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RELIABILITY CONCEPTS

Reliability Handbook

Volume - I

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APRIL 1962

MASTER

Aerojet-General[®] CORPORATION

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AEROJET-GENERAL CORPORATION

RELIABILITY HANDBOOK

VOLUME I - CONCEPTS*

Report No. 2258

April 1962

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* Volume II - Reliability Methods is issued under separate cover.

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FOREWORD

The Aerojet-General Corporation Reliability Handbook is issued in two volumes: Volume I - Concepts, and Volume II - Reliability Methods. This handbook has been prepared for the purpose of providing uniform concepts, methods, and standards of performance that will serve as guidelines in the formulation and implementation of reliability problems for all plants, divisions, projects, and sub-contractors of the Aerojet-General Corporation. Moreover, this handbook is intended to conform with all relevant military specifications and major customer requirements for reliability and sound contractual performance. Revisions of the Reliability Handbook will be issued when required or as improved concepts and methodology are developed.

Grateful acknowledgment is made to D. L. Dewing, who developed the basic concepts and prepared the original issue of Volume I; to the members of the Corporate Reliability Assurance staff, who prepared Volume II and the current version of Volume I; and to other personnel throughout Aerojet who contributed numerous supporting ideas and comments.

W. E. Campbell
Director of Reliability and Quality

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1 PRODUCT LIFE CYCLE

SECTION 1

INTRODUCTORY CONCEPTS

1.1 In order to properly interpret this manual, it will be necessary for the reader to have an understanding of reliability, its measurement, and the means through which it is achieved. Consequently, an attempt is made in the next few paragraphs and other sections of this document to provide this information.

1.2 DEFINITION OF TERMS

Considerable confusion has been caused by the lack of a standard definition of reliability, quality, and other related terms. To minimize this condition, a standard glossary of terms is included in Section 10 and it is expected that this glossary will be accepted and used by all personnel concerned in the interpretation of this handbook.

1.3 DEFINITION OF RELIABILITY

Reliability has different meanings to different people. Although there have been many definitions of reliability, almost all include the same four basic elements of probability, performance, environment, and time. In this handbook, reliability is defined as the probability that a product will perform its intended function for a specified period of time when used under specified environmental conditions. It is the antithesis of failure during use. Reliability is one of the two important attributes of a weapon system's effectiveness, the other attribute being capability. The Mahon Subcommittee* defined capability as pertaining to the damage inflicted upon the target when a weapon functions as intended, reliability as pertaining to the probability that a weapon will function as intended, and the effectiveness as roughly proportional to the product of these two.

A probability is the likelihood that an event will occur, expressed as a fraction between 0 and +1. Reliability is normally expressed as the probability of success, but may also be expressed in translated terms as mean time

* "Mahon Subcommittee Report on Reliability Efforts in Ballistic Missile Programs," April 21, 1958

between failures (MTBF), failure rate per 1000 hrs., or other ways as appropriate for the case in hand. Reliability is a product characteristic which can be built into a product by means of a deliberate control effort in all phases of contracting, design, manufacture and use. In other words, reliability is the value achieved by the designer and the faithfulness with which the design is executed, both in manufacture and in use.

1.4 INCREASED IMPORTANCE OF RELIABILITY

Reliability is a major factor in weapon system planning, management, and engineering. The problem of building a product to perform a specified function is not new. However, as products become more and more complex, the problem of building a reliable product has become more and more difficult. The addition of a compressed time dimension has added to the complexity of an already complex problem. A significant number of weapon systems have failed to achieve the required reliability in the time scheduled and at the estimated cost. Consequently, military planning has been upset, funds have been expended that might have been applied to more productive projects, and the operational use of weapon systems has been postponed, thereby diminishing our nation's military strength.

A few years ago, discussions of earth satellites, rocket trips to the moon or other planets was considered to be in the realm of science fiction. Today, man has advanced far into this endeavor. The chances of his getting back alive depends upon our ability to produce reliable equipment. Moreover, the task of producing reliable power for the space age is aggravated by the growing stringency of requirements for systems performance and accuracy. Increased efforts of reliability are made mandatory not only because of the increased complexity, increased performance and safety requirements, but also because of many other factors such as the high cost of weapon systems, the small quantity of products being manufactured, the requirements for accuracy, the more severe and unknown environments, the telescoping of research, development, manufacturing and test time, and, of course, last but not least, the need for qualitative superiority in the cold war.

1.4.1 A CONTRACTUAL REQUIREMENT

In recognition of past difficulties and the increasing importance of producing reliable equipment, the defense and space agencies are making

equipment reliability requirements a part of the contractual agreement. Moreover, reliability requirements are being stated numerically. For example, "the reliability of the equipment shall be at least 95% and it shall be demonstrated with a confidence of at least 90%." In addition, the contracting agencies are requiring a planned reliability effort to provide assurance that the contractor and supporting organizations will, in fact, deliver adequately reliable equipment at the end of the R and D and/or production program.

1.5 CAUSES OF UNRELIABILITY

Unreliability is the probability of failure and may be expressed numerically as 1 minus the reliability of the product. Chief causes of unreliability in complex equipment are:

- 1.5.1 Inadequate design attributable to one or more of the following:
 - a. Insufficient knowledge of the operational and non-operational environments.
 - b. Errors introduced in translating system requirements into design criteria.
 - c. Failure to accommodate adequately in the design for starting loads and transients and for interactions of adjacent components resulting from internal and external stress environments.
 - d. Failure to eliminate possibilities of occurrence for human errors in product manufacture and use.
 - e. Presence of uncontrollable wear and failure to minimize opportunities for such wear.
 - f. Use of unreliable components and parts.
 - g. Misapplication of parts.
 - h. Undue complexity of design.
 - i. Failure to provide adequate safety margins.
 - j. Inadequate testing of the design prior to release; includes use of test equipment with insufficient accuracy and precision.

1.5.2 Non-conformance of fabricated product to design standards attributable to:

- a. Use of improper material through incorrect purchase or application.

b. Use of machines, tooling, and other equipment with inadequate accuracy and precision.

c. Improper assembly.

d. Operator error.

e. Inadequate or faulty inspection.

1.5.3 Failure to use the product in accordance with design intent:

a. Overstress of equipment in non-operating state due to accidental drop, improper storage, etc.

b. Overstress of equipment during operational checkout due to loads in excess of design criteria.

c. Other operator error.

d. Use of equipment in jobs or missions for which it was not designed.

1.5.4 Failure to provide positive data collection, analysis, and feedback system so that modes of failure can be identified and eliminated or controlled.

1.6 OBJECTIVES OF A RELIABILITY PROGRAM

The primary objectives of a reliability program are to assure that:

a. Company products will perform their intended function safely and with the required level of reliability.

b. The customer will be satisfied with the reliability of Company products and the overall reliability program to the extent that he will purchase and repurchase Company products and services and so that the reputation of the Company as a reliable contractor will be maintained.

c. The total cost of achieving reliability goals for Company products will be comparable to or less than that for competitive products.

1.7 SCOPE OF RELIABILITY PROGRAM

A reliability program cannot be restricted to the design phase but must extend throughout the life cycle of a product from the very first operational planning of a system through contracting, research, development, testing, procurement, fabrication, assembly, inspection, packaging, shipping, storage, maintenance, and use. It must include the surveillance and integration of the

reliability effort of associate contractors, subcontractors, and vendors. It must have tangible effects upon both the technical and management activities of personnel in practically all departments of the Company.

1.8 ELEMENTS OF A RELIABILITY PROGRAM

A reliability program consists of the following elements which are described in the indicated sections of this handbook:

- a. A reliability project plan for each project giving reliability goals and the methods for the achievement and demonstration thereof. (See Section 3.2.5)
- b. A list of all required reliability assurance and control functions and the assignment of authority and responsibility for each function. (See Sections 2.1, 3.1, ..., 8.1)
- c. An organization and personnel capable of performing functions assigned. (See Section 2.2.3)
- d. Standards of performance and methods for performing each function. (See Sections 2.2, 3.2, ..., 8.2 and Sections 2.3, 3.3, ..., 8.3)
- e. Orientation and training in the performance of these functions. (See Section 2.2.10)
- f. Provision for the coordination and integration of all reliability control functions. (See Section 2.2.6)
- g. Budget control of all reliability control activities. (See Section 2.2.8)
- h. Management reports on reliability status and problems. (See Section 2.2.7)
- i. Audits of Reliability Assurance Program. (See Section 2.2.9)
- j. Corrective action. (See Section 2.2.13)

1.9 PROGRAM ORGANIZATION

The overall program must reveal an appreciation of reliability and the necessity for an organized approach for the attainment thereof. The reliability organization should reflect an important position in the overall organization. Any reliability program requires the full support and vigorous leadership of

top management in order to infuse a spirit of reliability consciousness throughout the entire group. A reliability program requires careful, detailed management and strong technical leadership and direction.

1.10 PROGRAM COSTS

The principal benefit of a comprehensive reliability program to the Company and the customer is the savings in cost. The requirements, as established in this manual, may be difficult to meet and may appear to conflict with the speedy development and production of a missile. Experience indicates, however, that a soundly conceived and faithfully executed reliability program will result in earlier attainment of a truly operational weapon system at the lowest possible cost. The attainment of high inherent design reliability requires additional engineering testing and controls which increases engineering time and development costs. This is particularly true where the contract calls for a statistically valid demonstration of reliability achievement. The higher the reliability goal, the greater will be the cost of achieving and demonstrating the required design reliability and of preventing reliability degradation during manufacture and use. A sound reliability program and the active participation of reliability specialists early in a missile program, however, can produce substantial savings in the overall time and money expended to achieve a specified level of reliability by:

- a. Minimizing the amount of redesign and design changes required.
- b. Reducing the number of tests required to obtain a specified amount of information by using statistically designed experiments.
- c. Avoiding over-design in non-essential areas.
- d. Achieving early isolation and solution of reliability problems through the use of reliability analysis-prediction techniques.
- e. Simplifying the design.
- f. Making intelligent trade-off considerations utilizing operations analysis techniques.
- g. Reducing the amount of scrap and the number of defective or discrepant units.
- h. Reducing the amount of rework required.

- i. Reducing the amount of spare parts required.
- j. Reducing the amount of maintenance required.
- k. Reducing the number of mission aborts.
- l. Conserving manpower, technical skills, and costs by proper assignment of functions and elimination of duplication.
- m. Reducing performance testing by using improved techniques in reliability prediction.
- n. Utilizing all available data to its maximum at the earliest date.
- o. Using a scientific approach to the solution of major Company problems.

1.11 BENEFITS OF A CORPORATE RELIABILITY PROGRAM

In a multiplant organization there are certain advantages of having a corporate reliability assurance program in addition to the plant, division, or project programs as indicated below.

1.11.1 A uniform approach to reliability among all divisions of the Company.

1.11.2 Lower total program costs: Reliability research, preparation of standard policies and procedures, reliability training, public relations on reliability, etc., can be accomplished by a small but competent central group, instead of being duplicated in each plant, division, or project.

1.11.3 Improved customer relations: Provides a central point of contact for the customer on major policy instructions and communications. The customer will understand the corporate program and will be assured of the type of reliability treatment on new contracts, regardless of what division, project, or organizational group of the Company is involved.

1.11.4 Meets customer requirements: Most customers have requested and prefer an overall Company program for reliability in addition to the reliability activity on individual projects. For example, MIL-R-27542 (USAF) states: ...

"3.3.3.1 Reliability Organization.- The program plan shall identify the organization responsible to management

for the over-all reliability function and shall clearly define its responsibility for both policy and action. It shall stipulate the authority delegated to this organization to enforce its policies and assure necessary action. Line organization responsibilities and the relationship between line, service, staff, and policy organizations for reliability shall be identified."

1.11.5 Interchange of data and information: A considerable amount of data and information is available in each project and division, and a vast amount of such information is received from external sources. A means of communicating the pertinent data and information among the several divisions of the Company is essential to prevent duplication of effort in many areas.

1.11.6 Reduces duplication: Since Company plants share common customers, suppliers, test equipment and other facilities and services, reliability problems will arise among divisions and a means for coordination is desirable. Proper coordination should reduce duplications of effort among plants in inspection, testing, and other areas.

1.11.7 Retention of specialists: Without a corporate program, reliability specialists are hired and trained for a given project. When that project is completed, when funds are reduced, or when it reaches the production stage, the reliability specialists are disseminated throughout the organization. Thus, a new project must start from scratch in building a reliability engineering group. There should be a means of retaining reliability specialists on reliability work, and this can be accomplished by a corporate and plant-wide coordination program.

1.12 ULTIMATE DETERMINING FACTORS FOR RELIABILITY

Although there are numerous factors which determine the reliability level achieved in a product, the ultimate determining factors are:

- a. Adequacy of the product design and associated design documentation.
- b. Conformance of delivered product to design specification.
- c. Appropriateness of product use.

{ The relative importance and quantitative relationships of these factors for specific situations are discussed below.

1.12.1 INHERENT DESIGN RELIABILITY (R_d)

Inherent design reliability (R_d) (see FIGURE 1*) is the reliability potential of the design prior to any degradation in manufacturing or use. It is the success rate that would be obtained at any given time if the design were frozen and an infinite number of products were manufactured exactly in accordance with that design and properly used under the specified environment. Reliability must be considered as one of the important design characteristics and must be inherent in the final design. Improvement in reliability is best accomplished in the early stages of development and test; consequently, the maximum reliability effort should be concentrated in that area. Moreover, reliability must be given timely and adequate consideration in all phases of product research, development, design, test, and procurement. Emphasis on design for reliability must continue until the result is a completely mature design of the hardware suitable for manufacture and use in the operational environment. The reliability of the design is reflected in the design standards.

Inherent design reliability may be improved in many ways including:

- a. Use of reliable components and parts.
- b. Proper application of parts.
- c. Simplification of the design.
- d. Derating of parts.
- e. Appropriate use of redundancy.
- f. Use of environmental controls.
- g. Use of failed parts analysis.
- h. Use of statistical techniques in the design of test programs and analysis of test data.
- i. Isolation of weakest link failures by increased severity testing.
- j. Provision for adequate safety margins between stress and strength distributions.
- k. Implementation of periodic design reviews by specialists.
- l. Aggressive monitoring of product reliability growth and feedback of collected information.

* FIGURE 1 is located at the end of this handbook.

- m. Use of standard approved products.
- n. Adequate qualification of non-standard parts.
- o. Completion of any required corrective action.

1.12.2 MANUFACTURING RELIABILITY (R_m)

Reliability of manufacturing (R_m) is the probability that there will be no degradation of the inherent design reliability during the manufacturing of the product. Manufacturing includes procurement, fabrication, assembly, and delivery of a product to the customer. Maintaining the control of reliability during fabrication requires a planned production, quality control, and testing program. In order to assure that the reliability of a product will not be degraded during manufacturing, it is necessary to maintain:

- a. A supplier selection and control program to assure that the suppliers are capable of achieving and maintaining the required level of performance.

- b. A high level of manufacturing skill and an effective quality control program in the factory which will ensure that the inherent design reliability of each item (or as much of this value as is feasible) is preserved during the manufacturing process.

1.12.3 USE RELIABILITY (R_u)

Use reliability (R_u) is the probability that there will be no degradation of inherent equipment reliability (R_e)* during operational use. Operational use includes all treatment to the product from the time it is delivered to the customer until it is finally used or consumed, and includes transporting, handling, storing, preflight inspection, checkout, maintenance, repair, etc. Use reliability may be improved by the establishment of proper operating and maintenance procedures, training of all operating and maintenance personnel, proper monitoring of all field operations, properly defined field inspection and testing, analysis of field failures, failed parts analysis, and corrective action.

1.12.4 OPERATIONAL RELIABILITY (R_o)

Operational reliability (R_o) is the probability that a product

 * NOTE: $R_e = R_d \times R_m$

will give satisfactory performance for a given period of time when used in the manner and for the purpose intended. This is the reliability actually achieved in operational use and is the value with which we are most concerned. Unless specified otherwise, the term reliability will be used to mean operational reliability. Operational reliability is the product of the inherent equipment reliability and the use reliability, or it is the product of the inherent design reliability, the reliability of manufacturing, and the reliability of use, that is,

$$R_o = R_d \times R_m \times R_u.$$

1.13 RESPONSIBILITIES OF CORPORATE, PLANT, AND PROJECT MANAGEMENT IN THE ACHIEVEMENT OF RELIABILITY GOALS

Corporate, plant, and project management should provide the mechanics and professional stimulus necessary to assure the timely achievement of reliability goals. This includes provision of the plans, organization, facilities, controls, and human motivations required. The purpose of this effort is not to treat the reliability function as a new and unique discipline, but rather to infuse new thinking and better techniques into the existing organizational structure, subject to the surveillance or coordination of reliability efforts to assure that all aspects of the reliability program are reviewed, considered, and resolved.

As a key participant in the reliability assurance program, management should:

- a. Manifest a genuine interest in reliability goals and problems.
- b. Infuse a spirit of Company-wide concern for the achievement of reliability goals.
- c. Provide firm monetary support and strong technical leadership for program activities.
- d. Provide guides for the formulation and conduct of the reliability program, including the identification of tasks or functions to be carried out and the assignment of responsibilities for their completion.
- e. Establish basic systems and policies for reliability.
- f. Establish methods for coordinating and integrating all reliability activities into a unified program.

These functions are closely related to the reliability control functions discussed in Section 1.14 following. Further details on the role of management in the reliability program are given in Section 2 of this Handbook.

1.14 PRINCIPAL AREAS OF RESPONSIBILITY

There are six principal areas of responsibility for the achievement of reliability:

- a. Contracting.
- b. Design.
- c. Procurement.
- d. Fabrication or assembly.
- e. Product delivery.
- f. Use.

(See outer circle, FIGURE 1*.) These primary functions are required whether the products being made are simple or complex.

