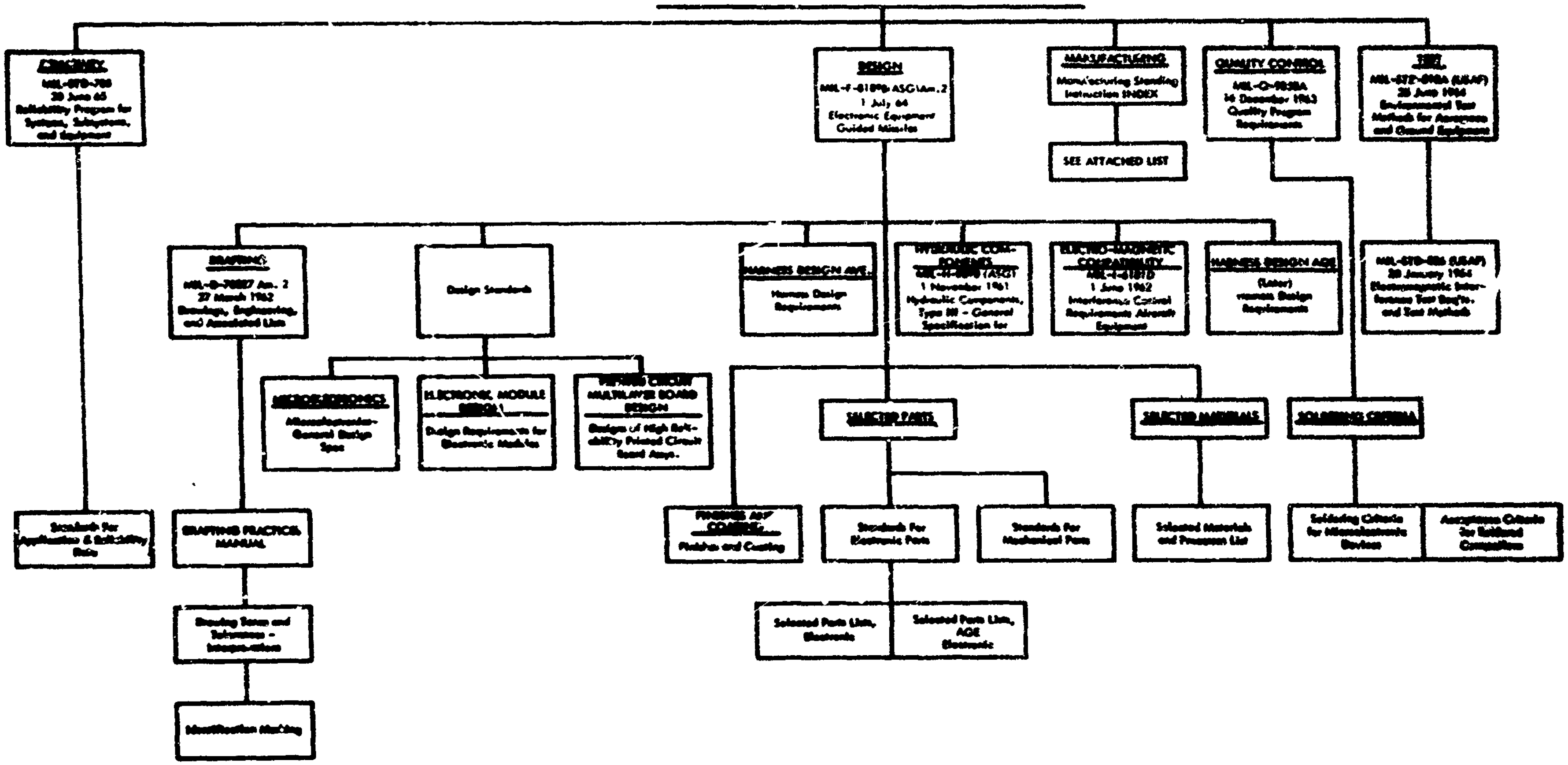

FIGURE 6-2. Sample Specification Tree for Standards

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(1) Creating hardware and software requirements for the total system, subsystems, and components.

(2) Estimating failure analysis reporting, based upon past history of similar-type programs.

(3) Estimating number and degree of design reviews to be conducted.

(4) Estimating number and degree of supplier reliability documents to be generated.

(5) Estimating number of components likely to be "make" or "buy" items.

(6) Estimating number and degree of qualification test reports to be generated.

(7) Estimating number and degree of quality control test instructions to be prepared.

More particularly, however, the tree will develop a clear picture of the impact of referenced specifications upon equipment producibility and can lead directly to the elimination of those which are unnecessary controls and which reduce producibility.

The specification tree also gives a quick look at the level of configuration control of hardware. Various levels of tree systems can be used, including the seven which follow.

6-2.1 TOP LEVEL REQUIREMENTS SPECIFICATIONS

Those specifications which define the technical requirements for the program; e.g., system and subsystem specifications, selected standard parts lists, environmental criteria and test requirements specifications, electromagnetic interference control specifications, supplier reliability requirements, quality control specifications, etc.

6-2.2 COMPONENT

A component is a combination of units or parts which together may be a functionally independent entity within a complete operating module or subsystem, but which provides a self-contained function necessary for proper operation. A component generally may be considered as the lowest level of disassembly of equipment possible, without destroying the item or requiring a refabrication cycle.

6-2.3 CONTRACT END ITEM (CEI)

CEI is a deliverable item of equipment or facility which is formally accepted by the procuring agency on a DD Form 250, Material Inspection and Receiving Report. It is the prime level of assembly for configuration management control and accountability, for provisioning spares, and for preparing technical manuals.

6-2.4 CRITICAL COMPONENT

A critical component is one for which a specification is prepared when it is necessary to specify and identify a component of a CEI which requires special engineering attention and qualification (engineering critical component) and to document a component which is part of a CEI required for multiple source procurement (logistics critical).

6-2.5 SPECIFICATION CONTROL LOG

This is a log maintained for the purpose of controlling the assignment of Specification Numbers.

6-2.6 DESIGN SPECIFICATION

A design specification is used to procure CEI's which must comply with requirements which are to be verified in test in addition to complying with drawing requirements.

6-2.7 UPDATING THE SPECIFICATION TREE

The specification tree must be updated periodically as the number of changes warrants. At the start of a program, this may be weekly or semimonthly, until the design is firm. The same data sources, concurrence, printing, and distribution procedures used for initial preparation should be used for updating. A distribution list and procedure should be generated for proper distribution of the tree and should be in accordance with an established program distribution list for technical data. The specification tree should be identified with the program title, date of issue, and program identification number. Subsequent revisions should retain the original identification number with a revision letter suffix and new date.

In support of the specification tree, a company standards tree may be required from the production contractor in order to provide a detailed translation of contract documentation of implementation within a contrac-

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tor's facility. This type of presentation assures that all personnel working on a specific program are aware of the nature and use of all required standards and specifications.

6-3 A MATERIAL SPECIFICATION SYSTEM UTILIZED IN INDUSTRY

The acceleration of material development has created a basic problem for designers and engineers; material options are so varied that they cannot easily be reduced to a manageable pattern. To efficiently overcome this material information problem, it is necessary to gather information on each material used, then organize it in three categories on the basis of user needs:

(1) *Properties:* All information useful to the designer in the process of selection, i.e., a properties profile for each material.

(2) *Specifications:* Information needed to identify or specify the material, to distinguish it from the world of available materials, and to assure that the material so identified does indeed have the selected properties when ordered.

(3) *Data for Ordering:* Data needed when physically placing an order.

One industrial organization alone maintains an automated retrieval system on 11,000 different raw and semifinished metals, nonmetals, and chemicals, and more than 600 machine-part drawings (nuts, bolts, fasteners, clamps) encompassing more than 6 million individually identified variations, each referenced to suppliers of tested performance. Each of these subjects is complete with all critical characteristics—mechanical, electrical, and magnetic; application guidance; machining, forming, and welding behavior; as well as comparative cost, specific grade available, quality requirements, and procurement guidance.

For each basic material covered, specific information is provided on individual grades offered, properties, applications and, whenever possible, comparative cost. The ready availability of information on a wide variety of alternative materials provides real assurance that a better decision can be made and implemented. For each material, a number of specific subgrades with clearly identified characteristics permits an unmistakable and concise description. Test methods are cited as specification information, and all other requirements are clearly identified.

The specification constitutes a concise statement of what is desired, and also serves as the basis for quality control planning and incoming inspection. The wide variety of subgrades tends to minimize the high cost of overspecification, the high risk of underspecification, and diminishes unauthorized substitution.

In this material information system, "Data for Ordering" constitutes a checklist of complete documentation, helpful hints as to size extras, quantity break points, normally stocked items, minimum order size, and a listing of tested sources of supply. Each listed supplier is automatically keyed for a copy of each material specification for which he is listed. He is invited to either approve the specification or offer such comments as may be appropriate.

There are numerous advantages to this arrangement. A fast estimate of current prices can be handled by telephone since the listed supplier has the latest issue of the specification. The writing of purchase orders is simplified. The buyer can then devote his time to those few purchases where either dollar volume or critical application requires an optimum vendor.

Updating the information is a critical factor. About 85% of the pages in the system are reviewed annually. At any point in time, all pages have reached the basic reference books during the preceding twelve months. About half the new pages are new information on previously covered materials, and the remainder deals with information on materials not previously covered.

After wide testing and use, the basic principles of the system have proven their value and relevance in material information systems of any size. These principles are:

(1) Separation of the data needed for design, specification, and ordering, yet identifying their interrelationships

(2) A coding system for each material, avoiding mix-ups and errors in transmission of information

(3) Indexing and cross-referencing

(4) Updating and adding to any part of the system

This sort of system organizes today's constantly widening material options into the manageable and useful pattern required by designers and engineers.

The design engineer, therefore, must appreciate and respect the use of specifications and standards. He must devote his design efforts in large measure to evaluation of every applicable detail of documentation and use each bit of information to best advantage in developing a producible commodity.

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REFERENCES

1. DOD Manual 4120.3-M, *Standardization Policies, Procedures, and Instructions.*
2. MIL-R-10509, *Resistors, Fixed Film, High Stability, General Specification for.*
3. MIL-S-19500, *Semiconductor Devices, General Specification for.*
4. MIL-D-1000, *Drawings, Engineering, and Associated Lists.*
5. MIL-STD-143, *Specifications and Standards, Order of Precedence for the Selection of.*

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CHAPTER 7

VALUE ENGINEERING TECHNIQUES

7-1 WHAT IS VALUE ENGINEERING?

Value engineering (VE) programs play an important role in achieving optimum system cost effectiveness, and contribute significantly to producibility objectives.

AR 11-26, *Value Engineering*[1] establishes the basic policies, responsibilities, and fundamental guidelines of AMC value engineering programs. AMCP 11-3, *Value Engineering Program Management Guidelines*[2], provides valuable guidelines and a bibliography.

This chapter does not attempt to define or expound on the total objectives or operating principles of a formal value engineering program. Rather, it illustrates the concept of value engineering as it applies to the objectives of producibility. While cost reduction is the basic purpose of value engineering, application of its principles frequently results in attaining other goals of producibility.

Value engineering is an organized effort directed at analyzing the function of hardware with the purpose of achieving the required functions at the lowest overall cost. There is frequently need for this approach to be an organized effort if the practices are to be applied by the design originator, who disciplines himself to observe the principles and practices of the value engineering effort. Too frequently these principles and practices are used only after the design is committed to production.

7-2 APPLICATIONS

Six basic elements or phases constitute the value engineering job plan. The elements are always distinct and separate, although in practice there is often some merging and overlapping. They are:

(1) *Orientation Phase:* selection and definition of the item to be studied. (The design engineer does not have the option of selection, but has the same need for definition.)

(2) *Information Phase:* arrival at a thorough understanding of the function of the object.

(3) *Speculation Phase:* development and application of creative thinking.

(4) *Analysis Phase:* evaluation and refinement of the ideas developed in the speculation phase.

(5) *Development Phase:* development and cost analysis of the several best alternatives.

(6) *Presentation Phase:* consolidation and review of the data developed, resulting in a decision to select one specific approach.

Fig. 7-1 illustrates the six phases of the value engineering job plan and the principal constituent elements of each phase. If, to the designer, step one is "everything", then every function becomes an obvious step in the design creation. If steps are missed or later circumstances change, then there is the need for formal value engineering.

The specific interests of value engineering are:

(1) What is it?
(2) What does it do?
(3) What does it cost?
(4) What is it worth?
(5) What else might do the job?
(6) What will it cost?
(7) Which is the least expensive?
(8) Will it meet requirements?

Once having defined the function, the value engineer, as does the designer, next embarks upon an intensive two-phase information gathering effort. First, specific information about the product itself—such as cost, quality and reliability requirements, maintainability characteristics, volume to be produced, development history, etc.—is collected. Second, general information concerning the proposed product—including present state-of-the-art, sources of supply, and processes to be employed in its manufacture—is compiled

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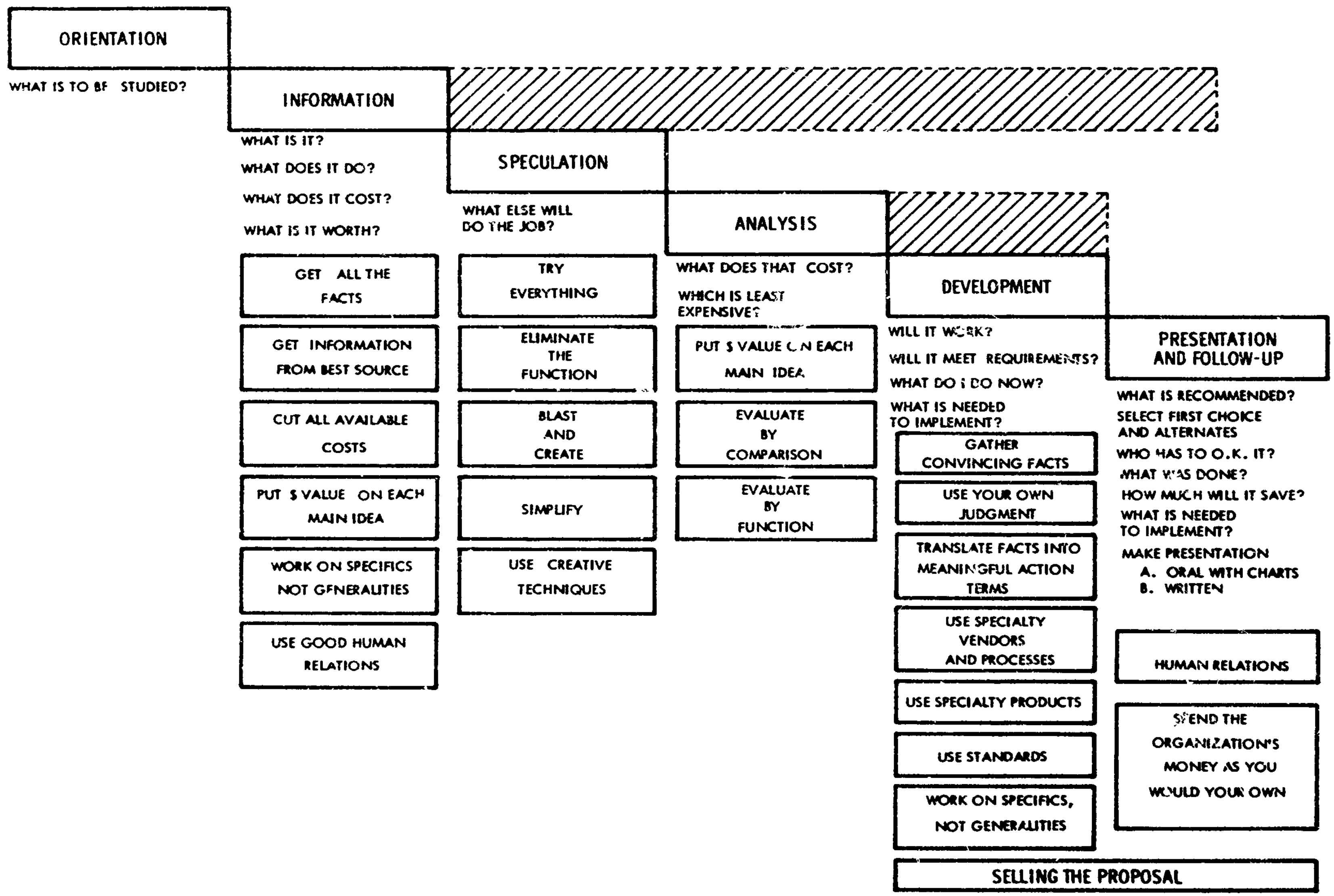

FIGURE 7-1. Value Engineering Job Plan Chart

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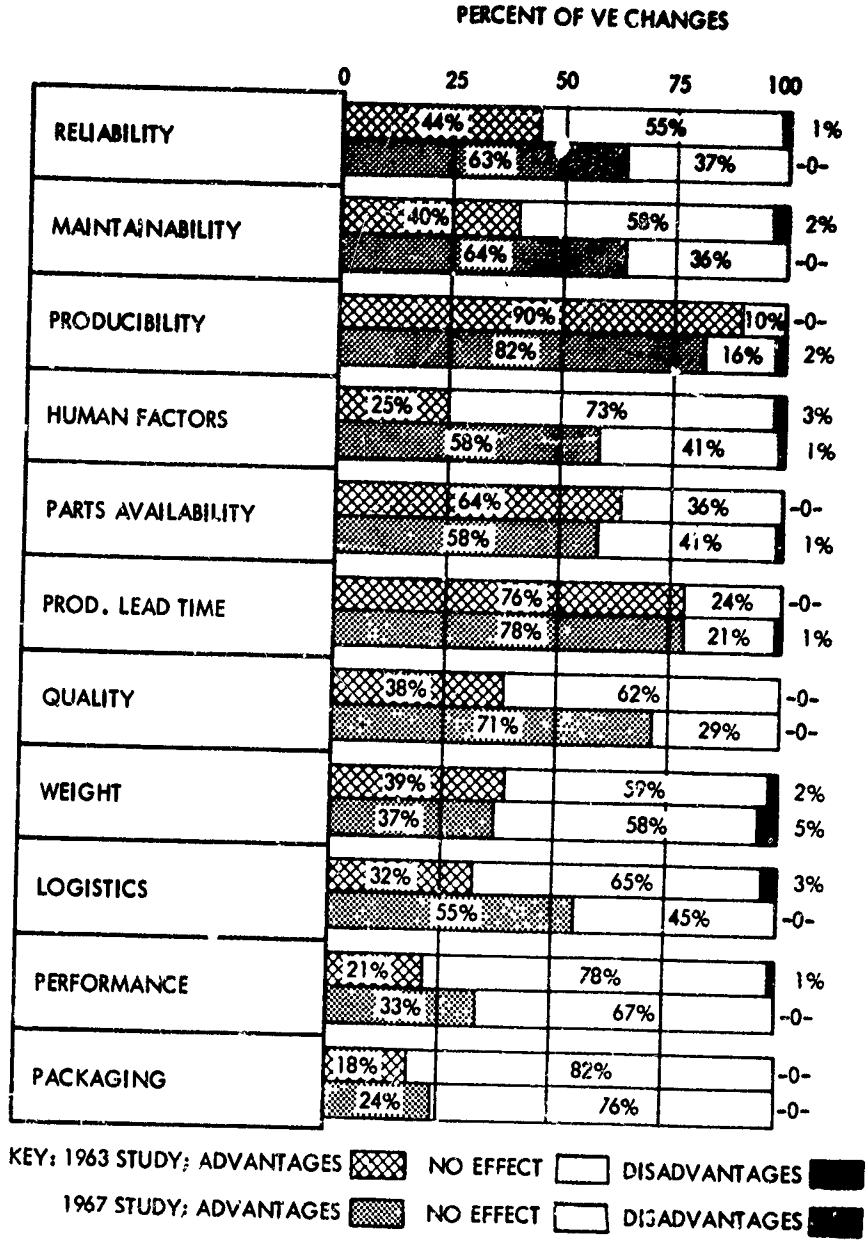

Sources:

1. Report of Te...l Subcommittee Special Committee on Value Engineering American Ordnance Association May, 1964
2. "Total Value Engineering Effectiveness Survey," by Eugene P. Noris, in A.O.A. Technical Report, Value Engineering combined with the proceedings of the technical meeting held at Andrews A. F. B., Maryland, October 4-5, 1967, (available from American Ordnance Association, Washington, D. C. $10.00).

FIGURE 7-2. Value Engineering Fringe Effect Study Results

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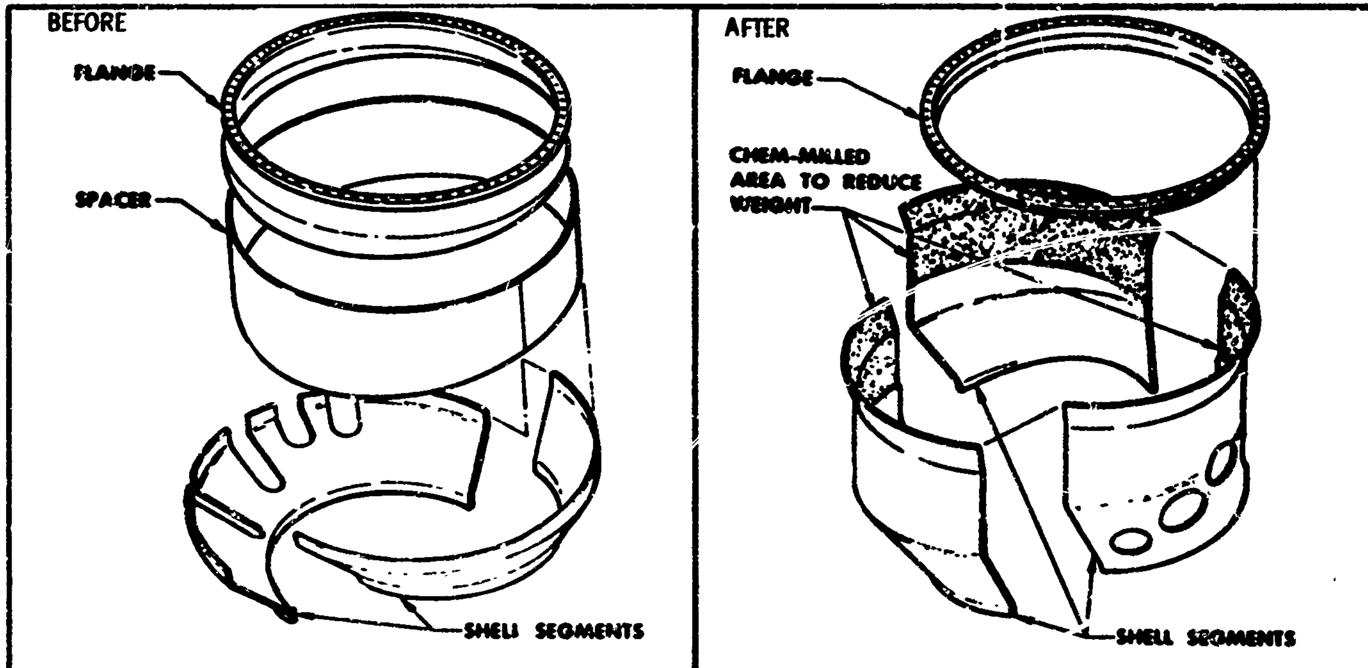

HEAT EXCHANGER - F-1 ROCKET ENGINE

IMPROVEMENTS		V/E FRINGE EFFECTS NO CHANGE	DISADVANTAGES
RELIABILITY	PARTS AVAILABILITY	PERFORMANCE	NONE
MAINTAINABILITY	PRODUCTION LEAD TIME	LOGISTICS	
PRODUCIBILITY	QUALITY	PACKAGING	
HUMAN FACTORS	WEIGHT		

CONFIGURATION: CHANGED
MATERIAL: UNCHANGED
PROCESS: CHANGED

FIGURE 7-3. Results of Value Engineering

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VALUE ENGINEERING PROJECT CHECKLIST							GROUP NO.
CHECK LIST OF ANALYSIS STIMULANTS IN DEVELOPING ALTERNATIVE DESIGNS							
NO.	A. FUNCTION	YES	NO	NO.	A. FUNCTION (CONTINUED)	YES	NO
	IS THIS DESIGN THE RESULT OF:			10.	CAN IT BE PUT:		
	a) CUSTOM?				a) ON THE OTHER END?		
	b) TRADITION?				b) IN THE MIDDLE?		
	c) OPINION?			11.	IS THERE OTHER PERTINENT INFORMATION AVAILABLE?		
2.	CAN THE SHAPE BE IMPROVED?			12.	COULD A VENDOR SUPPLY PERTINENT INFORMATION?		
3.	IS IT TOO COMPLEX TO BUILD IN MY HOME WORKSHOP?			13.	CAN THIS BE MADE EASIER TO USE?		
4.	WOULD IT BE IMPROVED IF:			14.	IS THERE SOMETHING SIMILAR TO THIS DESIGN THAT		
	a) TURNED INSIDE OUT?				COST LESS?		
	b) REVERSED?			15.	IS MOTION OR POWER WASTED?		
	c) TURNED UPSIDE DOWN?			16.	CAN REDESIGN ELIMINATE ANYTHING?		
5.	CAN IT BE DESIGNED:			17.	CAN A SIMPLER MANUFACTURING PROCESS BE USED?		
	a) SMALLER?			18.	CAN WEIGHT BE REDUCED?		
	b) SHORTER?			19.	CAN A PART DESIGNED FOR OTHER EQUIPMENT BE USED?		
	c) THINNER?			20.	IS THERE A LESS COSTLY PART THAT WILL PERFORM		
	d) LOWER?				THE SAME FUNCTION?		
6.	CAN THE DESIGN BE MADE TO SERVE ADDITIONAL FUNCTIONS?			21.	CAN THE DESIGN BE SIMPLIFIED?		
7.	CAN THE ORDER BE IMPROVED?			22.	CAN PARTS WITH SLIGHT DIFFERENCES BE MADE IDENTICAL?		
8.	WOULD IT BE IMPROVED IF IT WERE CARRIED?			23.	CAN COMPROMISES AND TRADE-OFFS BE USED TO A GREATER		
9.	COULD THE LAYOUT BE BETTER?				DEGREE?		
IF ANY ANSWER IS YES, EXPLAIN WHY.							

FIGURE 7-4. Value Engineering Project Checklist

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VALUE ENGINEERING PROJECT CHECKLIST

GROUP NO:

CHECK LIST OF ANALYSIS STIMULANTS IN DEVELOPING ALTERNATIVE DESIGNS

NO.	B. MATERIAL	YES	NO
24.	CAN A LESS EXPENSIVE MATERIAL BE USED?		
25.	CAN THE NUMBER OF DIFFERENT MATERIALS BE REDUCED?		
26.	ARE THERE NEWLY DEVELOPED MATERIALS THAT CAN BE USED?		
27.	CAN A LIGHTER GAUGE MATERIAL BE USED?		
28.	CAN ANY SPECIAL COATING OR TREATING BE ELIMINATED?		
29.	CAN ANOTHER MATERIAL BE USED THAT WOULD BE EASIER TO MACHINE?		
30.	CAN USE OF CRITICAL MATERIALS BE AVOIDED?		

IF ANY ANSWER IS YES, EXPLAIN WHY.

NO.	C. MACHINING	YES	NO
31.	IS IT NECESSARY TO IMPROVE CAST OR STOCK SURFACES?		
32.	HAVE ODD SIZE HOLES AND RADII BEEN USED?		
33.	CAN A FASTENER BE USED TO ELIMINATE TAPPING?		
34.	CAN WELD NUTS BE USED INSTEAD OF A TAPPED HOLE?		
35.	CAN ANY MACHINED SURFACES BE ELIMINATED?		
36.	WILL A FINER FINISH BE REQUIRED?		
37.	CAN ROLL PINS BE USED TO ELIMINATE REAMING?		

IF ANY ANSWER IS YES, EXPLAIN WHY.

FIGURE 7-4. Value Engineering Project Checklist (cont'd)

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VALUE ENGINEERING PROJECT CHECKLIST

GROUP NO.

CHECK LIST OF ANALYSIS STIMULANTS IN DEVELOPING ALTERNATIVE DESIGNS

NO.	D. SPECIFICATION AND STANDARDS	YES	NO	NO.	E. ASSEMBLY	YES	NO
38	IS NON-STANDARD INSPECTION EQUIPMENT NECESSARY?			49.	CAN TWO OR MORE PARTS BE COMBINED IN ONE?		
39.	CAN THE DESIGN BE STANDARDIZED TO A GREATER DEGREE?			50.	IS THERE A NEWLY DEVELOPED FASTENER TO SPEED ASSEMBLY?		
40.	CAN THE DESIGN USE STANDARD CUTTING TOOLS TO A GREATER DEGREE?			51.	CAN THE NUMBER OF ASSEMBLY HARDWARE SIZES BE MINIMIZED?		
41.	ARE TOLERANCES CLOSER THAN THEY NEED TO BE?			52.	CAN THE DESIGN BE CHANGED TO IMPROVE THE ASSEMBLY OR DISASSEMBLY OF PARTS?		
42.	IS THERE A STANDARD PART THAT CAN REPLACE A MANUFACTURED ITEM?			53.	CAN THE DESIGN BE IMPROVED TO MINIMIZE INSTALLATION OR MAINTENANCE PROBLEMS?		
43.	CAN A SPECIFICATION BE RELAXED OR ELIMINATED?						
44	CAN STANDARD HARDWARE BE USED TO A GREATER DEGREE?						
45	CAN STANDARD GAUGES BE USED TO A GREATER DEGREE?						
46.	ARE NON-STANDARD THREADS USED?						
47	CAN STOCK ITEMS BE USED TO A GREATER DEGREE?						
48	SHOULD PACKAGING SPECIFICATIONS BE RELAXED?						

IF ANY ANSWER IS YES, EXPLAIN WHY

IF ANY ANSWER IS YES, EXPLAIN WHY.

FIGURE 7-4. Value Engineering Project Checklist (cont'd)

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VALUE ENGINEERING PROJECT WORKSHEET					GROUP NO.
INFORMATION PHASE					
1. ITEM IDENTIFICATION			MAJOR FUNCTION		
PART NAME				PART NO.	
COMPONENT PART NAME	DWG. NO.	MATERIAL	QTY./ASSY.	SOURCE	SPECIFICATIONS

FIGURE 7-5. Value Engineering Identification Worksheet

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VALUE ENGINEERING PROJECT WORKSHEET		GROUP NO.
INFORMATION PHASE		
2. COST ANALYSIS	MAJOR FUNCTION	
PART NAME	PART NO.	

MAT'L ALLOY ____	WT PRICE ____	LABOR $ /Hr.	TOOLING $ /Hr.	ENGRG. $ /Hr.	REQ'D PT's	LOT SIZE ____ PTs.	LEARN FACTORS	FAB ASSY. ____	MISC. FACTORS

1	NON-RECURRING							RECURRING						
	2			3			4	5	6			7		8
DESCRIPTION	TOOLING			ENGR./PLAN			MISC. COSTS	MAT'L UNIT COST	SET-UP			RUN		MISC. COSTS
MAT'L, OPERATION, TOOLS, ETC.	HOURS	TOTAL COST	UNIT COST	HOURS	TOTAL COST	UNIT COST			HOURS	TOTAL COST	UNIT COST	HOURS	UNIT COST	
SUB-TOTALS: STD HOURS														
SUB-TOTALS: ACT HOURS														
SUB-TOTALS: TOTAL COSTS														
SUB-TOTALS: UNIT COSTS														
$ TOTAL UNIT COST														

FIGURE 7-6. Value Engineering Cost Analysis Worksheet

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At this point, a sound knowledge of the item under analysis has been developed and a basis for the most difficult and intangible phase of the process has been formulated. The purpose of the speculation phase, which may take many forms, is to generate ideas about the item's function and design, and to conceive of more economical and equally effective means of performing the same function. While it may reflect a number of preconceived ideas, a team "brainstorming" approach involving the several now-associated individuals is often helpful. In brainstorming sessions combinations and improvements are sought; quantity of ideas is an objective; "free-wheeling" is welcomed, and criticism of any idea presented is not permitted. Successful brainstorming depends on stimulating competition in idea-generation, and on unchallenged free-association. It involves participants who are not usually involved with the problem. Ideas should be documented and subsequently reviewed by persons who did not participate. The most promising ideas are then considered as alternatives

Design alternatives must first be checked for technical feasibility and then economic feasibility. This includes estimation of number of units to be produced, variable cost of manufacturing, fixed cost of manufacturing, and logistic costs of supporting and maintaining the alternative. However, if any of the following essential technical questions are answered negatively, it is pointless to investigate the economic advantages:

(1) Does the item meet performance requirements?
(2) Are quality requirements demonstrated?
(3) Are reliability requirements met?
(4) Is it compatible with the system of which it is a part?
(5) Are safety requirements met?
(6) Does the alternative improve (or at least not reduce) maintainability characteristics of itself or of the system to which it belongs?
(7) Does the alternative permit adequate provisioning, transporting, and storing of necessary support material for the alternative or the system of which it is a part?

The phases of a value engineering study closely parallel those of any design evolution. However, they benefit from precise definition and formal controls.

7-3 FRINGE EFFECTS

While value engineering appears to place principal emphasis upon cost aspects of the design, significant producibility fringe benefits are usually obtained through the application of their principles. Fig. 7-2 illustrates improvements achieved in producibility as a result of application of formal value engineering studies. While other significant improvements were also accomplished, the figure shows that producibility is the most significant fringe benficiary. The lower producibility bar shows an improvement in 82% of the cases studied. These resulted from the following specific producibility improvements:

(1) Reduction in number of operations: 30%
(2) Reduction in number of parts: 26%
(3) Fewer tools, gages, and tests: 15%
(4) More repeatable manufacture: 13%
(5) Relaxation of tolerances: 7%

Fig. 7-3 shows a typical value engineering improvement in design, which identifies fringe effect advantages of the modified design, including producibility. Other examples of value engineering results are found in DOD Pamphlet, *Reduce Costs and Improve Equipment Through Value Engineering*[3], and DOD VE Handbook H-111, *Value Engineering*[4]

7-4 CHECKLISTS

Checklists can be an important aid to the design engineer if used properly. They are devices to ensure that the simple common sense answer to a problem is not overlooked, and also are helpful in stimulating creative thinking. If each question on a checklist is answered objectively and the question "why?" is asked about the answer, a thought process will have been started and new avenues of approach are opened (i.e., one question will lead to another).

The checklist given in Fig. 7-4 may be a helpful aid to achieving maximum producibility.

7-5 WORKSHEETS

The worksheet is another valuable working tool because of its systematic approach to a host of variables in search of the best solution. While rigorous adherence to the worksheet is a key feature of value engineering, the use and format of the worksheet can be modified to suit individual needs of each design engineer. The actual importance of the worksheet is in direct proportion to the complexity of the problem.

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The six value engineering job plan phases and their relationship to principal worksheets are:

(1) *Orientation Phase:* worksheets are not used.

(2) *Information Phase:*

(a) Identification Worksheet (Fig. 7-5)

(b) Cost Analysis Worksheet (Fig. 7-6)

(c) Function, Worth, and Cost Evaluation Worksheet (Fig. 7-7). The worksheets used in this phase present a detailed identification of the component parts as related to their cost, worth, and function.

(3) *Speculation Phase:* the Creative Thinking Worksheet (Fig. 7-8) is used to list new ideas, no matter how extreme.

(4) *Analysis Phase:*

(a) Characteristic and Functional Comparison Worksheet (Fig. 7-9)

(b) Idea Evaluation Worksheet (Fig. 7-10)

(c) Cost Comparison Worksheet (Fig. 7-11)

The Analysis Phase worksheets are concerned with the selection of the most promising alternatives for further analysis and refinements.

(5) *Development Phase:* no worksheets are used since the majority of the work involves the documentation of the results of various tests employed.

(6) *Presentation Phase:* the Recommendation Worksheet (Fig. 7-12) illustrates a typical form for the final presentation.

REFERENCES

1. AR 11-26, *Value Engineering*, Suppl. 1.
2. AMCP 11-3, *Value Engineering Program Management Guidelines*, Chapter 8.
3. DOD Pamphlet (unnumbered), *Reduce Costs and Improve Equipment Through Value Engineering;* prepared by Directorate of Value Engineering, Jan. 1967, pp. 11-72. (Office of Assistant Secretary of Defense (Installations & Logistics)). (Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402–Price 50 cents.)
4. DOD VE Handbook H-111, *Value Engineering*. March 1963. pp. 16-23.

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VALUE ENGINEERING PROJECT WORKSHEET						GROUP NO.
INFORMATION PHASE						
3. FUNCTION, WORTH & COST EVALUATION				MAJOR FUNCTION		
PART NAME					PART NO.	
COMPONENT PART NAME	FUNCTION		BASIC	SECONDARY	VALUE	PRESENT ACTUAL COST
	VERB	NOUN				
				TOTAL		

FIGURE 7-7. Value Engineering Function, Worth, and Cost Evaluation Worksheet

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VALUE ENGINEERING PROJECT WORKSHEET				GROUP NO.
SPECULATION PHASE				
4. CREATIVE THINKING		MAJOR FUNCTION		
PART NAME			PART NO.	
NO.	CONTRIBUTED BY	SUMMARY DESCRIPTION	ENTERED DATE	ENTERED TIME

FIGURE 7-8. Value Engineering Creative Thinking Worksheet

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VALUE ENGINEERING PROJECT WORKSHEET				GROUP NO.
ANALYSIS PHASE				
5. CHARACTERISTIC & FUNCTION'L COMPARIS'N		MAJOR FUNCTION		
PART NAME			PART NO.	
NO.	SUMMARY DESCRIPTION	SIMILAR CHARACTERISTICS	MIGHT COST MORE	MIGHT COST LESS

FUNCTIONAL COMPARISON

NO.	IDENTIFICATION OF OTHER WAYS TO PERFORM FUNCTION	MIGHT COST MORE	MIGHT COST LESS

FIGURE 7-9. Value Engineering Characteristic and Functional Comparison Worksheet

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VALUE ENGINEERING PROJECT WORKSHEET	GROUP NO.
ANALYSIS PHASE	
6. [illegible] EVALUATION	MAJOR FUNCTION
PART NAME	PART NO.

IDEA	ADVANTAGES	DISADVANTAGES

FIGURE 7-10. Value Engineering Idea Evaluation Worksheet

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VALUE ENGINEERING PROJECT WORKSHEET	GROUP NO.
ANALYSIS PHASE	
7. COST COMPARISON	MAJOR FUNCTION
PART NAME	PART NO.

PRESENT DESIGN/METHOD #1

DESIGN/METHOD #2

DESIGN/METHOD #3

DESIGN/METHOD #4

DESIGN/METHOD #5

BREAK-EVEN POINTS

COST

QUANTITY

	COST ITEM	DES./METHOD #1 (PRES.)		DES./METHOD #2		DESIGN/METHOD #3		DESIGN/METHOD #4	
		TOTAL COST	UNIT COST	TOTAL COST	UNIT COST	TOTAL COST	UNIT COST	TOTAL COST	UNIT COST
NON-RECURRING	TOOLING								
	ENGINEERING								
	PLANNING								
	QUALIFICATION								
RECURRING	MATERIAL COST								
	SET-UP								
	RUN								
	COMPONENTS (O.P.)								
	COMPARATIVE ☐ TOTAL ☐ PARTIAL ☐	$	$	$	$	$	$	$	$

EVALUATION MADE DURING ☐ DESIGN ☐ PRODUCTION | ANALYSIS CODE 1 2 3

DEVELOPED BY | APPROVED

FIGURE 7-11. Value Engineering Cost Comparison Worksheet

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VALUE ENGINEERING PROJECT WORKSHEET		GROUP NO.
PRESENTATION PHASE		
8. RECOMMENDATION	MAJOR FUNCTION	
PART NAME	PART NO.	

CATEGORY		TYPE OF SAVINGS		PROGRAM AFFECTED
☐ ENGINEERING	☐ MKTG. & CUST. SERV.	☐ VE	☐ DoD	PROJECT/OTHER
☐ PROCUREMENT	☐ ADMINISTRATION	☐ OTHER	☐ NASA	
☐ MANUFACTURING	☐ GENERAL SERVICE		☐ OTHER	
☐ Q. R. A.				

DESCRIPTIVE TITLE

PREVIOUS METHOD

IMPROVE METHOD

PERIOD: ☐ ANNUAL, ☐ ONE TIME, ☐ CONTRACT	COMPUTATION OF SAVINGS
PREVIOUS METHOD COST	$
IMPROVED METHOD COST	$
GROSS SAVINGS	$
COST OF IMPLEMENTATION	
NET SAVINGS	$

BRANCH	DEPT. ORGN. NAME	DEPT. ORGN. NO.	APPROVED (COST REDUCTION MANAGER)

FIGURE 7-12. Value Engineering Recommendation Worksheet

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CHAPTER 8

SELECTION OF MATERIALS AND PROCESSES

8-1 INTRODUCTION

Effective material and process selections demand clear definitions of performance and producibility objectives and design constraints, liquidation of preconceptions and limiting generalizations, and the promotion of fresh ideas in the design process. There exists a huge and rapidly expanding selection of materials, processes, finishes, and coatings which can assist in the generation of new ideas.

It is all too easy to feel that time does not permit consideration of more than a fraction of the candidates available, and to rely exclusively on proven methods and procedures. Effectively accomplishing the full objectives requires a logical and systematic approach as well as recognition of the range and degree of influence of the variables which affect the eventual decision.

8-2 SELECTION CRITERIA

The selection of materials, processes, and associated techniques are not simultaneous functions of the design process. As developed in Chapter 3, selections must be made to some degree at all stages, from approach to hardware development and even manufacturing. It may be categorically stated that there is at present no formal method for pursuing the selection process. The guidelines developed here reflect the general approach currently used.

One producibility goal is to make a design flexible enough that many processes, materials, etc., may be used without functionally degrading the end item. The optimum selection would result from knowing a great number of facts, some of which are not always available, i.e., plant capacity, machine availability, labor considerations, etc. For many designs, an early selection may be premature and illfounded. Therefore, the approach offered here is necessarily general and not dogmatic.

During the review and definition of the requirements, it is frequently possible to rule out entire classes of materials based on their obvious inability to satisfy operational requirements, or on the basis of cost. However, if today's technology can make springs out of lead, one should not be too quick to brand a material as obviously unsuited. At this stage, only a broad outline of the material requirements is needed, primarily to determine whether the concept is seriously limited by the materials or requirements.

While most published selection processes treat material selection as one field and process selection as another, the two are inseparable. Thus, unless constraints are so restrictive that they prohibit material selection (and this does not occur as often as is believed), it is essential to think in terms of wide variety and gradations of materials and processes and to pursue a policy of judiciously combining experience with limited systematic analysis of alternatives in proportions which will create an effective design within the allotted time and budget. In order to do this, various techniques evolve in the selection of materials, processes, coatings, etc. These must be coupled with full conversance with the producibility goals for the project. The knowledge of intended lot size, permissible leadtimes, capability of the probable manufacturing base, etc., may permit legitimate exclusion of a number of materials and processes, and concentration on those with high potential.

Selection processes must operate within limits such as system performance or cost. For example, in considering the selection of materials for an application involving relatively simple types of loading and structural cross sections, a selection process may be performed by rating the entries on the basis of the formulas given in Table 8-1. Price-per-pound is usually given as raw material unit cost; however, design evaluation is usually in terms of a processed material cost (per pound, in early design stages). This cost figure can be derived by analyzing the steps that make up the process, the assembly steps influenced by process, set-up and leadtime costs if these present an economic penalty. If these estimates are for use in competitive procurement, national average values should be utilized as criteria.

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TABLE 8-1. TYPICAL FORMULAS BASED ON COST FOR PERFORMANCE

Type of Structure and Loading	Relative Cost for: Equal Strength	Relative Cost for: Equal Stiffness
Rectangles in Bending	$\left(\frac{YS_1}{YS_2}\right)^{1/2} \times \frac{\rho_2}{\rho_1} \times \frac{P_2}{P_1}$	$\left(\frac{E_1}{E_2}\right)^{1/3} \times \frac{\rho_2}{\rho_1} \times \frac{P_2}{P_1}$
Solid Cylinders in Bending	$\left(\frac{YS_1}{YS_2}\right)^{2/3} \times \frac{\rho_2}{\rho_1} \times \frac{P_2}{P_1}$	$\left(\frac{E_1}{E_2}\right)^{1/2} \times \frac{\rho_2}{\rho_1} \times \frac{P_2}{P_1}$
Solid Cylinders in Torsion	$\left(\frac{YS_1}{YS_2}\right)^{2/3} \times \frac{\rho_2}{\rho_1} \times \frac{P_2}{P_1}$	$\left(\frac{G_1}{G_2}\right)^{1/2} \times \frac{\rho_2}{\rho_1} \times \frac{P_2}{P_1}$
Solid Cylinders in Tension	$\left(\frac{YS_1}{YS_2}\right) \times \frac{\rho_2}{\rho_1} \times \frac{P_2}{P_1}$	$\left(\frac{G_1}{G_2}\right) \times \frac{\rho_2}{\rho_1} \times \frac{P_2}{P_1}$
Solid Cylinders as Columns	—	$\left(\frac{E_1}{E_2}\right)^{1/2} \times \frac{\rho_2}{\rho_1} \times \frac{P_2}{P_1}$
Cylindrical Pressure Vessels	$\left(\frac{YS_1}{YS_2}\right) \times \frac{\rho_2}{\rho_1} \times \frac{P_2}{P_1}$	—

YS = yield strength, psi; E = Young's modulus, psi; ρ = density, lb/cu in.; P = price, \$/lb.

G = modulus of rigidity

8-3 COST-EFFECTIVENESS

As has been emphasized many times in this handbook, cost-effectiveness—not cost—is the criterion. With respect to producibility goals, cost-effectiveness is a function of time and dollars. A process should not be selected that entails a production time exceeding that set forth in the producibility objectives. In his efforts to establish a cost for a processed material, the designer will be in a position to examine this time aspect of the problem as well. As an initial step, he should pinpoint the projected lot size or sizes, the project unit cost, and the maximum allowable production time. After defining all operations in the production of the design in question, the cost/time analysis for each of these can be plotted, as shown in Fig. 8-1. If consideration involves a number of different situations, e.g., a wide range of projected lot sizes, there will probably be several end points.

Cost/time trade-offs, which can also be plotted, should also be considered (see Fig. 8-2). Frequently, such a relationship may exist between producibility objectives and constraints, or the developing project may produce areas wherein time, performance, and cost involve trade-offs. When a chart, similar to Fig. 8-2, can be drawn depicting the situation, a forceful tool for cost-effectiveness analysis is available. From the end points so plotted, the cost-effective candidate can be determined.

This effectiveness is graphically delineated by the distance from the end points to the cost/time curve. The candidate with the greatest distance is most cost effective when trade-offs are involved. In the illustration, a<c<d<b. Process E is excluded since it lies in the unacceptable area of the plot. Process B then is the most suitable. Frequently, the relationship between time and unit cost are not defined. Only a target for each is given. For example, in the design of a component in a system, the maximum time allowable may be based on the time for

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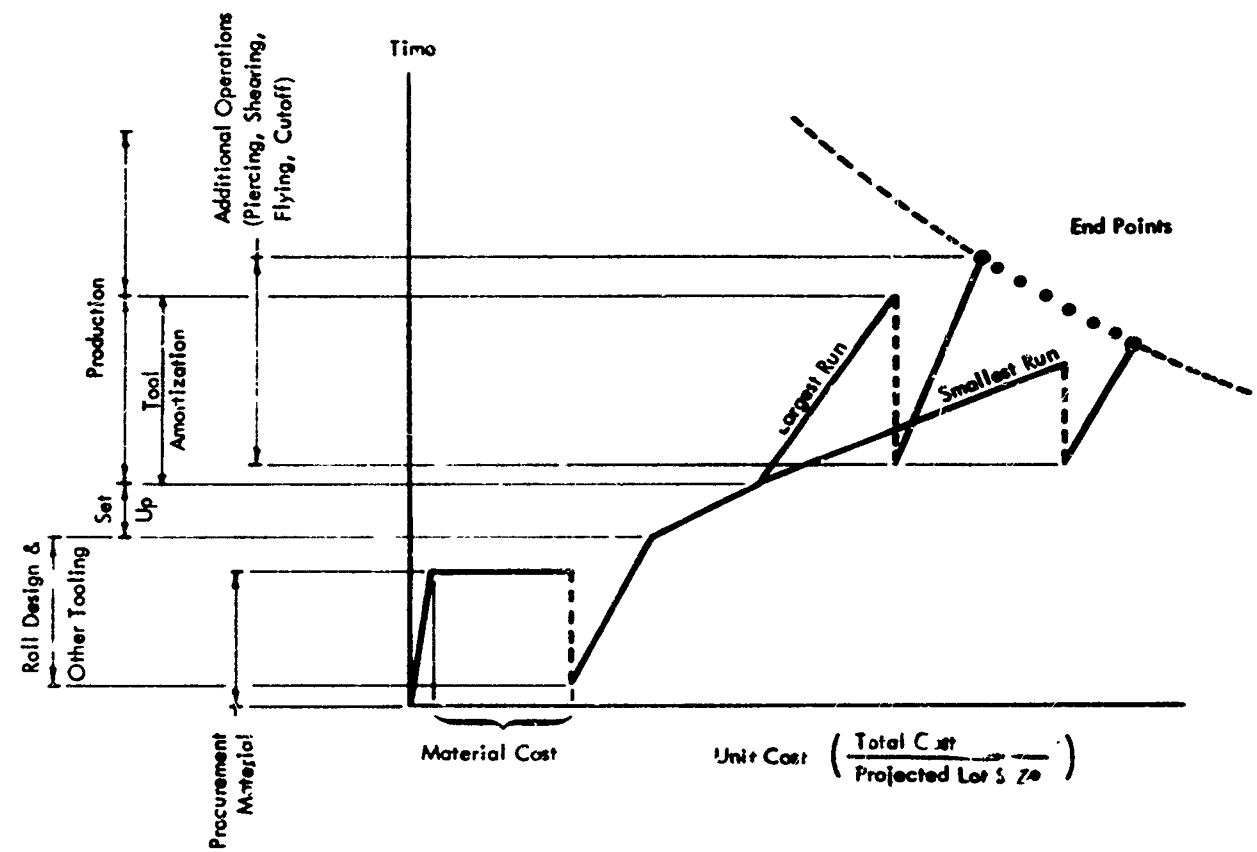

FIGURE 8-1. Cost/Time Analysis for Typical Cold Roll Forming Operation

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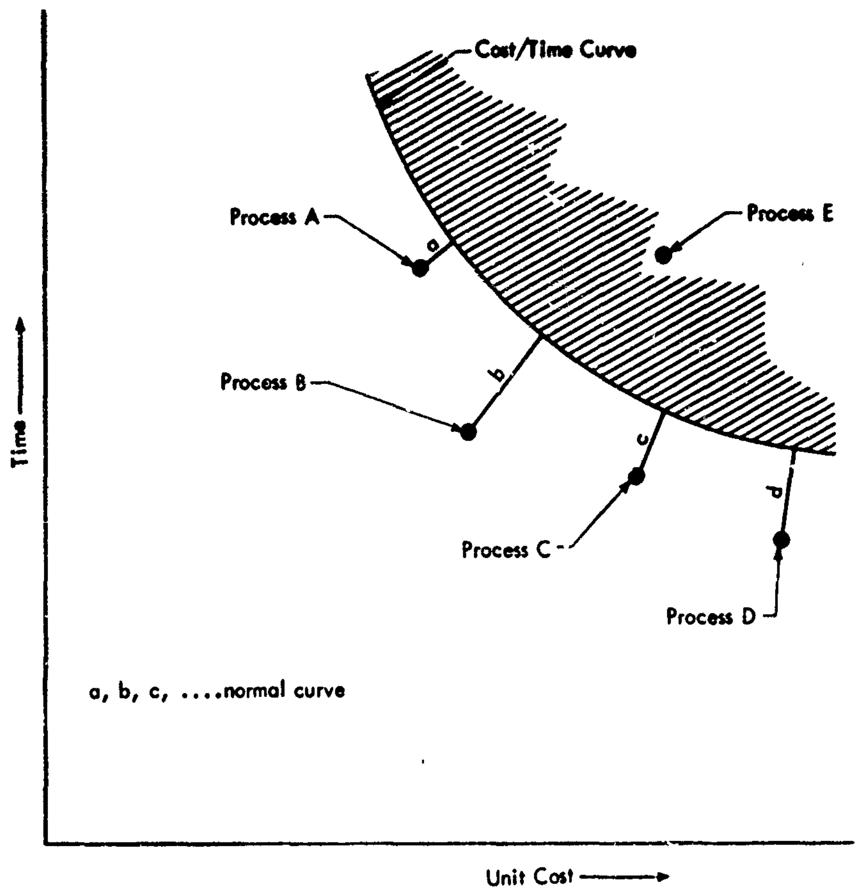

FIGURE 8-2. Cost/Time Curve for Candidate Selection

production of a mating subsystem. A decrease in process time does not measurably aid the cost-effectiveness of the component in question. The designer will need to modify similar curves and analytic methods using his best judgment to meet peculiar needs of specific problems.

8-4 SELECTION APPROACH

This approach, with its emphasis on the producibility goal of cost-effectiveness, has a great advantage over techniques which consider performance or material cost alone. However, still unanswered is which candidates are selected for analysis. Large numbers cannot easily be subjected to this process

There are two possibilities, external or internal In general, in the external approach the designing people are assisted in the selection process by another group. Many design activities have a group (or department) for the purpose of material selection with whom the design people should, and in many cases must, consult They are intimately familiar with the ramifications of many possible candidates. Nonetheless, the designer is responsible for the ultimate selection, he must analyze the suggestions of such a group, perhaps using the cost/time method. In any event he must be assured that the candidates meet producibility objectives in the optimum fashion. Frequently, a series of candidates must be considered. After checking the candidates for compliance with objectives and constraints, a choice from among them must be made and the cost/time method will give a rational method of approach that contains a minimum of bias, a factor that often leads the analyst toward a candidate.

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The internal approach is one performed by the designer himself. However, he may make use of sources outside his own organization and knowledge. If he properly defines the performance characteristics of the desired material or process, he may be able to utilize one of these sources to limit his candidates to a number easily handled by cost-effectiveness analysis techniques. Frequently, periodicals have checklists for particular areas that enable a designer to narrow the field. But the Army designer must remember that once he has a set of candidates, all of which meet functional requirements, the final selection must be based upon producibility considerations and not on the extent to which particular items may exceed minimum functional requirements. One common fault is to select a material which exceeds requirements on the basis that it "gives the design quality". A design that fulfills its objectives *has* "quality"; one that overfills its objectives is costly.

Frequently, feedback loops in the design process (Chapter 3) can be utilized as a selection tool. Having decided on an approach; a selection of material, process, etc., that seems feasible is made and steps are then taken to develop the design in some detail. The limitations that the selected items place upon detailed concepts and efforts to design around these will lead to different materials, processes, etc., that will better accomplish a particular function. This new selection will trigger new detail approaches which will, in turn, suggest new materials.

The techniques of value engineering may be applied at any stage in the design process. Judicious use of appropriate techniques (presented in Chapter 7) may effectively narrow the candidate field to those materials inherently able to best meet the goals of producibility.

As was pointed out in Chapter 4, the need exists for formal design reviews during the design process. These reviews—which combine the criticism of knowledgeable people in such fields as materials, production, maintainability, reliability, quality control, and human engineering in brainstorming sessions—give inputs, candidates, and functional approaches that, in combination with work otherwise done, may result in a small set of candidates amenable to cost-effectiveness analysis.

8-5 FUTURE POTENTIALS

Computer selection of materials can play an important role. Some organizations have computers with the ability to carry out material selections when care is taken in the preparation of inputs and the memory bank is sufficiently large and updated. It may one day be feasible to provide designers with individual and speedy access to computers via keyboards and quick response displays of the sketchpad type. The programs will not be fixed in advance but will permit, and require, human intervention at critical points. Using graphical, verbal, as well as mathematical languages, the designer may have the capability to explore situations not fully understood. Response time will be equal to, or less than, the cognition delay time so that considerations, interruptions, and new instructions can be given to the computer. The effect will be to permit the designer to make better informal leaps to new design, process, and material possibilities when it is decided to reject the last possibility which has been produced. The machine can take into account previous judgments which the operator (designer) cannot recall in detail. The effect of the intervention is to direct the automatic exploration away from unfruitful searches. With the details of standard parts; properties of materials; characteristics of processes, finishes, and coatings; standard procedures; and histories of previous designs (successful and unsuccessful) stored in the computer, alternatives can be presented.

Faced with the increasing number of available materials and processes, designers will have to spend more time on the selection process than they presently do. In order to achieve the best technological and producible solution, attempts should be made to enlarge experience and knowledge in this area and to increase the ability to go to the heart of the design and selection problem.

8-6 ROLE OF DECISION PHILOSOPHY

Planning and designing are both closely related to decision making. A decision becomes necessary only when more than one course of action is available. For example, the following questions requiring decisions are often encountered:

(1) Which technical alternative should be employed?

(2) How should tasks be evaluated, selected, and sequenced?

(3) What are the optimal approaches for programs, projects, tasks, and component parts; how should they be pursued over a period of time?

Between the time when the existence of a problem is recognized and the time when its solution is achieved, a number of steps must be taken. Among them are

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those steps which occur between the "recognition" event and the "solution" event; this is frequently referred to as the "decision process".

The decision process can be regarded as having the following essential ingredients:

(1) Personal objectives or preferences.

(2) Alternative courses of action, not all of which are equally good in the light of objectives or preferences.

(3) Forecast of the outcome of each alternative.

(4) Desire to make a choice among the alternatives that will, in some way, be the best choice.

A decision philosophy is a preferred set of standards used to judge the appropriateness of the steps in the decision process and a preferred way of employing these steps. The common human experiences of countless generations give rise to a "common decision philosophy", possessed and used by nearly everyone. We all grow up and live in an environment that is sometimes hostile, usually competitive, and often unpredictable. Problems frequently arise with little or no warning that require rapid solution. Usually, the sooner the problem is resolved, the less likely that unfavorable or even disastrous results will occur.

Within a common decision philosophy atmosphere, solutions are frequently perishable; an effective solution applied now might be worthless if applied later. We are conscious not only that time is running out but also that a delayed solution to the problem may cost us something; the longer we wait, the more the solution will cost.

If all the information about the problem and resources available to solve it were known, choice of the best solution would be relatively easy. Lack of time forces finding the solution which appears best in the light of the available information.

When a problem arises, we refer to previous experience of a similar problem in order to apply an old solution. If the same kind of problem arises often, we tend to use a standardized procedure (a checklist) for handling it Under the pressure of time or through careless thinking, only the similarities and not the differences are examined Thus, experience, properly used, can save much time and effort. Relying too heavily upon it can reject the opportunity to use very different, new, and far more effective solutions.

Common decision philosophy has the following key points:

(1) The problem is real, and it exists now

(2) The speed with which a decision is made and executed is usually more important to success than the exact nature of the action decided upon.

(3) If the initial decision turns out to be bad, the error may be discovered soon enough to permit correction.

The common decision philosophy is essentially short-range planning, usually applied to a rather specifically defined military requirement, the fulfillment of which has been determined to be technically feasible. This is the environment in which the Army design engineer usually finds himself. There is also long-range planning, which may, at times, become of concern to the same engineer.

Long-range planning is oriented to the solution of problems which may come into existence at some time in the future. This is obviously contrary to the common decision philosophy in that the problem is not real and pressing, and speed of solution is not required. When long-range planning is applied in the design phase, the need for the best solution must be so important that time can be traded off to increase the quality of the solution. The most significant distinctions between short- and long-range planning stem from differences in the purpose and the underlying philosophies. These are shown in Table 8-2.

It should be remembered that the development phase ordinarily extends from about seven to nine years, which often allows time for long-range thinking.

8-7 THE DECISION PROCESS

Even though the designer has studied his project and has become (hopefully) very knowledgeable, and is now ready to start to make decisions, there are factors in the decision making process which are not dependent on knowledge and experience. The following elements may unfavorably influence producibility decisions:

(1) Performance objectives

(2) Definition of producibility objectives

(3) Available mode of expression (design constraints)

(4) Judgment conditions

A brief examination of these elements produces the following:

(1) The performance objectives might be easily achieved or may be extremely difficult. The more difficult, the greater the attention they should receive, possibly to the detriment of other factors.

(2) The definition of the producibility objectives may be lax ("Do the best you can"), or be quite positive ("This device must be producible by any small machine shop"). In the latter case, considerable attention should be given to the equipment and facilities of the average small machine shop.

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TABLE 8-2. COMPARISON OF SHORT- AND LONG-RANGE PLANNING

	SHORT-RANGE	LONG-RANGE
OBJECTIVES:	Attainment of a stated requirement in the shortest possible time.	Obtaining the 'best' solution in the time frame without prior knowledge of what the solution will be.
TRADE-OFFS:	Degree of possible advancement traded off to shorten time of attainment.	Time, to the extent possible, traded off to attain greater capability.
ORIENTATION:	'Do the best you can' compatibility with adopted concepts.	Solution of a design problem in the form of an optimum combination of material and processes.
MANAGEMENT POLICY:	Confine consideration to those alternatives having the greatest possibility in the shortest time.	Consider all alternatives
	Eliminate alternatives and converge effort on a single material concept as rapidly as possible.	Continue consideration of all practical alternatives within available resources until evidence obtained no longer supports feasibility, external circumstances force a decision, or funds available cannot be further adjusted.
	Terminate task as soon as information obtained meets the needs at hand.	Continue task as long as it is efficiently producing information known to be useful and resources can be allocated.
TECHNICAL ASPECTS:	Attempts to exploit state-of-the-art rapidly; effort is largely empirical; may permit some attack on barrier problems; all approaches must be supported by factual data.	May investigate beyond current state-of-the-art; tends toward unorthodox approaches, but does not neglect more conventional approaches where large advancements are possible.
	Solutions to technical problems will be largely 'special case' solutions not planned to be (but may be) useful beyond the requirement at hand. 'special case' solutions are justifiable only for time saving.	Solutions to technical problems will be largely 'general' solutions applicable beyond the particular area of investigation.
	Much of the technical effort has 'brush fire' attributes; the emphasis on speed (for all practical purposes) limits the degree of exploitation of recent gain in fundamental knowledge from basic research; the effort is not likely to produce much improvement in long term producibility.	Provides ample time to engage in and follow through on creative thinking, allows time to develop and exploit the output of research and exploratory development activity, and thereby opens the door to profitable feedback.
PAYOFFS:	Results in one more generation in a series of generations of equipments each of which will have anticipated shortcomings attributable to time factors, while each generation may have favorable improvement coefficients, the result is still empirical product improvement or evolution.	Provides an orderly mechanism for introducing radical and revolutionary advancement, the end product should contain more features of design and production which ensure that it conforms with all of its performance objectives within the design constraints, and that it is highly producible

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TABLE 8-3. CHECKLIST OF 50 FAMILIAR ROADBLOCK QUOTATIONS

1. I agree but...
2. We've tried that too.
3. We did it this way.
4. Procedure won't permit.
5. It won't work.
6. There is no money budgeted for this.
7. Don't move too fast.
8. You can't do that.
9. It's never been done that way before.
10. Don't we have something just as good now?
11. It's not standard stock.
12. Costs too much.
13. Cost doesn't matter.
14. Too big (or too small) for us.
15. We've tried that before and it didn't work.
16. [illegible] not ready for that.
17. We can't do things that way.
18. We have the best system already.
19. Everybody does it this way.
20. We have too many new projects now.
21. It's policy.
22. It won't stand shock.
23. Not timely.
24. It's an untried gimmick.
25. Not for us.
26. It's difficult to maintain.
27. Not our responsibility.
28. Why should we change now?
29. We haven't tested it yet.
30. Impracticable.
31. Idea too radical.
32. Too complicated.
33. It isn't consistent.
34. Too theoretical.
35. I'm too busy to decide now.
36. That's unsound.
37. Not feasible.
38. Impossible.
39. The production department won't accept it.
40. The field will think we're long-haired.
41. Personnel aren't ready for this.
42. Engineering won't approve it.
43. The Army is different.
44. The men won't go for it.
45. You'd never be able to sell that to the management.
46. We don't have enough facts.
47. Can't see it.
48. Too much trouble to get started.
49. Doesn't conform to policy.
50. We don't have the manpower.

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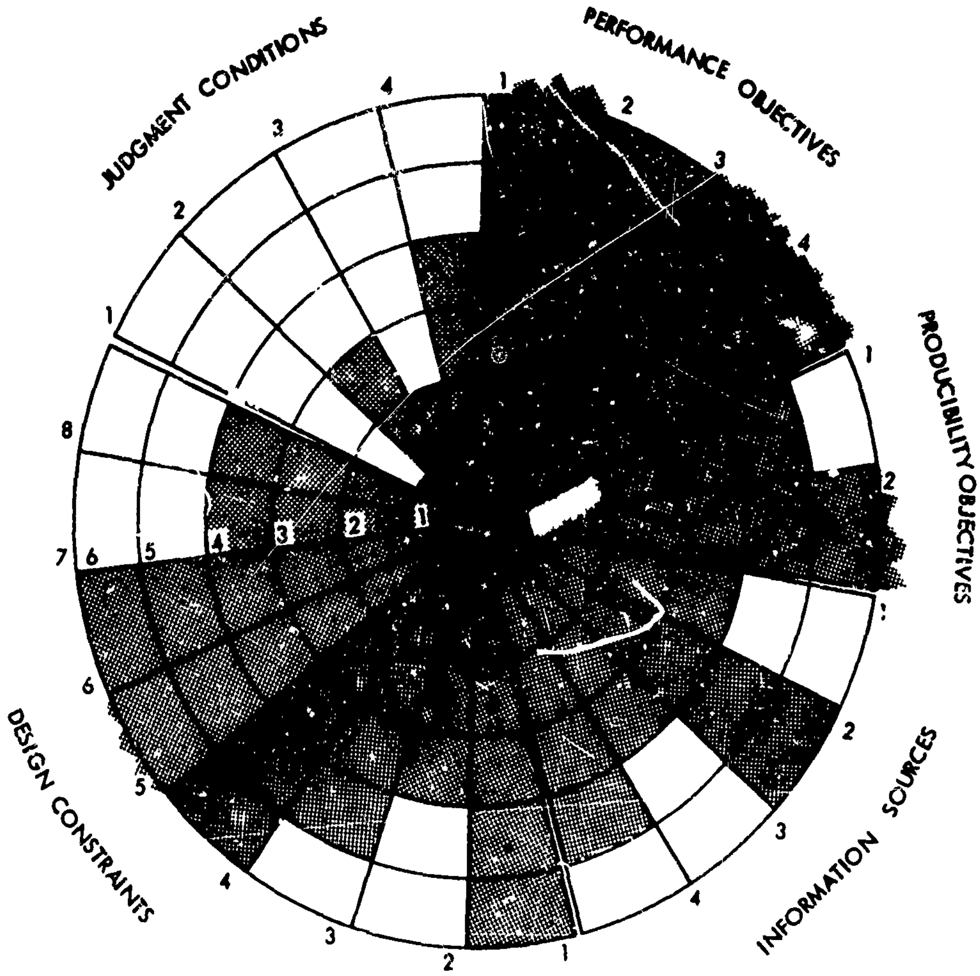

RADIAL SCALE - RELATIVE WEIGHT

1. Very Easy
2. Moderately Easy
3. Easy
4. Difficult
5. Very Difficult
6. Approaching the Impossible

FIGURE 8-3. Judgment Relevance Rating Diagram

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(3) The available mode of expression is largely controlled by the design constraints. If the specification calls for steel, the design cannot call for the use of brass.

(4) The judgment conditions include available time, quality of planning, budget, number of things the designer is trying to do at once, clarity of relationships (the up, down, and sideways), attitude of supervision, etc.

(5) The available sources of information will be numerous if the designer is operating in the environment of a large facility, extremely limited if he is remotely located and operating independently.

The design quality diagram approach (Chapter 1) can be modified to establish a rough judgment Relevance Rating Diagram (Fig. 8-3). The basic representation used in the process is a circle, divided into four parts, one for each of the elements affecting a decision. These pie-shaped elements can then be proportioned in consideration of the number of rating factors contained in each, and each factor shaded to indicate its relative weight, as shown on Fig. 8-3. Mathematical averaging may be used to arrive at the relative weight of each element and of the overall problem.

A "Checklist of 50 Familiar Roadblock Quotations" (Table 8-3) may prove interesting and useful[1]. The reader may wish to enter some of the listed roadblocks as factors in the preceding graphic representations, or they may cause him to search for information throughout the appendices. Certainly, he will recognize their influence on producibility, particularly in light of its exposition throughout the chapters of the handbook.

REFERENCES

1. ENGS No. SR-1, *Value Analysis*, published by the Army Chemical-Biological-Radiological Engineering Group, Army Chemical Center, Edgewood, Md., December 1961, Reprinted September 1962 and March 1963.

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PART TWO THE PRODUCTION ENVIRONMENT

CHAPTER 9

MATERIALS

9-1 GENERAL

The variety of materials available today has given the designer a broad latitude in selection and design. The number of materials has vastly increased, and private and Government-sponsored research will continue to expand the inventory available to the designer.

9-2 PURPOSE

This chapter alerts designers and engineers to some of the factors that exert an influence on the selection of a material. It is not intended to provide specific design information, data, or characteristics. Ready reference must be made to handbooks, specifications, periodicals, and other technical literature in which such information abounds.

The type of materials selected has a major impact on producibility. It influences equipment required, personnel skills, shop practices and processes, and production leadtime.

9-3 MATERIAL SELECTION FACTORS

The factors tabulated below are normally considered in the selection of a material in order to confirm its utility. The last five factors particularly affect producibility. Other less evident producibility factors, as they relate to the selection of a material, are discussed later in the chapter.

(1) Ultimate Tensile Strength
(2) Yield Strength
(3) Percentage Elongation and Reduction of Area
(4) Strength-to-weight Ratio
(5) Notch Toughness
(6) Fatigue Properties
(7) Creep Data
(8) Stress Rupture Data
(9) Elevated Temperature Properties
(10) Corrosion Resistance
(11) Weldability
(12) Machinability
(13) Forging Characteristics

9-4 MATERIAL PRODUCIBILITY OBJECTIVES

The producibility of any item or component is directly affected by the material from which it is fabricated. Upon selecting the material on the basis of its ability to do the job intended, another consideration enters into the picture. Certain characteristics or its availability may make one material more advantageous than some other for producibility purposes. Each of the producibility objectives introduced in Chapter 1 is strongly influenced by the material selected. Therefore, there is the need to provide guidance which can help achieve producibility through a wise selection of materials.

9-5 AVAILABILITY

9-5.1 CRITICAL MATERIALS

Certain materials are made from ores or products that are wholly available in the United States, others are imported from friendly or neutral countries. Some materials in ample supply during peacetime become critically short under conditions of wartime mobiliza-

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tion. To alleviate such shortages, the Government (under the Defense Production Act) established stockpile provisions for some 90 materials expected to become critical in wartime. Table 9-1 lists these materials, together with a description of their characteristics, source(s), unit cost (in 1967), and principal applications.

All of the materials in Table 9-1 are available to defense activities. Some are also available for sale to defense contractors or to private industry. Instructions regarding the conditions under which materials can be made available are published by the General Services Administration who controls the stockpile. The Defense Production Act also provides a means of controlling the use of other materials considered critical. This control is exercised by the Defense Materials System (DMS), which operates under the authority of regulations issued by the Business and Defense Services Administration (BDSA), Department of Commerce. AR 715-5[1] and AR 715-16[2] describe this operation. The latest edition of the regulations, together with the latest *Department of Defense Coded List of Materials*, will help the designer understand the magnitude of effort required to control and allocate critical materials. These regulations state that the design engineer must consider production methods, raw material requirements, sizes, and shapes; quantities to be produced; production lot sizes; and other elements of production often considered beyond the purview of the engineer.

9-5.2 STANDARD MILL PRODUCTS[3-7]

Much military equipment is made from one form or other of metal furnished to the manufacturer. However, despite the wide requirements of the military user, it is the commercial market that determines the range and forms of alloys available. In addition, the available sizes have generally been set within each industry. In Tables 9-2 through 9-12, some commercially available metallic alloys, the mill forms in which they can be purchased, and the conventional size ranges are given.

Since the capabilities of industry and individual suppliers vary under differing circumstances, information on specific alloy grades and sizes should be obtained directly from potential suppliers.

9-5.3 METAL SHAPES[3-7]

As outlined by Table 9-2 through 9-12, a wide variety of materials can be obtained in shapes fabricated to the requirements of the customer. The shape configurations carried as standard stock vary among producers. Thus, catalogs must be consulted for details.

At first glance, the use of special shapes could appear to have its disadvantages. However, fabrication time and cost savings outweigh the higher procurement cost and longer leadtime required for custom-made shapes.

Structural shapes are standard for the steel and aluminum industries. The aluminum industry fabricates a wide variety of architectural shapes. However, some producers have designated them as standard and made them stock items.

Standard steel structural shapes are designated as follows:

(1) Wide flange sections: Depth of flange x width across x weight per foot

(2) Beams and channels: Depth of section x weight per foot

(3) Angles: Length of leg x length of leg x thickness (fraction of an inch); also, length of leg x weight per foot (the longer leg is commonly stated first)

(4) Tees: Width of flange x overall stem depth x weight per foot

(5) Zees: Depth of section x flange width x thickness or weight per foot.

The standard aluminum structural shapes are designated as follows:

(1) I-Beams, H-Beams, Channels, and Zees: Thickness x flange width x depth

(2) Angles: Thickness x flange width

(3) Tees: Thickness x flange width x stem height

9-5.4 PREPLATED, PRECOATED, AND CLAD MATERIALS

The widespread commercial demand for preplated or precoated materials has greatly expanded the range of materials available to the designer. While some coatings merely improve appearance, most also will increase corrosion resistance or improve some other physical characteristic. For example, vinyl plastic-coated steels have wide decorative potential. However, vinyl film which has high corrosion resistance can be substituted for some other more expensive corrosion-resistant material. Table 9-13 lists some of the more common preplated or precoated materials, together with some typical applications. Table 9-14 and 9-15 show some of the more common clad metal combinations and their typical uses. Table 9-16 indicates the common prepainted metals and their typical applications.

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TABLE 9-1. STRATEGIC MATERIALS

MATERIAL, ITS COST AND SOURCES	MATERIAL DESCRIPTION	PRINCIPAL USES
ALUMINUM $461.21 per short ton United States, Canada, France, West Germany, Norway	Bluish white, silvery metal, easily drawn or forged. Lightweight (one-third lighter than steel), relatively strong, resistant to corrosion, electrically conductive. Derived from bauxite (see also).	Aircraft and missiles, electrical power transmission cables, containers and packaging, building products.
ALUMINUM OXIDE, ABRASIVE GRAIN $308.76 per short dry ton United States, Canada, France, West Germany, Austria	Made by crushing fused crude aluminum oxide; dust and iron gleaned from crushed material which is screened to 20 grain sizes. Ranging from grit No. 8 through grit No. 220.	Manufacturing grinding and cutting wheels, sharpening stones, coated abrasives, lapping compounds, and nonskid stair treads and steel walkways.
ALUMINUM OXIDE, FUSED CRUDE $117.57 per short ton United States, Canada, West Germany, France, Yugoslavia	Produced by fusing calcined abrasive bauxite, coke, iron, and titanium oxide under intense heat of electric arc reduction for about 24 hours, then cooling and crushing to minus 6 inches.	Manufacturing grinding wheels, sharpening stones, coated abrasives, grinding and lapping compounds, and nonskid stair treads and walkways.
ANTIMONY, METAL $639.86 per short ton Belgium, United States, Mexico, Yugoslavia	White, lustrous, brittle, crystalline, easily powdered metal; principal ore is stibnite.	Metallic: solder, battery plates, cable covers, type metal, and imparting hardness and smooth surfaces to soft-metal alloys. Nonmetallic. flame proofing chemicals and compounds, ceramics and glass products, and pigments.
ASBESTOS, AMOSITE $215.86 per short ton South Africa	Fibrous amphibole mineral, characterized by long, coarse, strong, resilient fibers. Has good tensile strength and better resistance to heat than crocidolite or chrysotile. Varies in color from gray and yellow to dark brown, with fiber lengths up to 6 inches.	Manufacturing woven insulating felt, heat insulation (pipe covering, block and segments), and marine insulating board. Long fiber amosite used principally in the manufacture of thermal insulation.
ASBESTOS, CHRYSOTILE $647.08 per short ton United States, Southern Rhodesia, Canada	Fibrous serpentive mineral characterized by length, strength, toughness, flexibility, a minimum of magnetic or conductive particles. The most flexible of asbestos fibers. Varies in color from green, gray, amber, to white. Texture is soft to harsh, also silky, with very good spinnability. Fiber lengths vary upward to three-fourths inch and longer.	Manufacturing asbestos textile products designed for electrical insulating applications (electrical cables, industrial equipment, magnet wire). Asbestos textiles made to withstand heat (brake-band lining and safety clothing).

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TABLE 9-1. STRATEGIC MATERIALS (CONT'D)

MATERIAL, ITS COST AND SOURCES	MATERIAL DESCRIPTION	PRINCIPAL USES
ASBESTOS, CROCIDOLITE $266.44 per short ton South Africa, Australia, Bolivia	Fibrous amphibole mineral of hornblende group, the blue asbestos of commerce. Has superior resistance to attack by acids. Texture varies from soft to harsh, with good flexibility and fair spinnability.	Manufacturing asbestos cement pipe, packing, and gaskets.
BAUXITE, METAL GRADE, JAMAICA TYPE $15.04 per long dry ton Jamaica, Haiti, Dominican Republic	Fine clay-like material, reddish-brown in color.	Mainly to produce alumina which is converted to aluminum. Also to produce abrasives and refractories, and in the chemical industry.
BAUXITE, METAL GRADE, SURINAM TYPE $15.68 per long dry ton Surinam, British Guinea, Indonesia, Ghana, Australia	Clay-like material, ranging from fines to lumps, dull white to brown in color.	Mainly to produce alumina, which is converted to aluminum. Also, to produce abrasives and refractories, and in the chemical and refractory industries.
BAUXITE, REFRACTORY GRADE $37.92 per long calcined tons British Guiana	Clay-like material that has been calcined, dull-white in color.	To produce high alumina refractories.
BERYL $1,198.95 per short ton United States, Brazil, Argentina	Opalescent material; blue, green, yellow, brown, or colorless; ranges in size from granular to large lumps or crystals.	To produce beryllium for production of beryllium copper alloys. Also, in the nuclear energy, aircraft, missiles, space fields.
BISMUTH $2.13 per pound Peru, Mexico, Canada, Yugoslavia	Grayish-white, brittle, hard, easily powdered metal with reddish tinge. Has low melting point (270° C) and a low thermal conductivity. Derived chiefly as byproduct of lead refining.	For low-melting (fusible) alloys and pharmaceuticals. Also, in other alloys as an additive to improve machinability of aluminum and malleable iron.
CADMIUM $1.81 per pound Belgium, Canada, Mexico, United States	Soft, bluish, silver-white metal obtained chiefly as byproduct of zinc smelting and refining.	Electroplating, pigments, bearing alloys and low melting (fusible) alloys.
CASTOR OIL $0.254 per pound Brazil, India, United States	Colorless to pale-yellowish viscous oil obtained from castor bean by pressing or solvent extraction.	In paints and varnish, linoleum, oilcloth, printing ink, soap; for petroleum demulsification; in lubricants and greases, hydraulic brake fluids, synthetic resins, textiles. Sebacic acid (important derivative) is starting material for certain types of nylon, plasticizers, synthetic resins.

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TABLE 9-1. STRATEGIC MATERIALS (CONT'D)

MATERIAL, ITS COST AND SOURCES	MATERIAL DESCRIPTION	PRINCIPAL USES
CELESTITE $46.46 per short ton England, Mexico	Strontium sulfate in form of friable mineral, usually coarsely crystalline. Concentration to usable ore and chemical manufacture of strontium compounds usually required for end use.	To produce dense red flame with high brilliance and visibility range for pyrotechnics (tracer ammunition, military flares, and marine distress signals). Also, glass and ceramics, lubricants, sugar refining, luminescent paints, drilling muds, electrolytic zinc refining, welding-rod coating, caustic soda.
CHROMITE, CHEMICAL GRADE $27.23 per short dry ton South Africa	Ore having submetallic to metallic luster, ranges in color from brownish to black. Varies in size from fines to granular and large lumps.	To produce chemicals such as chromic acid and zinc chromate. Chemicals used for anodizing, and manufacturing pigments for paint and leather tanning. Also, for production of plating for resistance to wear, corrosion and heat in engines, marine equipment, and military items.
CHROMITE, METALLURGICAL GRADE $83.51 per short dry ton Turkey, United States, Rhodesia, Philippines, U.S.S.R.	Hard lumpy ore with a small amount of fines, varying in color from brownish-black to black.	To produce ferrochromium and chromium metals used to produce alloy steel and other alloying agents. Adding chrome to steel improves hardness, tensile strength, and resistance to heat and corrosion.
CHROMITE, REFRACTORY GRADE $24.60 per short dry ton Philippines, Cuba	Has submetallic to metallic luster, ranges in color from brownish-black to black. Varies in size from fines, granular to large lumps.	Fines used to make mortar for constructing furnaces; larger material used for making furnace brick. Gives brick strength and stability at high temperatures, and resistance to shrinkage, spalling, and corrosion by slags and fluxes.
COBALT $2.19 per pound Congo, United States, Morocco, Canada, Rhodesia	Dark-grayish metal usually produced in form of rondelles, granules, lumps, cones, or thin broken pieces.	To produce high-temperature high-strength alloys, and permanent magnet materials. Also, for porcelain enamel, pigments, catalysts, varnishes, paints, inks, stock feed, cobalt-deficient soils.
COCONUT OIL $0.151 per pound Philippines	Nearly colorless fatty oil or white semisolid fat extracted from coconuts.	Making soap, foods, and as raw material in producing fatty acids, particularly lauric acid.
COLEMANITE $38.93 per long dry ton United States, Turkey	Soft mineral, transparent to translucent and colorless, also milky white, yellowish white, gray or muddy, varies in size from fines to lumps.	To produce boron for compounds used in glass and ceramics industries requiring their low melting point and excellent fluxing properties. Also, has germicidal properties; used in cleaning hides, and in plasters and paints to prevent mildew. Added to alloy steel to increase hardening qualities.

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TABLE 9-1. STRATEGIC MATERIALS (CONT'D)

MATERIAL, ITS COST AND SOURCES	MATERIAL DESCRIPTION	PRINCIPAL USES
COLUMBIUM $4.84 per pound Nigeria, Congo, Brazil, Canada	Platinum-gray ductile metal of high luster, obtained from columbite or tantalite.	For alloying, especially in stainless steel to inhibit intergranular corrosion and improve creep, impact and fatigue strength. Columbium carbides used in producing cutting tools.
COPPER $532.84 per short ton United States, Canada, Chile, Congo, Mexico	Reddish, tough, malleable, corrosion resistant, electrically conductive metal.	Electrical wires and equipment, tubes and pipes, and as base metal in brass and bronze.
CORDAGE FIBER, ABACA $0.252 per pound Philippines	Fiber (manila hemp) stripped from long leaves of Musa textiles, banana family plant growing in humid tropical climates.	Marine cordage, gut ropes, and construction.
CORDAGE FIBER, SISAL $0.135 per pound Portuguese Africa, Tanzania, Brazil	Fiber stripped from large leaves of tropical plant, Agave sisalana.	Rope, baler, binder, and wrapping twine; upholstery and padding; wire rope centers; reinforcement for paper and plastics.
CORUNDUM $195.77 per short ton South Africa, Southern Rhodesia, India	Naturally crystallized aluminum oxide, the second hardest mineral known. Has abrasive quality largely due to its basal cleavage, imparts new sharp cutting angles when used for grinding.	Grinding wheels used for grinding malleable iron castings; very fine grain generally preferred for grinding and polishing lenses.
CRYOLITE $276.13 per short ton United States	Sodium aluminum fluoride. Natural material largely replaced by synthetic cryolite; fluorspar converted to hydrofluoric acid of fluorine, neutralized with sodium carbonate and aluminum hydrate to produce cryolite.	Reducing alumina to aluminum using a bath of fused cryolite and aluminum fluoride is the electrolyte in which alumina is disassociated by electric current and a seal made between molten aluminum and the atmosphere. Ground cryolite used in enamels, glass, insecticides.
DIAMOND DIES, SMALL $31.32 per piece United States, Holland, France, Switzerland	Dies made from selected industrial diamonds, by drilling or electrically piercing the die hole.	Drawing fine size wire from hard metals for the electrical industry.
DIAMOND DIES $29.412 per piece United States, Holland, France, Switzerland	Same as small, except they are larger.	Same as small, except for size of wire drawn.
DIAMOND, INDUSTRIAL--CRUSHING BORT $2.11 per carat Congo, South Africa	Industrial grade of small particle size diamonds not suitable for gem or tool use.	Crushed into diamond powder for use in polishing and lapping, and as cutting agent in drilling very small holes in hard materials.

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TABLE 9-1. STRATEGIC MATERIALS (CONT'D)

MATERIAL, ITS COST AND SOURCES	MATERIAL DESCRIPTION	PRINCIPAL USES
DIAMOND, INDUSTRIAL: STONES $11.62 per carat Congo, Holland	Diamonds unsuitable as gems because of structure, color, flaws, or impurities.	In grinding wheels to shape and sharpen tungsten carbide cutting tools; as cutting edges of tools used for turning, grinding, and drilling hard metals
DIAMOND TOOLS $15.92 per piece United States, England, West Germany	Tools that have idustrial diamonds set in the cutting or grinding edge.	Cutting or grinding very hard metals.
FEATHERS AND DOWN, WATERFOWL $4.14 per pound China, Western Europe	Soft and pliant contour feathers and thick undercoating of down of ducks and geese.	As filler and heat-insulating material in sleeping bags, pillows, other bedding.
FLUORSPAR, ACID GRADE $52.85 per short dry ton United States, Mexico, Canada, Spain, Italy	Mineral of calcium fluoride. Only source of fluorine for industrial use except for very limited supply of cryolite and very low fluorine content in phosphate rock.	To make hydrofluoric acid. Used to produce synthetic cryolite, freon gas, alkylate for high-octane fuel, pickling steel, etched glass, many other minor uses. Cryolite used in making alloys of aluminum and magnesium and in refining the scrap of these metals.
FLUORSPAR, METALLURGICAL GRADE $45.70 per short dry ton United States, Mexico	Mineral of calcium fluoride. Metallurgical grade is granular; lumps up to 3 inches preferred by some steel companies. Contains minimum of 70 percent effective calcium fluoride, percentage of total calcium fluoride content, less 2-1/2 times silica content.	Facilitates fusion and transfer of impurities (sulfur and phosphorus) into the slag created by open-hearth process of making steel; adds to the fluidity of the slag. Also, as fluxes by iron foundries and manufacturers of ferroalloys.
GRAPHITE, NATURAL--CEYLON AMORPHOUS LUMP $217.42 per short ton Ceylon	Natural variety of element carbon; commonly known as plumbago. Grayish-black in color, with metallic tinge and unctuous feel. Good conductor of heat and electricity, resistant to acid and alkalies, easily molded.	Manufacturing of carbon brushes in electrical equipment. Also, many other uses.
GRAPHITE, NATURAL--MALAGASY, CRYSTALLINE $201.39 per short ton Malagasy Republic	Natural variety of element carbon; commonly known as plumbago. Grayish-black in color, with metallic tinge and unctuous feel. Good conductor of heat and electricity, resistant to acid and alkalies, easily molded.	Manufacturing of crucibles employed in refining and reducing gold and silver; in melting brass, bronze, and other copper-base alloys; for casting aluminum. Also, many other uses.
GRAPHITE, NATURAL--OTHER THAN CEYLON AND MALAGASY, CRYSTALLINE $345.63 per short ton Canada, Germany, United States	Natural variety of element carbon; commonly known as plumbago. Grayish-black in color, with metallic tinge and unctuous feel.	In lubricants, oilless bearings, packing, foundry facings.

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TABLE 9-1. STRATEGIC MATERIALS (CONT'D)

MATERIAL, ITS COST AND SOURCES	MATERIAL DESCRIPTION	PRINCIPAL USES
HYOSCINE $14,574 per ounce Australia	Colorless or white crystals known as hyoscine hydrobromide or scopolamine hydrobromide.	Control of motion sickness, in anesthetic compounds, in anti-spasmodics, for treating Parkinson's disease.
IODINE $1.28 per pound United States, Chile, Japan	Dense, grayish-black, crystalline material, having metallic luster and characteristic odor.	In medicine and antisepsis; in food supplements, in industrial processing; in producing titanium, silicon, hafnium, zirconium, and other strategic metals.
JEWEL BEARINGS $0.09 per piece United States, Switzerland, Japan, Italy, France	Manufactured from natural sapphires and rubies or from synthetic corundum stones.	Universal application in watches, meters, gyroscopes, other precision instruments; in places where friction and wear between small moving parts must be held to a minimum, shocks withstood, high pressures carried.
KYANITE--MULLITE $86.45 per short dry ton United States, Kenya	Metamorphic mineral of aluminum silicate used for refractory where low expansion is required, produces hard grog with high constancy of volume. Heated, kyanite becomes mullite, having different ratio of alumina to silica and less affected by high temperature than clay refractories.	Mullite for heavy-duty refractories where low expansion is required (tanks for molten glass and spark plug porcelain, pouring ladles and electric arc furnaces). Also, for melting high-copper brasses and bronzes, copper-nickel alloys, some ferrous alloys, zinc smelting, gold refining, manufacturing ceramics.
LEAD $288.21 per short ton United States, Canada, Mexico, Peru, Australia	Heavy, bluish-white, soft, easily fusible, malleable metal	Storage batteries, cable coverings, ammunition, gasoline additives, pigments, solder.
MAGNESIUM $726.08 per short ton United States, Norway, Germany	Light, silvery-white, ductile, easily machineable metal.	Structural forms for aircraft and missiles, forgings, castings, extrusions. Also, as alloy with aluminum and other metals.
MANGANESE, BATTERY GRADE NATURAL ORE $122.58 per short dry ton Ghana, Greece	Black material ranging from concentrates to small lumps.	In manufacturing dry-cell batteries.
MANGANESE, BATTERY GRADE, SYNTHETIC DIOXIDE $244.35 per short dry ton United States	Black material, usually passing U.S. standard sieve No. 60.	In manufacturing dry cells for batteries, mixed with natural grade to produce high-standard batteries for military use. Also, for special types of batteries for hearing aids and other small elements.

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TABLE 9-1. STRATEGIC MATERIALS (CONT'D)

MATERIAL, ITS COST AND SOURCES	MATERIAL DESCRIPTION	PRINCIPAL USES
MANGANESE ORE, CHEMICAL GRADE, TYPE A $68.44 per short dry ton Morocco, Cuba	Brownish-black to black ore in form of concentrates or lumps.	As oxidizing agent in chemical industry especially in manufacturing hydroquinone by the continuous process. Hydroquinone used as photographic developer, antioxidant, or inhibitor in compounding rubber in finished products, and in gasoline and medicinal processes.
MANGANESE ORE, CHEMICAL GRADE, TYPE B $67.46 per short dry ton Ghana, India, Chile, Cuba	Brownish-black to black ore in form of concentrates or lumps.	In producing potassium permanganate and other permanganate chemicals. Also, in producing manganese chloride, dye intermediates, glass and pottery coloring, electric lamps, welding rods, enamel frit, nicotinic acid.
MANGANESE ORE, METALLURGICAL GRADE $53.79 per short dry ton India, South Africa, Brazil, U.S.S.R.	Black ore in form of lumpy natural ore or agglomerated nodules or sinter.	In manufacturing manganese metal, ferromanganese, and special manganese alloys which are used to neutralize effects of sulfur and to remove oxygen. Also, added to special steels to contribute toughness and resistance to shock and abrasion.
MERCURY $182.299 per flask Spain, Italy, Mexico	Heavy, silvery-white, lustrous metal, liquid at normal temperatures. Primary source is cinnabar.	Metal: in industrial control instruments, thermometers, automatic switches, heat-exchange media, cathodes in manufacturing chlorine and caustic soda. Mercury compounds: in pharmaceuticals, chemicals, antifouling paints.
MICA, MUSCOVITE BLOCK, STAINED A/B AND BETTER $4.15 per pound India, Brazil, United States	Nonmetallic, crystalline mineral easily separated into thin sheets with good dielectric strength. Block mica not less than seven-thousandths of an inch thick with minimum usable area of 1 square inch. Stained A/B and better are higher quality groups containing less impurities. Less impurities allow a greater dielectric constant.	In electronic tubes as spacers, stained A/B and better quality groups more suitable for specialized tubes.
MICA, MUSCOVITE BLOCK, STAINED B AND LOWER $2.377 per pound India, Brazil, United States	Nonmetallic, crystalline mineral easily separated into thin sheets with good dielectric strength. Block mica not less than seven-thousandths of an inch thick with a minimum usable area of 1 square inch. Stained B and lower are lower quality groups containing more impurities. More impurities yield a lower dielectric constant.	In electronic tubes as spacers. Stained B and lower quality groups more suitable for less specialized tubes and nonelectric uses (insulation in electrical equipment).