1.14.1 CONTRACTING

The contract is a legal and binding agreement between the customer and contractor. This requires a concise and definitive statement of all contract requirements, including performance, environment, reliability, life, documentation, etc. These requirements must be compatible with one another, with other design parameters, and with the capability of the contractor and the state of the art. Requirements for additional funds, equipment, manpower, etc., must be considered, and corrective action taken when necessary.

1.14.2 DESIGN

This area includes the research, development, and testing necessary to provide drawings, specifications, and related documents which describe the product, incoming materials, methods of processing, testing, etc. The design should be compatible with the performance and reliability requirements, and should properly reflect the usage environment. Provisions must be made in the design for producibility, maintainability, human factors, storing, packaging, transporting, handling, etc., to make sure that the desired level of operational reliability will be achieved.

* FIGURE 1 is located at the end of this handbook.

Design Engineering plays a key role in the design control program, having the prime responsibility for achieving a product design with adequate inherent reliability. Design Engineering receives substantial support in this work from Reliability Engineering and other organizational groups of the Company.

1.14.3 PROCUREMENT

The procurement area consists of all functions connected with obtaining from suppliers and subcontractors reliable materials and parts which are consistent with the design standards.

1.14.4 FABRICATION

Fabrication or assembly consists of making or assembling the product in accordance with the design standards.

1.14.5 PRODUCT DELIVERY

Product delivery includes all operations involving the product from the time the product is manufactured or assembled until it is delivered to the customer in satisfactory condition. This includes final acceptance of the product, testing, packaging, preservation, in-plant shipping, handling, transportation, storage, etc.

Procurement, fabrication or assembly, and product delivery constitute the manufacturing area of responsibility at any time during the life cycle of a product from the first prototype through mass production.

1.14.6 USE

Use includes all events and operations involving the product from the time of delivery to the customer until the product is consumed or used, and includes handling, transporting, storage, checkout, etc., as well as actual use.

Unsatisfactory performance in any one of the above areas will cause degradation of product reliability, and will jeopardize chances of the product conforming fully to contract requirements.

1.15 RELIABILITY CONTROLS

For each area of prime responsibility, certain controls or special assistance may be necessary to assure that all functions are performed satisfactorily, and that errors are reduced to an insignificant value. Each control consists of establishing standards of performance, checking conformance to these standards, and taking corrective action when deviations from these standards are found. It may also consist of approving, reviewing, auditing, coordinating the work of those having prime responsibility, or providing special assistance in these fields.

The controls for the six primary functions consist of contract control, design control, incoming material control, process control, product control, and field control. These are shown in the second circle of the life cycle chart (FIGURE 1*) which we will call the "Control Loop." The sum of all of these controls will be referred to in this manual for convenience as "Reliability Controls."

In the case of a simple product, very few controls are necessary, and can probably be accomplished by primary line departments. Some receiving inspection, process controls, and final inspection might be desirable for simple products, but it is unlikely that any controls would be necessary in the contract, design, or field areas other than those normally performed by the departments having prime responsibility.

In the case of more complex items such as guided missiles, however, the line departments are usually not able to perform all of the functions, and special controls necessary for the achievement of high reliability and specialized assistance must be provided by personnel who are skilled in such techniques as reliability engineering, quality engineering, field services, etc. These control groups should be positioned in the organization in such a manner as to permit them to perform their control functions harmoniously and without bias. The control functions required in each of the six areas will vary somewhat with different products, different organizations, etc. However, the necessary control functions must be determined for each product and responsibility must be

* FIGURE 1 is located at the end of this handbook.

assigned for the performance thereof. An important part of the control loop is the collection, analysis, evaluation, and feedback of information to the proper source for corrective action as illustrated by the arrows in FIGURE 1*.

1.16 RELIABILITY ASSURANCE (MANAGEMENT CONTROL)

In addition to the establishment of adequate controls in the six prime responsibility areas which we have called "reliability controls", provisions must be made for the proper coordination and integration of these functions, if the desired level of reliability is to be assured. This function which we will call "reliability assurance", is primarily a management function and consists of the coordination of the planning, organization, assignment of functions, staffing, training, reporting, and budgeting of all reliability control functions.

In the case of simpler products or smaller divisions, the overall reliability assurance function may be satisfactorily performed by division or assistant division managers. For more complicated products and larger divisions, special staff assistance should be provided and given specific responsibility for the coordination of all reliability control activities.

1.17 ALLOCATION OF RESPONSIBILITIES

One of the principal parts of a reliability program is the assignment of responsibility and the delegation of commensurate authority to the proper organizational unit. This will stimulate the performance of the necessary control functions to meet reliability goals and to satisfy the customer, at the lowest possible cost. Only one person or organizational unit can have primary responsibility for the performance of a function, although others may share in this responsibility by approving, auditing, coordinating, or providing assistance. Responsibility should be assigned only to a person or group having capability of performance (manpower, knowledge, or equipment). It is also necessary that the proper time for the performance of these functions be indicated and enforced.

Sections 2.1, 3.1, ..., 8.1 of this handbook present lists of assurance and control functions, together with suggested assignments of responsibility and time of performance. These assignments are suggestions only, and are not

* FIGURE 1 is located at the end of this handbook.

intended to be inflexible, since the proper assignment must vary with the organization, type of product, and capability of the organizational units of the division concerned.

It is the responsibility of the Plant Manager or his designated reliability coordinator to assign responsibilities for these functions as a part of the reliability program for his plant. These functions may be broken down further if desired, and additional functions may be added. Sections 2.2, 3.2, ..., 8.2 give suggested standards of performance for each function, while Volume II of the Reliability Handbook entitled "Reliability Methods" contains applicable technical methods for attaining these standards.

1.18 ELEMENTS AND CHARACTERISTICS OF RELIABILITY ENGINEERING

Reliability Engineering is an engineering specialty in the same sense as is Stress Analysis, Materials Engineering, Systems Engineering, etc. It is used in many organizations as a management control function which assures that the product design conforms to contract reliability requirements. It should be pointed out that the Reliability Engineering (organizational) group is not necessarily expected to perform all reliability engineering control tasks since certain of these tasks may fall into adjoining work and organizational areas. However, the principal effort of Reliability Engineering is applied to the product design and its evolution; consequently, this effort is design oriented and may be effectively applied to the contract control and design control functions described in Sections 3 and 4 of this handbook.

There is no standard assignment of the reliability engineering function in the reliability organization structure. It may be a part of Quality Control, Plant Management, Project Management, Project Engineering, or Manufacturing. Moreover, it may be performed wholly by a staff group or it may work closely with Project Engineering and be assigned line responsibilities, or it may be assigned both staff and line responsibilities.

In those instances where Reliability Engineering is established as an organizational group, key reliability tasks may include:

- a. Preparation of reliability program plans.
- b. Completion of a reliability analysis of each candidate engineering design considered in developing the initial system design.

- c. Prediction of initial system reliability.
- d. Apportionment of system reliability requirements to sub-systems, components, etc.
- e. Formulation of reliability testing programs.
- f. Development and implementation of a reliability data collection, analysis, and feedback system.
- g. Monitoring of reliability growth.
- h. Provision of documentary evidence of proof of compliance to reliability requirements.

1.19 CLARIFICATION OF SOME CLOSELY RELATED TERMS

In concluding this discussion of introductory concepts, it seems appropriate first to clarify the significance of the term quality, then to consider the association of this concept with reliability, and finally to comment briefly upon the interpretations and use made in this handbook of the activities associated with the quality control and reliability engineering functions. Because of the loose terminology existing at the present time, particular emphasis should be given to the establishment of a clear understanding of the differences between functional and organizational activities.

The current looseness in terminology is a natural cause arising from the adaptive processes of an industrial organization to meet growth and changing technological requirements simultaneously. It is well known that in the early days of the Industrial Revolution the entrepreneur was more of an artisan who designed the product, made it himself, and acted as his own salesman. As the company grew, however, he had to relinquish many of the duties which he performed himself and instead was forced to concentrate on the management control of his enterprise. The historical growth of the Quality Control organization reflects, therefore, the natural growth of an industrial organization. It came into being as a check and a balance factor on other activities, such as development, procurement, and manufacturing, to assist in management control.

Initially, this activity was restricted to an inspection and screening process, with many of the present technical functions being accomplished with varying degrees of effectiveness through the associated efforts of Design Engineering, Manufacturing, and Plant Management. Because of the greater sim-

plicity of the product and smaller size of the enterprise, the elements of potential confusion over program and task responsibilities were at a minimum.

However, as product complexity increased and performance and reliability requirements became more stringent, a need developed for new and increasingly specialized engineering and management techniques. Management's first remedial action was to apply several specialized quality control techniques developed by Shewhart, Dodge, Romig, Fisher, and others. These techniques included: sampling plans for acceptance inspection, control charts for monitoring the quality of in-process material, design of experiments for machine-capability studies, tests of hypotheses, etc. Later, Management directed attention to the utilization of available reliability improvement techniques. New organizational groups such as Quality Engineering, Quality Assurance, and Reliability Engineering were successively established to assure maximum utilization of new techniques as they became available.

The addition of these new organizational elements to the industrial enterprise, meant that certain of the old quality and reliability control functions previously associated with Design Engineering, Manufacturing, Management, and other plant groups, were now to be reassigned according to Management's revised operational policies. It was with these evolutionary steps that inconsistencies and confusion were encountered, for these reassignments were not handled in a common manner by each industrial enterprise. Moreover, the older segments of the industrial enterprise were reluctant to relinquish functions which by history and precedent had been their sole possession.

This situation has, in fact, been one of the principal reasons why this handbook has been prepared. Moreover, it is believed that by following and implementing the principles set forth in this document, that much of the confusion among industrial personnel as to how they contribute to product quality, including reliability, will be dispelled.

1.19.1 DEFINITION OF QUALITY

As a characteristic, quality, like reliability, may be defined in several different ways. For example, it is sometimes defined as the degree of conformance of material to drawing and specification requirements. More

broadly, one may speak of the quality of the design, the quality of procurement or manufacture as related to the drawing requirements, the quality of performance of the product in the field, etc. Moreover, the quality of a specific characteristic may vary from a highly acceptable level to a completely unacceptable one.

For the purposes of this handbook, quality is defined as the degree of conformance of a product to:

- a. Design standards (drawings, purchase specifications, etc.), and
- b. Customer requirements of performance, reliability, and cost.

1.19.2 RELATIONSHIPS BETWEEN PRODUCT QUALITY AND PRODUCT RELIABILITY

With the broad definition of quality given above, product reliability is considered as a quality characteristic in the same sense as product performance and product cost.

It is noteworthy that Feigenbaum¹, a nationally recognized authority in the field of reliability and quality control, enumerates several individual characteristics of a product which, together, make up the composite of product quality. Characteristics which are considered to be elements of product quality include reliability, serviceability, maintainability, attractability, and cost. For example, the product is not reliable unless it is able to perform its intended function as called upon over its entire life cycle and under the intended conditions and environments of use. Furthermore, customer satisfaction is diminished by a product that is not readily maintainable and serviceable. Customer satisfaction is also influenced by the esthetic features of the product, hence, it must have attractability. When all such product characteristics affecting customer satisfaction, including cost, are in balance, "optimum quality" is achieved.

1.19.3 ROLE OF QUALITY CONTROL

Under the concept of "total quality control" expressed by

¹Feigenbaum, A. V., Total Quality Control, Engineering and Management, McGraw-Hill, 1961

Feigenbaum, quality control is a set of management control functions which assures that all quality characteristics, including reliability, serviceability, maintainability, attractability, performance, and cost, conform to customer expectations. This definition of the quality control function is to be used in the interpretation of this handbook.

Historically, Quality Control as an organization has never performed all of the control functions noted above which are required to assure conformance to product quality requirements. There were logical reasons for this in the past. These reasons exist at the present, and no doubt will continue to prevail in the future. In evidence of this, many of these control functions at Aerojet are assigned to organizational groups other than the Quality Control Division, with the result that the Quality Control organization is primarily engaged in activities which will ensure conformance of material to design standards. These standards give criteria for the procurement, manufacture, shipping, field handling, storage, field checkout, and use of the product.

In recognition of the similarity in end objectives of Reliability Engineering and Quality Control, it has been found effective in some instances to assign the functions of reliability engineering and quality engineering to a single organization such as the Reliability and Quality Control Division.

1.19.4 RECAPITULATION

All of the principal organizational groups of the Company must contribute to product reliability, and, more broadly speaking, to product quality. In an even more important way they assure, through integrated planning and action, an optimization of all important product factors: namely, performance, reliability, maintainability, serviceability, attractability, and cost.

In summary then, a quality product will be achieved if

- a. The product is correctly designed.
- b. The manufactured product conforms to design standards.
- c. The product is properly handled, correctly packaged, packed, shipped, and stored.
- d. The product is used correctly in the field, and

e. All related factors including cost, are sufficiently in balance to meet customer expectations.

Finally, while terms such as those used in this section (Section 1.19) need to be defined to enhance proper understanding and communication, the matter of primary consequence is to identify all important quality and reliability tasks to be performed, to assign individual responsibilities for each, and then see to it that each is accomplished. When this is done, any existing disagreements over semantics should assume minor value.

SECTION 2

RELIABILITY ASSURANCE (MANAGEMENT CONTROL)

This section provides detailed information on the role which corporate, plant, and project management should play in the planning, conduct, audit, and control of reliability programs. Several of these functions are to be performed prior to the detailing of a specific reliability program. Other functions are performed at various points in the reliability program. Pertinent material is presented according to the following outline:

- 2.1 Reliability assurance functions and suggested assignments of responsibilities
- 2.2 Standards of performance for reliability assurance functions
- 2.3 Reliability methods for reliability assurance functions

LEGEND FOR SECTION 2.1

DEGREE OF AUTHORITY AND RESPONSIBILITY

P = Prime authority = Has responsibility for satisfactory completion of task

A = Approval authority = A series function - may accept or reject work or action of (P)

R = Review authority = Reviews and requests corrective action from (P) when required

S = Supporting services = Provides requested services for (P)

TIME OF PERFORMANCE BY PRODUCT MATURITY

1. Detailed design study
2. Preprototype (design 95% complete)
3. Prototype (design firm)
4. Preproduction demonstration (PFRT)
5. Demonstration of service readiness (qualification tests)
6. Service evaluation (flight tests)
7. Full scale production (acceptance tests)
8. Demonstration of major product improvement

Suggested Assignments of Responsibility

2.1 RELIABILITY ASSURANCE FUNCTIONS
(MANAGEMENT CONTROL)

		RELIABILITY ASSURANCE FUNCTIONS (MANAGEMENT CONTROL)											Time-Phase							
		Customer or Cust. Rep.	Contract Adm. or Sales	Director R. & Q./Staff	Plant Manager	Project Engineering	Test	Material	Manufacturing	Reliability Engineering	Quality Control	Technical Services	1	2	3	4	5	6	7	8
2.1.1	Prepare reliability plan for each project	A	R	S	A	A			P	S			x	x	x	x	x	x	x	x
2.1.2	Assign responsibility for all reliability control functions			R	P								x	x	x	x	x	x	x	x
2.1.3	Organize and staff for reliability control functions			R	P								x	x	x	x	x	x	x	x
2.1.4	Establish standards of performance for reliability control functions																			
2.1.4.1	Corporate wide			P	R	P														
2.1.4.2	Plant wide			R	P															
2.1.5	Establish reliability methods			P		S	S	S	S	S	S		x	x	x	x	x	x	x	x
2.1.6	Coordinate												x	x	x	x	x	x	x	x
2.1.6.1	Interplant reliability activities and problems			P	S															
2.1.6.2	Intraplant reliability activities and problems		S	S	P	S	S	S	S	S	S									
2.1.6.3	Corporate wide public relations on reliability		S	P	S															
2.1.6.4	Plant or project public relations on reliability		S	S	P				S											
2.1.6.5	Reliability information interchange among plants		S	P	S	S	S	S	S	S	S									
2.1.6.6	Reliability information interchange within plants		S	S	P	S	S	S	S	S	S									
2.1.7	Provide management reports on reliability																			
2.1.7.1	Corporate reports			P	S				S	S	S		x	x	x	x	x	x	x	x
2.1.7.2	Plant reports				S	S			P	S	S		x	x	x	x	x	x	x	x

2.1 RELIABILITY ASSURANCE FUNCTIONS
(MANAGEMENT CONTROL)
(Continued)

Suggested Assignments of Responsibility

2.1		RELIABILITY ASSURANCE FUNCTIONS (MANAGEMENT CONTROL) (Continued)																		
		Customer or Cust. Rep.	Contract Adm. or Sales	Director R. & Q./Staff	Plant Manager	Project Engineering	Test	Material	Manufacturing	Reliability Engineering	Quality Control	Technical Services	Time-Phase							
													1	2	3	4	5	6	7	8
2.1.8	Budget control for plant reliability activities		R	P	S				S				x	x	x	x	x	x	x	x
2.1.9	Audit of reliability program		R	P					S	S	S		x	x	x	x	x	x	x	x
2.1.10	Orientation and training		P	S					S	S			x	x	x	x	x	x	x	x
2.1.11	Provide system for equipment calibration and control	R	A	P	S	S	S	S	S	S	S		x	x	x	x	x	x	x	x
2.1.12	Provide system for data collection, analysis, and feedback	R	A	P	S	S	S	S	S	S	S		x	x	x	x	x	x	x	x
2.1.13	Provide system for corrective action	R	A	P	S	S	S	S	S	S	S		x	x	x	x	x	x	x	x

2.2 STANDARDS OF PERFORMANCE FOR RELIABILITY ASSURANCE FUNCTIONS (MANAGEMENT CONTROL)

2.2.1 RELIABILITY PROGRAM PLAN

A reliability plan or proposal should be prepared for each project. Specific features and contents of such plans are discussed in Section 3.2.5.