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TABLE 9-1. STRATEGIC MATERIALS (CONT'D)

MATERIAL, ITS COST AND SOURCES	MATERIAL DESCRIPTION	PRINCIPAL USES
MICA, MUSCOVITE FILM, FIRST AND SECOND QUALITIES $5.64 per pound India, Brazil, United States	Nonmetallic, crystalline mineral easily separated into thin sheets with good dielectric strength. Film mica split from the higher quality block mica to specified thickness groups ranging from twelve-thousandths to four-thousandths of an inch. First-quality film equivalent in visual quality to fair stained block mica, and second-quality film to good stained block mica.	As dielectric in electrical capacitors; first and second qualities more desirable for specialized capacitors requiring extremely close capacitance tolerances.
MICA, MUSCOVITE FILM, THIRD QUALITY $5.268 per pound India, Brazil, United States	Nonmetallic, crystalline mineral easily separated into thin sheets with good dielectric strength. Film mica split from higher quality block mica to specified thickness groups ranging from twelve-thousandths to four-thousandths of an inch. Third-quality film equivalent in visual quality to stained A block mica.	Dielectric in electrical capacitors; and a small quantity used as inter-layer insulation for air-cooled transformer coils.
MICA, MUSCOVITE SPLITTINGS $1.04 per pound India	Same as muscovite block mica except in form of sheets of maximum thickness of twelve-thousandths of an inch and minimum usable area of seventy-five hundredths of a square inch.	In making dielectric tape and cloth used as insulation for field coils, armature windings, transformers, other electrical devices operating at high temperatures.
MICA, PHLOGOPITE BLOCK $1.36 per pound Malagasy Republic	Differs from muscovite [illegible] withstanding high temperatures with less deterioration, being resistant to abrasion across the edge of the laminae. Classified as "high heat" quality if for withstanding given high temperatures for stated periods of time.	Insulating material in soldering irons, high temperature coils; liners in proximity fuses, transformers, heater elements.
MICA, PHLOGOPITE SPLITTINGS $1 per pound Malagasy Republic	Same as phlogopite block mica except in form of thin laminae with maximum thickness of twelve-thousandths of an inch.	Used to make dielectric tape and cloth which is used as insulation for field coils, armature windings, transformers, and other electrical devices operating at high temperatures.
MOLYBDENUM $1.04 per pound United States, Chile, Canada	Hard silver-white metal obtained from molybdenite. Imparts a high-melting point, high strength, stiffness, and toughness to alloys.	An alloying metal in iron and steel; also, by electrical, chemical ceramic industries. Small quantities: as catalysts, welding rods, paints and pigments, lubricants, trace element in plant and animal metabolism.

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TABLE 9-1. STRATEGIC MATERIALS (CONT'D)

MATERIAL, ITS COST AND SOURCES	MATERIAL DESCRIPTION	PRINCIPAL USES
NICKEL $1,247.58 per short ton Canada, United States, New Caledonia, Cuba	Hard, silver-white, ductile metal having high resistance to corrosion and abrasion.	An alloy to strengthen and harden steel and other metals and to provide resistance against corrosion. Major use is as an alloy in steel, especially in producing stainless steels, high-temperature alloys, monel metal. Essential in production of jet engines, aircraft frames, armor plate, magnets, and in electroplating.
OPIUM $69.57 per pound Turkey, India	Dried exudate (from unripe capsules of poppy plant, Popaver somoniferum) containing various alkaloids, the most important being morphine. Appears in commerce as dark brown bricks or balls weighing a few pounds each.	As morphine used as an analgesic or pain-relieving agent of particular importance in shock treatment. Also, as codeine, which is used as a cough depressant and in relieving pain.
PALM OIL $0.179 per pound Congo, Indonesia	Yellowish oil, solid at room temperature, extracted from fruit of certain palms.	Processed into edible oil; in soapmaking; it largely supplanted in tinplating and in cold reduction of steel.
PLATINUM GROUP METALS--IRIDIUM $181.23 per troy ounce South Africa, Canada, United States, U.S.S.R.	Harder, tougher, denser, and higher melting point than other platinum group metals; luster similar to platinum; has slight yellowish cast. Slightly less than twice as heavy as lead and is one of the most corrosion resistant metals. Annealed iridium is four to five times as hard as annealed platinum.	Essentially, for alloying with platinum and palladium to increase hardness and corrosion resistance; small crucibles for high-temperature reactions; for extrusion dies for high-melting glasses. Is difficult to work, few of its mechanical properties are known.
PLATINUM GROUP METALS--PALLADIUM $19.31 per troy ounce Canada, South Africa, United States, U.S.S.R.	Least dense and has lowest melting point of six metals in platinum group. Weighs slightly more than half as much as platinum and has more brilliant luster.	Less costly and lighter palladium substituted for platinum (currant price of palladium is about one-third that of platinum). Is extremely ductile and malleable, but its physical and work hardening properties somewhat limit its use; absorbs hydrogen at moderate temperatures, hardening the metal.
PLATINUM GROUP METALS, PLATINUM $79.47 per troy ounce Canada, United States, South Africa, Colombia, U.S.S.R.	Heavy grayish-white noncorroding precious metal; very soft, ductile, malleable; does not tarnish at elevated temperatures; inert to common strong acids including nitric acid, but aqua regia slowly reacts with it. Alkali-metal hydroxides, especially with oxidizing agents, attack platinum, chlorine and fluorine react with it.	Used separately and in alloys or combinations with each other and other metals. Electrical: contacts, electrodes, filaments, resistance thermometers, resisters, thermocouples. Chemical: vessels cathodes, spinnerettes for organic filaments as rayon and for Fiberglas, burner nozzles, catalysts. Sundry: dentistry, jewelry, purification of hydrogen, precision instruments.

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TABLE 9-1. STRATEGIC MATERIALS (CONT'D)

MATERIAL, ITS COST AND SOURCES	MATERIAL DESCRIPTION	PRINCIPAL USES
PLATINUM GROUP METALS, RHODIUM $126.537 per troy ounce Canada, South Africa, United States, U.S.S.R.	Metal of platinum group; between platinum and iridium with respect to hardness, toughness, and melting point; maintains freedom from surface oxidation; has a lower specific electrical resistance than platinum or palladium.	Plating of scientific instruments silver and platinum jewelry, precision instruments for the measurement of the physical properties of corrosive liquids are plated with rhodium; plating of electric contacts for radio and audiofrequency circuits because of freedom from oxidation and low-contact resistance; coating of sliding or moving contacts to take advantage of great hardness; coating of mirrors and surfaces to maintain brilliancy. A thermocouple of platinum and rhodium alloy defines the International Temperature Scale between 630.5 and 1063° C.
PLATINUM GROUP METALS, RUTHENIUM $37.298 per troy ounce Canada, South Africa, U.S.S.R., United States	Gray or silverlike, brittle, nonductile metal of the platinum group; brittle at high temperatures; insoluble in acids, but is attacked by fused alkalies.	Is alloyed with platinum and palladium for a hard corrosion-resistant metal and is used for jewelry, contact points, and catalysts. Alloys not used at elevated temperatures under oxidizing conditions. Has been used for nibs of pens, phonograph needles, and pivots in instruments. High melting point, hardness, and brittleness limit satisfactory working of ruthenium mechanically.
PYRETHRUM $6.20 per pound Kenya, Japan	The kerosene extract of pyrethrum flowers; commonly marketed with the kerosene base containing 20-percent pyrethrins, the insecticidal principals.	Insecticides.
QUARTZ CRYSTALS $12.48 per pound Brazil	Form of silica occurring in hard hexagonal crystals or in crystalline masses; the most common of all solid minerals; may be colorless and transparent or colored.	In the production of piezoelectric units, optical parts, glass; in steel manufacture.
QUINIDINE $1.15 per ounce West Germany, Holland, Indonesia	White crystalline powder produced synthetically from quinine or naturally from cinchona bark, where it occurs along with quinine.	In medicine as a regulator of abnormal heart rhythm.
QUININE $0.632 per ounce Indonesia	White crystalline powder extracted from cinchona bark.	Antimalarial agent.

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TABLE 9-1. STRATEGIC MATERIALS (CONT'D)

MATERIAL, ITS COST AND SOURCES	MATERIAL DESCRIPTION	PRINCIPAL USES
RARE EARTHS $821.71 per short dry ton India, Brazil, United States	Group of 15 closely associated and similar elements belonging to rare earth group and often include thorium and yttrium, which are notable for electron-sensitive and light-sensitive nature. Ranges from white to pink powder, to a heavy, fine-grained, hard sand of light-brown to reddish-brown color.	In producing sparking metal in cigarette lighters. As misch metal added to steel bath to improve hot-working qualities. Also used in glass industry as coloring and polishing agent and as core in arc carbons, as well as in projectors, and searchlights. Also a source of individual rare earth elements such as europium (used in color television) and cerium (for polishing, fi[illegible], etc.).
RARE EARTHS RESIDUE $0.108 per pound United States	Fine powder, white to gray or light brown in color; a residue from the processing of euxenite concentrates to produce colombium and uranium compounds.	To produce any of 15 closely associated and similar elements notable for their electron-sensitive and light-sensitive qualities, and yttrium. Also, to produce misch metal used for alloying purposes, to produce carbon ore, cerium metal for lighter flints, magnesium alloys, and for coloring and decolorizing glass.
RUBBER $773.24 per long ton Indonesia, Malaya, Vietnam, Thailand, Liberia	Processed juice (liquid latex) obtained from tropical tree Hevea brasiliensis. Appears in commerce as densely packed bales made up of sheets of natural rubber. Must be vulcanized for useful application.	In the carcass of tires, particularly heavy duty tires for trucks, buses, and planes; has many miscellaneous industrial applications.
RUTILE $122.99 per short dry ton Australia, United States, South Africa, India	Fine sand varying in color from reddish-brown to black.	In the production of titanium sponge and as a stabilizer in welding rods. Also, in the ceramic industry to add color and strength.
SAPPHIRE AND RUBY $0.012 per carat Switzerland, United States	Crystalline aluminum oxide; synthesized by dropping finely ground aluminum oxide of great purity through the flame of an inverted oxyhydrogen blowpipe that operates within a combustion chamber.	Manufacturing jewel bearings.

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TABLE 9-1. STRATEGIC MATERIALS (CONT'D)

MATERIAL, ITS COST AND SOURCES	MATERIAL DESCRIPTION	PRINCIPAL USES
SELENIUM $5.50 per pound United States, Canada, Sweden, Japan, West Germany	Allotropic acidic element often called a semimetal or a metalloid; is a grayish-black powder; hexagonal form considered most stable under ordinary conditions, is a fair conductor of heat and electricity, is fairly inert to atmospheric conditions, has fair mechanical strength, and may be produced by heating any form of selenium until crystallation is complete. Some forms of selenium are toxic.	In the electronic industry as a semiconductor for dry plate rectifiers, photocells, solar batteries, television cameras; largest consumers are glass and ceramic industries as a decolorizer for green glass and with cadmium to produce ruby glass now used for permanent labels on bottles. Added to stainless steel for a degasifer and to increase machinability. Selenium dioxide is oxidizing agent for processing cortisone. Oxychloride is one of most powerful solvents known, used as solvent for phenolic resins.
SHELLAC $0.501 per pound India, Thailand	Purified form of excretion by lac insect; appears in commerce as brownish flakes.	For surface coating; as a binder for abrasives and mica; as an insulator in electrical components; numerous miscellaneous industrial applications.
SILICON CARBIDE, CRUDE $194.39 per short ton Canada, United States	Manufactured by fusing clean silica sand, coke, salt, and sawdust in an electric furnace. Process requires 36 hours for fusion and 24 hours for cooling. Cooled mass crushed to provide crude material with no lumps in excess of 4 inches. Exceeded in hardness by boron carbide and diamonds.	Abrasive grain is processed from crude silicon carbide and is used in the manufacture of grinding wheels, coated sheets, belts, and disks. Silicon carbide is preferred for grinding stone, materials that are hard or brittle or of low-tensile strength, such as cast iron, brass, aluminum, and leather. Silicon carbide does not soften or melt at temperatures below 4450° C. and is used for metallurgical refractory, but is less resistant to molten steel and basic slags. It is not attacked by most acids and is used in the chemical industries.
SILK, NOILS $1.257 per pound Japan, India, Italy, France	Silk fibers representing waste from textile industry.	Various silk cloths.
SILK, RAW $4.287 per pound Japan, Korea, Italy	Continuous silk filaments to skeins as reeled from cocoon of silkworm.	Medical sutures, bolting cloth, stencil silks used for screen printing, various miscellaneous uses.
SILK, WASTE $1.254 per pound Japan, India, Italy, France	Silk fibers representing waste from silk industry	Various silk cloths.

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TABLE 9-1. STRATEGIC MATERIALS (CONT'D)

MATERIAL, ITS COST AND SOURCES	MATERIAL DESCRIPTION	PRINCIPAL USES
SILVER $1.80 per troy ounce Mexico, United States, Canada, Peru	White metal characterized as intermediate between copper and gold in hardness; most ductile and malleable of all metals except gold; a better conductor of heat and electricity than all other metals; high resistance to corrosion; forms more insoluble salts than any other metal.	Manufacturing of photographic materials, silver solders and brazing alloys now used extensively in jet aircraft and space vehicles, optical goods, chemicals and antiseptics, dentistry and surgery, electrical contacts for light-duty circuits, high-efficiency batteries for aircraft and rockets, infiltration with tungsten carbide for rocket cones, coating for copper w[illegible] rockets, coinage, [illegible] for paper currency, be[illegible] in aircraft and rockets, sterling silverware, electroplate, jewelry.
SPERM OIL $0.203 per pound Norway, England, Japan, Netherlands	Yellowish oil extracted from sperm whale.	In cutting and grinding oils for high-speed precision work; as textile fiber lubricant, in metal treatment, and rust preventives.
TALC, STEATITE BLOCK AND LUMP $390.02 per short ton India, Italy	Talc is soft hydrous magnesium silicate; steatite is variety of pure talc with low impurities suitable for manufacturing ceramic single piece insulator shapes for very high frequency applications. Steatite may be in blocks which have been shaped by sawing or in lumps which have been cleaned.	Single-piece electronic tube spacers and sundry precision insulators for very high frequency electronic circuits, especially electronic transmitter tubes; insulators made from massive steatite are resistant to heat and continuous high frequency electronic paths.
TALC, STEATITE GROUND $59.27 per short ton United States	Talc is soft hydrous magnesium silicate; steatite is variety of high grade talc with low impurities suitable for manufacturing ceramic insulator shapes for very high frequency applications.	In producing shapes for steatite ceramics, 80 to 90 percent of ground steatite is mixed with about 5 percent of kaolin binder and flux (feldspar or alkaline earths), molded or extruded to shapes and dried. Shapes may be machined to final insulator design from extruded stock or mix may be molded directly to form final insulator shape; shapes are fired into finished shape known as synthetics in the insulator trade; has not replaced insulator shapes made from massive steatite.
TANTALUM $4.75 per pound Brazil, Mozambique	Hard silver-gray metal extracted from tantalite and columbite.	In producing electronics, such as power tubes, capacitors, rectifiers. Also, in equipment for chemical industry, in surgery for bone repairs; for optical glass, cutting tools, and as carbide in other wear-resistant alloys.

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TABLE 9-1. STRATEGIC MATERIALS (CONT'D)

MATERIAL, ITS COST AND SOURCES	MATERIAL DESCRIPTION	PRINCIPAL USES
THORIUM $4.54 per pound India, Brazil, South Africa	Gray powder or heavy malleable metal changing from silvery-white to dark-gray or black in air.	With tungsten or nickel in electrodes in gas-discharge lamps and in conversion of fissionable uranium; to make incandescent (Welsback) type gas light mantle. Its compounds are used in luminous paints and in flashlight powders. Compounded with nickel to produce a high-temperature alloy.
THORIUM RESIDUE $0.05 per pound United States	Fine powder, white to gray or brown in color. Material is residue from processing of euxenite concentrates where columbium and uranium have been extracted.	In incandescent gas mantles, luminous paints, and flashlight powders. Also, in nuclear reactors for conversion of fissionable material and to a lesser extent in refractories, polishing compounds, chemical products.
TIN $2,425.08 per long ton Malaya, Indonesia, Bolivia	Silvery-white, lustrous, ductile, corrosion resistant metal. Cassiterite is principal ore from which tin is derived by smelting.	In producing tinplate and terneplate, also, solders, bearing metals, bronze, casting alloys, foils, various chemicals.
TITANIUM SPONGE $6,631.82 per short ton United States, Japan, England	Hard, corrosion resistant, silver-gray, sponge-like metal only 56 percent as heavy as steel.	In producing titanium metal and titanium metal alloys requiring superior strength-weight ratios necessary for spacecraft and supersonic planes, surgical instruments, portable machine tools. Also, in chemical and paper-pulp industries.
TUNGSTEN $3.46 per pound United States, South Korea, Portugal, Bolivia, Communist China	Gray-white, heavy, high-melting, ductile, hard, metallic element derived from wolframite, scheelite, hubnerite or ferberite.	For electrical purposes, such as lamp filaments, contact points, lead-in wires for power tubes; for alloying, to increase hardness of other metals in making carbides for cutting tools, abrasives, dies; for special shapes such as tungsten nozzles in missiles.
VANADIUM $4,013.72 per short ton United States, Peru	Pale-gray metal with a silvery luster; readily alloys with iron and other metals.	Mainly by steel industry as alloy in producing high-strength structural steels, tool steels, and related products requiring toughness and strength at high temperatures.
VEGETABLE TANNIN EXTRACT, CHESTNUT $279 per long ton Italy, France, United States	A solid brown tannin extract from the wood of the chestnut tree.	In the tanning of heavy types of leather, such as sole and belting.
VEGETABLE TANNIN EXTRACT, QUEBRACHO $247.41 per long ton Argentina, Paraguay	Solid brown tannin extract from heartwood of quebracho tree.	In tanning leather, as an ingredient in petroleum well-drilling muds.

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TABLE 9-1. STRATEGIC MATERIALS (CONT'D)

MATERIAL, ITS COST AND SOURCES	MATERIAL DESCRIPTION	PRINCIPAL USES
VEGETABLE TANNIN EXTRACT, WATTLE $252.22 per long ton South Africa	Solid brown extract from bark of wattle tree.	In tanning heavy types of leathers such as sole and belting.
ZINC $279.47 per short ton Australia, Bolivia, Canada, United States	Bluish-white metallic element, easily fusible, somewhat brittle.	In diecasting and galvanizing; alloyed with copper to form brass; electrogalvanic properties useful in protecting steel and iron from corrosion. Also, in manufacturing batteries.
ZIRCONIUM ORE, BADDELEYITE $42.96 per short dry ton Brazil	Hard, brittle, lustrous, [illegible] ore, grayish in color.	In producing ceramics, refractories, foundry facings.
ZIRCONIUM ORE, ZIRCON $59.05 per short dry ton United States, Australia, Brazil	Hard, fine sand, yellowish to brownish in color.	In producing refractories, foundry facings, zirconium metal.

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TABLE 9-2. THICKNESS, SIZE RANGE, AND AVAILABILITY OF VARIOUS STANDARD FERROUS MILL FORMS*

A. DIMENSIONS OF STANDARD FERROUS MILL FORMS

FORM**	MATERIAL	THICKNESS RANGE (INCHES)	SIZE RANGE (INCHES)
STRIP:	Carbon steel, CR	<0.250	1/2 to 23-15/16 (width)
	Carbon steel, HR	0.025 to 0.229	12 max (width)
	Alloy steel, CR	0.230 to 0.247	23-15/16 max (width)
	Alloy steel, HR or CR	0.1799 to 0.2299	>6 to 23-15/16 (width)
	Stainless steel, CR	<3/16	<24 (width)
SHEET:	Carbon steel, CR	0.0142 to 0.0821	>12 (width)
	Carbon steel HR	0.0447 to 0.2299	12 to 48 (width)
	Alloy steel, HR or CR	<0.1799 0.180 to 0.2299	>48 (width) 12 to 48 (width)
	Stainless steel, HR or CR	<3/16	24 and over (width)
PLATE:	Carbon steel, HR	0.230 and over 0.180 and over	>8 to 48 (width) >48 (width)
	Alloy steel, HR or Heat Treated	0.230 and over 0.180 and over	>8 to 48 (width) >48 (width)
	Stainless steel, HR or Forged	3/16 and over	>10 (width)
BAR:	Carbon steel, HR	1/4 to 6 (square) 3/8 to 4-1/15 (hex)	6 max (width) 6 max (width)
	Alloy steel, HR	<5/16 to 9-1/2 (square) <1/2 to 3-1/2 (hex)	<1 to 6 max (width) <1 to 6 max (width)
	Alloy steel, Cold Finished	<5/16 to 4 (square) <5/16 to 3-1/8 (hex)	<3/4 to 12 (width) <3/4 to 12 (width)
	Stainless steel, Hot Finished	1/4 to 8 (square) 1/4 to 3-1/2 (hex)	1/4 to 10 (width) 1/4 to 10 (width)
	Stainless steel, Cold Finished	>1/2	>3/8 (width)
ROD:	Carbon steel, HR	7/32 to 4-7/64	Coils
	Alloy steel, HR or Heat Treated	7/32 and over	Coils
	Stainless Steel, HR	1/4 to 3/4	Coils
WIRE:	Carbon steel	0.004 to 0.625	Coils
	Alloy steel	0.020 to 0.099	Coils
	Stainless steel	0.003 to 0.500	Coils
TUBE, ROUND	Carbon steel, Hot or Cold Finished	3/16 to 10-3/4	0.028 to 0.250 (wall)
	Alloy steel, Hot or Cold Finished	3/16 to 10-3/4	0.022 to >0.203 (wall)
	Stainless steel, Hot or Cold Finished	<1/2 to 8-5/8	<0.15 to <0.300 (wall)

* For other information see MIL-HDBK H-3, Steel and Iron Wrought Products,[3] dated 27 November 1953, pp. 39 through 78, and Designers' Guide to Modern Steels,[4] published by the American Iron and Steel Institute, 150 E. 42nd St., New York, N.Y. 10017.

** Tin-coated steel foil and stainless steel foil with a thickness of 0.002 or less also is available.

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TABLE 9-2. THICKNESS, SIZE RANGE, AND AVAILABILITY OF VARIOUS STANDARD FERROUS MILL FORMS (CONT'D)

B. MILL SHAPES OF COMMERCIALLY AVAILABLE STEEL ALLOYS

MATERIAL	STRIP	SHEET	PLATES	BAR/ROD	SHAPES	WIRE	TUBE	FORGINGS	BILLETS
CARBON STEELS - HARDENING GRADES									
C1030	X	X	X	X	X	X	X	X	X
C1040	X	X	X	X	X	X	X	X	X
C1060	X			X				X	
C1080	X			X				X	
C1095	X			X				X	
C1137	X			X		X		X	
C1141				X					
C1144				X					
CARBON STEELS - CARBURIZING GRADES	X	X	X	X	X	X	X	X	X
CARBON STEELS - FREE CUTTING	AS COLD DRAWN SHAPES								
CARBON STEELS - HIGH-STRENGTH COLUMBIUM BEARING	X	X	X	X	X	X	X	X	X
CARBON STEELS - HIGH-STRENGTH VANADIUM BEARING	STRUCTURAL SHAPES AND PLATES								
CARBON STEELS - HIGH-STRENGTH, LOW ALLOY (ASTM Types)									
A94		X	X	X	X				
H242		X	X	X	X				
A440		X	X	X	X				
A441		X	X	X	X				
A374	X	X							
A375	X	X							
IRON-BASE SUPERALLOYS									
19-9DL	X	X	X	X		X	X	X	X
Unitemp 212	X	X		X		X			X
W-545	X	X	X	X				X	X
D-979		X		X				X	X
AMS-5700				X				X	X
A-286	X	X		X		X	X	X	X
V-57		X		X		X		X	X
IRON-BASE SUPERALLOYS (CONTINUED)									
16-25-6		X		X				X	X
Incoloy				X					X
Miltimet N-155*		X	X	X			X	X	
Refractaloy 26**	X			X				X	
S-590				X				X	
ALLOY STEELS - A151 TYPES									
1340				X				X	X
4063	X	X	X	X	X	X	X	X	X
4130	X	X	X	X	X	X	X	X	X
4140	X	X	X	X	X	X	X	X	X
4150	X	X	X	X	X	X	X	X	X
4320	X	X	X	X	X	X	X	X	X
4340	X	X	X	X	X	X	X	X	X
4620	X	X	X	X	X	X	X	X	X
4820			X	X			X	X	X
5140				X			X	X	
5150***				X			X	X	
6150	X	X	X	X	X	X	X	X	X
8620				X			X	X	X
8630				X			X	X	X
8650				X			X	X	X
8740				X			X	X	X
9255				X				X	X
ALLOY STEELS - ULTRA-HIGH STRENGTH									
Modified H-11	X	X	X	X		X		X	X
MX-2	X	X	X	X		X		X	X
300-M***	X	X	X	X		X		X	X
D-6A	X	X	X	X		X		X	X
9-4-.20 to 9-4-.45	X	X	X	X					X

* Also electrodes, sand and investment castings.
** Also springs.
*** Also as castings.

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TABLE 9-2. THICKNESS, SIZE RANGE, AND AVAILABILITY OF VARIOUS STANDARD FERROUS MILL FORMS (CONT'D)

C. MILL SHAPES OF COMMERCIALLY AVAILABLE STAINLESS STEEL ALLOYS

MATERIAL	STRIP	SHEET	PLATE	BAR/ ROD	SHAPES	WIRE	PIPE/ TUBE	FORGINGS	BILLETS
STAINLESS STEEL - AUSTENITIC (AISI TYPES)									
A201, 202	X	X	X	X					
301	X	X	X			X			
302	X	X	X	X		X	X		
302B	X	X	X	X					
303, 303Se				X		X		X	
304	X	X	X	X		X	X	X	
304L	X	X	X	X					
305	X	X	X			X			
308	X	X	X	X		X			
309, 309S	X	X	X	X		X			
310, 310S	X	X	X	X		X	X		
314		X	X	X					
316	X	X	X	X		X	X		
316L	X	X	X						
317	X	X	X	X					
321	X	X	X	X		X			
347, 348	X	X	X	X					
STAINLESS STEEL - MARTENSITIC									
403	X	X		X					
410, 414, 416	X	X	X	X	X	X	X		
416Se, 420, 431	X	X	X	X	X	X	X		
440A, 440B, 440C	X	X	X	X	X	X	X		
STAINLESS STEEL - FERRITIC									
405		X	X	X		X			
430, 446	X	X	X	X					
430F				X		X			
STAINLESS STEEL - AGE HARDENING									
Stainless W	X	X	X	X					X
AM 350*	X	X		X		X			
AM 355**, ***	X	X	X	X		X		X	
Almar 362	X	X		X		X	X	X	
17-4PH***, 17-7PH	ALL WROUGHT FORMS								
PH15-7Mo, 17-14CuMo	ALL WROUGHT FORMS								

*Also as foil and welded tubing.
** Also as electrodes.
*** 17-4PH, AM355, also as castings.

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TABLE 9-3. THICKNESS, SIZE RANGE, AND AVAILABILITY OF VARIOUS ALUMINUM ALLOYS

A. DIMENSIONS OF STANDARD MILL FORMS

FORM	THICKNESS RANGE (INCHES)	SIZE RANGE (INCHES)
FOIL	0.0002 to 0.0055	7 to 35 by 10 to 48 or 3/8 to 66 by 48 (dia) rolls
SHEET	0.006 to 0.249	3 to 120 by 36 to 360
PLATE	0.750 to 3.000	2 to 132 by 12 to 540
BAR - SQUARE	3/8 to 4.00	3/8 to 4 by 36 to 144
HEXAGONAL	3/8 to 3.00	3/8 to 3 by 36 to 144
RECTANGULAR	1/16 to 4.00	3/8 to 10 by 36 to 144
ROD	3/8 to 8.00	36 to 144
WIRE (ROUND)	0.010 to 0.374	5, 15, or 200 lb. spools
TUBE	1/8 to 14.0 (dia)	0.014 to 0.500

B. MILL SHAPES OF COMMERCIALLY AVAILABLE ALLOYS

MATERIAL	SHEET	PLATES	TUBE	PIPE	SHAPES	BAR/ROD	WIRE	RIVETS	FORGINGS	MATERIAL	SHEET	PLATES	TUBE	PIPE	SHAPES	BAR/ROD	WIRE	RIVETS	FORGINGS
EC*	X	X	X	X	X	X	X			5056						X	X	X	
1100**	X	X	X		X	X	X	X	X	5456	X	X	X		X	X			
1235, 1145	AS FOIL ONLY									5257	X								
1060	X	X	X							5457	X								
2011						X	X	X		5557	X								
2014	X	X	X		X	X			X	5657	X								
2017						X	X	X		5083	X	X	X		X	X			
2117							X	X		5086	X	X	X		X	X			
2018									X	6101*			X	X	X	X			
2218									X	6201*							X		
2618									X	6151									X
2219	X	X	X		X	X			X	6053						X	X	X	X
2024	X	X	X		X	X	X	X		6061	X	X	X	X	X	X	X	X	X
2025									X	6262			X		X	X	X		
3003**	X	X	X	X	X	X	X	X	X	6063			X	X	X				
3004	X	X	X							6463					X				
4032									X	6066			X		X	X			X
4043							X			6070			X		X				
5005	X	X				X	X	X		7001			X		X	X			X
5050	X	X	X			X	X			7039	X	X							
5052**	X	X	X			X	X	X		7072							X		
5252	X									7075	X	X	X		X	X	X	X	X
5154	X	X	X		X	X	X			7178	X	X			X	X			
5454	X	X	X		X	X				7079	X	X			X				X

*These alloys for electric conductors only.
**Also as foil.

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TABLE 9-4. THICKNESS, SIZE RANGE, AND AVAILABILITY OF STANDARD COPPER AND COPPER ALLOY MILL FORMS*

A. DIMENSIONS OF STANDARD MILL FORMS

FORM	THICKNESS RANGE (INCHES)	SIZE RANGE (INCHES)
STRIP	0.005 to 0.188	20 max (width)
SHEET	0.010 to 0.188	20 to 60 (width)
PLATE	>0.188 to 2.000	>12 to 60 (width)
BAR	>0.188 to 2.000	12 max (width)
ROD	1/4 to 3.00	312 max
WIRE	0.010 to 0.750	---
TUBE	1/8 to 12	0.010 to 5/8 (wall)

B. MILL SHAPES OF COMMERCIALLY AVAILABLE FORMS

MATERIAL	STRIP	SHEET	PLATE	BAR/ROD	SHAPES	WIRE	PIPE/TUBE	FORGINGS
O_2 Free Copper				X	X	X	X	
Tough Pitch Copper				X	X	X	X	
Phosphorus Deoxidized				X	X		X	
Tellurium Cu145				X				
Sulfur Cu147				X				
Zirconium Cu150				X		X		
Beryllium Cu172				X	X	X	X	
Chromium Cu182				X	X	X		X
Gilding 210	X					X		
220 Commercial Bronze	X	X	X	X		X	X	
226 Jewelry Bronze	X					X		
230 Red Brass	X	X				X	X	
240 Low Brass	X					X		
260 Cartridge Brass	X	X		X		X	X	
268, 270 Yellow Brass	X	X	X	X		X		
280 Muntz Metal	X	X	X	X			X	
314 Leaded Commercial Bronze				X				
330 Low Leaded Brass Tube							X	
332 High Leaded Brass Tube							X	
335 Low Leaded Brass	X		X	X			X	
340 Medium Leaded Brass	X		X	X			X	
342, 353 High Leaded Brass	X			X	X			
356 Extra High Leaded Brass	X			X				
360 Free Cutting Brass				X	X			
365, 366, 367, 368 Leaded Muntz Metal			X					
370 Free Cutting Muntz Metal							X	
377 Forging Brass				X	X			

MATERIAL	STRIP	SHEET	PLATE	BAR/ROD	SHAPES	WIRE	PIPE/TUBE	FORGINGS
385 Architectural Bronze				X	X			
442, 443, 444, 445 Admiralty			X			X	X	
464, 465, 466, 467 Naval Brass	X		X	X	X		X	
485 Leaded Naval Brass				X	X			
502 Phosphor Bronze E	X					X		
510 Phosphor Bronze A	X			X		X	X	
521 Phosphor Bronze B	X			X		X		
524 Phosphor Bronze C	X			X		X		
544 Phosphor Bronze, Free Cutting	X			X	X			
614 Al Bronze D		X	X	X		X	X	
647 Precip. Hard, SiSe Bronze								X
651 Low Si Bronze	X	X	X	X		X	X	
655 High Si Bronze	X	X	X	X		X	X	
675 Manganese Bronze A				X	X			
687 Aluminum Brass							X	
706 Cupro Ni	X		X	X		X	X	
710 Cupro Ni	X		X	X		X	X	
715 Cupro Ni	X		X	X		X	X	X
745 (65-10)	X	X		X	X	X		X
752 (65-18)	X	X		X	X	X		X
754 (65-15)	X	X		X	X	X		X
757 (65-12)	X	X		X	X	X		X
770 (55-18)	X	X		X	X	X		X

*NOTE: For further information, typical mechanical and specification data, see MIL-HDBK-698(MR), Copper and Copper Alloys,[5] dated 29 January 1965.

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TABLE 9-5. AVAILABILITY, THICKNESS, AND SIZE RANGE OF MILL FORMS OF MAGNESIUM ALLOYS *

FORM	THICKNESS RANGE (INCHES)	SIZE RANGE (INCHES, W x L)
SHEET	0.016 to 0.249	24 to 48 by 96 by 216
PLATE	0.250 to 6.000	48 by 96 to 144
BAR	1/8 to 3.500	1 to 6 by 144
ROD	1.4 to 10	144 (length)
TUBE	1/2 to 4 (dia)	0.065 to 0.250 (wall)

AVAILABILITY

Magnesium alloys are available in all the usual metal forms including: ingots and billets; sand, permanent mold, and die castings; forgings; extruded bars, rods, shapes, and tube; and rolled sheet, plate, and strip.

*MIL-HDBK-693(MR), Magnesium and Magnesium Alloys,[6] dated 30 September 1964, contains a comprehensive list of forms available for specific alloys, together with the applicable Military and industry specifications.

TABLE 9-6. AVAILABILITY, THICKNESS, AND SIZE RANGE OF MOLYBDENUM AND MOLYBDENUM BASE ALLOYS

FORM	THICKNESS RANGE (INCHES)	SIZE RANGE (INCHES)
FOIL	0.0025 to 0.004	12 by 76
SHEET	0.005 to 0.1875	14 to 36 by 36 to 96
PLATE	0.1875 to 1.500	36 by 72 to 132
BAR	>1/16 to 3.500	1 to 6 by 144
ROD	1/8 to 3/8	144 to 168
WIRE (ROUND)	1/16 to 1/8	1000 ft coils; 10 to 12 ft cut lengths

AVAILABILITY

Molybdenum metal is commercially available in practically any standard form. Standard size ranges are shown in the tabulation above.

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TABLE 9-7. THICKNESS, SIZE RANGE, AND AVAILABILITY OF TITANIUM AND TITANIUM ALLOYS

A. THICKNESS AND SIZE RANGE OF MILL FORMS

FORM	THICKNESS RANGE (INCHES)	SIZE RANGE (INCHES)
FOIL	0.00 to 0.010	24 (width) coils up to 2000 lbs
SHEET	>0.010	48 max (width)
PLATE	---	72 by 144 max
ROD	---	144 max
WIRE	0.045 min (dia)	Coils, or 12 ft cut lengths

NOTE: Over 40 titanium alloys are commercially available in a wide variety of standard shapes, including bars, forging billets, extruded shapes, plate, sheet, strip, wire, and tubing. The availability of some of the more common titanium alloys is shown by the following tabulation.

B. AVAILABLE MILL FORMS

MATERIAL	STRIP	SHEET	PLATE	BAR/ROD	WIRE	TUBE	FORGINGS	BILLETS
Unalloyed *, **	X	X	X	X	X	X	X	X
5 Al - 2.5 Sn *	X	X	X	X	X		X	X
5 Al - 5 Sn - 5 Zr		X	X	X			X	
8 Al - 1 Mo - 1 V		X	X	X			X	
7 Al - 4 Mo *				X			X	X
6 Al - 6 V - 2 Sn *		X	X	X			X	X
6 Al - 4 V *	X	X	X	X	X	X	X	X
2 Fe - 2 Cr - 2 Mo		X	X	X			X	X
8 Mn **	X	X	X					
13 V - 11 Cr - 3 Al *	X	X	X	X	X	X	X	X

* Also as foil.
** Also extruded forms.

NOTE: No standard system has been devised to designate the classification of titanium. Table II of MIL-HDBK-697(MR), Titanium and Titanium Alloys,[7] dated 1 June 1966, lists titanium materials available with the corresponding Government, industry, and metals society designations.

9-6 POWDER METALLURGY

The powder metallurgy technique is a process rather than a material. However, it is introduced at this point to remind the designer of its potential and unusual material capabilities. Powder metallurgy is defined as a process whereby products are made by pressing fine metal powder into the desired shape (in a mold) and then heating the compacted powder at some temperature below the melting point of the major constituent. The complete process has four major steps:

(1) Preparing the fine metal powder

(2) Mixing the powder

(3) Pressing the powder into the desired shape

(4) Heating (sintering) the compacted powder at an elevated temperature.

Powder metallurgy products are classified into four groups:

(1) Porous products (bearings and filters)

(2) Complete shapes that would require considerable machining if made by other processes

(3) Products made from materials which are difficult to machine (tungsten carbide)

(4) Products wherein the combined properties of two materials are desired (electric motor brushes, electrical contacts).

Powder metallurgy parts can be made in many compositions, but they cannot cover the range of physical and mechanical properties possible with wrought materials. There are also limitations on certain complex shapes and other configurations. However, the possible capabilities of the powder metallurgy technique should always be considered in the design process. Table 9-17 lists metals and alloys used to fabricate powder metallurgy parts. Iron, steel, copper, and copper alloys are the most commonly used.

There is no standard system for designating alloy compositions; however, the code designations of the Powder Metallurgy Parts Association (PMPA) are widely used. The system follows three basic rules:

(1) Prefix letters (Table 9-18) denote the general material

(2) Percentage of alloying elements and minor constituents (Table 9-19) follow the prefix

(3) A final letter (Table 9-20) gives the density of the part

For ferrous metals, the last two digits in the code series of four (Table 9-19) designate the carbon content. Contents up to 0.25% are regarded as zero. For nonferrous metals, these last two digits give the percentage of the major alloying element. The first two digits for both ferrous and nonferrous designate the percentage of the major alloying element.

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TABLE 9-8. THICKNESS, SIZE RANGE, AND AVAILABILITY OF VARIOUS NICKEL ALLOY MILL FORMS

A. THICKNESS AND SIZE RANGE OF MILL FORMS

FORM	THICKNESS RANGE (INCHES)	SIZE RANGE (INCHES)
STRIP	0.001 to 0.125	Coils, 14
PLATE	0.1875 to 4.000	10 to 150 (width)
BAR: SQUARE	3/8 to 2-1/4	3/8 to 2-1/4 by 360
HEXAGONAL	3/8 to 2-1/2	3/8 to 2-1/2 by 360
SQUARE FORGED	2-1/2 to 6	2-1/2 to 6 by 72
ROD: COLD DRAWN	1/16 to 4.00	456 max
HOT FINISHED	1/4 to 4.50	288 max
FORGED BILLETS	12 to 25	---
WIRE (ROUND):		
HOT ROLLED	1/4 to 7/8	Coils
COLD DRAWN	0.001 to 0.875	Coils
TUBE:		
COLD DRAWN	0.012 to 8.00	0.002 to 0.500
EXTRUDED	2-1/2 to 9-1/4	1/4 to 1.000

B. AVAILABLE MILL FORMS

MATERIAL	STRIP	SHEET	PLATE	BAR/ROD	SHAPES	WIRE	PIPE/TUBE	FORGINGS	BILLETS
NICKEL AND ALLOYS									
Nickel 200, 201	X	X	X	X	X		X		
Duranickel 301	X			X	X				
Monel 400, K-500	X	X	X	X	X		X		
NICKEL BASE SUPERALLOYS									
Inconel X-750	X	X	X	X	X	X	X		
Hastelloy B, C*	X	X	X	X		X	X	X	
Hastelloy X, Unitemp HX*		X	X	X		X	X	X	
Inconel 718	X	X	X	X				X	X
Udimet 500	X	X	X	X					X
Udimet 700			X	X					X
Waspaloy	X	X	X	X		X			X
Nicrotung	ONLY AS CASTINGS								
Rene 41, R-41*	X	X	X	X		X		X	
Unitemp 1753, M-252		X		X		X		X	X
Inconel 700				X					
Inconel 713, IN-100	ONLY AS CASTINGS								
LOW EXPANSION NICKEL ALLOYS									
Ni 36, Ni 42, Ni 47-50*	X	X	X	X		X	X	X	
Ni-Span C-902	X			X		X			

*Also as castings.

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TABLE 9-9. COMMERCIALLY AVAILABLE MILL FORMS OF TIN AND TIN ALLOYS

MATERIAL	MILL FORMS
TIN AND TIN ALLOYS	
Grade A Tin	Sheet, pipe/tube, foil, castings, powder
Hard Tin	Pipe/tube, foil
White Metal	Sheet, castings
Pewter	Sheet, castings
1(CY 44A), 2, 3	Precision inserts of babbitt lined strip, lined bearing shells, ingots, die castings
YC135A, PY1815A	Ingots, die castings
TIN-LEAD-ANTIMONY ALLOYS	
8, 8(YT 155A), Y10A, 13, 15	Small ingots and bars

TABLE 9-10. COMMERCIALLY AVAILABLE MILL FORMS OF TANTALUM, TUNGSTEN, AND MOLYBDENUM ALLOYS

MATERIAL	SHEET	PLATE	BAR/ROD	WIRE	PIPE/TUBE	BILLETS
Tantalum*	X		X	X	X	
Tungsten*	X	X	X	X	X	
Mo - .05 Ti, TZM (.05 Ti .01 Zr)**	X	X	X		X	X
Tantalum 10-W	X		X			
AVC N-25Re***		X		X	X	X
222(10.5 W, 2.4 Hf, .01 C			X			X

*Also as foil and powder.
**Also as forgings.
***Also as strips.

TABLE 9-11. COMMERCIALLY AVAILABLE MILL FORMS OF PRECIOUS METALS

METAL	STRIP	SHEET	BAR/ROD	WIRE	PIPE/TUBE	FOIL	POWDER
Gold		X	X	X	X	X	X
Silver	X	X	X	X	X		X
Platinum		X		X	X	X	X
Palladium		X		X	X	X	X
Rhodium		X		X			X
Ruthenium*	X		X				X
Osmium	--- CAST OR SINTERED PARTS ---						
Iridium		X	X	X	X		X

*Also as sintered parts

TABLE 9-12. COMMERCIALLY AVAILABLE MILL FORMS OF COBALT AND COBALT ALLOYS

MATERIAL	SHEET	PLATE	BAR/ROD	WIRE	FORGINGS	BILLETS
Cobalt	--- ROUNDELLE POWDERS ---					
UMCo-50*	X		X	X		
Nivco**	X	X	X	X	X	X
S-816	X		X	X		X
V-36	X		X	X		X
Haynes Alloy 25, L-605***	X	X	X	X	X	X
J-1570	X		X			X
J-1650	X		X	X		X
HS-21, HS-31, X-40	--INVESTMENT CASTINGS---					
HS-151, WI-52, SM-302, SM 322	CASTINGS					

*Also as castings.
**Also as strips.
***Also as pipe and tube.

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TABLE 9-13. TYPICAL APPLICATIONS FOR PREPLATED OR PRECOATED MATERIALS

SURFACE AND COATING METHOD ↓ / BASE METAL →	LOW CARBON STEEL	Cu BEARING STEEL	STEEL, ASTM A122	ZINC	ALUMINUM	BRASS	COPPER	Cu ASTM B101	APPLICATIONS ↓
Aluminum, Hot Dipped	Sh St	Sh St							Oven door liners, aircraft firewalls, mufflers, space heater baffles.
Aluminum, Hot Dipped			W						Guy wires, overhead ground wires.
Brass, Copper Plated				Sh St					Molding, ornaments, trim, badges, buttons.
Brass, Copper Plated	Sh St								Tubing, frames, luggage, hardware, costume jewelry.
Bronze	St								Ornamental trim, shell cases.
Chromium, Plated				Sh St	Sh St	Sh St	Sh St		Toys, reflectors, trim, auto accessories.
Chromium, Plated	Sh St								Heater and toaster shells.
Lead, Plated	Sh St								Telephone cable sheathing, containers.
Lead, Plated or Hot Dipped								Sh St	Roofing, flashing.
Lead, Hot Dipped	Sh St								Ammunition boxes, ducts.
Terne, Hot Dipped	Sh St								Gasoline tanks, door frames, paint and oil containers.
Nickel, Plated	Sh St								Toys, trays, knives, nameplates
Tin, Plated	Sh St								Food product cans, kitchenware, parts to be soldered.
Zinc, Plated	Sh St F								Lighting fixtures, spools, reels, oil cans, refrigerator parts.
Zinc, Hot Dipped*									Auto mufflers, refrigerator and air conditioner parts.
Zinc, Hot Dipped**									Water pipe, electrical and conduits.
Zinc, Hot Dipped	W								Fencing.

Key: Available Forms - Sh = Sheet
St = Strip
W = Wire
F = Flat Wire

*Available as plate, bar, sheet, strip, and shapes on low carbon steel (including ASTM A123).

**Available as tubing, pipe, and conduit on carbon or low alloy steel.

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TABLE 9-14. TYPICAL FORMS AND APPLICATIONS OF CLAD METALS (ALUMINUM, COPPER, AND COPPER ALLOYS)

SURFACE ↓ / BASE METAL →	LOW CARBON STEEL	CARBON STEEL	HIGH CARBON STEEL	LOW ALLOY STEEL	LOW ALLOY STEEL WITH BORON	STAINLESS STEEL	F-15 ALLOY	AUSTENITIC STAINLESS	COPPER	BERYLLIUM COPPER	ALUMINUM 2024	ALUMINUM 2014	ALUMINUM 5056	ALUMINUM 3003 & 3004	ALUMINUM 7075	APPLICATIONS
Aluminum	St															Anode plates for receiving tubes.
Aluminum with Nickel on other side	St															Anode plates for receiving tubes, except where temperature is too high for aluminum.
Aluminum 1100											Sh					Aircraft frames, cooking utensils.
Aluminum 6053												Sh				Aircraft fillings.
Aluminum 6053													W			Screen wire.
Aluminum 7072														Sh		Cooking utensils, gas tanks, bus trim.
Aluminum 7072															Sh	Aircraft structural parts.
Brass	St															Gaskets, frames, cosmetic cases.
Brass over Copper	W															Lamp stands, indoor TV antennas.
Copper		W R														Lead wire for electronic tubes, power lines.
Copper										St						Current carrying springs.
Copper	St W															Gaskets, radiator tanks, electric contacts.
Copper			St													Spiral type springs, clips.
Copper					W											Plated jewelry, grid supports for electron tubes.
Copper		P W		P W												Chemical process equipment, lead wires, soft seals.
Copper						St										Heat exchanger fins.
Copper							St									Semiconductors, power tubes.
Cupro-Nickel								W								Wire rope.
Cupro-Nickel	St															Chemical process equipment.
Phosphor Bronze									St							Current carrying springs and blades.

Key: St = Strip; Sh = Sheet; W = Wire; R = Ribbon; P = Plate.

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TABLE 9-15. TYPICAL FORMS AND APPLICATIONS OF CLAD METALS (STEEL, PRECIOUS METALS, AND OTHERS)

SURFACE ↓ / BASE METAL →	LOW CARBON STEEL	LOW ALLOY STEEL	STAINLESS STEEL	COPPER	BERYLLIUM COPPER	BRASS	ALUMINUM	ALUMINUM (1100, 5052)	SUPERALLOYS	BRONZE	NICKEL	APPLICATION ↓
Hardenable Steel				St								Current carrying springs, connectors, terminals.
Stainless Steel							C					Cookware, heat exchangers, appliances, trim.
Stainless 446, 52 Alloy, F-15 Alloy				W								Glass sealing wire for heaters.
Stainless 304, 310, Austenitic				St								Heat exchangers, power tube parts.
Stainless 430 Ferritic				St								Pots, pans, heating wells.
Stainless	P Sh	P										Process equipment.
Stainless, Ferritic	St											Auto bumpers, grills, trim, cooking utensils.
Lead	T			T								Heat exchanger coils for chemical processing equipment.
Inconel/Monel	P	P										Process equipment.
Nickel	W R											Typewriter key levers, grid support rods, tube lead-in wire.
Nickel				W R								Electrical circuits for high temperature environment.
A Nickel				W R								Electrical circuits in corrosive atmosphere.
A or L Nickel	P	P										Process equipment.
L Nickel	St					St						Process equipment.
330 Nickel	St											Anode plates for electronic tubes.
Hastelloy, Rene									H			Honeycomb, aerospace uses.
Platinum				T W		T W				T W	T W	Heat exchangers for chemical processes.
Silver				W R							W R	High temperature coils, radar cable braiding, lead wire.
Silver						T	T					Waveguides for electronic transmission lines.
Silver			St			St		St				Electrical contacts, slip rings.
Gold, 14 K or more		St W		St W		St W				St W	St W	Bursting disks, other chemical process equipment, lead wire.

Key: St = Strip; Sh = Sheet; P = Plate; T = Tube; W = Wire; R = Ribbon; H = Honeycomb.
C = Strip, Sheet, Plate

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TABLE 9-16. PREPAINTED METALS AND TYPICAL APPLICATIONS

PREPAINTED METAL COATING	ALUMINUM	STEEL, COLD ROLLED	TIN MILL BLACK PLATE STEEL	ELECTROLYTIC TIN STEEL	ELECTROGALVANIZED STEEL	HOT DIP GALVANIZED STEEL	ALUMINIZED STEEL	PREPLATED STEEL	TYPICAL APPLICATIONS
Alkyd-Amino	2	2	2	3	2	2	2	3	Venetian blinds, tool sheds, drums, pails, toys, auto parts.
Vinyl-Alkyd	2	2	2	3	2	2	2	3	Roof decking, license plates, baseboard heating covers.
Silicone-Alkyd	1	2	2	3	1	1	1	3	Telephone booths, building panels, mobile homes, siding.
Acrylic	1	1	2	3	1	1	1	3	Wall panels, siding, radio and TV cabinets, hot water jackets.
Epoxy (solution)	2	2	2	1	2	2	2	1	Air conditioners, vending machines, nondecorative interior uses.
Epoxy (ester)	1	2	2	1	2	2	2	1	Uses requiring high resistance to high temperature, humidity, and chemicals.
Polyester	1	1	1	1	1	1	1	1	Building panels, TV cabinets, appliance finishes.
Vinyl (solution)	1	1	1	1	1	1	1	1	Siding, small appliances, wall tile, curtain rods, deep draw parts.
Vinyl (organosol)	1	1	1	2	1	1	1	1	Siding, roof shingles, auto parts, deep draw parts.
Vinyl (plastisol)	1	1	1	2	1	1	1	2	Siding, luggage, business machines, furniture.
Polyvinyl Fluoride	1	2	2	2	2	1	1	2	Siding, roof shingles, chemical resistant parts.
Polyvinylidene Fluoride	1	2	2	2	2	1	1	2	Siding, roof shingles.

Key: 1 = Normal Combination; 2 = Combination Used Sometimes; 3 = Combination Not Used

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TABLE 9-17. SOME METAL COMPOSITIONS USED IN PRODUCING POWDERED METALLURGY PARTS

METAL	COMPOSITION
Aluminum and Some Alloys	Up to 99% pure
Beryllium	98% pure
Brass	90 Cu - 10 Zn, 85 Cu - 15 Zn, 78 Cu - 20 Zn - 1.5 Pb, 70 Cu - 30 Zn, 68.5 Cu - 30 Zn - 1.5 Pb, 60 Cu - 40 Zn
Bronze	93.5 Cu - 5 Sn - 1.5 Zn, 90 Cu - 10 Zn, 87.5 Cu - 8 Pb - 4 Sn, 79.5 Cu - 10 Pb - 10 Sn, 75 Cu - 25 Pb - 0.9 Sn, 69 Cu - 31 Pb - 0.9 Sn
Cobalt	Up to 99.9% pure
Copper	Up to 99.5 % pure
Cupro-Nickel	90 Ni - 10 Cu, 70 Ni - 30 Cu
Gold	Up to 99.9% pure
Hafnium	Experimental
Iron and Alloys of Iron	Up to 99.9% pure
Iron-Nickel	64 Fe - 36 Ni, 50 Fe - 50 Ni
Molybdenum	99.95% pure
Nickel and Alloys	Up to 99.9% pure, 67 Ni - 30 Cu - 3 Fe, Hastelloys, Inconel 713C
Steel	Low, medium, and high carbon; 2, 4, and 7% Ni steels; A151 4600 series steels; stainless types 202, 304, 304L, 304 and Ti, 316, 316L, 347, 347L, 410, 410L, 430
Titanium	Up to 99% pure, Ti - 6 Al - 4 V, Ti - 8 Al - 1 Mo - 1 V
Tungsten	Up to 99% pure
Zirconium and Alloys	Up to 99% pure

The rules that apply to stainless steel differ in that the prefix SS is followed by the AISI wrought designation.

Fig. 9-1 graphically displays the general range of yield strengths that can be obtained with the various powders used to fabricate powder metallurgy parts.

9-7 PLASTICS

Thousands of types and formulations of plastic are available to the designer; they evolve from some thirty distinct families of plastics. Table 9-21 lists some common plastics, the form in which they are generally available, and their typical applications. Designers contemplating the use of plastics should obtain a reference copy of Plastec Note 6A, *Government Specifications and Standards for Plastics, Covering Defense Engineering Materials and Applications*, dated July 1966. Copies are available from the Clearinghouse for Federal Scientific and Technical Information, U.S. Department of Commerce, 2585 Port Royal Road, Springfield, Va. 22151. Order document number AD-640 377.

Plastec Note 6A was prepared by the Plastics Technical Evaluation Center (PLASTEC), Picatinny Arsenal, Dover, New Jersey. It lists the specifications and standards for those plastic materials and plastics applications which are considered to be of interest to engineers concerned with the design, development, production, and handling of defense hardware. Included are specifications for the basic or raw materials, composite materials, and the items and applications of potential defense concern. Excluded are specifications on life-situation items: clothing, utensils and furniture, and decorating or preservative coatings. The body of the material in the document is presented in four parts:

(1) Part I—Specifications for or involving specific plastic materials title-stated or otherwise identified

(2) Part II—General reference documents

(3) Part III—Specifications for or involving unspecified plastics reference documents

(4) Part IV—A subject index, a numerical index

Plastec Note 6A contains complete citations for more than 700 specifications, including number, data,

TABLE 9-18. PMPA* PREFIX CODES

MATERIAL	COMPOSITION	CODE
Bronze	Copper - Tin	BT
Bronze, leaded	Copper - Tin - Lead**	BT
Brass	Copper - Zinc	BZ
Brass, leaded	Copper - Zinc - Lead	BZ
Iron or Iron Carbon	Iron or Iron - Carbon	F
Iron Alloy	Iron - Copper	FC
Iron Alloy	Iron - Nickel	FN
Iron Alloy	Iron & 15/25% Copper***	FX
Stainless Steel	AISI 303L, 316L, 410	SS

*Powder Metallurgy Parts Assn.
**Can contain up to 1.75% solid lubricant, such as graphite
***Infiltrated

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TABLE 9-19. PMPA* COMPOSITION CODES

MATERIAL	COMPOSITION	CODE
Iron	Fe - 0.25 Max C	0000
Iron - Carbon	99 Fe - 1.0 C	0010
Iron - Carbon	99 Fe - 0.5 C	0005
Iron - Copper	Fe - 10 Cu	1000
Iron - Nickel	Fe - 7 Ni	0700
Bronze	90 Cu - 10 Sn	0010
Leaded Bronze	87 Cu - 10 Sn - 3 Pb	0310
Stainless	AISI 316L	316

*Powder Metallurgy Parts Assn.

TABLE 9-20. PMPA* SUFFIX LETTER CODES

DENSITY RANGE (g/cc)	CODE
<6.0	N
6.0 < 6.4	P
6.4 < 6.8	R
6.8 < 7.2	S
7.2 < 7.5	T
7.5 < 8.0	U
≥8.0	W

*Powder Metallurgy Parts Assn.

title, existence of Qualified Products List, status of coordination among the services (limited to one, not limited, etc.), agency preparing the specification, and custodian(s) of the specification. Included as introductory material is a discussion of Government specifications and instructions on their procurement.

In addition to Plastec Note 6A, it is suggested that designers also obtain a copy of Federal Test Method Standard No. 406, *Plastics: Method of Testing*, dated 5 October 1961; together with a copy of MIL-HDBK-700(MR), *Plastics*, dated 1 November 1965.

The information and data contained in the three suggested references constitute the most suitable method of covering the broad subject of plastic materials. Providing detailed information in this handbook would be prohibitive.

9-8 COSTS

The design engineer is more interested in the properties of a material than he is in its composition or cost. Since there is interchangeability among materials, producers are promoting competition among ferrous metals, nonferrous metals, plastics, timber, ceramics, and glass. Each producer is defending his market and is seeking to enter the market of others. The presence of this competitive environment sets the stage for the discussion which follows and cost information. The comments necessarily are limited to the cost of the material used in the product. It is important, however, to recognize that the decisions made by the designer regarding a material have a far-reaching effect; they not only contribute heavily to the ultimate end item cost, but can be a determining factor in the life cycle cost of the entire system.

Figs. 9-2 through 9-6 illustrate price range data (circa 1967) for a variety of materials. By themselves, they are not significant, but may assist in assessing the competitive positions of the materials.

In considering costs, it is necessary to refine any material costs down to the actual cost of the material in the component. Strength, rigidity, space filling, and desirability of surface generally determine the selection of most engineering materials. Thus, it follows that cost per unit of strength would be the best index of material cost competitiveness. On this basis, some of the newer materials, which cost far more per pound than older ones, will be far out of proportion. This is particularly true in the case of plastics. On the other hand, such a cost comparison would not be valid in a situation where high corrosion resistance, high electrical conductivity, or some other special property were of primary importance at any (reasonable) cost.

Another cost relating to material selection is that of converting or processing the material into the finished product. Machining costs vary significantly between materials, even between alloy compositions of the same material. Another consideration should be the savings gained by careful segregation and recovery of scrap generated in processing operations. These can be significant in the case of the newer space age materials. Not all scrap material is usable, however. Plastics, for example, generally yield a low grade scrap useful only for secondary products such as toys, and titanium scrap has no applications, a significant (and unfortunate) factor because of its high cost and the large amounts lost during machining.

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TABLE 9-21. PLASTIC MATERIALS, FORMS GENERALLY AVAILABLE, AND PRINCIPAL USES

MATERIAL	FORMS	USES
ABS Resins	Molds, extrusions, sheets	Pipe, housewares, lawn equipment, chrome plated parts, shoe heels, luggage, cases, refrigerator linings.
Acetals	Molds, extrusions	Appliance parts, gears, auto products.
Acrylics	Castings	Aircraft canopies, drafting equipment, signs.
Acrylics	Molds, extrusions, sheets, film	Appliance parts, shoe heels, pump parts.
Alkyds	Molds, putty	Tube and socket bases, parts for electrical devices, stand-off insulators.
Cellulose Acetate	Molds, extrusions, sheets, film	Film, tape, appliance housings, tool handles, buttons, blister packaging.
Cellulose Acetate - Butyrate	Molds, extrusions, sheets, film	TV and radio knobs, pens, optical parts.
Cellulose Acetate - Propionate	Molds, extrusions, sheets, film	Telephones, steering wheels, pens, knobs, containers.
Cellulose Nitrate	Sheets	Pens, spectacle frames, drawing instruments
Ethyl Cellulose	Molds, extrusions, sheets, film	Radio housings, pen barrels, tool handles.
Diallyl Phthalate (Allylics)	Molds Putty Liquid	Resistor insulators, appliance fixtures. Housings, radomes, air ducts. Decorative sheets.
Epoxies	Molds, castings, liquid	Encapsulations, electrical applications, ablatives, high strength tubing, chemical resistant parts.
Fluorocarbons	Molds, extrusions	Chemical applications, gaskets, electronic components, wear surfaces.
Phenoxy	Molds, extrusions	Blow molded containers, light covers, electrical parts.
Melamines (Amino Resin)	Molds	Moldings, ornaments, electrical applications, kitchenware, food trays.
Nylon (Polyamides)	Molds, extrusions, castings, sheets, film	Gears, bushings, electrical insulation, wire jacketing, rollers, tubing, tape.
Phenolics	Molds	Pulleys, wheels, coil forms, photographic developing tanks, ignition parts.
Polyimides	Molds	Bearings, valves, and high temperature mechanical parts.
Polyphenylene Oxide	Molds	Nose cones, fuze covers, plumbing subject to hot water.
Polysulfones	Molds	Housings, valve bodies, bobbins.
Polyesters	Castings Molds	Electrical components, buttons. Chairs, housings, covers, helmets.
Polypropylenes	Molds, extrusions, sheets, film	Hospital ware, housings, electrical uses, wire coatings, appliances.
Polyethylenes	Molds, extrusions, castings	Kitchen utilityware, film wrapping, squeeze bottles, pipe, battery parts.
Polystyrene	Molds, extrusions, sheets, film, foam	Thin parts, electrical components, camera housings, TV cabinets.
Polyvinyls	Molds, extrusions, castings, sheets, film, foam	Adhesives, airtight bags, tubing, cable coating, safety glass interlayer.
Silicones	Molds, sheets	Structural electronic parts, encapsulated parts, high temperature structural or electrical parts.
Ureas	Molds	Housings for radios, business machines, switch plates, high arc resistant applications.

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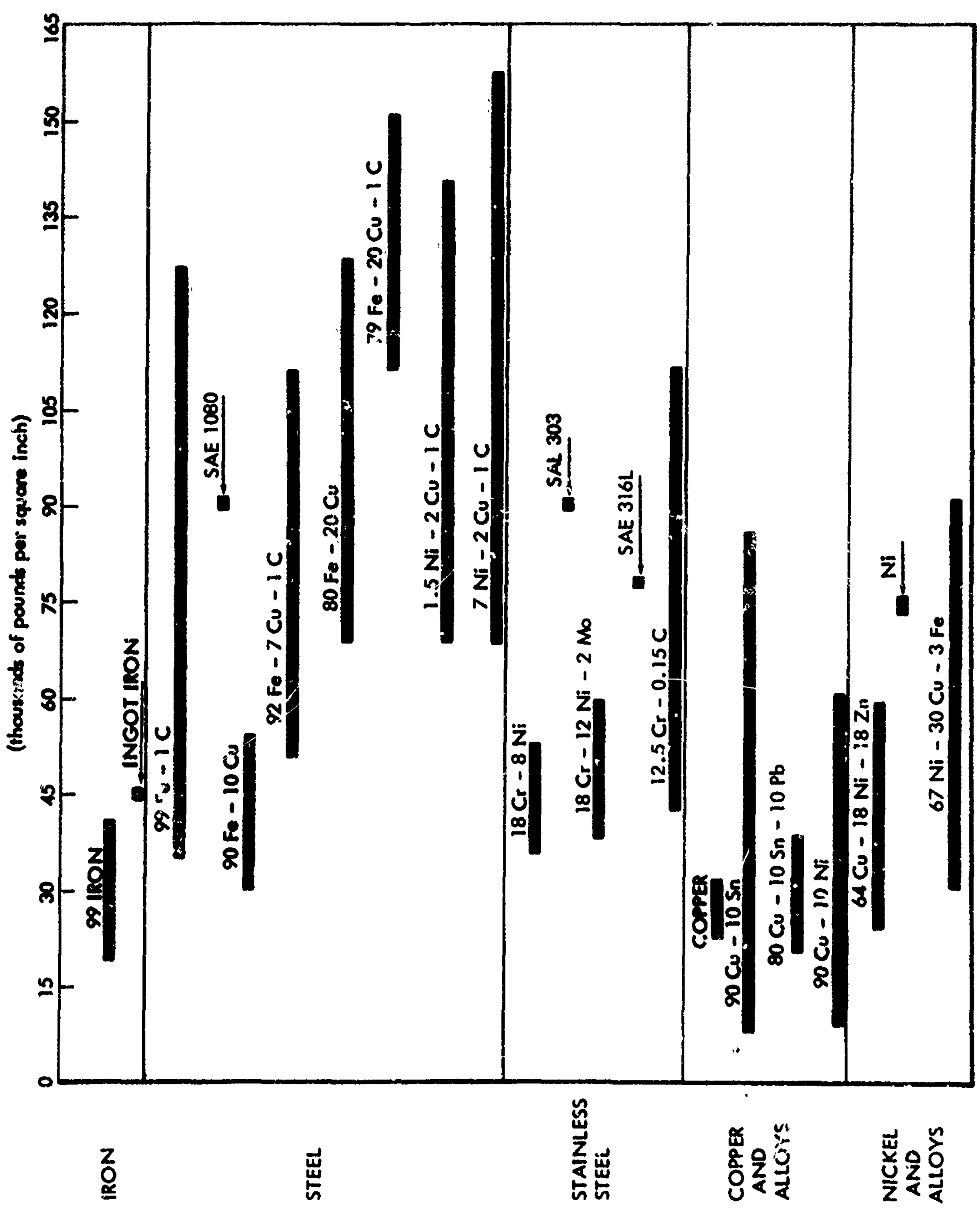

FIGURE 9-1. Typical Yield Strengths for Powder Metallurgy Parts

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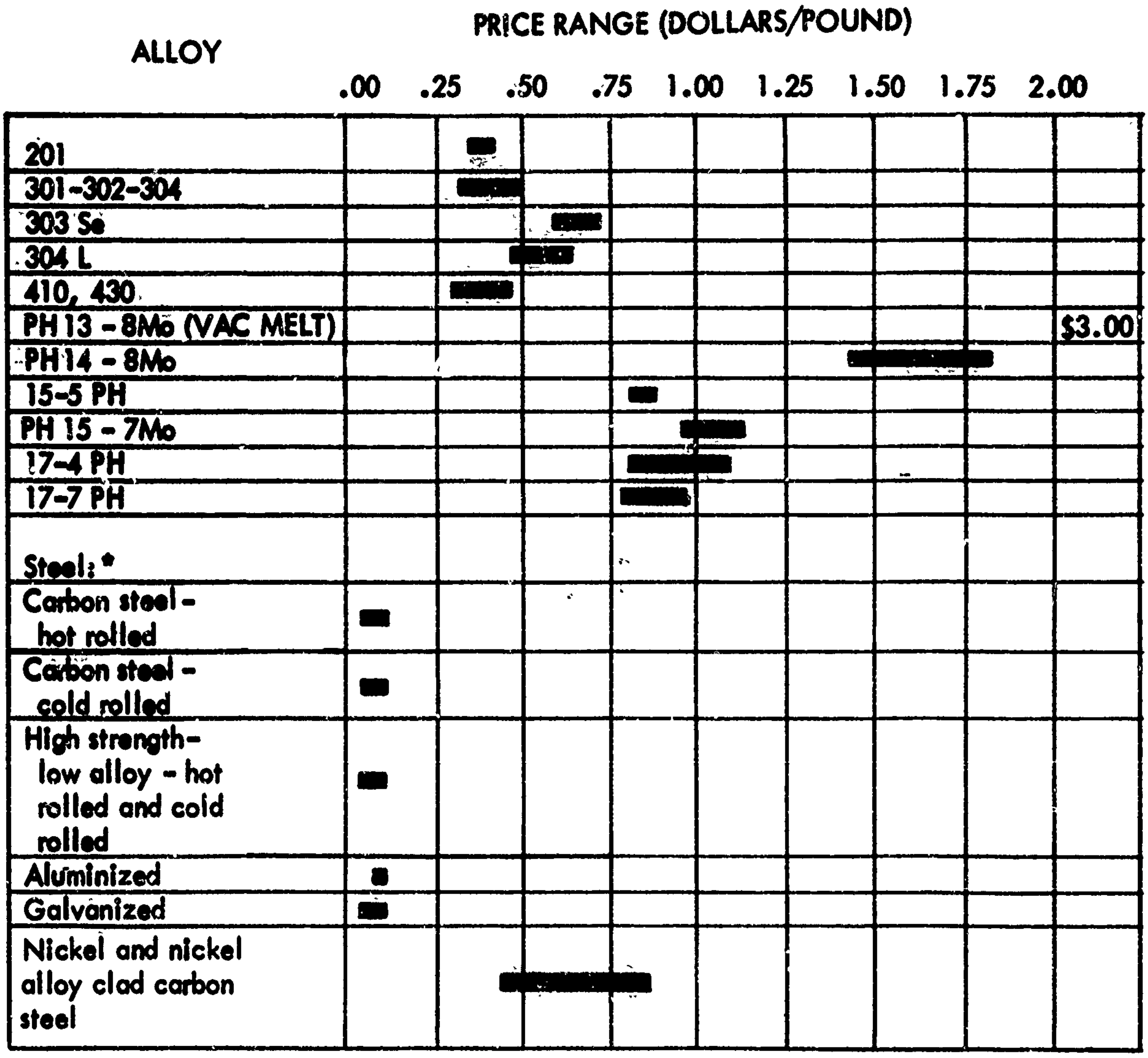

*Note: Tool Steel Ranges from .30 to $3.00/pound.

FIGURE 9-2. Price Ranges for Steel and Steel Alloys

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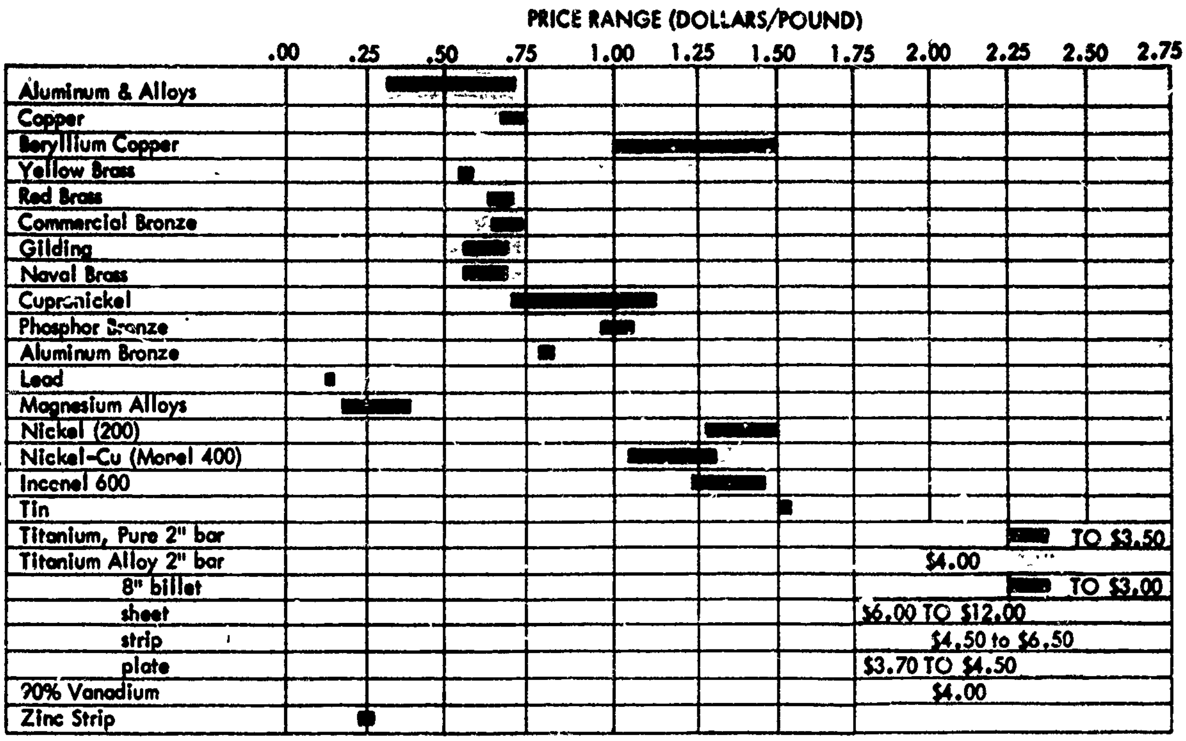

FIGURE 9-3. Price Ranges for Selected Metals

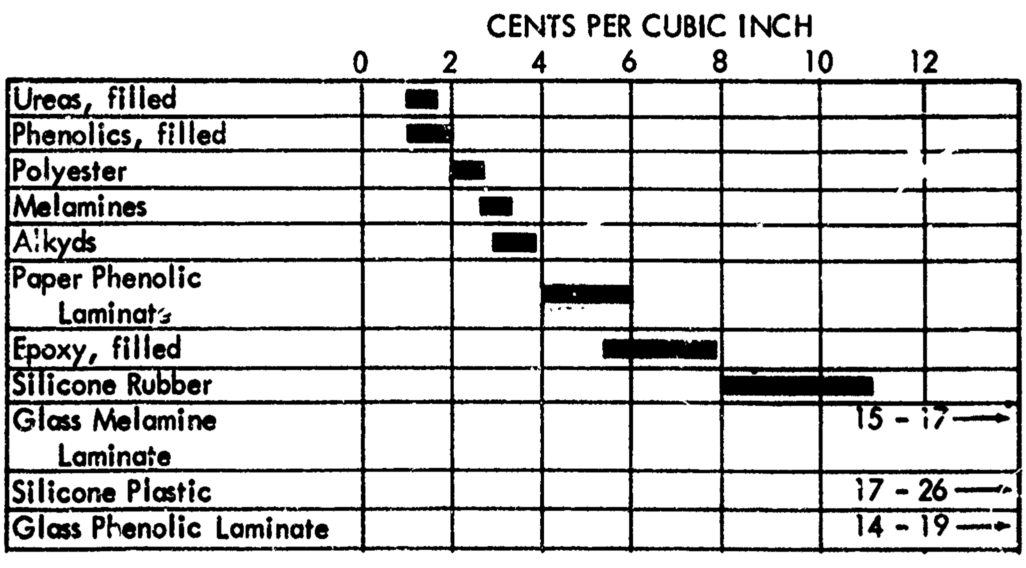

FIGURE 9-4. Basic Cost of Thermosetting Materials in Terms of Volumetric Cost

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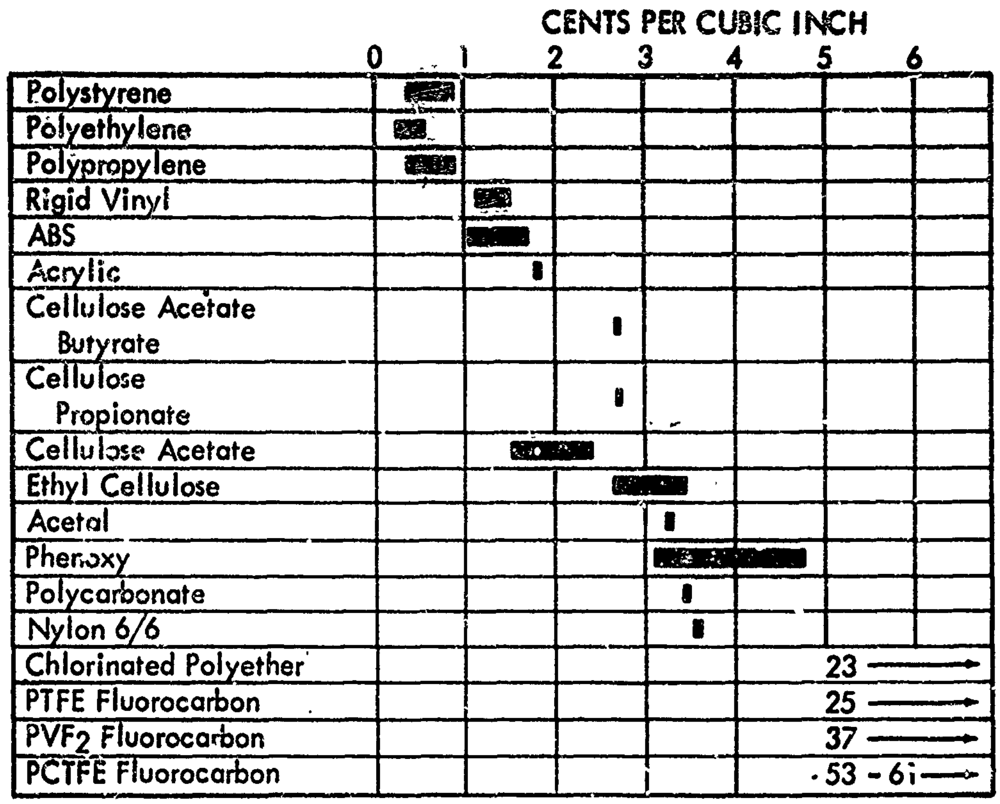

FIGURE 9-5. Basic Cost of Thermoplastics in Terms of Volumetric Cost

9-9 ACCIDENT HAZARDS

The designer exerts considerable influence on the presence of production hazards in his selection of materials (and production methods). However, the control of such design-dictated hazards is a direct burden on the producer. Production personnel ordinarily can cope with such problems, but some precautionary measures required cost both time and money, thereby thwarting the objectives of producibility. The designer must be aware of this potential impact on producibility and choose his materials accordingly.

No material is completely hazard-free in all forms and usages. Consideration must, therefore, be given to hazardous features of materials both during and subsequent to production. A source of abridged information is *Dangerous Properties of Industrial Materials*[8], section 12 of which categorizes hazard data on 10,000 common industrial materials into:

(1) General information about substances listed, such as synonyms, description, formula, and the physical constants.

(2) Hazard analyses, which include toxicological description, and which are further broken down into allergic and radiological hazards, and fire and explosion hazards.

(3) Countermeasures, or what may be done to mitigate the effects of using a given material, for instance, shipping regulations, storage and handling; first aid measures for exposed individuals, fire-fighting measures, ventilation controls, and personnel protection.

A second useful reference is Title 49, "Transportation", *Code of Federal Regulations*[9]. This document describes those materials and products which are defined as being transportation and shipping hazards and precautions required in their packaging and handling.

The basic sources of material-induced safety hazards can be readily classified. Those of most common occurrence are listed in Table 9-22. Also given is a brief description of their occurrence and some possible causes. Use of checklists of this type will serve to identify hazardous situations in actual use and in the logistic system as well as in production.

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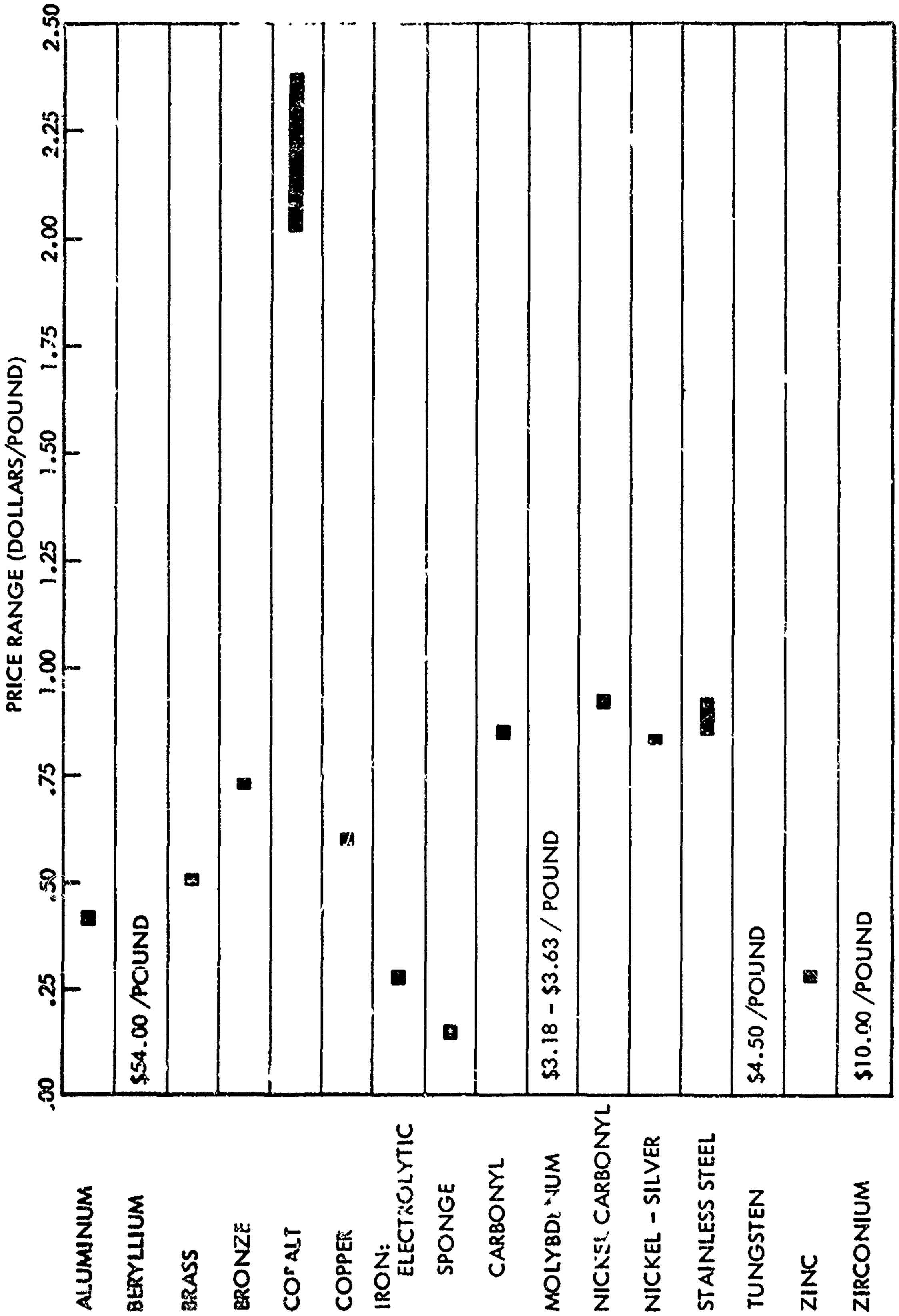

FIGURE 9-6. Cost of Metal Powders

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TABLE 9-22. BASIC CAUSES OF SAFETY HAZARDS*

HAZARD	OCCURRENCES	POSSIBLE CAUSES
ACCELERATION (Rate of change of velocity, ft/sec^2; g-loads)	Any mass which undergoes a change in velocity	Vehicle, body, or fluid being set into motion, being stopped, or changing speed Any body being dropped Impact by or against another body Friction or resistance to body motion Applied force against an unrestrained body
CONTAMINATION (Particle size, μ; Contaminant weight per volume, mg/l; Contaminant ratio, ppm; Particle count, no.)	Any system or equipment: Open to entry of dirt, dust, or other contaminants in presence of contaminants in which contaminants can be formed	Poor quality control Polymerization Microbial growth Inadequate protection from contaminants Filtration system overload or failure Solvent residues Inadequate solvent for cleaning Tropical environment Salt environment Oxide scale Metal particles Airborne particles Silica sand Lapping compound Process residues Organic fibers Plastic and elastomer fragments Misalignment or poor fitting of parts
CORROSION (Rate, in/yr, mm/yr)	Metals which react with air Any system with reactive chemicals Materials susceptible to moisture or airborne salts	Lack of compatibility of materials as designed Leakage of corrosive or reactive substances Exposure to unforeseen environment Damaged protective surfaces Flooding or immersion Condensation of atmospheric moisture Electrolyte corrosion (dissimilar metals) Stray electrical currents Vibration and fatigue Salt atmosphere

*Adapted from *System Safety Hazard Analysis*[10], pp. 12-24.

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TABLE 9-22. BASIC CAUSES OF SAFETY HAZARDS (CONT'D)

HAZARD	OCCURRENCES	POSSIBLE CAUSES
DISSOCIATION, CHEMICAL	Monopropellants, fuels, or oxidizers Explosives Organic materials Epoxy compounds	Temperature of compound raised to point reaction begins Presence of suitable catalyst Shock
ELECTRICAL (Potential, V; Current, A; Power and heat losses, w; Radiation, w/cm²)	Any "live" electrical circuit Power generators Natural electrical sources (lightning) Dry plastics and organic materials (static electricity) Batteries Other electrochemical reactions	Contact with live circuit erroneous connection Failure to discharge capacitive circuit Cutting through insulation Touching part of short circuit
EXPLOSION (Impact sensitivity, psi; TNT equivalency, lb; Temperature, °F)	Ordnance or munition systems Any fuel system High pressure equipment Cryogenic liquid system	Inadvertent activation of: High explosives Propellant explosives or combustible gases in containers or confined spaces Fine dusts and powders Combustible gases or liquids: In high concentrations In presence of strong oxidizers At high temperatures Activation of cracked or otherwise defective solid propellent motors Afterburning of confined combustion products Delayed combustion in a firing chamber Cold soaking of solid propellants Overpressurization of boilers, accumulators, or pressure vessels Warming closed cryogenic or other system containing highly volatile fluid Contact between water or moisture with water-sensitive materials such as molten sodium, postassium, or lithium; concentrated acids or alkalies; or similar substances

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TABLE 9-22. BASIC CAUSES OF SAFETY HAZARDS (CONT'D)

HAZARD	OCCURRENCES	POSSIBLE CAUSES
FIRE (Flash point, °F, AIT, °C; Flammability limits, %)	All normally combustible materials. Fuels: Propellants, liquid, solid, or gel Engine start: ethylene oxide, TEA, TEB Auxiliary power unit: hydrazine Heating: kerosene, fuel oil Solvents and cleaning agents Lubricants Welding gases Paints and varnishes Coolants: ammonia Elastomers (seals and gaskets) Hydraulic fluid Wood products Plastics Clothing Vegetation Refuse and trash Other organic materials Normally low combustible materials in presence of strong oxidizers of high temperatures: Solvents--trichloroethylene, methylene chloride Lubricants Hydraulic fluids Normally nonflammable metals in finely powdered form: Aluminum Magnesium Titanium Iron Afterburning of products of combustion of engine operation: carbon monoxide	Combustible mixture with initiating sources such as: Open flame: Welding processes and flame cutting Matches, smoking Gas heaters or process equipment Engine exhaust Nearby fires Sparks: Electrical Mechanical Chemical--carbon Catalyst Combustible mixture heated to autoignition temperature by: External heat sources: Electric heaters or hot plates Boilers, radiators, steam lines, and equipment Operating engines, motors, or compressors Exhaust stacks or manifolds Friction Inadequate dissipation of chemical reaction heat (spontaneous ignition): Oily rags Sawdust, excelsior Powdered plastics Compression of flammable mixture Hypergolic mixture, including sensitivity to water Pyrophoric reaction with air Radiation from nuclear detonation

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TABLE 9-22. BASIC CAUSES OF SAFETY HAZARDS (CONT'D)

HAZARD	OCCURRENCES	POSSIBLE CAUSES
HEAT AND TEMPERATURE (Heat, Btu, Btu/lb, Btu/ft^2; Temperature, °F, °C)		
High Temperature	Any fuel-consuming process	Fire or explosion
	Other exothermic chemical process	Other exothermic reaction
	Electrical equipment	Heat engine operations
	Solar energy	Electrical energy losses
	Biological or physiological processes	Aerodynamic or other vehicular friction
	Moving equipment or parts	Friction between moving parts or vehicle and surrounding medium
		Gas compression
		Inadequate heat dissipation
		Cooling system failure
		Welding, soldering, brazing, or metal cutting
		Proximity to operations involving large amounts of heat (radiation, convection, or conduction)
		Immersion in hot fluid
		Lack of insulation
		Exposure to sun or artificial light
		Hot climates or weather
		Human or animal heat output
		Organic decay processes
Low Temperature	Any heat removal process	Cold climate or weather
	Refrigerating or cryogenic systems	Endothermic reactions
	Polar, high altitude, or winter conditions	Mechanical cooling processes
		Gas expansion
		Rapid evaporation
		Inadequate heat supply
		Heat loss by radiation, conduction, or convection
		Solid propellant cold soaking
Temperature Variations	Any system or part which gains or loses heat	Gain or loss of heat due to radiation, conduction, or convection
		Input of electrical energy
		Gas expansion
		Diurnal heating and cooling
		Stopping and starting of heat engines

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TABLE 9-22. BASIC CAUSES OF SAFETY HAZARDS (CONT'D)

HAZARD	OCCURRENCES	POSSIBLE CAUSES
LEAKAGE (Volume, gpm or ft^3/min)	Any vessel or conductor which contains or is immersed in a fluid	Cracks caused by structural failure Hole caused by impact Porosity or other weld defect Inadequately fitted or tightened parts Fittings loosened by vibration Corroded metals or seals Worn parts Excessive fluid pressure Cuts in organic materials (seals, gaskets, hoses) Poorly designed connections Dirt or other solid contamination between mating surfaces Erroneously opened drains or fittings Overfilling of containers
MOISTURE (Relative humidity, F; Absolute humidity, gr/ft^3 of air) High Humidity	Wet climate or weather Proximity to bodies of water Moisture-producing processes Inflow of underground water Large amounts of vegetation Personnel in inadequately ventilated enclosures or equipment	High atmospheric humidity Rain, snow, hail, ice, or dew Flooding and immersion Leakage Prespiration Malfunction of air conditioning equipment Condensation on cold surfaces Presence of humidifying equipment Contact with water-absorbent materials such as concentrated acids and alkalies, ammonium perchlorate
Low Humidity	Dry climates or weather Proximity to hot, dry processes	Low atmospheric humidity Temperature increase without addition of moisture Operation of dehumidifying equipment

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TABLE 9-22. BASIC CAUSES OF SAFETY HAZARDS (CONT'D)

HAZARD	OCCURRENCES	POSSIBLE CAUSES
OXIDATION (OTHER THAN BY AIR)	Missile propellants	Chemical combination involving oxidants such as:
	Welding oxygen	Oxygen or ozone
	Oxygen for respiratory protective equipment	Halogens or halogen compounds
	Laboratory chemicals	Oxidizing acids and their salts:
	Process chemicals	Nitrates, chlorates, perchlorates, hypochlorites, chromates
	Cleaning compounds	Higher valence compounds of mercury, lead, selenium, and thallium
PRESSURE (Force per unit area, psi, mm Hg, atm)		
High	Hydraulic systems	Overpressurization
	Pneumatic systems	No pressure relief or vent
	Cryogenic systems	Faulty pressure or relief valve
	Pressurized containers	Heating of fluids with high vapor pressures
	Boilers	Warming cryogenic liquids in a closed or inadequately vented system
	Underwater vehicles	Impact
	Engine cylinders	Blast
		Container hit by fragments
		Failure or improper release of connectors
		Inadequate restraining devices
		Rapid submersion
		Deep submersion
		Water hammer (hydraulic shock)
Low	Vacuum systems	Compressor failure
	High altitude vehicles	Increase of altitude without pressure relief
	Space vehicles	Inadequate design against collapsing forces
		Increase in altitude without suitable respiratory equipment
		Rapid condensation of gas in a closed system
		Decrease in gas volume by combustion
		Cooling of hot gas in a closed system
Rapid Changes	High altitude vehicles	Rapid expansion of gas
	Space vehicles	High gas compression
	Underwater vehicles	Rapid changes of altitude
	Compressing or pumping equipment	Loss of cabin pressurization at high altitudes or in space
	Airfoils	
	Carburetors	

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TABLE 9-22. BASIC CAUSES OF SAFETY HAZARDS (CONT'D)

HAZARD	OCCURRENCES	POSSIBLE CAUSES
RADIATION (Energy density, Btu/ft^2; w/cm^2)		
Thermal (Infrared)	Any heat producing body or process	Solar radiation Flames Highly heated surface
Electromagnetic	Radar equipment Communication	Radar equipment operation Communications equipment operation
Ionizing	Radioactive materials X-ray equipment Radar equipment Communications equipment Nuclear weapons	Inadequate containment of radioactive materials Inadequate protection of equipment Excessive exposure to ionizing source
Ultraviolet	Electrical welding processes Light sources	Sunshine Welding arcs Germicidal lamps
REPLACEMENT, CHEMICAL	Fluorine and water Sodium and water Nitric acid and water	Replacement of a chemical radical by a more active one
SHOCK (Impact energy, lb/ft^2. Load, lb/g's)	Any part or piece of equipment	Impact Handling and transportation damage Blast Pneudraulic actuated devices Acceleration Electro-explosive detonating devices Water hammer Vibrations caused by heavy equipment

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TABLE 9-22. BASIC CAUSES OF SAFETY HAZARDS (CONT'D)

HAZARD	OCCURRENCES	POSSIBLE CAUSES
STRESS CONCENTRATIONS	Any load carrying part or solid material	Sharp corners, especially at line where two right angle planes meet Residuals caused by manufacturing processes such as machining, grinding, extruding, drawing Surface treatment such as shot peening, cold working, plating Assembly stresses caused by shrink or press fits, torquing Surface roughening due to corrosion, chemical action, abrasion, erosion Notch sensitivity due to scratches or blows Temperature variations on poor conductors due to heating, cooling, or heat treatment Welding arc start indentations Cyclic changes in stress from tension to compression Wide variations in temperature Change from high pressure to vacuum (or vice versa) without suitable equalization
STRESS REVERSALS (Frequency, cps, Hz)	Vibrating or oscillating equipment Flexing panels Cryogenic equipment High temperature equipment Vacuum equipment	Cyclic changes in stress from tension to compression (or vice versa) Wide variations in temperature Change from high pressure to vacuum (or vice versa) without suitable equalization
STRUCTURAL DAMAGE OR FAILURE (Total load, lb; Unit load, lb/in^2; Moment, in.-lb; Torque, lb-in.)	Any part, piece of equipment, vehicle, structure, container, or connector	Impact and shock: Blast Rough handling Object dropped on hard surface Hard object dropped on vulnerable part Momentum against hard object (collision) Moving object hitting vulnerable part Rotating part hitting foreign object Inadequate design strength Overloading Reduction of strength by: Corrosion Stress concentrations Poor workmanship Crimping

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TABLE 9-22. BASIC CAUSES OF SAFETY HAZARDS(CONT'D)

HAZARD	OCCURRENCES	POSSIBLE CAUSES
STRUCTURAL DAMAGE OR FAILURE (continued)		Excessive centrifugal force Overpressures due to internal or external fluids Poorly fitted or inadequately tightened parts Overtorquing Loss of strength due to high temperatures Expansion and distortion of parts due to heating Brittleness and loss of ductility due to cold Exposure to aerodynamic loads High accelerations Chafing of parts caused by vibration or other motion Fatigue due to vibration Cutting or punching by sharp pointed objects
TOXICITY (Concentration, ppm.: Dosage, mg/l.)	Any substance whose presence in relatively small amounts will produce physiological damage or disturbance Any situation where a lack of breathing oxygen may exist	Toxic gases, liquids, or metal particles Inadequate oxygen present for respiration: High altitudes Dilution by inert gases Combustion involving oxygen Lack of ventilation in occupied space Inadequate respiratory protection Inadequate skin protection Inadequate personal cleanliness Accidental ingestion Outgassing of substance at low ambient pressures
VIBRATION AND NOISE (Frequency, cps, Hz: Noise level, db)	Any type of mechanical equipment or parts	Rotating or reciprocating equipment Transportation Engine exhaust Flutter or buzz of aerodynamic surfaces Water hammer (hydraulic shock) Vibrating tools Misalignment of equipment, loose mountings Worn bearings High velocity fluid hitting a surface or object which can vibrate Cavitation in pumps and blowers

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TABLE 9-22. BASIC CAUSES OF SAFETY HAZARDS (CONT'D)

HAZARD	OCCURRENCES	POSSIBLE CAUSES
WEATHER AND ENVIRONMENT (Relative humidity, %; Absolute humidity, gr/ft^3; Wind velocity, mph; Contaminants, mg/m^3; Temperature, °F)	Any exposed location	Moisture: Rain Clouds Fog Snow: Hail Extreme cold Extreme heat Solar radiation High winds Inversion Airborne salts, dust, dirt, fungi Lightning

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9-10 INSPECTION

Inspection is an element affecting producibility in a very basic manner since some of the techniques for inspecting a finished product are dictated by the material selected for its manufacture.