2.2.2 ASSIGNMENT OF RESPONSIBILITY FOR RELIABILITY CONTROL FUNCTIONS

The reliability control functions essential for any reliability program are set forth in Sections 3.1, 4.1, ..., 8.1 of this handbook. The plant manager or his appointed reliability coordinator should review the functions listed therein with the cognizant supervisory personnel of his plant, and assign responsibility for the performance of these functions to the several organizational groups of his plant. Wherever possible, the assignment should be identical to that suggested in part one of Sections 2 through 8 so that optimum uniformity may be maintained among all reliability programs of the Company. It is assumed that the authority delegated to organizational groups will be commensurate with each assigned responsibility. If necessary, the list of functions may be broken down further to facilitate the assignment of responsibility, and additional functions may be added if required. However, all functions listed should be considered for each plant, division, and project. The degree of responsibility assigned for each function and the time for its performance should be indicated in accordance with Sections 3.1, 4.1, ..., 8.1.

2.2.3 ORGANIZATION AND STAFFING FOR RELIABILITY CONTROL FUNCTIONS

If there is to be uniformity among reliability organizations of the several plants, divisions or projects, there must be consistency in the assignments of the reliability control functions. Some deviations may be desirable, however, in recognition of differences in basic organization, group capabilities, facilities, etc. The important criterion is that each organizational group has the capability (personnel, knowledge, equipment, facilities, funds, etc.) to discharge its assigned responsibilities. Each organizational group should be staffed with personnel who have the necessary knowledge, experience, and training to perform the functions assigned. If this is not the

case, personnel should be hired or transferred into the group concerned, or existing personnel should be trained to perform these functions.

The plant manager or designated reliability coordinator is responsible for reviewing the assignment of functions relative to the capability of the organizational group concerned, and for reporting any discrepancies to the division heads concerned. If the discrepancy is not corrected in a reasonable length of time, corrective action should be initiated. Corrective action should consist of assigning necessary personnel, equipment, funds, etc., to the group as required to perform the function, or of transferring the function to some other organizational group.

2.2.4 STANDARDS OF PERFORMANCE

Suggested standards for the performance of each of the reliability control functions are given in Sections 3.2, 4.2, ..., 8.2 of this handbook. These standards are intended to comply with all relevant military specifications and major customer requirements and apply to all plants, divisions and projects. They should be reviewed by the plant manager or his designated reliability coordinator and supplementary standards should be prepared as necessary to implement the reliability programs in each plant.

2.2.5 RELIABILITY METHODS

A reliability research program should be conducted in order to make available the best possible technical methods to facilitate the performance of the essential control functions. This program should be concerned not only with the development of new reliability methods but also with the adaptation of existing theory considered beneficial to Company use.

Some of the important problem areas in which effective methods would be extremely helpful in promoting reliability include:

- a. Contracting for reliability.
- b. Building reliability into the design.
- c. Monitoring reliability (specifying, apportioning, estimating, predicting, measuring, demonstrating, etc.).
- d. Test planning and evaluation.
- e. Data processing and evaluation.

- f. Sampling.
- g. Improving accuracy and precision of reliability data.
- h. Preventing reliability degradation during manufacture and use.

- i. Accelerated reliability and life testing.

2.2.6 COORDINATION

2.2.6.1 Interdivisional Reliability Activities and Problems

The Corporate Director of Reliability is responsible for the coordination of reliability activities and problems concerning more than one plant. For this purpose periodic meetings should be held by the Director of Reliability with plant reliability representatives to exchange reliability information, promote uniform reliability concepts and thoughts, and to coordinate interplant reliability problems and other reliability activities which affect more than one plant.

2.2.6.2 Intradivisional Reliability Activities and Problems

The plant manager or the designated reliability coordinator in each plant is responsible for the coordination of all reliability control activities within his respective plant, and for assuring that reliability problems affecting more than one division or department are properly coordinated. To assist him in this function, a coordination committee should be set up, consisting of the plant manager or the reliability coordinator with the managers of the departments responsible for the performance of the several reliability control functions. This committee should meet periodically to discuss intra-plant policy and problems affecting product reliability. Problems that affect more than one plant should be referred to the Director of Reliability.

2.2.6.3 Corporate Public Relations on Reliability

Liaison between the Company and outside agencies on reliability matters affecting more than one plant should be conducted by the Director of Reliability or by others who do so with his knowledge and approval. This will include general liaison with such groups as the AIA, IAS, and military agencies. Visitors, correspondence, and inquiries on such matters should be referred to the Director of Reliability for action.

2.2.6.4 Plant, Division, or Project Public Relations

Liaison and public relations with an outside agency on reliability problems specifically related to the projects undertaken by a plant should be handled by the plant manager or his designated reliability coordinator or, with his knowledge and approval, by reliability engineers of the project. Copies of all correspondence affecting such meetings, interviews, etc., should be given to the plant reliability coordinator.

2.2.6.5 Reliability Information Interchange Among Plants

All reliability information of corporate-wide interest which is received from outside sources should be forwarded to the Director of Reliability who is responsible for dissemination of such information to the reliability coordinators of all divisions. Any such information received within a division should be collected by the reliability coordinator and forwarded to the Director's technical staff. This will include reliability progress reports, reliability information on components and parts, component parts specifications, reliability and statistical techniques, educational material bibliographies, data lists, new design techniques for reliability, etc.

2.2.6.6 Reliability Information Interchange Within Plants

All reliability information pertaining to a particular plant should be routed to and filed by the reliability coordinator of the plant concerned. Separate project files should be established as necessary. It is the responsibility of the reliability coordinator to make sure that such information is communicated to all cognizant departments in his division.

2.2.7 MANAGEMENT REPORTS

Reliability progress reports should be issued periodically by each project which compare the reliability status of the project with reliability goals, give summaries of part, component and system failures, and describe important reliability problem areas. A plant-wide summary of these reports should be made under the direction of the plant reliability coordinator and copies forwarded to the Director of Reliability, who will prepare and issue

a corporate summary report. Such reports will be primarily for Company use and will normally be in addition to those reports specifically requested by the customer.

2.2.8 BUDGET CONTROL

As indicated in Section 3.2.5.4, a budget should be prepared as a part of each reliability project plan. This budget should indicate the funds required for the completion of each task assignment. Actual costs of performance for each task assignment should be compiled through the normal project accounting system and compared with the budget at the end of each month by the reliability coordinator. In case of major discrepancies, corrective action should be taken. A copy of the deviations from budget and the reasons therefor should be compiled as part of the monthly progress report by the reliability coordinator.

In addition, a report showing the total costs of product assurance in a plant and the losses resulting from inadequate control should be compiled on a periodic basis. These costs should include total labor, material, and overhead for all product assurance functions, which include inspection, testing, quality control, field service, reliability engineering, and reliability assurance. Losses should include such items as scrap, defective and substandard product, rework wages, material usage variance, inventory adjustments for quality reasons, returned goods, and customer allowances.

2.2.9 AUDITING THE RELIABILITY ASSURANCE PROGRAM

The plant manager or his designated reliability coordinator, with the assistance of auditing services available within the company, should be responsible for auditing all product assurance activities on a periodic basis. The standards of performance for the essential control functions detailed in Sections 3.2 to 8.2 of this handbook should be used as a guide or standard for the audit. A re-audit should be made quarterly on all deficiencies found. Continuous follow-up should be made on major discrepancies until corrective action is taken.

2.2.10 RELIABILITY ORIENTATION AND TRAINING

One of the major causes of unreliability is human error. This

can be reduced through the proper selection of personnel, the preparation of adequate procedures, and personnel training. Therefore, a comprehensive training program should be provided all employees whose work has a significant effect upon the final reliability of the product. This program should consist of these five parts: reliability orientation, instruction in the use of selected reliability methods, training in special skills for assigned functions, promotion of reliability consciousness, and project orientation.

A suggested training program follows in Section 2.2.10.1.

2.2.10.1 Suggested Program for Training

	<u>Rel. Orien- tation</u>	<u>Pertinent* Reliability Methods</u>	<u>Special Skills of Assigned Functions</u>	<u>Reliability Con- sciousness</u>	<u>Proj. Orien- tation</u>
Corporate management personnel	x				
Customers and customer representatives	x				x
Reliability policy board	x				
Management personnel	x				
Corporate reliability assurance staff	x		x		x
Reliability coordinators	x	x			x
Reliability engineers	x	x			x
Quality engineers	x	x	x		x
Contract administrators	x	x	x		
Customer relations personnel	x	x	x		
Research personnel	x	x	x		
Project engineers	x	x	x		
Test engineers	x	x	x		
Purchasing	x	x	x	x	
Subcontractors and suppliers	x			x	
Receiving inspectors			x	x	
Production operators			x	x	
Process inspectors			x	x	

(continued)

* "Pertinent methods" include only those which will be used by the group indicated.

Suggested Program for Training (continued)

	<u>Rel. Orien- tation</u>	<u>Pertinent Reliability Methods</u>	<u>Special Skills of Assigned Functions</u>	<u>Reliability Con- sciousness</u>	<u>Proj. Orien- tation</u>
Final inspectors and test technicians			x	x	
Shipping, warehouse, and traffic personnel			x	x	
Field service personnel	x	x	x	x	x
Field operating and main-tenance personnel			x	x	x

2.2.10.2 Reliability Orientation

The purposes of reliability orientation are to:

- a. Promote an understanding of reliability concepts.
- b. Create an appreciation of the importance and need for an organized reliability program.
- c. Explain the benefits of an effective reliability program to the Company.
- d. Explain to all employees, whose work contributes significantly to product reliability, the corporate and division reliability programs, how each individual or group fits into the program, their responsibilities and expected contributions.

The reliability orientation program should be conducted by the plant manager or his appointed reliability coordinator through the distribution of copies of the reliability handbook, presentation of lectures, use of training films, etc.

2.2.10.3 Reliability Methods

The purpose of the training program on reliability methods is to promote the use of those methods which are most beneficial to Company programs which result from reliability research, either within the Company or from outside sources. Training in reliability methods should be conducted by competent reliability experts through dissemination of reliability handbooks,

and by conducting lectures, seminars, and training courses as required. Technical groups should be trained in those reliability methods which are pertinent to their assigned functions. For example, designers should be trained in techniques useful in designing for reliability; contract personnel in methods pertaining to contracting for reliability; test personnel in reliability testing; manufacturing and inspection personnel in methods relating to the prevention of reliability degradation during manufacturing; field personnel in methods pertaining to prevention of degradation of reliability during use; etc.

2.2.10.4 Special Skills

Training in special skills is for the purpose of improving the technical ability of all groups in their assigned functions which affect the reliability of the product. Responsibility for such technical training rests with the cognizant department supervisors and may be conducted through supervised training on the job in addition to formal and informal lectures and training courses.

2.2.10.5 Reliability Consciousness

The purpose of the reliability consciousness program is to improve product reliability through the promotion of reliability consciousness on the part of employees who fabricate, assemble, test, or handle the product in any way by explaining to them the relationship between their acts and the ultimate effectiveness of the Company's products. Training in reliability consciousness is the responsibility of the department supervisors, but requires the coordination of a reliability coordinator in promoting the use of posters, films, group meetings, etc.

2.2.10.6 Project Orientation

The purpose of this program is to orient all employees in specific knowledge of products as required to do their jobs most effectively. Project orientation is the responsibility of the project engineers and should be conducted through illustrated lectures, test demonstrations, etc. Such training should be arranged through a reliability coordinator.

2.2.11 SYSTEM FOR CONTROL AND CALIBRATION OF TEST EQUIPMENT

The system established by cognizant management personnel for the control and calibration of test equipment and should be capable of fulfilling the following requirements:

2.2.11.1 Measuring Devices

Unless otherwise specified in the contract, sufficient measuring devices should be provided and maintained to assure that all materials and supplies will conform to contract requirements. Measuring devices include: inspection gages; test instruments and equipment; production equipment which is used as media of inspection such as jigs, fixtures, control instruments, recording instruments, etc.; and any other device used to judge the performance, quality or reliability of products, materials or supplies at any time during the life cycle. Measuring devices include inspection and test equipment used in supplier's plants and in the field as well as in the plant.

2.2.11.2 Calibration of Measuring Devices

All such measuring devices should be calibrated against a measurement standard at established periods to assure continued accuracy and precision. A written schedule for the maintenance and calibration of such equipment based on the type, purpose, and degree of usage, should be available. This should include or refer to proper instructions for the nature of checks, the frequency of checks, allowable tolerances, etc. A written record of the dates of calibration and corrective action taken should be maintained.

2.2.11.3 Measurement Standards

Calibration as in Section 2.2.11.2 above should be traceable through plant secondary and primary measurement standards to the National Bureau of Standards. All plant primary and secondary calibration standards should be recalibrated according to an established schedule and should bear an appropriate sticker or other evidence of proper and current calibration.

2.2.11.4 Deliverable Material

All tests or inspections for the determination of reliability at any stage of the life cycle of a product which is to be delivered to the cus-

tomer should be performed only with measuring devices properly calibrated in conformance with the above policy.

2.2.12 SYSTEM FOR DATA COLLECTION, ANALYSIS AND FEEDBACK

One of the most important parts of a reliability program is the collection and processing of pertinent data with prompt feedback through line channels to obtain preventive or corrective action prior to the time the product reaches the customer or the field.

To facilitate the completion of this task, a data center should be established with responsibility for collecting, collating, processing, analyzing, summarizing, filing, and reporting reliability and quality data. One data center might serve more than one plant if desired.

The data system should preferably include the use of automatic equipment. Data should be processed and presented in a form which has optimum convenience and use to the several interested departments of the plant. The data system should be standardized sufficiently to facilitate sharing of common reliability data among the several plants, divisions, or projects of the company. The same data may also be automatically processed in the prescribed standard format required for delivery to the cognizant procurement activity in accordance with the terms of the contract.

The data center should process pertinent quality and reliability data wherever it may be generated throughout the life cycle of a product.

A Data Committee consisting of a member of the corporate reliability staff, with a member from each of the plant data centers, should be appointed. This committee should have the purpose of determining adequate data systems throughout the Company, standardizing such data systems where desirable, and exchanging data as desirable between the several plants.

The plant manager, or his appointed reliability coordinator, in each plant, with the assistance of the Data Committee, should determine the data that should be collected from each of the control areas in his plant; he should also determine the format and distribution for the reports being issued to various departments for evaluation, corrective or preventive action, and

reliability monitoring. A handbook of reliability data on common materials, parts, components, or products used by the Company should be maintained by a central group.

2.2.13 SYSTEM FOR CORRECTIVE ACTION

One of the key elements of the reliability assurance program is the data feedback and corrective action system. The life cycle chart, Figure 1*, illustrates the closed-loop feedback system. For each functional activity - contracting, design procurement, fabrication, delivery, and use - a control function is associated: contract control, design control, incoming material control, process control, product control, and field control.

One of the responsibilities of each control group is to collect necessary data from the operating area, analyze this data, and feed back the results to the groups having primary responsibility for taking corrective action. Deficiencies found in other areas are referred to the cognizant control group, which in turn follows up on corrective action. For example, a design error detected by the process control group during manufacturing should be referred to the design control personnel, who should in turn follow up on corrective action with the designer. The follow-up function is a very important aspect of the corrective action procedure and should be continued until a final solution has been reached relative to any discrepancy observed.

In addition to the corrective action taken on problems pointed out by day-to-day analysis of data, the Data Center should issue periodic reports for analysis and evaluation by the several control groups who will look for cumulative, systematic, or pattern failures, and other problems of a longer range.

The normal day-to-day reliability problems (such as sudden adverse changes in product reliabilities or departures from normal failure rates) can be properly handled through the corrective action system indicated above. However, for nearly every project, there are certain reliability problems (such as parts or components with high constant failure rates) which have been considered normal because of the long history of failures. Quite often, prob-

* Figure 1, Product Life Cycle Chart, is located at the end of this handbook.

lems of this kind are the maximum causes of product unreliability, and reliability can be improved only by making a major break-through in these areas. A break-through of this type requires that each division have a systematic approach for the solution of major reliability problems which will utilize the best talent and resources available within the division or corporation.

To assure timely and effective solutions to such problems, a Diagnostic Group should be appointed. This group would:

- a. Make a thorough reliability analysis of the product.
- b. List all components or parts where the achieved or predicted reliability is appreciably less than the reliability goals assigned.
- c. Assign priorities to the list based on an evaluation of the effect of these components or parts to the unreliability of the overall weapon system. (If this information is not available, other methods for establishing priorities may be used, such as total dollar loss resulting from failures, etc.)
- d. Select those few components or parts from the top of the priority list which contribute most to the unreliability of the system. (Usually a very few components are found to contribute most to the unreliability in a system or subsystem.)
- e. For the selected components, analyze all relevant past history and records to determine time and location of failures, modes of failure, causes of failure, corrective action taken, effectiveness of corrective action taken, etc.
- f. Classify the causes of failure, first by operating areas such as design, manufacturing, or use, and then by subdivisions under each of these, such as human errors, equipment errors, material failures, etc., and continue to resubdivide as necessary in order to separate the major causes from the minor ones.
- g. Isolate the major problems causing failures on the highest priority components, then establish a problem priority list according to the contribution to the unreliability of the system.
- h. Review the priority list of problems and initiate any obvious corrective action.

- i. Initiate planned experiments in an endeavor to isolate the true cause of failure, if the cause of failure is not known and the failure in question is a major contributor to unreliability.

The Diagnostic Group should establish such controls as are necessary to prevent recurrence of the problem. Periodic reports should discuss the status of these problems until a final solution has been reached. The problem list should be revised upon the completion of each reliability analysis to assure that the most critical problems are getting priority of attention.

2.3 RELIABILITY METHODS FOR RELIABILITY ASSURANCE CONTROL

Reliability methods developed for application to the reliability assurance control program are presented in Volume II of this handbook.

As an example, the reliability method RM 400-2 which follows may be utilized in auditing the reliability program.

RELIABILITY METHODS

<i>Aerojet-General</i> CORPORATION		RM 400-2
AZUSA, CALIFORNIA	SACRAMENTO, CALIFORNIA	PAGE 1 of 8
SUBJECT: AUDIT OF RELIABILITY PROGRAM		DATE OF ISSUE 2-15-62

PURPOSE:

To present a method for auditing a reliability program.

DISCUSSION:

The instructions presented may be applied in auditing reliability programs of suppliers, subcontractors, other companies, or any division of Aerojet-General.

Sections 2 through 8 of Volume I of the Aerojet-General Corporation Reliability Handbook, together with contract requirements established by the customer and the supplementary policies and procedures established by the plant, division, or project being audited, constitute the guide lines of standards for the audit. Seven categories should be rated: reliability assurance control, contract control, design control, incoming material control, process control, product control, and field control. These categories are considered to have equal importance in the overall reliability programs. Items to be rated are the essential reliability control functions for each category. These items are shown on the audit forms presented for each category, and are identical to those listed in Volume I of the Reliability Handbook. The number preceding each item is the number of the section which discusses the minimum performance standards for the corresponding function. Audit forms as presented should be used for all reliability program audits, and all auditors should be familiar with the area being audited.

PROCEDURE:

Each auditor should grade each item on the form according to the following instructions:

Column R - This is a "Reliability Factor", and indicates the importance of this item to the achievement of reliability in the specific plant and for the specific products being rated. If the performance of this item is considered to be very important or critical to reliability achievement, place "1" in Column R; if the effect is considered slight or nil, place "0" in Column R; if the effect is somewhere in between, place 1/2 in Column R; and if the item is not necessary or required for this plant or product, place "NA" - Not applicable - in this column.

Column M is the maximum rating that can be given for each item and depends upon the grade given in Column R. The relationship is as follows:

If Column R is	Column M is
1	14
1/2	9
0	4
NA	0

RELIABILITY METHODS

SUBJECT: AUDIT OF RELIABILITY PROGRAM	RM 400-2
	PAGE 2 OF 8

Column C is the coverage or completeness with which the function is performed in the plant concerned, and should be graded as a one-place decimal fraction between 0 for "No Performance", to 1 for "Complete Performance".

Column E is the effectiveness with which the function is performed in the given plant and is graded from 0 for "Ineffective" to 10 for "Effective".

Column P is the conformance to all applicable policy and procedures (see item 10.2.4 above) and is graded 2 for "Complete Conformance", 1 for "Partial Conformance", and 0 for "Non-Conformance".

Column "e" is the efficiency or cost with which the function is performed and is graded 2 for "Satisfactory Efficiency", 1 for "Partially Inefficient" and 0 for "Grossly Inefficient".

Column S is the score for each item and is computed from the equation
 $S = (RCE) + P + e$.

The score for each category is computed as a percent satisfactory by dividing the total of Column S by the total of Column M, multiplied by 100. The total score for the plant is computed by dividing the grand total of Column S by the grand total of Column M, and multiplying by 100. A score of 100% indicates that the plant or division being rated is performing all functions affecting the reliability of all its products completely, effectively, according to all rules and regulations, and at the lowest possible cost.

EXAMPLE:

Suppose that after investigation, we find that one of the items is 70% complete, 90% effective, policy is partially followed, and the cost is reasonable. The four possible ratings for the item based on the four grades of "R" would be as follows:

$$\begin{array}{rcl}
 (R \times C \times E) + P + e & = & S \quad M \\
 (1)(.7)(9) + 1 + 2 & = & 9 \quad 14 \\
 (1/2)(.7)(9) + 1 + 2 & = & 6 \quad 9 \\
 (0)(.7)(9) + 1 + 2 & = & 3 \quad 4 \\
 NA \quad -- \quad -- \quad -- & = & 0 \quad 0
 \end{array}$$

RELIABILITY PROGRAM AUDIT (CHECK LIST)

Score

 $(\frac{S}{M} \times 100)$

2.2 Reliability Assurance (Management Control)

(R x C x E) + P + e = S M

- 2.2.1 Reliability plan for each project
- 2.2.2 Assignment of responsibilities
- 2.2.3 Organization and staffing
- 2.2.4 Standards of performance
- 2.2.5 Reliability methods
- 2.2.6 Coordination of RA functions
- 2.2.7 Reports
- 2.2.8 Budget control
- 2.2.9 Program audit
- 2.2.10 Orientation and training program
- 2.2.11 System for control and calibration of test equipment
- 2.2.12 System for data collection, analysis and feedback
- 2.2.13 System for corrective action

(	)	+	+	=		
(	)	+	+	=		
(	)	+	+	=		
(	)	+	+	=		
(	)	+	+	=		
(	)	+	+	=		
(	)	+	+	=		
(	)	+	+	=		
(	)	+	+	=		
(	)	+	+	=		
(	)	+	+	=		
(	)	+	+	=		
(	)	+	+	=		
(	)	+	+	=		

Total

--	--	--

Score

 $(\frac{S}{M} \times 100)$

3.2 Contract Control

(R x C x E) + P + e = S M

- 3.2.1 Contract requirements
- 3.2.2 Critical requirements list
- 3.2.3 Tradeoff considerations
- 3.2.4 Clarification of contract
- 3.2.5 Reliability proposal or plan
- 3.2.6 Reliability monitoring system
- 3.2.7 Proof of compliance
- 3.2.8 Orientation and training (customer, Contract Adm., Cust. Rel.)
- 3.2.9 Corrective action on contract deficiencies)

(	)	+	+	=		
(	)	+	+	=		
(	)	+	+	=		
(	)	+	+	=		
(	)	+	+	=		
(	)	+	+	=		
(	)	+	+	=		
(	)	+	+	=		
(	)	+	+	=		

Total

--	--	--

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Score
$$(R \times C \times E) + P + e = S M \left(\frac{S}{M} \times 100 \right)$$

(	) +	+ =
(	) +	=
{	} +	+ =
{	}	+ =
{	}	+ =
{	}	+ =
{	}	+ =
{	}	+ =
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(	) +	=
{	} +	+ =
{	}	+ =
(	) +	+ =
{	} +	+ =
{	}	+ =
{	}	+ =

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RELIABILITY PROGRAM AUDIT
(CHECK LIST)

Score

5.2	<u>Incoming Material Control</u>	(R x C x E) + P + e = S M	($\frac{S}{M} \times 100$)
5.2.1	Standards for incoming material	() + + =	
5.2.2	Supplier or subcontract requirements	() + + =	
5.2.3	P.O.'s on subcontracts	() + + =	
5.2.4	Inspection and test equipment	() + + =	
5.2.5	Receiving or source inspection	() + + =	
5.2.6	Supplier evaluation and selection	() + + =	
5.2.7	Supplier rating	() + + =	
5.2.8	Supplier certification	() + + =	
5.2.9	Supplier surveillance and assistance	() + + =	
5.2.10	Approved supplier list	() + + =	
5.2.11	Preferred products list	() + + =	
5.2.12	Orientation and training (suppliers, receiving inspection, purchasing)	() + + =	
5.2.13	Calibration of inspection and test equipment	() + + =	
5.2.14	Inspection and test procedures	() + + =	
5.2.15	Acceptance or rejection (experimental)	() + + =	
	Acceptance or rejection (deliverable)	() + + =	
5.2.16	Identification of incoming materials	() + + =	
5.2.17	Control of discrepant materials	() + + =	
5.2.18	Segregation of materials	() + + =	
5.2.19	Data collection, analysis, and feedback	() + + =	
5.2.20	Corrective action with supplier (feedback)	() + + =	
Total			

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RELIABILITY PROGRAM AUDIT (CHECK LIST)

		Score				
		$(\frac{S}{M} \times 100)$				
6.2	Process Control	(R x C x E) + P + e = S M				
6.2.1	Process specifications	() + + =				
6.2.2	Workmanship standards	() + + =				
6.2.3	Process controls	() + + =				
6.2.4	Process capability studies	() + + =				
6.2.5	Pilot runs	() + + =				
6.2.6	Adequate process equipment	() + + =				
6.2.7	Inspection and test equipment	() + + =				
6.2.8	Waste control	() + + =				
6.2.9	Certification of special processes and operators	() + + =				
6.2.10	Orientation and training (production operators, process inspectors)	() + + =				
6.2.11	Calibration of inspection and test equipment	() + + =				
6.2.12	Acceptance inspection methods and procedures	() + + =				
6.2.13	Acceptance or rejection of in-process materials (experimental)	() + + =				
	Acceptance or rejection of in-process materials (deliverable)	() + + =				
6.2.14	Identification of in-process materials	() + + =				
6.2.15	Control of discrepant in-process materials	() + + =				
6.2.16	Segregation of in-process materials	() + + =				
6.2.17	Data collection, analysis, and feedback	() + + =				
6.2.18	Corrective action	() + + =				
Total						

RELIABILITY PROGRAM AUDIT
(CHECK LIST)

Score

7.2 Product Control

- 7.2.1 Acceptance inspection equipment
- 7.2.2 Inspection and testing of product
- 7.2.3 Design of packaging
- 7.2.4 Package testing
- 7.2.5 Packaging procedures
- 7.2.6 Shipping instructions
- 7.2.7 Warehouse and shipping inspection
- 7.2.8 Packaging and preservation of outgoing product
- 7.2.9 Orientation and training (final inspectors, shippers, packers, handlers, etc.)
- 7.2.10 Calibration of acceptance inspection equipment
- 7.2.11 Acceptance inspection methods and procedures
- 7.2.12 Acceptance or rejection of product
- 7.2.13 Identification of product
- 7.2.14 Control of discrepant product
- 7.2.15 Segregation of products
- 7.2.16 Data collection, analysis, and feedback
- 7.2.17 Corrective action

(R x C x E) + P + e = S M		
() + + =		
() + + =		
() + + =		
() + + =		
() + + =		
() + + =		
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() + + =		
() + + =		

 $\left(\frac{S}{M} \times 100\right)$

Total

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RELIABILITY PROGRAM AUDIT (CHECK LIST)

						Score	
		(R x C x E) + P + e = S M				$(\frac{S}{M} \times 100)$	
8.2	<u>Field Control</u>						
8.2.1	Operating manuals and procedures	(	)	+	+	=	
8.2.2	Field maintenance procedures	(	)	+	+	=	
8.2.3	All field operations	(	)	+	+	=	
8.2.4	Preflight inspection or testing	(	)	+	+	=	
8.2.5	Field failures and customer complaints	(	)	+	+	=	
8.2.6	Usage environments	(	)	+	+	=	
8.2.7	Technical assistance to customer or customer representative	(	)	+	+	=	
8.2.8	Contractor-furnished support equipment	(	)	+	+	=	
8.2.9	Spare parts	(	)	+	+	=	
8.2.10	Failed parts analysis (field)	(	)	+	+	=	
8.2.11	Flight testing	(	)	+	+	=	
8.2.12	Orientation and training (field service and customer personnel)	(	)	+	+	=	
8.2.13	Calibrate field equipment	(	)	+	+	=	
8.2.14	Acceptance inspection methods and procedures	(	)	+	+	=	
8.2.15	Acceptance or rejection of product	(	)	+	+	=	
8.2.16	Control of discrepant product	(	)	+	+	=	
8.2.17	Data collection, analysis, and feedback	(	)	+	+	=	
8.2.18	Corrective action	(	)	+	+	=	
Total							

SECTION 3

CONTRACT CONTROL

Contract Control is a type of management control which assures (a) a valid and realistic contract containing clear statements of the customer's requirements and contractor's obligations, and (b) the contractor's full and efficient compliance to these requirements.

Detailed information for this control is presented in this section according to the following outline:

- 3.1 Contract control functions and suggested assignments of responsibilities
- 3.2 Standards of performance for contract control functions
- 3.3 Reliability methods for contract control functions

LEGEND FOR SECTION 3.1

DEGREE OF AUTHORITY AND RESPONSIBILITY

- P = Prime authority = Has responsibility for satisfactory completion of task
- A = Approval authority = A series function - may accept or reject work or action of (P)
- R = Review authority = Reviews and requests corrective action from (P) when required
- S = Supporting services = Provides requested services for (P)

TIME OF PERFORMANCE BY PRODUCT MATURITY

1. Detailed design study
2. Preprototype (design 95% complete)
3. Prototype (design firm)
4. Preproduction demonstration (PFRT)
5. Demonstration of service readiness (qualification tests)
6. Service evaluation (flight tests)
7. Full scale production (acceptance tests)
8. Demonstration of major product improvement

3.1 CONTRACT CONTROL FUNCTIONS

Suggested Assignments of Responsibility

												Time-Phase												
		Customer or Cust. Rep.	Contract Adm. or Sales	Director R. & Q./Staff	Plant Manager	Project Engineering	Reliability Engineering	Quality Control							1	2	3	4	5	6	7	8		
3.1	3.1.1	Establish contract requirements	P	R			A	R	R								x	x	x	x	x	x	x	x
	3.1.2	Determine critical requirements	R	R			P	S	S								x	x	x	x	x	x	x	x
	3.1.3	Establish trade-offs (reliability vs performance, weight, cost, schedule, etc.)	A			A	P	S,R									x	x	x	x	x	x	x	x
	3.1.4	Clarify and interpret contract	A	P			A	R	R								x	x	x	x	x	x	x	x
	3.1.5	Prepare project reliability plan or proposal	A	R	S	A	A	P	S								x	x	x	x	x	x	x	x
	3.1.6	Monitor reliability growth			S	A	R	P	S								x	x	x	x	x	x	x	x
	3.1.7	Furnish proof of compliance (documentation)	A	R		R	R	P	S								x	x	x	x	x	x	x	x
	3.1.8	Provide orientation and training (customer, Contract Adm., Customer Relations)		S	S	P		S	S								x	x	x	x	x	x	x	x
	3.1.9	Assure corrective action in contract control	S	P	S	R	S	S	S								x	x	x	x	x	x	x	x

3.2 STANDARDS OF PERFORMANCE FOR CONTRACT CONTROL FUNCTIONS

3.2.1 CONTRACT REQUIREMENTS

A contract is a legal agreement between the customer and the contractor. Consequently it is important that the contract specify clearly what is required. Contract requirements should specify as appropriate:

- a. Performance requirements.
- b. Reliability requirements.
- c. Maintenance requirements.
- d. Length of life requirements.
- e. Safety requirements.
- f. Field needs.
- g. Environmental conditions.
- h. Operating time and conditions.
- i. Test conditions and methods.
- j. Documentation and other material required for proof of

compliance, such as reporting requirements, acceptance criteria, etc.

All contractual documents, bids, requests for quotations, quotations, letters, work statements, referenced MIL specifications, etc., should be reviewed by a designated control group prior to, or as soon as possible after the issuance of the contract. The purpose of the review is to ascertain that all contract requirements are clear and complete, that the requirements are compatible with each other and with the funds allotted, and with the manpower, facilities, processing equipment, testing equipment, etc., which are available in the Company. If any inconsistencies are found as a result of the contract review, corrective action should be taken by obtaining changes in contract requirements, improving the process by adding equipment, manpower, funds, etc., or by reducing the reliability requirements. A discussion of some of these contract requirements follows.

3.2.1.1 Performance Requirements

Performance requirements indicate exactly what is expected of the system or equipment when used under given environmental conditions. These performance requirements are based on mission requirements as indicated by the

military departments for military equipment, and on end use for commercial items. Performance requirements should include operating time and life requirements. Tolerance limits for each performance requirement are required.

For certain equipment, the operational planning is so broad and the weapon system is so complex that specific performance requirements cannot be stated. In this case, a design study contract should be awarded and design objectives given rather than performance requirements. Design objectives should be translated into performance requirements upon completion of the study contract.

3.2.1.2 Environment

Total environment is defined as the aggregate of all the conditions and influences which surround the life cycle and operation of components including:

- a. Physical location.
- b. Operational characteristics of and interaction with adjacent parts.
- c. Conditions of the surrounding use mediums such as temperature, humidity, contamination, etc.
- d. Conditions of use such as acceleration, shock, vibration, noise, radiation, etc.
- e. Manufacturing and installation environments.
- f. Conditions related to operational use such as storage, handling, packaging, transporting, readiness to fire, checkout, etc.

The designated control group should review environmental requirements of the contract, including all referenced MIL specifications and other documents containing environmental test requirements to assure that the environmental conditions are correctly and completely specified, that they are realistic, and that tolerance limits are given where applicable. If the operational and non-operational environments are not specified by the customer, the contractor should be authorized and funded to identify and measure these environments.

3.2.1.3 Reliability Requirements

There is an increasing trend for contracts to include reliability requirements in numerical terms with associated confidence levels.

Delineations of these requirements should be associated with specific performance requirements under given environmental conditions and should indicate the operating time or life required. Such requirements should be realistic, timely, and capable of being revised as necessary. To avoid confusion and controversy, the method of demonstrating reliability requirements should also be in the specification, including type, amount, time and location of inspection and testing, acceptance criteria, definition of success, sampling requirements, etc. Numerical reliability requirements may be stated in terms of mean-time-between-failure (MTBF), failure rate per 1000 hours, or probability of success for a given time under specified conditions.

In certain cases it may not be possible to specify reliability requirements because of the lack of verification tests, or because of the excessive cost, but whenever they are used, the requirements should be fully compatible with the amount of testing specified and the funds allotted. Reliability may be specified either as the minimum acceptable value at a given point in the program (the design objective at a specified period in the program), or as a growth curve showing the reliability requirement with time.

The designated control group should review all numerical reliability requirements to assure that they are properly specified and are compatible with the funds and tests permitted. It should determine if these requirements are realistic by computing the improvement required in present reliability levels of existing or similar equipment to meet the reliability specification. This should include the reliabilities assigned to subsystems, components, and parts as feasible. If compatible, these reliability requirements should then be used for test planning, improving the design, evaluation of progress, comparison with other projects, location of problem areas, and the like.

When reliability requirements or goals are not given as part of the contract, they should be specified by the designated control group as soon as this is feasible, and used for internal Company reliability control.

3.2.1.4 Acceptance Criteria

The contract should clearly state the acceptance criteria for studies, services and/or products to be provided. Acceptance criteria are the

criteria for proving that the specification performance requirements are met. They include:

- a. Design test requirements.
- b. Performance limits.
- c. Tolerances.
- d. Accuracies of measurement.
- e. Acceptable quality level or acceptable reliability levels.
- f. Confidence levels.