The paragraphs which follow describe some nondestructive testing procedures, all of them suitable for revealing material defects often encountered in manufacturing. Only a summary of the basic advantages and limitations of the most sensitive nondestructive tests is presented here for general consideration. Detailed information relating to the procedures, limitations, hazards, interpretation, and reference standards appropriate to the proper selection of nondestructive testing methods can be found in inspection guides, specifications, and manufacturing concern publications.

9-10.1 MAGNETIC PARTICLE TESTING

Magnetic particle testing, although not a thorough inspection, provides rapid visual indication of discontinuities at and below the surface to a depth of one-third or more of the thickness of the part. It is limited to those materials which will support magnetism (ferromagnetic materials). Limited areas only can be inspected at each application, and orientation of application is necessary since defects parallel to the magnetic field may be missed. Parts can be damaged by arcing or heating and caution must be exercised in applying the technique.

The visual reaction is the attraction of fluid particles or dry powder to the magnetic leakage field directly over the defect or discontinuity.

9-10.2 RADIOGRAPHY

Radiography (with an adequate energy source) provides relatively unlimited penetration. It provides a reasonably accurate shadow image of the interior of a material. Surface preparation is not critical, yet, the process allows a high degree of sensitivity. Permanent images are readily obtainable and a wide choice of equipment is available.

Both sides of the material must be studied, and careful alignment of the source and the registering media is required. The technique is unable to detect material weaknesses not caused by density differences; it will not resolve fine cracks, laminations, or segregations unless they are within a few degrees of the incident beam. Radiography methods and processing are critical, and interpretation of the results requires a knowledge of materials, techniques, and standards. High voltage and radiation sources must be monitored, and the equipment needed requires constant maintenance.

9-10.3 ULTRASONIC TESTING

Ultrasonic testing, which has a material penetration ability corresponding to the sound transmission index of the material, provides rapid visual indications of laminations, cracks, or other discontinuities presenting an interface perpendicular or angular to the axis of the transmitted sound beam.

Ultrasonic tests are limited to situations requiring the examination of objects which can be fluidly coupled to the generating surface, and surface preparation is critical for surface contract methods. The search unit must conform to the test surface, and an adequate couplant must be employed or the test objects must be adapted for immersion in a liquid. Ultrasonic testing fails to resolve discontinuities parallel to the sound beam. Both sides of the material must be essentially parallel, or extensive experience must be had with parts which can be sectioned in order to establish the standard pattern for that part.

Ordinary ultrasonic tests lose indications within the first 5/8-inch of transmission, and occasionally lose indications beyond the first major defect. Special techniques developed have reduced these limitations. However, experienced interpretation of the test results is mandatory. Images can be photographed or instrument recorded for test documentation purposes.

9-10.4 PENETRANTS

Penetrant tests, which disregard material size of shape, develop high contrast indications of discontinuities which are open to the surface of the material. Orientation of application is not necessary.

Penetrant tests are limited to the detection of surface discontinuities, as well as to a minimum depth/width ratio of 10:1. Surface preparation is quite critical, and the test procedures must be carefully controlled to avoid developing false indications. Penetrant tests inspect one side of the material only with each application, and indications must be photographed if they are to be recorded.

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Zyglo* penetrant is a method whereby detection is accomplished only by black light, and only surface ruptures or discontinuities are revealed. Zyglo penetrant inspection can be performed on magnetic or nonmagnetic materials.

9-11 CANDIDATE MATERIALS

Table 9-23 contains a list of parts and components, together with identification of some materials which have been used in their fabrication. While no listing can be all inclusive, the information the table conveys is considered appropriate for the designer seeking to select materials suitable to his design problem. It is a starting point, indicating an approach to constructing a similar tabulation restricted to components of immediate interest to the designer.

Tables 9-24 and 9-25 contain design problems and production problems that specifically pertain to materials, as discussed in Chapter 5. These tables supplement Table 5-1.

*Trade name, fluorescent penetrant, Magnaflux Corp., Chicago, Ill.

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8. Irving N. Sax, *Dangerous Properties of Materials,* Reinhold Publishing Corp., New York, N.Y., 3rd Ed., 1968.
9. *Code of Federal Regulations, Title 49, Transportation,* Parts 0 to 190, Office of the Federal Register, National Archives and Records Service, General Services Administration, Washington, D.C., January 1968. (Available from Government Printing Office, Washington, D.C)
10. *System Safety Hazard Analysis,* Directorate of Aerospace Safety, Deputy Inspector General for Inspection and Safety, U.S. Air Force, Norton AFB, California.

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS

AIR DUCTS

Synthetic: Rayon Vicose

AIRCRAFT ENCLOSURES
Transparent

Cast, molded or extruded acrylics: GP Types I & II

AIRCRAFT SHROUD ASSEMBLIES

Cast Stainless Steels: CF-8C

AIRCRAFT SKINS
High strength-weight ratio, corrosion resistance, high temperature

Wrought Age Hardenable Stainless Steels: W, 17-4 PH, 17-7 PH

AIRCRAFT STRUCTURAL PARTS

Cast magnesium alloys: ZE 41A-T5, ZK 51A-T5, ZH 62A-T5, K1A-F, ZK 61A-T6, QU 22A-T6, EZ 33A-T5, HK 31A-T6, HZ 32A-T5, AZ 63A, AZ 81A, AZ 91, AZ 291B, AZ 91C, AZ 92A, AM 100A

Wrought magnesium alloys: ZE 10A-H24, AZ 31B-H24, HK 31A-H24, HM 21A-T8, HM 31A-T5, AZ 31B-F, AZ 61A-F, AZ 80A-T5, ZK 60A-T5, AZ 10A-F

Wrought aluminum alloys: 7075, 7079, 7178

Cast aluminum alloys: C 355, A 356, 327

Wrought beryllium

High strength-weight ratio

Wrought Titanium alloys

High strength, high temperatures

Wrought ultra-high strength steels: Modified H-11

Wrought low alloy steels: 4130, 4140, 4150

Wrought or cast nickel base superalloys: Unitemp 1753, M-252

High strength

Molded epoxy laminates: Woven fabric

AMMUNITION COMPONENTS

Wrought copper alloys: 260 (Cartridge brass, 70%)

ARC BARRIERS
High temperature

Molded silicone laminates: Woven fabric

ARMOR

Wrought magnesium alloys: LA 141 A-T7

ARTILLERY SHELL BODIES

Malleable Cast Iron-Pearlitic: 48004, 50007, 53004

AXES

Carbon steel: C 1095

Alloy steel: 9255, 9261

AXLES

Wrought low alloy steels: 1340, 4130, 4140, 4150, 5140, 5150, 6150, 9255

AXLE HOUSINGS

Cast aluminum alloys: 356

BAFFLES
Hot air

Molded phenolic laminates: Glass fabric, asbestos fiber

BAGS
Airtight

Molded polyvinyl alcohol

BALL FLOATS

Wrought Copper alloys: CDA No.'s 110, 113, 114, 116 (Tough Pitch Copper)

BALLOONS

Molded or extruded rubber Polysulfide

BATTERY CAPS

Wrought copper alloy: CDA No. 240 (low brass, 80%)

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

BATTERY CASES

Molded or extruded modified polystyrenes: Heat and chemical resistant

BATTERY CLAMPS

Leaded yellow brass: BBII Grade 6B

BATTERY PARTS

Molded or extruded polyethylenes

BATTERY SEPARATORS

Synthetic felts: Acrylic

BEARINGS

Cast tin alloys: SAE Grades 10 & 12, See QQ-M-161 & ASTM B-23-61 or ASTM B105-52

Cast tin-lead-antimony alloys: QQ-T-390 SAE Grades

Cast copper-base alloys: Tin Bronzes, High Leaded Tin Bronze, High Strength Yellow Brass, Aluminum Bronze, Silicon Brass, Silicon Bronze

Copper alloys: CDA No.'s 172 (beryllium copper), 544 (phosphor bronze free-cutting)

Cast aluminum alloys: 122

Molded or extruded nylons

Molded or extruded acetal plastics: Acetal homopolymer, acetal copolymer

Molded or extruded carbon, graphite

Molded or extruded fluorocarbons: Ceramic reinforced (PTFE), Polytetrafluoroethylene (PTFE)

Silver, Wrought

Stainless Steel: ACI Type CF-16F

Carbon steels: C1117, C1118

BEARING ADAPTERS

Malleable cast iron-pearlite: 60003, 80002

BEARING CAPS

Cast aluminum alloy: Type 122

BEARING PLATES
Bridge

Wrought copper alloys: CDA No.'s 510, 521 (phosphor bronze EB)

BELTS

Molded or extruded rubber: Polybutadiene

High temperature

Chlorosulfonated polyethylene

Ozone resistant

Ethylene, propylene

Power transmission & conveyor

Natural rubber, Butadiene-styrene, Polyisoprene

BOAT HULLS
Small

Molded polyester laminates: Spray-up mat, Preform, Woven fabric

BOILERS

Cast nickel alloys: Monel 411 (Monel), Monel 505 (S Monel)

BOLTS

Wrought low alloy steels: 1340, 4130, 4150, 9255

Carbon steels - hardening grades: C 1030, C 1040, C 1050

Leaded Tin Bronze: BBII Grade 2C

Wrought copper alloys: CDA No.'s 464, 465 466, 467 (naval brass), 614 (Al Bronze D)

Large

CDA No.'s 280 (Muntz metal), 639 (Al-Si Bronze)

Heavy Duty

Wrought alloy steels: AISI No.'s 8620, 8630, 8640, 8650, 9255, 9261

High strength

Nickel-chromium-molybdenum steels: 8640, 8740, 8655, 8750

High strength, high heat, steam turbine

Wrought iron base superalloys (Cr-Ni): 19-9 DL, Unitemp 212, W 545, D-979, AMS 5700

High temperature

Wrought or cast nickel-base superalloys: Unitemp 1753, M-252

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

BOLTS
Hot or cold worked

Carbon steels: C 1015, C 1020

BRAKE DRUMS

Nodular or ductile cast irons: Type 100-70-03

Lightweight

Cast gray iron: Type 30

Aircraft

Cast aluminum alloys: Type 218

High strength, high heat

Cast gray iron: Type 40

BRAKE SEALS
Automotive, aircraft & missile

Molded or extruded rubber: Polytrifluorochloroethylene

BRUSHES
Electrical machinery

Molded or extruded carbon, graphite: General purpose, Premium

BULLET JACKETS

Wrought copper alloys: CDA No. 210 (Gilding, 95%)

BURNER SUPPORT RINGS
Jet Engine

Nodular or ductile cast irons: Type 80-55-06

BURNER TIPS

Cast heat resistant ferrous alloys: ACI Type HF

BURNER TUBES

Cast heat resistant ferrous alloys: ACI Type HU

BUSHINGS

Cast nickel alloys: Monel 411 (Monel) Monel 505 (S Monel)

Cast copper-base alloys: Tin bronze BBII grades 1A, 1B, 3A, 3B

BUSHINGS

Wrought copper alloys: CDA No. 172 (Beryllium copper), CDA No. 544 (phosphor bronze free-cutting)

Nitriding steels: Type 135, 135 modified, N, EZ, 5Ni-2Al

Cast stainless steels: ACI type CF-16F

Molded or extruded nylon

Molded or extruded acetal plastic

Fired mechanical or electrical ceramics: Alumina

Feed-through

Fired mechanical or electrical ceramics: Steatite

Corrosion resistant

Molded or extruded fluorocarbons: Ceramic-reinforced (PTFE)

Low pressure

Molded olefin copolymers: Ethylene ethyl acrylate (EEA), ethylene vinyl acetate (EVA)

Sleeve

Wrought copper alloys: CDA No's. 510 (phosphor bronze A), 521 (phosphor bronze B)

CABLE BRAIDING
Armor

Wrought aluminum alloys: 5056

CABLE CONNECTORS

Wrought copper alloys: CDA No. 651 (Low Si Bronze B)

CABLE JACKETING
Electrical

Molded or extruded rubber: Butadiene-acrylonitrile

Molded or extruded fluorocarbons: Poly trifluorochloroethylene (PTFCE)

Plastic foams: Cellular Polyethylene

Nylons: 6/10

CABLE SHEATHING

Wrought or cast lead alloy: Common lead (soft lead) 1% Sb-Lead

CAMS

Nodular or ductile cast irons: Type 80-55-06 or 120-09-02

Malleable cast iron-pearlitic: Grades 48004, 50007, 53004, 60003, 80002

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

CAMS

Wrought copper alloys: CDA Type 172 (beryllium copper)

Nitriding steels: Type 135, N, EZ, 5Ni-2Al

Heavy duty, carburized

8620, 8720, 8630

Wrought low alloy steels: AISI Types: 8620, 8630, 8650, 8740

CAMSHAFTS

Nodular or ductile cast irons: Type 100-70-03

Carbon steels - hardening grades: AISI C 1030, C 1040, C 1050

Nitriding steels: Types 135, N, EZ, 5Ni-2Al

Case hardened

Carbon steels - carburizing: Grades AISI C 1015, C 1020

CAPACITORS

Wrought tantalum

Molded or sheet mica: Natural muscovite

Molded alkyds

Industrial glass: Potash lead

CARBURETORS

Leaded red brass: BB11 Grade 4B

Cast aluminum alloys: Type 43

CIRCUIT BREAKERS

Molded melamines

CIRCUIT BREAKER COVERS

Molded alkyds: Granular (general purpose), Glass-reinforced (high impact)

CLUTCH DISKS

Wrought copper alloys: CDA No's. 510 (phosphor bronze A), 521 (phosphor bronze B), 655 (high Si Bronze A), 675 (manganese bronze A)

CLUTCH PLATES

Cast gray iron: Type 30

COIL FORMS
High shock and burning resistance

Molded melamines: Glass fiber reinforced

COIL SPRINGS

Wrought low alloy steels: AISI 4063, 4620, 5140, 5150, 9255, 9261

Carbon steels-hardening grades: C 1060, C 1080

Molded epoxy laminates

COILED TUBES

Wrought aluminum alloys: 5050

COLD DRAWING DIE

Wrought special purpose tool steels: Carbon tungsten F 1, F 2, F 3

COMPRESSOR BLADES
High temperature, high damping capacity

Cobalt alloys: Nivco

High strength, high temperature

Wrought high temperature steels: 1415 NW (Greek Ascoloy), 1430 (Lapelloy), 14 DVM (Chromoloy), 17-22 AS (14 MV)

COMPRESSOR BODIES

Cast gray iron: Type 30, 40

CONDENSERS

Wrought iron

Cast nickel alloys: Nickel 210

Wrought copper alloys: CDA No's. 442, 443, 444, 445

Molded epoxies

CONDENSER CANS

Wrought zinc alloys: Commercial rolled, Copper hardened rolled alloy, Rolled zinc alloy of Mg or Ti

CONDENSER PLATES

Wrought copper alloys: (Muntz metal) CDA No. 280; Naval brass CDA No's. 464, 465, 466, 467; CDA 706 (cupro-nickel, 10%); CDA 710 (cupro-nickel, 20%); CDA 715 (cupro-nickel, 30%); (Leaded Muntz metal) CDA No's. 365, 366, 367, 368; (Admiralty) CDA No's. 442, 443, 444, 445

CONNECTING RODS

Carbon steels-hardening grades: AISI C 1030, C 1040, C 1050

Malleable cast iron-pearlitic: Types 60003, 80002

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

CONNECTORS
Aircraft firewall

Fired ceramics: Cordierite

CONNECTOR INSERTS

Molded or extruded fluorocarbons: Polytrifluorochloroethylene (PTFCE)

CONNECTOR PLUGS

Molded epoxies, molded silicones

Aircraft firewall

Fired ceramic: Zircon

CONTAINERS

Molded or extruded polypropylenes

Molded or extruded celluose acetate butyrate plastics: ASTM Grades H4, MH, or S2

Molded ureas: ASTM Type 1

Rigid

Molded or extruded polystyrenes

CONVEYOR BELTS

Molded or extruded rubber: Natural rubber, Butadiene-styrene, Synthetic rubber

Chemical

Molded or extruded polyvinyl chloride copolymer: Vinylidene chloride

COTTER PINS

Wrought copper alloys: CDA 510 (phosphor bronze A), CDA 521 (phosphor bronze B)

COVERS

Molded or extruded polystyrenes: Glass fiber-filled
High temperature, high frequency

Molded silicone laminates: Woven fabrics

Pipe

Rigid plastic foams: Polystyrene

CRANES

Wrought high strength steels (Columbium or Vanadium Alloys)

Wrought aluminum alloys: 5456

CRANKCASES

Cast aluminum alloys: 195

CRANKSHAFTS

Nodular or ductile cast irons: 80-55-06

Carbon steels: AISI C 1030, AISI C 1040, AISI C 1050

Malleable cast iron-pearlitic: ACIS 60003, ACSI 80002, 45010, 45007

CRASH PADDING

Flexible plastic foam: Preformed Urethane

CUSHIONING

Flexible plastics or rubber foams: Silicone, Urethane, Butadiene-styrene, Urethane

Oil resistant

Neoprene

CUTTING BLADES

Wrought martensitic stainless steels: 414

CYLINDERS
High pressure

Cast gray iron: 60

Power or pump

Wrought copper alloys: 330 (low-leaded brass tube)

CYLINDER BLOCKS

Cast gray iron: AISI 30, 40

CYLINDER HEADS

Cast gray iron: ACSI 30, 40

Cast aluminum alloys: Types 122, 142, 355, 319

CYLINDER LINERS

Cast stainless steels, ACI Type CA-40, CC-50, CF-20

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

CYLINDER LINERS

Aircraft engines

Nitriding steels: 135, 135 modified, N, EZ, 5Ni2Al

DAMPENERS, SHOCK

Where felt is required

Wool felt, SAE F-5 Grade 12R1

DAMPENING PADS

Molded olefin copolymers: Ethylene ethyl acrylate (EEA), Ethylene vinyl acetate (EVA)

DAMPERS

Case heat resistant ferrous alloys: ACI Type HF

DIAPHRAGMS

Molded polyvinyl alcohol

Wrought copper alloys: 172 (Beryllium copper), 510 (phosphor bronze A), 521 (phosphor bronze C), 770 (55-18)

Molded or extruded rubber: Polysulfide, Silicone, Polytrifluorochloroethylene

Carburetor

Molded or extruded rubber: Butadiene-acrylonitrile

Chemical and thermal resistant

Molded and extruded rubber: Vitol

Steam

Molded and extruded rubber: Butyl

Valve

Molded or extruded fluorocarbons: Polytrifluorochloroethylene (PTFCE)

DIES

Nodular or ductile cast irons: AISI Types: 80-55-06 or 120-90-02

Wrought cold work - medium alloy tool steel: AISI Types A2, A4, A5, A7, A8, A10

Wrought cold work - oil hardening tool steels: AISI Types 01, 02, 06, 07

DIES

Wrought hot work molybdenum tool steels: AISI Types H41, H42, H43

Wrought hot work tungsten tool steels: AISI Types H20, H21, H22, H24, H25, H26

Wrought low alloy tool steels: AISI Types L1, L2, L3, L6, L7

Cast stainless steels: CA-40

Cast gray iron: 50

Hot forming

Cast gray iron: 60

Continuous casting

Molded or extruded carbon, graphite

Drop hammer

Cast zinc alloys: Types Ag40A (XXII), AC41A (XXV)

Low distortion

Wrought hot work chromium tool steels: AISI Types H10, H11, H14, H16, H19

Wear resistant

Wrought cold work high carbon, high chromium tool steels: AISI Types D1, D3, D4, D7

Shallow hardening, short run & shallow hardening, cold heading

Wrought water hardening tool steels: AISI Types W1, W2, W4, W5

Punching, shearing, and trimming

Wrought shock resisting tool steels: AISI Types S1, S2, S4, S5, S6, S7

DIFFERENTIAL HOUSINGS

Malleable cast iron-ferritic: 32510, 35018, 48004, 50007, 53004

DUCTS

Wrought aluminum alloys: 3003

Molded diallyl phthalates: Orlon, Dacron, Asbestos, or Glass fiber filled

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

DUCTS	FASTENERS
Cast heat resistant ferrous alloys: ACI Type HT	Wrought copper alloys: CDA 230 (red brass, 85%), CDA 260 (cartridge brass, 70%), CDA 268, CDA 270 (Yellow brass), CDA 314 (Leaded commercial bronze), CDA 332 (high-leaded brass tube), CDA 370 (free cutting Muntz Metal), CDA 485 (Leaded Naval brass), CDA 510 (phosphor bronze A), CDA 521 (phosphor bronze B)
Molded or extruded polyethylene	High conductivity
Molded phenolic laminates: Glass fabric or Asbestos fiber	Wrought copper alloys: CDA 145 (tellurium copper), CDA 147 (sulfur copper)
ELECTRICAL CONDUCTORS	High strength, mechanical
Wrought Copper Alloys: Tough Pitch Copper CDA No's. 110, 113, 114, 116	Wrought copper alloys: CDA 647 (precip. hard Si bronze
Wrought aluminum alloys: EC	Hot headed
ELECTRICAL CONTACTS	Wrought copper alloys: CDA 655 (high Si Bronze A)
Wrought copper alloys: 112 (beryllium copper), 502 (phosphor bronze E)	Slide
Wrought Tungsten	Wrought copper alloys: CDA 745 (65-10), 752 (65-18), 757 (65-12)
Wrought Molybdenum	High temperature
Wrought Silver	Wrought or cast nickel-base superalloys Unitemp 1753, M-252
Wrought Platinum	FILTERS
Wrought Palladium	Flexible plastic foam: Urethane 1-2
Wrought Osmium	Acid & solvent resistant, air
Voltage regulator	Synthetic felts: Acrylic, dacron polyester
Wrought Ruthenium	Jet air dust intake
ELECTRICAL HEATING ELEMENTS	Synthetic felts: Dacron polyester
Heat Resistant Ferrous Alloy: ACI Type HW	Water
ELECTRODE ARMS	Synthetic felts: Rayon viscose
Heat Resistant Ferrous Alloy: ACI Type HF	Chemical
EVAPORATORS	Molded or extruded carbon, graphite
Cast nickel alloy: Nickel 210 (Nickel)	Gas & air plug
FAN BLADES	Roll wool felt: SAE No. F10, Grade 9R1
Cast heat resistant ferrous alloys: ACI Type HA	FILTER BOWLS
FASTENERS	Oil
Wrought Aluminum alloys: 2011, 2017, 2024	Phenoxy plastic
Wrought free-cutting carbon steels: AISI Types B111, B1211, B1112, B1212, B1113, B1213	FILTER CARTRIDGES
	Fuel oil
	Synthetic felts: Rayon viscose

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

FITTINGS

Cast Copper base alloys: aluminum bronze, leaded nickel brass

Shock resistant, aircraft

Cast aluminum alloys: 220, 356

Aircraft

Cast aluminum alloys: 218; Wrought aluminum alloys: 2014

Aircraft compression

Wrought copper alloys: 639 (Al-Si Bronze)

Cast

Wrought copper alloys: 655 (high Si Bronze A)

Pressure pipe

Cast copper base alloys: 2C, 1A, 1B

Chemical

Molded or extruded fluorocarbons: polyvinylidene-fluoride (PVF)

Molded or extruded carbon, graphite: General purpose, Premium

Marine

Cast aluminum alloys: Type 218, 93

Cast Copper-base alloys: Leaded nickel bronze, silicon brass

Pipe

Nodular or ductile cast irons: AISI 60-40-18, AISI 60-45-12

Malleable cast iron-ferritic: AISI 32510, AISI 35018

Cast gray iron

Cast aluminum alloys: Type 43

Cast copper-base alloys: Leaded red brass

FLAME BARRIERS

Molded phenolic laminates: Glass fabric or Asbestos fiber

FLANGES

Cast copper-base alloys: Leaded yellow brass, BB11 Grade 6C

FLANGES
Forged pipe

Carbon steels-hardening grades: AISI C 1030, AISI C 1040, AISI C 1050

FLAT SPRINGS

Wrought low alloy steels: AISI 5140, AISI 5150, AISI 9255, AISI 9261

FLYWHEEL RING GEARS

Carbon steels - hardening grades: AISI C 1030, AISI C 1040, AISI C 1050

FUEL BURNER TIPS

Fired ceramic: Cordierite

FUEL IGNITERS

Fired ceramic: Steatite

FURNACES
High temperature strength, corrosion resistant

Wrought or cast nickel-base superalloys: Inconel X-750, Hastelloy B, Hastelloy C, Hastelloy X, Unitemp HX, Inconel 718

FURNACE BLOWERS

Cast heat resistant ferrous alloys: ACI Type HD

FURNACE CONVEYORS

Cast heat resistant ferrous alloys: ACI Type HE

FURNACE DOORS

Nodular or ductile cast irons

FURNACE GRATES

High silicon (Silal) cast irons

FURNACE RAILS

Cast heat resistant ferrous alloys: ACI Type HI

FURNACE ROLLERS

Cast Heat resistant ferrous alloys: ACI Type HA

FUSE BLOCKS

Molded Alkyds: Granular (general purpose), Glass-reinforced (high impact)

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

FUSE BLOCKS
Arc resistant, high shock, high frequency

Molded: Rubber phenolic (arc resistant)

FUSE CAPS

Wrought copper alloys: CDA No's. 219 (Gilding, 95%), 510 (phosphor bronze A), 521 (phosphor bronze B)

FUSE WIRES

Wrought iridium

GAS BURNER RINGS

Cast heat resistant ferrous alloys: ACI Type HF

GAS TURBINES

Wrought austenitic stainless steels: AISI 310, AISI 310S

Wrought iron-base Cr-Ni superalloys: 16-25-6

GAS TURBINE BLADES
High heat

Wrought or cast iron-base superalloys (Cr-Ni-Co): Multimet, N-155, Refractaloy 26, S-590, 19-9 DL

High temp, aircraft

Wrought or cast nickel-base alloys: Inconel 713, IN-100

GAS TURBINE BUCKETS
High temp, aircraft

Wrought cobalt-base superalloys: J-1570

GAS TURBINE VANES
High heat

Wrought or cast iron-base superalloys (Cr-Ni-Co): Multimet, N-155, Refractaloy 26, S-590, 19-9DL

High temp, aircraft

Wrought or cast nickel-base superalloys: Inconel 713, IN-100

GASKETS

Roll wool felts: SAE SPEC NO. F-2 Grade 16R2

GASKETS

Industrial paper: Fiber paper board

Molded or extruded fluorocarbons: Polytrifluorochloroethylene (PTFCE), Polytetrafluoroethylene (PTFE), Polyvinylidenefluoride (PVF)

Molded polyvinyl alcohol

Molded or extruded rubber: Polysulfide, Silicone, Polybutadiene, Natural rubber, Butadiene-styrene, Synthetic rubber, Butadiene-acrylonitrile

Automotive, aircraft, and missile

Polytrifluorochloroethylene

Chemical, thermal resistant

Molded or extruded rubber: Vinylidene fluoride-hexafluoropropylene

Extreme pressure lubricant, oil containing sulfur

Polyacrylate

High temperature oil, solvent resistant

Fluorosilicone

Search light

Polyacrylate

Chemical resistant

Synthetic felts: Acrylic

Corrosion resistant, high temperature

Teflon fluorocarbon

Sound absorbent

Rayon viscose

Corrosion resistant

Molded or extruded fluorocarbons: Ceramic-reinforced

GEARS

Nodular or ductile cast irons: 100-70-03, 120-90-02

Malleable cast iron-pearlitic: 60003, 80002

Wrought low alloy steels: 4130, 4140, 4150, 4620, 6150

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

GEARS

Cast copper-base alloys: Tin Bronze BBII Grades 1A & 1B; Leaded Tin Bronze BBII Grades 2C; Hi-Str Yellow Brass BBII Grades 7A & 8C; Al Bronze, BBII Grades 9A, 9B, 9C & 9D; Si Bronze BBII Grade 13B

Wrought copper alloys: CDA No's. 340 (Medium-leaded brass), 342 (high-leaded brass), 353 (high-leaded brass), 356 (extra-high-leaded brass), 360 (free-cutting brass), 544 (phosphor bronze, free-cutting), 639 (Al-Si bronze)

Carbon steels-hardening grades: AISI C 1030, AISI C 1040, AISI C 1050, AISI C 1095

Molded or extruded nylons: Type 6n, 6/6

Molded or extruded acetal plastics: Acetal homopolymer, Acetal copolymer

Heavy duty

Wrought low alloy steels: 8620, 8630, 8640, 8650, 8720, 8740, 8750, 4820, 4320, 4340

Slide

Wrought low alloy steels: 5140, 5150

Larg

Cast gray iron: 50

Timing

Cast aluminum alloys: 355

Carbon steels-carburizing grades: C 1117, C 1118

Transmission

Wrought low alloy steels: 5140, 5150

Malleable cast iron-pearlitic: 48004, 50007, 53004, 60003, 80002

GEAR BOXES

Cast gray iron: Class 30

GEAR HOUSING

Nodular or ductile cast irons: Grade 60-40-18, Grade 60-45-12

Cast aluminum alloys: Type B 195

GLASS MOLDS

Nodular or ductile cast irons

Cast heat resistant ferrous alloys: ACI Type HT

Wrought ferritic stainless steels: AISI Type 446

GOGGLE LENSES

Protective

Molded acrylics: Grades 5, 6, 8

GRATE BARS

Cast heat resistant ferrous alloys: ACI Type HC

GRATE BOXES

Nodular or ductile cast irons

GREASE RETAINERS

Roll wool felts: SAE SPEC NO. F6 or F7, Grades 12R2, 12R3

HAIRSPRINGS

Wrought low-expansion nickel alloys: Ni-Span-C902

HAMMERS

Carbon steels-hardening grades: C 1095

HAND TOOLS

Malleable cast iron-ferritic: 32510, 35018, 48004, 50007, 53004

Wrought magnesium alloys: AZ 31B-F, AZ 61A-F, AZ 80A-T5, ZK 60A-T5, AZ 10A-F

Cast magnesium alloys: AZ 63A, AZ 91, AZ 291B, AZ 92A, AM 100A, AZ 91C, AZ 81A

HANDLES

Molded phenolics

HEAT EXCHANGERS

Wrought austenitic stainless steels: AISI 310, AISI 310S

Cast stainless steels: ACI CN-7M

Wrought aluminum alloys: Type 1100, 3003

Wrought copper alloys: CDA 655 (high Si Bronze A)

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TABLE 9-23. RANDOM LISTING OF SOME ANDIDATE MATERIALS (CONT'D)

HEAT EXCHANGERS
Chemical resistant

Molded or extruded carbon, graphite

HEAT SHIELDS

Wrought tantalum: Tantalum-10W

HEATER CORES
Automotive

Fired ceramic: Cordierite

HEATING COILS

Cast stainless steels: ACI CF-3, ACI CF-8

Cast nickel alloys: Nickel 210

HINGES

Wrought copper alloys: Architectural bronze CDA 385

HOSES

Molded or extruded rubber

Aircraft, gasoline, oil

Butadiene acrylonitrile

Automotive, aircraft, & missiles

Polytrifluorochloroethylene

Flexible chemical & petroleum

Chlorosulfonated polyethylene

Oil

Polyacrylate

Ozone resistant

Ethylene, Propylene

Steam

Butyl

Flexible Metal

Wrought copper alloys: CDA 230 (Red brass, 85%), CDA 502 (phosphor bronze E)

HOUSINGS

Phenoxy plastics

HOUSINGS

Molded diallyl phthalates: Orlon, Dacron, Asbestos or Glass fiber-filled

Molded or extruded polypropylenes

Molded or extruded polystyrenes: Glass fiber-filled or heat and chemical resistant

HYDRAULIC ACCUMULATORS

Molded or extruded rubber: Urethane

HYDRAULIC CYLINDERS

Cast gray iron: Class 60

HYDRAULIC VALVES

Cast gray iron: Class 60

IGNITION PARTS

Molded alkyds: Granular (general purpose), Putty (electrical), Glass-reinforced (high impact)

IGNITION SYSTEMS
Aircraft

Molded silicones: General-mineral, Glass fiber, High impact - glass fiber

IMPELLERS

Nodular or ductile cast irons: Class 80-55-06

Cast stainless steels: CIA Type CA-15, CC-50

Heat & corrosion resistant

High nickel (Ni-Resist) Cast irons: Heat & corrosion resistant

Cast copper-base alloys: Tin Bronzes, Silicon Brass, Silicon Bronze

Molded or extruded fluorocarbons: Polytetrafluoroethylene (PTFE)

Aircraft supercharger

Cast aluminum alloys: Type 355

Corrosion, erosion resistant, pump

Cast stainless steels: ACI Type CD-4MCu

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

IMPELLERS Pump	**INSULATION** Wire
Cast copper-base alloys: Aluminum Bronze; BBll Grade 9A, 9B, 9C, 9D	Molded olefin copolymers: Ethylene butene, Propylene ethylene
Molded or extruded polycarbonate plastics: Polycarbonate (glass filled); stainless steel, martensitic AISI Type 920	Wire & cable
INSTRUMENTS Surgical	Molded or extruded polyethylene
Wrought copper alloys: CDA No. 770, Type 55-18	Molded olefin copolymers: Ethylene butene, Propylene ethylene
INSTRUMENT CASINGS	Electrical
Cast phenolics	Molded olefin copolymers: Ethylene ethyl acrylate (EEA), Ethylene vinyl acetate (EVA)
INSTRUMENT DIALS	Industrial glass: Borosilicate
Wrought copper alloys: 340 (medium-leaded brass)	Oil resist., electrical
INSTRUMENT PANELS	Molded or extruded rubber: Chloroprene
Molded phenolics: Arc resistant	Ozone resist., electrical
Molded or extruded polystyrenes: General purpose or Glass fiber-filled	Molded or extruded rubber: Ethylene, Propylene
INSTRUMENT PIVOTS	Car and truck
Wrought Osmium	Roll wool felts: SAE SPEC F-13, F-15, Grades 9R4, 9R5
INSTRUMENT PLATES	High frequency
Wrought copper alloys: 340 (medium-leaded brass)	Molded or extruded polyethylenes
INSULATION	Low moisture, absorption, electrical
Molded or extruded fluorocarbons: Polytrifluorochloroethylene (PTFCE)	Molded or extruded nylons
Roll wool felts: SAE SPEC F-11 Grade 9R2	Low temp., power wire
Synthetic felts: Dacron polyester	Molded or extruded polyvinylchloride or copolymers: Nonrigid-electrical
Industrial papers: Fiber paper board, Fiber board, Insulation paper	Motor mount
Building panel core	Synthetic felts: Rayon viscose
Rigid plastic foams: Phenolic	**INSULATORS**
Thermal	Molded diallyl phthalates: Orlon filled, Dacron filled, Asbestos filled, Glass fiber filled
Urethane, Silicone	Molded or extruded polystyrenes: General purpose
Flexible plastics or rubber foams: Silicone	

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

INSULATORS Corrosion resistant, electrical	**JACKETING** Wire
Molded or extruded fluorocarbons: Ceramic-reinforced	Molded and extruded nylons: Type 610
Electric line	**JAW CRUSHER PLATES**
Fired ceramics: Steatite	High chromium and molybdenum cast irons
High frequency	White cast irons
Alumina	**JET ENGINES** High temp, strength, and corrosion resistant
High temperature	Cast stainless steels: ACI-CK-20
Refractory Mullite	Wrought or cast nickel-base superalloys: Inconel X-750, Hastelloy B, Hastelloy C, Hastelloy X, Unitemp HX, Inconel 718, Udimet 500, Udimet 700, Waspaloy, Nicrotung, Rene-41, R-41
High voltage	Thermal shock resistant
Standard electrical	Cast cobalt-base superalloys: HS-21
Hot point	**JET ENGINE BLADES** High temperature
Cordierite	Wrought or cast nickel-base superalloys: Inconel 700
Low voltage	**JET ENGINE DISKS**
Standard electrical	Wrought iron-base superalloys (Cr-Ni): Incoloy 901
Suspension	**JOURNAL LUBRICATING PADS** Railroad
Standard electrical	Flexible plastics or rubber foams: Neoprene, Butadiene-acrylonitrile
Electrical	**JOURNAL LUBRICATORS**
Molded or extruded rubber: Butyl	Roll wool felts: SAE SPEC F-6, Grade 12R2
High & low temperature, electrical	**LAMP FILAMENTS**
Silicone	Wrought tungsten
High shock resistance, good electrical properties, high resistance to burning, standoff	**LANDING GEARS**
Molded melamines: Glass fiber reinforced	Wrought aluminum alloys: 5083
High temperature, high stability	High strength
Mold or sheet mica: Ceramoplastic, Glass bonded mica	Wrought ultra high strength steels: MX-2, 300-M, D-6A
JACKETING Electrical	High strength, high temperature
Molded or extruded fluorocarbons: Polyvinylidene fluoride (PVF)	Modified H-11
Low temperature power line	
Molded or extruded polyvinyl chloride and copolymers: Nonrigid - electrical	
Ozone resistant, electrical	
Molded or extruded rubber: Ethylene, Propylene	

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

LANDING GEARS
High strength-weight ratio, good toughness

Wrought ultra high strength steels: 4340, 25 Ni, 20 Ni, 18 Ni

LEAF SPRINGS

Wrought low alloy steels: AISI 4063, AISI 4620

High Strength

Molded epoxy laminates: Woven fabric

LIFE RAFTS

Molded rubber: Polysulfide

LIFE VESTS

Molded rubber: Polysulfide

LIGHT LOUVERS

Phenoxy plastics

LIGHTING FIXTURES

Molded melamines; Alpha cellulose, gen. purpose

Cast zinc alloys: Slush casting alloy

LIGHTING ARRESTORS

Fired ceramics: Grade-standard electrical

LININGS

Wrought copper alloys : CDH-330 (low-leaded brass tube)

Cast nickel alloys: Monel 411 (Monel) Monel 505 (S. Monel)

Car & truck, protective

Roll wool felts: SAE SPEC F-13, F-15, Grade 9R4, 9R5

Chemical equipment

Wrought gold

Low tolerance, life, and quality

Roll sheet wool felts: SAE SPEC F-51, Grade No. 16R-3X

LUBRICATORS
Durable, resilient felt service

Roll wool felts: SAE SPEC F-5, Grade 12R-1

MACHINE HOUSINGS

Molded polyester laminates: Mat, Woven fabric

MACHINE TOOLS

Cast gray iron: Type 40, Type 50

MACHINERY PARTS

Cast gray iron: Type 30

MAGNETS

Cobalt alloys

Wrought martensitic stainless steels: 420

MANIFOLDS

Cast aluminum alloys: Type 108

Aircraft exhaust

Cast nickel alloys: Inconel 610 (Inconel), Inconel 705 (S Inconel)

Exhaust

Cast heat resistant ferrous alloys: Type HH

High nickel (Ni-resist) cast irons: Heat and corrosion resistan.

METEORITE SHIELDS
High energy absorption

Wrought magnesium alloys: LA 141A-T7

MIRROR BLANKS
Telescope

Fired ceramics: Polycrystalline, Glass 9608

MISSILE STRUCTURAL PARTS

Wrought aluminum alloys: 7039

Wrought beryllium

Cast magnesium alloys: AZ 63A, AZ 81A, AZ 91, AZ 291B, AZ92A, AM 100A, AZ 91C, QE 22A-T6, EZ 33A-T5, HK 31A-T6, HZ 32A-T5, ZE 41A-T5, ZK 51A-T5, KI A-K, ZK 61A-T6

Wrought magnesium alloys: ZE 10A-H24, AZ 31B-H24, HK 31A-H24, HM 21A-T8, HM 31A-T5, AZ 31B-F, AZ 61A-F, AZ 80A-T5, ZK 60A-T5, AZ 10A-F

High strength

Cast aluminum alloys: C 355, A 356, 327

High temperature

Wrought tantalum: Tantalum - 10W

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

MISSILE STRUCTURAL PARTS High temperature, strength, and corrosion resistance	**NOSE CONES**
Wrought or cast nickel base superalloys: Inconel X-750, Hastelloy B, Hastelloy C, Hastelloy X, Unitemp HX, Inconel 718, Udimet 500, Udimet 700, Waspaloy, Nicrotung, Rene-41, R-41	Molded polyester laminates: Spray-up mat, Preform
High temp, high strength	Molded diallyl phthalates: Orlon-Filled, Dacron-Filled, Asbestos-filled, Glass fiber-filled
Wrought Columbium alloys: C-103, B-66, CB-752, C-129	Molded or extruded carbon, graphite: Recrystallized graphite
MISSILE BALLASTS	Molded phenolic laminates: Glass fabric, Asbestos fiber
Wrought depleted uranium	**NOZZLES**
MISSILE BODIES	Cast nickel alloys: Monel 411 (Monel), Monel 505 (S Monel)
Molded epoxy laminates: Filament wound	Molded melamines: Fabric
MISSILE MOTOR HOUSINGS High strength - weight ratio, good toughness	Molded polyester laminates: Spray-up mat, Preform
Wrought ultra high strength steels: AISI-4340, 25 Ni, 20 Ni, 18 Ni	Burner
MOLDS	Cast heat resistant ferrous alloys: HN, HE
Cast stainless steels: CA-40	High heat, gas turbine
MORTAR TUBING High strength - weight ratio, good toughness	Wrought or cast iron-base superalloys (Cr-Ni-Co): Multimet, N-155, Refractalloy 26, S-590, 19-9DL
Wrought ultra high strength steels: AISI-4340 25 Ni, 20 Ni, 18 Ni	Rocket
MOTOR HOUSINGS	Wrought tungsten, molybdenum AVC (70Mo, 30W)
Molded phenolics	Wrought tantalum: Tantalum - 10W
MOTOR SLOT WEDGES	Molded or extruded carbon, graphite: Recrystallized graphite
Molded silicones: General-mineral, Glass fiber, High impact-glass fiber	Spray
MOVIE PROJECTOR PARTS	Cast stainless steels: CF-8M, CF-12M
Molded or extruded acetal plastics: Acetal homopolymer, Acetal copolymer	Cast copper-base alloys: 6B
MUNITION PRIMERS	**NUCLEAR FUEL SHEETING**
Wrought copper alloys: 330 (low leaded brass tube)	Wrought tantalum, tungsten, molybdenum: AVC, N-25 Re
	NUCLEAR MODERATORS
	Molded or extruded carbon, graphite: General purpose, Premium

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

NUCLEAR REACTORS

Wrought tantalum

Wrought beryllium

Wrought hafnium

Fuel cladding

Wrought zirconium alloys: Reactor grade, Zircalloy-2

NUCLEAR REFLECTORS

Wrought or cast lead alloys: Chemical lead, Common lead (soft lead), Tellurium lead

Molded or extruded carbon graphite: General purpose, Premium

NUCLEAR SHIELDS

Wrought or cast lead alloys: Chemical lead, Common lead (soft lead), Tellurium lead

Wrought lead alloys: 1% Sb-lead, 4% Sb-lead, 6% Sb-lead, 8% Sb-lead, 9% Sb-lead

OIL PUMP BODY

Cast gray iron: 30

OIL RETAINERS

Roll wool felts: 12R3

Sheet wool felts: 12S1, 12S2, 12S3, 12S4

ORDNANCE EQUIPMENT

Cast magnesium alloys: ZE 41A-T5, ZK 51A-T5, ZH 62A-T5, K 1A-F, ZK 61A-T6, AZ 63A, AZ 91, AZ 291B, AZ 92A, AM 100A, AZ 91C, AZ 81A

ORDNANCE VEHICLES

Wrought magnesium alloys: AZ 31B-F, AZ 61A-F, AZ 80A-T5, ZK 60A-T5, AZ 10A-F, ZE 10A-H24, AZ 31B-H24

O-RINGS

Molded or extruded rubber: Silicone

Automotive, aircraft, and missile

Polytrifluorochloroethylene

Extreme pressure lubricant oil containing sulfur

Polyacrylate

High temp oil, solvent resistant

Fluorosilicone

OUTLET BOXES

Fired ceramics: Standard electrical grade

PACKINGS

Molded or extruded fluorocarbons: Polytetrafluoroethylene (PTFE), Ceramic-reinforced

PNEUMATIC INNER TUBES

Molded or extruded rubber: Natural rubber, Butadiene-styrene, Synthetic rubber, Butyl

PNEUMATIC TIRES

Molded or extruded rubber: Polybutadiene, Natural rubber, Butadiene-styrene, Synthetic rubber

PINIONS

Nodular or ductile cast irons: 120-90-02

Carbon steels-hardening grades: C 1030, C [illegible], C 1050, C 1095

Wrought copper alloys: CDA-360 (free [illegible]), CDA-544 (phosphor bronze [illegible]), CDA-639 (Al-Si bronze)

PIPES

Wrought aluminum alloys: 6061, 6063

Cast stainless steels: CE-30

Molded or extruded nylons

Molded or extruded ABS resins

Extruded cellulose acetate butyrate plastics: ASTM Grades H4, MH, S-2

Air, gas, oil, and gasoline

Wrought copper alloys: CDA 122 (Phosphorus deoxidized copper)

Pump

CDA 240 (low brass, 80%)

Seamless

CDA 655 (high Si Bronze A)

Caustic, coolant, fresh water & steam condenser

Wrought iron

Chemical handling, irrigation systems, natural gas

Molded or extruded polyethylenes

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

PIPES

Corrosion resistant

Wrought lead alloys: 4% Sb-lead, 6% Sb-lead, 8% Sb-lead, 9% Sb-lead

Gas

Phenoxy plastics

Good toughness

Propylene-ethylene polyallomer plastics

High temp, corrosion resistant

Chlorinated polyether plastics

Steam

High nickel (Ni-Resist) cast irons: Heat and corrosion resistant grade

Chemical

Extruded polyvinyl chloride copolymer: Vinylidene chloride

Molded or extruded fluorocarbons: Polytrifluorochloroethylene (PTFCE), Polytetrafluoroethylene (PTFE), Polyvinylidenefluoride (PVF)

Chemical resistant

Molded or extruded polyethylene

Molded or extruded carbon, graphite: General purpose or Premium Grade

High strength

Molded epoxy laminates: Woven fabric or Filament wound

Salt water

Wrought iron

Wrought copper alloys: CDA 706 (cupro-nickel, 10%), CDA 710 (cupro-nickel, 20%), 715 (cupro-nickel, 30%)

Water

CDA 122 (phosphorus deoxidized copper)

Wrought or cast tin alloys: Grade A tin

PIPE WRENCHES

Carbon steels-hardening grades: C 1095

PISTONS

Nodular or ductile cast iron: Type 120-70-03

Wrought low alloy steels: AISI 6150

Automotive

Cast aluminum alloys: Type 122

High strength, air compressor

Type 40-E

Outboard motor

Type A 13

Diesel

Type 142

Malleable cast iron-pearlitic: Type 60003, Type 80002

Pump

Leaded Tin Bronze: Grade 2C

PISTON PINS

Nitriding steels: Type 135, Type 135 mod. Type N, Type EZ, Type 5Ni-2Al

Carbon steels-carburizing grades: C 1117, C 1118

PISTON RINGS

Cast copper-base alloys: Tin Bronze, BBII, Grades 1A, 1B

Molded or extruded carbon, graphite: General Purpose or Premium Grade

PLASTIC MOLDS

Wrought mold steels: AISI Types P1. P2, P4, P5, P6, P20, P21

PLUNGER GUIDES

Wrought copper alloys: CDA 172 (Beryllium copper)

POTENTIOMETERS

Molded diallyl phthalates: Orlon-filled, Dacron-filled, Asbestos-filled, Glass fiber-filled

POURING SPOUTS

Cast heat resistant ferrous: ACI Type HD

PRESS FRAMES

Cast gray iron: Type 60

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

PRESSURE BOTTLES

Molded epoxy laminates: Filament wound

PRESSURE TANKS

Wrought aluminum alloys: 1100, 3003

PRESSURE VESSELS

Wrought aluminum alloys: 5454, 5456, 5083, 5086, 5154

PRIMER CAPS

Wrought copper alloys: CDA 220 (commercial bronze, 90%)

PRINTED CIRCUITS

Fired ceramic: Zircon

PROPELLERS

Cast copper-base alloys

Marine

Aluminum Bronze, BBII, Grades 9A, 9B, 9C, 9D, Silicon Bronze, BBII, Grade 13B

PROPELLER BLADES AND HUBS

Cast copper-base alloys, High Strength Yellow Brass, BBII Grade 8A

PROPELLER SHAFTS

Wrought copper alloys: Naval Brass, CDA No. 464

PROTECTIVE GARMENTS

Molded polyvinyl chloride: Nonrigid-general

PULLEYS

Molded phenolics

PULVERIZER RINGS

Ni-Hard cast irons

PUMPS

Nodular or ductile cast irons: Austenitic

Cast gray iron: Type 50

Cast stainless steels: ACI-CF-20, ACI-CH-20, ACI-CK-20

Chemical

Molded or extruded carbon, graphite: General purpose or Premium Grade

PUMPS

High strength

Wrought martensitic stainless steels: Type 431

PUMP HOUSINGS

Nodular or ductile cast irons: 60-40-18, 60-45-12

High nickel (Ni-Resist) cast irons: Heat and corrosion resistant grade

Cast stainless steels: ACI-CA-15, ACI-CC-50, ACI-CE-30

Cast copper-base alloys: Tin Bronze, BBII Grade 1A, 1B, Yellow Brass, High Strength, BBII Grade 7A, Aluminum Bronze, BBII Grade 9A, 9B, 9C, 9D

Fuel

Cast aluminum alloys: B 195

PUMP LINERS

White cast irons: Abrasion resistant grade

PUMP PARTS

Molded or extruded fluorocarbons: Polytrifluorochloroethylene (PTFCE)

High temperature, corrosion resistant

Chlorinated polyether plastics

PUMP PLUNGERS

Fired ceramic: Alumina

PUMP RODS

Wrought copper alloys: CDA 675 (manganese bronze A)

PYROMETER TUBES

Wrought ferritic stainless steels: AISI-446

RADIATION SHIELDING

Industrial glass: High lead grade

Wrought molybdenum

RADIATORS

Automotive

Wrought copper alloys: (Tough pitch copper), CDA No.'s 110, 113, 114, 116

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

RADIATOR CORES AND TANKS Automotive Wrought copper alloys: CDA-260 (cartridge brass, 70%) **RADOMES** Molded phenolic laminates: Glass fabric, Asbestos fiber Rigid plastic foams: Epoxy, Urethane Fired ceramics: Alumina, Polycrystalline, Glass 9606 High temp, aircraft Molded silicone laminates: Woven fabric **RAMS** Cast gray iron: Type 50 **RECTIFIER BASES** Wrought copper alloys: CDA 150 (Zirconium copper) **REELS** Magnetic tape Molded or extruded polystyrenes: Glass fiber-filled **REFLECTORS** Wrought magnesium alloys: ZE 10A-H24, AZ 31B-H24 Wrought copper alloys: CDA No.'s 268, 270 (yellow brass) Wrought aluminum alloys, Type 1100 Cast, molded or extruded acrylics Molded melamines: Alpha cellulose or General purpose **RELAY ASSEMBLIES** Molded epoxies **RESISTORS** Molded alkyds: Granular (general purpose), Putty (electrical), Glass - reinforced (high impact) Molded diallyl phthalates: Orlon, Dacron, Asbestos, or Glass fiber-filled Wirewound Molded epoxies **RESISTOR BOBBINS** Molded epoxies	**RESONATORS** Mechanical Wrought low expansion nickel alloy: Ni-SPAN-C 902 **RETORTS** Cast heat resistant ferrous alloys: ACI-HI, ACI-HK **RIFLE TUBING** Wrought ultra high strength steel: 4340 **RIVETS** Wrought copper alloys: CDA No.'s 110, 113, 114, 116 (Tough pitch copper) CDA No. 340 (Medium leaded brass) Wrought copper alloys: CDA No. 464-467 (Naval brass), [illegible] No. 745, Type 65-10 Hot & cold worked Carbon steels-carburizing grades: C 1015, C 1020 **ROCKER ARMS** Malleable cast iron-pearlitic: Types 50003, 80002 Cast copper-base alloys: Silicon Bronze, BBII, Grade 13B **ROCKET MOTOR CASES** High strength Molded epoxy laminates: Filament wound **ROCKET MOTOR HOUSINGS** High strength, thin-wall Wrought ultra high strength steels: MX-2, D-6A **ROLLS** Paper mill & rubber mill Nitriding steels: 135, 135 modified, N, EZ, 5Ni-2Al Printing Molded or extruded rubber: Butadiene-acrylonitrile **ROTATING BANDS** Wrought copper alloys: CDA-122 (phosphorus deoxidized copper)

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

ROTORS

Cast aluminum alloys: 355

Jet engine

Wrought iron-base superalloys (Cr-Ni): 16-25-6

ROTOR BLADES

Molded polyester laminates: Spray-up mat or Preform

Molded phenolic laminates: Glass fabric or Asbestos fiber

RUBBER MOLD CASTINGS

Wrought or cast tin alloy: White metal

SAFETY GOGGLE CUPS

Molded or extruded polyvinyl chloride: Non-rigid - general

SCREWS

Wrought copper alloys: CDA 314 (leaded commercial bronze); CDA 340 (medium-leaded brass); CDA 745 (65-10); CDA 752 (65-18)

SEALING RINGS

Molded or extruded carbon, graphite: General purpose or Premium Grade

SEALS

Molded or extruded rubber: Polysulfide, Silicone, Polybutadiene

Sheet wool felts: SAE Spec

Molded or extruded carbon, graphite: General purpose or Premium Grade

Air, moisture, sound and dirt resistant

Molded or extruded rubber: Natural rubber, Butadiene-styrene, Synthetic rubber

Automotive, aircraft and missile shaft

Polytrifluorochloroethylene

Critical, chemical and thermal resistant

Vinylidene fluoride hexafluoropropylene

High temperature, oil and solvent resistant

Fluorosilicone

SEALS

Oil

Roll wool felts: SAE SPEC F-2 Grade 16R2; SAE SPEC F-6 Grade 12R2; SAE SPEC F-1 Grade 16R1

Bearing

Sheet wool felts: Types 16S1, 12S1, 16S2, 12S2, 16S3, 12S3, 16S4, 12S4

Roll wool felts: SAE SPEC F-3 Grade 16R3

Precision ball and roller bearing

Roll wool felts: SAE SPEC F-50 Grade 16R1X

Hermetic

Molded or sheet mica: Ceramoplastic

High temperature

Synthetic felts

Weather resistant

Synthetic felts: Dacron polyester

Window air conditioner

Synthetic felts: Rayon viscose

Low pressure

Molded olefin copolymers: Ethylene ethyl acrylate (EEA); Ethylene vinyl acetate (EVA)

Oil resistant

Flexible plastics or rubber foams: Butadiene-acrylonitrile

SEAT FRAMES

Cast aluminum alloys: B195

SHAFTS

Cast stainless steel: ACI CA-15

Wrought copper alloys: CDA 544 (phosphor bronze free-cutting)

Nitriding steels: Types 135, 135 modified, N, EZ, 5Ni-2Al

Wrought low alloy steels: AISI 1340, 4130, 4140, 4150, 4620, 5140, 5150, 6150

Heavy duty

Wrought low alloy steels: AISI's 8620, 8630,

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

SHAFTS

Heavy duty

Wrought low alloy steels: AISI 8640, 8650, 8740, 8750

SHIELDS

Dust

Sheet wool felts: Type 12S1, 12S2, 12S3, 12S4

Oil, dust, and mud

Roll wool felts: SAE SPEC F-6, Grade 12R2

SHOCK ABSORBERS

Flexible plastics or rubber foams: Urethane

SLEEVES

Wrought free-cutting carbon steels: AISI B 111, B 1211, B 1112, B 1212, B 1113, B 1213

SLIP RINGS

Wrought copper alloys: CDA 150 Zirconium copper

SOCKETS

Electronic tube

Fired ceramic: Zircon, Steatite

Electrical

Wrought copper alloys: CDA-230 (red brass, 85%),

High strength

Wrought copper alloys: CDA-647 (precip, hard SiBronze)

SOLDERING IRON TIPS

Wrought copper alloys: CDA 150 (Zirconium copper)

High conductivity

Wrought copper alloys: CDA 145 (tellurium copper) CDA 147 (sulfur copper)

SPACERS

Wrought free-cutting carbon steels: AISI B 1111, B 1211, B 1112, B 1212, B 1113, B 1213

Industrial papers: Fiber paper board, Fiber board

SPACERS

Electrical instrument

Fired ceramics: Steatite

SPARK PLUGS

Insulation

Fired electrical ceramics: Alumina, Refractory mullite

SPINDLES

Nitriding steels: Type 135, 135 modified, N, EZ, 5Ni-2Al

SPRINGS

Carbon steels-hardening grades: C 1095

Wrought copper alloys: CDA No's. 268, 270 (yellow brass), 510 (phosphor bronze A), 521 (phosphor bronze B), 752 (65-18),

High strength

Wrought copper alloys: CDA No. 647 (precip, hard SiBronze)

Instrument

Wrought copper alloys: CDA No. 172 (beryllium copper)

STACK DAMPERS

Cast heat resistant ferrous alloys: ACI-HL

STEERING GEAR HOUSINGS

Malleable cast iron-ferritic: Type 32510, 35018

STEERING KNUCKLES

Wrought low alloy steels: AISI 5140, AISI 5150

STEERING WHEELS

Molded or extruded cellulose acetate propionate plastics

STRUCTURES

Building panel core

Rigid plastic foams: Phenolic 7-10

Gas cooled nuclear reactor

Wrought zirconium alloys: ATR, Reactor grade

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

STRUCTURES

Gas cooled nuclear reactor

Wrought zirconium alloys: Zircaloy-2

High temperature

Wrought tungsten

Wrought molybdenum

Space vehicle

Wrought columbium alloys

High temperature, space craft

Wrought tantalum: Tantalum-10W

Honey combed

Molded phenolic laminates: Glass fabric, Asbestos fiber

Low weight bridge

Wrought high strength steels: ASTM Types A 94, A 242, A 440, A 441, A 374, A 375

Primary and secondary aerospace

Wrought magnesium alloys: LA 141A-T7

SUPERCHARGER HOUSINGS

High Nickel (Ni-Resist) cast irons: Heat and corrosion resistant grade

SWITCHES

Wrought copper alloys: (Tough Pitch Copper), CDA No's. 110, 113, 114, 116

SWITCH COVERS

Molded alkyds: Granular (general purpose), Glass-reinforced (high impact)

SWITCH GEARS

Molded polyester laminates: Spray-up mat, Preform

SWITCH PARTS

Wrought copper alloys: CDA-510 (phosphor bronze A), CDA-521 (phosphor bronze B)

SWITCH PLATES

Molded epoxies

Molded ureas

TANKS

Chemical storage

Molded polyester laminates: Spray-up mat, woven fabric

Fuel

Molded phenolic laminates: Glass fabric, Asbestos fiber

High strength chemical

Molded epoxy laminates: Filament wound

Self-sealing fuel

Molded or extruded rubber: Butadiene-acrylonitrile

Storage

Molded or extruded polyvinyl chloride: Rigid type

Wrought aluminum alloys: 1100, 3003, 3004

TANK CARS

Railroad

Wrought aluminum alloys: 1060

TANK LININGS

Molded polyester laminates: Spray-up mat, Preformed

Molded or extruded fluorocarbons: Polytrifluorochloroethylene (PTFCE)

Molded or extruded rubber: Chlorosulfonated polyethylene

Chemical

Molded or extruded rubber: Natural rubber, Butadiene-styrene, Synthetic rubber

Petroleum and chemical

Molded or extruded rubber: Chloroprene

High temp, corrosion resis.

Chlorinated polyether plastics

Process

Molded or extruded polyethylenes

TAPES

Molded or extruded nylons

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

TAPES

Molded or extruded cellulose acetate plastics: H6-1, H4-1, H2-1, MH-1, MH-2, MS-1, MS-2, S2-1

TERMINAL BLOCKS

Fired ceramic: Cordierite

High temperature

Molded melamines: Mineral grade, Electrical grade

TERMINAL STRIPS

High shock resistant, good electrical properties, highly burn resistant

Molded melamines: Glass fiber

THERMAL BARRIERS
High temperature

Molded silicone laminates: Woven fabric

THERMOSTATIC BIMETAL

Wrought low-expansion nickel alloys: Ni 36, Ni 42

THERMOSTATS

Wrought ruthenium

THREAD GUIDES

Nitriding steels: Type 135, 135 modified, N, EZ, 5Ni-2Al

TIE RODS

Carbon steels-hardening grades: C 1030, C 1040, C 1050

TOOL HANDLES

Molded or extruded cellulose acetate plastics: H6-1, H4-1, H2-1, MH-1, MH-2, MS-1, MS-2, S2-1

Cast, molded or extruded acrylics: High impact

Molded or extruded ethyl cellulose plastics: A and B (high impact)

TOOL HOUSINGS
Portable

Molded or extruded polycarbonate plastics: Glass-filled

TORCH TIPS

High conductivity

Wrought copper alloys: CDA 145 (tellurium copper)

TORSION BARS

Carbon steels - hardening grades: C 1060, C 1080

TOWERS

Wrought high strength steels: (Vanadium) or Columbium bearing

TRANSMISSION HOUSINGS

Malleable cast iron pearlitic: Type 45010, 45007

Cast aluminum alloys: Type 356

TRUCK BODIES (LT. WEIGHT)

Wrought aluminum alloys: 5052

Wrought magnesium alloys: ZE 10A-H24, AZ 31B-H24

TRUCK PANELS

Wrought aluminum alloys: 3003

TRUCK ROOFS

Molded polyester laminates: Spray-up mat, Preform

TUBE ENVELOPES

Fired ceramics: Alumina

TUBE SPACERS

Molded or sheet mica: Natural muscovite

TUBING

Molded olefin copolymers: Ethylene ethyl acrylate (EEA), Ethylene vinyl acetate (EVA)

Molded or extruded nylons: Type 6/6

Wrought copper alloys: CDA 651 (low Al Bronze B), CDA 614 (Al Bronze D), CDA 687 (Aluminum), CDA 706 (Cupro-nickel, 10%), CDA 710 (Cupro-nickel, 20%), CDA 715 (Cupro-nickel, 30%)

Distiller

Wrought copper alloys: CDA 44?, CDA 443,

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

TUBING

Distiller

Wrought copper alloys: CDA 444, CDA 445, (Admiralty), CDA 687 (Aluminum brass)

Heat exchanger

Wrought copper alloys: CDA 122 (phosphorus deoxidized copper), 230 (red brass, 85%), CDA 442, CDA 443, CDA 444, CDA 445 (Admiralty), CDA 687 (Aluminum brass), CDA 706 (Cupro-nickel, 10%), CDA 710 (Cupro-nickel, 20%), CDA 715 (Cupro-nickel, 30%)

Aircraft

Wrought aluminum alloys: 5052

Hydraulic

Wrought aluminum alloys: 3004

Chemical

Cast stainless steels: CF-8C

Molded or extruded polyvinyl chloride copolymer: Vinylidene chloride

Chemical or oxygen

Molded polyvinyl alcohol

Collapsible

Wrought or cast tin alloys: Hard tin

Electronic

Wrought tungsten, molybdenum

Flexible chemical and petroleum

Molded or extruded rubber: Chlorosulfonated polyethylene, Chloroprene.

Heavy duty, aircraft

Wrought low alloy steels: AISI 8620, AISI 8630, AISI 8640, AISI 8650, AISI 8740, AISI 8750

Ignition

Industrial glass: Alumino-silicate

Radiant

Cast heat resistant ferrous alloys: ACI-HH, ACI-HN

TURBINE BLADES

Cast nickel alloys: Monel 411 (Monel), Monel 505 (S Monel)

Cast stainless steels: CA-15

Wrought ferritic stainless steels: 405

Wrought molybdenum

High strength

Wrought martensitic stainless steels: 403

High temperature

Cast cobalt-base superalloys: HS-31, X-40, HS 151, Wl 52

Jet engine

Wrought iron-base superalloys: (Cr-Ni), A-286, V-57

TURBINE BUCKETS

High strength, high temperature

Wrought high temperature steels: 1415 NW (Greek Ascoloy), 1430 MV (Lapelloy), 14 CVM (Chromoloy), 17-22 AS (14 MV)

Jet engine

Wrought or cast nickel-base superalloys: Unitemp 1753, M-252

TURBINE HOUSINGS

High strength, high temperature, aircraft and missile

Wrought ultra high strength steels: Modified H-11

Jet engine

Wrought iron-base superalloys: (Cr-Ni), A-286, V-57

TURNBUCKLE BARRELS

Aircraft

Wrought copper alloys: CDA No's. 464, 465, 466, 467 (Naval brass)

TURRET HOUSINGS

High strength

Cast aluminum alloys: 40-E

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

TYPEWRITER PARTS

Molded or extruded acetal plastics: Acetal homopolymer, Acetal copolymer

UNIVERSAL JOINT YOKES

Malleable cast iron-pearlitic: 48004, 50007, 53004, 60003, 80002

VALVES

Nodular or ductile cast irons: Austenitic

Cast copper-base alloys: Tin Bronze, BBII Grade 1A & 1B; Leaded Tin Bronze, BBII Grade 2A, 2B, 2C; Leaded Red Brass; Leaded Yellow Brass; Hi-Str Yellow Brass, Grade 7A; Leaded Ni Brass; Leaded Ni Bronze

Cast stainless steels: CH-20, CK-20, CF-20, CN-7M

Wrought martensitic stainless steels: 440A, 440B, 440C

Molded or extruded fluorocarbons: Polytetrafluoroethylene (PTFE)

Chemical

Molded or extruded carbon, graphite: General purpose or Premium Grade

Corrosion,erosion resistant

Cast stainless steels: CD-4MCu

High pressure steam

Cast stainless steels: CF-3M, CF-8M, CF-12M

High strength

Wrought martensitic stainless steels: 431

High strength, high heat aircraft

Wrought iron-base superalloys: (Cr-Ni), 19-9 DL, W 545, D-979, AMS 5700

High temperature

Cast copper base alloys: Leaded Ni-Bronze, Grade 11B

High temperature, corrosion resistant

Chlorinated polyether plastics

Pump

Fired ceramic: Zircon

VALVE BODIES

Cast gray iron: Type 50

Wrought copper alloys: 675 (manganese bronze A)

VALVE COMPONENTS

Wrought copper alloys: CDA 651 (Low Si Bronze B)

VALVE HOUSINGS

Nodular or ductile cast irons: Type 60-40-18, 60-45-12,

Malleable cast iron-pearlitic: Type 48004, 50007, 53004

Cast stainless steels: CB-30, CC-50, CE-30

Cast aluminum alloys: Type 108

Cast copper-base alloys: Leaded Tin Bronze Grade 2A

Low pressure

Cast copper-base alloys: Leaded Red Brass Grade 4A

VALVE LININGS

Molded or extruded fluorocarbons: Polytetrafluoroethylene (PTFE), Fluorinated ethylene propylene (FEP)

VALVE SEATS

Cast nickel alloys: Monel 411 (Monel), Monel 505 (S Monel)

Cast stainless steels: CC-50

Molded or extruded polyvinyl copolymer: Vinylidene chloride

Fired ceramics: Alumina

Corrosion Resistant

Molded or extruded fluorocarbons, Ceramic reinforced

VALVE SEAT DISKS

Molded or extruded rubber Polysulfide

VALVE SEAT INSERTS

High chromium and molybdenum cast irons

444-810 O - 71 - 13

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

VALVE SEAT INSERTS
High strength, high heat, aircraft

Wrought iron-base superalloys (Cr-Ni): 19-9 DL, Unitemp 212, W 545, D-979, AMS5700

VALVE SPRINGS

Wrought copper alloys: CDA 172 (beryllium copper)

VALVE STEMS

Wrought copper alloys: CDA 280 (Muntz metal), CDA 464, CDA 465, CDA 466, CDA 467 CDA 467 (Naval brass), CDA 485 (leaded Naval brass), CDA 675 (manganese Bronze A)

Cast copper-base alloys: Hi-strength Yellow Brass, BBII Grade 7A, 8A; Silicon Bronze, BBII Grade 13B

VIBRATION MOUNTS

Roll wool felts: SAE SPEC F-6 Grade 12R2; SAE SPEC F-2 Grade 16R2

WASHERS

Cast copper base alloys: Aluminum Bronze, BBII Grades 9A, 9B, 9C, 9D

Industrial papers: Fiber paper board, Fiber board

Sheet wool felts: Grades 12S1, 12S2, 12S3, 12S4,

Bearing seal

Sheet w' ' felts: Grades 20S1, 20S3, 26S2, 26S4

Grease and oil retaining

Sheet wool felts: Grades 16S1, 16S2, 16S3, 16S4

Corrosion resistant

Molded or extruded fluorocarbons: Ceramic-reinforced (PTFE)

Thrust

Wrought copper alloys: CDA 544 (phosphor bronze free-cutting)

Lock

Wrought copper alloys: CDA 510 (phosphor bronze A), CDA 521 (phosphor bronze B)

WASHERS
Lock

Low alloy Steel: 9255, 9261

WELDING EQUIPMENT

Wrought copper alloys: CDA 639 (Al-Si bronze)

WELDING TORCH TIPS
High conductivity

Wrought copper alloys: CDA 147 (sulfur copper)

WHEELS

Molded phenolics

Wrought copper alloys: CDA 342, CDA 353 (high-leaded brass), CDA 356 (extra high-leaded brass)

Wrought high strength steels (Columbium Bearing)

Wrought magnesium alloys: AZ31B-F, AZ61A-F, AZ80A-T5, ZK60A-T5, AZ10A-F

Cast magnesium alloys: AZ63A, AZ81A, AZ91, AZ291B, AZ91C, AZ92A, AM100A

Cast aluminum alloys: 356

Bus

Cast aluminum alloys: 195

Airplane tail

Molded or extruded rubber: Urethane

Fork lift truck

Molded or extruded rubber, Urethane

High temp, turbine

Case cobalt-base superalloys: HS-31, X-40, HS-151, WI 52

WHEEL HUBS

Malleable cast irons-pearlitic: 45010, 45007

WICKS

Oil and fluid

Sheet wool felts: Grades 16S1, 16S2, 16S3, 16S4

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TABLE 9-23. RANDOM LISTING OF SOME CANDIDATE MATERIALS (CONT'D)

WICK LUBRICATION
Roll wool felts: SAE SPEC F-1, Grade 16R1, Grade 18R1
WIRES
Precipitron, high damping capacity, high temperature
Cobalt alloys: Nivco
WIRE
Resistance
Wrought copper alloys: CDA 770 (55-18)
WIRES
Truss
Wrought copper alloys: CDA 510 (phosphor Bronze A), CDA 521 (phosphor Bronze B)
WIRE CONNECTORS
Wrought copper alloys: CDA 651 (Low Si Bronze B)
WIRE SUPPORTS
Fired ceramics: Standard electrical grade
X-RAY RODS
Fired ceramics: Standard electrical grade
X-RAY TUBES
Fired ceramics: Standard electrical grade

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TABLE 9-24. COMMON DESIGN PROBLEMS

Problem: DESIGN SPECIFICATIONS UNDULY RESTRICT OR PROHIBIT USE OF NEW MATERIALS.

Cause and Effect:

Designer restricts himself and the design to materials that have been proven or to materials that have become traditional.

Potential Solution:

Keep abreast of new material developments, e.g., prepainted steel or one of the preclad metal combinations, many of which could be more economical than bare metal subsequently plated or coated.

Problem: DESIGN SPECIFIES PECULIAR SHAPE WHICH REQUIRES EXTENSIVE MACHINING OR A SPECIAL EXTRUSION.

Cause and Effect:

Special extruded parts require long leadtime and costly as-is extensive machining.

Potential Solution:

Simplify the design geometry to use standard extrusions or minimum machining.

Problem: PHYSICAL AND FUNCTIONAL REQUIREMENTS OF DESIGN CAN BE MET WITH POWDERED METAL PART, BUT DESIGN CONFIGURATION RESTRICTS ITS USE.

Cause and Effect:

Use of powdered metallurgy parts whose physical and functional requirements are restricted by design configuration.

Potential Solution:

Redesign part, if possible, to permit its fabrication using powdered metal techniques.

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TABLE 9-24. COMMON DESIGN PROBLEMS (CONT'D)

Problem: SPECIFIED MATERIAL DIFFICULT OR IMPOSSIBLE TO FABRICATE ECONOMICALLY.

Cause and Effect:

Designer's desire to achieve ultimate in physical characteristics.

Potential Solutions:

Review the selection of material against requirements to determine if some other material or grade of material can be specified; investigate possibility of annealing to facilitate machining.

Problem: SPECIFIED MATERIAL NOT AVAILABLE IN QUANTITY.

Cause and Effect:

Material too new to be on the market in quantity; material proprietary or single source; supply of material committed to higher priority projects; material composition or configuration no longer in production.

Potential Solution:

Specify alternate materials; investigate supply sources before specifying material.

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TABLE 9-25. COMMON PRODUCTION PROBLEMS

Process: MULTILAYER FLEXIBLE CABLE.

Problem:

Electronic packages may be interconnected in a three-dimensional network. The multilayer, multiconductor flexible cable eliminates hand wiring but requires further development and investigation.

Application:

This process would have widespread application to multiple component electronic systems.

Process: PRINTED CIRCUIT-TUBELET.

Problem:

Production efficiency would be improved with the adaptation of the printed circuit-tubelet concept in the fabrication of electronic modules.

Application:

This concept could improve several Army missile systems.

Process: PROCESSING MESOMORPHIC MATERIALS.

Problem:

There is a void between the theory and the application of mesomorphic materials for use in direct viewing devices.

Application:

Study and evaluate ways and means of practical application of mesomorphic materials for use in direct viewing devices.

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TABLE 9-25. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: INCREASED R & D EFFORT WITH RESPECT TO ADVANCED POLYMERS.

Problem:

It is not yet possible to bulk produce and fabricate certain, what appear to be desirable, laboratory produced polymers.

Application:

Continue the R & D efforts to enable mass production of certain rubber polymers to include the fabrication of components.

Process: MANUFACTURING ALUMINUM TURRET RING BEARING WITH STEEL INSERTS.

Problem:

The use of plastic and aluminum in the manufacture must be studied as a substitute for steel in turret fabrication if significant reductions are to be made in both weight and cost.

Application:

A weight reduction of 40% to 50% along with reduced maintenance requirements may be achieved in turret fabrications.

Process: MANUFACTURING METHODS OF TRANSPARENT ARMOR.

Problem:

Convert laboratory research solutions of transparent armor components to practical application.

Application:

This effort will consider all items now made, or proposed, of plastic or glass intended for use as transparent armor.

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TABLE 9-25. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: FERRITE IMPROVED POWDERS.

Problem:

The problem in ferrite powders is the isolation and compaction of individual ferrous particles so that they can act as individual magnets. One of the main difficulties with magnetic materials is that their characteristics change with temperature, falling off drastically with high temperatures.

Application:

Transformers, inductors, and memory cores which could be improved and miniaturized.

Process: GUN TUBE STEELS.

Problem:

Service life of gun tubes subjected to sustained firing has been low due to the limitations of the present barrel steels.

Application:

Gun tubes, magazine tubes, and other relatively simple configurations.

Process: IMPROVED PRINTED CIRCUIT MATERIAL.

Problem:

A need exists for a repairable printed circuit board. At present, when a componen lead is unsoldered for removal, the pad may be overheated. When the lead is moved while the copper-to-epoxy adhesive is hot, the pad may loosen from the board, damaging it beyond repair.

Application:

All electronic systems employing printed circuit boards.

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TABLE 9-25. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: ALUMINUM-BRONZE CHEMICAL COMPOSITON AND MECHANICAL PROPERTIES.

Problem:

Although all classes of aluminum-bronze ingot and castings may be well within the chemical composition specified, the mechanical properties such as tensile strength and/or elongation do not meet minimum requirements.

Application:

Brushings, bearing, surfaces, etc.

Process: CONTROLLED CERAMIC CAPACITOR POWDER.

Problem:

Barium titanate, a basic material in capacitors, is not presently available in the required purity levels. The increasing use of miniaturization requires greater sophistication in the preparation of the materials used in ceramic capacitors.

Application:

Ceramic capacitors and systems containing ceramic capacitors.

Process: CRYSTAL GROWTH.

Problem:

Perfected controls are required for crystal growth to insure uniformity.

Application:

Established controls required for the economical production of ruby crystals to include, but not be limited to, maintaining uniform chromium doping, flawless growth, and uniform nutrient and run temperatures.

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CHAPTER 10

FABRICATION PROCESSES

10-1 GENERAL

This chapter acquaints the design engineer with some of the manufacturing processes used to convert a design into hardware. These processes fall into two general categories, material moving and material removing; the former generally being described as primary fabrication processes and the latter as secondary fabrication processes. While the two are frequently complementary, the primary processes are relatively waste free in that they "move" material, and the secondary are relatively wasteful in that they "remove" material.

10-2 PRIMARY FABRICATION PROCESSES

The essential primary fabrication processes are shown in generic form in Appendix C. Some of these processes may seem far removed from the designer; however, almost everything produced will have had its beginnings in one or more of these process operations. The designer who is not fully informed of the capabilities, techniques, and limitations of the various processes can waste time and money. He may fail to consider alternate methods of production or his design will be such that it does not realize the full benefits of the method selected.

This handbook briefly summarizes some of the capabilities and limitations of these manufacturing processes. Table 10-1 outlines some basic characteristics. Many texts and articles, particularly in trade journals, describe how to design for best results in these process operations and are a source of current and up-to-date information. It must be remembered that today's best method may be replaced tomorrow by new developments in manufacturing technology.

10-2.1 CASTING

Casting processes are basically similar in that the metal being formed is in a liquid or highly viscous state and is poured or injected into a cavity of a desired shape.

The use of castings for military equipment has been limited because they have been known to be typically weaker and less reliable than forged or wrought parts. However, rapid progress has been made in the development of high strength steel castings that can meet the requirements of military designers.

Castings offer considerable economic advantages because they conserve material and reduce the amount of finish machining required. This saving thereby enhances producibility, and the wide variety of casting methods and materials that can be cast permits almost unlimited sizes and configurations.

10-2.2 FORGING

Forging consists of working metals into a desired configuration under impact or pressure loading. This process permits fabricating the more complex shapes normally required today. Its value lies in a refined grain structure and flow patterns that are possible. Improved mechanical properties of the part and economical quantity production are results of this process.

For hot forging, furnace temperature, part temperature, and heating time vary with the metallurgical properties of the metal to be forged. Temperature ranges for various materials are illustrated in Fig. 10-1.

Precision forging is an extension of conventional forging practice, and is used to eliminate or minimize machining operations. The dimensional tolerances, surface finish, and surface metallurgical quality are equivalent to those produced by standard production machine tools.

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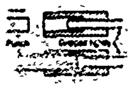
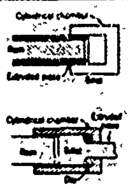
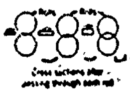
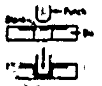
PROCESS/FORM	PROCESS CHARACTERISTICS	TYPICAL APPLICATION	EXPECTED TOLERANCES	
UPSET FORGING [illegible] bar stock is gripped by two dies. A third die strikes the protruding end of the bar stock forming the impression. 	PRO - High dimensional accuracy rapid production rate CON - Size and shape limitations. [illegible]	Axle shafts, engine cylinders, worm gears, flanges, sleeves, pinions.	Same as closed die forging	
COLD HEADING Wire up to one inch in diameter is fed into a die. Another die strikes the protruding end of the wire forming the impression.	PRO - High surface strength and finish, rapid production rate; tough, ductile, and crack resistant alloys, no material waste CON - Size, shape, and head volume limitations, internal stresses may form at critical points.	Bolts, nuts, rivets, electrical terminals and capacitor plates. Materials - Mainly steel wire	Shank and shoulder diameter Shank length Head diameter Head Height	3/16 dia.....±0.002 3/8 dia.....±0.003 3/4 dia.....±0.004 1 dia.....±0.005 0-1.........±0.030 1-2.........±0.0[illegible] [illegible]...........±0.090 >6.........±0.188 ±0.030 ±0.005
IMPACT EXTRUSION (Cold) Reverse Extrusion - A slug is placed in the die and struck with a punch. The metal flows up around the punch. Forward Extrusion - In this case, metal flows forward through an opening in the die. 	PRO - High strength, hardness, and surface finish; few secondary operations. CON - Shape and thickness limitations; low production rate; high skill level.	Aerosol cans, fire extinguishers, flashlight cases, military projectiles, rocket motors, piston pins. Materials - Mainly aluminum	Length Wall thickness Bottom thickness O.D. I.D.	< 3/16.....±0.010 > 3/16.....±0.015 0.004...±0.0002 0.14...±0.003 0.060...±.004 0.100...±0.010 >0.150...±0.020 ±0.003 to ±0.007 ±0.003 to ±0.005 ±0.000 to ±0.006
CUT EXTRUSION Heated metal is forced through a die having an aperture of the desired shape. The forms are then cut into proper lengths.	PRO - No porosity, complex shapes in one plane. CON - Size, shape, and tolerance limitations.	Tubing, hinges, aircraft wing spars. Materials - Mainly aluminum, copper, and magnesium	Flatness Straightness Curved surface Wall Thickness Cross Section Length	±0.004/in. of width ±0.050 to 0.0125/foot ±0.005/in. of cord length ±0.006 to ±0.010 ±0.006 to ±0.080 10 ft. .....±0.125 30 ft .....±0.500
ROLL FORMING Metal passes between a series of rolls in a continuous strip. The rolls gradually change the shape of the metal to the desired form. 	PRO - High dimensional accuracy and surface finish; few material limitations. CON - High tooling cost, shape limitations.	Aircraft framework, truck frames, tubular parts	Length Twist Angle Cross Section Straightness	±0.062 1/2 deg /ft 5 deg max. 1° to 2 deg ±0.002 to ±0.015 ±0.125 to ±0.500/12 ft
CUTTING Metal is completely sheared by stressing beyond the ultimate strength. This includes such operations as blanking, piercing, notching, shearing, trimming, and [illegible].	PRO - Few material, size, or shape limitations; high surface finish; rapid production rate; no porosity. CON - Thickness limitations; expensive tools; high material waste; sheared edges.	Key blanks, disks washers, gears, watch parts, buttons, latches.	Dimensional Flatness Squareness Hole	±0.003 to ±0.010 ±0.005 ±0.003 to ±0.010 ±0.005 to ±0.010
FORMING Metal is permanently deformed by stretching beyond its yield point. This includes such operations as folding, seaming, curling, and angle bending. 		Cartridge shells, aircraft fuselage and wing sections, panels, tractor parts, automobile fenders and hoods.	Angle	±0.010
DRAWING Metal is stretched but not beyond its yield point. This includes such operations as embossing and ironing. 		Hinges, utensils, brackets. Materials - Mainly aluminum, carbon steels, and copper.	Dimensional Draft Allowance	2...±0.005 to ±0.015 2-6.±0.008 to ±0.020 0-1/4 degrees
SPINNING A flat or preformed blank is turned on a lathe. The piece is formed over a hard wood or metal pattern using a simple wood or metal tool to apply pressure against the blank. 	PRO - High dimensional accuracy, surface finish, and strength; low material waste and tooling cost; few secondary operations. CON - Size, shape and material limitations.	Nose cones, light reflectors, tank heads, thin-wall precision tubing, flanged-end tubular parts.	Length Thickness I.D.	±0.005 ±0.002 < 6....±0.002 > 6....±0.003
ELECTROFORMING A mandrel is placed in an electroplating bath. After the desired metal thickness is obtained, the pattern is then removed leaving the formed piece.	PRO - Very high dimensional accuracy, surface finish, and intricacy; controlled properties few size limitations. CON - Low production rate, few materials; high skill level; reproduction of scratches.	Venturi nozzles, rocket thrust chambers, missile nose cones, reflectors, propeller blades.	Wall thickness Dimensional (Permanent Mandrel) Draft Allowance Dimensional (fusible mandrel)	± 0.0.1 ± 0.0002 ± 0.002
SCREW MACHINE Bar stock is fed, cut, and tooled to the desired shape. The four major types are the hand, single-spindle automatic, multi-spindle automatic, and Swiss-type automatic.	PRO - Very high production rate; high dimensional accuracy and surface; few material limitations. CON - Size and shape limitations.	Screws, bolts, high volume threaded parts.	Diameter Length Concentricity, TIR Hole	±0.0005 to ±0.003 < 2....±0.002 > 2....±0.005 ± 0.003 ±0.0005 to ±0.005

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...TOLERANCES	MACHINE FINISH ALLOWANCE	APPROXIMATE THICKNESS		APPROXIMATE SIZE		GEOMETRY CHARACT...		
	0.062 to 0.094 in.			Max Min	9 in. diameter bar 7/8 in. diameter bar			
3/16 dia.......±0.002 3/8 dia......±0.003 3/4 dia......±0.004 1 dia.......±0.00 0-1..........±0.030 1-2..........±0.060 2-6..........±0.090 >6..........±0.188 ±0.030 ±0.005				Max Min	3/4 in. diameter by 10 in. length 1/32 in. diameter by 1/16 in. length	Bosses Undercuts Inserts Holes	Yes Yes No No	Under...
<3/16....±0.010 >3/16....±0.015 0.004....±0.0002 0.145....±0.003 0.060....±004 0.100....±0.010 >0.150....±0.020 ±0.003 to ±0.007 ±0.003 to ±0.005 ±0.000 to ±0.006		Min Large parts	0.0035 in. 0.875 in.	Max Min	6 in. diameter for soft alloy - 4 in. diameter for hard alloy 3/16 diameter	Bosses Undercuts Inserts Holes	Yes No Yes Yes	On both... Possible At ele... Possible in the...
±0.004/in. of width ±0.050 to 0.0125/foot ±0.005/in. of cord length ±0.006 to ±0.010 ±0.005 to ±0.080 10 ft......±0.125 30 ft......±0.500		Min	0.035 in.	Max Min	10 in. diameter 1/16 in. diameter	Bosses Undercuts Inserts Holes	Yes Yes No Yes	 In direct...
±0.062 1/2 deg /ft 5 deg max. 1 to 2 deg ±0.002 to ±0.015 ±0.125 to ±0.500/12 ft		Min Max	0.003 in. 0.750 in.	Max Min	80 in. width Width a fraction of an in.	Bosses Undercuts Inserts Holes	Yes Yes No Yes	 If unifo...
±0.003 to ±0.010 ±0.005 ±0.003 to ±0.010 ±0.005 to ±0.010		Min	0.003 in.	Max Min	30 ft length 1/8 in. length	Bosses Undercuts Inserts Holes	Yes No No Yes	Width: Diameter ... metal th...
±0.010		Max Cold	0.750 in.			Bosses Undercuts Inserts Holes	Yes Yes No Yes	Width: Some diff...
<2...±0.005 to ±0.015 2-6...±0.008 to ±0.020 0-1/4 degrees		Max Hot	3.50 in.	Max Min	20 ft diameter 1/8 in. diameter	Bosses Undercuts Inserts Holes	 Yes No No	Width: d... Unless p...
±0.005 ±0.002 <6....±0.002 >6....±0.003		Min Medium parts Large parts	0.004 in. 0.025 in. 1.062 in.	Max Min	16 ft diameter 1/4 in. diameter	Bosses Undercuts Inserts Holes	No Yes No No	Annular... Possible Unless p...
± 0.001 ± 0.0002 ± 0.002		Min Large parts	0.0001 in. 0.500 in.	Max Min	Limited only by the size of plating tanks-generally 50 pounds. Ounces	Bosses Undercuts Inserts Holes	Yes Yes No Yes	Should be... Only with
±0.0005 to ±0.003 <2....±0.002 >2....±0.005 ± 0.003 ±0.0005 to ±0.005				Max Min	8 in. diameter by 3 ft in length 1/32 in. diameter by 1/16 in. length	Bosses Undercuts Inserts Holes	Yes Yes No Yes	At modera...

TABLE 10-1. ANALYSIS OF MANUFACTURING PROCESSES

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GEOMETRY CHARACTERISTICS		SURFACE SMOOTHNESS,	OPTIMUM LOT SIZE				EXPECTED COSTS				
		µ in. rms	Small	Medium	Large	Note	PRINCIPAL ELEMENTS	LOW	MEDIUM	HIGH	
		175-200		X →	X	Best suited for small parts	Raw Materials	X →	X		Labor cost is forging proce and scrap cost less than for
							Tooling			X	
							Direct Labor		X		
							Finishing		X		
							Scrap Loss		X		
Yes	Under or on top of head	100			X	Typically a mass production process	Raw Materials	X →	X		Labor and fini low because th process is vir matic.
Yes							Tooling		X		
No							Direct Labor	X			
No							Finishing	X			
							Scrap Loss	X			
Yes	On bottom at no added expense	10-70		X →	X	Minimum of 1500 pieces	Raw Materials		X		Little skilled required. Ma not require
No	Possible in secondary operation						Tooling		X		
Yes	At slower production rate						Direct Labor	X			
Yes	Possible with forward extrusion in the primary operation.						Finishing	X			
							Scrap Loss	X			
Yes		125-150	X →		X		Raw Materials		X		Extruded metals machined, howe or tumbling ar the sole finish
Yes							Tooling	X →	X		
No							Direct Labor	X			
Yes	In direction of extrusion						Finishing	X			
							Scrap Loss	X			
Yes		100			X	Minimum of 10,000 feet	Raw Materials	X →	X		Tooling in hig are expensive is automatic due to the
Yes							Tooling			X	
No							Direct Labor	X			
Yes	If uniformly spaced.						Finishing	X →	X		
							Scrap Loss	X			
Yes	Width: depth should be 4:1	150-175			X	Minimum of of 10,000 pieces but often used for short runs	Raw Materials	X →	X		blanking resid minimized by " careful sizing
No							Tooling		X →	X	
No							Direct Labor	X →	X		
Yes	Diameter should not be less than metal thickness						Finishing	X			
Yes	Width: depth should be 4:1						Scrap Loss		X →	X	
Yes											
No											
Yes	Some difficulty if hole is near bend										
	Width: depth should be 4:1										
Yes											
No											
No	Unless perforated blanks										
No	Annular ribs and beads possible	6-8	X			Quantities under 100 pieces; however certain shapes and sizes suitable for large quantities.	Raw Materials	X →	X		Highly skilled required. Mac seldom needed painting is of finishing requ
Yes								X			
No	Possible in secondary operation									X	
No	Unless perforated blanks						Finishing	X			
							Scrap Loss		X		
Yes	Should be as shallow as possible	2-8	X →		X		Raw Materials	X →		X	Molds must be accurate. Vir scrap waste or required.
Yes	Only with nonpermanent mandrels						Tooling			X	
No							Direct Labor		X →	X	
Yes							Finishing	X			
							Scrap Loss	X			
Yes	At moderate cost	5-50			X	Minimum of 1000 pieces for automatic machines, excellent for quantities in the millions.	Raw Materials	X →	X		Because operat matic, one man several machin can be high be removed in mac
Yes							Tooling	X			
No							Direct Labor	X			
Yes							Finishing	X			
							Scrap Loss	X →		X	

RING PROCESSES

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PRINCIPAL ELEMENTS	EXPECTED COST: LOW	MEDIUM	HIGH	NOTES	APPROXIMATE PRODUCTION RATE	APPROXIMATE PRODUCTION LEAD TIME	PROCESS REPEATABILITY (95% Confidence Level) GOOD PARTS PER 100
Raw Materials	X →	→ X		Labor cost is lowest of the forging processes. Finish and scrap cost are often less than for other forging processes.	250 to 80 parts/hour	6 weeks	95
Tooling			X				
Direct Labor		X					
Finishing		X					
Scrap Loss		X					
Raw Materials	X →	→ X		Labor and finish costs are low because the entire process is virtually automatic.	8000 to 5000 parts/hour	6 to 10 weeks	95
Tooling		X					
Direct Labor	X						
Finishing	X						
Scrap Loss	X						
Raw Materials		X		Little skilled labor is required. Many parts do not require machining.	700 to 400 parts/hour	6 to 10 weeks	99
Tooling		X					
Direct Labor	X						
Finishing	X						
Scrap Loss	X						
Raw Materials		X		Extruded metals are easily machined; however, deburring or tumbling are sometimes the sole finishing operation.	800 to 200 feet/hour	4 weeks	99
Tooling	X →	→ X					
Direct Labor	X						
Finishing	X						
Scrap Loss	X						
Raw Materials	X →	→ X		Tooling is high because rolls are expensive. The process is automatic with scrap loss due to the cutting of sections.	4000 to 1500 feet/hour	11 to 14 weeks	99
Tooling			X				
Direct Labor	X						
Finishing	X →	→ X					
Scrap Loss	X						
Raw Materials	X →	→ X		Blanking residue can be minimized by "nesting" and careful sizing of stock.	500 to 15 parts/hour	10 to 14 weeks	99
Tooling		X →	→ X				
Direct Labor	X →	→ X					
Finishing	X						
Scrap Loss		X →	→ X				
Raw Materials	X →	→ X		Highly skilled craftsmen are required. Machining is seldom needed. Cleaning and painting is often the only finishing required.	30 to 2 parts/hour	2 to 4 weeks	95 to 99
	X						
			X				
Finishing	X						
Scrap Loss		X					
Raw Materials	X →	→	→ X	Molds must be dimensionally accurate. Virtually no scrap waste or finishing is required.	60 to 1 parts/hour	6 weeks	99
Tooling			X				
Direct Labor		X →	→ X				
Finishing	X						
Scrap Loss	X						
Raw Materials	X →	→ X		Because operations are automatic, one man can operate several machines. Scrap loss can be high because metal removed in machining is waste.	2000 to 80 parts/hour	5 to 7 weeks	99
Tooling	X						
Direct Labor	X						
Finishing	X						
Scrap Loss	X →	→	→ X				

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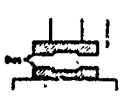
PROCESS FORM	PRODUCT CHARACTERISTICS	TYPICAL APPLICATIONS	EXPECTED TOLERANCES	
			GENERAL	TOLERANCE, IN.
SAND CASTING Green Sand: The mold cavity is formed by the packing of moist, bonded sand around a wooden or metallic pattern. This pattern is removed and molten metal poured into the cavity. The mold is destroyed after solidification of the castings.	PRO - Few material, size, or shape limitations; low tooling cost and lead time, high intricacy. CON - Tolerance limitations; finish machining necessary, finger projections impractical; some alloy restrictions.	Crankshafts, cylinder heads, manifolds, connecting rods, axles, machine tool bases and housings, valves, fittings, dies, water pipe, hand tools, bearings	Dimensional Draft allowance In pockets	±0.015 to ±0.250 1-3 degrees 3-10 degrees
Dry Sand The process is the same as above except the mold surfaces are given a refractory coating and dried before the mold is closed for pouring.	PRO - Finger Projections possible. CON - Size range more limited.	Large crankshafts, water pipes, axles, fittings, hand tools.		
SHELL MOLD CASTING A thermosetting plastic resin bond is mixed with a fine dry sand which is deposited on a heated pattern. The shell halves are stripped off and assembled. The shell is broken away from the finished casting.	PRO - High dimensional accuracy and surface finish, rapid production rate, good grain structure. CON - Size and material limitations; expensive patterns, equipment, and resin binder.	Crankshafts, camshafts, gears, valves, fittings, hardware, small aircraft components.	Dimensional Across parting line Draft allowance In pockets	±0.003 to ±0.062 ±0.005 to ±0.015 1/4-1 degrees 1-2 degrees
PLASTER MOLD CASTING Plaster slurry is poured over the pattern and allowed to set. The pattern is removed and the mold baked. The mold is destroyed after solidification of the casting.	PRO - High dimensional accuracy surface finish, and intricacy; low porosity. CON - Size and material limitations, time consuming process.	Gears, ratchet teeth, cams, pistons, wing nuts, locks, valves, hand tools, electric parts. Materials - Nonferrous metals	Dimensional Flatness Draft allowance In holes and pockets	±0.005 to ±0.010 ±0.007 to ±0.015 for surface larger than 6 in. sq. 1/2-3 degrees 0 degrees
INVESTMENT CASTING The mold cavity is formed by a wax, plastic, or frozen mercury pattern covered with a plaster investment. The pattern is melted out either before or during the baking of the plaster mold. The mold is destroyed after solidification of the casting.	PRO - Few material limitations, high dimensional accuracy, surface finish (highest with frozen mercury), and intricacy. CON - Size limitations; expensive patterns and molds, high labor cost.	Turbine blades, aircraft combustion chambers, sewing machine parts, hinges, numbering wheels, gears, cams. Materials - Mainly ferrous and nonferrous alloys	Dimensional Draft allowance	±0.002 to ±0.062 0-1/2 degrees
PERMANENT MOLD CASTING The mold cavity is machined into metal die blocks. The mold consist of two or more dies hinged and clamped together for easy removal of the casting. The mold is gravity fed.	PRO - High dimensional accuracy surface finish, and grain structure, repeated use of mold; low material waste and porosity. CON - Size, shape, and intricacy limitations; high tooling cost, high melting metals restrictions.	Cylinder heads, pistons, cylinder blocks, bolts, gear blanks, flat iron base plates, bearings, levers, impellers, auto brake cylinders.	Dimensional Draft allowance In pockets	±0.010 to ±0.062 2-3 degrees 4-5 degrees
DIE CASTING Molten metal is injected at high pressures into a split metal die.	PRO - Very high surface finish, dimensional accuracy, and intricacy; rapid production rate. CON - Size and material limitations; high tooling cost	Motors, office equipment, optical equipment. Materials - Usually zinc, aluminum, brass, tin, or magnesium.	Dimensional Across parting line Draft allowance	±0.001 to ±0.005 ±0.003 to ±0.010 2-5 degrees
CONTINUOUS CASTING Molten metal is continuously gravity-fed into a mold. The metal is rapidly cooled and withdrawn.	PRO - Rapid production rate; good mechanical properties, materials that cannot be extruded; no porosity or casting defects. CON - Material, shape, and cross-sectional area limitations.	Tubular parts, bushings, gears, seals, bearings. Materials - Mainly bronze	Dimensional Straightness	±0.005 to ±0 069 ±0.250/5ft
CENTRIFUGAL CASTING Molten metal is poured into a hollow cylinder mold spinning about a horizontal and vertical plane. The molten metal is held in place by centrifugal force.	PRO - Rapid production rate; few size limitations, good soundness and cleanliness. CON - Shape limitations, expensive equipment.	Pipes, rails, piston rings, bearings, bushings, gear blanks, wheels, stator shells, large gun barrels, cylinder liners, brake drums.	Dimensional Draft allowance	±0.031 to ±0.125 0-3 degrees
POWDER METALLURGY Powdered metal is placed in a mold and compressed. The formed part is then sintered in a furnace to a point below the melting point of its principal constituent.	PRO - High surface finish and tolerances; controlled properties; low material waste; use of difficult to alloy materials; self-lubricating properties. CON - Size and shape limitations	Metal filters, cams, self-lubricating bearings, gears, air diffusers, liquid separators.	Diameter Length Draft allowance Concentricity, TIR	1.5..+0.001-0.000 3.0..+0 002-0.000 6.0..±0 005-0.000 Small..+0.010-0.000 Large..+0.020-0.000 0 degrees 1.5dia...... ..±0.003 6.0dia.........±0.007
OPEN DIE FORGING The upper half of a die is raised and allowed to drop on heated metal placed over the lower half of the die. 	PRO - Few size limitations; inexpensive and simple tools; good strength characteristics. CON - Shape and tolerance limitations; finish machining necessary; high skill level and material waste.	Connecting rods, axles, crankshafts, discs, gear-blanks, pinion blanks, hooks, nuts, spindles.	Draft allowance	5-10 degrees
CLOSED DIE FORGING Heated metal is compressed between two dies forcing metal into its cavities. 	PRO - More intricacy and better properties than open die forging; high dimensional accuracy and process repeatability; low material waste. CON - Finish machining necessary.	Crankshafts, railroad car wheels, wing spars, landing gear support ribs, propeller shafts.	Thickness Shrinkage	+0.024-0.008 to -0.038+0.114 ±0.003
BLOCKER DIE FORGING Single impression dies employed.	PRO - Rapid production rate; lowest tooling cost. CON - Finish machining necessary; thick webs and large fillets.		Die wear	±0.003/2 lb weight of forging
CONVENTIONAL DIE FORGING Utilizes preblocked workpieces.	PRO - Less machining requirements. CON - Higher tooling cost.		Fillet and Corners Draft allowance	±0.090 to ±0.250 0-5 degrees
PRECISION DIE FORGING Permits minimum draft angle.	PRO - Closest tolerance, and least machining and material waste, thin webs and flanges. CON - Highest tooling cost.		Mismatching	±0.010 + ±0.002/6 lb weight of forging

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in.	MACHINE FINISH ALLOWANCE	APPROXIMATE THICKNESS			APPROXIMATE SIZE		GEOMETRY CHARACTERISTIC	
	Iron 0.094 to 0.375 in.	Min	0.1875 in.	Max	20 to 30 tons	Bosses	Yes	
	Steel 0.125 to 0.250 in.	Medium parts	0.250 to 0.500 in.	Min	Ounces	Undercuts	Yes	
	Nonferrous 0.062 to 0.250 in.	Large parts	0.438 to 0.563 in.	Max	5000 to 6000 pounds	Inserts	Yes	
				Min	Ounces	Holes	0.187 to 0.250 in.	Minimum diameter
	Not usually required	Min	0.0625 in.	Max	200 pounds	Bosses	Yes	
						Undercuts	Yes	
				Min	Ounces	Inserts	Yes	
						Holes	0.125 to 0.250	Minimum diameter
for an 6	0.031 in.	Min	0.040 in.	Max	200 pounds	Bosses	Yes	At moderate cost
						Undercuts	Yes	
		Large parts	0.053 in.	Min	Ounces	Inserts		
						Holes	0.500 in.	Minimum diameter
	0.010 to 0.025 in.	Min	0.020 in.	Max	100 pounds	Bosses	Yes	With an increase in skill le
						Undercuts	Yes	At a much higher cost
		Large parts	0.375 in.	Min	Ounces	Inserts		
						Holes	0.020 to 0.050 in.	Minimum diameter
	0.031 to 0.125 in.	Min	0.125 in.	Max	50 pounds	Bosses	Yes	
						Undercuts	Yes	
				Min	Ounces	Inserts	Yes	
						Holes	0.187 to 0.250 in.	Minimum diameter
	0.031 to 0.065 in.	Min	0.031 in.	Max	75 pounds	Bosses	Yes	
						Undercuts	Yes	At large cost and slower pro
		Large parts	0.313 in.	Min	Ounces	Inserts	Yes	At considerable decrease in p
						Holes	0.031 to 0.094 in	Minimum diameter
	0.031 to 0.094 in.	Min	0.125 in.	Max	9 in. length	Bosses	Yes	
						Undercuts	Yes	
				Min	1/2 in. length	Inserts	No	
						Holes	0.125 in.	Minimum diameter; only in direction of casting
	Ferrous 0.094 to 0.250 in.	Min	0.250 in.	Max	200 pounds	Bosses	Yes	With an increase in skill level
						Undercuts	No	
	Nonferrous 0.062 to 0.250 in.	Large parts	4 in.	Min	Ounces	Inserts	Yes	
						Holes	1 in	Minimum diameter
00 00		Min. Cylindrical Sections	0.050 in.	Max	12 in. diameter by 9 in. length	Bosses	Yes	
						Undercuts	No	Possible in secondary operat
C) 07		Min Flat Sections	0.032 in.	Min	1/16 in. diameter by 1/32 in. length	Inserts	Yes	But difficult and should be
						Holes	Yes	Holes less than 3/16 in. will crease tooling cost
	0.031 to 0.375 in.			Max	10,000 pounds			
				Min	Ounces			
	0.031 to 0.375 in.			Max	30 pounds			
lb				Min	Fraction of an ounce			

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ARACTERISTICS	SURFACE SMOOTHNESS, μ in. rms	OPTIMUM LOT SIZE: Small	Medium	Large	Note	EXPECTED COSTS: PRINCIPAL ELEMENTS	LOW	MEDIUM	HIGH	NOTES
	250-1000	X→	→	X	10 to 10,000 pieces	Raw Materials	X→	X		Requires much hand labor. Scr can usually be remelted.
						Tooling	X			
						Direct Labor	X→	→	X	
						Finishing			X	
inimum diameter						Scrap Loss		X		
	50-250			X		Raw Materials	X→	X		Only a minimum of surface finishing is required.
						Tooling	X→	X		
						Direct Labor	X			
						Finishing	X			
nimum diameter						Scrap Loss	X			
moderate cost	30-50	X→	X		100 to 2000 pieces, is best suited for small production lots	Raw Materials		X		Many skilled operators are required. Little machining is necessary and most scrap can be remolted.
						Tooling		X		
						Direct Labor			X	
						Finishing	X			
nimum diameter						Scrap Loss	X			
th an increase in skill level	20-85	X→	→	X	Up to several thousand pieces but is particularly suited for small production lots	Raw Materials			X	Tooling cost depend upon availability of model. Many skilled operators are required; however, machining is usually unnecessary and most scrap can be remelted.
a much higher cost						Tooling	X→	X		
						Direct Labor			X	
						Finishing	X			
nimum diameter						Scrap Loss	X			
	100-250			X	In the thousands	Raw Materials		X		Small or no machining is neede Applied coatings go on well. Scrap can usually be remelted.
						Tooling			X	
						Direct Labor		X		
						Finishing	X			
nimum diameter						Scrap Loss	X			
	40-100			X	1000 to hundreds of thousands	Raw Materials		X		Die costs are more expensive other casting methods. Typical die costs are from $200 to $3, Very little trimming is necess and scrap can usually be remel
large cost and slower production rate						Tooling			X	
considerable decrease in production rate						Direct Labor	X→	X		
						Finishing	X			
nimum diameter						Scrap Loss	X			
	125-150	X		X		Raw Materials	X→	X		Tooling cost is among the lowest of all processes using dies. The process is automatic with scrap loss resulting from the straightening and cutting.
						Tooling	X			
						Direct Labor	X			
						Finishing	X→	X		
nimum diameter; only in rection of casting						Scrap Loss	X			
th an increase in skill vel	100-500	X→	X		Minimum of a hundred pieces	Raw Materials		X		Tooling cost is low because molds are relatively simple.
						Tooling	X			
						Direct Labor	X→	X		
						Finishing	X			
nimum diameter						Scrap Loss	X			
	5-50			X	Minimum of 5,000 pieces; however, small runs are sometimes successful.	Raw Materials	X→	→	X	Machining is difficult but seldom needed. There is virtually no waste metal in the process.
ble in secondary operation						Tooling	X→	→	X	
difficult and should be avoided						Direct Labor	X			
						Finishing	X			
es less than 3/16 in. will increase tooling cost.						Scrap Loss	X			
	150-175			X	10,000 to 100,000 pieces, but often satisfactory for small lots.	Raw Materials	X			Typical die costs are $100 to $1,000. Skilled labor is required for heating, hammer work, and finishing.
						Tooling			X	
						Direct Labor		X→	X	
						Finishing			X	
						Scrap Loss			X	
	125-150		X→	X	Minimum of 1000 pieces	Raw Materials	X→	X		Finishing and scrap waste are high due to the poor utilization of materials.
						Tooling	X			
						Direct Labor		X		
						Finishing			X	
						Scrap Loss			X	
						Raw Materials	X→	X		All forgings have scaled surfaces which are usually removed.
						Tooling		X		
						Direct Labor		X		
						Finishing		X		
						Scrap Loss		X		
						Raw Materials	X→	X		Tooling cost is high because dies must be accurate.
						Tooling			X	
						Direct Labor				
						Finishing	[illegible]			

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PRINCIPAL ELEMENTS	EXPECTED COSTS LOW	MEDIUM	HIGH	NOTES	APPROXIMATE PRODUCTION RATE	APPROXIMATE PRODUCTION LEAD TIME	PROCESS REPEATABILITY (95% Confidence Level) GOOD PARTS PER 100
Raw Materials	X →	X		Requires much hand labor. Scrap can usually be remelted.	35 molds/day to 1/10 mold/day	4 to 8 weeks	90
Tooling	X						
Direct Labor	X →	→	X				
Finishing			X				
Scrap Loss		X					
Raw Materials	X →	X		Only a minimum of surface finishing is required.	200 to 8 molds/hour	5 to 6 weeks	90
Tooling	X →	X					
Direct Labor	X						
Finishing	X						
Scrap Loss	X						
Raw Materials		X		Many skilled operators are required. Little machining is necessary and most scrap can be remelted.	35 to 10 molds/hour	5 weeks	90
Tooling		X					
Direct Labor			X				
Finishing	X						
Scrap Loss	X						
Raw Materials			X	Tooling cost depend upon availability of model. Many skilled operators are required; however, machining is usually unnecessary and most scrap can be remelted.	30 to 2 molds/hour	4 to 5 weeks	90
Tooling	X →	X					
Direct Labor			X				
Finishing	X						
Scrap Loss	X						
Raw Materials		X		Small or no machining is needed. Applied coatings go on well. Scrap can usually be remelted.	100 to 8 parts/hour	7 to 10 weeks	90
Tooling			X				
Direct Labor		X					
Finishing	X						
Scrap Loss	X						
Raw Materials		X		Die costs are more expensive than other casting methods. Typical die costs are from $200 to $3,000. Very little trimming is necessary and scrap can usually be remelted.	1200 to 100 injections/hour	12 to 14 weeks	90 to 95
Tooling			X				
Direct Labor	X →	X					
Finishing	X						
Scrap Loss	X						
Raw Materials	X →	X		Tooling cost is among the lowest of all processes using dies. The process is automatic with scrap loss resulting from the straightening and cutting.	10 to 5 tons/hour		
Tooling	X						
Direct Labor	X						
Finishing	X →	X					
Scrap Loss	X						
Raw Materials		X		Tooling cost is low because molds are relatively simple.	2000 parts/hour to 50 parts/day		
Tooling	X						
Direct Labor	X →	X					
Finishing	X						
Scrap Loss	X						
Raw Materials	X →	→	X	Machining is difficult but seldom needed. There is virtually no waste metal in the process.	2500 to 800 parts/hour	9 to 10 weeks	95
Tooling	X →	→	X				
Direct Labor	X						
Finishing	X						
Scrap Loss	X						
Raw Materials	X			Typical die costs are $100 to $1,000. Skilled labor is required for heating, hammer work, and finishing.	800 to 75 parts/hour	10 to 12 weeks	95
Tooling			X				
Direct Labor		X →	X				
Finishing			X				
Scrap Loss			X				
Raw Materials	X →	X		Finishing and scrap waste are high due to the poor utilization of materials.			
Tooling	X						
Direct Labor		X					
Finishing			X				
Scrap Loss			X				
Raw Materials	X →	X		All forgings have scaled surfaces which are usually removed.	800 to 75 parts/hour	10 to 12 weeks	95
Tooling		X					
Direct Labor		X					
Finishing		X					
Scrap Loss		X					
Raw Materials	X →	X		Tooling cost is high because dies must be accurate			
Tooling			X				
Direct Labor							
Finishing	X						
Scrap Loss	X						

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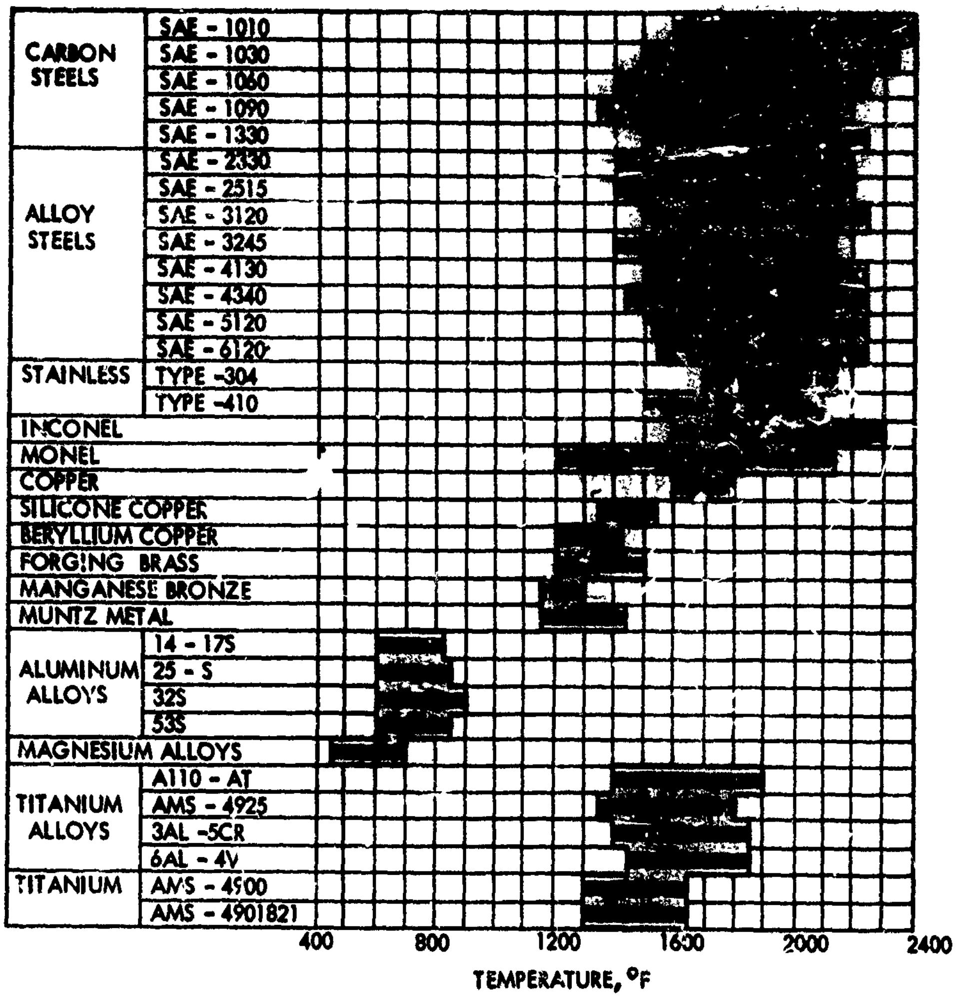

FIGURE 10-1. Forging Temperature Ranges for Various Materials

Contour rolling is a specialized forging method for the distribution of hot metal over large areas for relatively thin parts having various types of integral stiffening. The configurations may be uniform (symmetrical about a center-line) such as longitudinal ribs or panels, transverse ribs or panels, and isogon patterns (waffle-like); or they may be completely asymmetrical with ribs, panels, and bosses placed only in accordance with the stress and attachment requirements of the part.

The largest contour rolling mills currently (1967) in operation are capable of producing parts up to 30 inches wide and 72 inches long. A minimum section thickness of about 0.050 inch and a maximum thickness of up to 2 inches or more are obtainable. Schematic sketches of the operation are shown in Fig. 10-2. Contour rolling combines the advantages of conventional rolling and extruding actions to produce varied configurations over relatively large areas not otherwise economically obtainable. Typical contour rolled components are landing gears, bulkheads, turbine blades, propeller blades, and jet engine rings and shrouds.

The normal surface finish range for forged parts is from 125 to 250 microinches. The surface finish quality is dependent upon the quality of the die surfaces, cleanliness and surface condition of the blank, and the prevention of scaling during heating and forging. Normal tolerances for precision forgings range from +0.030 inch to -0.010 inch, depending upon the part configuration and production method. Finer finishes are possible by coining at room temperature or at temperatures from 800° to 1400°F. Dimensional tolerances as close as ±0.005 inch and as low as ±0.002 inch are obtainable by this process.

A special case of forging is high energy rate forming, in which metal parts are formed by the application of high pressures resulting from either a high velocity or

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a high force process. Since the energy transmitted to the part is proportional to the square of the velocity but only directly proportional to the force, high velocity processes are commonly used. Table 10-2 lists the characteristics of some of these metalworking processes, while Fig. 10-3 shows a schematic of the electrohydraulic process.

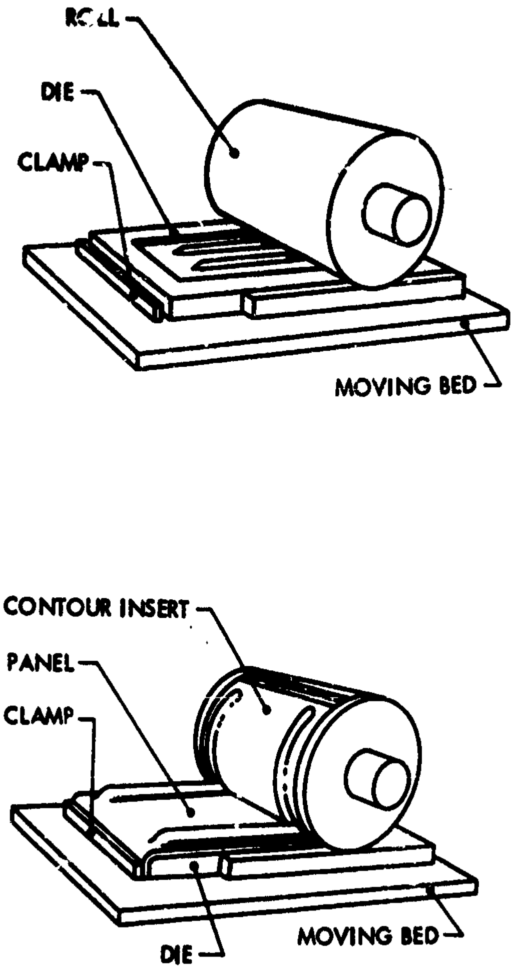

FIGURE 10-2. Contour Rolling

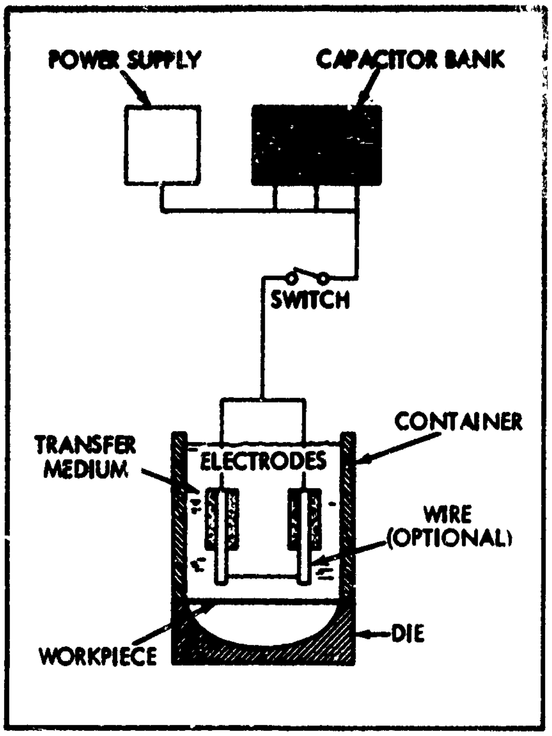

FIGURE 10-3. Components in Electrohydraulic Metalworking

Explosive metalworking operations can generally be classified as "confined" or "unconfined" systems. The confined system has distinct advantages for forming thin materials to close tolerances. However the operation imposes a size limitation. Unconfined systems are less efficient since only a small portion of the total energy from the explosive is utilized in the forming operation. However, the method is advantageous for large pieces or short runs since tooling requirements are greatly simplified. As illustrated in Fig. 10-4, the operation is performed underwater. The water acts as a ram and evenly transmits pressure to the metal causing it to flow against the die contour. A wide variety of explosives and detonators are used in such operations.

Positioning the explosive in the proper relation to the workpiece is achieved by a number of routine methods. Depending on the material to be formed, the water transfer medium may require treatment to prevent corrosion.

Materials are generally formed with explosives in an annealed condition and at ambient temperatures. Intermediate anneals may also be employed between successive forming operations. In some cases, stress-relieving treatments are required immediately after forming to prevent delayed cracking from residual stresses. For titanium and refractory metals, forming at elevated temperatures is desirable.

Explosive forming has been used most widely for producing parts from sheet metal. The maximum size of parts which can be formed is limited only by the size of tooling that can be constructed. Tolerances as close as ± 0.001 inch can be achieved on small parts, but working tolerances are normally ± 0.010 inch. Austenitic and precipitation-hardening stainless steels, and aluminum alloys have been formed with very little dif-

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TABLE 10-2. CHARACTERISTICS OF HIGH-VELOCITY METALWORKING PROCESSES

CONSIDERATIONS	HIGH EXPLOSIVE - STANDOFF	HIGH EXPLOSIVE - DIRECT CONTACT	PROPELLANT CLOSED DIE	GAS MIXTURES -	
				COMBUSTION	DETONATION
Metalworking Operations	Draw forming, expanding, flanging, stretch forming, coining, blanking, sizing, beading.	Hardening, welding, cutting, perforating, cladding, powder compacting.	Tube bulging, powder compacting, sizing, perforating, flanging.	Tube bulging, flanging, sizing, stretch forming, draw forming.	Draw forming, stretch forming.
Size Limitations	Limited only by available blank size, presently approximately 12 feet.	Part size not limiting.	1 inch to 5 feet diameter. Limited by equipment.	Up to 5 feet	Present: 1 foot diameter. Future: 9 feet diameter.
Shape Complexity	Small and intricate, large and simple.	Simple shapes.	Compound surfaces, non-symmetrical shapes.	Compound surfaces, nonsymmetrical shapes.	Simple dishes, domes, surfaces of revolution.
Principal Advantage	Neither pressure nor energy limited; i.e., large parts.	Extremely high pressures (1.5 to 7 million psi).	Reduces number of operations to produce complex parts.	Uniform pressures permitting accurate forming of thin parts.	Adaptability to production forming.
Capital Investment	Low.	Low.	Low.	Moderate.	Moderate to high.
Tooling Costs	Low.	None to low.	Moderate.	Moderate to high.	Moderate.
Labor Costs	High.	Moderate.	Low to moderate.	Moderate to high.	Moderate.
Production Rate	0.5 to 4 parts per hour or less depending on part and facility.	0.5 to 4 parts per hour depending on part and facility.	2 to 12 parts per hour depending on part and facility.	2 parts per hour or less	6 to 12 parts per hour.
Energy Costs	Low.	Low.	Low.	Low.	Very Low.
Leadtime Required to Place Facility in Operation	Short.	Short.	Short.	Moderate	Moderate to long.
Safety Considerations	Operation with trained personnel, safety equipment, and shielding.	Trained personnel.	Trained personnel.	Trained or experienced personnel.	Trained or experienced personnel.
Facility Location	Usually requires remote or special facility.	Field or plant.	In-plant or separate facility.	Separate facility.	In-plant.
Energy Range	Detonator to approximately 100 pounds high explosive at 1-2 x 10^6 ft-lb per lb	0.5 to 8 lb per ft^2 high explosive.	Low to moderate (squib, smokeless cartridge).	Low (burning gas mixtures).	Low to moderate (detonation wave in gas).
Workpiece Deformation Velocity	60 to 400 ft/sec	Not applicable.	50 to 200 ft/sec	60 to 100 ft/sec	60 to 200 ft/sec
Energy Transfer Medium	Water, elastomers, sand, molten salts.	Direct contact or buffer material.	Air or water, high velocity projectile or ram.	Gas pressure.	Gas pressure.

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TABLE 10-2. CHARACTERISTICS OF HIGH-VELOCITY METALWORKING PROCESSES (CONT'D)

CONSIDER-ATIONS	ELECTROMAGNETIC	ELECTROHYDRAULIC		
		EXPLODING BRIDGEWIRE	SPARK DISCHARGE	PNEUMATIC MECHANICAL
Metalworking Operations	Swaging, tube bulging sizing, flanging, shallow drawing, coining, blanking.	Tube bulging, drawing, flanging, coining, blanking, sizing.	Tube bulging, drawing, flanging, coining, blanking, sizing.	Forging, powder compacting, extruding.
Size Limitations	1 inch to 1 foot diameter; 4 feet diameter and larger in sizing operations.	1/4 inch to greater than 4 feet diameter	1/4 inch to greater than 4 feet diameter	Up to 2 feet diameter; larger on future machines.
Shape Complexity	Compound surfaces, corrective forming on large complex shapes.	Complex surfaces and shapes, especially tubular.	Complex surfaces and shapes, especially tubular.	Complex shapes, thin forged sections.
Principal Advantage	Controllability and repeatability, swaging operations.	Controllability and repeatability.	Controllability and repeatability.	Controllability and repeatability, close tolerances on forgings.
Capital Investment	Moderate to high.	Moderate.	Moderate.	Moderate.
Tooling Costs	High if work coil is regarded as part of tooling.	Low.	Low.	Moderate.
Labor Costs	Moderate.	Moderate.	Moderate.	Moderate.
Production Rate	Up to 1,000 parts per minute for simple parts and automated transfer equipment.	4 to 12 parts per hour or more depending on part complexity and equipment.	Up to approximately 50 parts per hour depending on part complexity and equipment.	Up to about 200 to 300 parts per hour with automatic equipment; depends on part complexity.
Energy Costs	Moderate.	Moderate.	Moderate.	Low.
Leadtime Required to Place Facility in Operation	Moderate to long.	Moderate to long.	Moderate.	Moderate.
Safety Considerations	Equipment interlocks, high voltage safety practices, trained personnel.	Equipment interlocks, high voltage safety practices, trained personnel.	Equipment interlocks, high voltage safety practices, trained personnel.	Guards and shields, trained personnel.
Facility Location	In-plant.	In-plant.	In-plant.	In-plant.
Energy Range	4500 to 175,000 ft-lb	20,000 to 175,000 ft-lb	10,000 to 100,000 ft-lb	Up to 500,000 ft-lb
Workpiece Deformation Velocity	50 to 200 ft/sec	50 to 200 ft/sec	50 to 200 ft/sec	50 to 200 ft/sec
Energy Transfer Medium	Air (could be operated in vacuum).	Water or other suitable liquid.	Water or other suitable liquid.	High velocity ram.

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ficulty. Work-hardened stainless steels are also readily formed with explosives. Through proper scheduling of preparatory work and annealing, optimum shapes may be formed with very little difficulty and optimum mechanical properties can be obtained after forming. In contrast, carbon steels can withstand only limited deformation.

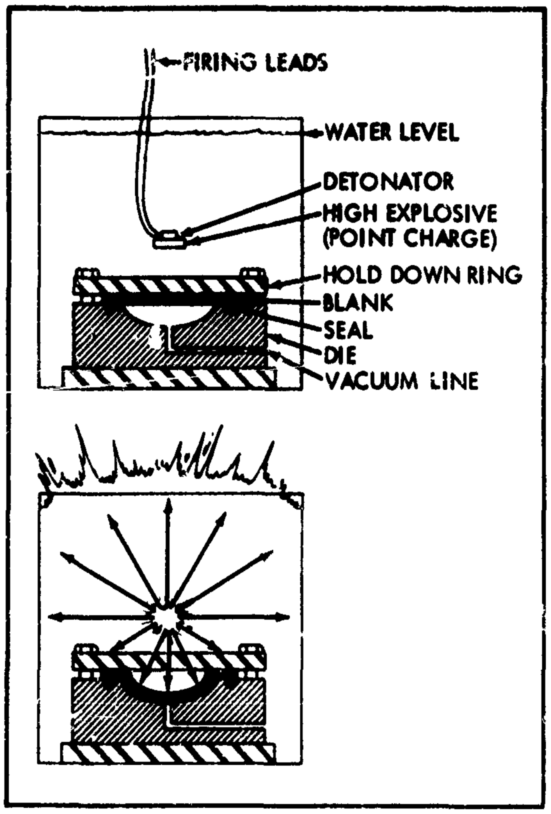

FIGURE 10-4. Schematic Diagram of the Explosive Forming Process

10-2.3 EXTRUSION

The continuous extrusion process yields many possibilities not economically attainable by other production methods. These include re-entrant angles and undercuts, thin wall tubing of large diameter, variations in section thickness, and many others. Although the designer has considerable freedom in placing metal where it will be most effective, there are some things that must be avoided in good extrusion design. The following give some indications of designs which should be avoided.

(1) Very thin sections with large circumscribing area.

(2) A thick wedge tapering to a thin edge. The metal will not fill the thin edge of the die properly during extrusion.

(3) A thin leg attached to a thick body of an extrusion should be limited to a length not exceeding ten times the leg thickness.

(4) Semi-closed shapes requiring long, thin die tongues.

(5) Hollow shapes with asymmetrical voids, or the voids having inadequate section thickness between them.

(6) Sharp outside corners. These result in excessive stress concentration and breakage of the die.

(7) Thin sections that must have close space tolerances.

Some of the advantages of the extrusion process include the following:

(1) Utilizes metal to maximum advantage, and provides maximum structural and mechanical properties.

(2) Permits extensive plastic working at elevated temperatures, producing a dense and homogeneous product, free from porosity, and having favorable grain flow characteristics.

(3) Encourages efficient production of large diameter, thin-walled tubular products having excellent concentricity and tolerance characteristics.

(4) Lowers machinery costs with attendant savings in material.

(5) Permits relatively economic die design as compared to forging and some drawing methods, thus allowing good application to short production runs and to design revisions.

(6) Consolidates several individually fabricated pieces into a single extrusion.

Impact extrusion is a combined forging and extrusion operation in which a slug is held in a die and transformed into the desired shape by a descending punch. The metal is plastically deformed, flowing into the impressions in the die and through the die orifice. A diagram illustrating the process is shown in Fig. 10-5.

10-3 SECONDARY FABRICATION PROCESSES

Secondary fabrication processes are shown in Appendix C. They generally encompass the material removal, cutting, and forming operations performed on material to bring it to the dimensions of the finished part.

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10-3.1 MATERIAL REMOVAL

Material removal operations include grinding and the various types of machining. Machining methods have been broken down into conventional mechanical machining, and the less common machining methods such as chemical milling, electrical discharge machining, electrochemical machining, and others.

The most common material removal method is that performed by mechanical machining. A wide variety of standard and special machine tools have been developed to control workpiece and cutting tool movement, thereby producing flat or curved surfaces as required. These basic motions are illustrated in Fig. 10-6.

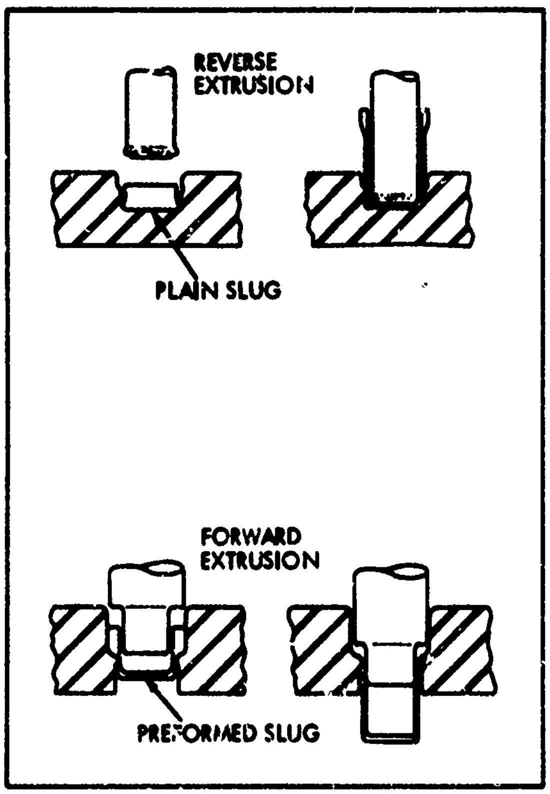

FIGURE 10-5. Impact Extrusion

Table 10-3 lists some of the normal machining processes and the machine tool or tools which normally perform each process. In a production environment, one of these machine tools will prove to be best suited for a specific job even though the operation could be performed on another tool.

Before discussing each of these mechanical processes, machinability and its influence on machining methods should be mentioned.

10-3.1.1 Machinability

Machinability has been defined as "a complex property of a material that controls the facility with which it can be cut to the size, shape, and surface finish required". This definition has been extended and interpreted in various numerical machinability ratings providing a basis for comparing the relative machinability of materials by indicating increasing machinability through increasing index ratings. The most widely

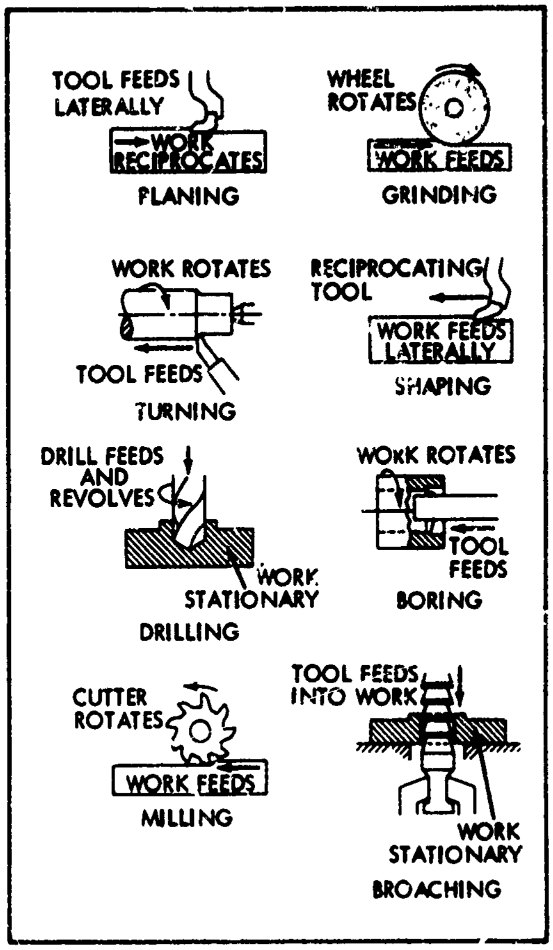

FIGURE 10-6. Basic Machine Tool Motions for Removing Material

known index is that of steel, which rates B1112 as 100 when turned under certain specified operating conditions. The copper machinability index uses free brass as 100, and the tool steel index uses W-1 tool steel as 100. These ratings are meant to apply to twining only; even then, they are limited in their usefulness. In the case of steel, tests have been conducted on lots of the index steel B1112, and it has been determined that actual

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TABLE 10-3. MACHINING OPERATIONS AND STANDARD MACHINE TOOLS

BORING	TURNING	DRILLING	MILLING	BROACHING
BORING MILL: Vertical Horizontal Precision ENGINE LATHES TURRET LATHES BAP MACHINES DRILL PRESSES MILLING MACHINES JIG BORER	LATHES: Engine Gap-frame Facing Duplicating Tracer Turret SCREW MACHINE SWISS-AUTOMATIC	DRILL PRESS: Hand Feed Power Feed TURRET LATHE RADIAL DRILLING MACHINES DRILLING MACHINES: Multiple Spindle Turret Gang Horizontal	MILLING MACHINES: Knee & Column Ram Type Rotary Head PLANER-MILLERS BED TYPE MILLERS	BROACHING MACHINES: Horizontal Vertical Pull-up Vertical Pull-down Vertical Single Ram Vertical Dual Ram Chain Type Surface Rotary
SHAPING	PLANING	TREPANNING	TAPPING	GRINDING
SHAPERS: Horizontal Vertical SLOTTERS	PLANERS: Open-Side Double-Housing Convertible Milling Double Cut	DRILL PRESS ENGINE LATHE TURRET LATHE	TAPPING MACHINES: Single Spindle Multiple Spindle Gang TURRET LATHE DRILL PRESS	GRINDING MACHINES: Cylindrical Centerless Surface Chucking - Internal Centerless - Internal Special

machinability varies from as much as 20% below to 60% above the nominal index figure. This is caused by the unintentional best allowable variations in carbon, sulfur, and silicon content found in the various heats.

In practice, it has been found that the machinability index is not reliable as a measure of productivity or economy in machining. It must be recognized that the relative economy of cutting two or more materials in a given operation (turning two steels of varying composition) is not necessarily the same as in another operation (tapping the two same steels). The machinability indices can be used as a guide to help an operator select a cutting speed for his first trial in machining a steel with which he is unfamiliar.

Fig. 10-7 compares the general machinability ranges for a number of metal alloys. Most metal handbooks and suppliers' brochures list the specific index obtained for most alloy compositions. Fig. 10-8 illustrates the influence of cutting speed on total cost per piece.

As a further source of data on machinability and the economics of machining, refer to AMC Pamphlet 700-1, *Logistics, Machining Data.*

10-3.1.2 Conventional Mechanical Machining Processes

Pertinent information on a number of conventional machining processes is presented in the paragraphs which follow.

10-3.1.2.1 Boring Operations

Boring is the generation of internal diameters about a spindle centerline with a single point cutting tool, to enlarge or finish holes or circular contours. Straight-through holes are most common; however, blind holes, stepped holes, holes with undercuts, or contoured holes can be bored. The minimum diameter for boring is about 0.250 inch; the maximum diameter is limited only by the size of the machine holding and rotating the workpiece.

Tolerances on large machines are:

(1) Bores 24 inches in diameter, +0.0005 to -0.0000 inch.

(2) Tolerances of ±0.001 inch on holes up to 6 inches, and greater limits on larger diameters are more producible.

(3) Hole location to ±0.0005 inch.

Tolerances on special production machines are:

(1) Small holes, ±0.0001 to ±0.0002 inch.

(2) Large bores (up to 15 inches), ±0.001 inch.

(3) Threads to a Class 3 fit.

Tolerances on jig borers are:

(1) Threads to a Class 4 fit.

(2) Hole location to 0.0001 inch.

10-3.1.2.2 Broaching Operations

Broaching is a machining process in which a cutting

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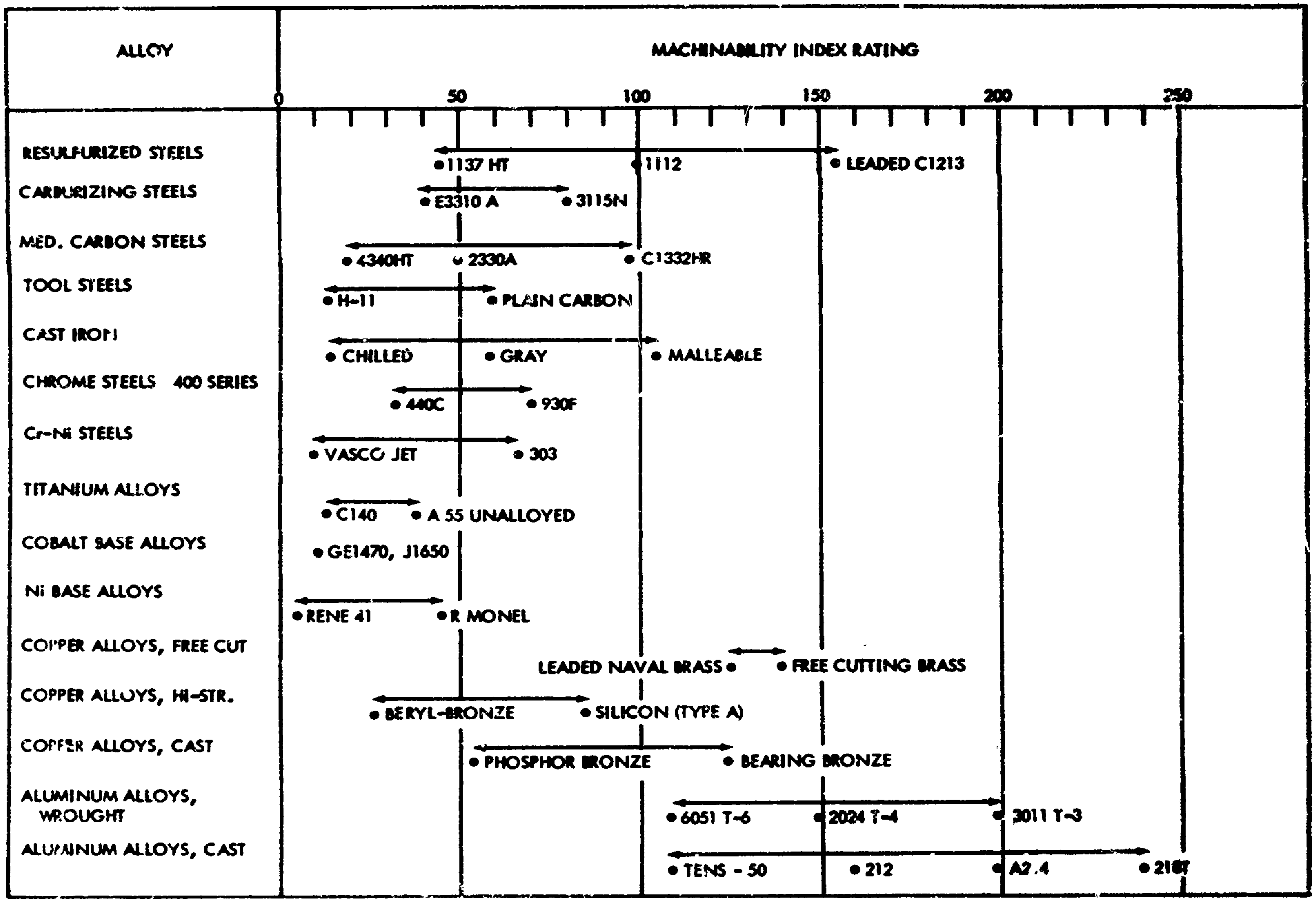

FIGURE 10-7. Comparison of Machinability Index Ratings for Some Selected Alloys

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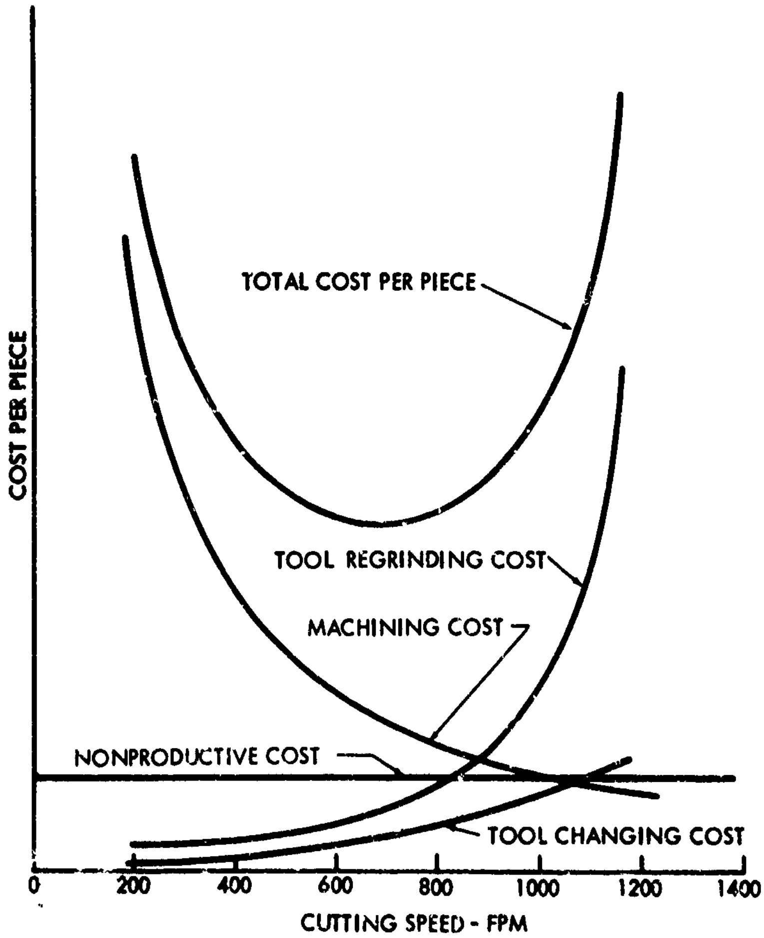

FIGURE 10-8. Total Cost Per Piece is the Sum of Tool Cost, Machining Cost, and Nonproductive Cost

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tool with multiple transverse cutting edges is pushed or pulled through a hole or over a surface to remove metal by axial cutting. Almost any surface can be broached if it is regular in the direction of broach travel, which must be in a straight line. The process is very adaptable to high production rates; however, broaching must be considered when designing parts if its benefits are to be realized.

The tolerances for the broaching process are:

(1) Round and square holes, ±0.0005 to ±0.001 inch.

(2) Plain splined holes, ±0.001 to ±0.002 inch on diameter and ±0.001 on spline width.

(3) Surfaces (straddle broached), ±0.001 inch; when design demands, ±0.0001 inch can be held on size and parallelism.

(4) Slots, ±0.0002 inch can be obtained; ±0.001 to ±0.002 inch is more economical.

(5) Surface finishes within 32 microinches are typical.

10-3.1.2.3 Drilling Operations

Drilling is performed by a rotary end-cutting tool with one or more cutting lips, and usually one or more flutes for the passage of chips and the admission of cutting fluid. This process is used to cut a hole in solid metal. Most holes drilled are in the diameter range of 1/8 to 1-1/2 inches; however, drills are obtainable for making holes ranging from 0.001 to 6 inches in diameter. It is recommended that drilled holes be produced, whenever practicable, by using standard diameter drills, of which there are five series, as follows:

(1) By decimal size, from 0.002 to 0.080 inch in half thousandths increments.

(2) By numbers, from 80 to 1, i.e., 0.0135 to 0.228 inch.

(3) By letters, from A to Z, i.e., from 0.234 to 0.413 inch.

(4) By fractions, from 1/64 to 3-1/2 inches in steps of 1/64 inch from 1/64 to 1-3/4 inches, steps of 1/32 inch from 1-25/32 to 2-1/4 inches, and steps of 1/16 inch from 2-5/16 to 3-1/2 inches.

(5) By millimeters, from 0.1 to 25 mm, in steps of 0.050 mm from 0.10 to 2.80 mm, steps of 0.10 mm from 0.10 to 10 mm, steps of 0.50 mm from 0.50 to 25.5 mm, and steps of 1.0 mm from 1 to 25 mm.

Close tolerances and smooth finishes cannot be maintained in normal drilling operations. Tolerances for drilling operations are:

(1) For twist drills up to one inch the hole may be as much as 0.003 over the normal drill size and as much as 0.005 out of round.

(2) For sizes larger than one inch the hole may be 0.010 oversize and 0.010 or more out of round. The finish of the holes over one inch will be rough. Close tolerances down to ±0.0002 inch may be maintained as desired by an additional reaming, honing, broaching, or grinding operation.

(3) With carbide gun drills a tolerance of ±0.0005 inch with a 5 to 8 microinch finish may be maintained without additional operation.

10-3.1.2.4 Generating or Gear Shaper Operations

This method of machining was developed primarily for generating gear teeth; however, its adaptability for generating eccentric shapes, cams, ratchets, and other unusual shapes has broadened its applications. A reciprocating cutting tool is used in conjunction with controlled movement of the workpiece (Fellows method), or the work is fixed while a reciprocating cutting head with individual teeth suited to the desired form being generated feeds in to produce the form (Shear-Speed method).

Precision tolerances are practical for production on Fellows or Shear-Speed shapers; however, commercial limits are perferable to speed production and assure lowest unit cost.

Tolerances which may be maintained in these generating and gear shaper methods are in the "precision quality" range as described in American Gear Manufacturers Association Quality Classes 8 through 12. In the interests of speed, production, and low cost the lowest acceptable AGMA Quality Class should be chosen.

10-3.1.2.5 Hobbing Operations

Hobbing, first used on cutting gears, may be applied to the production of almost any form that regularly repeats itself on the periphery of a circular part. The hob is designed so that the cutting teeth lie in a helical path around the tool. The hobbing machine rotates the workpiece and the hob, and controls the movement of the hob, causing the cutting teeth to move in a positive progression through the workpiece. Each tooth removes a small shaving and, since cutting action is continuous and automatically controlled, the desired full form outline is produced.

The tolerances for the hobbing process are:

(1) Large gears (10 inches OD), pitch diameter 0.001

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inch total.

(2) Gears (30 to 268 pitch), pitch diameter 0.0003 to 0.0005 inch.

(3) Profiles accurate to 0.0005 inch.

10-3.1.2.6 Milling Operations

Milling removes metal by a rotating multiple tooth cutter, the teeth removing a small amount of metal with each revolution of the spindle. Since the workpiece and the cutter can be moved in more than one direction at the same time, almost any surface can be machined. A wide variety of standard machine types are found in most shops, and many special machines have been designed and built for high volume production of specific parts.

The tolerances for the milling operation are:

(1) Conventional milling, ± 0.005 inch, 50 to 250 microinches.

(2) Carbide cutters, ± 0.0005 inch, 20 to 40 microinches.

10-3.1.2.7 Planing Operations

Planing is the removal of metal from horizontal, vertical, or angular surfaces of the workpiece. This is accomplished by moving the workpiece in a linear direction against one or more fixed single-point tools. Standard planers are available for making cuts up to 50 feet long. Planing is not for high production volume, but is best adapted to large work pieces and low volume jobs.

The tolerances connected with planing operations are:

(1) Precision flat surfaces, to ± 0.005 inch with surface finish from 125 to 500 microinches obtainable.

(2) Cast iron, ± 0.001 to ± 0.002 inch with a 60 microinch finish possible.

Tolerances on dimensions depend on the size and complexity of the part; however ± 0.001 to ± 0.005 inch can be held on small and medium dimensions.

10-3.1.2.8 Reaming Operations

Reaming is a machining operation in which a rotary tool takes a light cut, improving the accuracy and reducing the roughness of a hole surface. Most holes reamed are from 1/8 to 1-1/4 inch in diameter. Reamers for holes as small as 0.005 inch in diameter are available with the largest reamers about 6 inches in diameter. The length of the holes which can be reamed depends on the reamer and the accuracy required.

The tolerances for reamed holes are:

(1) Holes under 1/2 inch, 0.001 inch.

(2) Holes between 1/2 inch and 1 inch, 0.0015 inch.

(3) Holes over 1 inch, 0.002 inch.

Holes may be out of round by as much as size tolerance. Finishes of 40 microinches or less can be expected.

10-3.1.2.9 Shaping Operations

Shaping is a metal removal process whereby a single-point tool reciprocates in a linear direction against a stationary workpiece to form horizontal, vertical, or angular plane surfaces. Standard shapers have a stroke of 36 inches; therefore, the size of the work is limited. The shaper is generally considered to be inefficient; however, the short time required for setup and its inexpensive tooling make the process practical for some jobs. In addition, deep internal slots and certain operations in blind holes, awkward for broaching or milling, can be achieved.

The tolerances obtained on shapers are comparable to those achieved by planing.

10-3.1.2.10 Slotting Operations

Slotting is a shaping operation that was first developed to cut long slots or keyways. The ram carrying the cutting tool cuts on vertical downstroke which can be as great as 72 inches.

10-3.1.2.11 Trepanning Operations

Trepanning operations are used to produce round discs, large shallow through holes, circular grooves, or deep holes. One or more cutters revolving around a center produce a circular hole or a groove with a remaining solid center core. Discs up to 6 inches in diameter can be produced from plate, up to 1/4-inch thick in a hand-fed drill press. In a similar fashion, large through holes can be readily trepanned in plate or (by controlling the depth of the cut) circular grooves can be produced. Deep holes, 2 inches or more in diameter and 8 inches or more in depth, can be trepanned from solid stock.

Trepanning utilizes self-piloting cutting action, requires a pressurized cutting fluid system, and offers the following advantages over spade or twist drilling:

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(1) Closer diameter and straightness tolerances.
(2) Deeper holes.
(3) Higher metal removal rate.
(4) More valuable solid core produced.

Production rates for trepanning operations, as such, are not high; however, machining time on deep holes might be as much as 50% to 75% lower than on those made by center drilling, twist drilling, or boring.

10-3.1.2.12 Turning Operations

Turning is a machining process for generating external surfaces by the action of a cutting tool on a rotating workpiece. It may be combined with other operations such as facing, drilling, boring, reaming, threading, tapping, knurling, parting, and chamfering.

Tolerances on turret lathe machining are:

(1) High production runs, ±0.002 inch on diameters.
(2) With single cutter roller turner, ±0.001 inch.
(3) With multiple cutter roller turner, ±0.003 inch or greater.

Lengths and depths can be held to ±0.001 inch with standard stops. Surface finish, depending on material, will be about 60 microinches rms (root mean square) or less.

Tolerances with automatic screw machining are:

(1) Plain diameters up to 1 inch, ±0.0002 inch.
(2) Diameters between 1 and 2 inches, ±0.0003 inch.
(3) Diameters greater than 2 inches, ±0.005 inch.

These tolerances are normal practice for automatic screw machining. The specification of Class 2 threads is recommended unless the costs of producing Class 3 or 4 threads can be justified.

The tolerances on Swiss automatic machines are:

(1) On large machines (1/2-inch diameter), diameters can be held to ±0.0002; however, ±0.0005 favors production. Lengths to shoulders can be held to 0.0005; however, normal tolerances specified are ±0.002 to ±0.003 inch.
(2) On small machines, diameters can be held to ±0.0002 inch or less in production.
(3) Surface finish from 50 microinches to as fine as 5 microinches can be attained. Instrument parts as fine as 12 to 16 microinches can be produced.

10-3.1.2.13 Other Machining Processes

Although most machining is performed mechanically, several specialized methods have been developed on the basis of other principles. These methods are characterized by their ability to perform operations or remove metal that cannot be done by conventional mechanical machining. The process characteristics of eight of the more developed special machining methods, summarized by Table 10-4, are: ultrasonic machining, chemical machining, electron beam machining, electrical discharge machining, and electrochemical machining.

10-3.1.3 Grinding

The other principal metal removal method, other than machining, is grinding. Only those grinding processes primarily intended to remove material are covered in this discussion. Grinding processes, such as honing and lapping, are more appropriate to the production of finished surfaces; therefore, they are discussed later in the chapter under the heading of finishing processes.

10-3.1.3.1 Cylindrical Grinding

Cylindrical grinding is a method of grinding the outside surfaces of cylindrical parts. Four movements are involved: the workpiece rotates on centers or a mandrel; the grinding wheel rotates; the grinding wheel moves in or out from the workpiece; and the workpiece traverses the wheel (on some large machines, the wheel may traverse the workpiece).

Tolerances appropriate to the cylindrical grinding process are:

(1) Cylindrical grinders, ±0.0001 to ±0.0005 inch on diameters, if practical for production.
(2) Surface finish dependent on work material, grinding wheel grit size, and other factors; 32 to 63 microinches typical for production.

10-3.1.3.2 Centerless Grinding

Centerless grinding is a method of grinding the inner or outer surfaces of cylindrical parts; it is similar to cylindrical grinding except that the workpiece is not mounted on canters. Instead, it is supported by a work rest blade and a regulating wheel.

The tolerances for centerless grinding are:

(1) Dimensions, held within the range 0.00004 to 0.005 inch.
(2) Out of roundness, held to 0.00001 inch.

Closer tolerances increase the cost of grinding; ±0.0003 to ±0.0005 inch tolerance with 20 to 30 mi-

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TABLE 10-4. MACHINING PROCESS CHARACTERISTICS

ULTRASONIC MACHINING (USM)	LASER BEAM MACHINING (LBM)
PRINCIPLE	
Tool vibrated around 20,000 cycles per second by magnetostrictive transducer. Fine abrasive particles in a water slurry between tool and workpiece reach high velocities, dislodge material from workpiece. Cavity produced assumes shape of tool.	Electrical energy converted into narrow, single wave length beam of light. Beam can vaporize all refractory materials, can produce very small holes and small welds.
EQUIPMENT	
Machine tool equipped with transducer, generator power supply; specially shaped toolholder and tool; abrasive powder; pump for abrasive powder-water mix.	High voltage power supply; trigger transformer; excitation source; laser crystal; focusing lens.
TYPICAL APPLICATIONS	
Machining of nonmetallic, brittle, or hard materials, such as semiconductors (silicon, germanium), ceramics, glass, silicon carbide, tungsten carbide; production of accurate and odd shapes in nonmetallic, brittle, or hard materials - generally applied to materials harder than 64 R_C* (1/16 inch thickness maximum at 64 R_C).	Holes in all types of materials as small as 0.0002 inch (5 microns); weld 0.0005 inch wires; vaporize small increments of material.
TOLERANCES	
Practical: ±0.001 inch Possible: ±0.0005 inch (total)	Same size hole reproducible within 5%. In materials more than 0.010 inch thick, taper becomes noticeable.
SURFACE	
Roughing: 25 rms Finishing: 10 rms No heat affected surface produced.	Heat affected zones very thin; finish depends on material worked; cratering is dependent on factors such as energy, quality of optics, nature of material.
PRACTICAL REMOVAL RATES	
Feed rate: Tungsten carbide - 0.005 in./min Silicon carbide - 0.010 in./min Ceramics - 0.050 in./min Silicon (pure) - 0.070 in./min Average volume removal rates: Hardened tool steel - 0.0001 cu in./min Boron carbide - 0.0002 cu in./min Hardened stainless steel - 0.0008 cu in./min Silicon - 0.005 cu in./min Germanium - 0.006 cu in./min Carbon - 0.015 cu in./min Rate diminishes as abrasive breaks down; periodic additions and replacement desirable. Rate increased by forced application of abrasive.	0.020 inch hole in 0.020 inch thick tungsten sheet in less than 0.001 second is typical; 1/4 inch hole in 0.010 inch brass at same rate; 0.050 inch hole in brass at same rate; 0.050 inch hole in 0.050 inch ceramic at same rate. Lasers are available with repetition rates of 6 to 120 pulses per minute.

*Rockwell C hardness

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TABLE 10-4. MACHINING PROCESS CHARACTERISTICS (CONT'D)

CHEMICAL MACHINING (CHM)	ELECTRON BEAM MACHINING (EBM)
PRINCIPLE	
Metal removed by chemical or electrochemical attack of preferentially exposed surfaces. Essential steps: cleaning part; masking with tapes or resistant paints, or printing, using photoengraving techniques; etching, demasking; cleaning. Two processes involved: chemical milling, chemical blanking.	High velocity electrons focus on workpiece and vaporize material.
EQUIPMENT	
Chemical milling: Large or small, thick parts: Masking facilities, corrosion resistant processing tanks and fixtures, vented tanks or rooms. Chemical blanking: Small parts (including thin sheets): Tooling (artwork and photographic negatives), layout tables, photoengraving equipment, including manual or automatic and continuous spray etching machines.	Electron beam cutter with workpiece in vacuum of 10^{-4} mm of mercury or better.
TYPICAL APPLICATIONS	
Chemical milling: Shallow cavities or pockets; overall weight reduction; tapered sheets, plates, or extrusions for airframes. Chemical blanking: Printed circuit etching, decorative panels, thin stampings. Applicable to aluminum, magnesium, iron, copper, nickel and cobalt base alloys, refractory alloys such as tungsten, columbium, molybdenum.	Drilling holes as small as 0.0005 inch almost instantaneously in all materials, including ceramics; cutting closely spaced thin slots, e.g., 1/2 inch long slots 0.005 inch wide, spaced 0.010 inch apart in 0.025 inch thick alumina; scribing of thin films; removing broken taps of small diameter.
TOLERANCES	
For chemical milling and chemical blanking: Metal removal or thickness of sheet: 0.002 inch - tolerance, $\pm$0.001 to $\pm$0.002 inch 0.020 inch - tolerance, $\pm$0.004 to $\pm$0.010 inch 0.060 inch - tolerance, $\pm$0.006 to $\pm$0.012 inch Tolerances are function of masking or printing technique, configuration, size of part.	On 0.125 inch holes, $\pm$0.001 inch. On 0.0005 inch holes, $\pm$0.00005 inch to 0.0001 inch.
SURFACE	
Average values: Aluminum - 90 rms Magnesium - 50 rms Steel - 60 rms Titanium - 25 rms Tungsten - 50 rms	Finish data not available. Incident surface slightly cratered and walls of 0.125 inch holes contain refuse readily removed mechanically. Heat affected zone is practically nonexistent.
PRACTICAL REMOVAL RATES	
Penetration: 0.0005 to 0.003 in./min	0.0005 inch slots - 10 to 24 in./min in 0.010 inch material. Holes in sheet materials of all kinds 0.001 to 0.025 inch thick: 0.0125 inch diameter holes, less than 2 seconds; 0.0005 inch diameter holes, less than 0.1 second.

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TABLE 10-4. MACHINING PROCESS CHARACTERISTICS (CONT'D)

ELECTRICAL DISCHARGE MACHINING (EDM)	ELECTROCHEMICAL MACHINING (ECM)
PRINCIPLE	
Metal is removed by rapid spark discharge between negative electrode and positive conductive workpiece separated by about 0.001 inch by dielectric fluid. Workpiece material is melted, in part vaporized, and expelled from gap.	Controlled metal removal by anodic dissolution. DC current passes through flowing film of conductive solution which separates workpiece from electrode-tool. Workpiece is anode, tool the cathode.
EQUIPMENT	
Rigid machine tool for close control of spark gap; DC power source; servomechanism to control electrode movement; dielectric fluid pressure system and filter.	Machine tool must be rigid to withstand high fluid separating forces; must protect mechanical and electrical systems from corrosive electrolytes, and have provisions for venting of work areas. DC power source; electrolyte system, including pumps, filters, storage tanks, and heat exchanger; electrolyte clarifier may be required; servomechanism for process control optional.
TYPICAL APPLICATIONS	
Manufacture of: Dies (stamping, cold heading, forging, injection molding); carbide forming tools; tungsten parts; burrfree parts; odd shaped holes and cavities; small diameter deep holes; high strength and high hardness materials; narrow slots (0.002 to 0.012 inch wide); honeycomb cores and assemblies, other fragile parts.	High strength, high hardness materials; high temperature-alloy forgings; odd shaped holes and cavities; jet engine blade airfoils; small deep holes, jet engine blade cooling holes; deburring; face turning of discs; tungsten carbide machining; etching of numbers and letters in hard steels.
TOLERANCES	
Practical: ± 0.002 to ± 0.005 inch Possible: ± 0.0001 to ± 0.0005 inch	Practical: ± 0.005 inch Possible: ± 0.0005 inch
SURFACE	
Finish is affected by removal rate: 0.010 cu in./hr - 30 rms 0.5 cu in./hr - 200 rms 3.0 cu in./hr - 400 rms Heat affected zone: 0.0001 to 0.005 inch	4 to 50 rms easily attained. No heat affected surface or burrs created. Guard against selective etching in remote areas exposed to electrolyte by shields or dams.
PRACTICAL REMOVAL RATES	
About 0.00025 cu in./amp /min /brass electrode. About 0.0005 cu in./amp /min /graphite electrode	0.04 to 0.3 cu in./min /1000 amp 0.1 cu in./min /1000 amp often used for approximation. 1 cu in./min for 10,000 amp unit

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TABLE 10-4. MACHINING PROCESS CHARACTERISTICS (CONT'D)

PLASMA ARC MACHINING (PAM)	ABRASIVE JET MACHINING (AJM)
PRINCIPLE	
Material is displaced by a high velocity jet of high temperature ionized gas. The workpiece is heated by bombardment with electrons and by transfer of energy from the high temperature, high energy gas.	Material is removed from the workpiece by a high speed stream of abrasive particles carried by a gas flowing from a nozzle. The abrasive powder is entrained in the flowing gas stream in an orifice chamber and emerges from a small diameter nozzle at high velocity.
EQUIPMENT	
Plasma-arc torch, DC power 400 volts (open circuit), 200 volts (under pressure), 200 KW output gas, 70 to 400 cubic feet per hour. Nitrogen-hydrogen, argon-hydrogen, compressed air.	Dry, clean, oil-free supply of air, nitrogen, or carbon dioxide. CAUTION: Oxygen cannot be used. Abrasive materials: aluminum oxide, silicon carbide, dolomite, or sodium bicarbonate (these are not ordinarily used over). Dust removal system. Abrasive jet gun system, including tungsten carbide or synthetic sapphire nozzles (tungsten nozzles last from 12 to 30 hours, sapphire nozzles about 300 hours). Pantograph or cam system to automatically direct nozzle.
TYPICAL APPLICATIONS	
Chiefly for cutting stainless steel (4 to 5 inches) and aluminum alloys (up to 6 inches). Metals resistant to oxy-fuel gas cutting (magnesium, copper, titanium, nickel, and copper and nickel alloys) sometimes cut by PAM. PAM considered for turning, milling, and planing, but technique not yet fully developed.	Abrading and frosting glass; cleaning; cutting fine lines; machining semiconductors (germanium, silicon, gallium); deburring marking; cutting and etching materials (quartz, sapphire, mica, glass).
TOLERANCES	
In cutting, accuracy ordinarily ±3/32 to ±1/8 inch; with close control can be held to ±1/16 inch. Width of kerf usually 3/16 to 3/8 inch, but could be up to 1/2 inch on thick material.	Normal production, ±0.0005 inch; ±0.002 inch can be held with close control. Minimum width of cut is about 0.005 inch.
SURFACE	
Generally smoother than that achieved by gas cutting. Heat affected zone depends on metal being cut, its thickness, and cutting speed. Maximum of 3/16 inch could be effected on 1 inch stock; would be less at high speed.	Surface finish ranges from 20 to 50 microinches in most cases. 6 to 8 microinch finish can be obtained on glass with aluminum oxide or silicon carbide abrasives 10 microns in size. No heat damage to the surface.
PRACTICAL REMOVAL RATES	
Cutting speeds as high as 240 in./min have been achieved with large automatically guided machines.	

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croinches finish should be practical.

10-3.1.3.3 Surface Grinding

Surface grinding is accomplished by grinding wheels mounted on tables which move under the wheel in either horizontal or rotary passes.

Tolerances for surface grinding are:

(1) On surface grinders, flatness held to within 0.0002 to 0.0003 inch over 20 feet.

(2) On rotary table machines, flatness held to 0.0002 to 0.0005 inch, parallelism to 0.0004 to 0.0005 inch, and length to ± 0.0002 inch.

Surface finish generally is dependent on the material being ground; however, 2 microinches can be obtained in production on hardened steel.

10-3.1.3.4 Abrasive Belt Grinding

This method utilizes driven endless abrasive belts supported by suitable contact wheels providing opposing pressure to the workpiece in order to achieve stock removal.

The tolerances for abrasive belt grinding are:

(1) Flat surfaces, ± 0.002 inch flatness and parallelism.

(2) Centerless grinding operations, ± 0.0005 inch with fine grits, in production.

(3) Finishes of 10 incroinches are typical.

10-3.1.3.5 Other Grinding Methods

Table 10-5 describes the characteristics of two grinding processes that have the capability of performing certain specialized grinding operations. They depend on electrochemical reaction and an electrical spark to remove metal. The two processes summarized by the table are known as electrochemical grinding and electrical discharge grinding.

10-3.2 CUTTING

The discussion of cutting processes here is restricted to flame cutting and sawing. Most cutoff or contour cutting is accomplished by use of one of these two processes. Shear cutting may be used for straight cuts within the limitation of the available shear.

10-3.2.1 Flame Cutting

This process cuts ferrous metals by using a jet of pure oxygen directed at a point in the metal which has been heated to the fusion point. Mechanical flame cutting machines capable of cutting as many as 20 patterns simultaneously have been developed. Work from lightgage sheet to sheets as thick as 6 inches can be accommodated.

The accuracy of the flame cutting operation depends on the thickness of the material and how easily it can be cut, the method of clamping it, the distortion, and the inherent accuracy of the machine.

Tolerances for the flame cutting process are:

(1) Portable straight line machines, average $\pm 1/8$ inch.

(2) Portable shape cutting machines, $\pm 1/16$ inch possible.

(3) Stationary machines, $\pm 1/64$ inch.

The usual work distortion allowances which vary with the particular cut being made also must be considered. Kerf width varies from 1/32 inch to over 3/8 inch, depending on the size of the torch jet.

Cutting accomplished by the plasma jet technique is discussed in the machining section of this chapter.

10-3.2.2 Sawing

Sawing processes include hack sawing, circular cold sawing, and friction sawing. Hack sawing is relatively slow and is used in low output production primarily for cutoff operations. Circular cold sawing is applied in medium to high production cutoff and similar operations. Larger material and cuts can be handled better by circular cold sawing than with power-operated hack saws.

10-3.2.2.1 Band Sawing

This is the most widely used sawing method because it is versatile and capable of making relatively intricate contour cuts. A wide variety of saw blades including diamond and abrasive blades are available, making it possible to cut such substances as steel, tungsten carbide, glass, and vitreous materials.

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TABLE 10-5. GRINDING PROCESS CHARACTERISTICS

ELECTRICAL DISCHARGE GRINDING (EDG)	ELECTROCHEMICAL GRINDING (ECG)
PRINCIPLE	
Similar to electrical discharge machining, but negative electrode is in form of grinding wheel.	Metal removed by deplating; workpiece is anode; cathode is metal bonded grinding wheel with abrasive particles; most metal removed by deplating; 0.05 to 10% removed by abrasive.
EQUIPMENT	
Electrical discharge grinder equipped with variable speed drive; insulated wheel adapter; servomechanism to control table speed; dielectric fluid-coolant supply.	Grinder constructed to keep corrosive electrolytes from mechanical and electrical systems; dc power source; electrolyte system including pump, filter, storage tank, injector for electrolyte, and mist collector, metal bonded diamond or metal bonded aluminum oxide wheels.
TYPICAL APPLICATIONS	
Carbide form tools, hardened gear racks, thin slots closely spaced in hard materials, carbide crushing rolls, carbide lamination dies, carbide cutting tools, production grinding or intricate forms.	Grinding of carbides; fragile parts, including honeycomb; parts with burrfree, stressfree requirements - hydraulic applications, thin wall tubing, hypodermic needles; high strength, high temperature alloys sensitive to thermal damage; resharpening of throwaway carbide tools, milling cutters.
TOLERANCES	
Practical: ± 0.0002 inch Possible: ± 0.0005 inch	Possible and practical: ± 0.005 inch
SURFACE	
Finish is affected by removal rate: 0.15 cu in./hr - 125 rms 0.072 cu in./hr - 40 rms 0.012 cu in./hr - 15 rms	Tungsten carbides: 5 to 15 rms Steels: 15 to 30 rms (No finish pass required for those finishes. No heat affected area produced.)
PRACTICAL REMOVAL RATES	
0.01 to 0.15 cu in./hr	0.004 to 0.03 cu in./min /100 amp often used for approximation

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10-3.2.2.2 Friction Band Sawing

This method, sometimes referred to as high velocity sawing, is a frictional melting or burning process. The high friction speed permits contour cutting of extremely hard materials. Generally, it is limited to 1/2-inch thicknesses; however; 2-inch armor has been cut on a production basis.

The following tolerances apply to sawing process:

(1) Circular saws, cross cutting accuracy of 0.002 to 0.003 inch per inch.

(2) Conventional band sawing, 0.008 to 0.010 inch on layout line. With some magnifying arrangement, 0.003 inch can be achieved.

10-3.3 FINISHING

Finishing processes are those operations performed on a material for the purpose of attaining the desired surface characteristics. This discussion does not consider those chemical or electrolytic processes such as anodizing, parkerizing, etc. Information on honing, lapping, super-finishing, electrochemical honing, and rotofinishing (also considered a cleaning process) is presented.

Before considering these processes, the economic implications of obtaining a fine surface finish should be considered. The cost of production increases as the requirement for finer surface finishes increase. Fig. 10-9 illustrates how costs increase with increases in surface smoothness. From this chart, it is obvious that the designer should avoid prescribing a better surface finish than that actually required.

Tables 10-6 through 10-10 are listings of recommended surface requirements covering a variety of design contingencies.

Table 10-11 graphically illustrates the range of finishes that normally can be expected to result from various process operations. It shows that some finishes are practical and that others are physically attainable at increased cost and degradation of producibility. The influence of specified finishes on factors other than cost—i.e., production time equipment availability, worker skills, etc.—must also be considered.

TABLE 10-6. NONMATING SURFACES

AA Roughness Height Ratings	500	250	125	63	32	16	18	4
A. Clearance Holes		X						
B. Clearances & Reliefs								
1. Small			X					
2. Medium or large	X							
C. Cutoff length surfaces-sheared, sawed, etc.	X							
D. Datum Surfaces								
1. Less than 0.001 in. tolerance				X				
2. Tolerance of 0.001 in.			X					
E. Nuts, Bolt & Screw Heads, Unthreaded Shanks								
1. Finished (machined) bolts, screws			X					
2. Unfinished bolts		X						
F. Ends of Bolts, Pins, Screws & Studs		X						
G. Screwdriver & Wrench Slots		X						
H. Chamfers, Radii and Undercuts			X					
I. Handles			X					
J. Tool Runout-thread Relief			X					
K. Exterior Surfaces								
1. Housings cast	X							
2. Housings machined			X					
3. Guns through 30 mm			X					
4. Guns over 30 mm to 16 in.		X						
5. Painted surfaces, guns 75 mm to 16 in.	X							
6. Breechblocks				X				
L. Breech Mechanisms								
1. Guns through 30 mm				X				
2. Guns larger than 30 mm to 125 mm			X					
3. Guns 125 mm to 16 in.		X						

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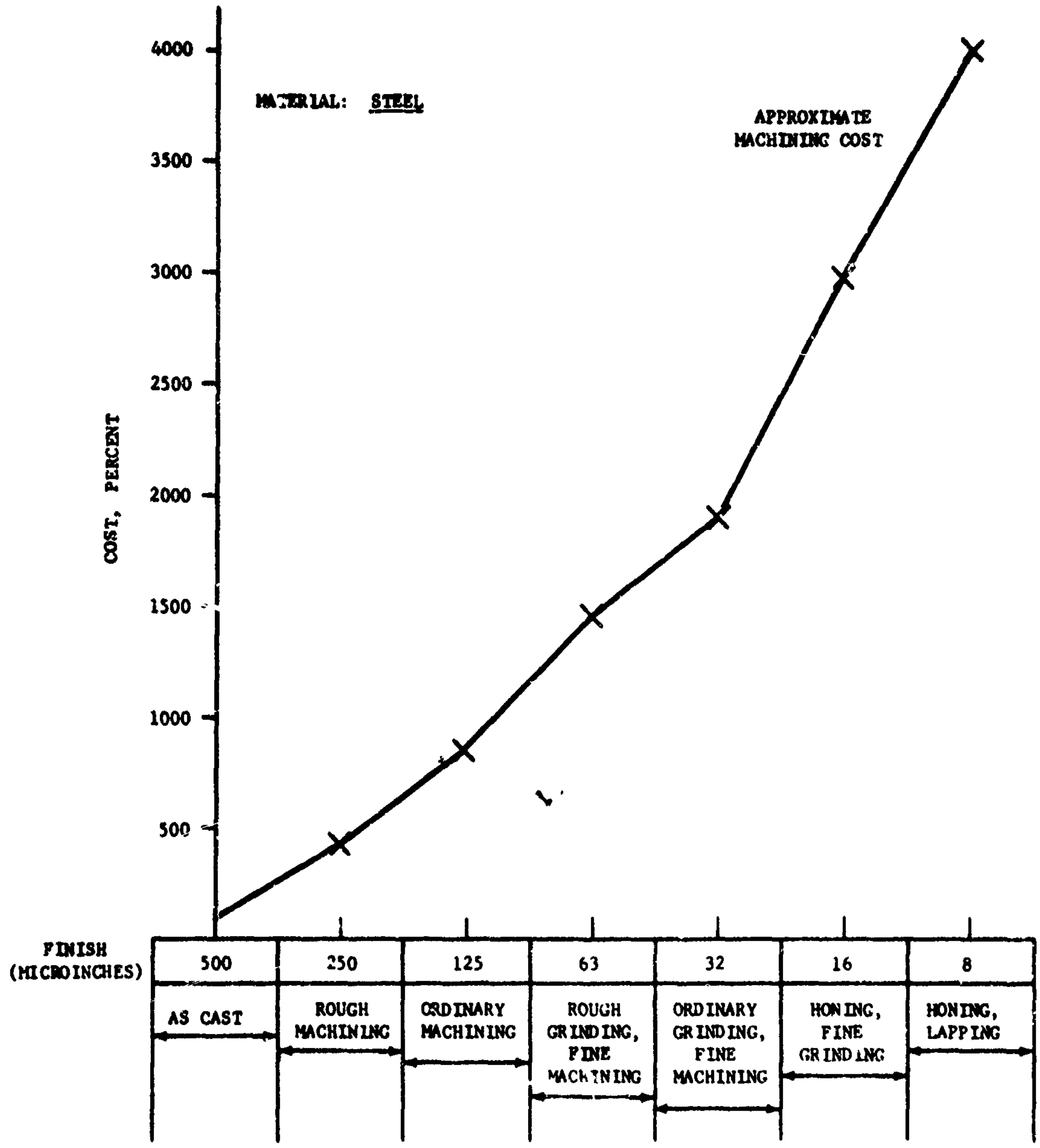

FIGURE 10-9. Machining Costs and Surface Finishes

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TABLE 10-7. MATING OR CONTACT SURFACES–STATIONARY

AA Roughness Height Ratings	500	250	125	63	32	16	8	4
A. Centralizing or Location Surfaces			X					
B. Clamping or Mounting Surfaces				X				
C. Housing, Bracket and Pedestal-pads (Base Surfaces)			X					
D. Surfaces for Copper Gaskets and Gasket Seats					X			
E. Surfaces for Soft, Flat Gaskets			X					
F. Gasket Surfaces (Minimum Surface Contact)				X				
G. Grooves for Injection Seals			X					
H. Surfaces for "O" Rings					X			
I. Grooves for Snap Rings			X					
J. Counterbored Surfaces								
1. Over 3/4 dia		X						
2. 3/4 dia and less			X					
K. Countersunk Surfaces			X					
L. Spotfaced Surfaces								
1. Over 3/4 dia		X						
2. 3/4 dia and less			X					
M. Dowel Pin Holes and Taper Pin Holes					X			
N. Parts of Breech Mechanism				X				
O. Inside Dia of Pinned Hubs, Collars, and Spacers				X				
P. Lens, Prism and Mirror Mounting Surfaces				X				
R. Spring Seat Surfaces			X					
S. Shafts and Bores for Ball Bearings								
1. Up to 2 in. dia					X			
2. Over 2 in. dia				X				
T. Shoulder Faces for Shafts and Housings (Ball Races)			X					
U. Surfaces Contacting Packing in Glands and Retainers				X				

10-3.3.1 Honing Operations

Honing is a refined form of grinding. Surface finish quality approaches that achieved by lapping. Honing is not an economical production operation, however. The principal difference between honing and grinding is that the abrasive stones have a large area of surface contact during honing; during grinding only line contact occurs. Stock removal is held to a minimum in the honing process.

The tolerances for honing are:

(1) Internal diameters over 4 inches held to within 0.0005 to 0.001 inch total variation.

(2) Bores smaller than 4 inches held closer ($\pm$0.0001 to $\pm$0.00025 inch on bores less than 1 inch).

(3) External honing held between 0.0001 and 0.0002 inch on long cylinders.

The surface finish obtainable depends on the material being honed. Hardened steel can be honed as low as 1 microinch; cast iron, bronze, or soft steel, between 80 and 3 microinches; and aluminum to about 15 microinches.

10-3.3.2 Lapping Operations

Lapping is another means of obtaining more accurate and smoother finishes than those possible with the finest grinding. It is a surface refining and stock removal process practicable in production if no more than 0.0005 inch of material is removed. The mating surfaces themselves are used with a fine abrasive to ensure an accurate fit.