The designated control group should assure that adequate acceptance criteria are available for determining the acceptability of material delivered to the customer. If this is not the case, corrective action should be taken.

3.2.1.5 Other Requirements

In addition to the requirements listed and/or explained above, contracts should specify package requirements, handling, and transportation requirements, storage requirements, applicable military specifications, materials to be furnished by the government and by the customer, field services required, and maintainability requirements. These requirements should also be reviewed by the cognizant control group, and made a part of their normal follow-up program.

3.2.2 CRITICAL REQUIREMENTS

After a review of all contract requirements, a list of those considered critical from the standpoint of reliability should be prepared and thoroughly evaluated. This list may include such items as:

- a. Performance requirements approaching the limit of the state of the art.
- b. Environmental conditions more severe than any previously tested for or encountered with existing equipment.
- c. Tolerances approaching the limit of the process capability of the plant.
- d. Reliability requirements or goals considerably higher than reliability predictions.

Critical requirements should receive priority in research and development test programs.

3.2.3 TRADE-OFFS

LN 9/25/68
Reliability requirements are based on operational requirements of the weapon system. An optimum balanced design is desired that will meet the actual needs of the operational requirements at the minimum cost. Consequently, trade-off considerations should be made against actual needs to obtain a balanced design that will prove to be the most effective for the service application. Other design parameters and contract requirements must be considered in addition to reliability, such as performance requirements, size, weight, cost, delivery schedule, accuracy, safety, maintainability, equipment serviceability, etc. Such trade-off considerations should be made on a mathematical or statistical basis to assure that the balanced design is the most effective for the service application.

3.2.4 CLARIFICATION AND INTERPRETATION

Every effort shall be made to avoid ambiguities in contracts. However, after a contract has been issued, if such ambiguities are found, it shall be up to Contract Administration to obtain clarification and interpretation. It is imperative that such clarifications and interpretations be disseminated to all persons concerned and be properly documented as part of the contract requirements.

3.2.5 RELIABILITY PLAN OR PROPOSAL

A specific reliability plan should be prepared for each project. Normally, this will be required by the customer as part of the contract proposal. In other cases, it may be included as a part of, or separated from, the regular development project plan as desired. The reliability plan should define what will be done under the contract to achieve and demonstrate reliability goals. It should include an initial reliability analysis, a task assignment schedule, and a budget as defined below.

3.2.5.1 Initial Reliability Analysis

The initial reliability analysis should preferably include:

- a. A review of reliability goals.
- b. A study of the relationship of reliability goals to other design parameters.
- c. A prediction of initial system reliability based on selected components and parts for two or more candidate designs.
- d. The computation of the expected reliability growth curve for the selected initial design.
- e. Determination of potential reliability problem areas.
- f. Suggestions for reliability improvements.

3.2.5.2 Task Assignment Schedule

The task assignment schedule should include a list of every task that will be performed to achieve and demonstrate the achievement of the reliability goals; a time-sequence schedule for the performance of each task; and assignments of responsibility for each task. The list may include all of the reliability program tasks described in this handbook.

3.2.5.3 Methods

Methods, techniques, procedures, controls, etc., should be collected or developed and implemented to facilitate the performance of each reliability task. (See Section 2.2.5)

3.2.5.4 Budgets

A budget, based on a best estimate of funds required to perform the proposed task assignments should be prepared as part of the plan for each project. The budget should distinguish between the normal reliability control functions required for any project and the special reliability demonstration and other reliability requirements of the contract in question. Additional information on budgeting may be found in Section 2.2.8.

3.2.6 MONITORING RELIABILITY GROWTH

Reliability monitoring is an important part of contract control. It is a design tool or concept by which reliability is quantitatively specified, apportioned to all elements of the product, predicted, assessed, estimated, or measured at predesignated times or monitoring points during the life cycle of a product. The estimate of product reliability when based on all

available data, can be compared with the established reliability goals to determine problem areas where design or processing improvement is required. It is a refinement in engineering practice which permits the calculation of the risks taken concerning design decisions, and is a valuable aid in the achievement of reliability goals. Reliability monitoring is continuous throughout all phases of a product's life cycle, and requires the collection, analysis, and feed-back of reliability information to the proper action activity and the appropriate follow-up on corrective action taken. No amount of monitoring will improve reliability unless it leads to improvement of the design, manufacturing, or field use of the product.

As part of the comprehensive reliability program, a continuous reliability monitoring system should be conducted for each project to include:

- a. Specifying reliability quantitatively for each system, subsystem, component, and part insofar as this apportionment is feasible and meaningful.
- b. Establishing monitoring points throughout the life cycle of the product for periodic formal reviews of reliability status.
- c. Estimating, assessing, or measuring reliability continuously during complete life cycle of the product so that the instantaneous reliability of the product or system can be described as precisely and accurately as possible. (This involves the use of reliability growth curves.)
- d. Performing reliability analysis at each monitoring point or oftener as required.
- e. Predicting reliability and comparing results with reliability goals.
- f. Demonstrating reliability achieved at designated points in the life cycle of the product as required by the contract.

3.2.6.1 Reliability Specifications

Reliability may be specified as a firm requirement or as a design objective. Quite often both a minimum requirement and a design objective is given for each stage of the life cycle or growth curve of the product. The reliability specification should give the probability of operational success

desired for each specific performance requirement, together with the confidence level and methods for the demonstration thereof.

3.2.6.1.1 Apportioning of Reliability Goals

The specified reliability values should be apportioned whenever feasible to each element of the product: subsystem, component and part, as indicated in Section 4.2.3.

3.2.6.2 Reliability Monitoring Points

Reliability should be evaluated or assessed at predesignated times or monitoring points during the life cycle of a product. The monitoring points recommended by the Office of the Secretary of Defense* consist of the following phases:

- a. Design study.
- b. Preprototype.
- c. Prototype.
- d. Preproduction demonstration.
- e. Demonstration of service readiness.
- f. Service evaluation.
- g. Full scale production.
- h. Demonstration of major product improvement.

The monitoring points should be established for a given project in advance as part of the reliability project plan. Applicable points from the above list should be selected for a given project, although others may be added if desired.

3.2.6.3 Estimation, Measurement, and Assessment of Reliability

3.2.6.3.1 Reliability Estimates

Inferential estimates of the reliability of products can often be made early in the design programs from an analysis of all the information available, such as reliability predictions; test results on parts and components; quality control acceptance inspection data; reliability data from similar parts

* Ad Hoc Group on Guided Missile Reliability (ACGMR), OSD Proposed Reliability Monitoring Program for Guided Missiles, April 1958

or components; etc. Experimental estimates of product reliability can be made from results of in-plant tests which simulate actual operational conditions. The state of the art at present is such that the methods of estimation are not always as precise and accurate as would be desired. However, useful estimates can be made early in the design phase and used for corrective action purposes before actual operational data are available.

3.2.6.3.2 Measurement of Achieved Reliability

Achieved reliability can only be measured under actual operational conditions. It may be defined as the ratio of the number of successful tests to the total test trials. However, useful estimates can be obtained from experimental tests when the correlation between simulated test conditions and actual operational conditions is known to be high.

3.2.6.3.3 Growth Curves

Growth curves showing the assessed reliability of a product should be maintained from the beginning of the program through development, qualification, production, use, and major product improvement. In this work it is important that all available applicable data be periodically integrated to provide the best possible estimate of reliability achievements.

3.2.6.4 Reliability Analyses

Reliability analyses consist of a thorough review of all reliability data and information available for a given project at each designated monitoring point in order to prepare a current prediction of operational reliability. This prediction is then compared against the assigned reliability goals to determine the principal reliability problems and the priority classification thereof. This information is necessary for the corrective action program (Section 2.2.13). Reliability analyses also provide information which can be used for:

- a. Determining whether or not reliability goals are realistic.
- b. Determining amount of maintenance and spare parts required.
- c. Monitoring the effectiveness of previous corrective action.
- d. Determining relationships between experimental estimates and achieved reliability.
- e. Evaluating trade-off design and contract parameters.

3.2.6.5 Reliability Predictions

Reliability predictions are made when the analyses indicated above provide adequate data. The first prediction is used to evaluate the original assignment of reliability goals, and later predictions are used to compare with the goals assigned. Predictions are indicators of the maturity of the design and the areas of over-design as well as under-design. All new reliability data or information is added to any previously collected or evaluated, so that a "best" estimate of instantaneous reliability is attained. The predictions become more accurate as the data becomes more plentiful, accurate, and precise.

Reliability project plans should indicate where reliability predictions are required, but in all products a reliability prediction should be made as part of the reliability analysis. The first reliability prediction should be made during the proposal stage, primarily to check on the establishment of realistic reliability goals and to indicate potential trouble areas. The second reliability prediction should be made during the hardware phase after certain stress-versus-strength data are obtained from testing of parts, components, etc. The third prediction should probably be made after the qualification test phase, but prior to field testing. The primary use of reliability prediction data is to obtain design information on product reliability prior to receiving data from field tests, so that corrective action can be undertaken as early in the development program as possible.

There are many methods of predicting reliability, several of which are described in this handbook. Reliability predictions vary with the product and data available, but may be based on:

- a. A complete system analysis considering the fabrication of each part, derating, operational environment, failure rate of standard parts, complexity of components, etc.
- b. The total number and types of parts used.
- c. Use of environmental stress curves.
- d. Use of mathematical failure models.
- e. The measured results of a sample tested under either actual or simulated environmental conditions.

f. The complexity of new equipment compared with the achieved reliability of existing equipment.

g. A knowledge of the environments to be used compared with achieved reliability under a known environment.

h. A starting reliability estimate or measurement, and estimating improvements due to design changes, etc.

3.2.6.6 Reliability Demonstrations

When quantitative reliability goals are specified in a contract, the method of demonstrating the achievement of these goals should be given. This may include the testing of a sufficient number of product units to prove compliance statistically for the confidence level stated under either simulated or actual operational conditions. It may include the testing of some units of product to failure; it may also include a reliability prediction based on test results of components, parts, or other elements of the product. It is important that all demonstration requirements be clearly specified in the contract or that provisions be made for defining these requirements early in the course of the contract.

Demonstration plans should be included in the reliability project plan or proposal and should include the method of demonstration including number of tests to be performed at each test site (plant, field, etc.); test conditions; statistical methods to be used in the analysis of test data; ground rules for classifying test outcomes as successes or failures, rules for including or excluding test data, etc.

3.2.7 PROOF OF COMPLIANCE

Proof of compliance is that action by a contractor which shows that all requirements of the contract have been fulfilled. It is a final accounting of the contract's execution and deliveries, indicating all approvals and waivers received. It may include a demonstration of reliability, but includes many other items which were required by the terms of the contract such as: certain test results, inspection reports, quality certifications, progress reports, and proof of quantity shipped including spare parts. Development contracts may also require such things as: engineering notebooks, manufacturing

drawings, ordnance classification of defects, installation drawings, operating and maintenance instruction manuals, and spare parts lists.

The designated control group should be responsible for preparing a check list of all such contract requirements at the beginning of each contract, for keeping this list current, and for maintaining follow-up on the compliance therewith in order to assure that all contract requirements are fulfilled to the satisfaction of the customer.

3.2.8 ORIENTATION AND TRAINING

(See Section 2.2.10)

3.2.9 CORRECTIVE ACTION

(See Section 2.2.13)

3.3 RELIABILITY METHODS FOR CONTRACT CONTROL

Reliability methods developed for application to the contract control program are presented in Volume II of this handbook.

Reliability methods RM 220-2b and RM 310-1 which follow are examples of methods that can be used to monitor reliability growth.

RELIABILITY METHODS

<i>Aerjet-General</i> CORPORATION		RM 220-2b
AZUSA, CALIFORNIA	SACRAMENTO, CALIFORNIA	PAGE
SUBJECT: ONE-SIDED (LOWER) CONFIDENCE LIMIT FOR A RELIABILITY		1 of 7
		DATE OF ISSUE
		3-1-60

PROBLEM:

To establish a lower confidence limit for the reliability of a population.

DISCUSSION:

The estimate of a reliability is subject to uncertainty due to sampling variation. A confidence interval is commonly used to designate the area of uncertainty by setting limits which have a specified probability of containing the true value. It may be desirable to set a 100% percent lower confidence limit only, which will have a probability γ , of being equal to or less than the actual reliability. Tables are presented in graphical form which give 50, 80, 90, 95, 99 and 99.5% lower confidence limits for 10 to 1000 trials with 0(1) 5(5) 50 observed failures. A 95% lower limit implies 95% assurance that the reliability is equal to or greater than the limit.

ASSUMPTIONS:

The reliability is estimated from a random sample from an infinite population. (A good approximation holds for populations down to 10 times the sample size.) Sampling variation follows the binomial distribution.

PROCEDURE:

From n trials, determine the number of failures c and successes $n - c$. The point estimate of reliability is $(n - c)/n$. Using the desired confidence level, select the appropriate table. Enter this table with the number of trials, n , and by using the curve for c failures, read the value of the lower confidence limit on the bottom scale.

EXAMPLE:

Three failures have been observed in 800 field firings of a certain missile booster rocket. The estimated reliability is $797/800 = 0.996$. If a 99% confidence limit is desired, the table for $\gamma = 0.99$ is chosen. With $n = 800$, the curve for $c = 3$ gives a lower limit of 0.988. It can be stated with 99% confidence that the reliability of the population is at least 0.988.

TABLES:

The tables which follow are based on the relation

$$\sum_{k=0}^c \binom{n}{k} (1 - R)^k (R)^{n-k} = 1 - \gamma$$

where n = sample size,

c = number of failures,

R = reliability value in decimal fraction, and

γ = assurance value in decimal fraction.

$$\gamma = 0.50$$

RELIABILITY METHODS

SUBJECT ONE-SIDED (LOWER) CONFIDENCE LIMITS FOR A RELIABILITY

RM 220-2b

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$$\gamma = 0.80$$

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$$\gamma = 0.90$$

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$$\gamma = 0.95$$

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$$\gamma = 0.99$$

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$$\gamma = 0.995$$

RELIABILITY METHODS

<i>Aerjet-General</i> CORPORATION AZUSA, CALIFORNIA SACRAMENTO, CALIFORNIA		RM 310-1 PAGE 1 OF 3 DATE OF ISSUE 5-16-60
SUBJECT: MEASURING THE RATE OF IMPROVEMENT OF RELIABILITY		

PROBLEM:

To measure the reliability growth rate of a product.

DISCUSSION:

Improvement in product reliability is expected during the evolutionary process of development. Product performance tests which are frequently used in the measurement of reliability are usually classified into groups, as the job at hand requires; for example, by some time period, by engineering changes, in blocks of n tests, or in blocks of k failures. If there is an ordering to these groups, a modified χ^2 technique can be used to measure the rate of reliability growth.

ASSUMPTIONS:

The test groups can be ordered and the individual tests comprise a sample from a binomial population.

LIMITATIONS:

This procedure can measure only the linear rate of growth.

PROCEDURE:

For k groups with n_i observations and f_i failures in the i th group we have

Group No.	1	2	3	...	k	Total
Successes	$n_1 - f_1 = S_1$	$n_2 - f_2 = S_2$	$n_3 - f_3 = S_3$	...	$n_k - f_k = S_k$	$n - f = S$
Failures	f_1	f_2	f_3	...	f_k	f
Total	n_1	n_2	n_3	...	n_k	N

The successes are now considered as a variate on which a regression is to be computed. The groups are considered equally spaced and orthogonal weights, w_i , are assigned. These weights are found in Appendix Table 13 in the column designated by L. A more extensive table of orthogonal weights can be found in Reference (2).

The estimate of the regression coefficient is

$$b = \frac{N \sum S_i w_i - S \sum n_i w_i}{N \sum n_i w_i^2 - (\sum n_i w_i)^2},$$

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SUBJECT: MEASURING THE RATE OF IMPROVEMENT OF RELIABILITY	RM 310-1
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and its estimated variance is

$$V(b) = \frac{S(f)}{S\{S \sum n_i w_i^2 - (\sum n_i w_i)^2\}}$$

The χ^2 estimate due to linear trend, with 1 degree of freedom, is

$$\chi_L^2 = \frac{b^2}{V(b)}$$

If χ_L^2 exceeds $\chi_{(\alpha,1)}^2$ (from Appendix Table 4), a positive rate of increase is asserted and its value is b. For example, with 1 df and $\alpha = .05$, $\chi_{(\alpha,1)}^2 = 3.84$. If χ_L^2 does not exceed $\chi_{(\alpha,1)}^2$, then there is no reason to assume an improvement in reliability has occurred.

EXAMPLE:

Seven hundred developmental tests were performed on a particular Auxiliary Power Supply System in 7 blocks of 100 tests each. χ_L^2 is computed as follows:

Group	1	2	3	4	5	6	7	Total
Successes	84	89	87	91	92	94	90	627
Failures	16	11	13	9	8	6	10	73
Totals	100	100	100	100	100	100	100	700

Orthogonal Weights	-3	-2	-1	0	+1	+2	+3
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$$\sum S_i w_i = -3(84) - 2(89) - 87 + 0 + 92 + 2(94) + 3(90) = 33$$

$$\sum n_i w_i = -3(100) - 2(100) - 100 + 0 + 100 + 2(100) + 3(100) = 0$$

$$\sum n_i w_i^2 = 9(100) + 4(100) + 100 + 0 + 100 + 4(100) + 9(100) = 2800$$

$$b = \frac{700(33) - 627(0)}{700(2800) - (0)^2} = .0117857$$

$$V(b) = \frac{(627)(73)}{700\{700(2800) - (0)^2\}} = .000033607$$

$$\chi_L^2 = \frac{b^2}{V(b)} = 4.16$$

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SUBJECT: MEASURING THE RATE OF IMPROVEMENT OF RELIABILITY

RM 310-1

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At the .05 significance level, $\chi^2_{(.05, 1)} = 3.84$. Since $\chi^2_L = 4.16 > 3.84$, objective certified evidence has been obtained showing reliability improvement. The estimated improvement is at a rate of 0.118 per test, or an increase in reliability of 1.18% per 100 tests.