Since material removal should be held to a minimum, the preliminary grinding operations must be extremely accurate in order for lapping to achieve its potential in accuracy. The tolerance variations total 0.00005 inch (typical). Surface roughness ranges between 0.5 and 2 microinches.

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TABLE 10-8. MATING OR BEARING SURFACES—SLIDING

AA Roughness Height Ratings	500	250	125	63	32	16	8	4
A. Gear Teeth and Screw Threads								
1. DP 10 or smaller								
a. General				X				
b. Precision					X			
2. Coarser than 10 DP				X				
3. Heavy loads					X			
4. Worms						X		
5. Worm Gears								
a. General					X			
b. Precision (lapped)						X		
c. For heavy loads					X			
6. Teeth of ratchets and pawls,			X					
7. Spline teeth				X				
8. Screw threads								
a. Chased		X						
b. Die or tap cut			X					
c. Milled								
1. 10 or more threads per inch				X				
2. Fewer than 10 threads per inch			X					
d. Ground threads and breech threads for guns						X		
e. Rolled threads							X	
B. Gibs and Ways					X			
C. Sliding Plates					X			
D. Sliding Plate Guides						X		
E. Slip Clutch Surfaces								
1. Metal to Metal				X				
2. Metal to Nonmetal					X			
F. Slip Ring Surfaces				X				
G. Valve Stems and Guide Bushings						X		
H. Cylinder Bores, Pistons and Piston Rods						X		
I. Surfaces of Fluid Seals								X
J. Valve Seats							X	
K. Bearing Seats Bolts, Nuts, Screw Heads			X					
L. Cam Surfaces and Followers								
1. Three dimensional						X		
2. Groove								
a. General					X			
b. Precision						X		
3. Flat or disc lobe								
a. General					X			
b. Precision						X		
4. Throwout type				X				
M. Locking Plungers (Round or Square End Holes)				X				
N. Keys and Keyways					X			
O. Breech & Firing Mechanisms of Cannons						X		
P. Parts Sliding in Packings						X		
R. Dynamic "O" Ring Seal Surfaces								X
S. Dynamic "[illegible]" Seal (Machined Finish - No Abrasive)						X		
T. Recoil Mechanisms & Equilibrators								
1. Anti-friction metal						X		
2. Copper rings					X			
3. Silver rings						X		
4. Control rods - bronze buffer ends				X				
5. Control rods: steel-control diameter					X			
6. Internal bronze surfaces				X				
U. Propellent Valves Shafts						X		
V. Rifling in Cannon Barrels								
1. Lands								
a. Cannon over 30 mm up to 75 mm							X	
b. Cannon 75 mm up						X		
2. Grooves								
a. Cannon over 30 mm up to 75 mm						X		
b. Cannon 75 mm up					X			
W. Barrel Chambers, Lands, and Grooves								
1. Guns through 30 mm					X			

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TABLE 10-9. MATING OR BEARING SURFACES–ROTATING

AA Roughness Height Ratings	500	250	125	63	32	16	8	4
A. Crankpins							X	
B. Pivot Holes - Pivot Pins					X			
C. Bearings - Ball Track							X	
D. Bearings Sleeve Type (Shaft OD-Bearing ID)								
1. General					X			
2. Precision						X		
E. Shaft OD Used With Jewel Bearing								X
F. Shaft OD Used With Oil Seal or "O" Ring						X		
G. Piston Pins								X
H. Friction Differential Faces							X	
I. Variable Speed Drives - Cone, Disc and Cylinder Faces							X	
J. Hub, Collar and Shaft Face Bearing Surfaces								
1. General				X				
2. Precision					X			
K. Pressure Lubricated Bearings								X
M. Propeller Blades								X

10-3.3.3 Superfinishing

Superfinishing represents the ultimate in refined surface finishes for production parts. It differs from lapping and honing in that abrading is conducted at low speeds and low pressures, in a flood of low viscosity lubricant.

High tolerances and finishes, comparable to these attainable by honing, are possible with superfinishing. However, an unworked, undisturbed crystalline surface is produced. Accuracy is mandatory during the preparatory operations because production superfinishing will not remove gross out of roundness, taper, or straightness deviations.

10-3.3.4 Electrochemical Honing (ECH)

In electrochemical honing, conventional honing is combined with an anodic dissolution of the workpiece. The process is a faster operation, and features longer abrasive life and improved deburring action. Current equipment development limits this process to internal cylinder honing.

The tolerances and finishes achievable with electrochemical honing are comparable to those achieved by conventional methods. The most significant advantage of the process is its speed and economy (relative to abrasive costs).

10-3.3.5 Rotofinishing

Rotofinishing is a mechanical grinding and honing process using special abrasives which are tumbled in a barrel with the parts to be finished. High production rates can be attained, and the finishing cost per piece is minimal. Not all parts can be rotofinished because of their design; however, its availability without sacrifice of producibility makes it a highly desirable process to the designer.

Ordinarily, the processing done before barrel finishing sets the tolerance limits since the overall reduction in dimensions should not exceed a few tenths. Surface finishes obtainable also are determined by prior processing. For example, tumbling will reduce a 500-microinch finish to 80, a 60-microinch finish to 15, and a 15-microinch finish to 3.

Tables 10-12 and 10-13 contain common design and production problems specifically pertaining to fabrication as discussed in Chapter 5. These tables supplement Table 5-1.

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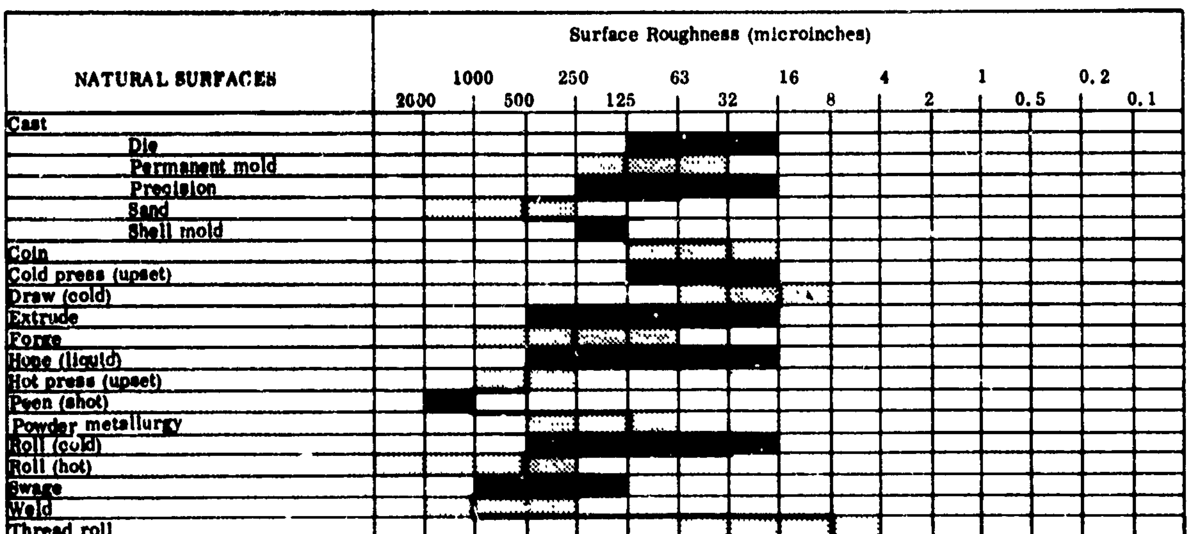
TABLE 10-10. INTERFERENCE FITS

AA Roughness Height Ratings	500	250	125	63	32	16	8	4
A. Push Fit					X			
B. Keys and Keyways				X				
C. Drive and Press Fits								
1. Holes and shafts to 2 in. dia					X			
2. Holes and shafts over 2 in. dia				X				

TABLE 10-11. INHERENT SURFACE ROUGHNESS AND PRACTICAL TOLERANCES OF VARIOUS PRODUCTION METHODS

Left of heavy line: practical finishes at commercial costs
Right of heavy line: obtainable finishes at increased costs
Range of surface roughness for each process is indicated by shaded areas



Normal practice tolerance for average size parts (+ or -)								
	0.045	0.08	0.015	0.002	0.001	0.0005	0.00015	0.00008
	0.031	0.015	0.005	0.001	0.0005	0.00025	0.00010	0.00005

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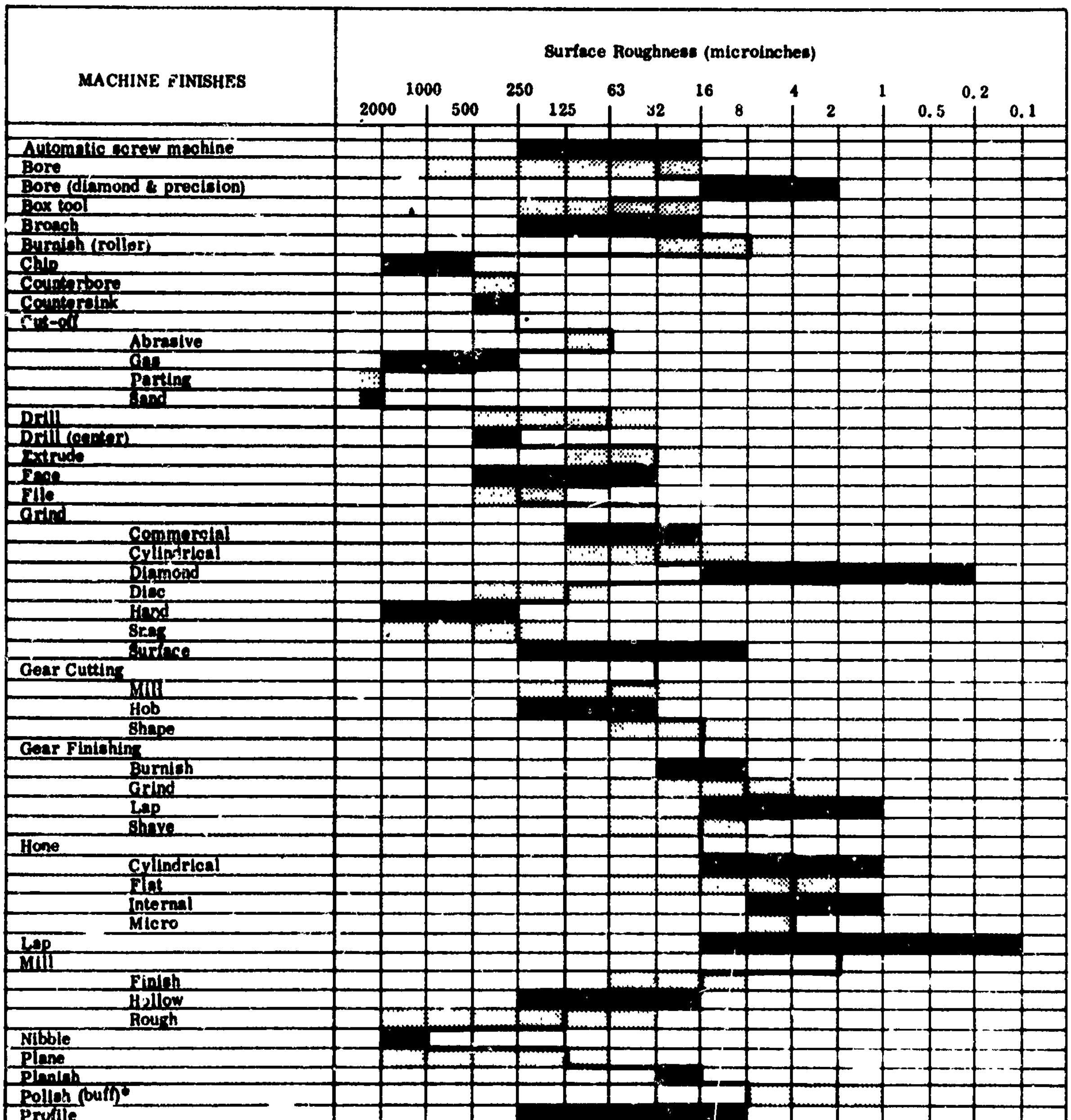
TABLE 10-11. INHERENT SURFACE ROUGHNESS AND PRACTICAL TOLERANCES OF VARIOUS PRODUCTION METHODS (CONT'D)

Left of heavy line: practical finishes at commercial costs
Right of heavy line: obtainable finishes at increased costs
Range of surface roughness for each process is indicated by shaded areas



Normal practice tolerance for average size parts (+ or -)	0.045	0.08	0.015	0.002	0.001	0.0005	0.00015	0.00008
	0.031	0.015	0.005	0.001	0.0005	0.00025	0.00010	0.00005

* Dependent on previous finish, grit, and grade of abrasive

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TABLE 10-11. INHERENT SURFACE ROUGHNESS AND PRACTICAL TOLERANCES OF VARIOUS PRODUCTION METHODS (CONT'D)

Left of heavy line: practical finishes at commercial costs
Right of heavy line: obtainable finishes at increased costs
Range of surface roughness for each process is indicated by shaded areas

MACHINE FINISHES	Surface Roughness (microinches) 2000	1000	500	250	125	63	32	16	8	4	2	1	0.5	0.2	0.1
Punch															
Ream															
Saw															
Scrape															
Shape															
Shear															
Slot															
Spin															
Spot face															
Superfinish															
Cylinder															
Flat															
Turn															
Smooth															
Rough															
Diamond															
PROTECTIVE & MECHANICAL FINISHES															
Galvanize*															
Oxide - black coat**															
Phosphate coat															
Plate (0.0025 dep.)*															
Plate (0.0005 dep.)*															
Sheridize															
Mechanical barrel finish															

Normal practice tolerance for average size parts (+ or -)								
	0.045 / 0.031	0.08 / 0.015	0.015 / 0.005	0.002 / 0.001	0.001 / 0.0005	0.0005 / 0.00025	0.00015 / 0.00010	0.00008 / 0.00005

*Roughness increases with thickness of deposit
**Surface on which applied does not change

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TABLE 10-12. COMMON DESIGN PROBLEMS

<u>Problem</u>: AS-CAST OR AS-FORGED FINISHES SELDOM USED.

<u>Cause and Effect</u>:

Machining of cast or forged finishes in cases not involving dimensional tolerances do nothing more than improve the finishes, increase cost, and retard production.

<u>Potential Solution</u>:

Eliminate requirement for machining, if possible; change casting method to produce the necessary finish without applying subsequent machining.

<u>Problem</u>: DESIGN CALLS FOR SHEET METAL TO BE STRESSED BEYOND WORKING LIMIT.

<u>Cause and Effect</u>:

Corner radii too tight.

<u>Potential Solution</u>:

Design for larger corner radii.

<u>Problem</u>: DESIGN DIFFICULT TO FORGE.

<u>Cause and Effect</u>:

Webs and ribs too thin leads to requirement for repeated blows, high pressures, or repeated heatings; this results in slow production and higher die costs.

<u>Potential Solution</u>:

Redesign part or forging, and be prepared to do more machining; use cast part.

<u>Problem</u>: FLATNESS REQUIREMENTS TOO TIGHT FOR SHEET METAL PART.

<u>Cause and Effect</u>:

Bending flanges creates residual stresses which cause part to warp

<u>Potential Solution</u>:

Reduce flatness requirement if possible.

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TABLE 10-12. COMMON DESIGN PROBLEMS (CONT'D)

Problem: INTERNAL CORNER RADII TOO SMALL ON MILLED PARTS.

Cause and Effect

Requires use of small milling cutters which results in long uneconomic machining times

Potential Solution:

Maximize internal corner radii for parts to be milled.

Problem: LARGE CORNER RADII ON TURNED PARTS.

Cause and Effect:

Requires round form tools with resulting machining problems; requires duplicating attachment on lathes.

Potential Solution:

Use small radii or sharp corners where possible, if undesirable stress concentrations will not result.

Problem: DESIGN DIFFICULT TO CAST.

Cause and Effect:

Wrong alloy specified yields a high rejection rate; overly thin sections specified leads to high rejection rates and slow production; poor sizing and shape specifications result in high rejection rates and slow production; slow production is caused by omission of allowances for draft and the requirement for multipart molds. High rejection rates are noted when insufficient allowances are left for finishing

Potential Solution:

Redesign casting; change material specification.

Problem: DESIGN REQUIRES EXCESSIVE MACHINING FROM BAR STOCK.

Cause and Effect:

Turned parts that contain two different diameters require that bar stock size be greater than the larger diameter. This results in a requirement for excessive machining on the smaller diameter

Potential Solution:

Make part in two pieces, change to cast or forged part

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TABLE 10-12. COMMON DESIGN PROBLEMS (CONT'D)

Problem: DRAWING SPECIFICATIONS UNDULY RESTRICT PRODUCTION PERSONNEL TO ONE MANUFACTURING PROCESS.

Cause and Effect:

The designer must have a general knowledge of the processes to be used to translate his design into hardware, but he should not specify the process. If he does, he may cause unnecessary production problems, e.g., proper equipment may not be available, etc.

Potential Solution:

Do not specify production process operations or sequence unless absolutely necessary to achieve the objectives of the design. Specify alternate materials, e.g., a range of steels, or casting or forging; this gives production personnel a wide latitude in process selection.

Problem: WRONG TYPE OF CASTING SPECIFIED.

Cause and Effect:

Finish and tolerances specified cannot be achieved with casting method required by design; finish and tolerance specified can be achieved by using a more economical casting method.

Potential Solution:

Casting costs are sensitive to changes in production quantities and rates; therefore, careful analysis of the required production quantities must precede the selection of a casting method.

Problem: NO PROVISION FOR HOLDING PART DURING FABRICATION.

Cause and Effect:

Parts must be rigidly held and located for accurate machining. Special effort will be required to prepare the workpiece for machining.

Potential Solution:

Make provisions for gripping surfaces or locating points in the design, if they do not affect the function of the part. Provide gripping surfaces that will be removed after certain phases of the production process have been completed.

Problem: PARTS CANNOT BE SUBASSEMBLED.

Cause and Effect:

Limits number of workers able to participate in production; may require greater number of skilled personnel

Potential Solution:

Redesign component or assembly so that it can be broken down into subassemblies.

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TABLE 10-12. COMMON DESIGN PROBLEMS (CONT'D)

Problem: UNNECESSARY USE OF RETURN FLANGE.

Cause and Effect:

Requires considerable extra effort for fabrication.

Potential Solution:

Redesign to avoid use of return flanges unless absolutely necessary.

Problem: EXPENSIVE SPECIAL TOOLING AND EQUIPMENT REQUIRED FOR PRODUCTION.

Cause and Effect:

Parts cannot be fabricated as designed without special tooling.

Potential Solution:

Consult with production and manufacturing personnel and solicit their ideas; redesign part; change the design so that another material can be substituted.

Problem: FINISH REQUIREMENTS PROHIBIT USE OF ECONOMICAL SPEEDS AND FEEDS.

Cause and Effect:

Fine finish requires that machines be operated with fine cuts and fine feeds, thus increasing costs proportionately

Potential Solution:

Review finish requirements with a view toward altering them.

Problem: FLANGE HEIGHTS TOO SHORT.

Cause and Effect:

Interference between metal pieces meeting at corner bend causes metal to pucker

Potential Solution:

Redesign notch with provision for sufficient clearance, provide for filing or hammering operation.

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TABLE 10-13. COMMON PRODUCTION PROBLEMS

Process: ADVANCED TECHNOLOGICAL PROCESSES.

Problem:

The use of structural materials of increased strength and hardness introduce increasing problems in manufacture. New manufacturing processes recently developed and introduced show great potential of enabling the machining of many of these new materials. However, these "breakthroughs" such as Combustion Machining and Cavitation Machining, must be developed further and analyzed to determine application benefits and limits before they are ready to be implemented in production.

Application:

All components falling within the scope of material removal.

Process: ALUMINUM FORGING TECHNIQUES (GENERAL).

Problem:

Establishing and maintaining a dependable aluminum forging source capability must be done on an operational level.

Application

All current lightweight weapons utilizing aluminum forgings, even more applicable to future weapons.

Process CABLE TWISTING MACHINE.

Problem:

There is no commercially available machine for manufacturing twisted cables (with conductors formed of twisted strands) which can economically handle small requirements of varying size.

Application:

Survey available commercial machines for usable segments or components which can be adapted to constructing an all-purpose cable twister and those necessary features not available must be designed and fabricated.

Process. CASTING.

Problem:

General improvement in foundry technology is necessary before the economies of casting can be fully realized. The basic problem is lack of reliability (process control).

Application

Applies to all weapon systems using cast metal products. Process controls, new methods, and equipment.

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TABLE 10-13. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: CASTING, GRAIN REFINEMENT.

Problem:

Present state-of-the-art centrifugal castings do not approach the tensile strength of the wrought product.

Application:

Rotating bands for large caliber projectiles. Vibratory motions applied during solidification.

Process: CASTING SUBSTITUTES FOR FORGINGS.

Problem.

Lack of determination and dissemination of proper casting techniques prior to production frequently prevents its substitution for forging.

Application:

Ferrous and nonferrous castings used for highly stressed components. Controlled solidification and heat treatment after casting.

Process: CHEMICAL MILLING AND BLANKING.

Problem:

The shaping of complex parts which require very intricate machining setups and the use of heavy materials are very difficult to machine by conventional metal-removal processes.

Application:

Any manufacturing operation involving sheet heavier than 0.060" thick and plate up to 1/2 in. thick, photoengraving techniques.

Process: CHLORINE MACHINING.

Problem:

In many machining operations, burrs are produced which must be removed either by machining or a hand finishing operation which is costly and time-consuming. A process is needed that not only attains a desirable finish but it must lend itself to high metal removal rates without imparting residual stresses or distortions.

Application.

Any molybdenum, tantalum, etc., process where general metal removal or improved surface finish is required would benefit from this chlorine process.

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TABLE 10-13. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: COLD FORMING TECHNIQUES--SMALL CALIBER GUN BARREL TUBES THROUGH 40 mm.

Problem:

Barrel fabricating techniques must be modernized to reduce the amount of machinery and plant space required by current production methods.

Application:

This process would benefit all small arms and armament items.

Process: COLD FORMING TECHNIQUES--GUN BARREL TUBES OVER 40 mm.

Problem:

Production costs, bore quality, and fatigue life of gun tubes produced by current methods need to be improved.

Application:

This process would apply to gun barrel tubes ranging from 40 mm through 105 mm.

Process: DEVELOPMENT OF FORGING PRACTICE, BETA-TYPE ALLOY.

Problem:

On the basis of evaluations to date, the alloy TI-8MO-8V-2FE-3AL appears to be an improvement over the currently available beta-type alloy. Forging characteristics need to be determined and a recommended practice established.

Application:

High strength titanium alloys are used in a variety of weapon structures, rocket motor cases being an example.

Process: DEVELOPMENT OF INJECTION MOLDING OF RUBBER COMPONENTS

Problem:

Lack of technical guidance for the injection molding of rubber components.

Application:

Investigate and evaluate the general development of injection molding covering materials, equipments, and techniques.

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TABLE 10-13. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: DRILLING.

Problem:

Improve precision drilling techniques for small arms and aircraft armament items to reduce costs in fabrication.

Application:

Wide application to production requiring precision drilling operations, High helix drills, gun drilling, trepanning, spade drilling, BTA System, etc., should be investigated.

Process: ELECTRICAL DISCHARGE MACHINING (EDM).

Problem:

Slow machining rates, excessive tool wear, and arcing control selection of better dielectrics, etc., are problems which need to be improved upon.

Application:

Fabrication of weapon components using common and exotic metals.

Process: ELECTROCHEM... MACHINING (ECM).

Problem:

Electrode insulation life and removal of the precipitate from the electrolyte are the more urgent areas requiring development.

Application:

Gun barrels, nozzle openings in rifle breeches, and sectoring the breech threads on gun tubes.

Process ELECTROLYTIC GRINDING.

Problem:

Excessive time and money is expended in the conventional abrasive honing process.

Application

Gun barrel manufacture and other applications involving extremely hard materials and requiring close tolerances would benefit from the electrolytic grinding process.

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TABLE 10-13. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: EMBRITTLEMENT MACHINING (SURFACE ACTIVE AGENTS).

Problem:

Machining times and costs must be reduced in the processing of the difficult-to-machine metals and alloys. This is especially true in the production of gun tubes where high rates of metal removal are usually necessary.

Application:

Where high rates of metal removal are required, particulary gun tubes.

Process: ENGINEERING STUDY AND APPLICATION OF PLASTICS FOR GUN COMPONENTS.

Problem:

Too little is known of the practical application of plastics and elastomers for their use in fabricating gun components.

Application:

Potential benefits such as cost, weight, and wear reduction, plus added corrosion and shock-vibration resistance, dictate the requirement for continued study of plastics as alternate materials in gun components.

Process: EXPLOSIVE FORMING.

Problem:

Present-day steel and aluminum armor fabrication is done by welding or die-quenching processes. Both of these methods are costly in time and equipment.

Application:

Armor sections which demonstrate cost reduction potential.

Process: FABRICATION OF SMALL CALIBER METALLIC CARTRIDGE CASES.

Problem:

An economical process to pierce, extrude, head, and form required concentric cavities in small caliber metallic cartridge cases within tight limits has yet to be developed.

Application:

High-cyclic firing rate weapons.

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TABLE 10-13. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: FABRICATION OF SMALL CALIBER TRACER BULLETS.

Problem:

There is no specific machine for the manufacture of small caliber tracer bullets.

Application:

Research and engineering efforts are required to explore and decide on materials, methodology, and equipments to manufacture both existing conventional and possibly new (unconventional) small caliber tracer bullets.

Process: FORGING COMBAT VEHICLE TRACKS.

Problem:

Cost of forging steel end connectors for combat vehicle tracks is excessive.

Application:

Steel end connectors and other precision components, shaw casting process.

Process: FORGING HIGH CARBON STEEL.

Problem:

Current production methods involve excessive processing costs and scrap losses in high carbon and alloy steels processing.

Application:

152 mm XM409 HEAT Projectile, 107 mm XM502, 105 mm M456, 155 mm XM483, 76 mm M495. Steels cast directly to shape; ready for forge process finish.

Process: IMPROVE PRODUCTION TECHNIQUES FOR LASER RODS.

Problem:

Present production "know-how" and methods for producing laser rods are too costly and time consuming.

Application:

Thoroughly investigate and resolve, if practical, the adaption of precision optical (glass) production methodology, equipments and techniques to shaping inorganic crystalline and noncrystalline doped glass materials to high tolerance optical specifications.

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TABLE 10-13. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: ION BEAM MACHINING .

Problem:

Production time must be reduced in producing holes and routed shapes in refractory materials, high strength metals, and nonmetallics required for such items as missiles, electronic apparatus, and small arms components.

Application:

Broad application to production requiring material removal of high hardness materials which exceed the capacity of edge type cutting tools.

Process: LASER BEAM METAL REMOVAL .

Problem:

Obtaining proper size and finish without harmful metallurgical surface effects on refractory and high hardness materials frequently exceeds the capability of edge type cutting tools.

Application:

Information obtained about laser application to production methods should benefit all material that must be shaped by a material removal process.

Process: MACHINING NONMETALLIC MATERIALS. .

Problem:

The manufacture of nonmetallic components (ceramics, graphites, plastics, carbides, etc.,) often require specialized, costly, high precision equipment and tools and unique techniques.

Application:

Study and establish the use of tool wear rate, wear geometry, and force measurements to determine the most favorable turning, drilling, milling, grinding, and pocketing characterisitcs for important nonmetallic materials.

Process: MANUFACTURING MINIATURIZED COMPONENTS AND CARTRIDGES.

Problem:

There is a lack of knowledge and manufacturing capability to produce miniature cartridges and miniaturized components.

Application:

The manufacture of miniature cartridges and primers, including a micro-ballistic sidearm that may be electrically (1.5v) fired, requires the design and development of equipment for forming in one continuous operation.

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TABLE 10-13. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: MANUFACTURING SMALL CALIBER JACKETED BULLETS OF LESS THAN CAL .22.

Problem:

The lack of specific machinery for producing microcaliber bullets of calibers .14 through .20.

Application:

Design and produce an efficient machine capable of continuous line production of small caliber jacketed bullets of less than caliber .22.

Process: METAL REMOVAL AT ELEVATED TEMPERATURES.

Problem:

Difficulties in the shearing and blanking of the beryllium alloys, high-strength nickel, and the tungsten alloys at room temperature require technique development.

Application:

Potential application to all components where rough machining is required.

Process: METHODS FOR CONTINUOUS HOT-PRESSING METAL CARBIDES.

Problem:

Change hot-pressing from the existing limited batch and gang hot-molding operation to continuous type operation.

Application:

Laboratory solutions to this problem exist; however, converting this information into production technology is necessary.

Process: MILLING.

Problem:

Improve tool life and surface quality to increase production efficiency.

Application:

Wide application to all face milling cutters. Investigation of the angle of engagement and disengagement of face milling cutters.

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TABLE 10-13. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: MULTILAYER PRINTED CIRCUITS.

Problem:

Weight and size of component assemblies must be reduced. Multilayer printed circuits should be developed and evaluated to this end.

Application:

Nuclear weapon systems, programming devices, telemetry units, etc., would benefit from the development of this process.

Process: NEW CUTTING TOOL MATERIALS.

Problem:

Improved cutting speeds are needed to reduce leadtime and production costs. The available types of ceramic and carbide tools should be evaluated.

Application:

Broad application to any production which could benefit from high speed metal removal.

Process: PERFECTION AND APPLICATION OF METAL COLD FORMING TECHNIQUES.

Problem:

This new industrial process must be investigated and evaluated as it concerns the application of precision internal shapers to form tubular metal components.

Application:

The technology developed would apply to tubular shapers requiring precision internal configuration, such as barrels or tubes in small arms, and various other internal forms, such as gears and splines.

Process: PLASMA ARC METAL REMOVAL.

Problem:

In the manufacture of components such as breechblocks, large amounts of material must be removed rapidly.

Application:

Widespread application in production requiring high cutting speeds.

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TABLE 10-13. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: PNEUMATIC-MECHANICAL FORGING TECHNIQUE.

Problem:

Data on the reaction of materials to this method of forging is required before it can be determined that pneumatic-mechanical forged material will meet design requirements.

Application:

To be determined by tests.

Process: PRECISION EXTRUSION LIMITS.

Problem:

Further development and testing is required in the impact extrusion process. Process variables must be established.

Application.

Gun tubes and other components.

Process: PRECISION FORGING OF SPIRAL BEVEL GEARS.

Problem:

Spiral bevel gears are presently manufactured at high cost because of extensive machining from a forged gear blank.

Application:

Gas turbine powered helicopters. Precision forming to near final tolerance requirements.

Process: PRECISION FORGING TECHNIQUES.

Problem:

Extensive machining is required to achieve the final shape of a forging processed with present techniques.

Application:

All current and future forging operations which now require further machining after forging has been completed. Perfection and application of precision forging techniques.

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TABLE 10-13. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: PROCESSING METHODS AND EQUIPMENTS FOR PRODUCING SMALL CALIBER CASELESS AMMUNITION.

Problem:

There presently exists the capability for producing caseless ammunition only by laboratory techniques.

Application:

An R&D feasibility and exploratory development program is required of the problem areas in continuous manufacture of caseless ammunication and its associated hardware.

Process: PRODUCTION ENCAPSULATION OF ELECTRONIC MODULES.

Problem:

Lack of standards for encapsulating methods, materials, and techniques.

Application:

Investigate, evaluate, and publish standards concerning the encapsulation of electronic modules giving particular attention to those used in missiles and tactical components.

Process: PRODUCTION ENGINEERING FOR PRECISION OPTICAL MANUFACTURE.

Problem:

The manufacture of precision optical elements is too costly.

Application:

Research, test, and resolve the application of automatic data processing techniques and capabilities to produce optics within the required narrow tolerances and without undue expenditure.

Process. ROLLED AND WELDED PREFORMS FOR HYDROSPUN MISSILE MOTOR CASES.

Problem:

At present, ring forgings are procured in the normalized and rough machined state. These forgings are relatively expensive due to material lost in machining and the cost of annealing.

Application:

This process would reduce production costs of missile motor cases.

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TABLE 10-13. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: SAND MOLD CASTING.

Problem:

Solidification characteristics of sand molds limit their use despite their economy and usefulness.

Application:

Tank hulls, turrets, gun mounts. Controlled solidification.

Process: SHARPLY-FOCUSED VORTEX OF ELECTRICALLY CHARGED ABRASIVE PARTICLES.

Problem:

In the machining of brittle nonconductive materials, average volume removal rates are extremely low in the ultrasonic machining process (USM). Other processes (electrical discharge machining and electrochemical machining) fail principally because the work material must be electrically conductive for the process to be used.

Application:

The machining of brittle nonconductive materials.

Process: STATIC CASTING.

Problem:

There is a size beyond which the static casting of a one-piece projectile body becomes impractical. Centrifugal casting is not yet a suitable alternative process.

Application:

Manufacture of projectile bodies, 155 mm and larger.

Process TITANIUM CASTING.

Problem:

Present production methods of melting titanium are slow and result in characteristics inferior to the slag cover consumable electrode technique.

Application:

Titanium alloy plate for use on U. S. Army armored vehicles and U. S. Navy deep diving submersibles, cold-mold arc melting technique.

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TABLE 10-13. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: TOOL VIBRATION.

Problem:

Tool chipping and poor finishes are caused by excessive vibration. Acceptable levels of vibration, which would allow efficient operation of machine tools, must be established, along with methods of detecting the causes for purposes of correction.

Application:

This program applies to machine tools and varied other equipments where excessive vibration is a problem.

Process: USE OF CARBIDE GRINDING BURRS IN LIEU OF ABRASIVE GRINDING WHEELS.

Problem:

The time standard and costliness of the existing method of grinding powder chamber contours must be reduced.

Application:

Any application where exact contours are presently "dressed" on the abrasive grinding wheel.

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CHAPTER 11

HEAT TREATING AND CLEANING PROCESSES

11-1 HEAT TREATING

Heat treatment is a process which, through heating and cooling, changes the properties of a metal. This handbook briefly considers some of the basic heat treating principles and some of the properties that can be obtained by applying standard heat treating procedures. Appendix C contains a generic chart of the physical metallurgy processes, further expanding the heat treatment processes discussed herein. Some common design problems are presented in Table 11-6 and some common production problems are given in Table 11-7. These tables are located at the end of this chapter.

11-2 MATERIAL SELECTION AND DESIGN FOR HEAT TREATMENT

The manner in which heat treatment affects the material and the design is discussed. Upon selecting a material for a specific part, the designer's first task is to ensure that the material meets the intended service requirements. To do this, he must first consider the composition, hardening qualities, and various external factors of steels. Certain metallurgical characteristics will influence his decision. For example, tempering martensitic steel is necessary to optimize its mechanical properties. These properties are relatively uniform over the full range of hardness. However, ductility and toughness increase as carbon content decreases.

Thus, if the designer specifies the shape of the part and its hardness, he has roughly established the other mechanical properties. The problem then becomes one of obtaining a tempered martensitic structure, free of internal stresses and combined with the lowest possible carbon content.

The objective of designing for heat treatment is to minimize temperature gradients in the piece during quenching. The presence of temperature gradients sets up internal stresses in the part which, if severe, will result in cracks and distortion.

Some general rules of designing for heat treatment are:

(1) Insert radii or fillets at all re-entrant angles or corners.

(2) Eliminate blind holes, if possible, by continuing the hole through the part.

(3) Strive to have sections of the part contain the same amount of metal so the piece will heat and cool uniformly.

11-3 HARDENING

Hardening of steel is accomplished by heating it to a temperature above the transformation range, holding it until transformation to austenite is complete, and then removing it from the furnace and quenching it. The cooling can be interrupted at an isothermal step at a temperature above ambient, or it can continue without interruption to room temperature. The hardening processes to be considered are quenching and tempering, martempering and austempering, and maraging.

11-3.1 QUENCHING AND TEMPERING

The simplest hardening procedure is cooling the heated steel to room temperature by quenching it in some cooling medium. Air, oil, water, and brine are the most common coolants. Table 11-1 lists some quenching media together with their characteristics.

Selection of the quenching medium depends on the size of the piece being quenched and its composition, the primary objective being to cool the piece fast

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TABLE 11-1. QUENCHING MATERIALS AND THEIR USES

QUENCHING MEDIA	APPLICATIONS
WATER	Ordinary tap water is used; it is the commonest and cheapest quenching medium. Uneven cooling resulting in uneven hardening, warping, and/or cracking is common. Nonuniform hardening is reduced by adequate circulation of the water. Hot water is generally undesirable as a quenching medium; maximum water temperature should not exceed 70°F.
BRINE	Common salt (sodium chloride) dissolved in water (usually 5% to 10% salt by weight) makes a more efficient quenching medium than water; the most efficient quenching action occurs with a 9% salt brine. Brine tends to rust the workpieces; also, all fittings in brine-circulating system must be of same material to avoid corrosion. Quenching efficiency of brines is less affected by increases in temperature than that of water. Usual operating range is 70° to 110°F. High quenching efficiency (elimination of soft spots) can be obtained with little or no agitation of the brine or workpieces.
CAUSTIC SODA	Solutions containing 2% to 7% caustic soda by weight (sodium hydroxide) having quenching efficiencies similar to those of brines (and superior to those of water). Most efficient quenching action occurs with a 3% solution. Caustic soda solutions may injure the skin of workmen; however, when both caustic soda and caustic soda solutions are properly handled, there is little or no danger to personnel. High quenching efficiencies are obtained without agitation.
OIL	Various types of quenching oils are on the market, and their quenching abilities are quite similar (when the better grades or composite quenching oils are compared). Oil is a less drastic quenching medium than water or the water solutions. Oil is expensive compared with water and should be kept within a definite range of operating temperatures (i.e., 90° to 140°F); quenching efficiency is improved if oil temperature is maintained in upper part of this range. Approximately 1 gallon of oil per pound of steel quenched per hour is required.
MOLTEN SALT	Work is quenched directly into molten, or fused, salt baths in the various interrupted-quench processes, such as martempering and austempering (upon removal from the salt quench, the parts are usually air cooled). For martempering, salt is usually kept at about 400°F.; at this temperature, agitated molten salt produces a cooling rate equivalent to that of oil. Austempering usually requires salt temperatures between 400° and 800°F. Salts used for quenching generally have an operating range between 300° and 1100°F. A smaller quantity of salt, when compared to oil, is required because its specific heat is about double that of the oils. Agitation and control of temperature (so that the salt may be either heated or cooled, as needed) are required.
AIR (AND GAS)	Air cooling or quenching is limited to air-hardening alloy steels and to interrupted-quench work; the workpieces are usually cooled in still air, although cooling in an air blast is sometimes used. A cooled, nonoxidizing gas is used to quench light steel parts without scaling in some limited applications.
REFRIGERATED MEDIA	After quenching in one of the above listed media (sometimes before and sometimes after tempering), the hardened workpieces may be further cooled in refrigerated chambers to promote complete transformation

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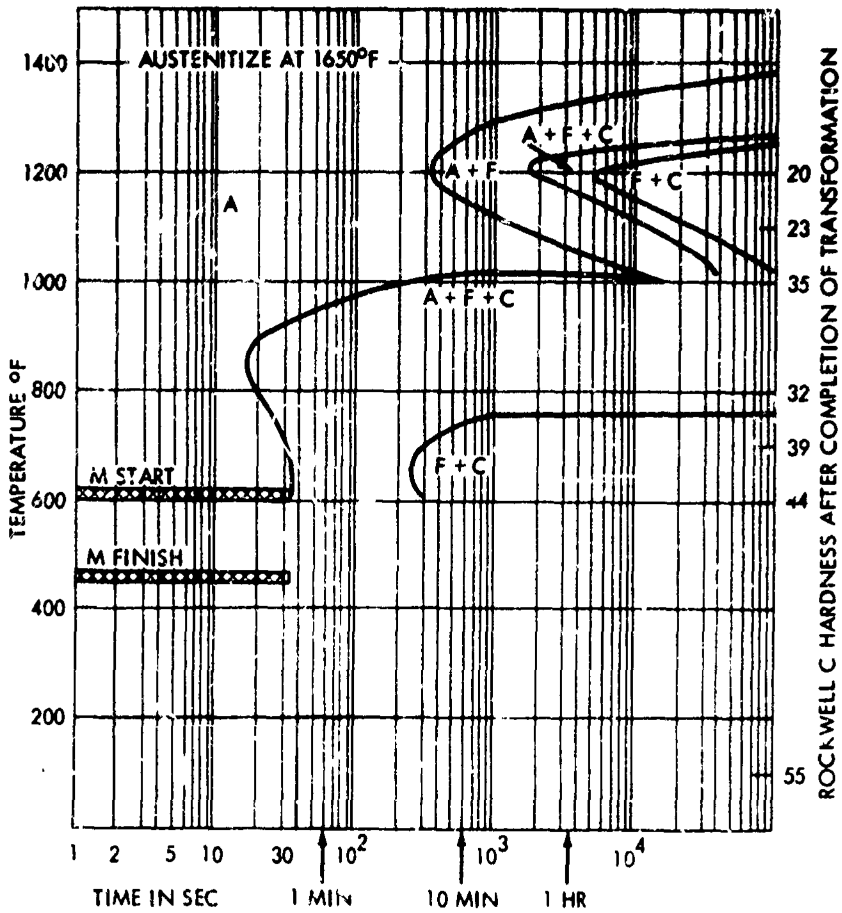

FIGURE 11-1. Isothermal Transformation Diagram (for AMS 6434 Steel)

enough to pass the nose on the TTT curve before transformation starts, thus obtaining a completely martensitic structure. A typical diagram is presented in Fig. 11-1, for AMS 6434 steel. Similar diagrams exist for most steel analyses, and reference to the appropriate one will allow evaluation of the desirable speed of quench. The diagram presented in Fig 11-1 shows that the particular material must be cooled within 30 seconds to below 400°F to produce a 90%-100% martensitic structure. A critical cooling time exists for every material analysis; the length of this interval must be considered in selecting the quenching media

For optimum results, it is necessary that the quench bath have adequate and uniform heat extracting ability. Only under such conditions is uniformity in hardening achieved, not only throughout a single part, but also from one part to the next The heat extraction rate varies widely depending upon the mass of the part, the amount of surface area available for heat transfer, the quenching medium, and the amount of circulation or agitation of the medium Properly quenched steel will consist entirely of the hard, brittle, and metastable constituent martensite

Since the quenching process creates internal stresses, "as quenched" steel is brittle, and further processing, known as tempering, must take place Tempering consists of reheating the steel to a temperature below the transformation range (between 300° and 1200°F) and then cooling it to room temperature The temperature selected varies in order to obtain the best compromise between ductility and strength The higher the temperature, the greater the ductility but also the greater the loss in hardness and strength The following properties and mass effects must be considered when selecting a quenching method

(1) Properties Qualities, such as yield strength, yield

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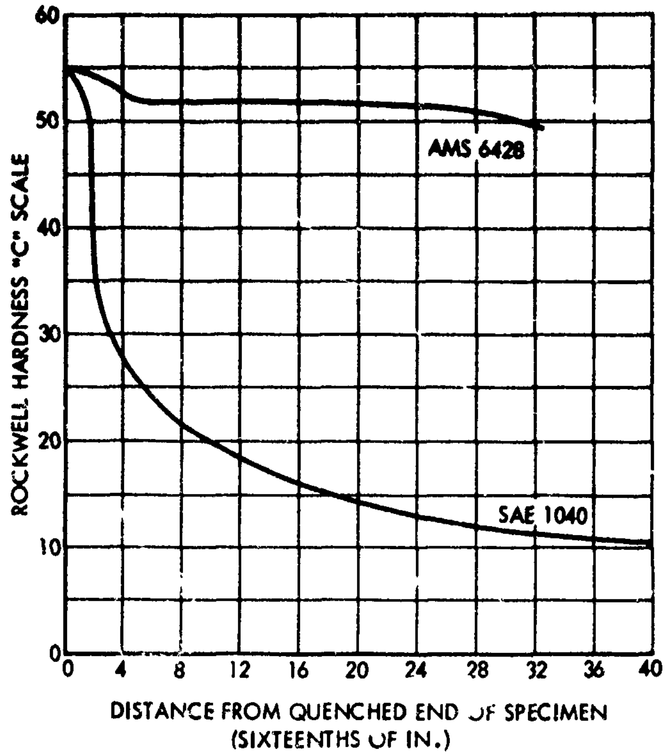

FIGURE 11-2. Comparative Jominy Hardenability of Shallow Hardened SAE 1040 Steel and Deep Hardened AMS 6428 Steel

point, percent elongation, and percent reduction, are obtainable on quenching and tempering and can be furnished by steel suppliers.

(2) Mass effect: Mass affects cooling rate by decreasing the rate as the mass increases. If the cooling rate is not high enough to produce a complete martensitic structure, some nonmartensitic constituents will result, with a corresponding effect on mechanical properties.

The ability to fully harden is measured by means of the Jominy End Quench Test. Fig. 11-2 presents a comparative Jominy Hardenability Chart for two steels, AMS 6428 and SAE 1040. It can be seen that the AMS 6428 steel is deep hardened, showing Rockwell C49 out to 2-in. depth; SAE 1040 is shallow hardened, maintaining a hardness of Rockwell C45 only to 1/8-in. depth.

11-3.2 MARTEMPERING

The martempering process modifies the quench and temper process by quenching to a temperature just above that where martensite forms and holding at this point just long enough to equalize the temperature in the part, then cooling it in air. This causes the martensitic transformation to occur at low transformation and thermal stress conditions because of the small temperature differential in the piece.

11-3.3 AUSTEMPERING

Austempering is similar to martempering, but holds above the martensitic transformation temperature until transformation to a constituent called bainite takes place. The properties of bainite are similar to those of tempered martensite at the same hardness.

11-3.4 MARAGING

Maraging (from martensite and aging) is a heat treating process where the steel is aged for several hours at approximately 900°F. This process increases compression strength and reduces brittleness

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11-4 ANNEALING

A number of different types of annealing are possible, with the choice dictated by the requirements of the situation.

11-4.1 FULL ANNEALING

Full annealing is a softening process accomplished by holding the steel above the transformation temperature long enough to complete the transformation to austenite, and then cooling it slowly to below the transformation range.

Annealed hypoeutectoid steels (steel with less than 0.83% carbon) consists of ferrite and pearlite. Hypereutectoid steels (steel with more than 0.83% carbon) consist of pearlite and cementite.

11-4.2 ISOTHERMAL ANNEALING

This annealing process provides better control (uniformity and fineness) over the formation of pearlite. It requires the extra step of holding the heated steel (after it is transformed to austenite) in a salt bath at a selected temperature below the transformation range until the pearlitic transformation has been completed. Providing the hardness is satisfactory, the pearlitic structure in carbon and alloy steels with 0.20% to 0.50% carbon exhibits good machinability characteristics.

11-4.3 SPHEROIDIZING

Spheroidizing steel converts the carbide into globules through prolonged heating at or just below the critical temperatures followed by slow cooling. The procedure varies with type of steel, the size of the object treated, and the purpose. Spheroidizing may be applied to all classes of carbon steels.

Spheroidizing reduces hardness and improves shaping characteristics. In the steels above 0.60% carbon, spheroidizing improves machinability.

11-4.4 PROCESS ANNEALING

Process annealing is applied to cold worked, low carbon, and low alloy steels to cause them to recrystallize ferrite grains that were distorted during the cold working. It is accomplished by heating to a temperature below the transformation range (1000° to 1200°F) until recrystallization takes place.

11-4.5 STRESS RELIEVING

Stress relieving is an annealing process conducted at 850° to 1200°F. It reduces residual stresses, improves dimensional stability, and restores ductility after cold working.

11-5 NORMALIZING

The normalizing process heats steel to about 100° above the transformation range and cools it in still air. Depending on the composition, the resulting structure will be pearlite, pearlite and ferrite, or pearlite and cementite.

Normalizing cancels the effect of previous heat treatment or cold working, and ensures that later reheating for hardening or annealing will produce a homogeneous austenite. In addition, normalizing or normalizing followed by tempering can be used as the final heat treatment in some applications of medium carbon alloy steels (such as 4130 or 8630 types). With these steels, the alloy often confers sufficient strength without quenching. Normalizing can also be used for parts that are too large for liquid quenching.

11-6 INDUCTION HEAT TREATING

In this process heat is generated in the work piece by subjecting it to the influence of a varying electromagnetic field created by a flow of alternating electrical current in a coil. The magnetic field of the coil induces current to flow around closed paths in generally predictable patterns, depending upon the shape of the coil and geometry of the work. The current encounters resistance and the power loss manifests itself in the form of heat. The configuration of the coil is defined by the shape of the work piece and heat pattern required. Its effectiveness varies inversely with its distance from the work, but it must be far enough away to prevent flashover to the work. The heat penetration depth is dependent upon, along with other factors, the frequency of the coil current and the length of time the coil is energized. The heat zone depth is directly proportional to time and inversely proportional to the frequency of

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the alternating current applied to the coil.

Selection of induction heating over other methods may be influenced by any of the following factors:

(1) Speed of heat generation in a definite area and to a specific depth.

(2) Accurate heat control for repetitive heating assures product uniformity.

(3) Adaptability to high speed production work.

Practical applications of these factors include surface hardening, through hardening, tempering, stress relieving, annealing, forging, upsetting, and hot coining.

11-7 SURFACE HARDENING METHODS

There are several methods available to increase hardness along critical surfaces. These produce a hard surface and a softer interior. When applied to alloy steels, great core strength can be combined with extreme surface hardness, resulting in a composite structure capable of withstanding certain kinds of stresses to a high degree. Where low or moderate core strength can be tolerated, cheaply fabricated low price carbon steels can be used in combination with the surface hardened conditions. Maximum carbon content of carburizing steel is 0.25% for plain carbon material and alloy steel having over 2% added elements. For alloy content of 1% to 2%, carbon content may be up to 0.40%. The methods are described in the paragraphs which follow and are also discussed in Chapter 13, Coating Materials and Methods

(1) Cyanide Case Hardening (Nitriding)—Part is held in molten sodium cyanide; generally used for shallow case on small parts.

(a) Type of case: carbon-nitrogen

(b) Operating range: 1400° to 1600°F

(c) Time at temperature. 1 minute to 1 hour

(d) Case depths obtainable: 0.001 in. to 0.010 in

(2) Activated Cyanide Case—Part is held in molten sodium cyanide salt plus a calcium barium salt as a catalyst.

(a) Type of case: carbon-nitrogen

(b) Operating range: 1200° to 1675°F

(c) Time at temperature up to 3 hours

(d) Case depths obtainable: 0.10 in. to 0.40 in.

(3) Salt Bath Carburizing (Nitriding)—Part is held in molten salt bath containing a minimum of sodium cyanide plus other carburizing compounds.

(a) Type of case: carbon-nitrogen

(b) Operating range: 1650° to 1850°F

(c) Time at temperature: up to 15 hours

(d) Case depths obtainable: 0.025 in. to 0.160 in.

(4) Pack Carburizing—Part is packed in a powder composed largely of charcoal and sealed in an alloy carburizing pot or box.

(a) Type of case: carbon

(b) Operating range: 1550° to 1750°F

(c) Time at temperature: 3 to 48 hours

(d) Case depths obtainable: 0.025 in. to 0.250 in.

(5) Gas Carburizing—Part is placed in gas atmosphere rich in carbon obtained by cracking an air-gas mixture enriched with propane or butane.

(a) Type of case: carbon

(b) Time at temperature (1700° to 1800°F): 1 to 8 hours

(c) Case depths obtainable: 0.010 in. to 0.060 in.

(6) Flame Hardening—Flame is applied to part either stationary or while moving until area reaches quench temperature for material; part is quenched and tempered to desired surface hardness; the carbon content should be 0.35% or more for appreciable hardening; best range is 0.40% to 0.50% carbon

(a) Type of case. tempered martensite

(b) Time at temperature (indicated by time-temperature-depth relation which depends upon fuel used). heat long enough to attain quench temperature

(c) Depth hardness obtainable. 0.030 in. to 0.250 in or more

(7) Shot Peening—Part is abraded with hardened metal balls of various sizes. While developing a residual surface compressive stress, the surface hardness also increases due to effects of cold working. Effective depth 0.003 in to 0.010 in on thin pieces and up to 0.025 in for thicker parts

(8) Induction Heating—Part is heated to quench temperature by use of induction coil and quenched to martensite, section is tempered to desired hardness

(9) Chrome Plating—Parts may be plated with chromium to give a hard wear surface of approximately Rockwell C60. The thickness may vary from 0.003 in. to 0.010 in.

11-8 CLEANING

Cleaning is not always considered part of the production process, but something that takes place after the product is made. This thinking is erroneous. Cleaning is an important part of the production process, even if it is the last step. As much care should go into the selection of the cleaning process and equipment as into any production operation.

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11-8.1 SELECTION OF A CLEANING PROCESS

Selection of a cleaning process is influenced by the type of soil to be removed, the degree of cleanliness required on subsequent operations, the base material to be cleaned, the fragility, size, and intricacy of the part, and the cost.

The generic chart of cleaning processes, Appendix C, illustrates the available cleaning processes. They are broken down into mechanical, chemical, or electrochemical types. These processes and their applicability are discussed later in the chapter.

11-8.2 SOIL TYPES

The six types of soil that might be picked up or generated in production operations are shown in Fig. 11-3. Each of these contaminants can be removed by one or more of the cleaning processes. One method will be preferred depending on other selection factors, notably subsequent operations.

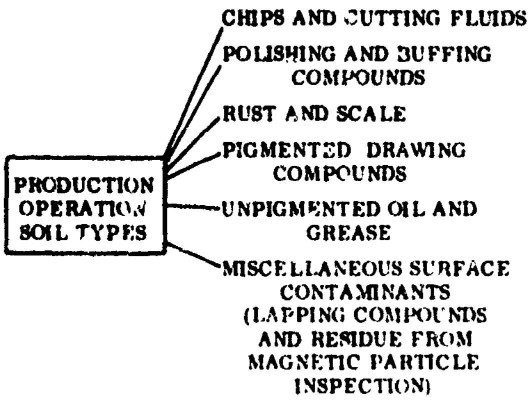

FIGURE 11-3. Soil Types Normally Generated by Production Operations

11-8.3 SUBSEQUENT OPERATIONS

11-8.3.1 Phosphating

How well a phosphate coating adheres depends on the cleanliness of the surface. The presence of oil, drawing compounds, and coolants will cause poor adhesion. Alkaline cleaners must be used with caution because, if carried over into phosphating tanks, they will neutralize the acid phosphating solution.

11-8.3.2 Painting

Paint films will fail prematurely if surfaces are not carefully prepared. Oil, grease, dirt, rust scale, water, and salts must be removed. Both mechanical and chemical cleaners are commonly used to meet the rigid requirements for surface cleaners.

11-8.3.3 Electroplating

Electroplating operations require the greatest of cleanliness and surface preparation. Four steps are commonly called for before plating: (1) precleaning with a solvent, (2) intermediate cleaning with alkaline solutions, (3) electrocleaning, and (4) acid cleaning. This last step conditions the surface, removes light oxide films from previous cleaning, and micro-etches the surface.

11-8.3.4 Bonding

To bond properly, adhesives must be applied to clean grease-free surfaces. In some cases, degreasing with a solvent is sufficient. In others, however, wire brush cleaning or sand blasting may be required to prepare an ideal bonding surface. In the case of aluminum, it may be necessary to pretreat the surface with a chromic sulfuric acid to achieve a good bond.

TABLE 11-2. CLEANING METHODS SUITABLE FOR IN-PROCESS INSPECTION OPERATIONS

SOIL	CLEANING METHOD
Pigmented Drawing Compounds	Low Production - Hot emulsion, hand slush, spray emulsion, Vapor slush degrease. High Production - Automatic spray emulsion.
Unpigmented Oil and Grease	Low Production - Emulsion dip or spray. Vapor degrease. Cold solvent dip. Alkaline dip, rinse, dry. High Production - Automatic vapor degrease. Emulsion, tumble, spray, rinse, dry.
Chips and Cutting Fluid	Low Production - Alkaline dip and surfactant. Solvent Steam High Production - Alkaline dip or spray and emulsion surfactant.

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TABLE 11-3. CLEANING METHODS IN PREPARATION FOR PLATING

SOIL	CLEANING METHOD
Pigmented Drawing Compounds	Low Production - Alkaline soak, hot rinse, hand wipe. High Production - Hot emulsion or alkaline soak, hot rinse, electrolyte alkaline hot rinse.
Unpigmented Oil and Grease	Low Production - Emulsion soak, barrel rinse, Electrolytic alkaline, rinse, hydrochloric acid dip, rinse. High Production - Automatic vapor degrease, electrolytic alkaline, rinse, hydrochloric acid dip, rinse.
Chips and Cutting Fluid	Low Production - Alkaline dip, rinse, electrolytic alkaline, rinse, acid dip, rinse. High Production - Same as low production, except soak rather than dip.
Polishing and Buffing Compounds	Low Production - Surfactant, rinse, electroclean. Emulsion spray or soak, rinse, alkaline spray or soak, rinse, electroclean Solvent presoak, alkaline soak or spray, electroclean. High Production - Surfactant, alkaline soak, spray rinse, electrolytic alkaline Emulsion spray or soak, rinse, alkaline spray or soak, rinse, electroclean. Solvent presoak, alkaline soak or spray, electroclean.

TABLE 11-4. CLEANING METHODS IN PREPARATION FOR PHOSPHATING

SOIL	CLEANING METHOD
Pigmented Drawing Compounds	Low Production - Hot emulsion hand slush, spray emulsion, hot rinse, wipe. High Production - Alkaline soak, hot rinse, alkaline spray, hot rinse.
Unpigmented Oil and Grease	Low Production - Emulsion dip or spray, rinse. Vapor degrease. High Production - Emulsion power spray, rinse. Vapor degrease Acid clean.
Chips and Cutting Fluid	Low Production - Alkaline dip, emulsion surfactant. Solvent or vapor rinse. High Production - Alkaline dip or spray and emulsion surfactant.
Polishing Compounds	Low Production - Surfactant, rinse. Emulsion soak, rinse. High Production - Surfactant, alkaline spray, spray rinse Emulsion spray, rinse.

11-8.3.5 In-process Cleaning

In-process cleaning methods facilitate inspection and gaging procedures and correct location in jigs and fixtures. Using the two parameters, type of soil and purpose of the cleaning, tables have been constructed which enumerate typical cleaning processes that can be used. Table 11-2 (cleaning in-process), Table 11-3 (preparation for plating), Table 11-4 (preparation for phosphating), and Table 11-5 (preparation for painting or bonding) give cleaning information helpful for the particular situations indicated.

11-9 CLEANING METHODS

11-9.1 MECHANICAL CLEANING METHODS

The mechanical cleaning methods include grinding, brushing, abrasive blasting, steam or flame jet cleaning, and tumbling. The paragraphs which follow give a brief description of the processes.

11-9.1.1 Grinding

Grinding cleans by wearing away dirt, usually taking part of the base metal with it. This method is commonly used to remove coarse irregularities as well as dirt from castings and other forms. Grinding is done with motorized grinding wheels or abrasive belts, both stationary and portable

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TABLE 11-5. CLEANING METHODS IN PREPARATION FOR PAINTING AND BONDING

SOIL	CLEANING METHOD
Pigmented Drawing Compounds	Low Production - Hot alkaline, blow off, wipe. Vapor slush degrease, wipe. Acid clean. High Production - Alkaline soak, rinse, alkaline spray rinse.
Unpigmented Oil and Grease	Low Production - Vapor degrease Phosphoric acid clean. High Production - Automatic vapor degrease.
Chips and Cutting Fluid	Low Production - Alkaline dip and emulsion surfactant. Solvent or vapor. High Production - Alkaline dip or spray and emulsion surfactant.
Polishing Compounds	Low Production - Agitated soak and rinse. Emulsion soak, rinse. High Production - Surfactant alkaline spray and rinse.

11-9.1.2 Brushing

Brushing is an abrasive operation done with wire or fiber brushes, mounted on a motor driven wheel. Different brushes and various kinds, lengths, and gages of wire, fibers, or hair, give a wide range of abrasive action. For heavy abrasion, steel wire is used. Mild abrasive action is obtained with tampico (plant) fiber, horsehair, and other bristles. Moderate abrasion is done with soft, fine wire made from nickel-silver, brass, etc.

Wire brushing may be uneconomical since further cleaning is usually required. Tenacious scale, dirt, embedded sand, and paint must be removed. However, almost any part that does not have precise dimensions and can be easily handled by the operator may be wire brushed. Wire brushing also may be used on most types of steel or iron. With stainless steel and aluminum, wire particles may become embedded in the surface and later corrode, producing surface staining and the appearance of poor corrosion resistance. Use of stainless steel brushes will overcome this problem. When wire brushes are used on magnesium, close control of dust is necessary because of the explosive nature of magnesium dust.

11-9.1.3 Abrasive Blasting

This method consists of bombarding a surface with an abrasive at high velocity. Many abrasives (sand, steel shot, steel grit or crushed shot, silicon carbide, cut wire rice hulls, corn cobs, and alumina) may be used. Air is usually the transfer medium for the abrasive but liquid can also be used.

The effects of the abrasive blast vary according to type and hardness of the abrasive, particle size of the abrasive, velocity at impact, and angle of impact with the surface. On metal, sand gives a matte finish which varies with the grit size and pressure used. Steel grit produces a matte finish that is similar to that produced with sand, and steel shot produces a bright finish.

Blasting produces a good bonding surface for paints and may be used for castings, forgings, stampings, welds, and heat-treated parts of all shapes and sizes. Guarding against possible dust explosions may be required.

Blasting is also a rapid method of removing scale, rust, and burrs and is widely used on cast iron, carbon and alloy steels, nickel, and titanium. To avoid contamination by embedded particles of a metallic abrasive, nonmetallic abrasives are used on stainless steel, copper, brass, bronze, zinc, aluminum, tin, and lead. Abrasive blasting should not be used on magnesium since the abrasive particles reduce corrosion resistance. Also, stringent dust control methods are necessary to prevent explosions.

Blasting can be used instead of some chemical cleaning methods because it leaves a mechanically and somewhat chemically clean surface. It does not however, remove heavy coats of grease. Also, blasting cannot be used on parts where the dimensions must be retained. Thus, it has limited use on complex, curved surfaces, and on parts with deep crevices, threads, or machined surfaces.

11-9.1.4 Steam or Flame Jet Cleaning

Cleaning with steam or flame jets is an economical method of removing loose scale on large, unwieldy, ferrous metal parts. It is not suitable for cleaning nonferrous metals. In the steam jet process, a jet of high pressure steam is directed onto the surface and physically removes heavy scale. Oil and dirt-bearing grease can be removed by adding chemical cleaners to the jet stream. In the flame jet process, an oxyacetylene flame rapidly heats the scale which then breaks away from the metal because of the different rates of thermal expansion of scale and metal. Flame jets are also used to remove old paint prior to refinishing.

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11-9.1.5 Tumbling

The tumbling operation consists of rotating a barrel containing small parts, either alone or with abrasives and lubricating (cushioning) liquids. Cleaning, deburring, abrading, work hardening, burnishing, or combinations of these may take place, depending on the type of barrel and media. The main advantage of this cleaning process is its low cost. Large volumes of small parts can be handled, and several treatments and rinses can be carried out in the same barrel, thus avoiding transferring pieces from one piece of equipment to another. Tumbling as a means of finishing is discussed in Chapter 10.

11-9.2 ELECTROCHEMICAL CLEANING METHODS

11-9.2.1 Electropolishing

Most electropolishing methods are patented proprietary processes that represent a wide range of electrolytes and operating details. In general, the metal is made the anode at high current density in a concentrated acid bath. The action involves a rapid attack on the elevated spots in the rough finish and a minimum attack on the depressed ones. A smoothing or rounding off results in a brillant finish.

Electropolishing is applicable to most metals, with the exception of mild steel. The main advantage of this process is that it can be used to polish thin sectioned or intricate shapes which are too cumbersome for mechanical wheel finishing. Electropolishing is useful before plating since it removes or diminishes scratches, burrs, and unwanted sharp edges. Plated metal coatings may be brightened by an electropolishing process. Any surface defects (such as seams or deep pits) are revealed, however, and metal that tends to pit cannot be satisfactorily electropolished. Electropolishing is also much more expensive than barrel tumbling.

11-9.2.2 Electrolytic Alkaline Cleaning

This method speeds up alkaline cleaning by generating gas to aid agitation and soil removal. The alkaline solution is the electrolyte; the metal to be cleaned is one electrode, and the tank or a steel plate is the other electrode. When current is applied, the water in the electrolyte decomposes to form oxygen at the anode and hydrogen at the cathode. The gas bubbles break up the film of soil rapidly. Some disadvantages of electrolytic alkaline cleaning are: certain impurities in the tank may plate out on the surface; chlorides in the bath may cause pitting; the possibility exists that hydrogen embrittlement of hardened steel parts will occur; zinc, aluminum, brass, lead, tin, solders, etc., are attacked by strong alkaline cleaners.

11-9.2.3 Electrolytic Pickling

The advantage of applying an electric current to pickling is similar to that for alkaline cleaning. The liberation of gas mechanically loosens scale and speeds up the process. In electrolytic pickling, the bath may be either acid or alkaline. In the acid process, the metal is made the cathode in a dilute sulfuric acid bath. In the alkaline process, the bath is a strong cyanide solution containing a complexing agent. The metal can be either the anode or the cathode, or a periodically reversing current can be used. In the alkaline bath, organic matter can be removed and there is less attack on the metal.

The process has certain limitations in that the temperature and concentration of the bath must be closely controlled and prolonged pickling produces a deeply pitted surface. Dimensions may be seriously altered by dissolving of the metal and acid may be trapped in holes and crevices of complex forms. The process is applicable to sheet, sand and die cast aluminum; copper and its alloys, iron and steel; stainless steel; magnesium and its alloys; and nickel and its alloys.

11-9.3 CHEMICAL CLEANING METHODS

The principal chemical cleaning methods are solvent cleaning, emulsion cleaning, alkaline cleaning, acid cleaning, pickling, descaling with sodium hydride, and paint stripping.

11-9.3.1 Solvent Cleaning

Solvent cleaning is one of the most widely used methods of cleaning metal surfaces. The solvents include petroleum or coal tar hydrocarbons and chlorinated hydrocarbons as such, as emulsions, and as diphase systems. The types of soil most efficiently removed are unsaponifiable mineral oils and greases. Solvent cleaning is economical for high production work, particularly when the surface must be immediately ready for further treatment. Solvent cleaning can be used for any metal. Parts dry rapidly after cleaning. Solvent clean-

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ing has these limitations: solid soils, saponifiable greases, and metallic soaps are often not removed; a residual oil film may be left on the surface; flammability and toxicity hazards are present; material costs are higher than for alkaline cleaning; and distillation is necessary to keep the solvent clean.

The following methods are used in solvent cleaning:

(1) Soak or tank cleaning–All three forms of solvent (straight, emulsion, and diphase systems) may be used. The parts are immersed in the solvent, and some form of mechanical agitation is provided.

(2) Spray degreasing—The heated solvent (either straight or emulsified) is pressure-sprayed on the surface. Spray degreasing is usually followed by rinsing with clean solvent or by alkaline cleaning.

(3) Vapor degreasing—The parts to be cleaned are suspended in the upper part of a vessel containing boiling solvent, usually chlorinated hydrocarbon such as trichloroethylene. The solvent vapors condense on the surface and clean it as the liquid returns to the solvent reservoir. This method probably provides the most efficient and economical means of removing mineral oil and grease.

(4) Ultrasonic cleaning—This method utilizes ultrasonic vibrations in a liquid to obtain unusually rapid and thorough cleaning. It is based on the use of piezoelectric materials or transducers The violent action thoroughly scrubs the metal surface. The liquid penetrates into deep crevices in the metal part and removes minute particles of insoluble soils, greases, oils, and metal chips, which are difficult to remove by other methods. Chlorinated solvents are commonly used in ultrasonic degreasers, although alkaline solutions can also be used. Ultrasonic cleaning is rapid and produces a very clean surface, even with complex shapes.

11-9.3.2 Emulsion Cleaning

The emulsion cleaning process uses common organic solvents dispersed in an aqueous medium with the aid of an emulsifying agent. The cleaning process is conducted between room temperature and 180°F. The solvents used are generally petroleum base; the emulsifiers include polyethers, glycerols, polyalcohols, high molecular weight sodium or amine soaps of hydrocarbon sulfonates, and others. Emulsion cleaners are applied by spray and dip tank methods. Dip tanks are preferred for small parts that must be placed in baskets, tubular parts, intricate castings, and other complicated shapes.

Emulsion cleaning of some parts is not recommended unless it can be followed by some other cleaning method to remove trapped emulsion which would impair subsequent finishing operations. Parts in this category include sand core brass plumbing fixtures, tubular parts for furniture, and parts with lapped and spot welded sections.

Emulsion cleaning is less costly than solvent cleaning because it uses relatively small amounts of expensive solvent and large amounts of water. It is safe to use with most metals if the pH remains below 10. It also leaves a rust preventive film of oil on cleaned parts, which may or may not be advantageous.

11-9.3.3 Alkaline Cleaning

Alkaline cleaning, in all of its forms, is probably the most widely used cleaning method. Alkaline compounds in aqueous solution are extremely effective for the removal of organic and water-soluble soils, vegetable and animal greases, and any solid dirt that may be embedded in a surface. It is the least expensive cleaning method for high production operations.

Alkaline cleaners work by detergent action and saponification. They displace the dirt from the surface and suspend it in the solution. Fatty soils are saponified. Alkaline cleaning is done in soak tanks and by pressure spray. In some cases, heat or mechanical agitation is used and, for rapid action, an electric current. In cases where electro-finishing is necessary, other cleaning methods must be followed by alkaline cleaning. To eliminate traces of alkali, an alkaline cleaned surface must be thoroughly rinsed or neutralized prior to most finishing operations since poor rinsing causes paints to deteriorate Zinc, aluminum, lead, tin solders, and brass are attacked by strong alkaline cleaners. Inhibited cleaners are required for these metals.

11-9.3.4 Acid Cleaning

Acid cleaning is commonly used on light soil and rust. Although acid cleaning involves pickling, such treatments must be considered distinct from straight pickling. Acid cleaners are usually water solutions of phosphoric acid, organic solvents, acid-stable detergents, and wetting agents.

Acid cleaning is performed, either hot or cold, in soak tanks and spray systems Cleaning is done by emulsifying oils on the surface and dissolving or undercutting oxide films. A slight etch is usually left on the surface Acid cleaning is unsuitable for removing heavy coats of grease, oil, and dirt because a deep etch would result from the long immersion time necessary for

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thorough cleaning. This process is used on ferrous metals, copper, and aluminum alloys. It is seldom used on nickel, magnesium, lead, or tin.

11-9.3.5 Pickling

Pickling is an acidic treatment for chemically removing surface oxide, scale, and dirt from a metal. Wide variations are possible by the type, strength, and temperatures of the acid solutions used. The acid is selected on the basis of the metal to be pickled and the type of foreign material to be removed.

Hydrochloric and sulfuric acids are commonly used for ferrous surfaces. Hydrochloric acid, which attacks metal rapidly, is used cold. Sulfuric acid, with a slower rate of attack, is heated. Phosphoric acid, the slowest acting of all types, is used where it is important to obtain a steel surface free from carbonaceous smut. Hydrofluoric acid is used to remove embedded sand from molding or sand blasting operations. For nonferrous surfaces, particularly aluminum and magnesium, many combinations of acids are used. Some of these are chromic, acetic, nitric, and hydrofluoric, together with certain inorganic salts.

A properly controlled pickling bath is much more efficient for scale and rust removal than mechanical abrasion. However, pickling must be followed by a thorough rinsing and neutralizing. Hydrochloric and sulfuric acids, unless thoroughly removed, can cause organic finishing difficulties. Pickling is applicable to sheet, sand, and die-cast aluminum and its alloys; copper and its alloys; iron and steel; stainless steel; magnesium and its alloys; and nickel and its alloys.

11-9.3.6 Descaling

The sodium hydride process is a metal descaling process that avoids several disadvantages of conventional pickling and other methods. It is suitable for ferrous metals, copper, nickel, and titanium. It easily removes hot rolling, annealing, and heat treatment scale from both ferrous and nonferrous metals.

In the process, sodium hydride is generated by reacting metallic sodium and anhydrous ammonia. The immersion bath consists of fused sodium hydroxide, at approximately 700°F, containing approximately 2% sodium hydride. Descaling is carried out by immersing the metal part in the hot molten bath. The sodium hydride reacts with the metal oxides, and the reduction takes place within a minute. The metal is removed, drained, and immersed in water. The generated steam mechanically loosens the reduced flaky metal. A water rinse and a short acid dip remove traces of remaining alkali and brighten the surface.

The process has these advantages: the base metal is unaffected; the bath attacks only the scale, making it impossible to lose metal by over-treatment (an appreciable saving when processing expensive alloys); the same bath can be used for several metals; hydrogen embrittlement is impossible as the metal under treatment cannot absorb hydrogen (the tendency is to drive off any hydrogen present in the metal); the fluid bath penetrates deeply into minute recesses and complex shapes; both oxides and organic soils are removed, leaving a very clean surface; and, occasionally, the process can be combined with heat treatment.

The principal disadvantages are: thin sections may buckle or warp at the temperature used (700°F); it is uneconomical for light oxide films; it is not a useful process where draw temperature of steel is less than 700°F; and it is not suitable for low melting metals and alloys of magnesium, zinc, tin, aluminum, and lead because they are readily attacked by caustic soda.

11-9.3.7 Paint Stripping or Removing

Stripping off old paint finishes is often neccessary before applying new ones. It can be done by a combination of chemical strippers and mechanical action. The type of stripper used depends on the paint film to be removed. Strong, aqueous alkali solutions are used for paints based on drying oils and polymerized resins. In other cases, mixtures of organic solvents work well. A third type employs a mixture of alkalies, solvents, and wetting agents.

All paint stripping requires some sort of mechanical assistance, usually brushing, to remove the loosened film. Even after thorough rinsing, the metal surface may require one of the other cleaning procedures. Stripping is usually a quick acting method of removing paint from old painted surfaces but, on occasion, may require long periods of time to attain best results. Some strippers are toxic and flammable; some strippers attack the metal surfaces.

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TABLE 11-6. COMMON DESIGN PROBLEMS

Problem: MACHINING OPERATIONS ARE SPECIFIED AFTER HEAT TREATMENT.

Cause and Effect:

The best design, material, and heat treatment may result in distortion which must be alleviated by machining.

Potential Solution:

Change process sequence to permit annealing, rough machining, heat treatment, and finish machining or grinding as an example.

Problem: PART DISTORTS OR CRACKS DURING HEAT TREATMENT.

Cause and Effect:

Quenching to obtain desired hardness sets up stress in part, causing it to distort or crack.

Potential Solution:

Change material or change process to marquench or some other heat treatment process. Review design to improve sectional distribution, e.g., add holes to equalize sectional volumes, use generous fillets. If distortion cannot be eliminated, machining after heat treatment can be specified, however, this is a costly alternative.

Problem: SPECIFIED MATERIAL IS NOT READILY MACHINED.

Cause and Effect:

Some materials, after having been subjected to cold working, may have internal stresses or be work hardened.

Potential Solution:

Prescribe heat treatment to improve machinability.

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TABLE 11-7. COMMON PRODUCTION PROBLEMS

Process: CARBURIZING (CASE HARDENING) FERROUS MATERIALS.

Problem:

Gas versus liquid carburizing is more amenable to large-scale production and can be performed in a shorter time, but this process introduces many variables which affect the strength, toughness and behavior of components.

Application:

Process improvements will be applicable to carburizing components for weapons.

Process: INVESTIGATION OF EMBRITTLEMENT CONCERNING GUN COMPONENTS.

Problem:

Hydrogen embrittlement of high strength steels has caused premature failure of weapons and components.

Application:

Investigate and resolve practical means of controlling embrittlement; considering but not limited to, barrier coatings, electrolytic post treatments, as well as variations in electrolytes.

Process: PRODUCTION OF DUAL-HARDNESS ARMOR PLATE.

Problem:

Heat treatment and joining.

Application:

Develop production methods (after specifications) for dual-hardness armor plate, including joining, and field test to obtain superior protection for a given weight or equivalent protection for lesser weight.

Process: SURFACE TREATMENT TO EXTEND LIFE OF GUN COMPONENTS

Problem:

The severe galling that occurs when titanium is acted upon by rubbing or sliding forces has prevented its use as a light metal substitute for steel in modern weaponry.

Application:

Gun components having lightweight, high strength requirements.

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CHAPTER 12

JOINING METHODS

12-1 GENERAL

The complexities of modern industry have demanded development of new and improved methods of joining materials. The selection of a joining method deserves the same degree of attention as any other facet of the design, and exerts a strong influence on the material selection.

Charts in Appendix C display a variety of joining techniques currently available to the engineer. The capabilities, applications, and limitations of the principal techniques as they relate to producibility are discussed in the paragraphs which follow. Some common design problems are presented in Table 12-4, and some common production problems are given in Table 12-5. These tables are located at the end of this chapter.

12-2 MECHANICAL FASTENING

Mechanical joints can be divided into those which are permanently fastened and those which are held with fasteners which permit disassembly. Over 500,000 commercially available devices can be identified by name, type, size, and material.

In selecting a fastener, the designer is constrained by the current Military Specifications, Standards, or published handbooks which prescribe military hardware type items. While this is an important contribution to standardization, only a small percentage of the fasteners available have Military Specification numbers. Many excellent or superior fasteners may be overlooked, and the producibility of the product and its reliability could be improved by using them. Should this be the case, early action to prepare Military Specifications must be taken. The material and physical characteristics must be established and recognized so that there will be no delay when the fasteners are required in procurement for prototype or production quantities.

In addition to load considerations, the following criteria should be considered when selecting a fastener for a particular application:

(1) How long should the fastener last?

(2) Should it be capable of being used over and over, or will it be discarded after one use and replaced?

(3) What are the consequences if the fastener is lost or not available in the field?

(4) Will the fastener require tools to install or operate? If so, are they in the supply system? Are they standard tools available to the user?

(5) What is the environment that the fastener will operate in? Hot? Cold? Corrosive? Etc.

(6) Should the fastener be nonmagnetic?

(7) Will the fastener join dissimilar materials/metals?

(8) What type of vibrations are present that might fatigue or loosen the fastener?

An expanded checklist of this type will aid in selecting the best fastener for the purpose.

For fasteners producing permanent joints, the field of selection is much narrower. However, a similar checklist would assist in attacking the problem. In addition, if a permanent joint is required or can be used, the field widens to include other methods of joining.

12-3 METALLURGICAL JOINING

Metallurgical joining includes such processes as welding, brazing, soldering, and solid state bonding. These methods create joints that are normally considered permanent. Soldered and brazed joints, however, may be disassembled.

12-3.1 WELDING

There are some 40 welding processes in use by indus-

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try today. Information in Table 12-1 will assist in classifying these processes. The capabilities of the processes overlap in some areas; usually, one will have a specific advantage over another in a particular application. For example, in some cases, only one welding process can do the job; in others, two or more processes could do the job although one will probably do it better.

Selecting the optimum method requires analysis of the design, the joint requirements, metals to be joined, configuration of parts, production quantity involved, production rates desired, and equipment available. Table 12-2 is a guide containing information to assist in making the selection. More comprehensive guides to recommended practices are published in most welding handbooks. The principal welding processes are discussed in the paragraphs which follow.

12-3.1.1 Arc Welding

Arc welding is a versatile and widely used welding process wherein the heat of an electric arc is used to bring metals to a molten state. Almost all arc welding now employs a shielded arc to protect weld metal from impurities and embrittlements. The method is fast and suitable for automatic production methods. Six principal arc welding processes are described briefly in the paragraphs which follow.

12-3.1.1.1 Coated Electrode Arc Welding

A coated electrode is a metallic core wire of a specified chemical analysis covered with a formulated coating. The coating forms an atmospheric protection about the arc, aids the metal transfer, alters the chemical composition of the metal deposited, and forms a protective slag over the weld deposit. Most ferrous metals and some nonferrous metals—such as aluminum alloys, bronzes, and high nickel alloys, such as Inconel and Monel—can be welded with prescribed electrodes. Welding electrodes are classified by the American Welding Society (AWS) and the American Society for Testing Materials (ASTM) on the basis of the composition of the metal deposit, tensile strength, type of welding current, and welding position of the electrode. Welding electrodes in each class may have been developed by different electrode manufacturers. Coated electrodes also are found in various sizes depending on the diameter of the core wire, which ranges from 3/64 in. to 3/8 in. Selection of the proper electrode depends on the type and thickness of the material to be welded, the physical requirements of weld deposits, the response of the weld metal to heat treatment, the position in which the weldment is to be made, and the configuration of the materials in all thicknesses except extremely thin sheet stock.

12-3.1.1.2 Inert Gas Metal Arc Consumable Electrode Welding

The inert gas metal arc consumable electrode welding process is relatively new and employs small diameter wire and high current density. This results in a relatively high rate of metal deposit. Specially designed welding equipment is required to perform the various functions of this method of welding which can be used either partially or fully automatically. The selection of the filler wire is dependent upon the material to be welded and the mechanical properties of the weld metal deposit. The inert gas metal arc consumable electrode process can be used to weld carbon and stainless steels, and specific alloys of aluminum, copper, nickel, and titanium. It is especially applicable to heavy materials or where relatively rapid travel speeds are required on thin sections of material. Fig. 12-1 is a schematic diagram of equipment used for this type of welding.

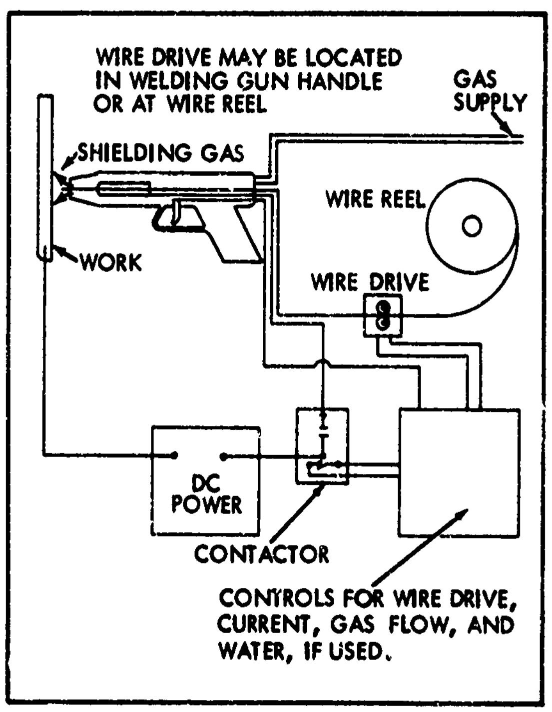

FIGURE 12-1. Schematic Diagram of Equipment for Inert Gas Metal Arc Consumable Electrode Welding

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TABLE 12-1. BASIC WELDING PROCESSES

- WELDING
  - ARC
    - CARBON ELECTRODE
      - UNSHIELDED
        - CARBON ARC
        - TWIN CARBON ARC
      - SHIELDED
        - CARBON ARC
        - INERT GAS CARBON ARC
    - METAL ELECTRODE
      - SHIELDED
        - STUD
        - SUBMERGED ARC
        - ATOMIC HYDROGEN
        - COATED ELECTRODE
      - UNSHIELDED - STUD
  - LASER
  - FLOW
  - INDUCTION
  - GAS
    - OXYACETYLENE
    - OXYHYDROGEN
    - AIR ACETYLENE
    - PRESSURE GAS
  - THERMIT
    - PRESSURE
    - NONPRESSURE
  - FORGE
    - ROLL
    - HAMMER
    - DIE
  - ELECTRON BEAM
    - VACUUM
    - NONVACUUM
  - RESISTANCE
    - PROJECTION
    - UPSET
    - SPOT
    - SEAM
    - PROJECTION
    - FLASH
  - PLASMA
    - ARC
    - ELECTRON BEAM

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TABLE 12-2. RECOMMENDED WELDING PROCESSES

	SHIELDED METAL-ARC (1)	SUBMERGED ARC	ATOMIC HYDROGEN	INERT GAS—TUNGSTEN ARC	INERT GAS—METAL ARC	FLASH WELDING	SPOT WELDING	SEAM WELDING	GAS WELDING (2)	BRAZING—FURNACE	BRAZING—TORCH	THERMIT
A. BASED ON WELDED MATERIALS												
Low carbon mild steel types - SAE 1010, SAE 1020	R*	R	S*	S	S	R	R	R	R	R	S	S
Medium carbon steel types - SAE 1030, SAE 1050	R	R	S	S	S	R	R	S	R	R	S	S
Wrought alloy engineering steels - SAE 4130, SAE 4340	R	R	S	S	S	R	R	NR*	S	S	NR	S
High alloy stainless steels, austenitic types - AISI 301-309-316	R	R	R	R	R	R	R	R	S	S	S	NR
Stainless steels, ferritic and martensitic types - AISI 405-430	R	S	S	S	S	S	S	S	S	S	S	NR
High temperature alloys - 19-9DL, 16-25-6	R	S	S	S	S	S	S	R	S	NR	NR	NR
Cast iron, Gray iron	S	NR	NR	S	NR	NR	NA*	NA	R	NR	R	S
Aluminum and aluminum alloys	S	NR	S	R	R	S	R	S	S	R	R	NA
Nickel and nickel alloys	R	S	S	R	R	S	R	S	S	S	R	NR
Copper and copper alloys	NR	NR	NR	R	R	S	S	NR	S	S	R	NR
Magnesium and magnesium alloys	NA	NA	NR	R	S	NR	S	NR	NR	NR	NR	NA
Silver	NR	NR	R	R	S	S	NR	NR	R	S	R	NR
Gold, Platinum, Iridium	NR	NR	R	R	S	S	S	NR	R	S	R	NR
Titanium and titanium alloys	NA	NA	NA	R	NR	S	S	NR	NA	NR	S	NA
Uranium, Molybdenum, Vanadium, Zirconium, Tungsten	NA	NA	NR	R	NR	S	S	S	NR	NR	NR	NR
B. BASED ON JOINT DESIGN												
Butt Joint — Light section (3)	S	S	R	R	NR	NR	NA	NA	R	NR	S	NA
Butt Joint — Heavy section (4)	R	R	S	S	R	R	NA	NA	S	NR	S	R
Lap Joint — Light section	R	S	S	R	NR	NR	R	R	R	R	R	NA
Lap Joint — Heavy section	R	R	S	S	R	R	R	R	S	R	R	NA
Fillet Joint — Light section	R	S	S	R	NR	NR	NA	NA	R	R	R	NA
Fillet Joint — Heavy section	R	R	R	S	R	R	NA	NA	S	R	R	NA
Edge Joint — Light section	NR	NR	R	R	NR	NR	NA	R	R	NA	S	NA
Edge Joint — Heavy section	R	S	S	S	S	S	NA	R	S	NA	S	NA
Overlay welding	R	R	R	R	R	R	NA	NA	R	NR	S	NR

NOTES: (1) Shielded Metal-Arc (coated electrode).
(2) Gas Welding (Oxyacetylene).
(3) Light section - 0.005 to 0.125 inch.
(4) Heavy section - 1/8 inch and over.

*Key: R = Recommended
S = Satisfactory
NR = Not Recommended
NA = Not Applicable

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12-3.1.1.3 Inert Gas Tungsten Arc Welding

This process is an electric arc welding method where coalescence is produced by heating with an electric arc between a metallic tungsten electrode and the work (Fig. 12-2). Tungsten electrodes are used because they have a higher melting point when contained within an inert protective atmosphere such as helium or argon gas. Filler wire may be added manually. The type of filler wire used depends on the material to be welded and the mechanical requirements of the weld deposit. The tungsten arc welding process is applicable to materials such as carbon steels, stainless steels, aluminum alloys and is frequently recommended for welding dissimilar metals.

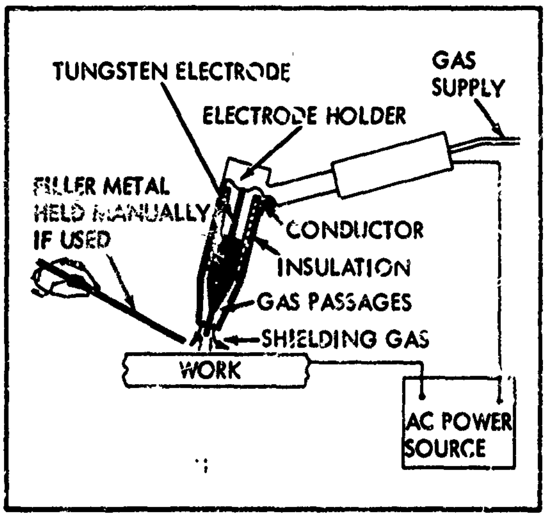

FIGURE 12-2. Schematic Diagram of Equipment for Inert Gas Tungsten Arc Welding

12-3.1.1.4 Submerged Arc Welding

Submerged arc welding is an arc welding process wherein coalescence is produced by heating with an electric arc or arcs between a bare wire electrode or electrodes and the work. The welding is shielded by a blanket of granular fusible material on the work. The granular material is referred to as a flux, although it does not perform the functions usually ascribed to it. Filler wire is fed continuously by the welding equipment to maintain a constant voltage at a predetermined welding current and voltage. A hopper feeds the flux by gravity ahead of the arc. The diameter of the filler wire ranges from 1/8 in. to 3/8 in. and the type of wire depends on the material to be welded and the mechanical properties required. The composition of the flux differs depending on the material to be welded, the filler wire used, and the application. Submerged arc welding is best suited where relatively heavy weld deposits are required. Most carbon, low alloy, and stainless steels can be readily welded with the submerged arc process. Nonferrous alloys such as nickel, Monel, Inconel, copper-nickel, and copper-silicon can also be successfully welded with this process

12-3.1.1.5 Atomic Hydrogen Welding

In this arc welding process heat is obtained from the electric arc between two metallic electrodes in an atmosphere of hydrogen. The work, however, is not a part of the electrical circuit. The hydrogen in its normal state (molecular hydrogen) is diatomic and, when subjected to high welding temperatures, is dissociated into atomic hydrogen. Filler wire, which is dependent upon the material to be welded, may be added to the weld deposit if necessary. Because there is a sudden decrease in temperature at a short distance from the arc stream where the atomic hydrogen recombines to form molecular hydrogen, the amount of heat applied to the work can be closely controlled. The atomic hydrogen welding process is applicable to carbon and alloy steels, aluminum, and nickel alloys such as Monel and Inconel.

12-3.1.1.6 Plasma Arc Welding

Plasma arc welding is one of the latest fusion welding techniques. It utilizes a high velocity plasma stream consisting of inert gas ionized in an electric arc. Materials up to 0.250 in. can be welded in one pass. It offers advantages over gas tungsten arc welding in that its arc is more stable, square butt-joints can be welded, it is faster, and welds can be produced without filler material. Fig. 12-3 is a schematic diagram of a plasma arc gun.

12-3.1.2 Resistance Welding

Resistance welding, one of the principal welding methods, employs electrical energy to generate heat for melting. It is adaptable to very high production rates, produces high uniformity, and requires less skillful op-

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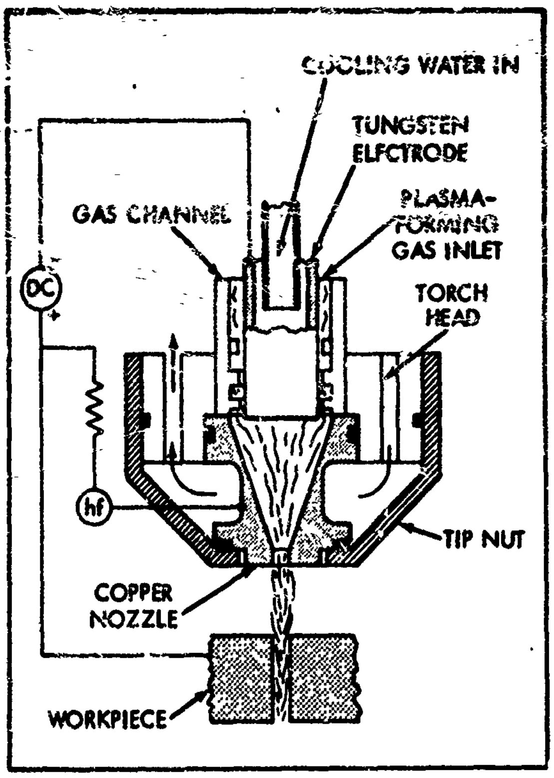

FIGURE 12-3. Schematic Diagram of a Plasma Arc Gun

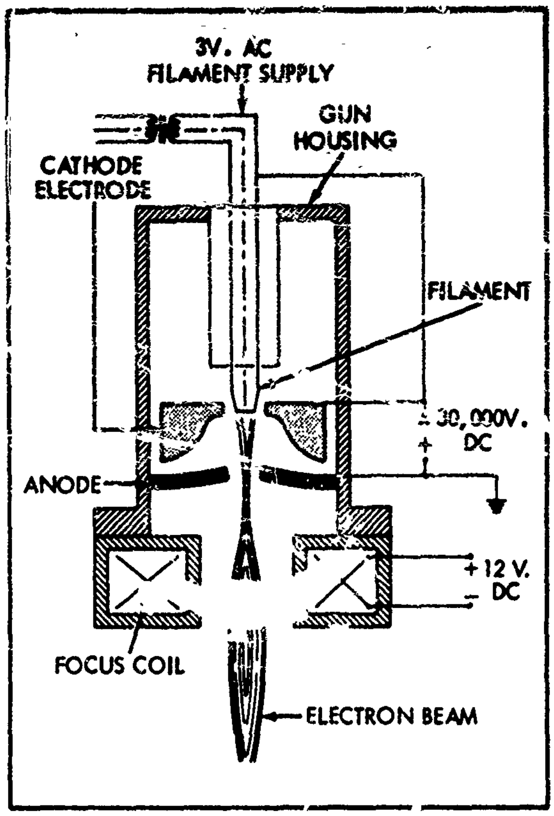

FIGURE 12-4. Schematic Diagram of Typical Electron Beam Gun

erators for specialized applications. To take advantage of these features of resistance welding, however, the large power, air pressure, and water requirements for cooling must be considered. The process may involve substantial capital equipment outlay.

12-3.1.3 Gas Welding

This method provides heat by burning a mixture of oxygen and gas, usually acetylene. It is not suitable for high production rates except on light-gage metals or alloys with low melting points. It is adaptable to low production rates and quantities and requires little capital equipment, but requires skilled welders.

12-3.1.4 Thermit Welding

The thermit welding process generates heat by a reaction involving finely divided aluminum and iron oxide. The method is not suitable for high production. It is generally used to fabricate large weldments or to repair castings; however, it can be used to make electrical cable connections and fine wire joints.

12-3.1.5 Electron Beam Welding

The kinetic energy of an electron beam which has impacted the workpiece in a finely focused high intensity stream of electrons produces the required heat in this process. In some machines the workpieces must be contained in a vacuum atmosphere, although recently, nonvacuum electron beam welding techniques have been developed. Since heat is localized, narrow welds which practically eliminate distortion can be made. Changes in mechanical properties are minor because the low energy input does little to change the microstructure. Welds can be made on material ranging from a few thousandths to 3/4 in. thick. Speeds can range from 10 in. per min to 300 in. per min for thin material. Steel, stainless steel, high temperature and refractory alloys, and alloys of titanium, aluminum, and copper can be welded with this technique. Fig. 12-4 is a schematic diagram of an electron beam gun.

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TABLE 12-3. METALS AND ALLOYS SUCCESSFULLY JOINED BY ULTRASONIC WELDING OR IN WHICH WELDING FEASIBILITY HAS BEEN DEMONSTRATED

	Al	Be	Cb	Cu	Ge	Au	Fe	Pb	Mg	Mo	Ni	Pd	Pt	Re	Si	Ag	Ta	Sn	Ti	W	U	Zr
Aluminum	X	X		X	X	X	X		X	X	X	X	X		X	X	X	X	X		X	X
Beryllium		X		X			X												X			
Columbium			X								X						X					
Copper				X		X	X		X	X	X		X			X	X		X			X
Germanium						X							X									
Gold						X	X				X		X		X	X			X	X		X
Iron							X			X	X		X	X		X	X		X	X	X	X
Lead								X														
Magnesium									X							X			X			
Molybdenum										X	X						X		X	X		X
Nickel											X		X	X		X	X		X	X		
Palladium												X				X						
Platinum													X		X							
Rhenium														X			X		X			
Silicon																	X					
Silver																X	X					X
Tantalum																	X		X	X		
Tin																		X				
Titanium																			X	X		
Tungsten																				X		
Uranium																					X	X
Zirconium																						X

Blank spaces do not necessarily mean that a welding combination is impossible or impractical.

Adapted from Welding Handbook, American Welding Society, 5th ed., vol. 3, 1964, p. 49.9.

12-3.1.6 Ultrasonic Welding

Ultrasonic welding produces a metallurgical bond applying ultrasonic energy to joined or clamped workpieces. There is no fusion of the weld metal since weld temperature only approaches 35% of the absolute melting temperature of the metal. This solid state process produces a minimum of oxides or other impurities. Ultrasonic welding is chiefly used for aluminum but can be used for most metals and makes possible the joining of many dissimilar metals. Table 12-3 illustrates some of the metal combinations that can be joined by ultrasonic welding.

12-3.1.7 Summary

In summary, all of the welding techniques present one common problem to the designer, i.e., the quality of the welds is dependent on the correct application of production techniques. In some processes, operator skill is more important than in others. However, in many welding operations on military equipment, specifications require certification that the operators can consistently produce welds that meet the applicable specifications. This and the requirement for exceptionally close quality control and inspection procedures are elements that the designer should consider in his design cycle.

12-3.2 SOLDERING

Soldering is a process where coalescence between the metal parts being joined is produced by heating to temperatures below 800°F and by using nonferrous fillers with temperatures lower than the base metals being joined. Soldering is used in assemblies with low stresses, in which good electrical and thermal conductivity are important, and in assemblies where a her-

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-metic seal is desired. Precleaning and fluxing are important to ensure good flow and wetting by the solder. Heating methods employed include soldering irons, flame heating, dipping, gas-heated spraying; and induction, resistance, and oven heating.

12-3.3 SOLID-STATE BONDING

In theory, solid-state bonding is simple: similar or dissimilar metals are metallurgically joined by interdiffusion of atoms mating across the joint. In practice it is not so simple. There are several solid-state bonding processes, discussed in the subsequent paragraphs, which are in varying stages of development and can effect sound solid-state bonds.

12-3.3.1 Roll Bonding

Roll bonding is oldest method of solid-state bonding used to produce clad materials. Two pieces of metal in intimate contact are heated and deformed at the same time. Conventional rolling mills can be utilized.

12-3.3.2 Friction Bonding

In this method the use of friction bonding is limited since one of the parts must be cylindrical. Friction heat is obtained at the joint by rotating two surfaces against each other under a constant load.

12-3.3.3 Extrusion Bonding

Extrusion bonding uses the conventional tube extrusion process which joins dissimilar metal tubing together. Each combination, size, and metal will require special development effort.

12-3.3.4 Explosive Bonding

Pressure and heat are produced by exploding similar or dissimilar metals together. This process is used extensively to make metals corrosion resistant. Heat exchangers, reaction vessels, and clad coin stock can be produced by this process.

12-3.3.5 Hot Press, Isostatic Pressure, and Vacuum Furnace Bonding

These processes produce no deformation during bonding but diffuse metal atoms across an atomically clean joint by applying heat and pressure for predetermined periods of time. Since surface cleanliness is crucial to the process, operations are all performed in inert or vacuum atmospheres.

12-3.4 BRAZING

B. . is a process where coalescence is produced by heating the part to a suitable temperature above 800°F and using a nonferrous filler metal with a melting point below that of the base metals. The filler metal is distributed by capillary action between the closely fitted surfaces of the joint. The methods used to obtain the necessary temperatures are numerous.

The properties of the brazing filler metals are most important and must meet the following criteria:

(1) The filler metal must be able to effectively wet the base metals at the operating temperatures so as to have good total contact and make a good joint.

(2) The filler's melting temperature and flowing action must be suitable for good distribution and good capillary action.

(3) The filler's chemical characteristics must be suitable, and must create no undesirable interaction with the base metals.

(4) The filler's mechanical characteristics must also be suitable, such as sufficient strength, etc.

In brazing, care must be taken to avoid certain degeneration of the base metals—such as hydrogen, sulphur, or phosphorus embrittlement; stress cracking, etc. Parts should be designed so that they will be self-positioning during brazing in order to ease assembly and cut down on rejects from misalignment. Also, assemblies should be designed, when possible, so that gravity flow will aid capillary action during the brazing operation.

It is important that the clearances between the parts being joined be small. When metals with different coefficients of expansion are being joined, the clearance at brazing temperature may be different from that at room temperature. Finally, proper fluxes must be used to effectively neutralize or render harmless any undesirable products of the brazing in order to promote a good bond. The principal types of brazing are discussed in the paragraphs which follow.

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12-3.4.1 Torch Brazing

In torch brazing, the heat required by the process is furnished by a gas torch. Several fuels are commonly used. The work is cleaned, prepared, fluxed, and heated by a hand-held torch until the temperature is deemed correct. Then, filler metal is fed in, melted, and absorbed by capillary action, with any excess forming a fillet. The process can be mechanized, however, by prepositioning the filler metal and having stationary flames provide a heating zone with the work moving through it. Some advantages to this process are:

(1) Simple to set up.
(2) No points of stress concentration.
(3) Leadtime short.
(4) No special production tooling generally required.
(5) Good strong joints can be produced.
(6) Method adaptable to many metals and shapes.
(7) Finished assembly stress-free.

Some disadvantages of torch brazing are:

(1) Clearances must be accurate for good capillary action. (Requires more precise machining and tighter tolerances.)
(2) Fairly high operator skill required to make satisfactory joints.
(3) Production speed slow.
(4) Atmosphere in which torch brazing is done cannot be readily controlled.
(5) Disassembly quite difficult.

12-3.4.2 Furnace Brazing

This process brings the parts being worked up to the proper temperature in a furnace. The heat may be furnished by flames or by electrical coils and there may or may not be a special atmosphere. The brazing filler metal is usually preplaced. Work can either be batch-loaded or continuously fed through by means of conveyor belts, etc. As in other types of brazing, the temperature and clearances between the parts must be closely controlled.

Some advantages of furnace brazing are:

(1) Very good joints can be made.
(2) Finished assembly free of stresses; no points of stress concentration.
(3) Method easily adaptable to economical high-output operation.
(4) Relatively low skill level required for production.
(5) Generally used for steel parts; process also effective with other metals and with dissimilar metals.

Some disadvantages are:

(1) Tolerance in parts quite close, requiring expensive machining before brazing.
(2) Clearance problems result from joining parts made of metals with different expansion coefficients.

12-3.4.3 Induction Brazing

In induction brazing, the heat required is generated by inducing eddy currents with a high-frequency alternating field in an induction coil closely coupled to the workpieces. There is no actual current flow between the induction coil or coils and the workpieces. The frequency range is from 10 kHz to MHz. The lower the frequency, the deeper the penetration. Normally, smaller induction coils are air-cooled with the larger installations using water cooling. Inasmuch as the eddy currents, and consequently the heating, can be limited to the surfaces of the pieces, it is possible to heat rapidly only the section holding the brazing filler metal. Thus, the bond is rapidly completed without heating the entire assembly. Also, the heat input per unit time can be faster than that required for other methods. The brazing filler metal is generally prefluxed in the form of washers, rings, powders, or coatings on the base metals. Controlled atmospheres can also be used with induction brazing. Some advantages of induction brazing are:

(1) Good joints can be achieved.
(2) No points of stress concentrations; finished assemblies stress-free.
(3) Method very fast, allowing high output.
(4) Heating can be concentrated at the surfaces being joined, with little heat loss.
(5) Once timing cycle is adjusted correctly, very uniform results are achieved. Therefore, method is adaptable to various metals, sizes, shapes.

Some disadvantages are:

(1) Disassembly difficult.
(2) Coupling distances between coils and work must be kept small.
(3) A thick wall being joined to a thin one creates danger of over-heating the joint.
(4) Part design must allow preplacement of metal.

12-3.4.4 Dip Brazing

The heat required for this operation is obtained by dipping the workpiece in a molten bath. The molten batch can consist of a salt bath (which is essentially the flux) or of molten filler metal. In a flux bath, the filler metal is preplaced prior to dipping. In a metal bath,

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there is generally a cover of molten flux on the surface of the metal bath, and the parts being immersed must first go through the flux.

Some advantages are:

(1) Easily controllable bath temperature.
(2) No stress concentration, stress-free joints.
(3) Skill level required fairly low.
(4) Process leadtime short.

Some disadvantages are:

(1) Process generally limited to smaller parts.
(2) Considerable cleaning, in some cases, required after brazing.
(3) Large baths of molten material are a safety hazard.

12-3.4.5 Resistance Brazing

The heat required for this method is obtained by passing a current through the pieces being joined. Most of the heat is generated by the resistance at the contact electrodes from which it is then conducted to the workpieces. The same equipment used for resistance welding can be used (with slight modifications) for resistance brazing. The voltage range is from 5 to 25 volts, and the current range is 50 to several thousand amperes, depending on the size of the workpiece. The brazing filler metal is generally preplaced.

Some advantages are:

(1) Pressure exerted to keep electrodes in good contact tends to squeeze out filler metal, thus producing a good bond.
(2) Leadtime low.

Some disadvantages are:

(1) Disassembly difficult.
(2) Electrodes require frequent cleaning.
(3) Joints must be accessible from both sides to apply pressure.
(4) Process generally limited to small parts since uniform heating is difficult to maintain.
(5) Current flow timing at operator's discretion, leading to uncertain process repeatability.

12-3.4.6 Flow Brazing

In this process, workpieces are preheated and molten filler is poured over the joint until brazing temperature is reached. The pouring operation is then stopped, and the brazing operation is completed. This relatively old brazing process has been largely replaced by other more effective methods.

12-3.4.7 Ultrasonic Brazing

In this process, the brazing is effected by the close application of acoustical energy to the workpieces. This process has not yet been widely used in industrial applications.

12-3.4.8 Block Brazing

The required brazing temperature is obtained by heating large metal blocks in a furnace and then bringing them into contact with the workpieces. Heat is then transferred by conduction. Like flow brazing, this method is now virtually obsolete.

12-4 CHEMICAL JOINING

Chemical joining is defined as the holding together of two or more parts by the application of a chemical agent between the parts which, by means of a chemical interaction, creates a holding bond. The chemical agent can itself become the bond or part of the bond, or it may simply induce a reaction in the parts being joined, with the bond being directly between them.

The reaction is chemically triggered; this may be accomplished by heat application, a catalyst, pressure, evaporation of a dispersant, or some combination of all of these. Recent developments in high strength adhesives have opened up entirely new fields of applications for chemical bonding.

12-4.1 ADHESIVES

Adhesives are substances which hold material together by surface attachment. They can be classified by form, by chemical composition, by vehicle, or by bonding type. The ideal adhesive bond is one in which ultimate failure would occur in the materials being bonded rather than in the adhesive itself, or in the adhesion between it and the materials being held. Adhesive joints have the stresses distributed uniformly over the entire bonding area, with no stress concentrations (such as those found in mechanical fastenings) and without internal thermal stress (such as are created by welding). A great variety of dissimilar materials can be joined and adhesives can also serve as insulators or seals. Adhesives must be selected on a case basis. Factors to be considered in selecting an adhesive include:

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(1) Type of materials. The adhesion of the adhesive to the materials must be sufficient to supply the required holding power.

(2) Design of the joint to be bonded is important, inasmuch as extreme stress concentrations must be avoided.

(3) Constraints on the bonding process. If the assemblies being joined cannot be subjected to any high temperatures, heat-activated adhesives are then ruled out. Also, in a fast-moving production line, an adhesive with a long curing time would not be satisfactory.

(4) Ultimate strength required of the bond. Adhesives satisfactory for low stress materials might be unsatisfactory for a high stress demand.

(5) Cost of the adhesives. Price can vary from insignificant to very high for some of the more exotic bonding agents.

The various types of adhesives available are discussed in the paragraphs which follow.

12-4.1.1 Natural Adhesives

Natural adhesives, for the most part, are those obtained from animal and vegetable sources. These include natural gums and resins, fish, hide and bone glues. Normally, natural adhesives are applied in a liquid solution (generally water), although other liquids can be found in use. The bond is created as the solution (dispersant) evaporates.

Some advantages of natural adhesives are:

(1) Generally low cost, easy availability.

(2) Good resistance to heat.

(3) Easily applied, low skill level required.

(4) Long shelf life. (Not generally affected by long storage before use.)

(5) Short leadtime.

(6) Easily adapted to automated, high speed production.

(7) Good repeatability.

Some disadvantages are:

(1) Generally low bond strength.

(2) When bonding nonporous substances, no way for dispersant to evaporate except through the glue line itself, thus leading to long setting times or weak spots in the bond.

(3) Dispersant can have detrimental effect on materials being bonded.

(4) Generally poor resistance to moisture.

12-4.1.2 Thermoplastic Adhesives

Thermoplastic adhesives are primarily synthetic resins. They include the acrylics, asphalt, polyring acetate, etc. They have higher bonding strength, and much better resistance to moisture and rot than do the natural adhesives. However, they tend to creep with a rise in temperature. Thermoplastic adhesives are available in solid, liquid, and granular form. They can be solvent activated or heat activated. Some other characteristics are:

(1) Applicable to most materials, but especially to porous substances or substances that can be heated to effect the curing.

(2) Can be applied by low skill personnel.

(3) Generally available on market.

(4) Suited to high speed production.

(5) Good shelf life.

(6) Joints generally impervious to moisture, fungus, etc.

(7) Not suitable for nonheatable, nonporous materials.

(8) Temperature limit about 200°F.

12-4.1.3 Thermosetting Adhesives

Thermosetting adhesives usually come in two parts, a partically cured resin and a catalyst which triggers the hardening reaction when mixed. Some of the compounds, however, are one-part and must be kept under refrigeration since they are heat-cured by room temperatures Similarly, some two-part compounds can be kept from setting, after mixing, by refrigeration. Sometimes, the addition of heat is necessary to complete the reaction; in some cases, generated heat alone is the curing agent. Normally, the only pressure required is that needed to keep the parts together. The joints formed are stronger than thermoplastic, natural, and elastomeric bonds and heat resistance is good, in some cases up to 500°F. Thermosetting adhesives are relatively new with other types continuously being developed for specialized applications. Some of these more exotic applications include the honeycomb panels for aircraft and missile work which have extremely high strength-to-weight ratios. They show little tendency to creep under load and thus can be used for structural as well as continuously stressed parts.

12-4.1.4 Elastomeric Adhesives

Elastomeric adhesives produce a nonrigid bond. Included in the group are natural rubber, silicones, neoprene, etc. Their bonds stretch and bend under load, and recover their shape after load is removed, providing the elastic limit has not been exceeded. The vehicles

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for application are varied, and the adhesives can be one-component, two-component, or heat cured.

Some advantages are:

(1) Generally good resistance to moisture, most fungi, and many solvents.

(2) Adaptable to high production.

(3) Relatively inexpensive.

Some disadvantages are:

(1) Low joint strength.

(2) Unpleasant odors.

TABLE 12-4. COMMON DESIGN PROBLEMS

Problem: DESIGN SPECIFIES SPOT RESISTANCE WELDING BUT LOCATES SPOTS IN AREAS THAT CANNOT BE REACHED WITH TIPS.

Cause and Effect:

Excessive costs for tooling and special tips when they are not needed; many welding arrangements can be achieved using standard tips and holders, an advantage the designer should try to benefit from if he specifies spot resistance welding.

Potential Solution:

Redesign part to utilize standard equipment.

Problem: DESIGN SPECIFIES WELDING WHICH DOES NOT MATCH REQUIREMENTS.

Cause and Effect:

Heavy weld bead might result in joint stronger than parts it is holding together; too small a bead on heavy metal parts will take more time to lay and be of poorer quality than one of the proper size.

Potential Solution:

Specify welds that meet, but do not exceed, requirements.

Problem: PARTS ARE DIFFICULT TO ASSEMBLE.

Cause and Effect:

Not enough room is provided for assemblers to use hands and/or tools; available room precludes seeing work.

Potential Solution:

Provide access holes to facilitate assembly; make parts self-locating; make parts fit loosely without requiring exact alignment.

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TABLE 12-4. COMMON DESIGN PROBLEMS (CONT'D)

Problem: WELDED ASSEMBLIES THAT PROVIDE INSUFFICIENT OR NO ALLOWANCE FOR WARPAGE.

Cause and Effect:

Heat-induced weldments warp on cooling as a result of shrinkage in the weld metal.

Potential Solution:

Allow for warping during the design; provide straightening or machining operations after welding; change welding technique specified.

Problem: WELDING IS SPECIFIED IN LOCATIONS OR AREAS AT WHICH PERFORMING THE PROCESS IS IMPOSSIBLE FOR LACK OF ROOM OR OTHER REASONS.

Cause and Effect:

A welder given insufficient room in which to operate will produce poor welds, high defects, and slow production output.

Potential Solution:

Design with welding space in mind; design part for some other means of joining; change sequence of assembly.

TABLE 12-5. COMMON PRODUCTION PROBLEMS

Process: ANNULAR CATHODE FUSION WELDING.

Problem:

Welding and cleaning time must be reduced in order to reduce production costs.

Application:

This process would benefit several types of manufactured items, including heavy or light tubing, pipe, drive shafts, gears to shafts, exhaust pipes, etc.

Process: AUTOMATIC WELDING OF JOINTS OF COMPLEX GEOMETRY.

Problem:

A welding machine capable of three-dimensional control must be developed to adapt automatic weld control production techniques to complex geometries.

Application:

Widespread application to areas of production involving geometrically complex design.

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TABLE 12-5. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: ELECTRON BEAM WELDING.

Problem:

Welding quality must be improved to reduce production costs. Costs can be reduced by eliminating assembly distortions and speeding production rates.

Application:

Wide-spread application in the manufacture of joined metallic components.

Process: EXPLOSIVE PRESSURE (IMPACT) WELDING.

Problem:

This joining process has not yet been developed to the extent that it can immediately satisfy Army applications.

Application:

This process would benefit a broad range of field operations.

Process: IMPROVED TECHNIQUES FOR BONDING GLASS COMPONENTS.

Problem:

There is a dearth of recorded knowledge with respect to cementing glass to glass and glass to metal.

Application:

Review, establish, and maintain current technical data (including theory) relating to bonding optics.

Process: JOINING DISSIMILAR METALS.

Problem:

While composite fabrications are advantageous due to the combined properties of their material elements, joining dissimilar metals by a thermal process is likely to impair the structural benefit or corrosion resistance otherwise attainable.

Application:

All weldments of dissimilar metals.

Process: SEMI-AUTOMATIC WELDING OF STEEL ARMOR.

Problem:

While the gas metal arc (consumable electrode) process has been used successfully with other steel materials, difficulties have been experienced with joining heavy thicknesses of steel armor. Results of prior work warrant further investigation of this process.

Application:

This process can be used for heavy armor fabrication connected with production vehicles.

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TABLE 12-5. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: SOLDERING.

Problem:

To take full advantage of printed-circuitry production methods, little time can be expended in making the solder wet and flow well in the joint area. Soldering times must be kept at a minimum to prevent damage to the printed board and to the components. In order to obtain the high degree of reliability needed for the successful operation of space age devices, a thorough and coordinated study of all the ramifications of solderability should be made.

Application:

Widespread application throughout the fabrication of varied electronic devices.

Process: SOLID RIVETING.

Problem:

Work is required to develop rivet material with suitable forming characteristics for high strength metal joints.

Application:

The production process of various materials including columbium, molybdenum and tungsten alloys.

Process: MECHANICAL FASTENING.

Problem:

There are many problems in design, production and use of fasteners made from materials compatible with advanced weapon requirements. Modified physical characteristics sometimes required are often ignored until fasteners are required for test or prototype construction. This is usually too late, and poor availability or performance results.

Application:

Broad application in the joining of dissimilar materials. Use of multi-piece, insert type, collet-core design nuts may be a solution.

Process: RESISTANCE WELDING.

Problem:

The need to progressively upset the material in the welding area introduces very difficult mechanical problems in application for sheet-to-sheet built jobs and the like.

Application:

This process offers flexibility, minimum fixture requirements, and minimum warpage and distortion to a broad range of manufacturing area—excluding molybdenum and tungsten.

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TABLE 12-5. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: SEALING MATERIALS AND METHODS FOR MILITARY VEHICLES.

Problem:

There is a lack of specifications for both sealing materials and sealed joints.

Application:

Review, establish, and maintain current technical data to include materials, design, and techniques, including the indoctrination and training of implementing personnel.

Process: BRAZING AND SOLDERING DEEP SECTIONED COMPLEX STRUCTURES

Problem:

The temperature gradient existing between the outside and center of deep sectioned complex structures prevents satisfactory joining by usual brazing and/or soldering means.

Application:

Develop and resolve materials, equipments, and techniques to apply heat internally to large complex assemblies when brazing or soldering.

Process: CIRCUIT INTERCONNECTION IMPROVEMENTS.

Problem:

Techniques and equipment for the control of time, temperature and other factors affecting the characteristics of connectors, components and subassemblies must be studied.

Application:

Could improve reliability and reduce size, weight and cost of cabling.

Process: EFFECT AND CONTROL OF FLAWS IN WELDS.

Problem:

The occurrence of various flaws in weld deposits has been an inherent problem with welding since this means of fabrication was conceived.

Application:

Considering the number of items which must be fabricated by welding, the savings in both time and money would be considerable.

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TABLE 12-5. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: SUBMERGED ARC WELDING.

Problem:

To obtain maximum efficiency from this process, it should be developed for use in heavier plate sections.

Application:

A successful program will be applicable to the production fabrication of all armored vehicles.

Process: WELDED OVERLAY ROTATING BAND.

Problem:

Banding operations have not been optimized for production activity. Production procedures and equipment must be developed.

Application:

This process would apply to several types of current and experimental ammunition.

Process: WELDING AS A MAINTENANCE TECHNIQUE.

Problem:

Present design criteria do not permit the use of weld repair on cannon, mortar, or recoilless rifle barrels, resulting in costly discarding of gun tubes.

Application:

The results of this project could extend the life of gun tubes and apply to several other areas.

Process: WELDING OF HIGH STRENGTH ALUMINUM ALLOYS.

Problem:

Weldability has been an important factor restricting the selection of high strength alloys in the construction of tactical and personnel carrying vehicles.

Application:

Satisfactory welding of high strength aluminum alloys will permit their use for production of lightweight vehicles.

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TABLE 12-5. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: WELDING OF HIGH STRENGTH CONSTRUCTIONAL STEELS.

Problem:

The welding of high-strength steels without loss of strength charcteristics must be studied comprehensively.

Application:

High strength steels that can be welded in a manner suitable for production application will result in military vehicles capable of high performance and structural integrity for meeting modern delivery concepts.

Process: WELDING SPECIFICATIONS AND STANDARDS

Problem:

Government specifications and standards have not been kept up-to-date with the rapidly changing technology of welding techniques.

Application:

Widespread application to all production requiring the weldment of ferrous and nonferrous materials.

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CHAPTER 13

COATING MATERIALS AND METHODS

13-1 GENERAL

The principal reason for applying protective coatings is to upgrade the corrosion resistance of ferrous metals (and some nonferrous metals). Thus, coatings can improve performance and reduce cost by obviating the need for using more costly corrosion resistant metals. Other advantages include improving appearance, resistance to wear, and abrasion.

The Coatings chart (Appendix B) displays the four basic methods employed to apply coating materials, and the appropriate technique/material combination commonly associated with each. The four broad categories are metallurgical, electrochemical, chemical, and mechanical. The principal coating methods, characteristics, and typical applications of these categories are outlined in this chapter. In addition, some comments relative to corrosion as they relate to the deterioration of materials are included. For a more detailed treatment of corrosion, see MIL-HDBK-721(MR), *Corrosion and Corrosion Protection of Metals*. Also included therein is a listing of specifications for protective finishes, processes, and materials. The Corrosion Properties chart (also Appendix B) shows the generic tree relating to corrosion processes. Some common design problems are presented in Table 13-8 and some common production problems are given in Table 13-9. These tables are located at the end of this chapter.

13-2 NATURE OF CORROSION

Corrosive attack of metals involves complex processes and is evidenced by tarnish, general attack, pitting, or perforation of the metal. The attack varies with the metal, and with the environment and conditions to which the metal is subjected. Corrosion can be defined as the deterioration of a metal through a chemical or electrochemical reaction with its environment.

Corrosion may proceed at slow or fast rates, the rate being controlled by the metal undergoing attack, by the environment, by the concentration of reactants, and by the prevailing temperature. Inasmuch as the metal may vary from high purity to an alloy containing various other elements, a wide variety of corrosion behavior is possible. Physical structure variability—because of heat treatment, quenching, cold working, etc.—also influences susceptibility to corrosion. Furthermore, the shape, form, or finish of the metal—e.g., concave shapes, sumps for the accumulation of corrodants, cast or wrought forms, and grit blasted or mechanical finishes—influence the rate of reaction between the metal and the corrosive agents.

Environmental conditions such as moisture, chemical contaminants, and temperature can accentuate or moderate corrosive reactions to a significant degree; they can also influence the nature and extent of damage to metals. The many variables and factors related to the corrosive environment should be analyzed and understood as fully as possible, so that workable and dependable measures can be devised to control the corrosion process.

13-2.1 TYPES OF CORROSION

There are several types and forms of corrosion which are evidenced as uniform corrosive attack over the surfaces of the metal, or as concentrated attack at local or isolated areas. Corrosion can be broken down into the following categories:

(1) Uniform corrosion.
(2) Galvanic or dissimilar metal corrosion.
(3) Concentration-cell corrosion.
(4) Stress corrosion.
(5) Fretting corrosion.
(6) High temperature corrosion.

Other terms applied to specific modes of attack or

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effects, and encompassing one or more of the processes listed above include:

(1) Pitting corrosion.
(2) Intergranular corrosion.
(3) Erosion corrosion.
(4) Impingement (molecular rearrangement) corrosion.
(5) Cavitation corrosion.
(6) Fatigue corrosion (results are the same as (4) above).
(7) Filiform corrosion.
(8) Dezincification.
(9) Graphitization.
(10) Biological.

13-2.2 PROTECTION AGAINST CORROSION

Since almost every situation presents the possibility that some form of corrosion will occur, appropriate means of protection must be routinely considered during the design process. The design engineer developing military equipment which involves metals must prescribe measures for protecting that equipment from corrosive attack. The details of each application are different, but the approach is the same. The design engineer must know the functional requirements of the design, the environmental conditions most likely to be encountered by the item in use, the materials available for consideration in the design, and the protective measures that can be employed.

In analyzing and correcting a potential or existing corrosive situation, four principal steps are involved. These are:

(1) Considering the metal and ascertaining whether the choice is good or whether other metals might be more appropriate to the intended application.
(2) Determining the environmental condition which will prevail and, if warranted or if possible, altering it.
(3) Reviewing the design of the structure in which the metal or metals are employed and considering modifications which could alleviate the cause of damage.
(4) Providing the metal with a coating or treatment to protect it from the attacking medium.

13-3 STUDYING THE CORROSION PROBLEM

Even though the design engineer may be aware of the numerous aspects of a corrosive environment, and can recommend the appropriate protective measures, it is difficult to achieve a design that satisfies all requirements. Metals or alloys which might possess higher resistance to corrosion might be unacceptable because of processing or other factors. The design engineer may be forced to exchange some corrosion resistance for workability, mechanical properties, fabricability, availability, or cost. If corrosion resistance is a major design requirement, some alloys with excellent corrosion resistance may be selected despite other less desirable characteristics. The engineer must study the problem and be guided by the priority of requirements.

Fabrication and assembly methods have a distinct effect on corrosion occurrence, extent, and type. When fabricating and assembling metal components, an essential problem is to avoid any physical or structural transformations that will leave the product susceptible to uniform or localized corrosion. It is impossible to generalize and declare that a certain operation such as bolting, brazing, casting, riveting, soldering, or welding, will leave a metal more vulnerable to corrosion. The application, the environment, and the characteristics of the metal or alloy and its physical relation to adjacent and different metals determine relative resistance to attack. The design engineer must consult specialized sources for data on each metal and method; even a brief inquiry will indicate the intricacy of such problems.

The corrosion resistance of bolted joints may be affected by the composition (and electrode potential difference) of the bolts and the joined parts, as well as by the presence of trapped moisture, stress, type of exposure in service, and by faulty installation.

Brazing involves the use of a brazing metal that melts and flows at a temperature lower than that of the alloys being joined. It is important to note that the chemical and physical characteristics in the area of the brazed bond may make it susceptible to concentration-cell corrosion.

Although soldering does not require that the joined metals be heated to their melting points, difficulties may arise due to the difference in potential between the solder and the joined metal. Certain metals cannot be used in corrosive environments if soldered. In joining aluminum, for instance, the corrosion resistance of brazed or welded joints is generally superior to that of soldered joints.

Similarly, welding requires careful consideration and adherence to appropriate procedures. In the welding of solid, corrosion-resistant materials, maximum resistance can be maintained if the filler rod has substantially the same corrosion resistance as the metal. Generally, it is necessary to select the proper welding rod and

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coating, to use the proper technique for depositing the weld material, and to avoid gas pockets, laps, undercuts, and excessive nonmetallic (slag) inclusions. Such welding defects can lead to localized corrosion. Precautions are important when welding alloys that are susceptible to corrosion. Correct welding temperatures, heat treatment after welding, careful attention to all defects in the area of the weld, and removal of all weld spatters are essential to ensuring corrosion resistance.

13-4 COATING METHODS AND MATERIALS

Several methods of coating or treating materials to resist corrosion are possible. These processes often impart other desirable properties to the material, e.g., those affecting wear, heat, hardness, appearance, etc. Some coatings with such desirable properties are applied as the primary goal and corrosion protection as a secondary benefit. However, in no case should a coating process which improves appearance, wear, hardness, etc., at the expense of corrosion resistance be selected.

In Appendix C, coatings are classified into four groups: metallurgical, electrochemical, chemical, and mechanical. The first group depends on metallurgical adhesion (flame spraying); the second depends on an electrochemical reaction for application (anodizing, electroplating, etc.); the third on a chemical reaction (immersion and conversion coatings); and the fourth on mechanical adhesion (paint, elastomeric coatings, etc.). The principal techniques comprising each of these categories are discussed in the paragraphs which follow.

13-4.1 METALLURGICAL COATINGS

Four major types of metallurgical coating methods are described herein, i.e., flame spraying, weld deposition, diffusion, and hot dipped metal.

13-4.1.1 Flame-sprayed Coatings

Flame-sprayed coatings are applied by spraying molten material onto a previously prepared surface. Its principal value is in increasing the wear resistance of metal parts; however, it is useful in building up worn and damaged parts, as well as in providing corrosion protection, and heat and oxidation resistance. Generally, flame-sprayed coatings are applied to metals; some plastics, graphite, wood, and paper also can be coated by flame spraying. Flame-sprayed coating can be applied to cast iron, steel, aluminum, copper, brass, bronze, molybdenum, titanium, magnesium, nickel, and beryllium.

There are three principal methods of applying flame-sprayed coatings. Briefly, their characteristics are:

(1) Oxyacetylene Spraying—This process uses an oxyacetylene flame to melt the material to be sprayed. The material is fed into a chamber as wire (1/8 in. to 3/16 in. in diameter), as a powder, or as a rod. The material, after being melted, is atomized by an air blast and blown onto a previously prepared surface of the material to be coated.

(2) Detonation Spraying—Accurately measured quantities of powdered metal or ceramic, oxygen, and acetylene are pressure-fed into a gun chamber and ignited by a timed spark. The resultant detonation hurls the then melted powder out of a gun barrel at high velocity to impact the material to be coated. The controlled detonations build up the coating to a desired thickness. The high noise level requires that the operation be isolated and remote controlled.

(3) Plasma Spraying—Plasma spraying utilizes the plasma-arc gun used for plasma-arc machining (described in Chapter 10). The high temperatures (up to 2,000°F) of the plasma-arc permit it to use any known solid inorganic material which will melt without decomposition. The coating material is fed into the gun in the form of powder. It gives a denser and better bonded metal or ceramic coating than that possible with either oxyacetylene or oxyhydrogen spraying.

The coating materials which can be used with the flame spraying include metals, ceramics, carbides, borides, and silicides. Briefly, their characteristics are:

(1) Metals—A wide variety of metals can be applied as flame-sprayed coatings. Table 13-1 covers some of them, together with their typical applications.

(2) Ceramics—Ceramic materials are useful as coatings in that they provide refractory properties, insulation, erosion resistance, oxidation and corrosion resistance, or electrical resistance. The oxides of aluminum and zirconium are the most commonly used materials.

(3) Carbides—The carbides are generally used for wear-resistant coatings, tungsten being the most common.

(4) Borides and Silicides—Flame-sprayed borides are used as neutron absorbers in nuclear applications. The silicides are useful in high temperature applications.

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TABLE 13-1. METALS THAT CAN BE FLAME-SPRAYED AND PRINCIPAL APPLICATIONS

METAL	APPLICATION
ALUMINUM	Corrosion protection in industrial and salt atmospheres, electrical applications
BABBITT	For bearing buildup
BORON	Neutron absorber
CADMIUM	Corrosion resistance
COBALT	For hardfacing
COPPER	Electrical applications, aluminum, bronze, and phosphor bronze are used for general purpose wear applications
CARBON STEEL	AISI grades 1010, 1025, and 1080 are used for rebuilding worn parts and wear resistance
HAFNIUM	Neutron flux depressor
IRON	Magnetic applications
LEAD	Nuclear shielding, resistance against acids
MAGNESIUM	Corrosion resistance
MANGANESE	Hardfacing and wear
MOLYBDENUM	Hard wearing surfaces, bonding between substrate and sprayed ceramic coatings, buildup material
NICKEL	Hardfacing, corrosion-resistant coating
PLATINUM	Electrical contacts, high temperature electrical connectors
SILICON	Wear resistant coatings
SILVER	Electrical contacts
STAINLESS STEEL	Corrosion protection, wear resistant applications
TANTALUM	High temperature applications
TIN	Electrical contact coating, food container coating
TITANIUM	Corrosion and oxidation resistance at high temperature (1000°F)
TUNGSTEN	Metal and nonmetallic parts exposed to high temperature, as a means of fabricating intricate parts from tungsten
ZINC	General atmospheric corrosion resistance
ZIRCONIUM	Nuclear applications

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13-4.1.2 Weld Deposition Coatings

Weld deposition coatings are applied to produce a hard, wear-resistant facing on less expensive base metals or ones with special engineering properties, e.g., toughness. These facings are applied in thicknesses between 1/16 and 1/4 in. by any standard fusion welding process. The use of these hard facings is generally restricted to ferrous metals but, with some difficulty, copper, bronze, and brass can be faced.

Over 100 facing materials for use with weld deposition coatings are available. They have been classified by the American Welding Society and the American Society for Metals in order of increasing toughness or in order of decreasing abrasion resistance. Despite their name, hard facings are often applied for corrosion or thermal applications. Table 13-2 lists the major facing materials and their properties.

13-4.1.3 Diffusion Coatings

A diffusion coating is a surface alloying treatment for metal, produced by changing the surface composition of the metal and thereby improving its properties. It is accomplished by heating metals to high temperatures while the surface is in contact with some appropriate compound. Diffusion coating results in wear- and abrasion-resistant surfaces; however, they are also used to obtain corrosion- and heat-resistant surfaces. Table 13-3 lists the properties of some diffusion coating processes and their basic uses.

13-4.1.4 Hot Dipped Metal Coatings

This process, generally applied to iron and steel, consists of dipping the material to be protected in a molten bath of a more corrosion-resistant metal. Aluminum, zinc, lead, tin, and lead-tin alloy are the principal materials applied by hot dipping, as indicated by Table 13-4.

13-4.2 ELECTROCHEMICAL COATINGS

Electroplating, anodizing, and hard anodizing are the major electrochemical coating techniques discussed herein.

13-4.2.1 Electroplating

Electroplated coatings are applied in a wide variety of metals and alloys. They provide wear resistance, corrosion resistance, hardness, and reflectance; they also, in general, add to the attractiveness. It is probably the most widely used industrial process for applying coatings.

Electroplating is an electrochemical process consisting of an electrolytic cell formed by the object to be coated (cathode), and an anode in an aqueous solution of salts of the metal to be deposited. The application of voltage causes the metal ions in the solution to be attracted to the object to be plated (the cathode), where they gain electrons and are deposited as pure metal on

TABLE 13-2. HARD FACING MATERIALS USED FOR WELD DEPOSITION

MATERIAL	PROPERTIES	MATERIAL	PROPERTIES
TUNGSTEN CARBIDE	Highest hardness and best wear resistance	NICKEL BASE ALLOYS	Used where abrasion resistance plus resistance to heat and/or corrosion are required
HIGH CHROMIUM IRON	Best for metal to metal wear, inexpensive	COPPER BASE ALLOYS	Used where a combination of corrosion resistance and liquid erosion is needed
MARTENSITIC IRON	Good abrasion resistance	MARTENSITIC STEELS	Good combination of low cost, hardness, strength, abrasion resistance, good impact resistance, and fairly high toughness
AUSTENITIC IRON	Less abrasion resistance than martensitic, less tendency to crack	AUSTENITIC STEELS	Used for moderately abrasive applications or as a buildup material
COBALT BASE ALLOYS	Used where wear and abrasion resistance must be combined with resistance to heat and oxidation or corrosion		

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TABLE 13-3. DIFFUSION COATING PROCESSES

PROCESS	BASE METAL	SURFACE MIXTURE	USE
CALORIZED	Carbon and low alloy steel	Aluminum compound or Al Cl vapor	Resistance to high temperature oxidation makes useful for furnace parts, chemical pots, air heater tubes.
CARBURIZED	Carbon and low carbon alloy steels	Solid, liquid, or gaseous carbon	Gears, cams, pawls, shafts.
CYANIDED	Carbon and low carbon alloy steels	Carbon and nitrogen	Gears, cams, pawls, shafts.
NITRIDED	Special steels for nitriding, medium carbon Cr Mo steel, stainless steel, some cast iron	Nitrogen in contact with ammonia	Gears, cams, pawls, shafts.
CHROMIZED	Carbon steels, alloy steel, cast iron, stainless, iron powder parts	Chromium	High resistance to wear, abrasion, and corrosion; high hardness. Aircraft, railroad, and auto parts; tools.
NICKEL-PHOSPHORUS	Ferrous metal	Nickel phosphorus	Pipe and fittings because of high corrosion resistance.
IRON-ALUMINUM	Cobalt, nickel, and iron base superalloys, carbon and stainless steel, some copper alloys	Iron-aluminum	Gas turbine blades and components subjected to high temperatures.
NICKEL-ALUMINUM	Nickel base alloys	Iron-aluminum	Gas turbine blades and components subjected to high temperatures.
SILICIDES AND METAL ADDITIVES	Columbium, molybdenum, tantalum, tungsten	Silicides or metal additives	Aerospace components subjected to high temperatures, 3000°F. for a short time.
SILICONIZED	Low carbon, low sulfur steel	Silicon carbide and chlorine	Pump shafts, cylinder liners, valve guides, and valves.
SHERARDIZED	Ferrous metal	Zinc	Small parts that must resist atmospheric corrosion, electrical conduit.

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TABLE 13-4. HOT DIP COATINGS

COATING	BASE METAL	PROPERTIES	USES
ALUMINUM	Steel, cast iron	Protects equipment subject to corrosion and heat up to 1000°F. Minimizes high temperature oxidation and permits use of inexpensive materials for use in corrosive or high temperature applications.	Oil refinery process piping, appliance parts, furnace heater tubes, brazing fixtures.
ZINC	Steel	Combines high corrosion resistance with low cost. Effective life generally is in proportion to thickness.	Nails, wire, tanks, boilers, pails, hardware, lighting standards.
LEAD	Steel, copper	High resistance to atmospheric corrosion and chemicals. Protective oxide film regenerates itself when damaged.	Wire, pole-line hardware, bolts, tanks, barrels, cans, air ducts, outdoor gutters, flashing, and siding.
TIN	Steel, cast iron, copper	Good resistance to tarnishing and staining indoors, and in contact with foods. Sheet lends itself to stamping, drawing, rolling; readily soldered.	Milk cans, food grinders, cooking pans, kitchen utensils, and electronic parts. (Food cans generally are electrolytically tin plated.)
LEAD-TIN ALLOY (TERNE)	Steel, copper	Provides some advantage of tin coatings at lower cost; ductility and good adhesion allow deep drawing; excellent paint-holding properties; good solderability.	Roofing, gasoline tanks, oil filters, capacitor and condenser cans, connectors, printed circuits.

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TABLE 13-5. ELECTROPLATED COATINGS, CHARACTERISTICS, AND APPLICATIONS

PLATING	BASIC MATERIAL	ABRASION RESISTANCE	ADHESION	THICKNESS, MIL	CHARACTERISTICS AND TYPICAL USES
ALUMINUM	Steel, iron, copper, magnesium, silver, gold, zinc, nickel	Poor	--	0.25+	Corrosion-resistant; can substitute for hot-dipped aluminum (not too common)
CADMIUM	Steel, iron, copper	Fair	Good	0.15 to 0.5	Pleasing appearance, good corrosion protection indoors on iron and steel; outdoor corrosion resistance varies; electronic chassis, aircraft, and military outdoor uses
CHROMIUM	Ferrous, nonferrous metals, ABS plastics	Excellent	Excellent	0.01 to 12	Excellent resistance to wear, abrasion, and corrosion; decorative corrosion-resistant coating on automobile exterior and interior trim, appliances, and business machines; bearing applications and to build up worn surfaces
COBALT	Iron, steel, copper	Good	--	0.1 to 1.0	Expensive; infrequently used alone except for applications where high hardness is needed and on mirrors and reflectors
COPPER	Most ferrous, nonferrous metals	Poor	Excellent	0.1 to 3	Good appearance (when polished and/or lacquered) and corrosion-resistant; high electrical and thermal conductivity; wire coatings, stop-off coatings during heat treatment and chemical milling; lubricant drawing; thermally conductive coatings on cooking utensils
GOLD	Copper, brass, nickel silver	Poor to Good	Excellent	0.002 to 2.0	Resistant to tarnishing, chemical attack, and high temperature oxidation; pen points, jewelry, watch cases, musical instruments, reflectors, nameplates, eyeglass frames, trophies, novelties, electrical contacts, various electronic parts
INDIUM	Silver-plated steel, lead-bearing metals	Poor unless diffused	Excellent when diffused	1.1	Tarnish-resistant, malleable, and ductile; overlay diffusion coating on silver-plated steel bearings for high-speed aircraft engines
IRON	Ferrous metals	Very Good	Very Good	125+	Easily fabricated and plated over; build-up of undersized parts; electrotypes; forming of molds
LEAD	Ferrous metals, copper	Poor	Good	0.5 to 50	Resistant to many acids, hot corrosive gases, and corrosive atmospheres; normally deposited by hot dipping; electroplated for chemical equipment, brine refrigerating tanks, metal gas shells, nuts and bolts, and storage battery parts
NICKEL	Most ferrous, nonferrous metals	Good to Very Good	Very Good	0.1 to 20	Excellent appearance, resistant to chemical and corrosive atmospheres; decorative applications either alone or as a heavy base for thin chromium electroplates; trim for automobiles, appliances, business machines, and consumer goods

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TABLE 13-5. ELECTROPLATED COATINGS, CHARACTERISTICS, AND APPLICATIONS (CONT'D)

PLATING	BASIC MATERIAL	ABRASION RESISTANCE	ADHESION	THICKNESS, MIL	CHARACTERISTICS AND TYPICAL USES
PLATINUM	Gold, copper	Poor	--	Flash up to 2	Good appearance, tarnish- and corrosion-resistant; for protection of surfaces that must withstand unusual corrosive environments
RHODIUM	Most ferrous, nonferrous metals	High	Good	0.001 to 1	Brilliant white color, tarnish- and corrosion-resistant, good electrical conductivity; decorative applications, musical instruments, medical and surgical parts, laboratory equipment, optical goods, electrical contacts, reflectors, and mirrors
SILVER	Most ferrous, nonferrous metals	Good	Good	0.1 to 1	Excellent appearance, high electrical conductivity, good resistance to many chemicals; decorative applications, tableware, hollow-ware, cigarette lighters, musical instruments; industrial applications, bearings, surgical instruments, chemical equipment, and electrical contacts
TIN	Usually ferrous metals	Poor unalloyed	Good	0.015 to 0.5	Corrosion-resistant, attractive appearance, hygenic, easily soldered, good bearing properties; food and beverage containers, refrigerator evaporators, food and dairy equipment, hardware, and electronic parts
ZINC	Usually ferrous metals	Poor	Excellent	0.1 to 2	High corrosion resistance; appliance and automotive parts; pipe couplings, bolts, nuts, rivets, washers, nails, and buckles; electrical conduit pipe, screening, telephone exchange equipment, and iron and sheet castings
COBALT-NICKEL	--	Very good	Good	0.1	Wide range of magnetic properties; magnetic recording, permanent coating on computer memory drums; electroforming
COPPER-TIN (BRONZE)	Steel, copper, brass, zinc	Good	Excellent	0.5	Inexpensive red bronze coatings; nickel and chromium undercoating; stop-off coatings for steel; speculum coatings
COPPER-ZINC (BRASS)	Iron, steel, aluminum, zinc	Poor	Excellent	0.1	Rich appearance, little resistance to outdoors and tarnishing indoors; decorative uses; promotes rubber-steel adhesion
LEAD-TIN	Steel, copper, brass	Poor	Good	0.2	Harder and more protective than lead; good friction and bearing properties; corrosion protection; soldering aid
TIN-NICKEL	Most ferrous, nonferrous metals	Good	Generally good	0.5	Good decorative properties; resists tarnishing; solderable; miscellaneous domestic, industrial, and surgical uses
TIN-ZINC	Most ferrous, nonferrous metals	Good	Good	0.15	Good corrosion resistance, excellent solderability; various electronic applications; galvanic protection of steel parts contacting aluminum

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its surface. This process is fairly inexpensive. The equipment used is versatile in that it can handle different shapes and sizes of work; with little modification it can be used to apply different coating materials. The nature of the process itself makes it difficult to achieve plating on contours, grooves, fins, ribs, recesses, and angled edges. It is imperative that the designer consider these factors in designing the configuration of parts.

Table 13-5 lists characteristics and applications for some of the common electroplating materials. In addition to the platings shown in the table, alloy electroplating techniques that give a coating having a better appearance and properties than coatings consisting of one metal alone are available. In this fashion, brass, bronze, cobalt-nickel, nickel-iron, tin-zinc, and other alloys can be electrodeposited. Alloy plating must be employed in order to deposit some metals, e.g., tungsten.

13-4.2.2 Anodizing

The natural oxide film on aluminum is 0.0000005 in. thick; the anodizing process creates an oxide film ranging from 0.00005 to 0.005 in. thick on the surface. The anodic film gives the metal a glaze-like surface which is highly resistant to weather, corrosion, abrasion, and wear. It can impart a wide range of colors to the material; the anodized finish is immune to chalking, blistering, and cracking because the film is integral with the metal itself.

In the anodizing process, the aluminum part is made the anode rather than the cathode, the opposite of conventional electroplating. The electrolyte consists of solution which yields oxygen by electrolysis. The passage of an electrical current results in the flow of oxygen to the aluminum part, where it combines chemically to form and build up an oxide film. Properties of this film—such as thickness, hardness, and porosity—depend on the aluminum alloy and temper, the electrolyte and its concentration, the voltage, the current density, the temperature, the degree of agitation, positioning, and other factors.

Anodizing can be utilized on parts such as truck and bus panels, small arms, and portable tools, as well as various architectural applications.

13-4.2.3 Hard Anodizing

Of recent interest is the increasing use of hard-anodized films (0.001 to 0.005 in. thick) because of their outstanding wear- and abrasion-resistant qualities. Table 13-6 lists some typical applications of hard anodizing that have been successful.

TABLE 13-6. APPLICATIONS FOR HARD ANODIZING

Aircraft abrasion strips	Hydraulic parts
Aircraft undercarriage legs	Mechanical computer gears
Air impellers, fans	Metal spray pistols
Bearings	Nozzles
Cams	Pistons
Clutch and brake disks	Rollers
Control valves	Screw threads on jacks
Doorhandles	Surgical splints
Film projector parts	Timing gears
Fuel and oil pump housings	Valves

13-4.3 CHEMICAL COATINGS

Phosphate and chromate coating processes are the most important of the chemical techniques. The techniques are described in the paragraphs which follow.

13-4.3.1 Phosphate Coatings

Phosphate coatings may provide for one or all of the qualities such as protection against corrosion, an organic coating base, improved retention of break-in lubricants, improved abrasion resistance, and an absorbent layer for rust preventive oils. Phosphate coatings normally are applied to iron, steel, zinc, aluminum, cadmium, and tin. They are applied by either brushing, dipping, or spraying.

There are four types of phosphate coating, having the following characteristics:

(1) Zinc phosphate—Provides best corrosion resistance; is a good absorbent base for lubricants and cold drawing compounds.

(2) Heavy zinc phosphate—Used principally as a binder for rust preventive wax and oil.

(3) Iron phosphate—The lightest of the phosphate coatings; used almost entirely as base for paint on parts not exposed to weather.

(4) Manganese phosphate—The heaviest phosphate coating; coarse structure retains larger quantity of lubricant and rust preventive oil; also used to prevent galling of moving parts and as a corrosion preventive.

The steps involved in the application of phosphate coatings and the time intervals they consume are:

(1) Cleaning—3 min. to 10 min.

(2) Rinsing—30 sec. to 60 sec.

(3) Phosphating—2 min. to 40 min.

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(4) Rinsing—30 sec. to 60 sec.
(5) Acidulated rinsing—30 sec. to 60 sec.
(6) Drying—3 min. to 5 min.

Paint or lubrication should be applied as soon as possible after drying; otherwise additional cleaning and drying steps will be necessary.

13-4.3.2 Chromate Coatings

Chromate coatings are simple and economical to apply; they provide a corrosion-resistant surface film, an excellent base for paint, and may be a decorative finish. They are applied to aluminum and aluminum alloys, zinc and cadmium plate, zinc castings and galvanized metal, and to a lesser extent on copper, tin, magnesium, silver, and chromium. These coatings may be applied by dipping, brushing, spraying, swabbing, and electrolytically.

Chromate coatings exhibit the characteristics of being "self-healing" in that scratches and minor abrasions are protected by a bleeding of the chromium coating onto the damaged area. The coatings can be dyed a variety of colors; in the undyed state, they vary from clear and highly polished to a flat black (depending on treating method used, substrate material, and thickness of the coating).

13-4.4 MECHANICAL COATINGS

Elastomeric, vitreous enamel, and paint coatings are among the commonly used mechanical coatings; they are covered in the discussions which follow.

13-4.4.1 Elastomer Coatings

Elastomeric coatings may be applied to most metals, glass, wood, fabric, concrete, and most other materials. In addition to being elastic, they offer a wide range of interesting protective properties. The five major elastomer types used in coating are:

(1) Polychloroprene (Neoprene).
(2) Chlorosulfonated polyethylene (Hypalon).
(3) Urethane.
(4) Polysulfide.
(5) Fluoroelastomer.

Combinations of the above are sometimes used, one as a primer and the other as a top coating. This enables the designer to take advantage of the best properties of each.

The typical properties of elastomeric coating materials are listed in Table 13-7. Elastomers are usually applied manually by spraying, brushing, rolling, etc. For production line use of the process, they can be applied by dipping.

13-4.4.2 Vitreous Enamel Coatings

Vitreous or porcelain enamel coatings may be applied to metal or cast iron. They provide a hard glass-like surface which has excellent resistance to atmospheric corrosion and most acids; they can be attractive and have the ability to absorb radiant heat energy. The coating is applied (after fabrication of the part) by dipping or spraying a water suspension of powdered ceramic material onto the surface. After drying, the coating is fused at a temperature in the range of between 1400° and 1600°F.

The colors and variety of finish attainable range over a wide variety of colors and color combinations (speckled, stippled, etc.).

13-4.4.3 Paint, Varnish, Lacquer, and Related Coatings

Paint offers probably the most versatile type of coating for protecting metals against corrosion and for protecting wood against weathering. Generally, a properly applied paint coating offers much higher corrosion resistance than an inorganic finish such as a plated coating or a bare surface coating. Therefore, whenever the nature of the part and its intended usage allow, it should be painted. It is recognized that materials such as varnish, lacquer, sealer and certain bituminous coatings, strictly speaking, are not paint; however, for this purpose, they are considered as "paint".

An important consideration is that paint, as purchased, is in liquid form. Unlike a piece of cloth, a plastic floor or wall tile, or a wood shingle, paint as purchased is not a finished product, but has to be applied to the surface and allowed to dry. Thus, the skill and conditions of application of the liquid paint are of importance for the protection of the surface.

Of major importance in painting is the proper preparation of the surface prior to the application of the paint. If the surface is improperly prepared, the best paint may fail to give the desired protection. On the other hand, a paint of only medium quality may give good service when applied to a properly prepared surface. A clean and dry surface, free from oil, dirt, dust, moisture, rust, mill scale, and any other foreign matter is of prime importance. After the surface is thoroughly

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TABLE 13-7. GENERAL PROPERTIES OF ELASTOMERIC COATINGS

	NEOPRENE	HYPALON	URETHANE	POLYSULFIDE	FLUOROELASTOMER
ACID RESISTANCE	G*	G to E	P to F	F	E
ADHESION	G to E	F to G	G	G	F to G
ALKALI RESISTANCE	F to G	E	P	F	P
ELECTRICAL	F to G	F to G	F to G	F	F to G
HEAT RESISTANCE	G to E	G to E	G	F to G	E
OIL RESISTANCE	G	G to E	E	E	E
OZONE RESISTANCE	G to E	E	E	G	E
PERMEABILITY	G	G to E	F	E	E
SOLVENT RESISTANCE	F	P	F to G	G	G
TOUGHNESS	G	F to G	E	F	F to G
WATER RESISTANCE	G to E	G to E	G	G	E
WEATHERABILITY	G to E	E	G to E	G to E	E
TEMPERATURE RANGE, °F	200/225	275/300	up to 225	215	450

*Legend: P - Poor
F - Fair
G - Good
E - Excellent

clean, another step is the application of the surface treatment. Proper surface treatments applied to clean steel, zinc, aluminum, and magnesium prolong the protective life of the paint coating.

A further important consideration in painting is the thickness of the dry film. If the coat is too thin, the protection of the painted surface may be inadequate. Up to a practical limit, the thicker the paint coat, the more durable is the painted coating. Generally the paint is applied in several thin coats in order to obtain the proper total film thickness.

Other important considerations are the use of correct type of paint and use of good quality paint. Three paints may be of satisfactory quality, but one is designed to prime wood, another to prime steel, and the third to prime aluminum. The quality of the paint (provided it has been prior tested) is assured by the detail requirements of the many Military and Federal Specifications. In general, the title of the specification indicates the intended use of the paint.

Four types of transparent coatings in use are varnish, shellac, lacquer, and linseed oil. A brief description of their characteristics are:

(1) Varnish—Varnish may be classed as a spirit or oleo-resinous. A spirit varnish is one whose film is comprised of materials with the lacquer being converted from the wet to dry state by the evaporation of the solvent. An oil varnish is a combination of drying oil, resin, thinner, and drier. When this varnish is spread in a thin film, the wet film is converted to dry film by oxidation.

(2) Shellac—This product is actually a spirit varnish, consisting of shellac resin dissolved in alcohol—usually about four pounds of the lac resin dissolved in one gallon of alcohol. When shellac varnish is spread in a thin film, it dries by simple evaporation of the alcohol, leaving a continuous film of the dry shellac.

(3) Lacquer—A typical clear cellulose lacquer consists of nitrocellulose, a resin such as an alkyd, a plasticizer, and volatile solvents. A film of this lacquer dries by solvent evaporation. There are several other kinds of lacquer, for example, vinyl lacquer in which the nonvolatile vehicle consists of vinyl resin and plasticizer. Other clear lacquers may have acrylic ester resin bases alone, or in combination with cellulose nitrate, ethyl cellulose, and vinyl resins.

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(4) Linseed oil—This drying oil is used as a clear coating. When linseed oil is spread in a thin film, it absorbs and combines with oxygen from the air and is converted to a dry film of linoxyn.

Pigmented coatings include oil-type paints, varnish enamels, lacquer enamels, sealers, undercoaters, surfacers, and some stains. Brief descriptions of the oil-type paints, varnish enamels, and lacquer enamels follow:

(1) Oil type paints—These paints consist principally of drying oil (usually linseed), thinner and drier as the vehicle, mixed with pigments. The paint can be applied by brushing or spraying, but generally it is applied by brushing.

(2) Varnish enamels—The term enamel is an abbreviation of enamel paint, e.g., a paint suggestive of a porcelain enamel in hardness, smoothness, and gloss. These features are imparted by the use of a varnish vehicle in place of oil.

(3) Lacquer enamels—Pigmented lacquers (lacquer enamels) based on cellulose derivatives—for example, cellulose nitrate—may be used on tanks, trucks, ammunition and automotive components, and on other surfaces. These lacquer coatings dry chiefly by the evaporation of the volatile solvents and diluents, with little or no oxidation. The pigmented lacquers have the same composition as the clear lacquers except for the addition of pigment. These lacquers are applied by spraying and the film dries rapidly (within a few minutes). Pigmented lacquers can be formulated to dry with a glossy, semi-glossy, or lusterless finish.

TABLE 13-8. A COMMON DESIGN PROBLEM

Problem: PROTECTIVE FINISH NOT PROPERLY DELINEATED.

Cause and Effect:

Lack of information results in poor quality, poor bonding, or a coating that is not as desired or required.

Potential Solution:

Review of design to ensure that metal preparations, prime coats (the number of thicknesses, the material specifications), and final costs (the same factors) are as specified. Include all applicable Military Specifications in the listing.

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TABLE 13-9. COMMON PRODUCTION PROBLEMS

Process: AUTOMATED PLATING OF GUN BARRELS.

Problem:

Present-day electroplating and electropolishing of gun barrel bores are too costly.

Application:

Study and evaluate automated techniques so that the bores of gun barrels can be electroplated and electropolished without having to measure bore diameters during processing.

Process: APPLICATION OF EROSION-RESISTANT COATINGS.

Problem:

The ultimate of gun tube life saving cannot be realized by electrodepositing chromium alone because of the engraving (erosion) forces of the rotating band of the accelerating projectiles.

Application:

All commodities requiring improved erosion resistance.

Process: COATINGS ON ALUMINUM AND STAINLESS STEEL.

Problem:

Present surface coatings on aluminum and stainless steel wear off and become bright. To prevent this, some durable coating is needed. In addition, surface wear would expose only additional nonreflective areas.

Application:

Night vision equipment and other items made of aluminum and stainless steel.

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TABLE 13-9. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: PLASMA ARC COATING PROCESSES.

Problem:

In order to obtain optimum properties of plasma arc sprayed coatings, studies must be made to define the variables in the process: i.e., plasma gas, gas velocity, powder, feed characteristics, feed rate and distance, and orientation of surface for deposition.

Application:

Deposition coatings and building up shapes of refractory materials. All weapon systems where refractory or extreme abrasion resistance coatings are required.

Process: PLASMA COATINGS BY CHEMICAL REACTION.

Problem:

Use of the plasma gun has acquired wide popularity as a means for spraying refractory powders onto graphite or other materials. However, the bond to the substrate is a mechanical bond and under some conditions there is lack of integrity.

Application:

Coating of jet vanes, nozzles, leading edges, and other specialized missile components.

Process: PROPRIETARY COATINGS.

Problem:

Many new proprietary coatings and processes for applying electroplated or other finishes are on the market; however, the only information concerning them is that provided by sales promotional literature.

Application:

Many Army programs could benefit from these new coatings and developments; however, they first must be tested and evaluated by responsible agencies before they can be utilized.

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TABLE 13-9. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: CORROSION RESULTING FROM DISSIMILAR METALS IN WEAPONS.

Problem:

Adjacent dissimilar metals and even surface finishes contribute to the corrosion of gun components.

Application:

Corrosion potential incident to weapons, particularly cannon.

Process: ELECTROPHORETIC COATING OF AMMUNITION COMPONENTS.

Problem:

There exist numerous problems associated with conventional (spray, dip, brush, etc.) methods of application of organic coatings.

Application:

Production of ammunition components.

Process: ELECTROLYTIC PLATING PROCESSES FOR GUN COMPONENTS.

Problem:

The electroplating of gun components is not a fixed art and existing processes require continued review and upgrading.

Application:

Gun components requiring plating to reduce wear.

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TABLE 13-9. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: CHROMATE COATINGS ON ZINC- OR CADMIUM-PLATED STEEL.

Problem:

Dyed chromate coatings applied over zinc- or cadmium-plated steel are not colorfast. Neither are the dyed chromate coatings on aluminum.

Application:

Any application which requires colored steel or aluminum surfaces.

Process: CHROME COATINGS IN GUN BORES.

Problem:

Current chrome plated coatings in gun bores exhibit certain limitations which preclude much greater improvement in their expected life span.

Application:

Gun bores, or any other item requiring an erosion resistant coating, could benefit from a coating exhibiting better corrosion resistance than that offered by chromium.

Process: CHROMIUM AND CADMIUM PLATING.

Problem:

Chromium and cadmium plating and pickling processes are common sources of detrimental hydrogen embrittlement. Long post heat soaks offset the possibility of cracking and failure caused by embrittlement; however, they are time-consuming and expensive.

Application:

Weapon components requiring the beneficial effects of plating.

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TABLE 13-9. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: VAPOR DEPOSITION AND OXIDATION-RESISTANT HIGH TEMPERATURE COATINGS.

Problem:

Carbides, nitrides, and borides are well known for their refractory qualities, but their usefulness is limited by the difficulties these materials offer to forming into finished products.

Application:

Processing parameters using tungsten, molybdenum, and certain carbides and nitrides.

Process: ION-NITRIDING (GLOW DISCHARGE AS A HEAT TREAT PROCESS).

Problem:

While this process is widely acclaimed in Europe, there is little technical information about it in the United States. Ion-nitriding in Europe is currently being used on several weapon barrels and its potential for other applications is generally acknowledged.

Application:

Components that require a surface hardened layer; i.e., gears, cams, piston pins, valve seats, etc.

Process: NONREFLECTIVE ALUMINUM AND STAINLESS STEEL.

Problem:

Aluminum and stainless steel components cause undesirable light reflections in combat situations.

Application:

Determine dulling processes for coatings or preventive impregnation of the reflective metals to decrease tactical hazards.

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TABLE 13-9. COMMON PRODUCTION PROBLEMS (CONT'D)

Process: PAINT USED ON ARMY EQUIPMENT.

Problem:

Paint is used on many items of Army equipment. It is applied by atomized spraying, dipping, or brushing; these processes are expensive with respect to both equipment and labor costs. Electrocoating and electrostatic spraying exhibit advantages in these and other areas.

Application:

An Army program having a requirement for the application of paint could benefit from specification of improved paint application methods.

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PART THREE INFORMATION SOURCES

APPENDIX A

THE TECHNICAL INFORMATION ENVIRONMENT

A-1 INTRODUCTION

The material presented in this appendix gives first a general review of important considerations in using and acquiring technical information in the design functions. Following, then, are compilations of specific sources which are frequently used by engineers and scientists. Use of the information available contributes to the skills of the designer and to the products of his effort.

A-2 SEARCHING THE LITERATURE

A-2.1 INFORMATION SEARCH PROBLEMS

Producibility is not a key search term in any of the generally used indexing systems, nor does it appear as a generic term in the DOD *Thesaurus of Scientific and Engineering Terms*[1]. This should not prove unduly surprising since the producibility of any design is the product of many actions by the design organization rather than the actions themselves. It does, however, complicate the apparent task of searching for information or data on the subject.

Once the concept of producibility is grasped, the search for information appropriate to any design effort need not be unduly complex if it is approached in an organized and logical manner. Many of the companion handbooks of the AMCP 706-series discuss specific design attributes of the commodities which they cover and a high degree of producibility is inherent in these design approaches. However these, in general, represent traditional approaches, while objectives and constraints of new requirements usually demand extensive innovation and the search for information concerning recently developed concepts.

The stockpile of available information advances at an estimated rate of 100,000 published pages per day and an unsystematic search will almost certainly only generate trivia and irrelevance.

A basic knowledge of cataloging systems described previously will be of major assistance—it being a lot simpler to get along with the discrepancies and get to the right bookshelf than to search through the whole library. Indexes and abstracts may be helpful, and the automated data retrieval system may provide the right way if the user knows the right question. All systems suffer from one drawback—they involve two groups of people: one classifying information and storing it, and the other attempting to retrieve it. If the classifier has not stored the information so that it can be reached by a term which the user is likely to use, the information will probably remain untapped. The services of a professional information specialist, or the traditional librarian, will frequently be of considerable value. However, these services may be unavailable and, even when they are, it is incumbent upon the potential user to provide sufficiently descriptive explanation of the information being sought to permit a search to be made which will retrieve information of probable value while avoiding the recovery of mountains of extraneous junk.

A-2.2 INFORMATION ROADMAPPING

Any engineer is well aware that there are normally four inherent relationships in any design situation. The area of interest has input and output parameters, su-

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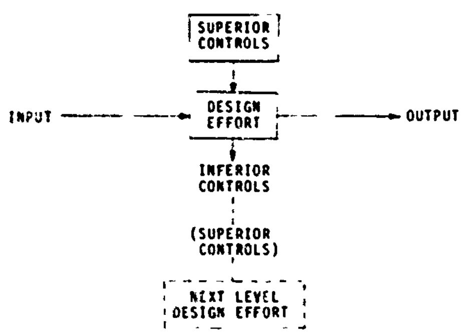
perior controls (demands or constraints which must be met) and inferior controls (products which appear as "superior controls" at directly related sublevels of design).

The design effort consists of accepting the inputs, in the form in which they are presented, and designing a subsystem, assembly, or subassembly which accomplishes a prescribed reaction to present a required output. It must do so within the restrictions of the superior controls, or constraints and must avoid the creation of inferior controls which are impossible to live with at the next lower level of design effort. This is one of the key elements of system engineering and may be simply expressed as:



This is a fundamental design effort roadmap. All factors external to the actual design effort must be known and correlated if the design is to achieve its objective. The situation is completely analogous to that of information storage and retrieval. A search for information frequently results from the existence of a problem. If the "problem" is substituted for "design effort", the same relationships will be found to exist. The well organized information system attempts to anticipate the problem by structuring the information in the same general relationship. Unfortunately, however, in practice these relationships tend to change with each individual application.

A number of structured roadmaps exist which attempt to provide a fairly universal and logical relationship of facts. These serve to improve interdisciplinary communication and also as a fundamental structure for information storage and retrieval. Among the most recent and extensive of these is the previously mentioned DOD Thesaurus jointly prepared by DOD and the Engineers Joint Council. This Thesaurus provides a structured, generic tree relationship (illustrated in Fig. A-1) between 17,810 engineering and scientific descriptors-key terms. The structure provides the identical relationship as illustrated above. Each main entry identifies (among other things) any Broader (higher order) Terms (BT), Narrower (lower order) Terms (NT) and Related (same level) Terms (RT). It thus represents a tabulated roadmap, components of which can be put together in almost any combination as a means of initiating an information search. For example, if (in Fig. A-1) information is sought on Nitrile Rubber, the Thesaurus recommends the use of Diene resins as the key term. If a search is unfruitful, it might be pursued under the broader term of addition resins or, if the question can be more specifically defined, under one of the six narrower terms. Even the related terms may prove useful. Appendices B, C, and D each present a series of special roadmaps developed to assist in the acquisition of information necessary to the design, production, and logistic support of Army commodities (in fact, the roadmaps in Appendix D are a generic tree presentation of the terminology used by the Defense Logistics Studies Information Exchange (DLSIE) at the U. S. Army Logistics Management Center, and these are the terms used to query that agency for information). A brief bibliography is provided in Appendices B and C, structured on the same basis as the roadmaps to which they relate. The vast nature of the information resources which must frequently be tapped and its rate of change precludes incorporation of more detailed bibliographic listings and the user will frequently find the roadmaps useful, in conjunction with the balance of this appendix, in properly identifying the nature of the information which is sought as well as its most probable source.

A-2.3 DEVELOPING AN INFORMATION ROADMAP

A-2.3.1 Selection of Terms

When the roadmaps to get to the information do not exist, or are outdated and unreliable, the user can build his own. This may take the form of a term index; a thesaurus or a generic tree; a flow chart; a PERT network; or a specification tree. Each one is simply a slight variation of:

(1) What is this a part of?
(2) What are its constituents?
(3) What is associated with it?

With a little practice, it will frequently be found that simply building the roadmap has provided the answer,

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or its construction has caused its builder to rearrange information and discover the answer. The builder is presented with a jigsaw puzzle in which all the pieces have the same geometry and can therefore be fitted together in a combination. What is more, he has a random number of pieces. He may ignore or recognize each. He may put pieces together in a manner which suits the development of his interests and which serves as an aid in the solution of his problems.

The process will delete terms which are inappropriate to the problem, and retain and organize those which have some bearing.

A-2.3.2 Ranking by Degree of Relationship

After relating the terms to the problem, the terms may be ranked.

Virtually any situation has an input-output relationship. There are functions which impact upon it and those which it impacts upon. With this in mind, the previously identified terms may be plotted on a grid shown in Fig. A-2. Though shown graphically here, this may frequently be simply a mental exercise.

Each of the terms accepted can be related by order of magnitude and entered on the chart. This will establish some order of probable significance of the terms and demonstrate their distribution. After creating the distribution, the originator may discover that it doesn't relate to this problem. When this occurs, he may deduce one of three things:

(1) He doesn't understand the problem (fog factor)

(2) He doesn't really have a problem. (Again, probably fog factor. At least, he may have discovered that all the answers are under his own control.)

(3) This just never happened before (in which case he should return to the first two).

A-3 SOURCES OF TECHNICAL INFORMATION AND DATA

The information required in design efforts is concentrated in the following broad categories of published materials[2]:

(1) Technical books in specialized subject areas

(2) Journals and periodicals

(3) Documents (including technical reports and findings)

(4) Other materials (specifications, standards, pamphlets, trade catalogs, Government documents)

For ready reference, a brief summary of these sources and the applicable indexes are given in Fig. A-3. The indexes are consulted first since they direct the searcher to the specific information contained in the sources.

A-3.1 TECHNICAL BOOKS

Most books are arranged in libraries by classification systems, which have the common objective of grouping books on the same and related subjects in logical relation to each other. Generally, either the Library of Congress or the Dewey Decimal Classification System is used. Fig. A-4 presents a summary of these systems in general and in the areas of science and technology. Familiarity with these systems will enable a searcher to learn where material is likely to be located.

A-3.2 JOURNALS AND PERIODICALS

Journals and periodicals are invaluable aids to any designer. It is probable that the first awareness of a real or potential advancement which will be of direct benefit to design activities will be published either through a professional association or a technical periodical or journal. These publications are a means of providing current information concerning results of research and technical information, and they represent a chronological record of advances being made in specific subject areas.

Information found in technical journals is often more recent and more specific in detail than that found in books. On the other hand, such information is more scattered and difficult to obtain. For this reason, it is necessary to consult the several indexes available for periodical literature. These include:

(1) *Reader's Guide to Periodical Literature*[3]

(2) *Engineering Index*[4]

(3) *Applied Science and Technology Index*[5]

(4) *Ulrich's International Periodicals Directory*[6]

A-3.3 DOCUMENTATION AND INFORMATION ANALYSIS CENTERS

Documents, including technical reports, are a significant source of information available. To enable users (and potential users) of this type of data, centers have been established to collect, abstract, index, and disseminate technical reports and findings. It is becoming increasingly essential that contributors to technology be

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familiar with the services and utilize the services of the documentation centers. Four major documentation centers for general needs include:

(1) Defense Documentation Center, DOD

(2) Technical Information Facility, NASA

(3) Division of Technical Information-Extension, AEC

(4) Clearinghouse for Federal Scientific and Technical Information, Institute for Applied Technology, National Bureau of Standards, U.S. Department of Commerce.

In addition to documentation centers, information analysis centers have been established which review or analyze scientific or engineering data. The primary function of these centers is to provide answers to questions, rather than references to documents for someone to read. These centers are mission- and subject-oriented centers whose mission is to review, analyze, appraise, and summarize information and to provide evaluation services to users in their respective fields.

The list of documentation and information centers which follows has been compiled from several sources[7,8,9]. Other compilations which may be helpful include *Directory of Special Libraries and Information Centers*[10] and *Directory of Federally Supported Information Analysis Centers*[11]. The centers listed have been grouped by sponsoring agency, including:

(1) Department of Defense

(2) Army

(3) Navy

(4) Air Force

(5) National Aeronautics and Space Administration

(6) Atomic Energy Commission

(7) Other Government Agencies

(8) Industrial and Trade Associations

A subject index to the centers concludes the presentation.

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(1) DEPARTMENT OF DEFENSE

1-1 ARPA, ADVANCED RESEARCH PROJECTS AGENCY

Technical Coverage: Ballistic missile radiation analysis, ballistic missile defense, seismic information and analysis, and remote-area conflict information.

1-2 BDIAC, BATTELLE-DEFENDER INFORMATION ANALYSIS CENTER

Technical Coverage: Ballistic missile defense, penetration aids, decoy technology, electromagnetics, electronic countermeasures, flight mechanics, vehicle dynamics, nuclear effects, and re-entry systems' vulnerability; R&D information pertaining thereto.

1-3 BAMIRAC, BALLISTIC MISSILE RADIATION ANALYSIS CENTER

Technical Coverage: Ballistic missile phenomena, with primary emphasis on optical radiation.

1-4 DASA, DEFENSE ATOMIC SUPPORT AGENCY

Technical Coverage: Nuclear-weapon-effects research testing and safety mechanisms; training and evaluation of test results.

1-5 DASA DATA CENTER

Technical Coverage: Effect of nuclear explosions on electromagnetic propagation; effect of electromagnetic pulse on electrical and electronic material; air-blast field predictions; blast scaling; blast loading and response, blast simulation techniques; hardened instrumentation; ionospheric instrumentation; computer programs used in NWER studies.

1-6 WSEG, WEAPON SYSTEMS EVALUATION GROUP

Technical Coverage: Weapon systems evaluations and studies.

1-7 DSA, DEFENSE SUPPLY AGENCY

Technical Coverage: Documentation in all areas of DOD interest.

1-8 IAC, INFORMATION ANALYSIS CENTER

Technical Coverage: Shock and vibration, chemical propulsion, counterinsurgency, hibernation, entomology, remote-area conflict.

1-9 DDC, DEFENSE DOCUMENTATION CENTER

Technical Coverage: Documentation on scientific and technical information.

1-10 HEIAS, HUMAN ENGINEERING INFORMATION AND ANALYSIS SERVICE

Technical Coverage: Human factors engineering and analysis.

1-11 SVIC, SHOCK AND VIBRATION INFORMATION CENTER

Technical Coverage: Mechanics, mechanical engineering, shock and vibration.

(2) ARMY

2-1 AEC, ARMY ELECTRONICS COMMAND

Technical Coverage: Nuclear, plasma, and solid-state physics, geophysics, meteorology, radio communications, automatic data processing, aerospace electronics, combat radar, electronic warfare, detection systems, frequency controls, electronic parts and components.

2-2 AMC, REDSTONE SCIENTIFIC INFORMATION CENTER

Technical Coverage: Aerospace logistics, operations, ballistics, fire control, fuzes, warheads, and related missile and rocket ordnance.

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2-3 *ARDC, ABERDEEN RESEARCH AND DEVELOPMENT CENTER*

Technical Coverage: Ballistic measurements, weapon systems evaluations, operations research, reliability, quality assurance, test-data analysis, probability and mathematical analyses.

2-4 *NTIAC, NONDESTRUCTIVE TESTING INFORMATION ANALYSIS CENTER*

Technical Coverage: Nondestructive-test data on materials, acquired through radiography, ultrasonics, electromagnetic and other NDT methods.

2-5 *AWC, ARMY WEAPONS COMMAND*

Technical Coverage: Engineering research data on cannon, mortars, howitzers, and antitank and antiaircraft weapons, including recoil mechanisms, fire control equipment, feed mechanisms, optical equipment, and nondestructive-testing equipment.

2-6 *AMC, ARMY MOBILITY COMMAND*

Technical Coverage: Data on high-performance helicopters, advanced V/STOL aircraft, propulsion systems, radiation-protection devices, tactical land vehicles, rail motive power, high-speed amphibians, aerial delivery equipment, parachute systems, etc.

2-7 *AMC, ARMY MUNITIONS COMMAND*

Technical Coverage: Nuclear and non-nuclear projectiles, rocket and missile warheads, mechanical fuze timers, mines, mine fuzing, pyrotechnics, propellant actuated devices, toxic chemical munitions, flame weapon systems, and incendiary devices; also numerical analysis, mathematical statistics, probability and operations-research methodology.

2-8 *PLASTEC, PLASTICS TECHNICAL EVALUATION CENTER*

Technical Coverage: Plastic materials, with emphasis on plastics in structural weapon systems, electrical and electronic applications, packaging and mechanical devices.

2-9 *ATEC, ARMY TEST AND EVALUATION COMMAND*

Technical Coverage: Weapons, equipment and all materiel and techniques used by the Army.

2-10 *ACRREL, ARMY COLD REGIONS RESEARCH AND ENGINEERING LABORATORY*

Technical Coverage: Physical, mechanical and structural properties and behavior of snow, ice and frozen ground; geology, geophysics, geography, meteorology; engineering and technology; environmental conditions and physics; military applications.

2-11 *ARDC, ABERDEEN RESEARCH AND DEVELOPMENT CENTER*

Technical Coverage: Scientific and technical information regarding human factors affecting military operations and materiel.

2-12 *ARDC, ABERDEEN RESEARCH AND DEVELOPMENT CENTER*

Technical Coverage: Chemical cleaning and corrosion; paint, varnish, and lacquer; automotive chemicals, fuels, and lubricants.

2-13 *ANL, ARMY NATICK LABORATORIES*

Technical Coverage: Physical, life and earth sciences, and engineering as applied to food, living, and weapons military equipment.

2-14 *HDL, HARRY DIAMOND LABORATORIES*

Technical Coverage: Systems research in fuzing, ranging, guidance and detection; instrumentation, measurement and simulation; electronic and electrical components; nuclear weapons effects; basic research in electromagnetic properties of plasma, nonlinear circuits and lasers.

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2-15 *ANDL, ARMY NUCLEAR DEFENSE LABORATORY*

Technical Coverage: Nuclear radiation, residual radiation, shielding, radiological defense and radiation effects.

2-16 *DEFENSE LOGISTICS STUDIES INFORMATION EXCHANGE, ARMY LOGISTICS MANAGEMENT CENTER*

Technical Coverage: Logistics and related subject material.

2-17 *TAERS, THE ARMY EQUIPMENT RECORD SYSTEM*

Technical Coverage: Maintenance-management data, part repair and replacement frequency, maintenance resources, and manpower requirements.

(3) NAVY

3-1 *NARDIS, NAVY AUTOMATED RESEARCH & DEVELOPMENT INFORMATION SYSTEM*

Technical Coverage: Technical and management information on Navy research and development projects.

3-2 *DMPS, DEPOT MAINTENANCE PLANNING SYSTEM*

Technical Coverage: Technical simulation.

3-3 *ADCS, AIRCRAFT DIRECTIVES CONFIGURATION SYSTEM*

Technical Coverage: Aircraft maintenance.

3-4 *AMMRL, AIRCRAFT MAINTENANCE MATERIAL READINESS LIST*

Technical Coverage: Aircraft maintenance.

3-5 *SMACS, SERIALIZED MISSILE ACCOUNTING AND CONTROL SYSTEM*

Technical Coverage: Ordnance maintenance.

3-6 *UADPS, UNIFORM AUTOMATIC DATA PROCESSING SYSTEM FOR INDUSTRIAL NAVY AIR STATIONS*

Technical Coverage: Aircraft maintenance.

3-7 *TDS, TECHNICAL DATA SYSTEM (NAVAIR)*

Technical Coverage: Analysis of Naval weapon systems effectiveness and support development programs.

3-8 *TDS, TECHNICAL DATA SYSTEM (NAVFAC)*

Technical Coverage: Engineering and scientific fields relating to docks and Naval shore facilities.

3-9 *ALREP, MISSILE PERFORMANCE DATA AND RETRIEVAL SYSTEM AIR-LAUNCHED MISSILES*

Technical Coverage: Reliability and performance of air-launched missiles fired by fleet operational units.

3-10 *ASROC IDENTIFICATION AND TRANSACTION SYSTEM*

Technical Coverage: ASROC component usage, serviceability status, service environments for surveillance, and service life studies.

3-11 *UWSRD, UNDERWATER WEAPON SYSTEMS RELIABILITY DATA*

Technical Coverage: Reliability evaluations of underwater weapon systems.

3-12 *UWSDDMS, UNDERWATER WEAPON SYSTEMS DESIGN DISCLOSURE MANAGEMENT SYSTEM*

Technical Coverage: Service engineering and maintenance for underwater weapon systems.

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3-13 *IHS, INFORMATION HANDLING SYSTEM*

Technical Coverage: Engineering calculations, drawings, design sketches, technical data, and tables on NWC weapon testing.

3-14 *ADP SYSTEM FOR SUMMARIZATION QEL SURVEILLANCE AND FLEET-FIRING OF VT FUZES*

Technical Coverage: Component reliability of VT fuze performance.

3-15 *ADP SYSTEM FOR SUMMARIZATION OF Q L SURVEILLANCE OF NAVY GUN AMMUNITION*

Technical Coverage: Performance reliability of Naval gun ammunition.

3-16 *ADP SYSTEM FOR FLEET-FIRED NAVY GUN AMMUNITION*

Technical Coverage: Reliability of stockpile ammunition.

3-17 *SMS, CONFIGURATION MANAGEMENT MONITORING SYSTEM*

Technical Coverage: Missile systems engineering for Engineering Change Proposals, ORDALTS, and SHIPALTS.

3-18 *SMS, ENGINEERING DRAWINGS AND DOCUMENTATION SUPPORT SYSTEM*

Technical Coverage: Missile systems engineering drawings and data.

3-19 *SMS, CONFIGURATION ACCOUNTING SYSTEM*

Technical Coverage: Missile systems reliability studies and predicted failure rates.

3-20 *UICP, UNIFORM INVENTORY CONTROL POINT PROGRAM*

Technical Coverage: Repair parts, allowance lists, and provisioning requirements.

3-21 *ADP, SYSTEM FOR INDEXING AND RETRIEVAL OF ENGINEERING DRAWINGS AND TECHNICAL REFERENCES*

Technical Coverage: Technical data on components and weapon systems.

3-22 *ADP SYSTEM FOR THE NAVY CALIBRATION PROGRAM, NUCLEAR WEAPON TEST SETS*

Technical Coverage: Reliability of test and measuring equipment for nuclear weapons.

3-23 *ADP SYSTEM FOR NAVY CALIBRATION PROGRAM FOR MEC, POMONA*

Technical Coverage: Reliability of test and measuring equipment.

3-24 *USNIRS, UNDERWATER SHIP NOISE INFORMATION RETRIEVAL SYSTEM*

Technical Coverage: The physics of underwater ship noise, ship silencing, and mine warfare.

3-25 *VSMF, MARINE ENGINEERING FILE*

Technical Coverage: Electronic and mechanical product data for research and development maintenance engineering.

3-26 *DSD, DIVING SYSTEMS DEVELOPMENT*

Technical Coverage: Underwater-diving-systems evaluation and human-factors analysis.

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3-27 *LYQAL, LEAD YARD QUALITY ASSURANCE LISTS*

Technical Coverage: Shipbuilding and submarine maintenance quality-assurance data.

3-28 *NUMIS, NAVY UNIFORM MANAGEMENT INFORMATION SYSTEM*

Technical Coverage: Ordnance maintenance.

3-29 *NODC, NATIONAL OCEANOGRAPHIC DATA CENTER*

Technical Coverage: Physical, geological and biological aspects of oceanography and related environments.

3-30 *CPIA, CHEMICAL PROPULSION INFORMATION AGENCY*

Technical Coverage: Research, development, test and evaluation information on chemical rockets.

3-31 *IIAC, INFRARED INFORMATION ANALYSIS CENTER*

Technical Coverage: Infrared physics and technology, including solid-state physics, radiation physics and optics, infrared spectroscopy, atmospheric phenomena, information processing, military infrared equipment, industrial and medical infrared and related subjects.

3-32 *NSD-PHILA, NAVAL SUPPLY DEPOT-PHILADELPHIA*

Technical Coverage: DOD and Federal Specifications and Standards; related publications and handbooks.

3-33 *LIBRARY INFORMATION SEARCH AND RETRIEVAL DATA SYSTEM*

Technical Coverage: Subject search file arranged by descriptor number and containing descriptors, descriptor code numbers and accession numbers of reports posted; master report file containing bibliographic data for each report title in the system, arranged by accession number; a document file.

3-34 *LIBRARY INFORMATION RETRIEVAL PROGRAM*

Technical Coverage: Technical data system, research, and engineering.

3-35 *DOCUMENT INFORMATION RETRIEVAL*

Technical Coverage: Scientific and technical documents, technical reports, and information pertinent to Naval weapon personnel.

3-36 *SMS TECHNICAL LIBRARY INDEX CONTROL SYSTEM*

Technical Coverage: Technical information and documentation regarding ship missile systems.

3-37 *PROJECT SHARP AUTOMATED LIBRARY INFORMATION STORAGE AND RETRIEVAL SYSTEM*

Technical Coverage: Marine engineering and ship maintenance.

3-38 *MDCS (SHIP), MAINTENANCE DATA COLLECTION SUBSYSTEM*

Technical Coverage: Maintenance and equipment malfunction data, including operating times and active repair times.

3-39 *MDCS (AVIATION), MAINTENANCE DATA COLLECTION SUBSYSTEM*

Technical Coverage: Maintenance, aircraft statistical, and man-hours data, including support actions and maintenance actions.

3-40 *FARADA, TRI-SERVICE AND NASA FAILURE RATE DATA PROGRAM*

Technical Coverage: Comprises the collection, summarization, analysis, compilation and distribution of failure-rate and failure-mode data for use in reliability and maintainability prediction by the Army, Navy, Air Force, and NASA.

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3-41 IDEP, INTERAGENCY DATA EXCHANGE PROGRAM

Technical Coverage: Qualification reports, engineering analysis, contractor high-reliability specifications, materials reports, processing, failure analysis, and general technical reports—all as related to parts and components.

3-42 MEARS, MAINTENANCE ENGINEERING ANALYSIS RECORDS SYSTEM (WR-30)

Technical Coverage: Integrated maintenance data for aeronautical weapons, weapon systems, and related equipment.

3-43 OPTEVFOR, OPERATIONAL TEST AND EVALUATION FORCE

Technical Coverage: Performance and maintenance data on preproduction equipments.

3-44 FMSAEG, FLEET MISSILE SYSTEM ANALYSIS AND EVALUATION GROUP

Technical Coverage: Reliability, maintainability, and availability data for fire control radars and computers, search radars, guided missile launching systems, weapon direction systems, test equipment, and missiles.

3-45 ARMMS, AUTOMATED RELIABILITY AND MAINTAINABILITY MEASUREMENT SYSTEM

Technical Coverage: Reliability and maintainability characteristics.

3-46 MEAL, UNIVERSITY OF PENNSYLVANIA MODULE ENGINEERING ANALYSIS LIBRARY

Technical Coverage: Electrical and physical characteristics of Naval electronic assemblies. User-computer mean-time-between-failures and mean-time-to-repair factors on a contractual, predicted and actual basis.

3-47 NAVSECNORDIV DATA BANK

Technical Coverage: Reliability, maintenance, and equipment performance data.

3-48 BWAMMIS, ARMAMENT MAINTENANCE MANAGEMENT INFORMATION SYSTEM

Technical Coverage: Shipboard weapon systems maintenance.