The data and regression line are plotted on FIGURE 1. This was obtained by letting the line pass through the average reliability and then adding or subtracting, as required, 1.18 per 100 test trials.

FIGURE 1

OBSERVED SUCCESSES OR RELIABILITY PER ORDERED GROUPS OF 100 TESTS

REFERENCES:

Armitage, P., "Tests for Linear Trends in Proportions and Frequencies", Biometrics, Vol. 11, No. 3, September 1955

Fisher, Ronald A., and Yates, Frank, Statistical Tables, Hafner Publishing Co., Inc., New York, 1949

SECTION 4

DESIGN CONTROL

Design Control is a management control which is used to develop assurance that the product design conforms to contract requirements. Detailed information related to this control is presented in this section according to the following outline:

- 4.1 Design control functions and suggested assignments of responsibilities
- 4.2 Standards of performance for design control functions
- 4.3 Reliability methods for design control functions

LEGEND FOR SECTION 4.1

DEGREE OF AUTHORITY AND RESPONSIBILITY

- P = Prime authority = Has responsibility for satisfactory completion of task
- A = Approval authority = A series function - may accept or reject work or action of (P)
- R = Review authority = Reviews and requests corrective action from (P) when required
- S = Supporting services = Provides requested services for (P)

TIME OF PERFORMANCE BY PRODUCT MATURITY

1. Detailed design study
2. Preprototype (design 95% complete)
3. Prototype (design firm)
4. Preproduction demonstration (PFRT)
5. Demonstration of service readiness (qualification tests)
6. Service evaluation (flight tests)
7. Full scale production (acceptance tests)
8. Demonstration of major product improvement

4.1 DESIGN CONTROL FUNCTIONS

Suggested Assignments of Responsibility

	Customer or Cust. Rep.	Contract Adm. or Sales	Director R. & Q./Staff	Plant Manager	Project Engineering	Test	Material	Manufacturing	Reliability Engineering	Quality Control	Technical Services	Time-Phase							
												1	2	3	4	5	6	7	8
4.1.1 Convert contract requirements into design criteria				P				R				x							
4.1.2 Prepare control system design				P				R				x							
4.1.3 Apportion reliability goals to subsystems, components, and parts				A				P				x							
4.1.4 Collect and maintain reliability data on parts and components		S		R				P	S			x	x	x	x	x	x	x	x
4.1.5 Prepare critical parts list				R				P				x	x						
4.1.6 Determine modes of failure for critical parts				R	S			P	S			x	x	x					
4.1.7 Prepare design standards (drawings and specifications)				P				R	R			x	x	x					
4.1.8 Provide classification of defects				P			S	R	R			x	x	x					
4.1.9 Provide qualification testing of parts and components				P	S			R	S				x	x					
4.1.10 Establish design change control system				P				R	R			x	x	x	x	x	x	x	x
4.1.11 Conduct design review			R	P	S	S	S	S	S	S			x	x	x		x		x
4.1.12 Provide development test equipment				A	P			R				x	x	x					
4.1.13 Prepare development test methods and procedures				A	P			R				x	x	x					
4.1.14 Prepare test specifications																			
(a) development				P	S			A				x	x	x					
(b) reliability				S	S			P	S			x	x	x					
4.1.15 Provide statistical planning and evaluation		S		A				P	R			x	x	x	x	x			
4.1.16 Plan and perform development, environmental, and qualification tests				P	S			R	S			x	x	x	x	x			
4.1.17 Plan and perform reliability and life tests				R	S			P	S					x	x	x			

Suggested Assignments of Responsibility

4.1 DESIGN CONTROL FUNCTIONS (Continued)

	Customer or Cust. Rep.	Contract Adm. or Sales	Director R. & Q./Staff	Plant Manager	Project Engineering	Test	Materiel	Manufacturing	Reliability Engineering	Quality Control	Technical Services	Time-Phase							
												1	2	3	4	5	6	7	8
4.1.18 Perform failure analysis - in-plant tests				P	S			S	S			x	x	x	x	x			
4.1.19 Provide orientation and training (engineering: design, reliability, test, quality, etc.)		S	P					S	S			x	x	x					
4.1.20 Calibrate test equipment					P			R	S,R			x	x	x	x	x			
4.1.21 Provide system for data collection, analysis, and feedback				S	S			P	R			x	x	x	x	x	x		
4.1.22 Assure corrective action in design control	S	S	R	S	S	S	S	P	R	S		x	x	x	x	x	x	x	x

4.2 STANDARDS OF PERFORMANCE FOR DESIGN CONTROL FUNCTIONS

4.2.1 DESIGN CRITERIA

With the establishment of realistic contract requirements, the first step in the design of a new product is the translation of these requirements into design criteria. Design criteria include such data as loads, inputs, outputs, stresses, applied safety factors or margins, and requirements for producibility, maintenance, storage, packaging, and human engineering. The design engineer is responsible for the establishment of these design criteria. However, special assistance should be provided him as required in the computation of proper criteria through the use of systems simulation and operations analysis techniques. The compatibility of the design criteria with the contract requirements should be established and corrective action taken as necessary.

4.2.2 INITIAL SYSTEM DESIGN

The initial system design consists of the preliminary selection of a system configuration which is believed to possess the greatest potential for satisfying system contract requirements. The system configuration includes, for each functional subsystem required, a description of its general geometry and size, its physical location in the system, and its content in detail down to each component part. It includes the selection and application of specific components and component parts.

The initial system design should be determined by a careful evaluation of the potentials of two or more candidate designs. The potential of each design should be evaluated by considering its anticipated costs (development, production, handling, maintenance, and use); ease of handling, storage, maintenance and use; availability (readiness); performance characteristics; use reliability, etc.

The potential reliability of each candidate design should be estimated by completing a reliability analysis which includes:

- a. Making a compilation of all pertinent reliability data or failure rates for parts and components.
- b. Predicting overall reliability of each candidate system based on observed or estimated reliabilities of the parts and components.

c. Comparing the predicted values with reliability goals established by the customer.

The proper selection and application of parts and components is vital to the overall product reliability, and should be carefully reviewed as a part of the independent design review of the system. (See Section 4.2.11)

4.2.2.1 Criteria for the Selection of Parts and Components

The following criteria should be used for the selection of parts and components and for the review of same:

a. Company, industry, or military standard parts with known reliability levels should be used wherever possible to lower cost, standardize tooling, permit common stocking and to require less training, assistance, inspection and testing.

b. All parts having a reliability compatible with the reliability goal should be selected when reliability data are available.

c. Reliability data used should be applicable to anticipated environmental and test usage conditions.

d. Adequate margins of safety must be established and maintained between operational and environmental stress distributions and strength distributions of the part or material concerned.

e. When adequate reliability information is not available for certain parts, an estimated reliability value should be assigned, based on the review of all failure data from past tests or usage, either in the supplier's plant, Company plant, or as furnished by military and industry sources.

f. Reliability predictions can often be made through an analysis of the mechanism of failure based on factors such as the materials, configuration, assembly and processes to be used.

g. When no information is available for a part or component, qualification tests should be conducted on such items as soon as possible to provide data for reliability estimation and corrective action as required.

4.2.3 APPORTIONING OF RELIABILITY

If reliability goals or requirements are not established in

the contract for all subsystems, components, and parts, this should be accomplished whenever feasible by the designated control group as a part of the design and reliability analysis program indicated above. In addition to this preliminary reliability apportioning, continuing studies should be undertaken to establish, as early as possible, a formal basis for revising as necessary the quantitative reliability goals for systems, subsystems, and components.

These studies should cover all phases of the life cycle of a product which are under the control of the Company from design through manufacturing. The continuing studies should evaluate the program's feasibility, the effectiveness of trade-offs, and the compatibility of reliability goals assigned to each part or component with the effect of the part or component on the reliability of the overall system. Tentative reliability goals should be established for each major phase of the program and phased with the program review points.

4.2.4 RELIABILITY DATA (COMPONENTS AND PARTS)

The designated control group for each product should maintain reliability data on all parts and components concerned with the product. This information should be collected, summarized, and reported to the designated design control group by the cognizant centers. In addition, pertinent data should be shared with other projects, divisions, plants, and companies through the mechanism of data exchange committees. Reliability data considered to be of permanent value to the Company should be collected and maintained on a permanent basis. The maximum practical amount of data on part and component reliability, together with the associated environmental conditions, should be provided to the designer to enable him to employ the most favorable components in the product design.

4.2.5 CRITICAL PARTS LISTS

A list of all parts for which the reliability goal is higher than the concurrent estimated reliability should be maintained by the cognizant control group, with follow-up and evaluation of the corrective action taken. A discussion of the use of the critical parts list in a corrective action program is included as part of Section 2.2.13.

4.2.6 MODES OF FAILURE

The modes of failures of all critical parts should be determined in order that the frequencies of such failures may be studied and controlled. This will require an analysis of the environments to which each part of the equipment is to be subjected, the properties of the materials which are to be used, and the knowledge of the methods and processes which will be used in manufacture and operations. Modes of failure may be determined by stress analysis, by analysis of previous test results, by conducting special laboratory tests, by tests to failure, etc. Modes of failure are required to make realistic reliability predictions, and to determine the margin of safety required to prevent failures due to variations in materials, processes, workmanship, etc.

4.2.7 DESIGN STANDARDS (ENGINEERING DESIGN DOCUMENTATION)

Design standards should be prepared and should include all drawings, specifications, and related documents which describe the product and its detailed components. They should specify the methods of processing, testing, packaging, shipping, storage, handling and use. They should also include product component and part drawings and specifications, process specifications, test specifications, packaging specifications, and any other related documents. Furthermore, all contract requirements for performance, reliability, operating time, life, etc., should be contained in the design standards.

4.2.8 CLASSIFICATION OF DEFECTS (CHARACTERISTICS)

The possible defects of a given product should be listed and grouped in accordance with their estimated effect on the reliability of the system of which this product is a part. Defects should be classified during the original systems analysis study, or during the systems review. Classification should be in accordance with contractual requirements.

The classifications of defects are used for evaluating the seriousness of departures from established requirements, as an important factor in setting the extent of inspection, and as a basis for formulating sound engineering and material review decisions.

A procedure for the classification of defects follows:

- a. Determine the performance requirements for the product and classify these as critical, major, or minor.
- b. Categorize product into systems, subsystems, components, and parts.
- c. Determine those parts, components, or subsystems, the failure of which would prevent the system from meeting each performance requirement.
- d. Determine the mode of failure for each part which would cause this part to fail.
- e. Determine the characteristics of the part which permits each mode of failure.
- f. Associate the parts, defects, and modes of failures, with each performance requirement and classify accordingly.

4.2.9 PARTS QUALIFICATION TESTING (DESIGN PROOF TESTS)

After selecting the product design, a planned program should be undertaken to fully qualify all parts and components of the product and finally the product itself. Every key part or component which has not previously been fully qualified for the specified performance, environment, and reliability requirements should be included in the qualification test program. (This program is not limited to the government qualified products list.)

The objectives of the parts qualification tests are:

- a. To make sure that the reliability of all parts, components, and products meet the established reliability goals.
- b. To determine the significant modes of failure.
- c. To verify the performance capability of the particular design for the intended application.
- d. To determine that no serious design weaknesses exist which could cause inconsistent performance or a high probability of failure.
- e. To serve as a basis for the evaluation of assembly and component test methods.

A parts qualification program should be covered by adequate specifications, and should be planned and evaluated on a statistical basis. Parts qualification testing should include the use of peripheral stress testing, testing to failure, and marginal checking techniques as appropriate.

4.2.10 DRAWING AND CHANGE CONTROL

A system should be established and maintained to assure adequate control of drawings, specifications, and other technical requirements and all changes thereto. This system should assure that the latest applicable drawings, specifications, or other documents will be available at the time and place of testing or inspection, or for other needs.

When design changes, product improvement changes, process changes, or any other design changes are considered, the effect of the proposed change on the reliability of the system should be evaluated to help determine whether the change should be implemented. The same considerations given to the basic design to produce a reliable system, including periodic formal design reviews, should be accomplished in the case of design change considerations. The design change control system should assure that obsolete drawings, specifications, and information are removed from all points of issue and use. All changes should be processed in a manner which will assure accomplishment of the change in the affected supplies at the specified effectivity point. A record of the effectivity of changes should be maintained.

4.2.11 DESIGN REVIEW

A critical review of design standards should be conducted at specified points during the design history of a product. The purpose of this review is to promote reliability growth through the use of the most effective reliability and design techniques, and through the early detection and removal of design inadequacies. The design review:

- a. Provides a periodic opportunity to evaluate the design with respect to design goals and requirements.

- b. Offers increased opportunity for interchange of information among the various personnel and organizational groups contributing to the product design.

- c. Improves the opportunities for achieving a balanced trade-off among characteristics of the design.
- d. Provides a method for obtaining expert assistance in specialized areas.
- e. Provides a documented record of the design at selected points during the design history.

Each formal design review should determine the readiness of the design to proceed to the next step of the design cycle. Thus, premature transitions from one design step to the next, which may be costly in the long run, may be prevented or minimized.

The design engineer with responsibility for the integrity of the design should schedule, conduct, and document the formal design review, and assure that appropriate action is taken on recommendations of the review committee. The cognizant design engineer should supply the review committee with information in advance of the formal meeting.

A formal design review should be held prior to each major transition point (expensive step) in the design cycle.

4.2.12 DEVELOPMENT TEST EQUIPMENT

The inherent design reliability of a product is influenced greatly by the adequacy, accuracy, precision, and applicability of the test data which is obtained by the designer from test of the product and its component parts during the research and development program. Consequently, it is imperative that there be adequate test equipment to provide accurate and precise information relative to required tests. Environmental conditioning equipment should simulate true operational conditions as far as possible, or there should be a method for translating test results to operational or use conditions.

All test equipment used to measure performance, environmental conditions, etc., should preferably have an accuracy at least ten times greater than the tolerance interval required of the parameters of the hardware or product being tested.

The design or test engineer is responsible for designing and specifying all test equipment required for the adequate testing of the product according to design engineering and contract requirements. The test source is also responsible for obtaining this equipment and installing, calibrating, maintaining, and using it in the proper manner to obtain accurate and precise test results. This work should be compatible with the system and policies established by plant and corporate management relative to these operations.

4.2.13 DEVELOPMENT TEST METHODS AND PROCEDURES

The test source is responsible for providing methods and procedures required for development testing. These methods and procedures include a list of all equipment required; means of assembling, calibrating, maintaining, and using equipment; instructions to technicians; methods of controlling test or environmental conditions; safety precautions; and methods of recording, processing, and reporting data.

4.2.14 TEST SPECIFICATIONS

Test specifications should be issued by the cognizant design engineer to the pertinent test source for each product. This specification should indicate:

- a. Number of items to be tested.
- b. Sampling method required.
- c. Performance characteristics to be tested.
- d. Environmental or test conditions with allowable tolerance limits.
- e. Acceptance criteria.
- f. Type of data to be recorded, test reports required.
- g. Special instructions for the test.

4.2.15 STATISTICAL TEST PLANNING AND EVALUATION

Test programs should be carefully planned using concepts of statistical test design in order to assure conclusions which have statistical validity and which give results within the required confidence levels. Tests having no valid correlation with performance and reliability requirements are

clearly a waste of time, funds, manpower, and facilities. The practice of specifying rigid requirements for a product without a satisfactory method of testing to prove compliance is also a waste of effort.

Tests should be planned on an integrated basis and should be included as part of the reliability project plan. Test should be scheduled so as to be compatible with delivery schedules for the product. All conditions of the test, as well as courses of action for various test alternatives, should be determined and agreed upon before testing is started.

In planning a test program, consideration should be given to test conditions, performance requirements, reliability requirements, environmental requirements, reliability objectives, sample size, levels of stress, method of analyzing data, etc. Moreover, it is important to remember that a sound statistical test plan will provide the maximum amount of pertinent information for the number of items tested. Where sufficient details are not known to design a test properly, this information should be acquired by going to the appropriate source. In many cases this will require the conduct of "exploratory" tests.

4.2.16 DEVELOPMENT TESTING

A completely integrated series of evaluation tests should be conducted during the research and development of a product to assure that the product, with any modifications required to correct deficiencies exhibited during the tests, will meet the operational and performance requirements of the contract. The integrated test program should preferably cover:

- a. Parts qualification tests (Section 4.2.9).
- b. Engineering evaluation or performance tests.
- c. Environmental tests.
- d. Flight readiness tests (PFRT)
- e. Product qualification tests.
- f. Service evaluation tests.

Although these tests are performed for somewhat different reasons, it is very important that all tests including reliability and life tests comprise an integral part of the overall test program so that the required test information can be obtained by the minimum number of tests possible.

4.2.16.1 Engineering Evaluation Tests

Engineering evaluation or performance tests are used to:

- a. Determine reliability of parts and components.
- b. Identify, analyze, and correct modes of failure.
- c. Determine effects of varied stress levels resulting from different combinations and sequences of environment.
- d. Provide information for specifying tolerances, designing tests, establishing test limits, and setting acceptance criteria.

All elements of parts of the product which have a bearing on the inherent design reliability should be tested as early as possible in the development program to establish their suitability for use as part of the product. A current record of evaluation test results should be maintained and used for making improvements in the design which will increase the inherent design reliability. These data are also required to make estimates of the reliability of the overall product and the complete operational system.

4.2.16.2 Environmental Testing

The importance of environmental testing to the reliability program cannot be overestimated. Neither the designer nor the reliability engineer has completed his job until it has been shown that the product can operate satisfactorily under realistic environmental conditions.

Since much of the environmental testing program is conducted during development by environmental simulation, it is important that the product's operational and non-operational environments be accurately determined for effective test program planning and implementation. The need to obtain environmental test equipment, capable of simulating the required environments, is also of critical importance.

Environmental testing should be conducted from the early stages of product design to the delivery of a production item. These tests may include tests for shock, vibration, temperature, humidity, pressure, and other pertinent environmental factors. Specific factors selected and their combinations and sequence of application must be compatible with contractual test requirements.