3-49 GMSR, GUIDED MISSILE VARIABLE INFORMATION PROCESSING RETRIEVAL SYSTEM

Technical Coverage: Technical data and information on configuration and OrdAlt Management Program for Surface-Launched Guided Missiles.

3-50 ADP SYSTEM FOR AIR LAUNCHED MISSILE GUIDANCE AND CONTROL SECTIONS

Technical Coverage: Missile component reliability for Sidewinder and Sparrow III.

3-51 MFS-A, SURFACE MISSILE SYSTEMS AVAILABILITY EVALUATION

Technical Coverage: Reliability, maintainability, logistics, configuration control, Planned Maintenance System implementation, cost and logistic projection, availability, and effectiveness in the areas of fire control radars, search radars, fire control computers, weapon direction systems, and guided missile launching systems.

3-52 IRIA, INFRARED INFORMATION AND ANALYSIS CENTER

Technical Coverage: Infrared research and technology, particular emphasis on military technology.

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(4) AIR FORCE

4-1 AFOAR, AIR FORCE OFFICE OF AEROSPACE RESEARCH

Technical Coverage: Engineering and scientific information applicable to aerospace technology; specifically, the following: Basic research

propulsion—energy sources, energy release and transformation, conversion to useful work, theoretical and experimental techniques

materials—internal structures and properties of matter, structure and properties of interfaces, proposed synthetic methods, theoretical and experimental techniques

electronics—particle physics, interaction of fields and matter, transfer of electromagnetic energy, information sciences

geophysics—planetary lower atmosphere, upper atmosphere, space environment, experimental and theoretical techniques

life sciences—molecular and cellular biology, biological organization, integrative and regulatory functions, complex higher-order functions, individual and group performance and behavior, theoretical techniques

aeromechanics—flow field properties, mechanics of flight, experimental and theoretical techniques Applied research, including nuclear weapon effects, nuclear applications, aerospace environment.

4-2 AFOSR, AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

Technical Coverage: Engineering, chemical, physical and mathematical sciences; life and information sciences, and research analysis.

4-3 AFCRL, AIR FORCE CAMBRIDGE RESEARCH LABORATORIES

Technical Coverage: Basic research—computer and mathematical sciences, electronic materials sciences, electromagnetic radiation, astrosurveillance sciences, propagation sciences, communication sciences, instrumentation and general engineering. Geophysical research—photochemistry, thermal radiation, research instrumentation, atmospheric circulation, terrestrial sciences, ionospheric physics, aerophysics and meteorological development.

4-4 AFARL, AIR FORCE AERONAUTICAL RESEARCH LABORATORIES

Technical Coverage: Research information and data on metallurgy, ceramics, chemistry, physics, applied mathematics, aeromechanics, and propulsion.

4-5 AFIT, AIR FORCE INSTITUTE OF TECHNOLOGY

Technical Coverage: Educational and research information in the technical areas of engineering, systems and logistics.

4-6 AFASI, AIR FORCE AEROSPACE STUDIES INSTITUTE

Technical Coverage: Aeronautical, chemical, and electrical engineering; military science and history.

4-7 AFOAO, AIR FORCE OPERATIONS ANALYSIS OFFICE

Technical Coverage: Reliability and accuracy; statistical and mathematical techniques. Space systems: testing, test analysis, and design. Weapon systems: evaluation, costs, logistics, and maintenance.

4-8 AFREIC, AIR FORCE RADIATION EFFECTS INFORMATION CENTER

Technical Coverage: Effects of nuclear radiation on materials, components, and systems that might be used in a nuclear-powered airborne weapon system and associated ground support equipment; effects of nuclear bursts, pulsed radiation and space radiation on materials, components, and systems.

4-9 AFEPIC, AIR FORCE ELECTRONIC PROPERTIES INFORMATION CENTER

Technical Coverage: Major categories of materials covered by EPIC include: semiconductors, insulators, ferroelectric dielectrics, metals, ferrites, ferromagnetics, electroluminescent materials, thermionic emitters, and super-conductors.

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4-10 *AFMPDC, AIR FORCE MECHANICAL PROPERTIES DATA CENTER*

Technical Coverage: Mechanical properties of structural materials, with primary emphasis on metals, and secondary emphasis on plastics, including test procedures, material formulation, processing, and environments.

4-11 *AFDMIC, AIR FORCE DEFENSE METALS INFORMATION CENTER*

Technical Coverage: Properties, fabrication, and applications of aluminum, titanium, beryllium, magnesium, tungsten, molybdenum, columbium, tantalum, rhenium, stainless steels, hot-work die steels, low-alloy hardenable steels, nickel-base superalloys, cobalt-base superalloys, and iron-base superalloys.

4-12 *AFCGIC, AIR FORCE CERAMICS AND GRAPHITE INFORMATION CENTER*

Technical Coverage: Inorganic nonmetallic materials, metal oxides, sulfides, carbides, borides, nitrides, silicides, intermetallics, metalloid elements and their refractory compounds, glasses and vitreous adhesives, lubricants and sealants, inorganic cements, and carbons and graphites. Composites of these materials, together and with other materials, including coatings. Mechanical testing for high-modulus and brittle materials and composites.

4-13 *AFTPRC, AIR FORCE THERMOPHYSICAL PROPERTIES RESEARCH CENTER*

Technical Coverage: Thermophysical properties of all substances and seven properties: viscosity, thermal conductivity, thermal diffusivity, diffusion coefficient, specific heat, thermal radiative properties–spectral and total (emissivity, reflectivity, absorptivity, transmissivity), coefficient of expansion, and Prandtl number.

4-14 *AFMDC, AIR FORCE MACHINABILITY DATA CENTER*

Technical Coverage: All types of materials and all material removal operations, including conventional machining and alternate removal processes.

4-15 *AFAMIC, AIR FORCE AEROSPACE MATERIALS INFORMATION CENTER*

Technical Coverage: Adhesives, coating, lubricants, fibrous materials, oils, polymers, various types of manufacturing procedures, methods of materials evaluation and related materials.

4-16 *AFSC, AIR FORCE SYSTEMS COMMAND*

Technical Coverage: All phases of engineering research and development for materials and operations in the areas of aerospace and weapons.

4-17 *AFM 66-1 AIR FORCE MAINTENANCE DATA COLLECTION SYSTEM*

Technical Coverage: Maintenance data; maintenance analysis and control; failed-parts summaries; and maintenance manpower management in the areas of aircraft, missiles, electronic communications, ground equipment, and munitions.

4-18 *RADC–RELIABILITY ANALYSIS CENTRAL*

Technical Coverage: Part failure rates, part characteristic-drift data, and part failure-mode and failure-mechanism data as a function of time and stress. Part failure distributions and distribution parameters, part application information, and environmental limitations. Parts of established reliability, part characteristics, including physical attributes and pertinent electrical and performance properties. Relationships between reliability properties and part characteristics as established by materials, process controls, quality controls, function and cost. Comparison of reliability obtained under field operation with reliability obtained under laboratory and qualification tests, and part test programs. The foregoing with regard to electronic parts, semiconductor integrated circuits, and electromechanical and mechanical parts.

4-19 *AIR FORCE PROJECT RAND*

Technical Coverage: Game theory, logistics, materials, mathematics, reliability, statistics, system analysis, in the fields of aircraft, missiles, communications, cost analysis, electronics, propellants, propulsion, radar,

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and space flight, as well as other related fields.

4-20 *AIR FORCE MATERIALS LABORATORY*

Technical Coverage: Mechanical, physical and thermophysical properties of all materials, including metals and alloys, electrical encapsulating materials, structural plastics, ceramics, and graphite.

4-21 *DEFENSE CERAMIC INFORMATION CENTER*

Technical Coverage: Composition of materials: borides, carbides, carbon (graphite), nitrides, oxides, sulfides, silicides, intermetallic compounds, metalloid elements and glasses in the form of monophase and polyphase ceramic bodies, coatings, fibers, composites, and foams. Applications, property and performance data, processing and fabricating methods, testing methods, and fundamental aspects of processing and behavior of the materials.

(5) NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

5-1 *STAR, SCIENTIFIC AND TECHNICAL AEROSPACE REPORTS*

Technical Coverage: Scientific and technical reports of NASA and its contractors, government agencies, universities, and research organizations throughout the world.

5-2 *NASA, FIELD DATA SOURCES*

Technical Coverage: Scientific and technical information in the aerospace field.

5-3 *NASA HEADQUARTERS AND FIELD LIBRARIES*

Technical Coverage: Aerospace scientific and technical information.

5-4 *NASA REGIONAL TECHNICAL REPORT CENTERS*

Technical Coverage: Technical reports generated by NASA, The Atomic Energy Commission, The Department of Defense and other Government agencies.

5-5 *NASA RESEARCH IN PROGRESS CENTER*

Technical Coverage: Basic and applied research in physics, chemistry, mathematics, earth sciences, materials, and electronics.

5-6 *NASA TECHNOLOGICAL INFORMATION UTILIZATION ACTIVITY*

Technical Coverage: Devices, materials, processes and techniques developed by NASA and its contractors.

5-7 *NASA APIC/PRINCE INFORMATION CENTER*

Technical Coverage: Technical information on parts and materials, specifications, and testing results.

5-8 *RATR, RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS*

Technical Coverage: Reliability information as related to aerospace research, development and operation; specifically, space probes and manned space vehicles and all equipment components.

5-9 *CRYOGENIC DATA CENTER, CRYOGENIC DATA COMPILATION UNIT*

Technical Coverage: Cryogenic, thermodynamic properties, fluid mixtures, properties of fluids, transport properties, properties of solids, thermophysical properties.

5-10 *SCIENTIFIC AND TECHNICAL INFORMATION DIVISION*

Technical Coverage: The scientific and technical information generated by NASA, and the information generated by other agencies and governments in the aerospace sciences and all related fields.

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(6) ATOMIC ENERGY COMMISSION

6-1 *AEC DIVISION OF TECHNICAL INFORMATION*

Technical Coverage: Nuclear science and related sciences.

6-2 *AEC DIVISION OF TECHNICAL INFORMATION EXTENSION*

Technical Coverage: Nuclear research and development.

6-3 *DIVISION OF RESEARCH, AEC*

Technical Coverage: Physics, mathematics, chemistry, metallurgy, materials, and controlled thermonuclear reactions, as applied to the atomic energy program.

6-4 *DIVISION OF BIOLOGY AND MEDICINE, AEC*

Technical Coverage: Medicine, biology, biological applications of radioisotopes, and environmental studies related to atomic energy.

6-5 *DIVISION OF ISOTOPES DEVELOPMENT, AEC*

Technical Coverage: High-intensity radiation; interaction of radiation and matter.

6-6 *DIVISION OF REACTOR DEVELOPMENT, AEC*

Technical Coverage: Nuclear reactor systems and associated chemical-processing and waste-disposal operations.

6-7 *DIVISION OF MILITARY APPLICATIONS, AEC*

Technical Coverage: Nuclear weapons and weapon systems.

6-8 *DIVISION OF PEACEFUL NUCLEAR EXPLOSIVES, AEC*

Technical Coverage: Physics, chemistry, seismology, and related subjects applicable to excavation, mining, water-resource development, and oil recovery.

6-10 *DIVISION OF RAW MATERIALS, AEC*

Technical Coverage: Ores capable of yielding fissionable or potentially fissionable materials.

6-11 *DIVISION OF PRODUCTION, AEC*

Technical Coverage: Related fields of nuclear material production.

6-12 *DIVISION OF OPERATIONAL SAFETY, AEC*

Technical Coverage: Industrial health, safety, fire protection, and radiation protection.

6-13 *REACTOR PHYSICS CONSTANTS CENTER*

Technical Coverage: Physical data on reactor constants, such as nuclear-physics data pertinent to diffusion lengths, migration lengths, Fermi age, slowing-down constants, etc.).

6-14 *REACTOR CROSS SECTION EVALUATION GROUP*

Technical Coverage: Thermal cross sections, resonance parameters, cross-section curves, and angular distributions for elements and isotopes.

6-15 *NEUTRON CROSS SECTION COMPILATION GROUP*

Technical Coverage: All available information regarding neutron cross sections of materials.

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6-16 *NEUTRON CROSS SECTIONS, LAWRENCE RADIATION LABORATORY*

Technical Coverage: Measurements of neutron cross sections for all reactions with neutron energies between 0.001 and 15 Mev; differential and integral cross sections for all isotopes.

6-17 *CHARGED PARTICLE CROSS SECTION INFORMATION CENTER*

Technical Coverage: Nuclear cross sections of charged particles.

6-18 *NUCLEAR DATA PROJECT*

Technical Coverage: Nuclear-energy levels (experimental), basic nuclear physics not organized by existing nuclear classifications; specifically, low-energy basic nuclear physics, nuclear masses, spins, levels, moments, half lives, decay schemes, reactions and isotopic abundances.

6-19 *ATOMIC AND MOLECULAR PROCESSES INFORMATION CENTER*

Technical Coverage: Information concerning atomic and molecular processes; specifically, (1) heavy particle interactions, (2) particle interactions with electric and magnetic fields, and (3) particle penetration into matter; also, atomic and molecular structure, and transport phenomena in gases.

6-20 *ISOTOPES INFORMATION CENTER*

Technical Coverage: Isotope production, gaging radiography, process radiation, isotopes in biology and medicine, isotope power sources, isotope safety, isotope tracers, activation analysis.

6-21 *NFTIC, NUCLEAR FUEL TECHNOLOGY INFORMATION CENTER*

Technical Coverage: Metallurgy, metallography, ceramics technology, welding and brazing, nondestructive testing, irradiation testing, remote fabrication, reprocessing, economics.

6-22 *NUCLEAR SAFETY INFORMATION CENTER*

Technical Coverage: Containment of nuclear facilities; fission product release, transport and removal; meteorological considerations; nuclear instrumentation, control and safety systems; radioactive effluent control, monitoring, movement and dosage; reactor transients, kinetics and stability; operational safety and experience.

6-23 *RADIATION SHIELDING INFORMATION CENTER*

Technical Coverage: Shielding information related to radiation from reactors, weapons, and accelerators and radiation occurring in space.

6-24 *RARE EARTH INFORMATION CENTER*

Technical Coverage: Solid-state physics, physical and mechanical metallurgy of the rare-earth metals and their metallic and semi-metallic alloys.

6-25 *RESEARCH MATERIALS INFORMATION CENTER*

Technical Coverage: Optical properties, magnetic properties, electrical properties, crystal structure, physical properties, preparation methods, characterization methods, crystal growth.

(7) OTHER GOVERNMENT AGENCIES

7-1 *ALBANY METALLURGY RESEARCH CENTER*

Technical Coverage: Basic thermodynamic data on heat capacity, heat of formation, entropy, and other properties of metals and compounds. Specialized data on zirconium and hafnium

7-2 *BOULDER CITY METALLURGY RESEARCH LABORATORY*

Technical Coverage. Chemical metallurgy, pyrometallurgy, and electrometallurgy

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7-3 COLLEGE PARK METALLURGY RESEARCH CENTER

Technical Coverage: Corrosion resistance of high-purity metals and alloys. Metallurgy.

7-4 HIGH PRESSURE DATA CENTER

Technical Coverage: High-pressure research ($P > 1$ k bar).

7-5 INORGANIC MATERIALS DIVISION

Technical Coverage: Constants, properties, constitution and microstructure of nonmetallic inorganic substances including ceramics, glass, and refractories.

7-6 MATERIALS ADVISORY BOARD

Technical Coverage: Metallurgy and organic and inorganic metallic materials.

7-7 METALLURGY DIVISION

Technical Coverage: Structure and properties of metals (fatigue and fracture), creep, electrodeposited coatings, stress corrosion, phase transformations, crystal growth, alloy physics, diffusion, reactions at metal surfaces, and imperfections in metal crystals.

7-8 MINNEAPOLIS METALLURGY RESEARCH CENTER

Technical Coverage: Basic and applied research in mineral dressing, hydrometallurgy, pyrometallurgy, thermodynamics, and physical chemistry. New blast furnace techniques.

7-9 NATIONAL REFERRAL CENTER FOR SCIENCE AND TECHNOLOGY

Technical Coverage: All phases of scientific and technical information.

7-10 NATIONAL STANDARD REFERENCE DATA SYSTEM

Technical Coverage: Nuclear properties, atomic and molecular properties, thermodynamic and transport properties, solid-state, chemical kinetics, colloid and surface properties, and mechanical properties.

7-11 NORRIS METALLURGY RESEARCH LABORATORY

Technical Coverage: Pyrometallurgy, electrometallurgy, ceramics, and synthetic material preparation. Techniques for coating refractory metals, alloying and metal plating. Preparation and evaluation of pure metals.

7-12 RENO METALLURGY RESEARCH CENTER

Technical Coverage: Chemical metallurgy, pyrometallurgy, electrometallurgy, hydrometallurgy, and thermodynamics.

7-13 ROLLA METALLURGY RESEARCH CENTER

Technical Coverage: Mineral dressing, chemical metallurgy, electrometallurgy, and physical metallurgy. Properties and behavior of metals under a variety of conditions.

7-14 SALT LAKE CITY METALLURGY RESEARCH CENTER

Technical Coverage: Mineral dressing, hydrometallurgy and pyrometallurgy. Extraction and refining methods, alloying, and metal-plating processes.

7-15 TUCSON METALLURGY RESEARCH LABORATORY

Technical Coverage: Mineral dressing, pyrometallurgy, and hydrometallurgy.

7-16 TUSCALOOSA METALLURGY RESEARCH CENTER

Technical Coverage: Metallurgical research in thermodynamics, physical benefication, hydrometallurgy, pyrometallurgy, and extractive metallurgy.

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(8) INDUSTRIAL AND TRADE ASSOCIATIONS

8-1 *AMERICAN CERAMIC SOCIETY*

Technical Coverage: Ceramics, glass, refractories, porcelain enamels, cermets, composites, whitewares, structural clay products, chemistry, solid state physics, and instrumentation for high temperature reactions.

8-2 *ALLOY CASTING INSTITUTE*

Technical Coverage: Cast high alloys.

8-3 *AMERICAN WELDING SOCIETY*

Technical Coverage: Soldering, brazing, resistance welding.

8-4 *AMERICAN SOCIETY FOR METALS*

Technical Coverage: Scope ranges from ores and concentrates to heat treating and fabrication; from nonmetallic materials similar to metals in nature and properties to solid-state physics, mechanical engineering, electrical engineering, inorganic chemistry, and nuclear engineering as related to metals.

8-5 *AMERICAN ZINC INSTITUTE*

Technical Coverage: Technical and application engineering related to the zinc industry, galvanizing, die-casting, rolled zinc, zinc oxide, zinc chemicals, building construction, corrosion, cathodic protection, electric cells, toxicity, paints, pigments, plating, coating, alloys, and metallurgy.

8-6 *CHEMICAL ABSTRACTS SERVICE*

Technical Coverage: All aspects of chemistry, including chemical engineering.

8-7 *COBALT INFORMATION CENTER*

Technical Coverage: Metallurgy and chemistry of cobalt.

8-8 *COPPER DEVELOPMENT ASSOCIATION DATA CENTER*

Technical Coverage: Copper technology.

8-9 *FUEL CELL INFORMATION INDEX*

Technical Coverage: Fuel cell type, electrodes, electrolytes, fuels, application, theory, techniques, materials of construction, competitive systems.

8-10 *GIC, GERMANIUM INFORMATION CENTER*

Technical Coverage: Germanium: analytical techniques, batteries, detectors, glasses, thermometry, crystals, device development, electrochemical properties, thin films, infrared properties, inorganic chemistry, alloys, magnetic properties, radiation effects, surface phenomena, thermoelectric properties, optical properties, organic chemistry, piezoelectric properties.

8-11 *METAL POWDER INDUSTRIES FEDERATION--AMERICAN*

Technical Coverage: Powder metallurgy processes, products, and equipment; metal powders, magnetic cores, including iron powders and ferrites, chemical and pyrotechnic powders and metallic-paint pigments; and oil-impregnated bearings.

8-12 *NATIONAL RESEARCH CORPORATION*

Technical Coverage: Refractory metals, powder metallurgy, vacuum technology and equipment, ultrahigh vacuum, metal coating, vacuum fusion, space simulation, super-conductivity, and cryogenics

8-13 *NUCLEAR METALS INCORPORATED*

Technical Coverage: Nuclear technology, principally reactor engineering and technology, and high temperature materials and refractory metals, as well as related areas of chemistry and chemical engineering.

8-14 *PNEUMODYNAMICS CORPORATION*

Technical Coverage: Hydraulic and hydraulic-pneumatic shock absorption and mitigation, machining and processing of high-strength metals, flash butt welding of metals, and plastic wrapping and molding.

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8-15 *RESEARCH INSTITUTE UNIVERSITY OF DAYTON*

Technical Coverage: Adhesives, ceramics, cermets, graphites, coatings, elastomers, lubricants, electrical and electronic materials, fibrous materials, metals, oils, plastics, polymers, and manufacturing methods.

8-16 *REYNOLDS METALS COMPANY TECHNICAL INFORMATION CENTER*

Technical Coverage: Aluminum, aluminum alloys, alumina, bauxite, production, fabrication, uses, finishing, corrosion, metallurgy, castings, wrought products, packaging, printing, joining, forming, properties, natural resources, standards, and chemicals.

8-17 *SOCIETY FOR NONDESTRUCTIVE TESTING*

Technical Coverage: Techniques for the nondestructive testing of metals, ceramics, wood, plastics, and components.

8-18 *THE SOCIETY OF THE PLASTICS INDUSTRY*

Technical Coverage: Plastics.

8-19 *TIN RESEARCH INSTITUTE*

Technical Coverage: Tin technology, including: tinplate and terneplate, solders, bronze, white metal bearings, pewter, hot dipped tin coatings, electroplated coatings, collapsible tubes, and tin chemicals.

8-20 *TRANSDUCER INFORMATION CENTER*

Technical Coverage: Transducers, instrumentation, electronics, calibration, reliability, bioelectronics, strain gages.

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DATA SUBJECT INDEX

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EXAMPLES OF ENTRIES AND NOTATIONS IN THESAURUS OF TERMS

A. This is the main entry position for the descriptor, when in that position it appears in bold faced type.

B. UF-Used For. The descriptor at the main entry is to be used for any term listed under this notation. See E, where reciprocal entries are displayed.

C. The dagger (†) in front of a term signifies that two or more descriptors are to be used in coordination for that term. The term entry should be consulted to determine these descriptors. In this case Nitrile rubber has three USE descriptors (See L) while Polydiene resins, without a dagger, has only one (See M).

D. The dash (—) symbol in front of a descriptor indicates that the descriptor has narrower terms (not shown) and that the main entry should be consulted to determine these.

E. USE USE reference. It refers the user to the preferred descriptor or descriptors. USE and UF reciprocate throughout.

DESCRIPTOR ENTRY

DIENE RESINS 1109 1110

HOMOPOLYMERS AND COPOLYMERS

UF † Nitrile Rubber
Polydiene Resins
BT Addition Resins
NT ABS Resins
Butyl Resins
Chloroprene Resins
Polybutadiene
Polyisoprene
Styrenebutadiene Resin
RT — Thermoplastic Resins
Thermosetting Resins

COORDINATE USE REFERENCE ENTRY

NITRILE RUBBER
USE Acrylonitrile Copolymers
Diene Resins
Synthetic Elastomers

SINGLE USE REFERENCE ENTRY

POLYDIENE RESINS
USE Diene Resins

F. The four digit numbers following each descriptor at its main entry indicate the Subject Category Fields (first two digits) and Groups (last two digits). Consult the Subject Category Index.

G. Scope Note. Used only when some clarification as to the descriptor's meaning may be needed.

H. These terms are USE references, not descriptors. They will appear as main entries in bold faced italics (See E).

I. BT=Broader Term. Descriptors under this notation represent a generically broader class which includes the main entry descriptor as a lesser term.

J. NT=Narrower Terms. The reciprocal of I. above.

K. Related terms are not considered as belonging in the same generic class as the main entry descriptor; but as having close association or relationship to it.

L. All descriptors shown under USE should be used in coordination to represent the entry; both for indexing and searching. (This multiple USE situation occurs relatively few times.)

M. The single USE reference is the more common situation. One descriptor is used for one USE reference term.

FIGURE A-1. Illustrations of DOD Thesaurus of Engineering and Scientific Terms

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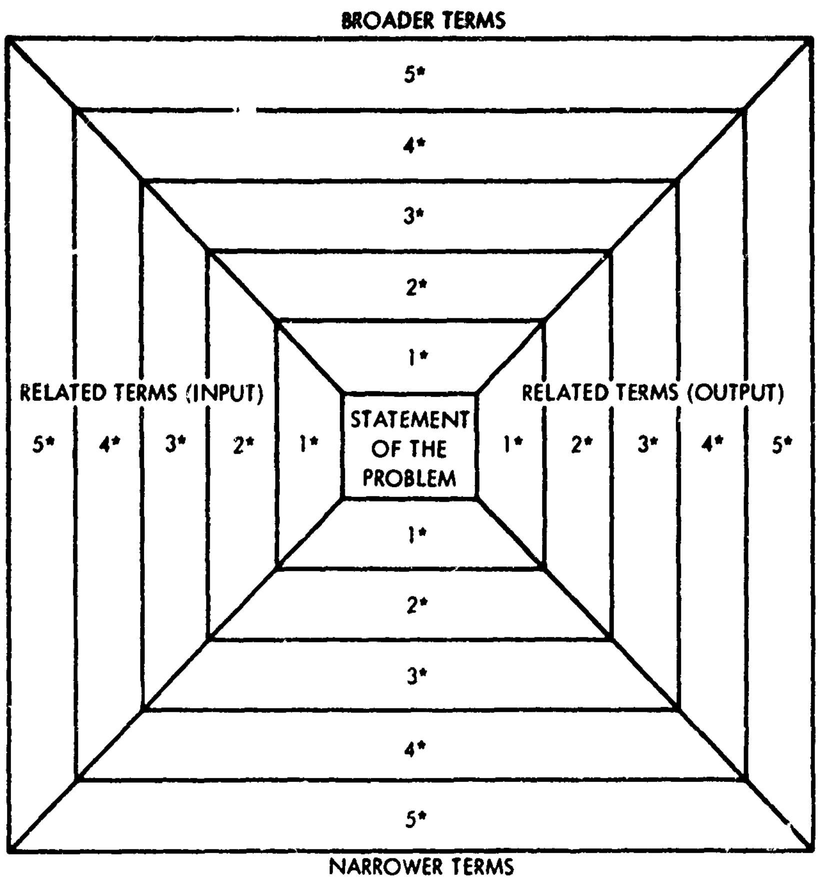

* TERMS ARE RANKED BY APPARENT DEGREE OF RELATIONSHIP.

FIGURE A-2. Term Relationship Grid

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CATEGORY	REMARKS		USER'S GUIDES
TECHNICAL BOOKS	INCLUDES:	Encyclopedias Handbooks Directories Bibliographies	Classification system Library card catalogs Publisher's Trade List Annual Books in Print Subject Guide to Books in Print Dissertation Abstracts American Scientific Books
JOURNALS AND PERIODICALS	INCLUDES:	Magazines Proceedings Transactions	Reader's Guide to Periodical Literature (general) Engineering Index Applied Science and Technology Index Proceedings in Print Air University Library Index
TECHNICAL REPORTS (DOCUMENTS)	SOURCES:	Department of Defense NASA AEC Other Federal Agencies Industrial & Commercial	U.S. Government Research & Development Reports Technical Abstract Bulletin (U), bulletins confidential Scientific and Technical Aerospace Reports (STAR) Nuclear Science Abstracts U. S. Government Research & Development Reports Consult sources indicated under REMARKS.
OTHER MATERIALS	INCLUDES:	Specifications and Standards Trade Catalogs Government pamphlets and related material	NASA Specifications and Standards (NASA SP-9000) Department of Defense Index of Specifications and Standards Index of Federal Specifications and Standards Catalog of American Standards Chemical Engineering Catalog (CEC) Chemical Materials Catalog (CMC) Electronic Engineers Master Catalog (EEM) Mechanical Engineers Catalog Sweets Catalogs: Architecture, Product Design, Industrial Construction, Plant Engineering, Light Construction, Metalworking Equipment Thomas Register of American Manufacturers. Monthly catalog of United States Government Publications

FIGURE A-3. Basic Categories of Published Technical Information and Associated Guides to Use

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General Outline

LIBRARY OF CONGRESS		DEWEY DECIMAL	
A	General Works. Polygraphy	000	General Works
B-BJ	Philosophy	100	Philosophy
BL-BX	Religion	200	Religion
C	Auxiliary Sciences to History	300	Social Science
D	Universal and Old World History	400	Language
E-F	American History	500	Pure Science
G	Geology, Anthropology, Folklore, etc.	600	Technology
H	General Social Science	700	The Arts
HA	Statistics	800	Literature
HB-HJ	Economics	900	History
HM-HX	Sociology		
J	Political Science		
K	Law		
L	Education		
M	Music		
N	Fine Arts		
P	Language and Literature		
Q	Science		
R	Medicine		
S	Agriculture		
T	Technology		
U	Military Science		
V	Naval Science		
Z	Bibliography and Library Science		

Science

LIBRARY OF CONGRESS		DEWEY DECIMAL	
Q	General Science	500	Pure Science
QA	Mathematics	510	Mathematics
QB	Astronomy	520	Astronomy
QC	Physics	530	Physics
QD	Chemistry	540	Chemistry
QE	Geology	550	Geology
QH	Natural History, General Biology	560	Paleontology
QK	Botany	570	Biology, Anthropology
QL	Zoology	580	Botany
QM	Human Anatomy	590	Zoology
QP	Human Physiology		
QR	Bacteriology, Microbiology		

Technology

LIBRARY OF CONGRESS		DEWEY DECIMAL	
T	Technology	600	Technology
TA	Engineering and Building, General	610	Medical Sciences
TC	Hydraulic Engineering, Harbors, Rivers, Canals.	620	Engineering
		630	Agriculture
TD	Sanitary and Municipal Engineering	640	Home Economics
TE	Roads and Pavements	650	Business
TF	Railroad Engineering and Operation	660	Chemical Technology
TG	Bridge and Roof Engineering	670	Manufacturers
TH	Building. Fire Prevention and Extinction.	680	Other Manufacturers
TJ	Mechanical Engineering	690	Building Construction
TK	Electrical Engineering and Industries. Electronics. Atomic Power		
TL	Motor Vehicles. Cycles. Aeronautics		
TN	Mining Engineering. Mineral Industries		
TP	Chemical Technology		
TR	Photography		
TS	Manufacturers		
TT	Mechanic Trades, Arts and Crafts		
TX	Domestic Science		

FIGURE A-4. Summary of Library of Congress and Dewey Decimal Classification Systems

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A-3.4 ABSTRACTING AND INDEXING SERVICES

The keys to the world's published literature of science and technology are the bibliographical services which, through their abstracting and indexing publication, aid in the documentation of the journal literature, making it readily available to all scientists and engineers. These services are described in *A Guide to the World's Abstracting and Indexing Services in Science and Technology*[12]. Included are "bulletins, journals, card services, and fiches issued by an association, Government agency, library, professional society technical organization, or commercial body and containing abstracts and/or references to currently published scientific and technical literature in the form of periodical articles, pamphlets, books, patents, technical reports, and related materials".

A-3.5 SCIENTIFIC AND TECHNICAL ORGANIZATIONS

Scientific societies and associations play a vital role in the dissemination of scientific and technological information. Every scientific discipline has at least one society devoted to its interest. The functions of these societies are to bring their members together in conventions, conferences, seminars, and symposia to discuss advances in their fields, and to publish journals that disseminate information on advancement in their field.

Army scientific and technical people are usually active members of the societies in their disciplines. They attend society meetings and receive society journals. Their active role is supplemented by the cooperation of the learned societies, many to consider research problems or to evaluate proposals for new systems.

Solutions to Army problems frequently emerge from research in disciplines other than those to which the problem appears most directly related. Because of this, it may prove beneficial to hold membership not only in the society of one's own discipline, but also in those of related specialties.

Details concerning these scientific and technical organizations may be found in *The Encyclopedia of Associations*[13] and *International Scientific Organizations*[14].

A-3.6 TRADE, BUSINESS, AND COMMERCIAL ORGANIZATIONS

Many of these organizations sponsor committees and task groups to work with DOD agencies in the establishment of standards and specifications or to resolve standing problems in DOD-industry working relationships, terminology, or procedure. Many also operate informational services from which general or specific answers to problems may be sought.

While professional association membership is generally individual, that in trade, business, and commercial organizations is usually corporate. Nevertheless, these associations are also dedicated to the objective of dissemination of information.

Details of these trade, business and commercial organizations may be found in *The Encyclopedia of Associations*[13] and *International Scientific Organizations*[14].

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REFERENCES

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2. DA Pam 70-1, *User's Guide to Technical Library Services*, April 1967.

3. *Reader's Guide to Periodical Literature*, H. W. Wilson Co., Bronx, N.Y., 1900. (Published semi-monthly; annual cumulation.)

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5. *Applied Science and Technology Index*, H. W. Wilson Co., Bronx, N.Y., 1958. (Issued monthly; quarterly cumulation; annual cumulation.) (Supersedes *Industrial Arts Index*, 1913-1957.)

6. *Ulrich's International Periodicals Directory*, R. R. Bowker Co., New York, N.Y., 12th Ed., 1967. Vol. I, *Scientific, Technical and Medical;* Vol. II, *Arts, Humanities, Business, and Social Sciences.*

7. *Reliability and Maintainability Data-Source Guide*, System Effectiveness Branch, Electronics Division, U.S. Naval Applied Science Laboratory, Brooklyn, N.Y., 1967. (AD-659 195)

8. *Directory of Selected Specialized Information Services, Ad-Hoc Forum of Scientific and Technical Information Analysis Center Manager, Directors, and Professional Analysts held at Batelle Memorial Institute, Columbus, Ohio, November 9-11, 1965.* (USAEC, Division of Technical Information, CONF-651131 (App.)).

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10. Anthony Kruzas, Ed., *Directory of Special Libraries and Information Centers*, Gale Research Co., Detroit, Mich., 2d Ed., 1968.

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APPENDIX B

THE DESIGN ENVIRONMENT

B-1 INTRODUCTION

Army materiel is influenced by the principal environments of design, production, and use. From a producibility standpoint, the use and logistic environments are synonymous. Within each environmental situation, specifics will differ, depending on various factors such as commodity; complexity; development and production schedules; usage time frame; and strategic, tactical, and support factors. Nevertheless, each of the three environments includes many factors of influence which will repetitively occur.

B-2 DESIGN ENVIRONMENT GENERIC TREES

This appendix provides a series of generic trees, or road maps, which describe the main elements of the design environment, together with the constituent elements of each (see Figs. B-1 through B-6). These are followed by a bibliography of references to source material which will assist in securing information necessary to achieve effective performance within the design environment.

B-3 BIBLIOGRAPHY

B-3.1 SYSTEM DESCRIPTION

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3. American Society of Tool and Manufacturing Engineers, *Manufacturing, Planning, and Estimating Handbook*, McGraw-Hill Book Co., N.Y., 1963.
4. American Society of Tool and Manufacturing Engineers, *Tool Engineers Handbook*, McGraw-Hill Book Co., N.Y., 2d Edition, 1959.
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12. G. B. Carson, *Production Handbook*, Ronald Press Co., N.Y., 2d Edition, 1958.
13. W. E. Clason, *Electrotechnical Dictionary*, American Elsevier Publishing Co., N.Y., 1964.
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17. Samuel Eilon, *Elements of Production Planning and Control*, The Free Press, N.Y., 1962.
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DEVELOPMENT

- SYSTEM DESCRIPTION
  Fig. B-2
- PROGRAM PLAN
  Fig. B-3
- PROPERTIES OF MATERIALS
  - Mechanical
    Fig. B-4
  - Physical
    Fig. B-5
  - Chemical, Corrosive, and Thermodynamic
    Fig. B-6
- PRODUCTION ENVIRONMENT
  Fig. C-1
- LOGISTIC ENVIRONMENT
  Fig. D-1

DEVELOPMENT

FIGURE B-1. Development Environment Generic Trees

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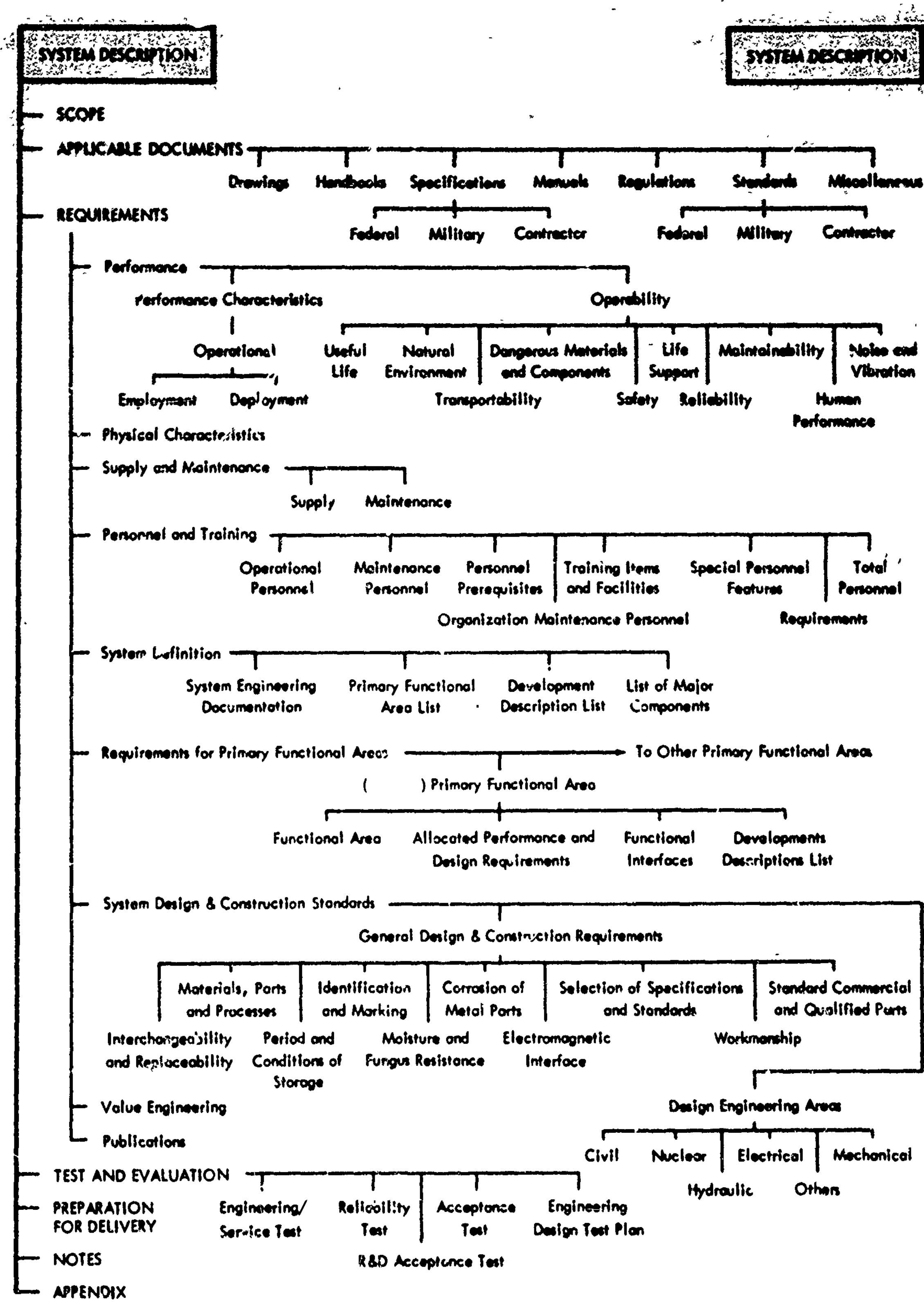

FIGURE B-2. System Description Tree

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B-3.1.1 SCOPE

ARMY REGULATIONS

70-17	System/Project/Management
70-36	Space System Research and Development
120-10	Nonindustrial Facilities for Mobilization
310-4	Military Publications: Index of Technical Manuals, Technical Bulletins, Supply Manuals (Types 7, 8, and 9), Supply Bulletins, Lubrication Orders, and Modification Work Orders
415-20	Design Approval
700-35	Product Improvement of Materiel
715-7	Advance Validation of Technical Data Required for DSA Procurement
795-19	Functions and Responsibilities of International Logistics and Activities

DA PAMPHLETS

1-51	Management Analysis in the Department of the Army

AMC REGULATIONS

70-18	AMC Engineering Design Handbook
705-13	Inertial Systems/Components Development

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AMC PAMPHLETS

705-1, Vol. 1	Principles and Philosophy
705-1, Vol. 2	Objectives for Technology
705-2	Planning A Guide for Estimating Development Cycle Administrative Leadtime
706-108	Elements of Armament Engineering, Part Three, Weapon Systems and Components
706-136	Servomechanisms, Section 1, Theory
706-137	Servomechanisms, Section 2, Measurement and Signal Converters
706-215(C)	Fuzes, Proximity, Electrical, Part Five (U)
706-242	Design for Control of Projectile Flight Characteristics

B-3.1.2 APPLICABLE DOCUMENTS

MILITARY STANDARDS

MIL-STD-100	Engineering Drawing Practices
MIL-STD-105	Sampling Procedures and Tables for Inspection by Attributes
MIL-STD-109	Quality Assurance Terms and Definitions
MIL-STD-120	Gage Inspection
MIL-STD-252	Wired Equipment, Classification of Visual and Mechanical Defects
MIL-STD-414	Sampling Procedures and Tables for Inspection by Variables for Percent Defective
MIL-STD-454	Standard Requirements for Electronic Equipment

MILITARY SPECIFICATIONS

MIL-D-1000	Drawing, Engineering and Associated Lists
MIL-S-6872	Soldering Process, General Specification for
MIL-Q-9858	Quality Program Requirements
MIL-I-45208	Inspection System Requirements
MIL-I-45607	Inspection Equipment, Supply and Maintenance for Ordnance
MIL-S-45743	Soldering, Manual Type, High Reliability, Electrical Connections for Missile Systems, Procedures for

MILITARY HANDBOOKS

H-50	Evaluation of a Contractor's Quality Program
MIL-HDBK-52	Evaluation of Contractor's Calibration System
H-53	Guide for Sampling Inspection
H-106	Multi-level Continuous Sampling Procedures and Tables for Inspection by Attributes
H-107	Inspection and Quality Control, Single Level Continuous Sampling Procedures and Tables for Inspection by Attributes
H-109	Quality Control and Reliability, Statistical Procedures for Determining Validity of Suppliers' Attributes Inspection

DA PAMPHLETS

310-35	Index of International Standardization Agreements
325-5	Federal Statistical Standards

ARMY REGULATIONS

70-22	Centers for Analysis of Scientific and Technical Information

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335-5	Standard Computation of Rates
420-16	Technical Data Report (Reports Control Symbol ENG-94(R5))
700-47	Defense Standardization Program
700-75	Use of Metric Units of Measurement in United States Army Weapons
700-76	International Standards for Length and Mass
715-10	Standardization, Policies, Procedures, and Instructions (Also identified as Defense Standardization Manual 4120.3-M (formerly DMS-200))
750-42	Distribution of Technical Data for Maintenance Support of Aircraft Systems and Related Equipment

AMC REGULATIONS

18-5, Vols. 1-5	Methods and Standards
18-5, Vol. 6	Methods and Standards-Systems Analysis and Design Change 1
70-33	Airworthiness Qualifications of U.S. Army Aircraft Systems
105-85	Joint Policy for Single Service Testing of Communications Electronic Test Equipment
310-6	Quality Assurance Publications
700-6	Quality Assurance System
700-34	Release of End Items for Issue
700-40	Area Standardization of Army Equipment
702-1	Guide for Expanding and Sustaining the Zero Defects Concepts
70-43	Technical Channels for ARPA Orders
70-51	USAMC System of Type Designations for Development and Adapted Items of Materiel
715-16	Defense Materiels System
715-33	AMC Production — Base Support Program
715-35	Military Urgency Determinations
715-73	U.S. Army Materiel Command Industrial Readiness Assurance Program

OTHER

ASPR	Armed Services Procurement Regulation
DCAS	Purchased Material Quality Inspection Manual
DODD 4155.11	Improved Management for Quality and Reliability Assurance of Material
DSAM 4135.3	Evaluation of Contractor's Inspection System
DSAM 8200.1	Procurement Quality Assurance Manual
DSAR 8205.1	Preparation and Distribution of Material Inspection and Receiving Reports

B-3.1.3 REQUIREMENTS

AMC REGULATIONS

70-14	Processing Qualitative Materiel Requirements, Small Development Requirements, and Qualitative Materiel Development Objectives

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70-28	Systems Analysis
70-30	Concept Formulation, Prerequisites to Initiating Engineering or Operating Systems Development Effort

B-3.1.3.1 RELIABILITY

MILITARY STANDARDS

MIL-STD-690	Life Testing Sampling Procedure for Establishing Levels of Reliability and Confidence in Electronic Parts and Specifications
MIL-STD-721	Definitions of Terms for Reliability Engineering
MIL-STD-756	Procedure for Prediction and Reporting Prediction of Reliability of Weapon Systems
MIL-STD-757	Reliability Evaluation from Demonstration Area
MIL-STD-781	Reliability Tests Exponential Distribution
MIL-STD-785	Requirements for Reliability Program for Systems and Equipment
MIL-STD-790	Reliability Assurance Program for Electronic Parts Specifications
MIL-STD-839	Parts with Established Reliability Levels, Selection and Use of
MIL-STD-1304	Reliability Reports

MILITARY SPECIFICATIONS

MIL-R-22732	Reliability Requirements for Shipboard and Ground Electronic Equipment
MIL-R-22973	Reliability Index Determination for Avionic Equipment Models, General Specification for
MIL-R-38100	Reliability and Quality Assurance Requirements for Established Reliability Parts, General Specification for

ARMY REGULATIONS

705-50 Suppl. 1	Army Materiel Reliability and Maintainability

OTHER

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Downloaded from http://www.everyspec.com

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B-3.1.3.2 MAINTAINABILITY

MILITARY STANDARDS

MIL-STD-280	Definitions of Terms for Equipment Divisions
MIL-STD-470	Maintainability Requirements for Systems and Equipment
MIL-STD-471	Maintainability Demonstration
MIL-STD-721	Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors, and Safety

MILITARY HANDBOOKS

MIL-HDBK-472	Maintainability Prediction

ARMY REGULATIONS

705-26	Maintainability Program for Materiel and Equipment
750-6	Maintenance Planning Allocation and Coordination

AMC REGULATIONS

700-60	Maintainability Program for AMC Materiel
750-6	Maintenance Engineering Objectives
750-7	Depot Maintenance Pilot Overhaul and Recondition Testing
750-15	Maintenance Support Planning
750-17	Serviceability and Maintenance Standards
750-33	Economic Evaluation of Maintenance Support Alternatives

AMC PAMPHLETS

706-134	Maintainability Guide for Design

OTHER

USA OMC	Maintainability Design Factors
T.O. 00-20 Series	Supplements to AFM 66-1, Maintenance Management

B-3.1.3.3 HUMAN PERFORMANCE

MILITARY STANDARDS

MIL-STD-1472	Human Engineering Design Criteria for Military Systems, Equipment and Facilities

MILITARY SPECIFICATIONS

MIL-H-22174	Human Factors Data for Aircraft and Missile Systems
MIL-H-24148	Human Engineering Requirements for Bureau of Ships-Systems and Equipment
MIL-D-26239	Data, Qualitative and Quantitative Personnel Requirements Information

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MIL-H-27894	Human Engineering Requirements for Aerospace Systems and Equipment
MIL-H-46819	Human Factors Engineering in Development of Missile Systems
MIL-H-46855	Human Engineering Requirements for Military Systems, Equipment, and Facilities

ARMY REGULATIONS

70-8	Human Factors and Social Sciences Research
602-1 Suppl. 1	Human Factors Engineering Program

AMC REGULATIONS

10-4	Mission and Functions of the Human Engineering Laboratories, Aberdeen Proving Ground, Md.

OTHER

HEL Standard S-1-63	Maximum Noise Level for Army Materiel Command Equipment
HEL Standard S-2-64	Human Factors Engineering Design Standard for Vehicle Fighting Compartments
HEL Standard S-3-65	Human Factors Engineering Design Standard for Missile Systems and Related Equipment
HEL Standard S-4-65	Human Factors Engineering Requirements for the Development of U. S. Army Materiel
TM 11	Report of Preliminary Observations of Human Engineering Problems under Desert Conditions
TM 20	Visual Efficiency under Desert Conditions
TM 21-62	Manual of Standard Practice for Human Factors in Vehicle Design

B-3.1.3.4 SAFETY

MILITARY SPECIFICATIONS

MIL-A-19531	Aircraft Maintenance and Engineering Inspection Requirements
MIL-S-23069	Safety Requirements, Minimum, for Air Launched Guided Missiles
MIL-S-38130	Safety Engineering of Systems and Associated Subsystems and Equipment

ARMY REGULATIONS

385-10	Army Safety Program
385-25	Studies and Reviews, Nuclear Weapon Systems Operational Surety Program
385-30	Safety Color Code Markings and Signs
385-80	Nuclear Reactor Systems Health and Safety

AMC REGULATIONS

10-18	Mission and Functions of U.S. Army Materiel Command Field Safety Agency
385-1	Safety Responsibilities
385-12	Verification of Safety of Materiel From Development Through Testing, Production, and Supply to Disposition
385-100	Safety Manual
385-225	Safety Requirements for Manufacturing and Processing Military Pyrotechnics
385-226	Safety Requirements for Manufacturing Nitroglycerin

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385-228 Safety Requirements for Manufacturing Small Arms Ammunition

385-102 Safety Regulations for Chemical Agents GB and VX

385-104 Safety Criteria for Processing, Handling and Decontamination

AMC PAMPHLETS

706-186 Military Pyrotechnics, Part Two, Safety, Procedures and Glossary

B-3.1.3.5 SUPPLY AND MAINTENANCE

ARMY REGULATIONS

11-14 Materiel Readiness

32-5 Introduction of New Clothing and Textile Items Into Department of Defense Supply System

700-16 Distribution Planning for Principal Items of Equipment Change 1

708-12 Federal Manual for Supply Cataloging, Chapter 2: Item Identification (Cataloging Manual M 1-2)

708-13 Federal Manual for Supply Cataloging, Chapter 3: Supply Classification (Cataloging Manual M 1-3)

708-14 Federal Manual for Supply Cataloging, Chapter 4: Operating Procedures (Cataloging Manual M 1-4)

708-16 Federal Manual for Supply Cataloging, Chapter 6: Operating Forms (Cataloging Manual M 1-6)

708-17 Federal Manual for Supply Cataloging Chapter 7: Format and Content of the Federal Supply Catalog, Department of Defense Section (Cataloging Manual M 1-7)

708-19 Federal Manual for Supply Cataloging, Chapter 9: Input and Output Codes (Cataloging Manual M 1-9)

750-1 Maintenance Concepts

750-6 Maintenance Support Planning

750-12 Cooperative Logistics Maintenance Support and Services Arrangements

795-25 Policies, Responsibilities, and Procedures for Supply Support Arrangements

AMC REGULATIONS

700-1 Designation of Army Class Manager Activities for DSA-/GSA-Assigned Items

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700-51 Petroleum and Chemical Responsibilities of Charleston, New Cumberland, and Sharpe Army Depots

701-10 Introduction of New Items into the DOD Supply System

750-6 Maintenance Engineering Objectives

750-15 Integrated Logistics Support

B-3.1.3.6 FUNCTIONAL INTERFACES

AMC REGULATIONS

700-21 Communications Equipment Installed in Vehicles at Army Depots and Manufacturer's Plants

B-3.1.3.7 ELECTRICAL

ARMY REGULATIONS

105-67 Reporting and Updating of Electromagnetic Data

705-19 Electrical System in Motor Vehicles

AMC REGULATIONS

705-6 Radio Frequency Allocations and Assignments

705-10(C) Quick Reaction Capability for Electronic Warfare (U)

B-3.1.3.8 ELECTROMAGNETIC INTERFERENCE

ARMY REGULATIONS

11-13 Army Electromagnetic Compatibility Program Changes 1-3

B-3.1.3.9 STANDARD COMMERCIAL AND QUALIFIED PARTS

AMC REGULATIONS

700-36 Use of Brand Name Products

B-3.1.3.10 M[illegible] [illegible]DUCTS, AND PRO[illegible]

MILITARY HANDBOOKS

MIL-HDBK-7 Lumber and Allied Products

H-8 Steel and Wrought Iron Products

MIL-HDBK-149 Rubber and Rubber-Like Materials

MIL-HDBK-203 Manufacturers Symbols and Designations for Anti-Friction Bearings

MIL-HDBK-212 Gasket Materials (Nonmetallic)

MIL-HDBK-223 Coded List of Materials

MIL-HDBK-691(MR) Adhesives

MIL-HDBK-692 Guide to Selection of Rubber O-Rings

MIL-HDBK-693(MR) Magnesium and Magnesium Alloy

MIL-HDBK-694A(MR) Aluminum and Aluminum Alloys

MIL-HDBK-697(MR) Titanium and Titanium Alloys

MIL-HDBK-698(MR) Copper and Copper Alloys

MIL-HDBK-700 Change 1 24 June 1966 Plastics

MIL-HDBK-723(MR) Steel and Iron Wrought Products

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AMC REGULATIONS

700-??	Manufacturing Methods and Technology Program
715-17	Availability of Strategic and Critical Materials in Government Inventory
715-43	Studies on Availabilities of Materials
715-44	Department of Defense Coded List of Materials

AMC PAMPHLETS

700-1	Machinery Data
706-331	Compensating Elements
706-340	Carriages and Mounts—General
706-341	Cradles
706-342	Recoil Systems
706-343	Top Carriages
706-344	Bottom Carriages
706-345	Equilibrators
706-346	Elevating Mechanisms
706-347	Traversing Mechanisms
706-355	The Automotive Assembly
706-356	Automotive Suspensions

B-3.1.3.11 PERIOD AND CONDITIONS OF STORAGE

ARMY REGULATIONS

740-12	Covered and Open Storage of Supplies
740-20	Preparation of Military Materiel for Shipment
740-22	Care of Supplies in Storage, Inspection, and Reporting
743-108	Storage and Handling of Cellulose Nitrate Film

AMC REGULATIONS

385-21	Determination of Ammunition and Explosives Characteristics That Influence Handling, Storage, and Transportation Criteria
700-52	Nuclear Weapon Maintenance and Storage Operations
740-8	Storage Modernization Plan

B-3.1.3.12 IDENTIFICATION AND MARKING

ARMY REGULATIONS

385-65	Identification of Inert Ammunition and Ammunition Components

B-3.1.3.13 SYSTEM DESIGN AND CONSTRUCTION STANDARDS—DESIGN ENGINEERING AREAS

ARMY REGULATIONS

70-38	Research, Development, Test and Evaluation of Materiel for Extreme Climatic Conditions
715-16	Engineer Functional Components System (Theater of Operations Construction Planning)
(0) 700-65	Nuclear Weapons and Nuclear Weapons Materiel

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AMC REGULATIONS

50-2	AMC Nuclear Weapons Surety Program
70-23	Research and Development Laboratory Notebooks
70-26	Electronic Warfare Research and Development for Army Missiles
70-32	Aeronautical Design Standards (ADS) for U.S. Army Aircraft Systems
70-34	Coordination of Research and Development of Electron Devices
105-1	Telecommunications Fixed Plant Requirements Planning Programming and Project Development
105-11	Nontactical Vehicular Radio Operations
705-1	AMC Nuclear Weapons Effect Research and Test Program Coordinating Committee
70-47	Radio Frequency Vulnerability of Nuclear Weapon Systems and Nuclear Munitions

B-3.1.4 VALUE ENGINEERING

MILITARY SPECIFICATIONS

MIL-V-21237	Value Engineering of Naval Ordnance Equipment
MIL-V-38352	Value Engineering Program Requirements
MIL-V-45201	Value Analysis of Ordnance Equipment
MIL-V-55051	Value Engineering of Signal Corps Equipment

ARMY REGULATIONS

11-8	Cost Reduction Program
11-20	Army Cost Reduction Program
11-25	Reduction of Lead Time
11-26	Value Engineering
5-11	Zero Defects Program
700-11	Reduction of Equipment Requirements
715-22	High Dollar Spare Parts Breakout Program

AMC REGULATIONS

11-[illegible]	AMC Cost Reduction Program

AMC PAMPHLETS

11-1	Value Analysis
11-3	Value Engineering Program Management Guidelines
11-4	AMC Cost Reduction Program Directory

OTHER

ASPR 1-1705	Value Engineering
ASDP 70-1	Guide to Value Engineering
DOD H-111	Value Engineering
DOD Inst. 5010.8	DOD Value Engineering Program (I&L)

B-3.1.5 TEST AND EVALUATION

ARMY REGULATIONS

70-10	Army Materiel Testing

AMC REGULATIONS

10-24	Mission and Major Functions of the U. S. Army Test and Evaluation Command

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11-4, Vol. 5	AMC Resource Management System Program Budgeting for Research, Development, Test, and Evaluation
70-7	Test and Evaluation of Materiel
420-19	Testing and Inspecting Unfired Pressure Vessels and Gas Compressors
700-6	AMC Quality Assurance System
700-9	Army Metrology and Calibration System
700-30	AMC Zero Defects Program
700-38	Test and Evaluation of Materiel – Correction of Defects Found During Materiel Life Cycle Testing
700-39	Steel Armor Plate for Testing Ammunition
702-1	Independent Product Assessment
702-2	Inspection Equipment Design, Supply, and Maintenance
702-4	Quality Assurance Provisions–Depot Maintenance and Supply Operations Nonhazardous Materiel
702-6	Product Quality Analysis and Liaison Operations
715-502	AMC Regulation on Inspection Equipment Testing and Calibration Operations
715-503	Sampling Procedures and Tables for Inspection by Variables with Separate Criteria on Mean and Variability
715-504	Acceptance Inspection Equipment Design Regulation for Materiel
715-505 (Vols. 3, 5, 8)	Test Procedures for Cartridges (7.62 mm, cal .45, and 20 mm)
750-25	Inspection, Testing, and Maintenance of Lifting Devices

B-3.1.6 PREPARATION FOR DELIVERY

ARMY REGULATIONS

740-17	Excessive Packaging
740-21	Preparation of Vehicles for Oversea Shipment
746-5	Color and Marking of Army Materiel

AMC REGULATIONS

700-18	Responsibilities for the Packaging of Army Materiel
746-2	Packing of Army Materiel

AMC PAMPHLETS

706-121	Packaging and Pack Engineering

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PROGRAM PLAN *

PROGRAM PLAN

- SYSTEM DESCRIPTION
- WORK BREAKDOWN STRUCTURES (Level 1, Sample Only)
  - System Test and Evaluation
    - Test Planning and Integration
    - Flight Simulation
    - Flight Test Program
  - System Integration
    - Operation Integration
    - Design Integration
    - Design Analysis and Support
    - Materials and Processes
    - Mockups
  - System Support
    - Logistics Support—General
    - Spares
    - Ground Support Equipment
    - Operational Facilities
    - Service Engineering
    - Data and Handbooks
    - Training and Training Equipment
  - System Major Assemblies
    - Airframe Structures
      - Fuselage
      - Wing
      - Landing Gear
      - Engine Installation
      - Nacelles
      - Empennage
    - Airframe Subsystem
      - Environmental Control
      - Electrical Power
      - Communications/Navigation
      - Flight Deck
      - Flight Controls and Hydraulics
      - Landing Gear
      - Starting
      - Cargo Accommodations
      - Fire Detection and Extinguishing
      - Accessory Drive
      - Engine Inlet Anti-Icing
      - Aircraft Integrated Data System (AIDS)
    - Propulsion System
      - Engine Coordination
      - Installed Performance
      - Exhaust/Thrust Reverser
      - Air Induction System
      - Propulsion Controls
      - Noise
      - Air Induction System
      - Installation
      - Fuel System
  - Quality Assurance
    - Reliability
    - Human Engineering
    - Configuration Management
    - Standardization
    - Logistic Management
    - Life Support
    - Value Engineering
    - Interface Management
    - Maintainability
    - Quality Control
      - Production
      - Design
    - Safety
  - Program Management
    - Program Management and Controls
    - Data Management
    - Facilities Plan
    - Economics
    - Cost Analysis

* See note following page

FIGURE B-3. Program Plan

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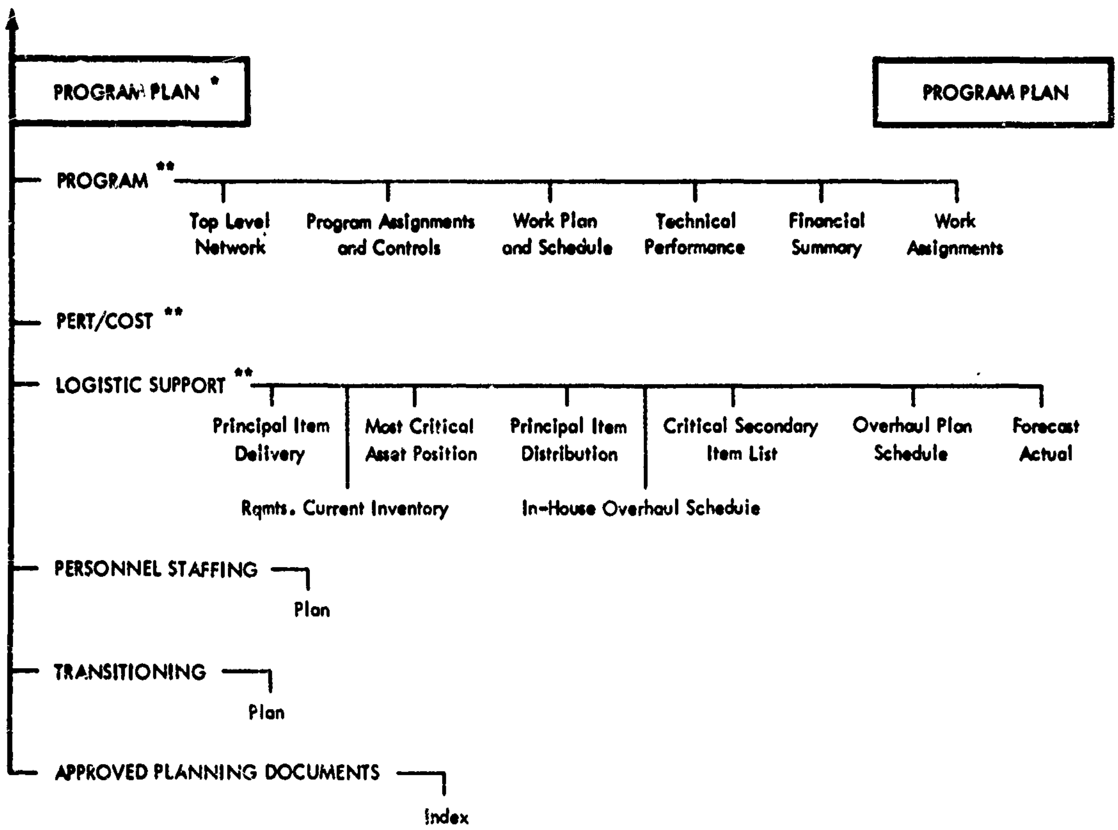

* Program Management Master Plan (PM_2P) For Major Programs

Other Plan Formats As Prescribed By AMC Or Individual Commands For Smaller Programs

**Lower Level Breakout Parallels And Extends Work Breakdown Structure

Figure B-3. Program Plan (Continued)

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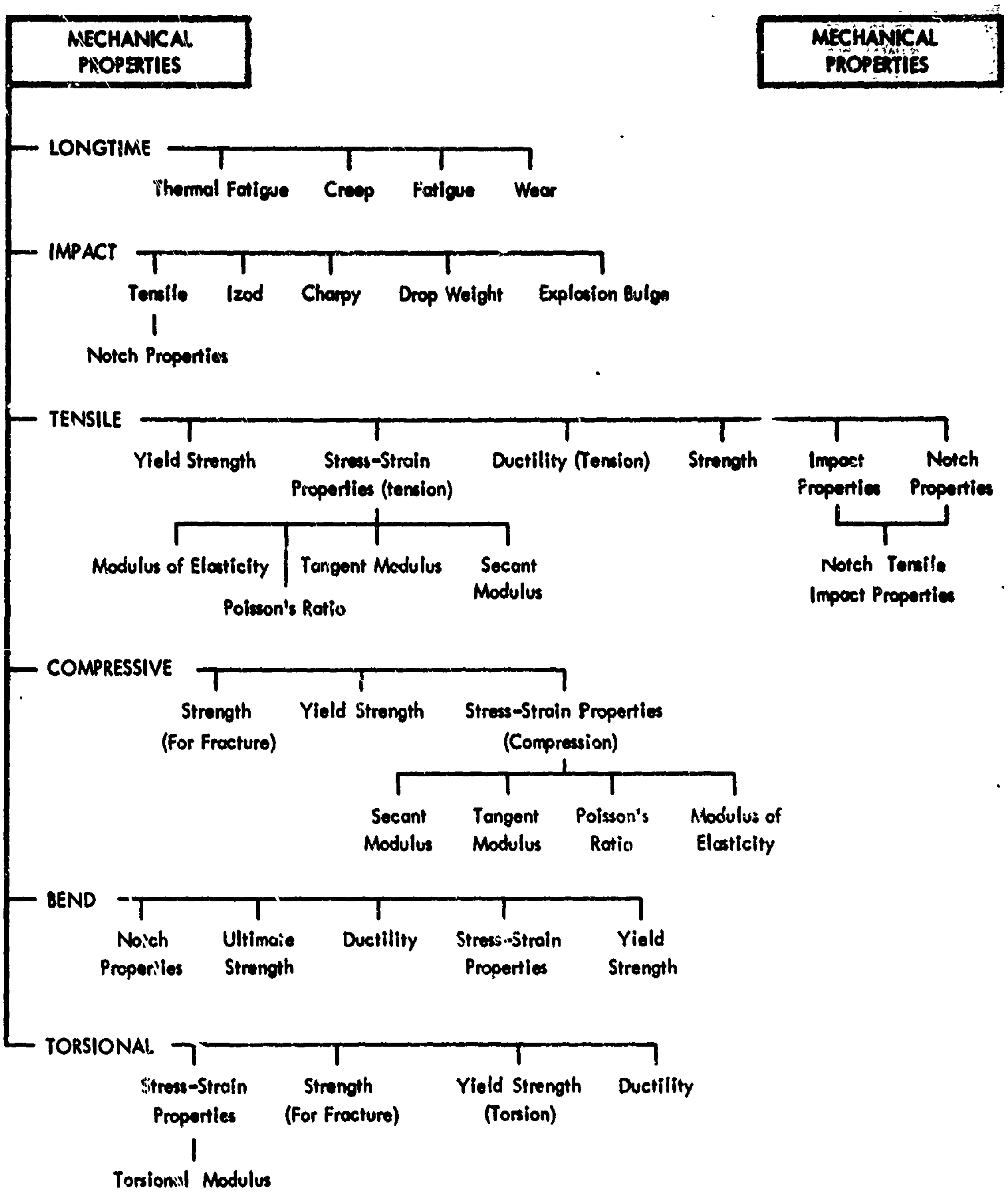

FIGURE B-4. Mechanical Properties

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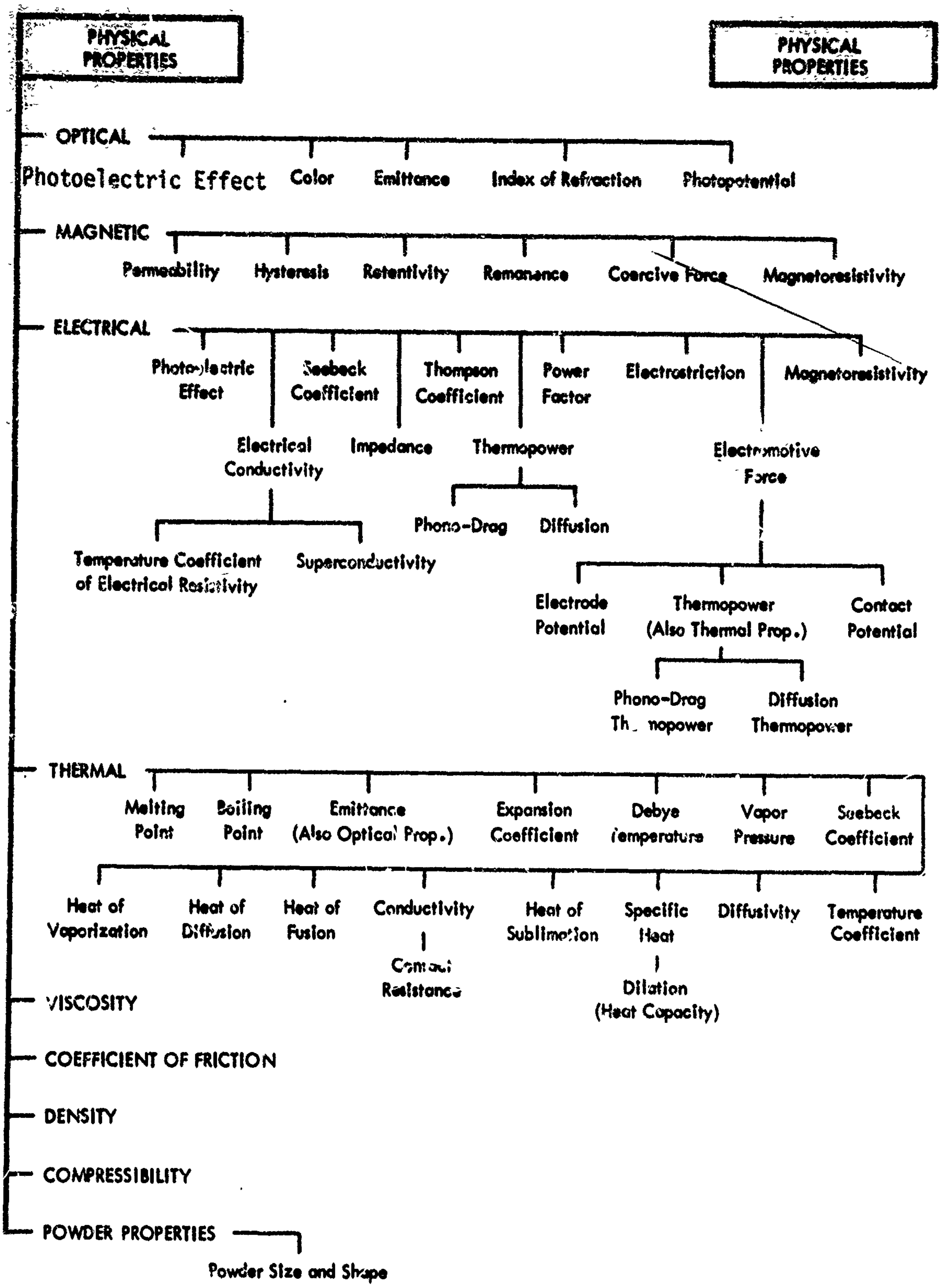

FIGURE B-5. Physical Properties

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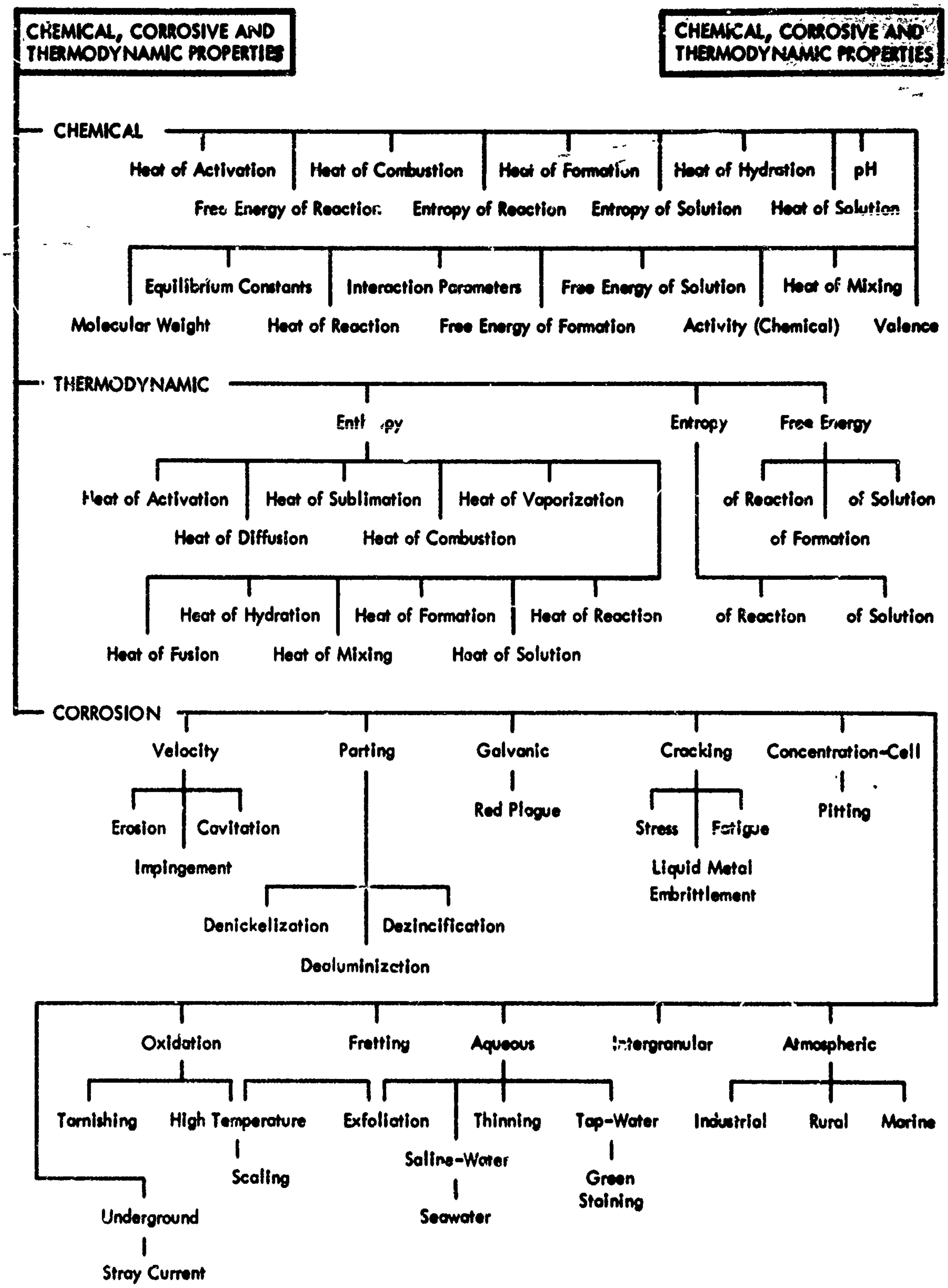

FIGURE B-6. Chemical, Corrosive, and Thermodynamic Properties

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APPENDIX C

THE PRODUCTION ENVIRONMENT

C-1 INTRODUCTION

Fig. B-1 identifies the production and logistic environments as being generic elements of the design environment. While these follow in chronological sequence, all necessary planning to accommodate their limitations and benefit from any advantages must be accomplished in the design phase; and the engineering product (the Technical Data Package) must fully reflect and implement this planning.

C-2 PRODUCTION ENVIRONMENT GENERIC TREES

Appendix C is organized to facilitate identification of requirements and potential problems as well as assist in the acquisition of necessary information. The generic trees (Figs. C-1 through C-14) are, themselves, informational and may frequently serve to alleviate the need for further information searches.

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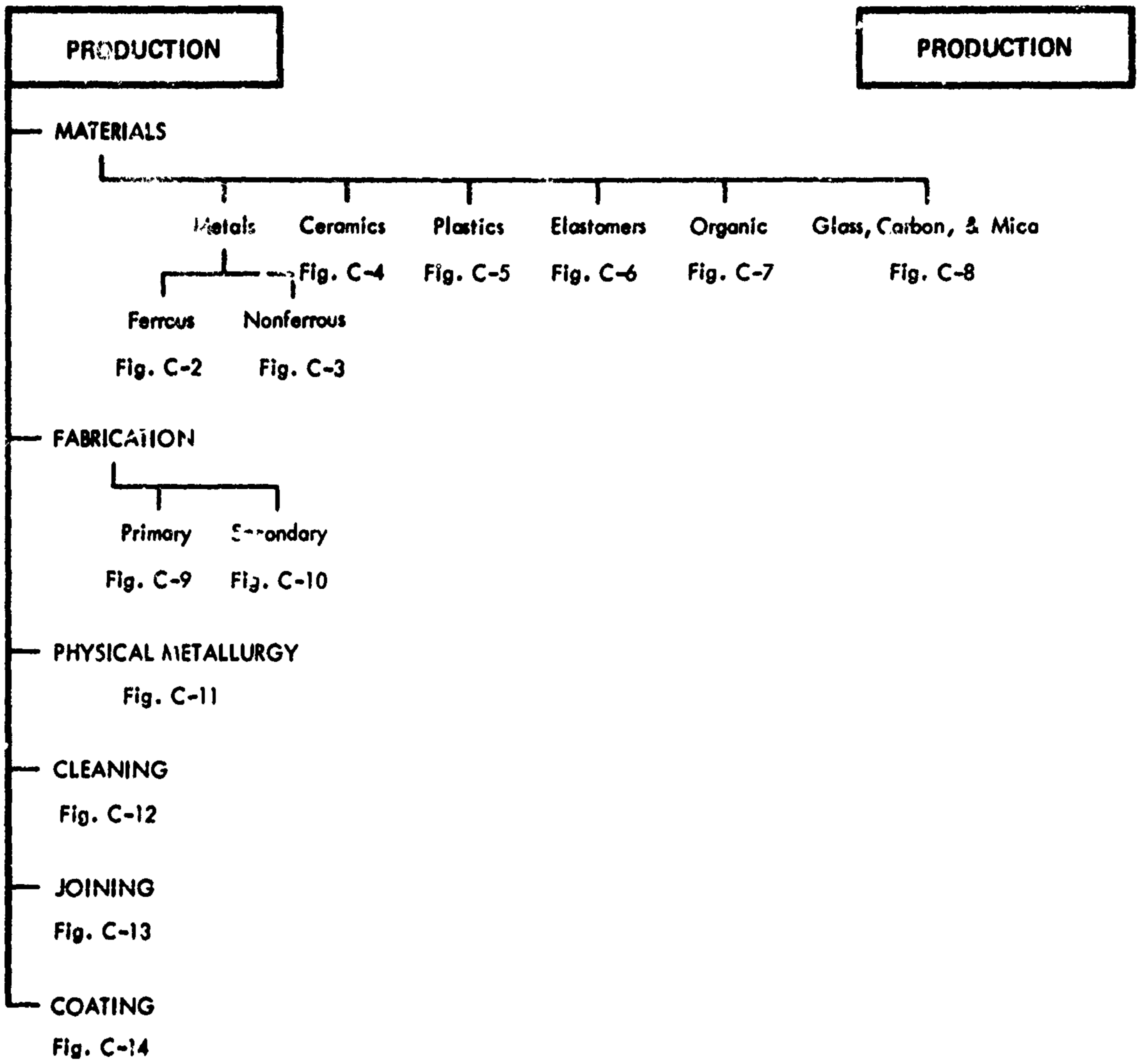

FIGURE C-1. Production Environment Generic Trees

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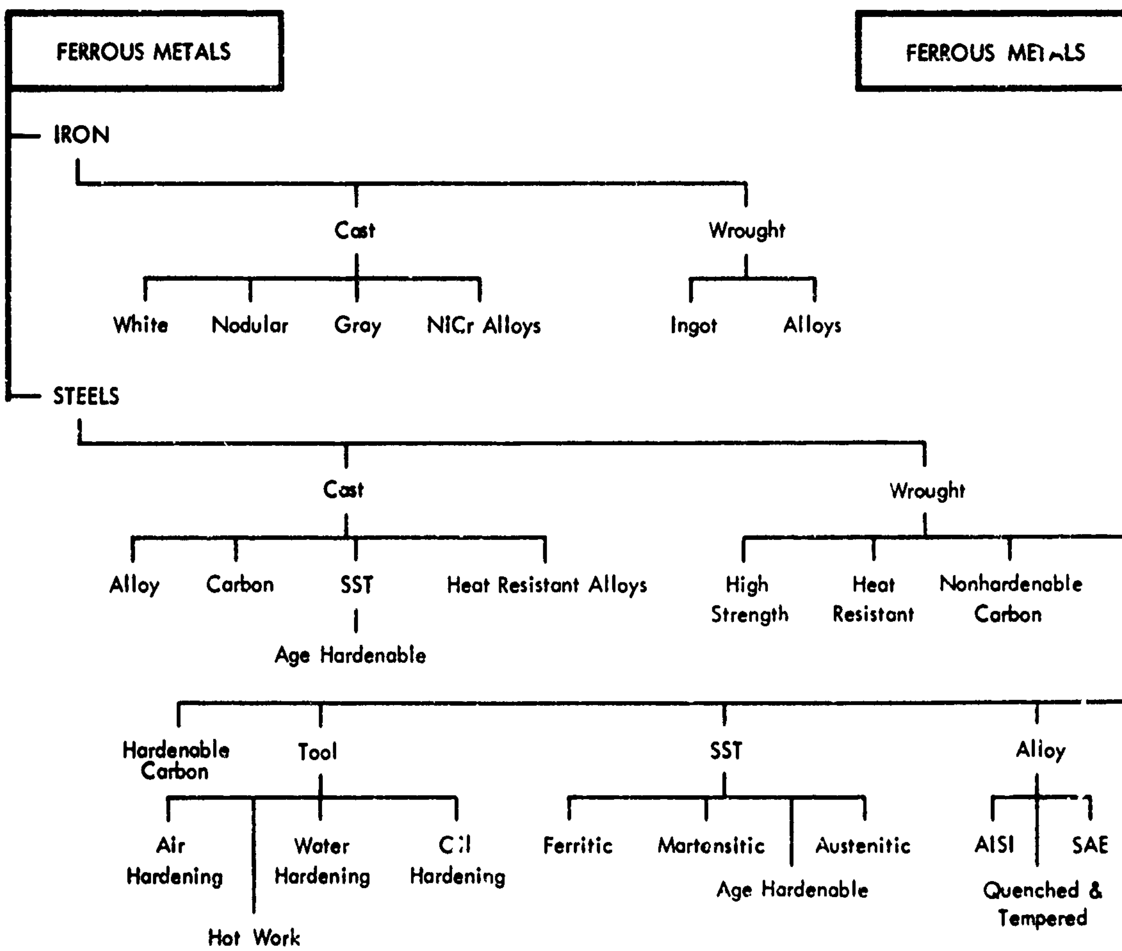

FIGURE C-2. Ferrous Metals

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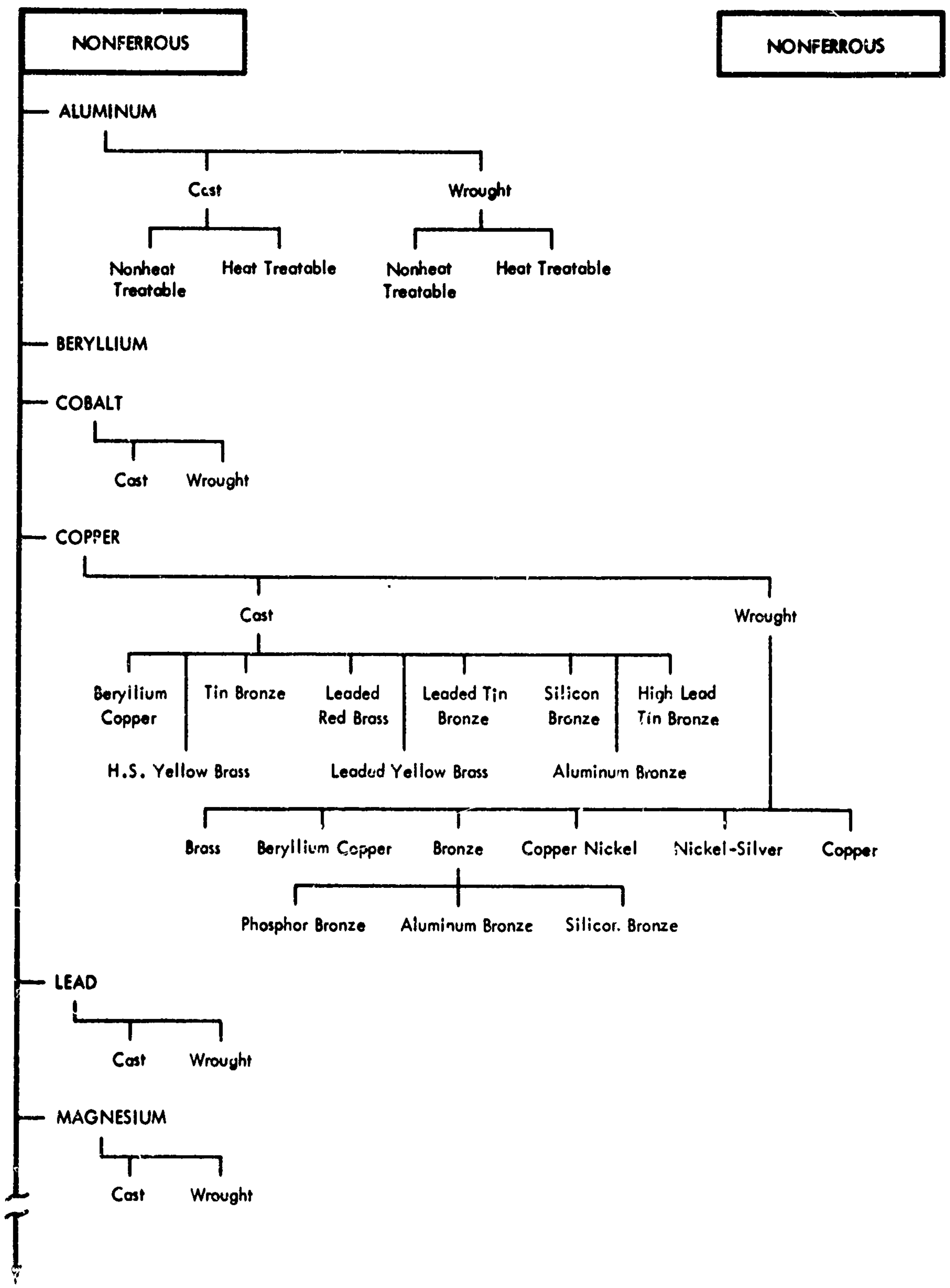

FIGURE C-3. Nonferrous Metals

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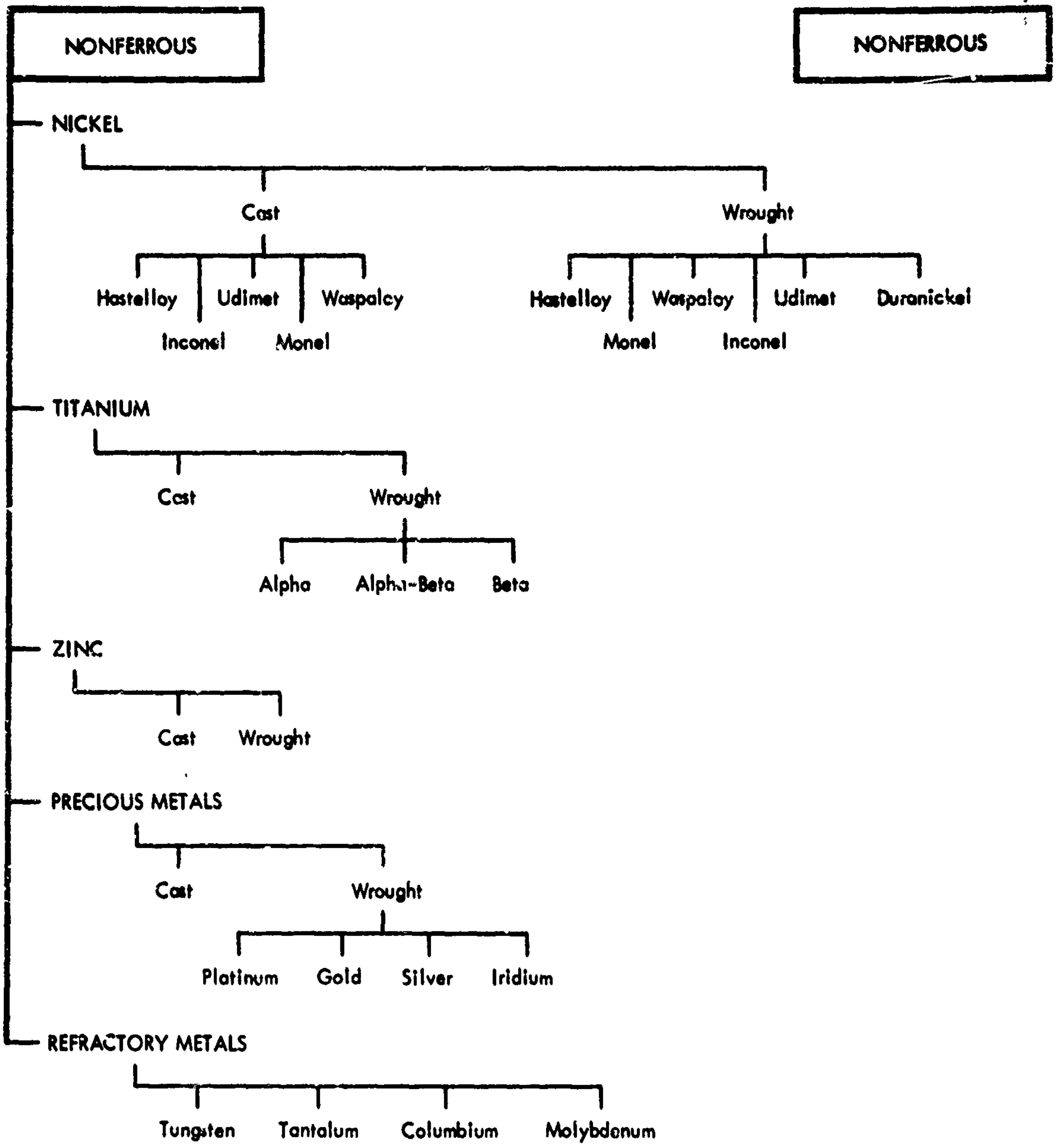

FIGURE C-3. Nonferrous Metals (Cont'd)