4.2.16.3 Proof Tests

Proof flight rating or prototype tests are the first tests conducted on the completed product. They are used to demonstrate whether or not the product is ready for qualification testing. Proof flight rating tests are conducted to:

- a. Determine compliance with performance requirements.
- b. Reveal weaknesses in the design.
- c. Check design criteria.
- d. Determine critical test methods or conditions that will be required for later qualification or service evaluation tests.

4.2.16.4 Product Qualification Tests

Qualification tests are made on the final product prior to service evaluation to show that production units, made under full scale manufacturing conditions, are capable of meeting contractual requirements. For maximum economy and assurance, these tests are best made under a simulated environment somewhat more severe than the anticipated service conditions. In this activity, as in any test program, feedback, corrective action, and follow-up procedures must be followed for maximum effectiveness.

4.2.16.5 Service Evaluation Testing

Service evaluation testing is the field testing of regular production units, and is often conducted by the using agency. This is the final proof that the product will meet performance requirements under field conditions. The feedback of information from field testing is mandatory to effect design improvements prior to or during full scale production.

4.2.17 TESTING RELIABILITY AND LIFE

Nearly all tests of a product and its components provide information which is useful in assessing product reliability. However, when tests are performed for the specific purpose of measuring product reliability, such tests are designated as reliability tests. Life tests, in particular, are those tests which are conducted to estimate the expected shelf life or expected operating life of the product.

Reliability and life tests should be an integral part of the overall test program, and wherever feasible, reliability and life testing should be made a part of the development tests or acceptance inspection tests.

Many military contracts now contain reliability clauses which require a demonstration of reliability. It is anticipated that an increasing number of such contracts will be written in the future because of the growing concern over reliability problems which are associated with equipment of increased complexity. Because demonstration tests can be very costly, the requirements for such tests should be defined in the proposal stage as part of the proposal or program plan.

The following points should be kept in mind when preparing requirements for reliability demonstration tests:

- a. Completely valid demonstration of system reliability can only be achieved by testing complete systems in the actual field environment.
- b. The customer should either completely detail the demonstration test requirements, or require the contractor to prepare test plans to meet defined risks. In the latter case, either the confidence level or the operating characteristic curve required should be stated.
- c. The demonstration plan should at least define the sampling procedure, ground rules for classifying test results, accept-reject criteria, and procedures for analysis and reporting of failures.
- d. Sufficient planning should be provided in project schedules to allow for conducting reliability tests of prototypes and to make design modifications if required before the production run is started.
- e. The operating sequence should be based on normal operation for the equipment, and the failure criteria should be carefully chosen to provide adequate assurance that all failures will be detected without making the test too cumbersome.
- f. The operating sequence and the detection of failures should be automatic to the fullest practical extent.

4.2.18 FAILURE ANALYSIS (IN-PLANT TESTS)

When a failure occurs during an in-plant test, a failure report should be prepared and sent to the cognizant Design Control Group together with

all pertinent data relative to the failure. The failed part should be reviewed by the design engineer, who should fill out a "Failed Part Analysis Form," sending it to the Design Control Group. The Design Control Group should maintain a record of all failures and malfunctions, and differentiate between those due to design techniques, equipment failure, and human errors. The information reported should include the accumulated operating time or operating cycles of the product at all points thereof and the conditions of the test. It is up to the Design Control Group to make certain that effective corrective action is taken on a timely basis to reduce or prevent repetition of failures. More information relative to failure analysis and reporting is presented in Section 8.2.12.

4.2.19 ORIENTATION AND TRAINING

(See Section 2.2.10)

4.2.20 CALIBRATION OF TEST EQUIPMENT

(See Section 2.2.11)

4.2.21 SYSTEM FOR DATA COLLECTION, ANALYSIS AND FEEDBACK

(See Section 2.2.12)

4.2.22 CORRECTIVE ACTION

(See Section 2.2.13)

4.3 RELIABILITY METHODS FOR DESIGN CONTROL

Reliability methods developed for application to the design control program are presented in Volume II of this handbook.

Reliability methods RM 230-1 and RM 210-7 which follow are examples of methods that can be used in developing the initial system design.

RELIABILITY METHODS

<i>Aerjet-General</i> CORPORATION		RM 230-1
AZUSA, CALIFORNIA	SACRAMENTO, CALIFORNIA	PAGE
SUBJECT: SAFETY MARGINS		1 of 6
		DATE OF ISSUE 3-1-60

PROBLEM:

To establish design specifications which will assure reliability.

DISCUSSION:

During its lifetime a system must exist and operate in an environment which is made up of various stresses such as temperature, pressure, atmosphere, shock, vibration, aging, wearout, etc. In order to survive and operate in this environment without failure, the system must be stronger than the stresses encountered. Many of the stresses are a function of time, however, initial failures or failures in systems with short operating lives are a result of overstressing with time a less important factor. FIGURE 1 illustrates overlapping stress and strength distributions.

FIGURE 1

OVERLAPPING STRENGTH AND STRESS DISTRIBUTIONS

Safety factors are conventionally used in order to separate mean stress and strength and thus increase the probability of survival (reliability). Safety factors, however, do not consider the inherent variability within either the stress distribution or the strength distribution. A more satisfactory approach is the principle of safety margins. Safety margins are expressed as standard deviations from the mean and they take into account the variability as well as the average level of the environmental stresses and the system strengths. By designing high safety margins into all components, it is possible to arrive at a system with high reliability. FIGURE 2 illustrates strength and stress distributions separated by safety margins.

FIGURE 2

DISTRIBUTIONS SEPARATED BY SAFETY MARGINS

A maximum stress limit is determined beyond which it is extremely unlikely that stresses will occur. In order to determine this limit for a particular characteristic, for example, temperature, it is necessary to know the distribution of frequencies of stress occurrence along the scale of the characteristic. This can be estimated from the mean and standard deviation of observed stresses. (See RM 020-1 and RM 020-2.) Ordinarily where the form of the distribution is known and many observations are available, the practical limits of the distribution can be predicted and the probability of a particular stress occurring can be stated with confidence. However, stresses for new systems in strange environments are often largely unknown and knowledge is dependent upon calculations and laboratory tests. In this case a safety margin of six or more standard deviations is added to the mean stress to arrive at the maximum stress limit. The safety margin to be used increases with lack of knowledge of the stress distribution and/or higher required reliabilities.

Similarly in order to determine the mean strength for a component it is necessary to know the distribution of frequencies of failure occurrence along the scale of the characteristic. This can only be determined from tests to failure. These would include time to failure, where time is a major part of the environment, as well as stress to failure tests. (See RM 220-6a.)

When estimates of the mean and standard deviation of the strength distribution are obtained, the mean strength should have a safety margin of at least five standard deviations above the previously obtained stress limit. If not, the required strength and stress safety margins must be obtained by either increasing the mean strength or reducing the variability or scatter of the strength distribution. Alternatively or simultaneously it may be possible to reduce the stress limit by insulation, cushioning, sealing, etc.

The principal of safety margins is essentially distribution free in that no knowledge of the form of the stress or strength distribution is assumed. When such knowledge becomes available from accumulated information, it is usually possible to reduce the safety margins if desirable for weight or performance reasons. However, even if the limits of the strength and stress distributions are well established, it may be necessary to allow a contingency margin between the distribution limits to allow for future uncertainties such as manufacturing, storage, training, etc. This is illustrated in FIGURE 3. Contingency margins are commonly expressed as multiples of the standard deviation of the strength distribution.

FIGURE 3

DISTRIBUTIONS SEPARATED BY CONTINGENCY MARGINS

Where environmental stress appears high and low on the scale of the characteristic, such as extremely high and low temperatures, there will be two stress limits and two strength distributions.

Safety margins apply not only to strength distributions but also to performance distributions under environmental stresses. In this case there are usually two critical limits for performance output which are specified according to service needs. The performance output of an operating component may be shifted or become more variable or both under environmental stress as illustrated in FIGURE 4.

These performance distributions must be obtained from environmental testing and should be obtained at the maximum stress limit for the component, and preferably during stress to failure or time to failure tests. At the maximum stress limit a safety margin of at least 8 standard deviations between the mean and either of the critical performance limits is recommended. This is illustrated in FIGURE 5.

FIGURE 4

DISTRIBUTION CHANGES DUE TO STRESS

FIGURE 5

SAFETY MARGINS FOR PERFORMANCE OUTPUT

In this case the performance is assumed to be distributed symmetrically around the mean performance.

These safety margins also are subject to revision up or down according to the knowledge of the performance distributions, their change under stress, and to the criticalness of component operation. However, it should be remembered that increased reliability results from increased safety margins.

Since estimates of the standard deviation as well as the mean are subject to variation which decreases with larger numbers of observations, it is important to obtain as many observations as possible in estimating the location and spread of the stress, strength and performance distributions. To compensate for small sample size, when determining safety margins, the standard deviation is multiplied by a risk factor. The enlarged standard deviation is then used to establish the safety margin. These factors are shown in FIGURE 6.

FIGURE 6

FACTORS FOR ADJUSTING STANDARD DEVIATION

If the distributions are known to be normal then the distribution limits can be determined by tolerance factors (see RM 220-3a) which take into account the variability of both the mean and standard deviation. A contingency margin can then be added to obtain the required safety margins.

Safety margins make use of statistical methods not for the purpose of measurement of reliability but to achieve high system reliability by separating the stress and failure distributions sufficiently. It is becoming increasingly evident that component reliabilities for complex systems must be too high to be proved by any reasonable number of measurements.

REFERENCES:

Lusser, "Reliability Through Safety Margins", Redstone Arsenal, Alabama,
October 1958

Lusser, "General Specification for the Safety Margins Required for Guided
Missile Components", (NAMTC Tech. Report No. 84), Pt. Mugu, California,
10 July 1951

RELIABILITY METHODS

<i>Aerjet-General</i> CORPORATION AZUSA, CALIFORNIA SACRAMENTO, CALIFORNIA		RM 210-7
SUBJECT: FUNDAMENTAL REDUNDANCY CONCEPTS		PAGE
		1 OF 4
		DATE OF ISSUE
		2-1-60

PROBLEM:

To discuss some fundamental concepts of redundancy and problems related to the use of redundancy in product design.

DISCUSSION:

Redundancy might be defined as the existence of more than one means of accomplishing a given task, where all means must fail before there is an overall failure of the task. As applied to reliability, redundancy concerns the practice of paralleling two or more elements, such as parts, circuits, components, modules, equipments, or even complete systems, such that, ideally, they will independently perform the same function. Failure of any one or more of the elements should neither cause failure of the desired function nor affect the probability of successful operation of any of the remaining paralleled elements. It is obvious that the use of redundancy in design should improve the probability of accomplishing a given task over what would be experienced with a single element whose failure would cause an immediate loss of the desired function. One should not expect something for nothing, however. The use of redundancy does introduce certain practical problems, which will be subsequently mentioned, which tend to mitigate against its indiscriminate use as a reliability improvement technique.

Redundancy may be further classified as (1) functional and (2) standby, which are defined as follows:

1. Functional redundancy exists when two or more means are operating simultaneously to accomplish a task, and less than the total number is capable of performing the function in the event of failure of less than all of the primary and alternate means.
2. Standby redundancy exists when there is provided one or more alternative means of accomplishing a task that is switched in or transferred into operation by a malfunction sensing device when the primary means fail.

The basic redundancy configuration is the simple parallel-redundant model shown in Figure 1. The configuration consists of k elements in parallel, which provide k-1 alternate paths for accomplishing the task function should the primary means fail. The reliability of the model may be calculated using the equations given. Using the configuration and the given assumptions, the reliability will always be larger than or at least equal to the reliability of the most reliable element.

Reliability Equations

General case:
$$R_s = 1 - (1-r_1)(1-r_2) \dots (1-r_k) \quad (1)$$

With all r's equal to r:
$$R_s = 1 - (1-r)^k \quad (2)$$

Figure 1

Simple Parallel Redundant Model

The assumption of independence of redundant elements is frequently not justified. In fact, since the elements in a parallel redundant configuration perform the same task, rather than independent sub-tasks, interrelationships between failures may be even more likely than in a series element configuration. While the assumption of independence gives a pessimistic estimate of reliability for a series configuration, in a parallel redundant configuration, it gives an optimistic estimate which may not be realized. For parallel redundant elements whose failures may not be independent, the use of conditional probabilities may be useful. For two non-independent elements in parallel, the probability of system success (i.e., the reliability of the parallel configuration) is equal to

$$R_s = 1 - (\text{Probability of failure of element 1}) \cdot (\text{Probability of failure of element 2 conditional on failure of element 1})$$

or

$$R_s = \text{Probability of success of element 1} + (\text{Probability of success of element 2}) - (\text{Probability of success of both elements})$$

For a further discussion of conditional probabilities, see RM 210-2. These concepts can also be extended to multi-element parallel systems.

Discussions of more complex system configurations are contained in other sections of this handbook.

ASSUMPTIONS:

It is assumed that there is complete independence of each element, any one of which is capable of performing the required function.

LIMITATIONS AND PROBLEMS RELATED TO THE USE OF REDUNDANCY:

While redundancy may appear to be a panacea to the problem of achieving high reliability, there are many factors relating to redundancy that must be considered in optimizing the design configuration of an equipment or system. Some of the more important considerations may be briefly summarized as follows:

1. The most obvious fact is that redundancy requires multiple elements with concomitant multiple costs.
2. Redundancy increases weight and consumes additional space. These considerations are often of extreme importance, especially in airborne systems.
3. System design, which is already complicated by the stringency of performance requirements becomes even more complex when employing redundancy because practical recognition must be accorded the fact that elements used to sense failure and perform the switching and transfer functions may become extremely complex in themselves and may thus present more of a hazard to reliability than the condition they are intended to alleviate.
4. When an attempt is made to arrange physical elements capable of performing in such a way that they are functionally parallel-redundant, interactions often result which drastically alter the performance of the overall task function. As an example, if an attempt is made to improve the reliability of performance of a servo-mechanism by paralleling the existing servo with another capable of performing the same function, this may set up new feedback loops which drastically alter system performance.

PROCEDURE:

Equations (1) and (2) may be used to calculate the reliability of parallel redundant configurations. For convenience in making accurate estimates when the element reliabilities are equal, the table in RM 210-5 may be used. This table provides values of R_s for $k = 4(1)9$ and $r = .50(.01).99$.

EXAMPLES:

1. Three elements having reliabilities of $r_1 = .90$, $r_2 = .85$, and $r_3 = .80$ are arranged in a parallel redundant configuration. Each element is capable of performing the task independent of the other elements. What is the reliability of the configuration? Using Equation (1),

$$\begin{aligned} R_s &= 1 - [(1 - .90)(1 - .85)(1 - .80)] \\ &= 1 - [(.1)(.15)(.20)] = 1 - .003 \\ &= .997 \end{aligned}$$

2. Given four identical elements each having a reliability of .50 arranged in parallel, find the reliability of the configuration. From Table 1 of RM 210-5, enter with $k = 4$ and $r = .5$. Obtain $R_s = .9375$. These may also be solved using Equation (2):

$$R_s = 1 - (1 - .5)^4 = .9375$$

SECTION 5

INCOMING MATERIAL CONTROL

Incoming Material Control is a management control which is exercised to assure that incoming materials conform to design standards at the optimum cost. Information relating to this control is presented in this section according to the following outline:

- 5.1 Incoming material control functions and suggested assignments of responsibilities
- 5.2 Standards of performance for incoming material control functions
- 5.3 Reliability methods for incoming material control functions

LEGEND FOR SECTION 5.1

DEGREE OF AUTHORITY AND RESPONSIBILITY

- P = Prime authority = Has responsibility for satisfactory completion of task
- A = Approval authority = A series function - may accept or reject work or action of (P)
- R = Review authority = Reviews and requests corrective action from (P) when required
- S = Supporting services = Provides requested services for (P)

TIME OF PERFORMANCE BY PRODUCT MATURITY

1. Detailed design study
2. Preprototype (design 95% complete)
3. Prototype (design firm)
4. Preproduction demonstration (PFRT)
5. Demonstration of service readiness (qualification tests)
6. Service evaluation (flight tests)
7. Full scale production (acceptance tests)
8. Demonstration of major product improvement

Suggested Assignments of Responsibility

5.1 INCOMING MATERIAL CONTROL FUNCTIONS

												Time-Phase							
												1	2	3	4	5	6	7	8
5.1.1	Prepare standards for incoming material (drawings, specifications, etc.)				P				R	R		x	x	x					
5.1.2	Establish supplier or subcontract requirements				A		P		R	R		x	x	x					
5.1.3	Issue P.O.'s on subcontracts				S	S	P		R	A		x	x	x	x	x	x	x	x
5.1.4	Provide inspection and test equipment				S	S	S	S	R	P		x	x	x				x	
5.1.5	Perform receiving or source inspection					S				P		x	x	x	x	x	x	x	x
5.1.6	Perform supplier evaluation and selection				A		P		S,A	S,A		x	x	x	x	x	x		
5.1.7	Establish supplier rating						P		R	P		x	x	x	x	x	x	x	x
5.1.8	Certify suppliers						P		A	A								x	
5.1.9	Provide supplier surveillance and assistance				S		P	S	S	S		x	x	x	x	x	x	x	x
5.1.10	Maintain approved supplier list						P		A	A		x	x	x	x	x	x	x	x
5.1.11	Maintain preferred products list						P		S,A	S,R		x	x	x	x	x	x	x	x
5.1.12	Provide orientation and training (suppliers, Receiving Inspection, Purchasing)		S	P			S		S	S		x	x	x	x	x	x	x	x
5.1.13	Calibrate inspection and test equipment					S		S		P		x	x	x	x	x	x	x	x
5.1.15	Accept or reject material (experimental)				A				A	P		x	x	x	x				
-----	Accept or reject material (deliverable)				R				R	P							x	x	x
5.1.16	Provide identification of incoming material				S		S			P		x	x	x	x	x	x	x	x
5.1.17	Provide control of discrepant material	A			A				A	P		x	x	x	x	x	x	x	x
5.1.18	Provide for segregation of material						P			A		x	x	x	x	x	x	x	x
5.1.19	Provide system for data collection, analysis, and feedback				R		S		R	P		x	x	x	x	x	x	x	x
5.1.20	Assure corrective action in incoming material control		S	R	S	S	S	S	S	P		x	x	x	x	x	x	x	x

5.2 PERFORMANCE STANDARDS FOR INCOMING MATERIAL CONTROL FUNCTIONS

5.2.1 INCOMING MATERIAL STANDARDS

Incoming material may be classified into these six categories:

- a. Raw materials including chemicals, metal stock, etc.
- b. Military standard parts or components.
- c. Offshelf or catalog items made to standard specifications set by the producer or seller.
- d. General items (parts, components, assemblies, etc.) purchased to Aerojet (called Company) drawings and specifications.
- e. Subcontracted items where subcontractor provides his own design.
- f. Government-furnished or customer-furnished materials, parts, or equipment.