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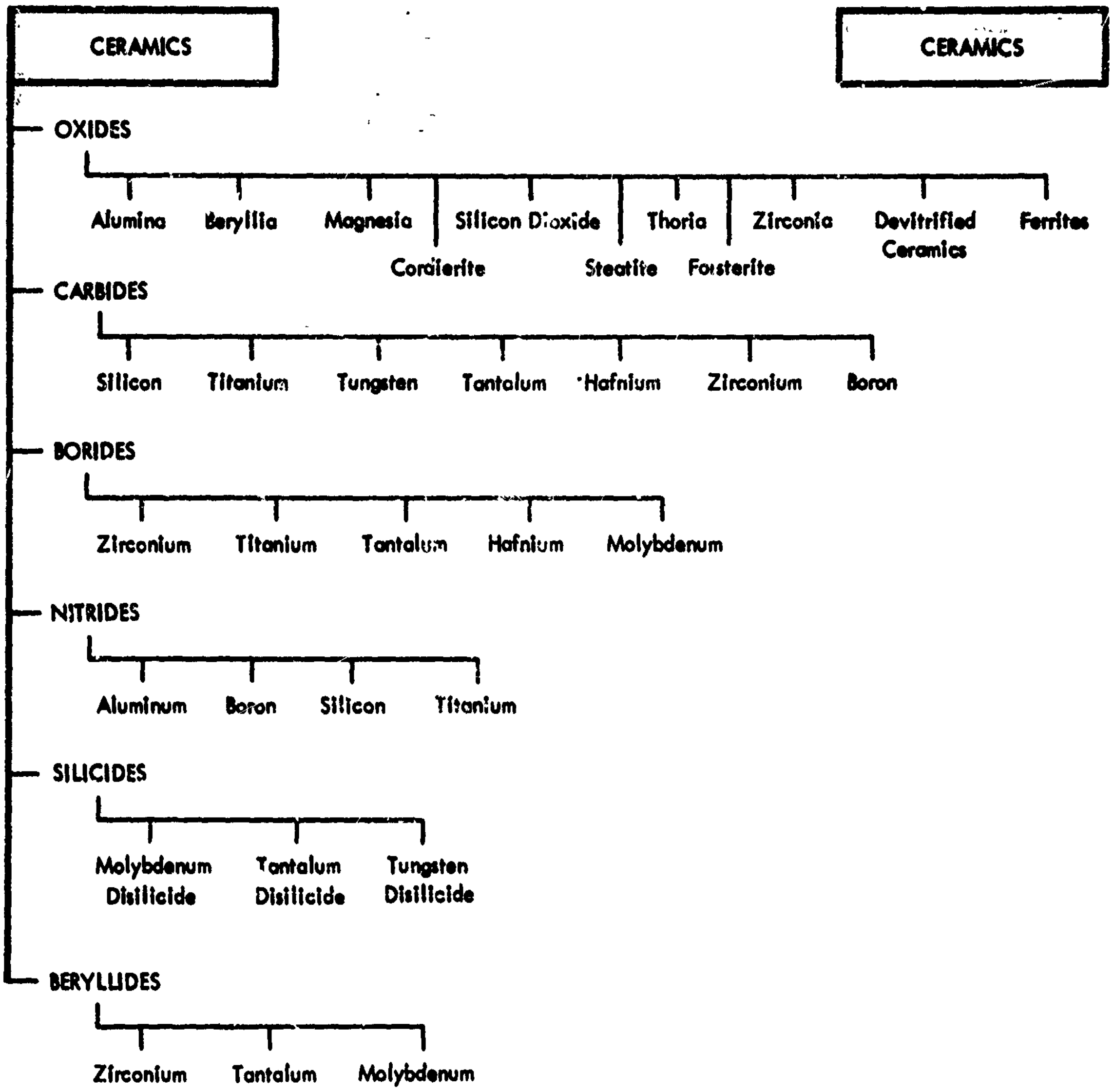

FIGURE C-4. Ceramics

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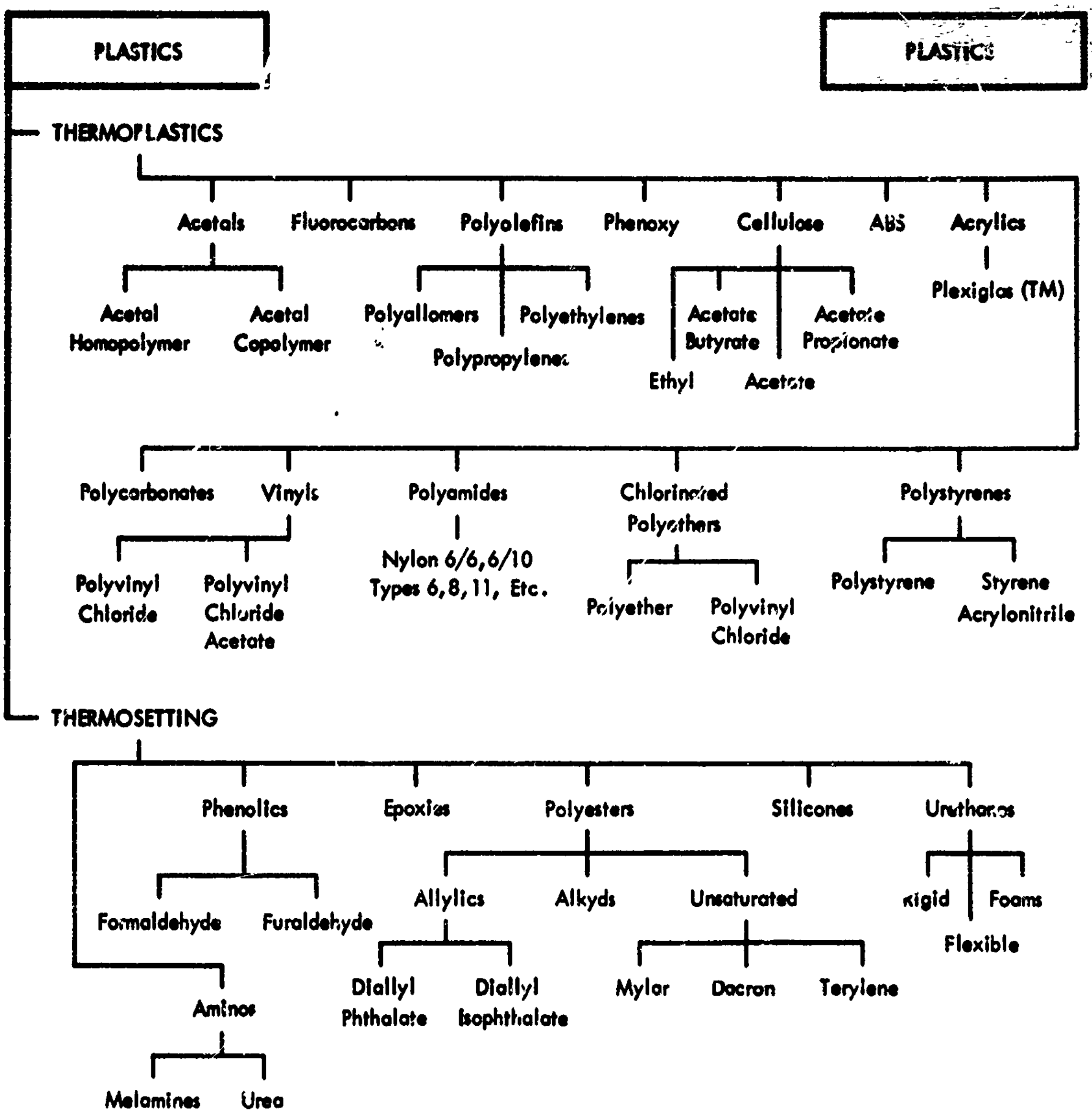

FIGURE C-5. Plastics

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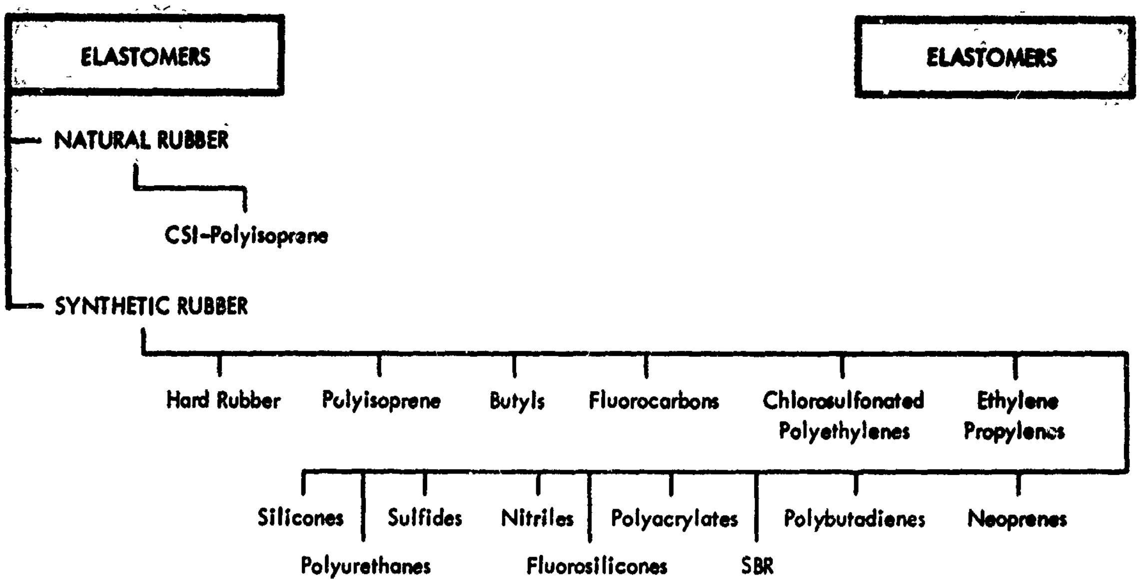

FIGURE C-6. Elastomers

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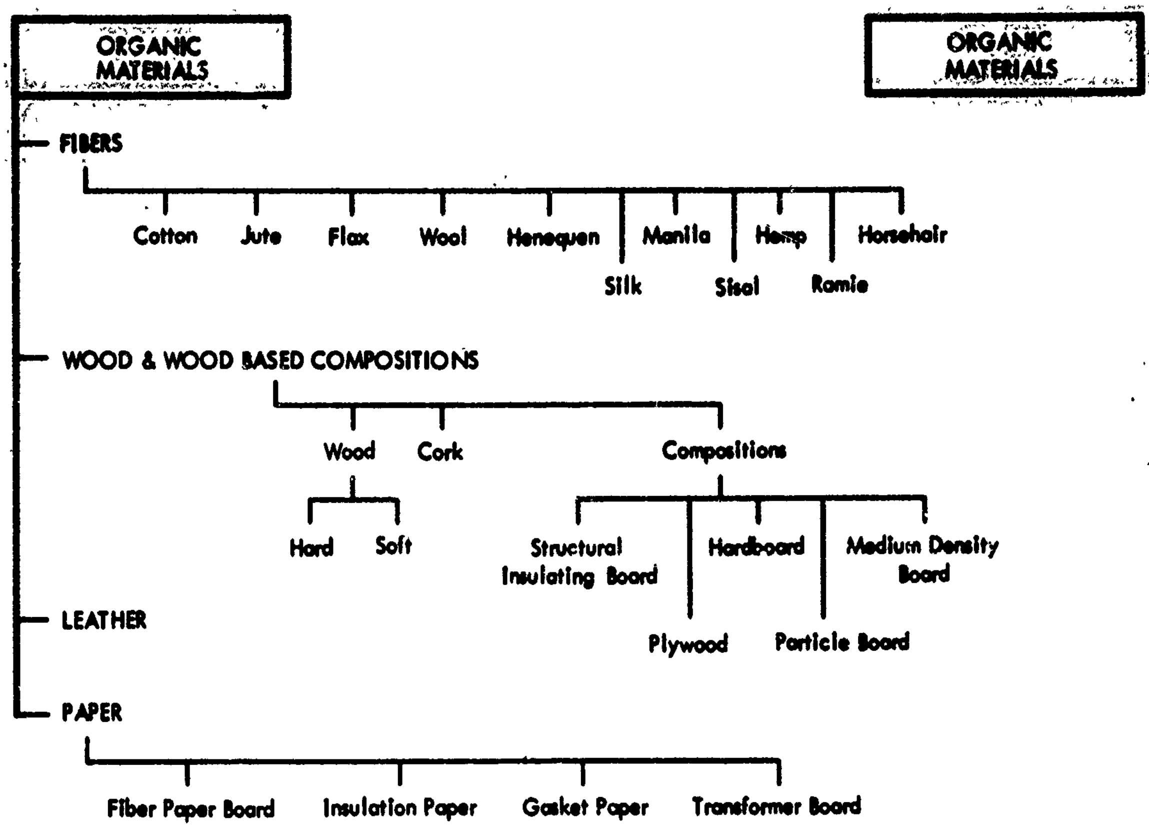

FIGURE C-7. Organic Materials

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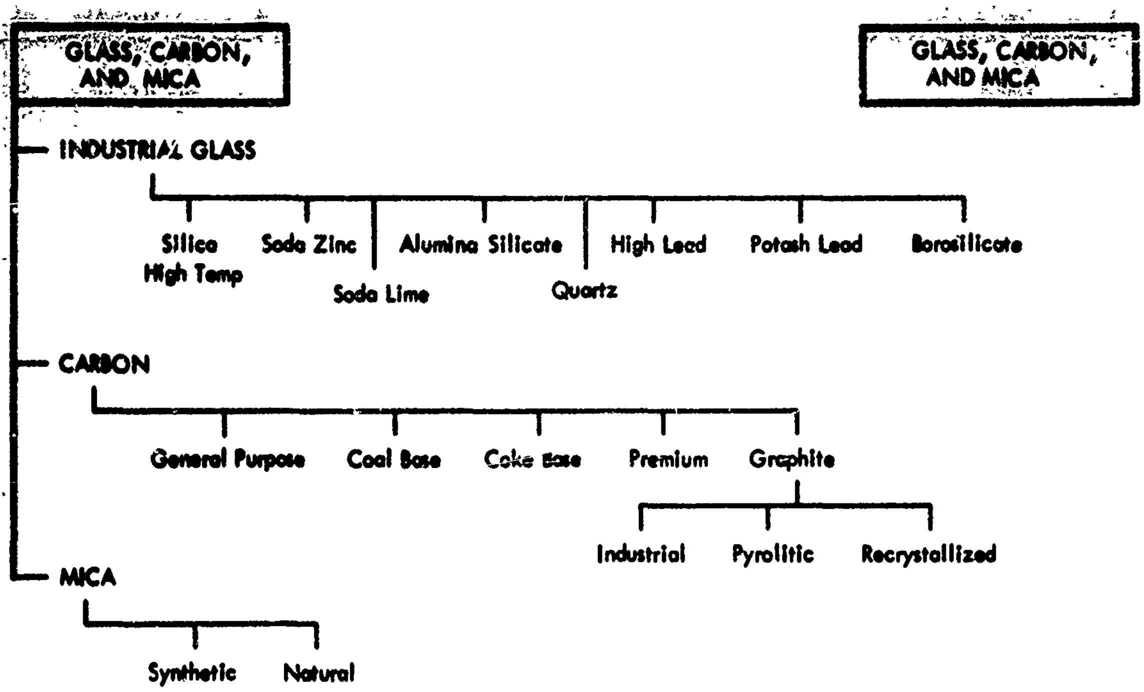

FIGURE C-8. Glass, Carbon, and Mica

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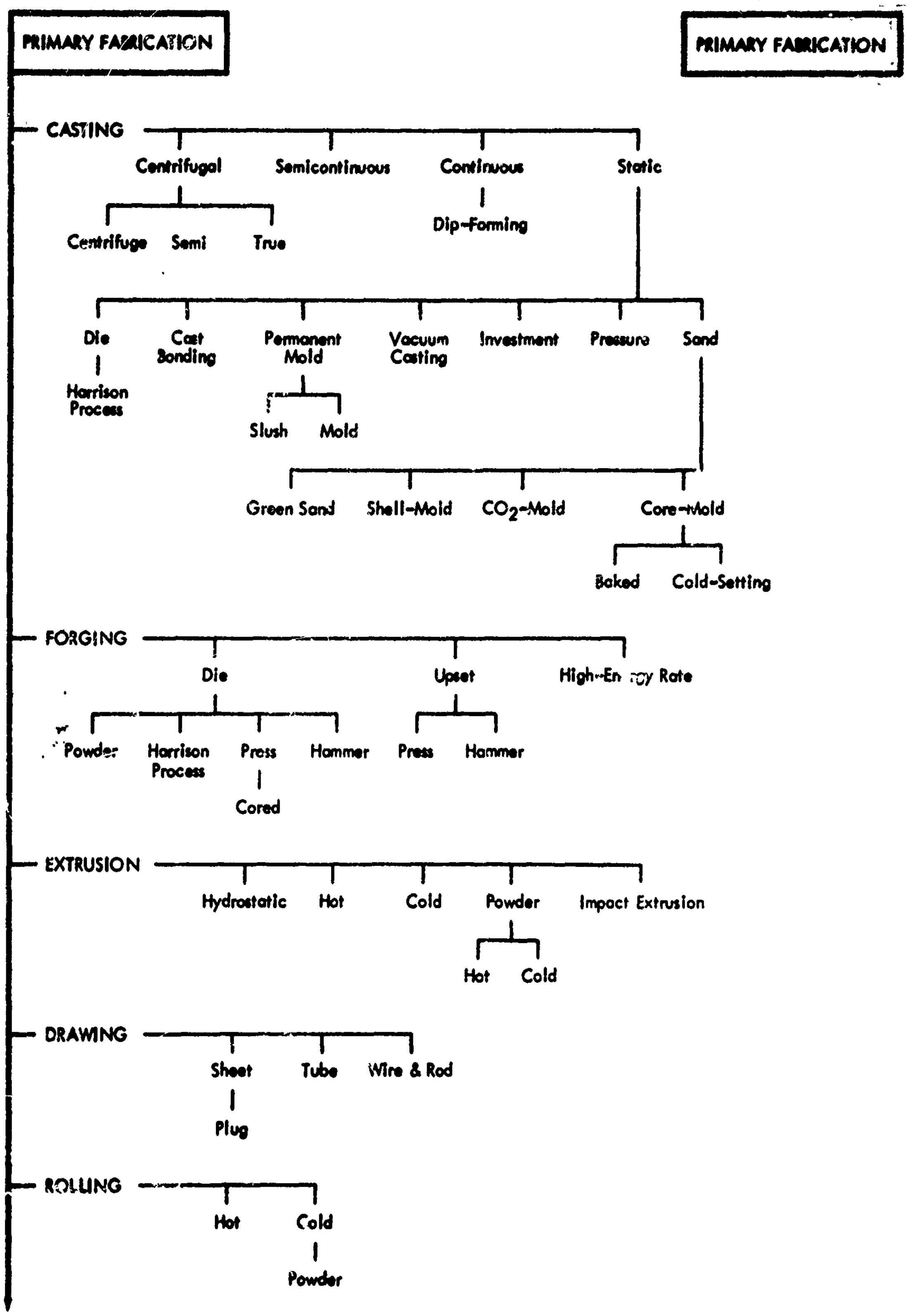

FIGURE C-9. Primary Fabrication

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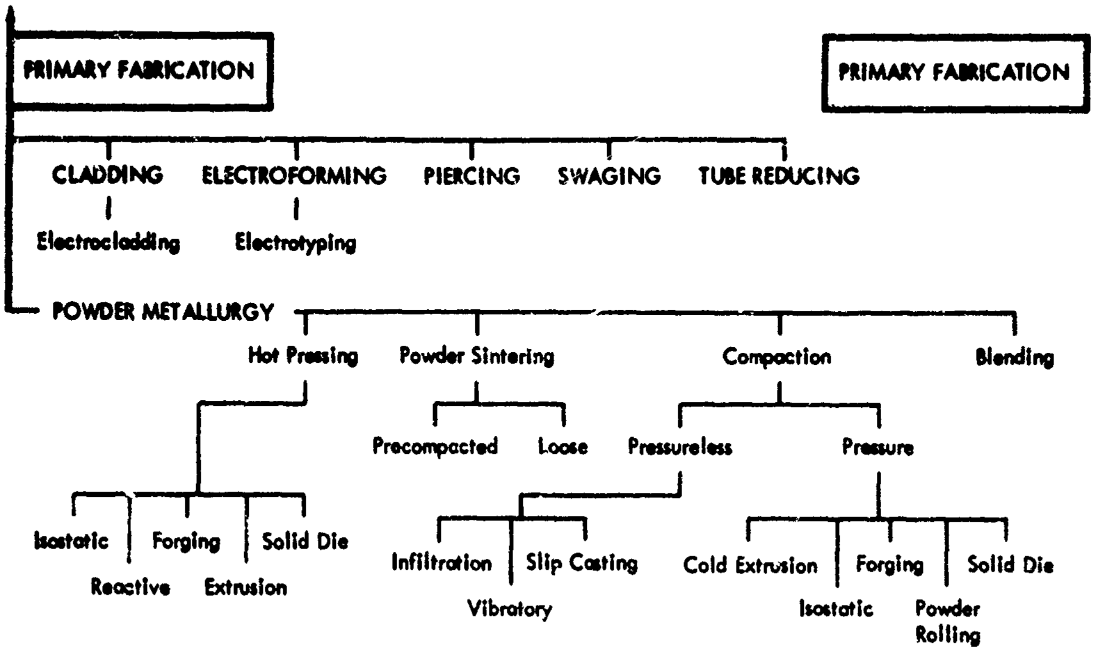

FIGURE C-9. Primary Fabrication (Cont'd)

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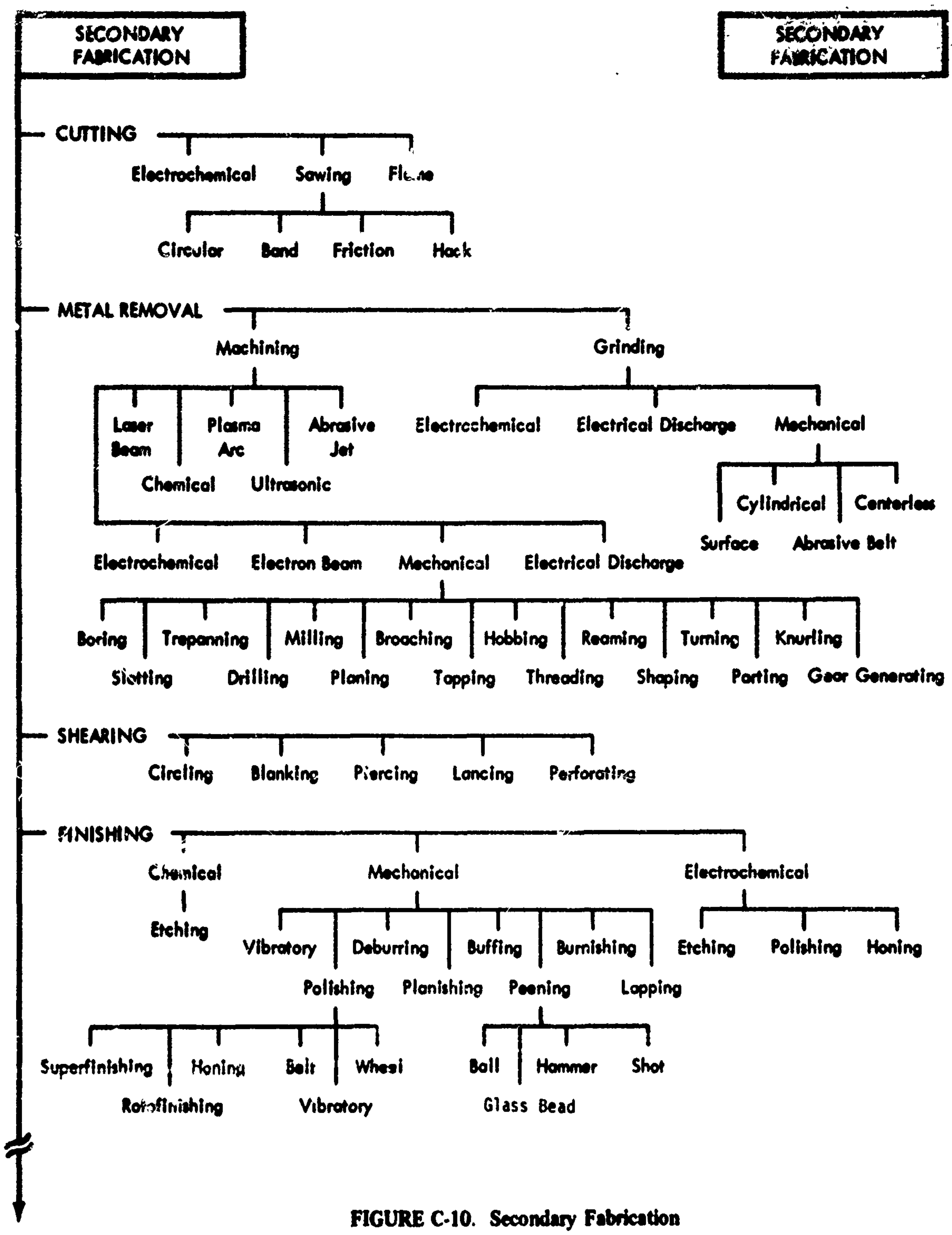

FIGURE C-10. Secondary Fabrication

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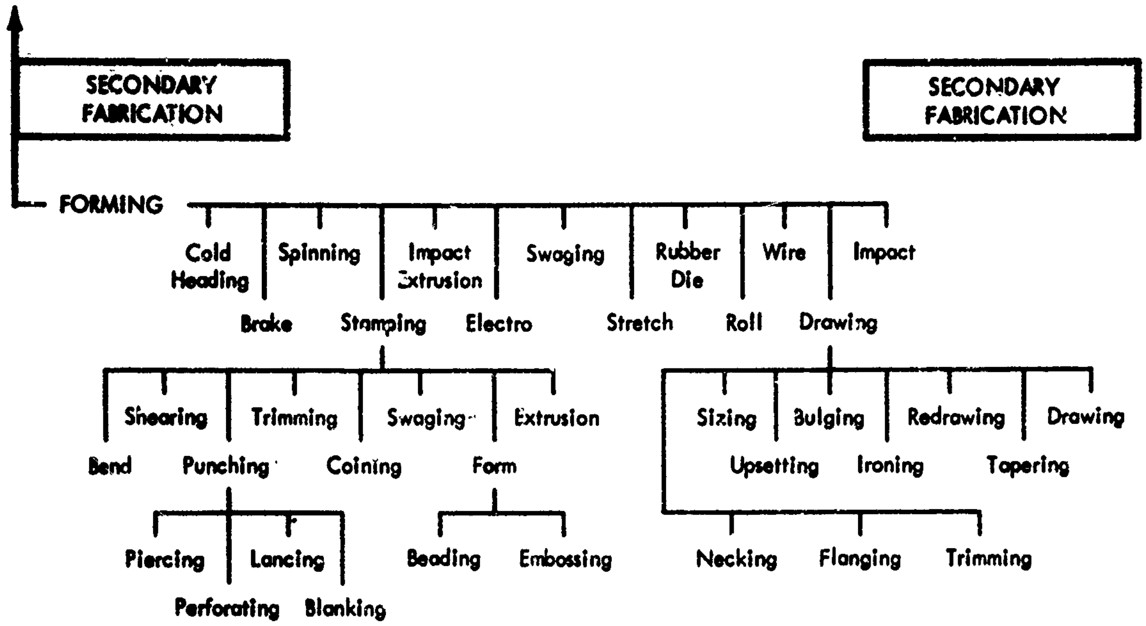

FIGURE C-10. Secondary Fabrication (Cont'd)

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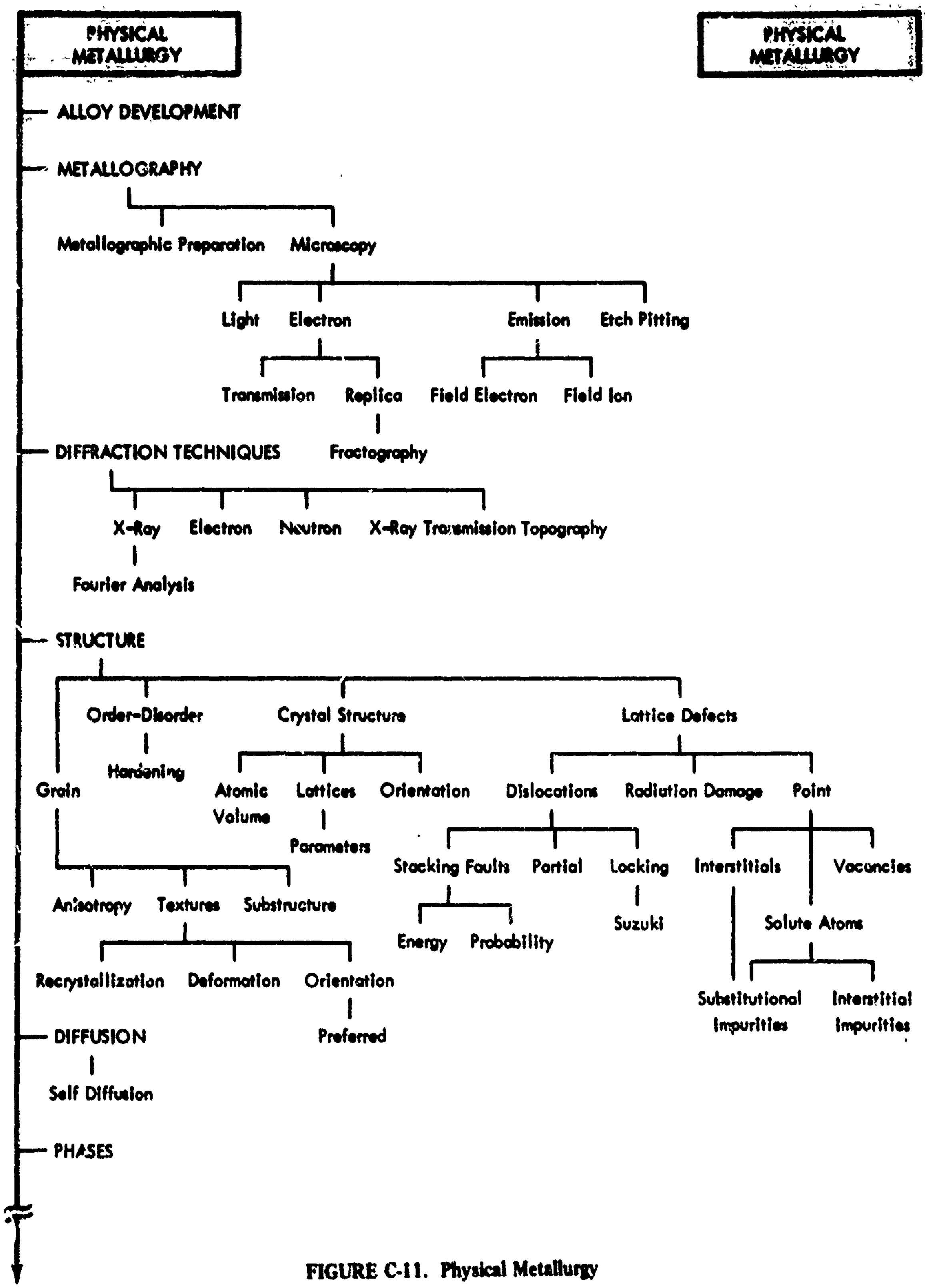

FIGURE C-11. Physical Metallurgy

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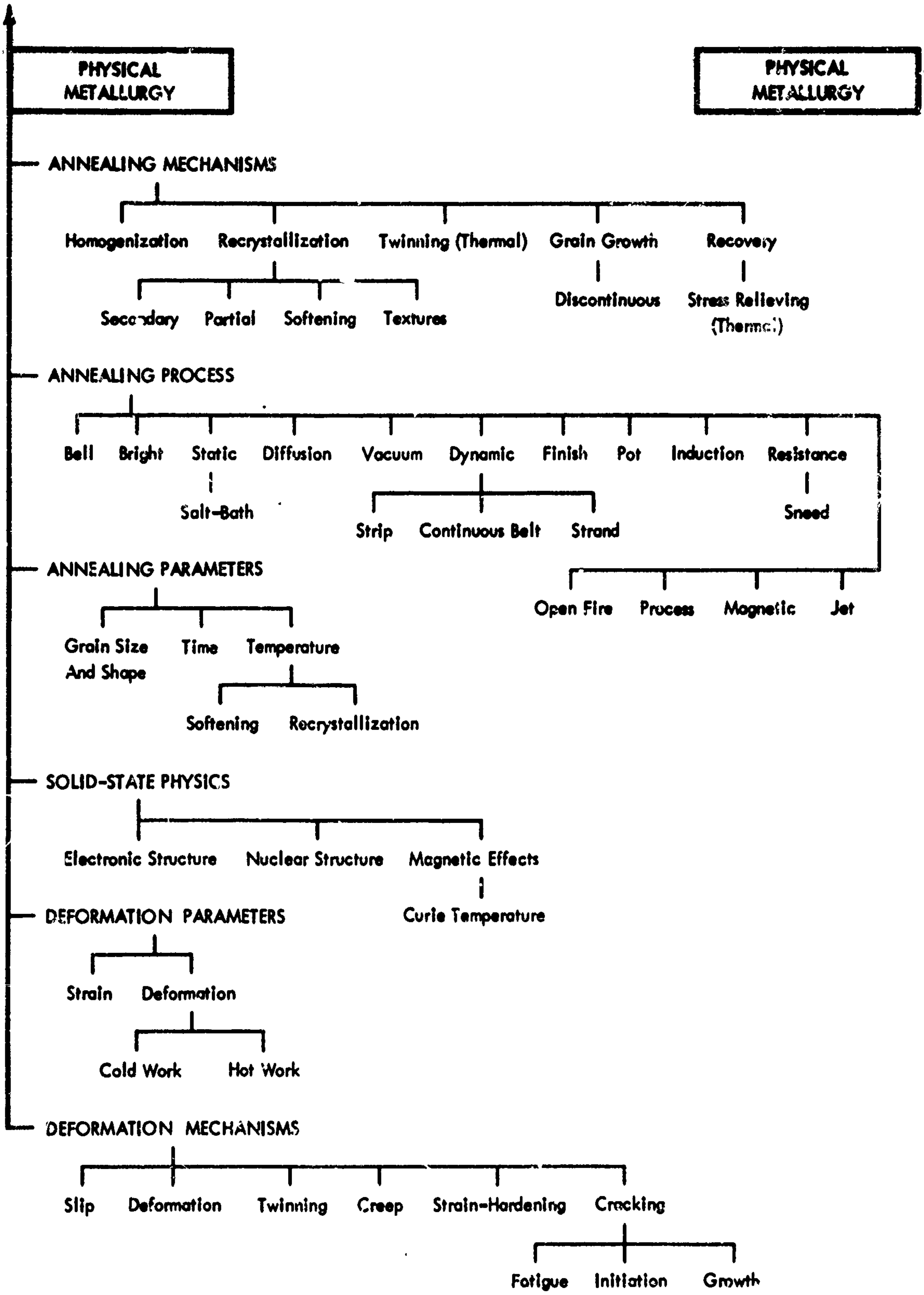

FIGURE C-11. Physical Metallurgy (Cont'd)

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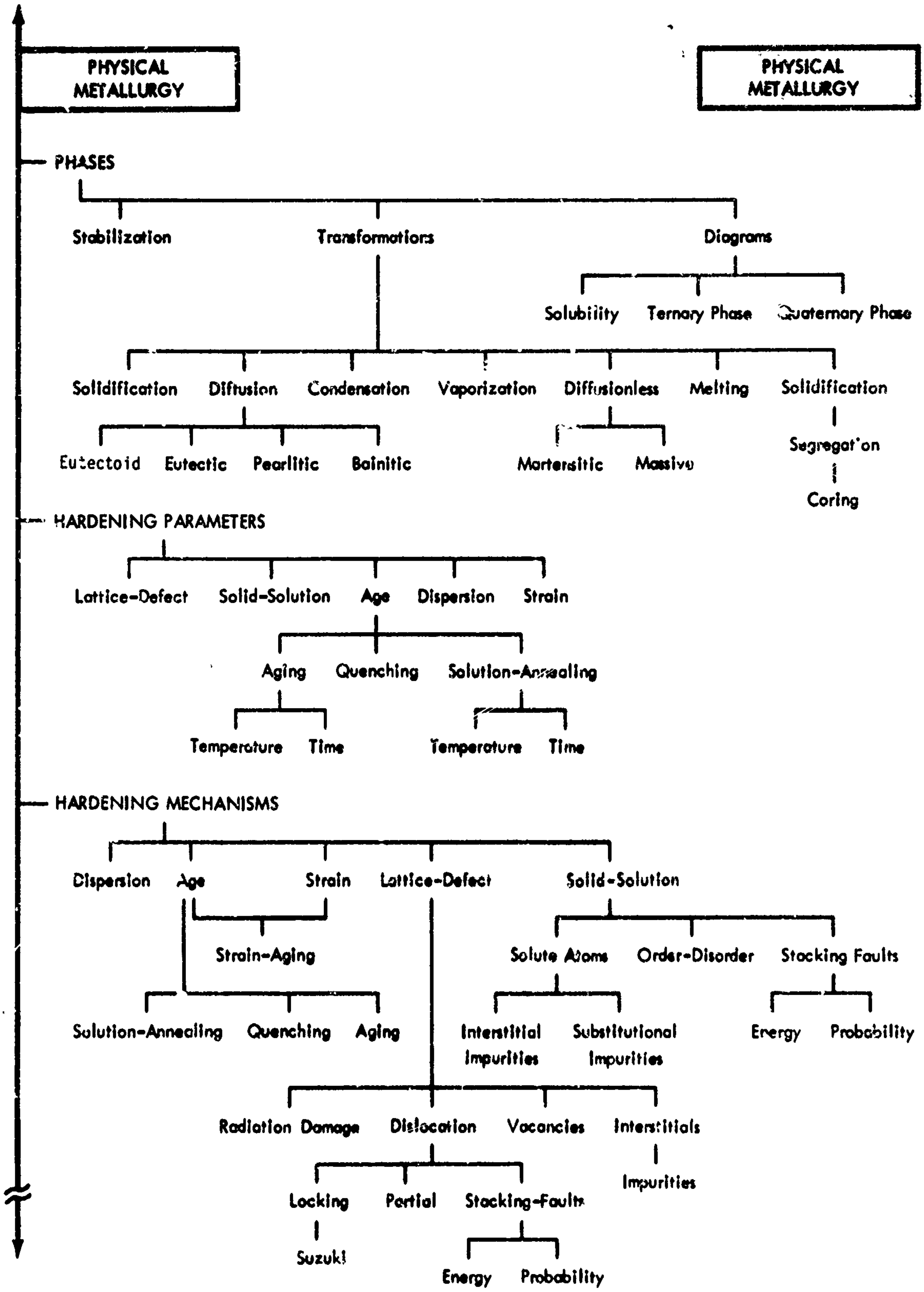

FIGURE C-11. Physical Metallurgy (Cont'd)

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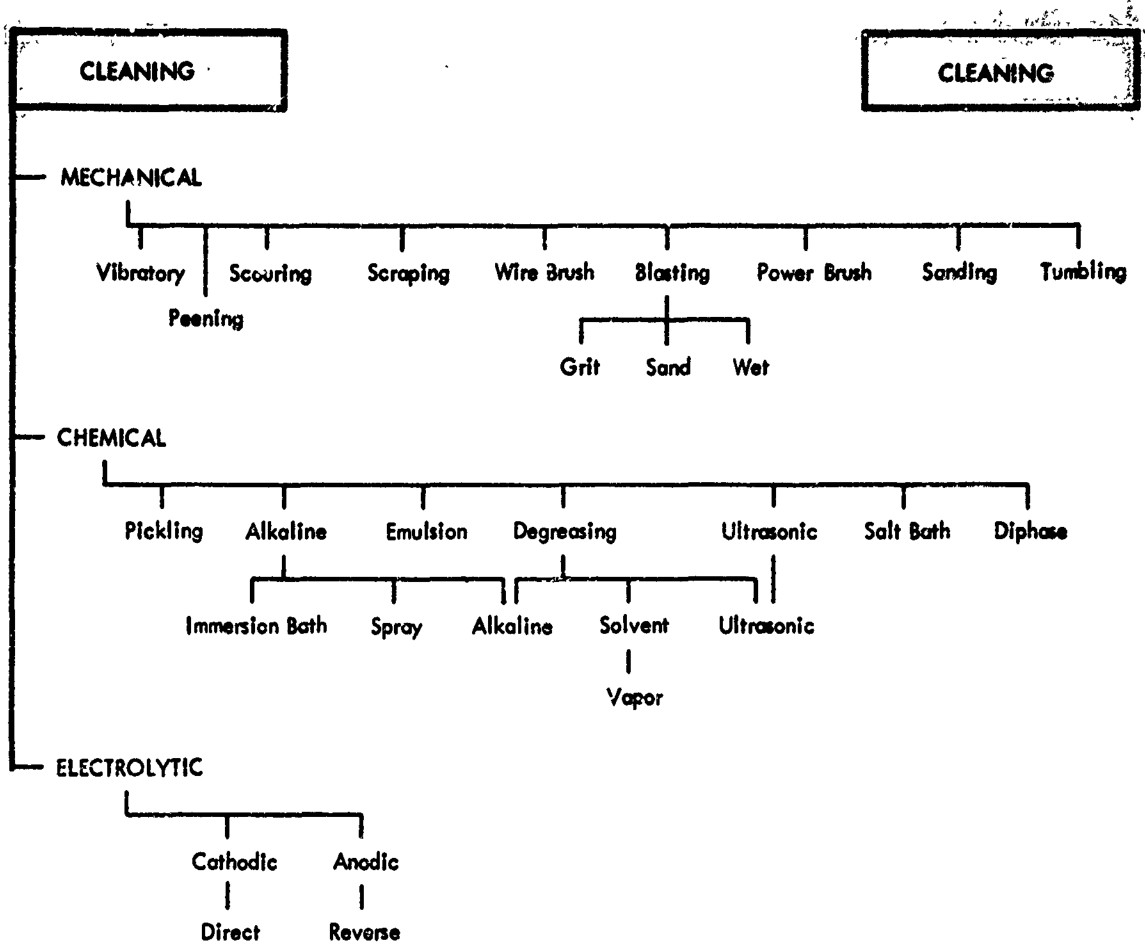

FIGURE C-12. Cleaning

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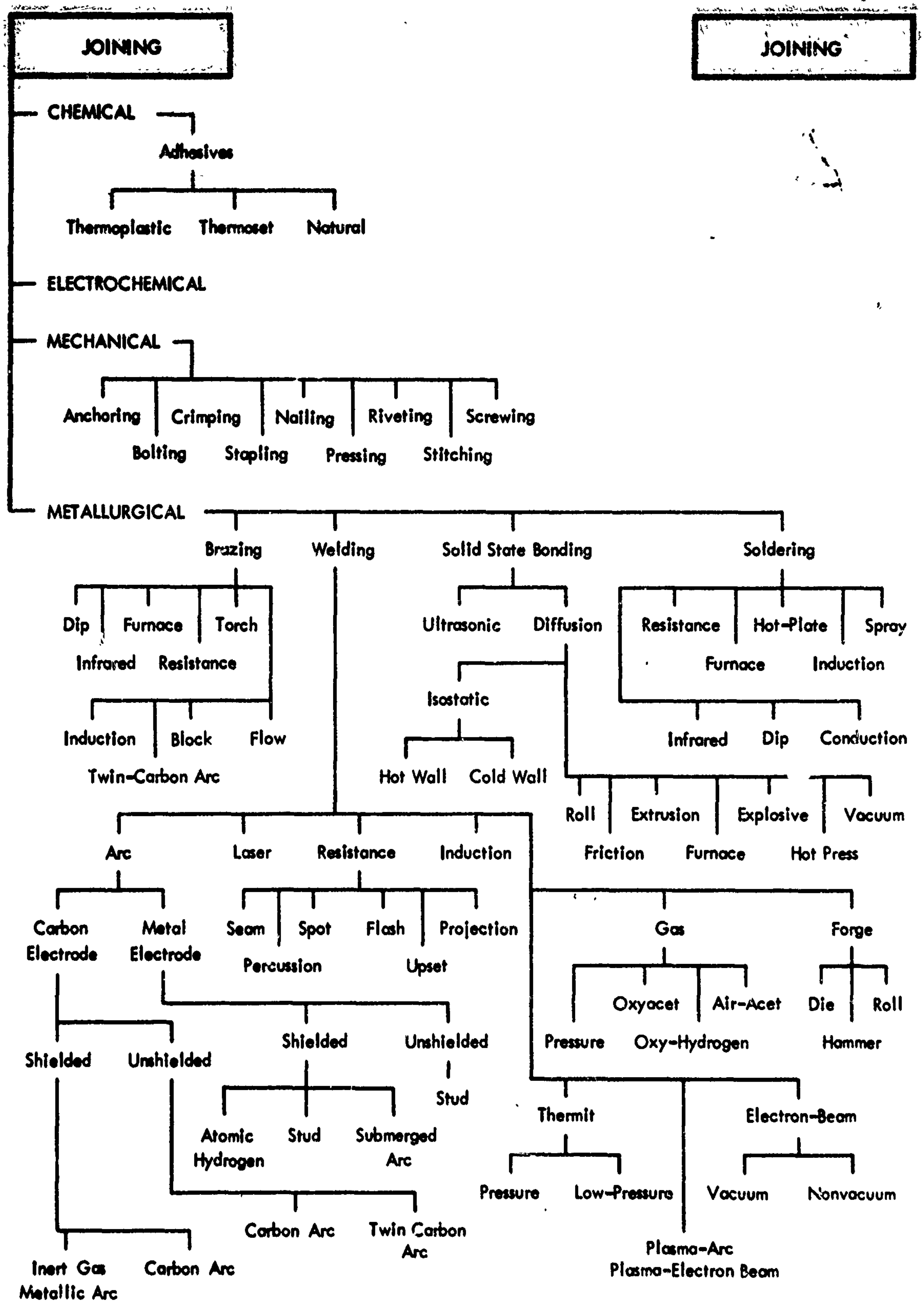

FIGURE C-13. Joining

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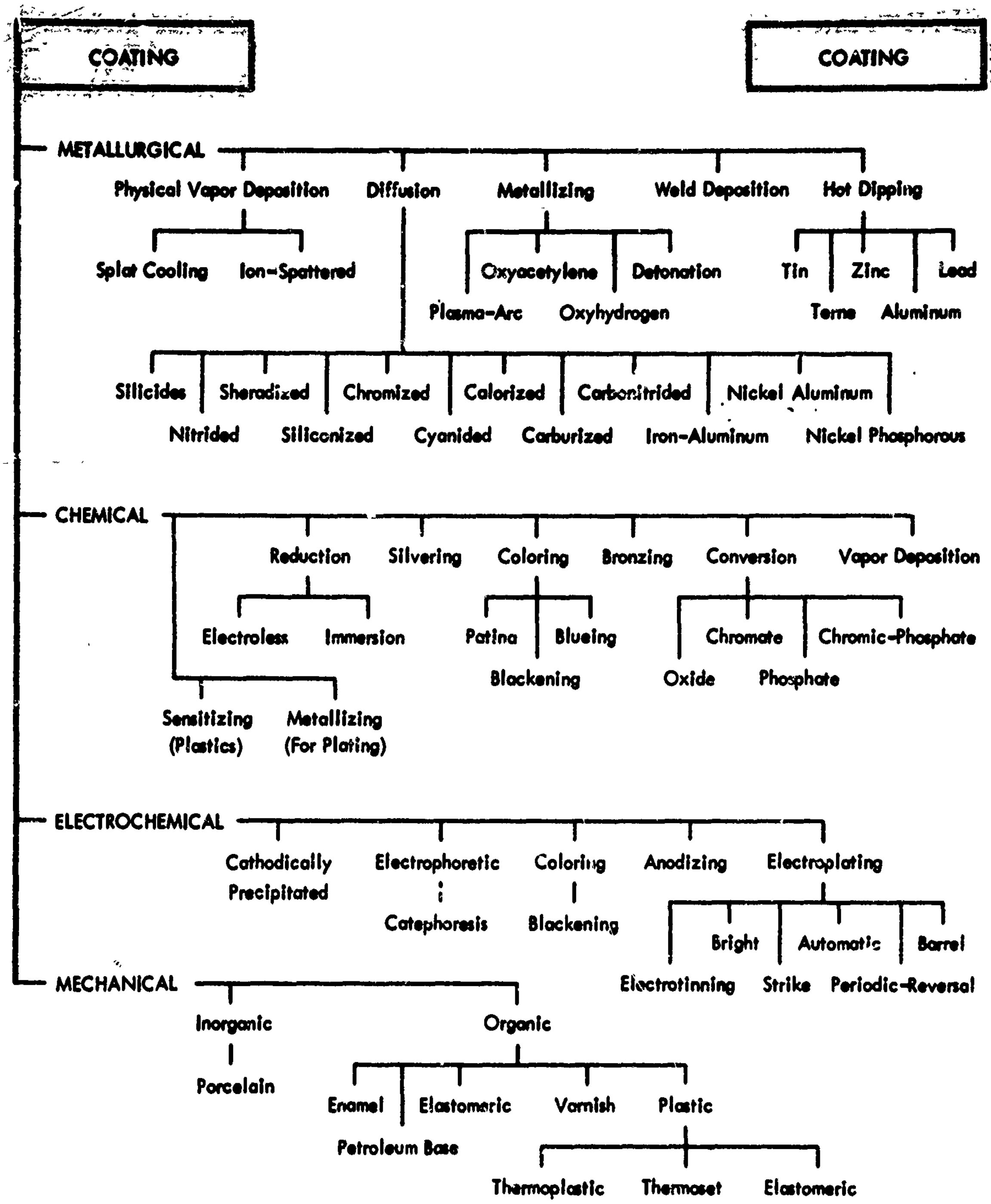

FIGURE C-14. Coating

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APPENDIX D

THE LOGISTIC ENVIRONMENT

D-1 INTRODUCTION

The Defense Logistics Studies Information Exchange (DLSIE) serves as a focal point for DOD—on behalf of each armed service—for the accumulation, abstracting, and retrieval of information concerning all aspects of logistic support of field equipment. The Exchange, therefore, reviews and abstracts a substantial volume of material having a direct bearing upon producibility and its objectives. The use of DLSIE periodical indexes and special bibliographies will frequently facilitate access to producibility reports and data. Fig. D-1 shows a generic tree breakdown of the principal logistics elements.

D-2 FUNCTION OF DEFENSE LOGISTICS STUDIES INFORMATION EXCHANGE (DLSIE)

The mission of DLSIE is to collect, store, and disseminate information about logistic studies and related material for DOD.

The principal method for disseminating logistic study information is an *Annual Bibliography of Logistics Studies and Related Documents* published on 1 January with supplements 1 April, 1 July, and 1 October. These bibliographies are comprised of completed, in-process, and planned logistic studies and related material. Most citations contain an abstract of the content of the study and each publication is variously indexed.

The published bibliographies are distributed automatically to the military departments and other defense agencies which perform or have responsibility for the supervision of logistic research. Other Government agencies and Government-certified civilian organizations may obtain copies upon request to the Exchange.

Since bibliographic data about all studies in the system are stored on computer magnetic tape, specially compiled comprehensive bibliographies pertaining to specific subjects can also be furnished. Requesters for this individual service should use the form shown herein, or they may telephone the request and the relevant information to the DLSIE.

The Exchange does not furnish or loan documents; however, a perpetual inventory of logistic studies is maintained and will be made available at the Exchange to properly authorized personnel of the defense community who may write, call, or visit the exchange at any time for further information or or assistance. The mailing address is:

Commandant
U.S. Army Logistics Management Center
ATTN: Defense Logistics Studies
Information Exchange
Fort Lee, Virginia 23801

REQUEST FOR SPECIAL LOGISTICS STUDIES BIBLIOGRAPHY

Defense Logistics Studies Information
Exchange
U. S. Army Logistics Management Center
Fort Lee, Virginia 23801

Logistics Subject Area: (e.g., Financial Controls in Material Management)

Other Descriptive Terms: (e.g., Financial management: Commodity management: Army, Navy, Air Force, and Defense stock funds: etc.)

Other Information: (Elaborate on the central theme by giving a brief resume of the proposed scope and objectives of the study along with any other pertinent information available).

Send special bibliography to: (Rank, Name, and Address)

D-2.1 HOW TO REQUISITION DOCUMENTS LISTED IN A DLSIE BIBLIOGRAPHY

The DLSIE Bibliographies are prepared by ADP in a standardized format, the elements of which are explained

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in Table D-1. Procedures for obtaining documents listed in bibliographies are:

(1) If the citation contains an AD Number (See Item 6 in Table D-1), requisition from Defense Documentation Center for Scientific and Technical Information (DDC), Cameron Station, Alexandria, Virginia, 22314 (formerly ASTIA). The AD Number is the only information needed. Requests can be processed quickly when a DDC Document Request Form (DDC Form 1, obtainable from DDC) is submitted.

(2) If the citation does not contain an AD Number, requisition from the sponsor, (see Item 1 in Table D-1). The following information should be furnished: full title, references, date of publication, and the name of the contractor if it is included in the citation. The use of Inter-Agency Document Request (DD Form 1142) will simplify and expedite reply. In the requisition, designate the appropriate authority for obtaining copies – Department of Defense Instruction 5154.19, Air Force Regulation No. 400-37, Army Regulations No. 1-12, Secretary of the Navy Instruction 4000.24, or Defense Supply Agency Regulation No. 4100-1.

Theses available for loan only (indicated at end of abstract) should be requested through library channels.

Books, articles from periodicals, and items involving costs may also be requested through library channels or purchased from the publisher.

D-2.2 LOGISTIC BIBLIOGRAPHY

During the development of this handbook, DLSIE furnished a number of special bibliographies – in mechanical printout form which were run on behalf of the development of the handbook – using a series of selected terms which had a direct bearing upon producibility.

Approximately 50 terms were utilized. One such run alone (in the highly significant field of cost control) called out approximately 320 documents and sources of information identified to the sponsoring agency in the following sequence:

(1) DOD
(2) ARMY
(3) AIR FORCE
(4) NAVY
(5) DEFENSE SUPPLY AGENCY
(6) CONTRACTOR AND CIVILIAN AGENCIES

Any bibliography with respect to the document content of interest to this appendix starts to become out-of-date the day it is prepared. Accordingly, a listing of this type is not included. However, see:

(1) Annual Bibliography and its quarterly updates described in par. D-2.

(2) Par. D-2.1 – How to Requisition Documents Listed in a DLSIE Bibliography.

(3) Table D-2 of this appendix.

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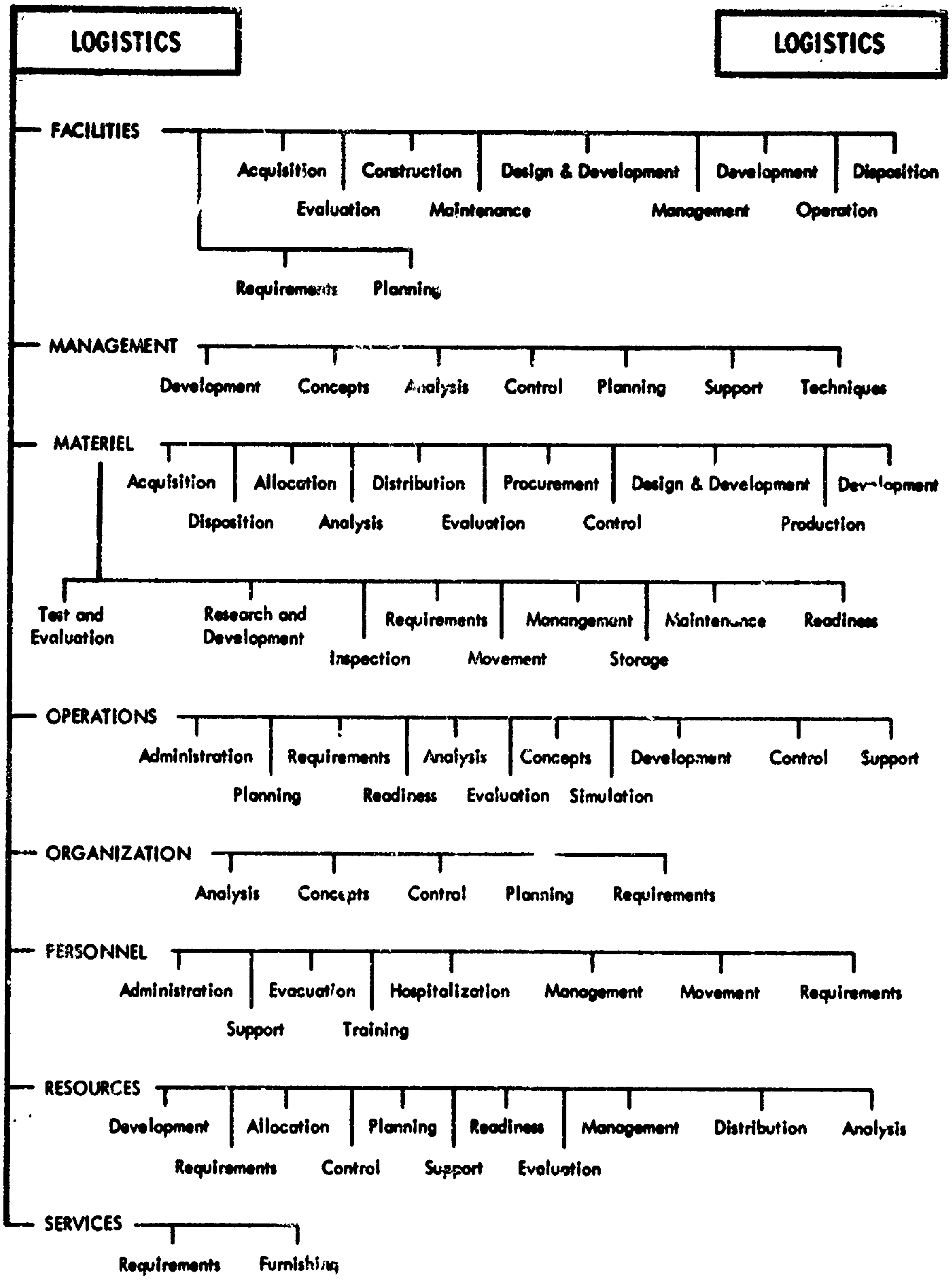

FIGURE D-1. Logistic Generic Tree (See Table D-2 for Additional Terms)

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TABLE D-1. HOW TO INTERPRET DLSIE BIBLIOGRAPHIC DATA

1. The name of the sponsor or publisher is shown as the heading of each bibliographic citation.

2. N/A.

3. Title of the document followed by personal author when applicable.

4. Identifying information.

5. Logistic document number intended only for internal control by the Exchange.

6. Accessioned document number of the Defense Documentation Center for Scientific and Technical Information (DDC).

7. Identifying information.

8. Time period of study application.

9. Shown to aid the user in deciding if he wishes to obtain a copy.

10. The bibliography contains citations of studies planned, in-process, suspended, or completed. The status of planned or in-process studies is updated in succeeding bibliographies according to information received by the Exchange.

11. The category assigned, e.g., unclassified, confidential, secret, top secret, and for which standards in handling, storing, and disseminating have been established.

12. Date of contemplated study is shown as additional identifying information. For other than completed studies, an expected completion date is shown whenever such information has been furnished the Exchange.

13. Abstract of published material or scope statement for planned, in-process, or suspended study projects.

14. Indexing or retrieval terms.

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OFFICE OF THE CHIEF OF ENGINEERS, US ARMY, WASHINGTON, D.C.
  METHODS OF ESTIMATING PRODUCTION CAPACITY FOR THE
  PARM SYSTEM, BY STANELY TRUSTMAN.
  REFERENCE.   RM-OU-236-4.   CONTRACT NO. DA-18-020-ENG-
                                           3673
               LD 16549C           AD 814 139
  CONTRACTOR.  RESEARCH TRIANGLE INSTITUTE
  TIME FRAME:  TF N/    TYPE OF DOCU.   CONTRACT STUDY
  NO. OF PAGES:  119    STATUS:  COMPLETED
  DEFENSE CLASS.  UNCLASSIFIED   DATE PUBLISHED:  6/66

(UNCLASSIFIED) THIS REPORT HAS THREE OBJECTIVES.  THE FIRST
IS THE REPORTING OF A COMPILATION OF APPROXIMATELY 250 TRADE
ASSOCIATIONS THAT MAY OFFER NEW SOURCES OF CAPACITY INFOR-
MATION FOR THE VARIOUS SECTORS IN THE PARM (PROGRAM ANA-
LYSIS FOR RESOURCES MANAGEMENT) MODELS.  THE SECOND IS TO
PROVIDE A METHOD FOR FORECASTING PERFORMANCE POTENTIAL DATA
TO A FUTURE POINT IN TIME WITH EXPONENTIAL SMOOTHING.  THE
THIRD OBJECTIVE IS TO RELATE PERFORMANCE POTENTIAL TO SOME
MEASURE OF CAPACITY, WHICH IS NEEDED FOR PARM DATA FILES.
SECTION II OF THE REPORT CONTAINS AN EVALUATION OF SOME OF
THE CURRENT METHODS USED TO ESTIMATE PRODUCTIVE CAPACITY.
THE LETTER OF INQUIRY WHICH WAS SENT TO TRADE ASSOCIATIONS
TO DETERMINE THE AVAILABILITY OF NEW INDUSTRY SOURCES OF
CAPACITY INFORMATION IS DISCUSSED IN SECTION III.  THE
CONCEPT OF PERFORMANCE POTENTIAL AS A MEANS OF ESTIMATING
CAPACITY IS PRESENTED IN SECTION IV.  SECTION V INVESTIGATES
THE RELATIONSHIP BETWEEN PERFORMANCE POTENTIAL AND CAPACITY.
THE METHOD USED TO FORECAST CAPACITY IS DEPICTED GRAPHICALLY
FOR TWO INDUSTRIAL SECTORS.

SUBJECT DESCRIPTORS:
  RESOURCES, MANAGEMENT PRODUCTION CONCEPTS,
                   INDUSTRIAL READINESS, PARM
```

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TABLE D-2. ADDITIONAL LOGISTIC TERMS

LOGISTICS

3 M
ACE
ACMS
ADMINISTRATIVE SUPPORT
ADPE
ADPS
ADSAF
ADVANCED BASES
AERIAL SUPPLY
AEROMEDICAL EVACUATION
AERONAUTICAL EQUIPMENT
AFLOAT SUPPLY SYSTEMS
AIR ASSAULT DIVISIONS
AIR DEFENSE
AIR FORCE SUPPORT
AIR LOGISTICS
AIR MOBILITY
AIR MOVEMENT
AIR SUPPORT
AIR TRANSPORT
AIR TRANSPORTATION
AIRBORNE OPERATIONS
AIRCRAFT
AIRCRAFT CAPABILITY
AIRCRAFT CARRIERS
AIRCRAFT COMPONENTS
AIRCRAFT ENGINES
AIRCRAFT MAINTENANCE
AIRCRAFT SQUADRONS
AIRCRAFT SUPPORT
AIRDROPS
AIRFIELDS
AIRLIFT
AIRLIFT CAPABILITIES
AIRMOBILE OPERATIONS
AIRTRANS-70'S
ALLIED FORCES
ALLOWANCE LIST MODELS
ALLOWANCE LISTS
ALPHA
AMMIP
AMMUNITION
AMPHIBIOUS CARGO
AMPHIBIOUS OPERATIONS
AMPHIBIOUS SUPPORT
AMPHIBIOUS SYSTEMS
AMPHIBIOUS TRANSPORT
AMPHIBIOUS VEHICLES
AMSM
ANALYTIC MODELS
APPLIED RESEARCH
ARCTIC REGIONS
AREA OF OPERATIONS
ARMORED UNITS
ARMS CONTROL
ARMY MATERIEL COMMAND
ARMY MEDICAL SERVICE
ARMY REORGANIZATION
ARMY SCHOOL SYSTEMS
ARMY-70
ARMY-75
ARMY-80
ARSTRIKE
ARTILLERY UNITS
ASSAULT FORCE MODELS
ASTRONAUTICS
AUDITS
AUTH STOCKAGE LISTS
AUTODIN
AUTOMATIC TEST EQUIPMENT
AUTOMATION
AUTOPROBE
AUTOSATE
AUTOSTRAD
AVIATION SUPPLY
BAKER BOARD
BASE DEVELOPMENT
BASIC RESEARCH
BIBLIOGRAPHIES
BIDDING THEORY
BIG LIFT
BOMBS

LOGISTICS

BOMS
BREAKWATERS
BUDGET ALLOCATIONS
BUDGET FORMULATION
BUDGETARY CONTROL
BUDGETS
BUDOCKS
BUILDINGS
BULK FUELS
BULK PETROLEUM
BULLPUP "A"
BULLPUP "B"
C-5A
CALIBRATION SERVICES
CANADIAN DEFENCE FORCES
CAPITAL PLANT EQUIPMENT
CAPRI
CAREER MANAGEMENT
CARGO
CARGO HANDLING
CARGO MOVEMENT
CARGO OPERATIONS
CASSARS
CASUALTIES
CASUALTY ESTIMATION
CATALOGING
CBR
CBR DEFENSE
CBR MATERIEL
CBR WARFARE
CBU
CCIS
CCIS-70
CENTRALIZED MANAGEMENT
CENTRALIZED SYSTEMS
CHECKOUT EQUIPMENT
CHEMICAL AGENTS
CIVIL AFFAIRS
CIVIL DEFENSE
CIVIL ENGINEERING
CLEAN ROOMS

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TABLE D-2. ADDITIONAL LOGISTIC TERMS (CONT'D)

LOGISTICS		LOGISTICS
CLOTHING AND EQUIPMENT	CONUS	DICE
COBOL	CORPS OF ENGINEERS	DIMES
COCOAS	COSMOS	DISTRIBUTION SYSTEMS
COD	COST ACCOUNTING	DIVISIONS
COIN	COST ANALYSIS	DOCTRINE
COMBAT DEVELOPMENTS	COST CONTROL	DRONES
COMBAT GROUPS	COST EFFECTIVENESS	DRYDOCKS
COMBAT ITEMS	COST MODELS	ECONOMIC ASSISTANCE
COMBAT SERVICE SUPPORT	COST REDUCTION	ECONOMIC IMPACT PROJECT
COMBAT UNIFORMS	COST REDUCTION PROGRAM	ECONOMIC ORDER QUANTITY
COMBAT UNITS	COST SCHEDULING	ECONOMIC STABILITY
COMBAT VEHICLES	COST TO ORDER	ELECTRICAL MATERIEL
COMBAT ZONE	COSTAR	ELECTRONIC EQUIPMENT
COMBINED OPERATIONS	COUNTERINSURGENCY	ELECTRONIC SYSTEMS
COMMAND AND CONTROL	CPE SYSTEM	ENGINEERING EQUIPMENT
COMMERCIAL OPERATIONS	CRITICAL PATH METHOD	ENGINEER SUPPORT
COMMISSARIES	CROSS SERVICING	ENGINEERING DATA
COMMODITY MANAGEMENT	CRYPTOLOGISTICS	ENVIRONMENTAL FACTORS
COMMUNICATIONS	CYBERNETICS	EOQ
COMMUNICATIONS NETWORKS	DAIS	EQUIPMENT
COMMUNICATIONS SYSTEMS	DAMAGE CONTROL	EQUIPMENT COSTS
COMMUNICATIONS ZONE	DAMS AND LOCKS	EQUIPMENT REPLACEMENT
COMMZ	DART	REQUIPMENT REQUIREMENTS
COMPELS	DASH	EVALUATION TECHNIQUES
COMPTROLLER FUNCTIONS	DATA COLLECTION	EXCESS PROPERTY
COMPUTER PROGRAMS	DATA SYSTEMS	EXCHANGE SERVICE
COMPUTERS	DECISION MODELS	EXERCISES
CONCEPTS	DECISION RULES	EXTRATERRESTRIAL BASES
CONEX	DECONTAMINATION	FACILITY REQUIREMENTS
CONFIGURATION MANAGEMENT	DECONTAMINATION SYSTEMS	FACTS
CONSTRUCTION EQUIPMENT	DEEP OCEAN AREAS	FAILURE RATE DATA
CONSUMPTION RATES	DEFENSE SUPPLY AGENCY	FAMILY HOUSING
CONTAINERIZATION	DEMAND DATA	FAR EAST
CONTAINERS	DEMAND FORECASTING	FBM SYSTEM SUPPORT
CONTINGENCY PLANS	DEPARTMENT OF DEFENSE	FDIS
CONTRACT DEFINITION	DEPARTMENT OF THE AF	FIELD ARMY
CONTRACT MANAGEMENT	DEPARTMENT OF THE ARMY	FIELD HOSPITALS
CONTRACTOR DATA	DEPARTMENT OF THE NAVY	FIELD MAINTENANCE
CONTRACTOR EVALUATIONS	DEPOT MAINTENANCE	FILL
CONTRACTOR SUPPORT	DEPOTS	FINANCIAL MANAGEMENT

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TABLE D-2. ADDITIONAL LOGISTIC TERMS (CONT'D)

LOGISTICS

LOGISTICS

FIRE SERVICE	INDIVIDUAL TRAINING	JOINT OPERATIONS
FIREFIGHTING EQUIPMENT	INDUSTRIAL DYNAMICS	JOINT REQUIREMENTS
FIRM	INDUSTRIAL ENGINEERING	JUNGLE OPERATIONS
FISCAL POLICIES	INDUSTRIAL FUNDS	KC-135
FLEET MARINE FORCE	INDUSTRIAL MANAGEMENT	LANCE
FOOD SERVICE	INDUSTRIAL MOBILIZATION	LAND TRANSPORTATION
FOREIGN ARMED FORCES	INDUSTRIAL OPERATIONS	LAOS
FORTRAN	INDUSTRIAL READINESS	LAUNCH SYSTEMS
FUELS	INDUSTRIAL RESEARCH	LAUNDRY EQUIPMENT
GAME THEORY	INFANTRY	LAUNDRY SERVICES
GAMES	INFORMATION RETRIEVAL	LEAD TIME
GAO	INFORMATION SYSTEMS	LEARNING CURVES
GENERAL SUPPLIES	INITIAL PROVISIONING	LEASE VS PURCHASE
GENERAL WAR	INLAND WATERWAYS	LEVEL OF SUPPLY
GERT	INSECT CONTROL	LIFE CYCLE COST
GLADEYE	INSPECTIONS	LIFE SUPPORT SYSTEMS
GOER	INSTALLATIONS	LIMITED WAR
GOLD FLOW	INTEGRATED MANAGEMENT	LINEAR PROGRAMMING
GREENLAND	INTEGRATED SYSTEMS	LINES OF COMMUNICATION
GROUND EFFECT MACHINES	INTELLIGENCE	LOGEX
GROUND SUPPORT	INTELLIGENCE DATA	LOGISTICAL COMMANDS
GROUP DYNAMICS	INTERNATIONAL	LOGISTIC CONCEPTS
GUERILLA WARFARE	INTERNATIONAL LOGISTICS	LOGISTIC MANAGEMENT
GUNS	INTERNATIONAL POLICIES	LOGISTIC OPERATIONS
HAINES BOARD	INTERNATIONAL SUPPORT	LOGISTIC PLANNING
HARBOR STRUCTURES	INTERSERVICE SUPPLY	LOGISTIC READINESS
HELICOPTER ASSAULT FORCE	INTRACONS	LOGISTIC RESEARCH
HELICOPTERS	INVENTORY ANALYSIS	LOGISTIC SUPPORT
HERO PROGRAM	INVENTORY CONTROL	LOGISTIC SYSTEMS
HI-VALUE ITEMS	INVENTORY METHODS	LOGISTIC TRAINING
HIGHWAY	INVENTORY MODELS	LUNAR BASES
HOSPITAL SHIPS	INVENTORY POLICIES	MAC
HOSPITALS	INVENTORY SMOOTHING	MAINTAINABILITY
HOUSEHOLD GOODS	INVENTORY SYSTEMS	MAINTENANCE ENGINEERING
HUMAN FACTORS	IPE	MAINTENANCE MANAGEMENT
HUMIDITY CONTROL	IRON CROSS	MAINTENANCE METHODS
IDEP	IRON SHIELD	MAINTENACE MODELS
INCENTIVE CONTRACTS	IRRADIATED FOODS	MAINTENANCE SHOPS
INCENTIVE SYSTEMS	ITEM MANAGEMENT CODES	MAINTENANCE STANDARDS
INDIVIDUAL EQUIPMENT	JCS	MAINTENANCE SUPPORT

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TABLE D-2. ADDITIONAL LOGISTIC TERMS (CONT'D)

LOGISTICS

LOGISTICS

MAINTENANCE SYSTEMS
MAINTENANCE TRAINING
MAINTENANCE WORKLOADS
MANAGEMENT
MANAGEMENT ANALYSIS
MANAGEMENT CONCEPTS
MANAGEMENT CONTROL
MANAGEMENT IMPROVEMENT
MANAGEMENT METHODS
MANAGEMENT OBJECTIVES
MANAGEMENT PLANNING
MANAGEMENT SYSTEMS
MANAGEMENT TECHNIQUES
MANAGEMENT TRAINING
MANPOWER CONTROL
MANPOWER MANAGEMENT
MANPOWER REQUIREMENTS
MANPOWER UTILIZATION
MAP
MARADS
MARINE RAILWAYS
MARK 4, GUN POD
MARKING SYSTEMS
MATERIALS HANDLING
MATERIALS HANDLING EQUIP
MATERIEL READINESS
MATHEMATICAL ANALYSIS
MATHEMATICAL MODELS
MATHEMATICAL RESEARCH
MATS
MAULER
MAW
MCB
MEADS
MEDICAL SERVICES
MEDICAL SUPPLY
MERCHANT MARINE
MESS MANAGEMENT
METEOROLOGICAL DATA
METHODS IMPROVEMENT
METRI

MICROMODULES
MIDDLE EAST
MILITARY ASSISTANCE
MILITARY BASES
MILITARY DEPARTMENTS
MILITARY ESSENTIALITY
MILITARY POLICE
MILITARY REQUIREMENTS
MILITARY SERVICES
MILSCAP
MILSTAMP
MILSTRIP
MINUTEMAN
MIP
MISSILE BASES
MISSILE SUPPORT
MISSILE SYSTEMS
MISSILES
MK 94 MOD O
MMMIS
MOBILE SUPPORT UNITS
MOBILITY
MOBILIZATION
MOBILIZATION PLANNING
MODELS
MODERN MISER
MODERNIZATION PROGRAMS
MODULAR CRITERIA
MONTE CARLO
MOON
MOORINGS
MORL
MOTOR VEHICLES
MOVECAP
MOVEMENT CONTROL
MPL
MSTS
MULTI-YEAR PROCUREMENT
NAPALM
NATIONAL DEFENSE
NATIONAL ECONOMY

NATIONAL EMERGENCY
NATIONAL LEVEL
NATIONAL LOGISTICS
NATIONAL OBJECTIVES
NATIONAL POLICY
NATIONAL PROGRAMS
NATIONAL SECURITY
NATO
NATO FORCES
NATO LOGISTICS
NAVAL AIR STATIONS
NAVAL LOGISTICS
NAVY CAMPS
NAVY PROGRAMS
NAVY SHORE FACILITIES
NAVY SUPPLY SYSTEM
NICPS
NIKE ZEUS
NORTHERN OPERATIONS
NUCLEAR DEFENSE
NUCLEAR POWER
NUCLEAR RADIATION
NUCLEAR WARFARE
NUCLEAR WEAPONS
OCEAN TRANSPORATION
OCEANOGRAPHY
OFF-ROAD MOBILITY
OFFICER TRAINING
OFFSHORE PROCUREMENT
OJT
OPERATION ARM
OPERATIONS CONCEPTS
OPERATIONS RESEARCH
ORDNANCE
ORDNANCE ITEMS
ORDNANCE SERVICES
OREGON TRAIL
ORGANIZATION ANALYSIS
ORGANIZATION CONCEPTS
OUTPATIENT CLINICS
OVER-THE-BEACH

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TABLE D-2. ADDITIONAL LOGISTIC TERMS (CONT'D)

LOGISTICS

OVERHAUL
OVERSEA COMMAND
OVERSEA SUPPLY AGENCIES
OVERSEAS BASES
PACKAGING
PACKING AND CRATING
PALLETIZATION
PAMUSA
PARM
PARTICIPATIVE MANAGEMENT
PEMA
PERFORMANCE ANALYSIS
PERSONNEL MANAGEMENT
PERSONNEL SYSTEM MODELS
PERT
PERT/COST
PETROLEUM
PIERS
PIPELINE REQUIREMENTS
PIPELINES
PLADS
PLANET
PLANNING
PLANNING CYCLES
PLANNING FACTORS
PLANNING TECHNIQUES
POL
POLAR REGIONS
POLARIS
POLICIES
POWER SOURCES
POWER SYSTEMS
POWER UNITS
POWS
PRACTICES
PREDICTION METHODS
PREPOSITIONING
PRESCRIBED LOADS
PRESERVATION
PRESERVATION METHODS
PREVENTIVE MAINTENANCE
PREVENTIVE MEDICINE
PRICE COMPETITION
PRINCIPAL ITEMS
PRISM
PRISONERS OF WAR
PROCUREMENT
PROCUREMENT COSTS
PROCUREMENT MANAGEMENT
PROCUREMENT MODELS
PRODUCTION BASE
PRODUCTION CONCEPTS
PRODUCTION CONTROL
PRODUCTION MODELS
PRODUCTION PLANNING
PRODUCTION SMOOTHING
PRODUCTIVITY MEASUREMENT
PROGRAM ANALYSIS
PROGRAM MANAGEMENT
PROGRAMMING
PROGRAMMING MODELS
PROGRAMS
PROJECT
PROJECT AGILE
PROJECT AIM
PROJECT COAMS
PROJECT DEFINITION PHASE
PROJECT FLATTOP
PROJECT MAC
PROJECT MANAGEMENT
PROJECT MASTER
PROJECT OTTER
PROJECT PACE
PROJECT PERMA
PROJECT PRIME
PROJECT TRANSIM
PROTECTIVE CLOTHING
PROVISIONING MODELS
PROVISIONING POLICIES
PSYCHOLOGICAL OPERATIONS
QDRI
QMDO

LOGISTICS

QUALITY CONTROL
QUEUING MODELS
QUICK GAMING
QUICO
R&D PROGRAMS
RADAR SYSTEMS
RADIOACTIVE MATERIALS
RADIOLOGICAL DEFENSE
RADIOLOGICAL SURVEY
RADIOS
RAIL TRANSPORTATION
RAMMS
RAS SYSTEM
RATIONS
READINESS
READINESS MODELS
REAL PROPERTY
REAR AREA SECURITY
REBUILD
RECOGNITION SYSTEMS
RECORDS ADMINISTRATION
RECOVERY SYSTEMS
REFRIGERATION
REFUELING IN THE AIR
RELIABILITY
REORGANIZATION
REPAIR CRITERIA
REPAIR PARTS
REPAIRABLE ITEMS
REPLACEMENT FACTORS
REPLACEMENT POLICIES
REPLACEMENT SYSTEMS
REPORT CONTROL SYSTEMS
REPORTS AND REPORTING
REPUBLIC OF KOREA
REPUBLIC OF VIETNAM
REQUIREMENTS
REQUIREMENTS MANAGEMENT
REQUISITION CONTROL
RESEARCH AGENCIES

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TABLE D-2. ADDITIONAL LOGISTIC TERMS (CONT'D)

LOGISTICS

RESEARCH AND DEVELOPMENT	SHIP STORE	STOCKAGE PLANS
RESEARCH LABORATORIES	SHIP TO SHORE SYSTEMS	STOCKPILE MANAGEMENT
RESEARCH METHODS	SHIPBOARD	STOCKPILE-TO-TARGET
RESEARCH PROGRAMS	SHIPBUILDING	STORAGE
RESEARCH TECHNIQUES	SHIPPING	STORAGE OPERATIONS
RESERVE COMPONENTS	SHIPS	STRAF
RESOURCES MANAGEMENT	SHIPYARDS	STRATEGIC MATERIALS
ROAD	SHORE FACILITIES	STRATMAS
ROAD DIVISIONS	SHRIKE	STRIVE
ROCKEYE II	SIDEWINDER I-C	SUBMARINES
RODAC-70	SIGNAL EQUIPMENT	SUBROC
ROKA	SIGNAL SERVICES	SUBSISTENCE
ROLL ON ROLL OFF	SIGNAL UNITS	SUNSPOT
ROTATION SYSTEMS	SIMSCRIPT	SUPERSONIC AIRCRAFT
SADEYE	SIMULATIONS	SUPPLIES
SAFETY SERVICE	SINGLE MANAGER	SUPPLY - CLASS I
SALFO	SMALL BUSINESS PROGRAM	SUPPLY - CLASS II
SAM	SOUTHEAST ASIA	SUPPLY - CLASS III
SAMPLING TECHNIQUES	SPACE LOGISTICS	SUPPLY - CLASS V
SAMSOM	SPACE OPERATIONS	SUPPLY AFLOAT
SANITARY ENGINEERING	SPACECRAFT	SUPPLY ECONOMY
SANITATION SYSTEMS	SPARE PARTS	SUPPLY OFFICERS
SATELLITES	SPARE PARTS SUPPLY	SUPPLY PERFORMANCE
SATS	SPARROW III	SUPPLY SUPPORT
SATURN V	SPECIAL EQUIPMENT	SUPPLY SYSTEMS
SCHEDULING	SPECIAL FORCES	SUPPORT COMMANDS
SCHNELLSPIEL	SPECIFICATIONS	SUPPORT CONCEPTS
SEA HAWK	SPREMAT	SUPPORT EQUIPMENT
SEA-WATER CONVERSION	SST	SUPPORT PLANNING
SEALIFT	STANDARDIZATION	SUPPORT SERVICES
SEALIFT CAPABILITIES	STATE OF THE ART	SUPPORT SYSTEMS
SEAPORTS	STATISTICAL ANALYSIS	SURPLUS PROPERTY
SEARCH AND RESCUE	STATISTICAL CONTROL	SYSTEMS
SECONDARY ITEMS	STATISTICAL SAMPLING	SYSTEM ANALYSIS
SENSORS	STOCK CONTROL	SYSTEM EFFECTIVENESS
SERGEANT	STOCK CONTROL SYSTEMS	SYSTEM ENGINEERING
SHELTERS	STOCK FUND	SYSTEM MANAGEMENT
SHIELDING	STOCK LEVELS	SYSTEM RESEARCH
SHIP DESIGN	STOCK POINTS	TAC
SHIP OVERHAUL	STOCKAGE OBJECTIVES	TAERS

LOGISTICS

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TABLE D-2. ADDITIONAL LOGISTIC TERMS (CONT'D)

LOGISTICS

- TALOS
- TANKERS
- TANKS
- TARGETS
- TASTA-70
- TAWS
- TECHNICAL DATA
- TECHNICAL MANUALS
- TECHNIQUES
- TECSTAR
- TEDPAS
- TERMINAL COMMANDS
- TERMINAL FACILITIES
- TERMINAL OPERATIONS
- THAILAND
- THEATER ARMY
- THEATERSPIEL
- TIMMS
- TIRES
- TITAN I
- TITAN IIIC
- TORPEDOS
- TRACKED VEHICLES
- TRAFFIC MANAGEMENT
- TRAILERS
- TRAINING AIDS
- TRANSP MOVEMENTS
- TRANSPORT AIRCRAFT
- TRANSPORTABILITY
- TRANSPORTATION
- TRANSPORTATION MODELS
- TRANSPORTATION NETWORKS
- TRANSPORTATION SERVICES
- TRANSPORTATION SUPPORT
- TRANSPORTATION SYSTEMS
- TROPICAL REGIONS
- TRUCK TRANSPORT
- TRUCKS
- UNCONVENTIONAL WARFARE
- UNDERDEVELOPED AREAS
- UNDERSEAS TRANSPORT
- UNDERWATER OPERATIONS
- UNDERWATER STORAGE
- UNDERWATER REPLENISHMENT
- UNIFICATION
- UNIFIED COMMANDS
- UNITIZATION
- US AIR FORCE
- US ARMED FORCES
- US ARMY
- US MARINE CORPS
- US NAVY
- USAREUR
- USCONARC
- USSR
- USSR ARMIES

LOGISTICS

- UTILITIES
- VALUE ENGINEERING
- VEHICLES
- VIET CONG
- VSL COMPUTATIONS
- WALLEYE
- WAR GAMES
- WAR PLANS
- WAREHOUSES
- WAREHOUSING METHODS
- WARFARE
- WARNING SYSTEMS
- WARSHIPS
- WASTE DISPOSAL
- WATER
- WATER SUPPLY
- WATER SYSTEMS
- WEAPON SYSTEMS
- WEAPONS
- WEAPON CARRIERS
- WEAPON SUPPORT
- WEIGHTED GUIDELINES
- WETEYE
- WHOLESALE LOGISTICS
- WORK ANALYSIS
- WORK MEASUREMENT
- WORLD WAR II
- ZERO DEFECTS

Each of the foregoing terms may be utilized as an independent searching term. Many of them may also be used in combination with terms in Fig. D-1 and would thus become third level modifiers in that generic tree as

MATERIEL
- Resources
- Production
  - Cost Reduction
  - Lead Time
  - Methods Improvement

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INDEX

NOTE:

This handbook was developed prior to the release and distribution of the Department of Defense *Thesaurus of Scientific and Engineering Terms.* The Thesaurus, or generic tree, concept utilized in the handbook, particularly Appendices A to D, can be used to considerable advantage in conjunction with the DOD publication, which provides generic structuring for some 23,000 terms.

To facilitate use of the DOD Thesaurus, minor changes have been made to some terms in this index to align them with those of the Thesaurus, where these changes do not detract from the utility of the index. All DOD Thesaurus terms which appear in the index are so identified (singular/plural differences not affecting interpretation have been ignored). Many other related terms not identified in the index will be found in the Thesaurus and may also be used to stimulate or simplify information search tasks. Since information structuring in automated information retrieval systems is usually based on similar generic concepts, combined use of this index, the generic trees, and the DOD Thesaurus may particularly simplify the task of querying data banks such as those listed in Appendix A.

Main indexing terms which appear in the DOD Thesaurus are preceded by an asterisk. Terms appearing in the generic trees in Appendices B, C, or D have their generic tree page number shown in parentheses, as: *Aluminum coating, (C-24), 13-4, 13-7; *Alloys, reference sources, A-12; Configuration management, (B-15), 2-1, 2-9, 4-4.

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ENGINEERING DESIGN HANDBOOKS

Listed below are the Handbooks which have been published or are currently under preparation. Handbooks with publication dates prior to 1 August 1962 were published as 20-series Ordnance Corps Pamphlets. AMC Circular 310-38, 19 July 1963, redesignated those publications as 706-series AMC Pamphlets (e.g., ORDP 20-138 was redesignated AMCP 706-138). All new, reprinted, or revised Handbooks are being published as 706-series AMC Pamphlets.

No. AMCP 706-	Title
100	Design Guidance for Producibility
104	Value Engineering
106	Elements of Armament Engineering, Part One, Sources of Energy
107	Elements of Armament Engineering, Part Two, Ballistics
108	Elements of Armament Engineering, Part Three, Weapon Systems and Components
109	Tables of the Cumulative Binomial Probabilities
110	Experimental Statistics, Section 1, Basic Concepts and Analysis of Measurement Data
111	Experimental Statistics, Section 2, Analysis of Enumerative and Classificatory Data
112	Experimental Statistics, Section 3, Planning and Analysis of Comparative Experiments
113	Experimental Statistics, Section 4, Special Topics
114	Experimental Statistics, Section 5, Tables
115	Environmental Series, Part One, Basic Environmental Concepts
116	*Environmental Series, Part Two, Basic Environmental Factors
120	Criteria for Environmental Control of Mobile Systems
121	**Packaging and Pack Enginee[illegible]ing
123	Hydraulic Fluids
125	Electrical Wire and Cable
127	Infrared Military Systems, Part One
128(S)	*Infrared Military Systems, Part Two (U)
130	Design for Air Transport and Airdrop of Materiel
133	*Maintainability Engineering Theory and Pract
134	Maintainability Guide for Design
135	Inventions, Patents, and Related Matters
136	Servomechanisms, Section 1, Theory
137	Servomechanisms, Section 2, Measurement and Signal Converters
138	Servomechanisms, Section 3, Amplification
139	Servomechanisms, Section 4, Power Elements and System Design
140	Trajectories, Differential Effects, and Data for Proj[illegible]es
145	*Dynamics [illegible] Tracking Gimbal System
150	Interior B[illegible]llistics of Guns
160(S)	Elements [illegible] Terminal Ballistics, Part One, Kill Mechani[illegible] and Vulnerability (U)
161(S)	Elements of Terminal Ballistics, Part Two, Collection and Analysis of Data Concerning Targets (U)
162(SRD)	Elements of Terminal Ballistics, Part Three, Application to Missile and Space Targets (U)
165	Liquid-Filled Projectile Design
170(C)	**Armor and Its Application (U)
175	Solid Propellants, Part One
176(C)	Solid Propellants, Part Two (U)
177	Properties of Explosives of Military Interest
178(C)	+Properties of Explosives of Military Interest, Section 2 (U) (REPLACED BY -177)
179	Explosive Trains
180	*Principles of Explosive Behavior
185	Military Pyrotechnics, Part One, Theory and Application
186	Military Pyrotechnics, Part Two, Safety, Procedures and Glossary
187	Military Pyrotechnics, Part Three, Properties of Materials Used in Pyrotechnic Compositions
188	*Military Pyrotechnics, Part Four, Design of Ammunition for Pyrotechnic Effects
189	Military Pyrotechnics, Part Five, Bibliography
190	*Army Weapon System Analysis
191	System Analysis and Cost-Effectiveness
195	*Development Guide for Reliability, Part One, Introduction, Background, and Planning for Army Mate[illegible]iel Requirements
196	*Development Guide for Reliability, Part Two, Design for Reliability
197	*Development Guide for Reliability, Part Three, Reliability Prediction
198	*Development Guide for Reliability, Part Four, Reliability Measurement
199	*Development Guide for Reliability, Part Five, Contracting for Reliability
200	*Development Guide for Reliability, Part Six, Mathematical Appendix and Glossary

No. AMCP 706-	Title
201	*Rotorcraft Engineering, Part One, Preliminary Design
202	*Rotorcraft Engineering, Part Two, Detail Design
203	*Rotorcraft Engineering, Part Three, Qualification Assurance
205	*Timing Systems and Components
210	Fuzes
211(C)	Fuzes, Proximity, Electrical, Part One (U)
212(S)	Fuzes, Proximity, Electrical, Part Two (U)
213(S)	Fuzes, Proximity, Elect[illegible]ical, Part Three (U)
214(S)	Fuzes, Proximity, Electrical, Part Four (U)
2[illegible]5(C)	Fuzes, Proximity, Electrical, Part Five (U)
235	*Hardening Weapon Systems Against RF Energy
239(S)	*Small Arms Ammunition (U)
240(S)	Grenades (U)
241(S)	*Land Mines (U)
242	Design for Control of Projectile Flight Characteristics (REPLACES -246)
244	Ammunition, Section 1, Artillery Ammunition--General, with Table of Contents, Glossary, and Index for Series
245(C)	Ammunition, Section 2, Design for Terminal Effects (U)
246	+Ammunition, Section 3, Design for Control of Flight Characteristics (REPLACED BY -242)
247	Ammunition, Section 4, Design for Projection
248	+Ammunition, Section 5, Inspection Aspects of Artillery Ammunition Design
[illegible]	Ammunition, Section 6, Manufacture of Metallic Components of Artillery Ammunition
[illegible]	Guns--General
[illegible]	Muzz[illegible] Devices
[illegible]	[illegible]un Tubes
[illegible]	[illegible]ctral Characteristics of Muzzle Flash
[illegible]	[illegible]omatic Weapons
[illegible]	Propellant Actuated Devices
280	Design of Aerodynamically Stabilized Free Rockets
281(SRD)	Weapon System Effectiveness (U)
282	+Propulsion and Propellants (REPLACED BY -285)
283	Aerodynamics
284(C)	Trajectories (U)
285	Elements of Aircraft and Missile Propulsion (REPLACES -282)
286	Structures
290(C)	Warheads--General (U)
291	Surface-to-Air Missiles, Part One, System Integration
292	Surface-to-Air Missiles, Part Two, Weapon Control
293	Surface-to-Air Missiles, Part Three, Computers
294(S)	Surface-to-Air Missiles, Part Four, Missile Armament (U)
295(S)	Surface-to-Air Missiles, Part Five, Countermeasures (U)
296	Surface-to-Air Missiles, Part Six, Structures and Power Sources
297(S)	Surface-to-Air Missiles, Part Seven, Sample Problem (U)
327	Fire Control Systems--General
329	Fire Control Computing Systems
331	Compensating Elements
335(SRD)	*Design Engineers' Nuclear Effects Manual, Volume I, Munitions and Weapon Systems (U)
336(SRD)	*Design Engineers' Nuclear Effects Manual, Volume II, Electronic Systems and Logistical Systems (U)
337(SRD)	*Design Engineers' Nuclear Effects Manual, Volume III, Nuclear Environment (U)
338(SRD)	*Design Engineers' Nuclear Effects Manual, Volume IV, Nuclear Effects (U)
340	Carriages and Mounts--General
341	Cradles
342	Recoil Systems
343	Top Carriages
344	Bottom Carriages
345	Equilibrators
346	Elevating Mechanisms
347	Traversing Mechanisms
350	Wheeled Amphibians
355	The Automotive Assembly
356	Automotive Suspensions
357	Automotive Bodies and Hulls

*UNDER PREPARATION--not available

**REVISION UNDER PREPARATION

+OBSOLETE--out of stock