Design standards (Section 4.2.7) such as drawings, specifications, and related documents must be available which properly describe each of the above categories. These standards should include reliability requirements either directly, by reference to an applicable military or Company specification, by reference to a special reliability specification, or indirectly by inclusion in the purchase order or subcontract requirements.

Either military or Company specifications may be used for the purchase and acceptance of raw materials, but it is important that these specifications include a list of all important characteristics (critical and major) together with specification limits on each. In addition, any special instructions such as packaging, handling, and storage and requirements for inspection or test data should be included in the purchase order if these requirements are not given in the specification. Usually, test certifications are required as part of the military procurement requirements.

Drawings and specifications for military standard parts are normally available, but will not necessarily describe the reliability necessary for a particular application. Therefore, reliability requirements should either be given in the purchase order or specifications should be revised to include the reliability requirements.

Offshelf or catalog items are produced to a supplier's own drawings and specifications and are offered for sale to the public. Such drawings and specifications may not guarantee the required level of reliability. Consequently, the test specifications should include adequate test specifications for testing the items before use. Items requiring a high level of reliability should not be purchased as offshelf or catalog items unless sufficient data from past experience indicates that the items are likely to be satisfactory.

Drawings and specifications for purchased parts or components should be subjected to the same treatment as design standards used for fabrication in the plant. This includes the establishment of reliability requirements, apportionment of reliability requirements to all elements of the product, design reviews, reliability monitoring, etc. Testing for compliance to reliability data by the supplier should be included in the purchase requirements.

In the case of subcontracted parts, or cases where the design is accomplished by a subcontractor, it should be required that the subcontractor have a reliability program meeting the requirements given in Sections 1 and 2 of this handbook. This will require the same control over the subcontractor's design as that required for designs made by the Company's engineering departments.

Design standards for government or customer furnished equipment must be available and should be checked for reliability the same as for any other equipment.

5.2.2 SUBCONTRACT REQUIREMENTS

The relationship between the Company and the subcontractor should be similar to the relationship between the customer and the Company (see Section 3.2.1) so far as reliability requirements are concerned. The Company should require the subcontractor's reliability program to meet the same standards established for Company plants or divisions. Adequate channels of communication should be maintained with each subcontractor, and clear and well-defined specifications, acceptance criteria, and other contractual re-

quirements for reliability of the supplied product should be provided. Contractual requirements include performance, environmental and reliability requirements, requirements for qualification testing, acceptance criteria, warranties, life testing and test-to-failure requirements, and quality data requirements. Acceptance criteria should include acceptable reliability levels and/or acceptable quality levels, consumer and producer risks, numerical reliability requirements, confidence levels, requirements for feedback of failure rate data, etc.

A reliability specification should be prepared for major subcontracts which will be referenced as part of the purchase order or subcontract. This specification should include:

- a. The requirements for the subcontractor's reliability program.
- b. The requirements for a reliability project plan.
- c. The numerical reliability goal assigned to the subcontracted product.
- d. The reliability allocation given to the components of the subcontracted product or the method by which these numerical requirements will be assigned.
- e. The system used by the Company for reliability monitoring and predictions.
- f. Procedures for review of the subcontractor's design.
- g. The selection and qualification of subcontractor purchased parts.
- h. Provisions for data exchange between Company and subcontractor.
- i. Requirements for failure reporting, analysis and corrective action, usage reporting, serialization, lot identification, and material segregation.
- j. Acceptance tests to be conducted by the subcontractor and by the Company.
- k. Types of data and reports required from the subcontractor.
- l. The reliability demonstration requirements.
- m. Any other reliability assurance provisions deemed necessary.

5.2.3 PURCHASE ORDERS OR SUBCONTRACTS

Purchase orders or subcontracts are the official agreements between the Company and the supplier and are the prime responsibility of the Purchasing Department. Purchase orders or subcontracts should include either directly, or by reference to the proper specifications or other documents, the reliability requirements for all products purchased. Purchase orders or subcontracts should include all supplier or subcontract requirements including performance requirements, reliability requirements, testing requirements, environmental requirements, etc., as indicated in the above paragraph. Purchase orders or subcontracts for standard materials or parts should be reviewed by Quality Control to assure that all quality requirements are properly called out in the contract.

In the case of subcontracts where the design is furnished by the subcontractor, the purchase order or subcontract should be reviewed by a reliability engineer to assure that reliability requirements are properly called out. Subcontracts of this type should call out the Company's general reliability specification, and also reference specifications relating to packaging, preservation, environmental testing, sampling, and acceptance testing.

5.2.4 INSPECTION AND TEST EQUIPMENT

Adequate inspection and test equipment should be provided for the acceptance of all incoming materials. This equipment should be adequate to accept material for reliability requirements as well as for other subcontract requirements. Preferably, the equipment should be at least 10 times as accurate as the product characteristic being tested and should be properly calibrated.

5.2.5 RECEIVING OR SOURCE INSPECTION

Incoming materials may be accepted either in the supplier's plant or in the Company's plant. The latter is usually more desirable. However, there are some circumstances under which source inspection is preferred. Acceptance inspection may be accomplished by the supplier or by the Company as agreed. It is important that such inspections contain acceptance and rejection criteria for product reliability as well as for other design parameters.

5.2.6 SUPPLIER EVALUATION AND SELECTION

All new suppliers, whose material is classified into categories d and e (see Section 5.2.1), should be thoroughly evaluated before purchase orders or subcontracts are placed with them, so that their capabilities and limitations may be known in advance. This should include a review of the engineering, quality control, manufacturing, and test facilities of the supplier. This review should normally be accomplished by members of Quality Control, Manufacturing, and Purchasing. For parts and components which are classified as critical or major from the reliability standpoint, a complete audit of the reliability program of the subcontractor should be included.

New suppliers should be selected by the Purchasing Department on the basis of combined regular supplier evaluations and reliability analyses. Current suppliers should be selected for new purchase orders or subcontracts on the basis of their past performance and their proven ability to meet reliability requirements.

5.2.7 SUPPLIER RATING

Existing suppliers and subcontractors should be rated according to their past performance. Where possible, this rating should consist of a comparison between reliability goals and reliability achievements. Where reliability goals have not been specified, the rating should be based on the quality of lots received.

A supplier reliability rating should include the nature of the discrepancies found, the nature of the required improvements, and the type of work the supplier can do on a reliable basis.

5.2.8 SUPPLIER CERTIFICATION

Reliability of incoming materials can sometimes be improved through the use of supplier certification programs, wherein the supplier does acceptance inspection and testing in accordance with a mutually approved plan and submits to the Company the resulting data, which then serves as a basis for acceptance or rejection of the material. The certification program is useful only where repeat orders are being received for a raw material or component part. Supplier certification agreements should be arranged by the Purchasing Department with the approval of the Quality Control Department.

By certifying a supplier, the Company is indicating that this supplier is preferred by virtue of the quality and uniformity of his product and by the reliability of his test data. Therefore, other things being equal, the Purchasing Department should give preference to certified suppliers.

Supplier certification offers the following potential advantages to the Company:

- a. Reduced testing costs.
- b. Reduced variation in the quality of the material.
- c. Prompt use of raw material as received.
- d. Additional test data on important characteristics at now extra cost.
- e. A desirable close-working relationship between the Company and the supplier.

5.2.8.1 Steps in Supplier Certification

The following steps should be performed in the supplier certification program:

- a. Determine the list of suppliers and materials or items which should be certified as based upon a consideration of economics and product reliability.
- b. Review the specifications for the materials or parts concerned to make sure that they meet all requirements for reliability and quality.
- c. Discuss the program with the supplier in order to reach an agreement on specifications, sampling and testing procedures, methods, data requirements, and methods of submitting data.
- d. Upon agreement as in c above, establish a trial period in which the supplier performs the acceptance inspection and submits the data with the shipments of raw materials or parts to Receiving Inspection. Receiving Inspection reinspects the lots and compares data with information received from the supplier. The trial period is continued until all differences between the Company and the supplier are worked out, and sufficient data have been received to demonstrate an acceptable level of reliability in the supplier's test results.
- e. Upon satisfactory completion of a trial period, a formal certification agreement should be worked out between the supplier and the Com-

pany. The supplier should agree to continue, as he has during the trial period, to properly identify material and submit test data in accordance with the methods agreed upon between himself and the Company.

f. Following certification, material should be used from the certified suppliers upon receipt and approval of the test data which they submit, except that an audit should be made from time to time by the Receiving Inspection Department. Audits will be quite frequent on more critical requirements and less frequent on the less critical characteristics of the item concerned. The audit should be carefully planned making full use of statistical program design techniques to assure validity and adequacy of audit data.

g. Whenever the audit reveals a greater difference in test results than should be expected by normal testing error, the certification program should be temporarily stopped until such time as the reason has been found and corrected, after which the certification program may continue. The same type of certification agreement may be effected between Company plants, as required.

5.2.9 SUPPLIER SURVEILLANCE AND ASSISTANCE

A constant surveillance program should be conducted over suppliers and subcontractors responsible for design and/or fabrication of major or critical parts. This surveillance and assistance consists of feedback of failure information, suggestions for improvement, assistance and follow-up in problem solving. It also includes providing information on new methods, providing new quality control and manufacturing techniques, giving design support, providing specialists, etc. Occasionally, it is desirable that a full time quality or reliability engineer be assigned to a supplier's plant to assist him in delivering a reliable product. In certain instances where the requirements for materials or products are not specific, the only method of assuring reliability of the subcontractor's product is a surveillance of his reliability and quality programs, followed by corrective action on important discrepancies.

5.2.10 APPROVED SUPPLIER LIST

An approved supplier list should be maintained by the Purchasing Department. This list should consist of new suppliers or subcontractors who have been evaluated and found satisfactory by an evaluation committee.

It should also include past or present suppliers whose record of quality, reliability, and delivery has been found to be satisfactory.

The Quality Control Department should maintain records of each supplier, and should inform the Purchasing Department if any supplier's record is unsatisfactory. A supplier who has an unsatisfactory quality or reliability rating should not be given any new orders until he has rectified his deficiencies, unless, of course, he is a sole source. Every effort should be made to provide multiple sources for major and critical parts.

5.2.11 PREFERRED PRODUCTS LIST

A list of supplied parts or components, requiring a high level of reliability, which have been tested and found to have satisfactory reliability should be maintained by each plant and used by Purchasing for reordering. Pertinent data should be exchanged through the Data Interchange Committee with other plants, divisions, or projects as required.

5.2.12 ORIENTATION AND TRAINING

(See Section 2.2.10)

5.2.13 CONTROL OF MEASURING DEVICES

(See Section 2.2.11)

5.2.14 ACCEPTANCE INSPECTION METHODS AND PROCEDURES

Acceptance inspection denotes inspections and tests which are performed on incoming materials, in-process materials, outgoing products, and where applicable, on products in the field, for the purpose of determining acceptability (or non-acceptability) of material consigned or scheduled for ultimate delivery to and use by the Company or its customer.

Detailed written inspection and test procedures should be available for the acceptance inspection of all such materials. These procedures should include the characteristics to be inspected, the sequence of inspection operations, the method of inspection, tools or equipment required, the criteria for acceptance (AQL's, tolerance limits, confidence levels, etc.), procedure for disposition of discrepant material, and the records or reports

required. Acceptance inspection procedures should include requirements for reliability as well as other contract requirements. In certain cases, visual standards, photographs, etc., may be required to properly indicate to inspection personnel the difference between acceptable or rejectable materials.

5.2.15 ACCEPTANCE OR REJECTION OF MATERIALS

Incoming materials, materials in-process, outgoing products, and products in the field should be inspected according to the inspection and test procedures.

If such materials are to be delivered to the Company's customer, acceptance can be made only in accordance with established quality control procedures and any deviations from standards should be referred to a Material Review Board which is constituted in accordance with the requirements of MIL-Q-9858.

If such materials are to be entirely consumed for test purposes within the Company as part of the R and D program, the final decision as to the acceptance of materials which do not meet standards should rest with the cognizant Design Engineering Group. However, appropriate notations of such deviation from standards should be made by the Inspection Group. In no case should a product be delivered to the Company's customer when it has deviations from established standards, unless it is approved by the customer. The distinction then in the acceptance or rejection of materials will be the difference between experimental and deliverable products.

5.2.16 IDENTIFICATION OF MATERIALS

An adequate material identification system should be established which will indicate the inspection status of all materials and supplies by means of stamps, tags, cards, tickets, etc., and which will accurately identify the material at each stage of processing. Procedures must be enforced which will prevent either a loss of identity or the establishment of an incorrect identification of materials. Particular care should be taken to control rejected or questionable material so that it will not become mixed with acceptable material. Wherever possible, the material identification should be maintained during processing. These instructions are in addition to any specific instructions that may be required by the Company for the identification of materials.

5.2.17 CONTROL OF DISCREPANT PRODUCTS AND MATERIALS

All incoming materials, materials in process, or final products, as well as materials in the field, which do not meet quality standards, should be submitted to Material Review prior to delivery to the Company or its customer. Such a review should be in conformance with the procedure outlined in MIL-Q-9858. When sub-standard material is detected, it should be properly identified and segregated to prevent its utilization in the process or shipment with acceptable product.

The acceptance of non-conforming supplies is a prerogative of the Company and/or its customer and should be performed according to prescribed requirements and procedures. All non-conforming supplies should, if practicable, be diverted from normal material movement channels and should be positively identified to prevent use until disposition is made. Holding areas mutually agreeable to the Company and to the government representatives should be provided.

5.2.18 SEGREGATION OF MATERIALS

Adequate arrangements should be made for segregating materials as required to achieve a high level of reliability. Reliable parts should be stored separately from normal parts.

5.2.19 SYSTEM FOR DATA COLLECTION, ANALYSIS, AND FEEDBACK

(See Section 2.2.12)

5.2.20 CORRECTIVE ACTION

(See Section 2.2.13)

5.3 RELIABILITY METHODS FOR INCOMING MATERIAL CONTROL

Reliability methods and other guides developed for application to the incoming material program are presented in the following Aerojet-General Corporation documents: Volume II of this handbook, the Quality Control Standards Manual, and the Quality Control Policies and Procedures Manual.

SECTION 6

PROCESS CONTROL

Process Control is a management control which is exercised to assure that a product conforms during fabrication to design and process standards at the optimum cost. Pertinent information is presented in this section according to the following outline:

- 6.1 Process control functions and suggested assignments of responsibilities
- 6.2 Standards of performance for process control functions
- 6.3 Reliability methods for process control functions

LEGEND FOR SECTION 6.1

DEGREE OF AUTHORITY AND RESPONSIBILITY

P = Prime authority = Has responsibility for satisfactory completion of task

A = Approval authority = A series function - may accept or reject work or action of (P)

R = Review authority = Reviews and requests corrective action from (P) when required

S = Supporting services = Provides requested services for (P)

TIME OF PERFORMANCE BY PRODUCT MATURITY

1. Detailed design study
2. Preprototype (design 95% complete)
3. Prototype (design firm)
4. Preproduction demonstration (PFRT)
5. Demonstration of service readiness (qualification tests)
6. Service evaluation (flight tests)
7. Full scale production (acceptance tests)
8. Demonstration of major product improvement

Suggested Assignments of Responsibility

6.1 PROCESS CONTROL FUNCTIONS

		Customer or Cust. Rep.	Contract Adm. or Sales	Director R. & Q./Staff	Plant Manager	Project Engineering	Test	Material	Manufacturing	Reliability Engineering	Quality Engineering	Technical Control	Technical Service	Time-Phase							
														1	2	3	4	5	6	7	8
6.1.1	Prepare process specifications				P			A	R	A				x	x	x			x		
6.1.2	Prepare workmanship standards				R			P	R	A				x	x	x	x	x	x		
6.1.3	Establish process controls							A		P								x	x		
6.1.4	Perform process capability studies				R			R		P				x	x	x	x	x	x		
6.1.5	Perform pilot runs				R			P		S								x	x		
6.1.6	Provide adequate process equipment				S			P		A					x	x	x	x	x		
6.1.7	Provide inspection and test equipment				S	S		S		P				x	x	x	x	x	x		
6.1.8	Establish waste control system			R				S		P				x	x	x	x	x	x	x	
6.1.9	Certify special processes and operators	A				S		S		P				x	x	x				x	
6.1.10	Provide orientation and training (production operators, process inspectors)			P				S		S				x	x	x	x	x	x	x	x
6.1.11	Calibrate inspection and test equipment					S		S		P				x	x	x	x	x	x	x	x
----	Calibrate processing equipment							S		P				x	x	x	x	x	x	x	x
6.1.12	Provide acceptance inspection methods and procedures									S	P			x	x	x	x	x	x		
6.1.13	Accept or reject in-process materials (experimental)				A					A	P			x	x	x	x	x			
----	Accept or reject in-process materials (deliverable)				R					R	P								x	x	x
6.1.14	Provide identification of in-process materials				S	S		S		P				x	x	x	x	x	x	x	x
6.1.15	Establish control of discrepant in-process materials	A			A			A		P				x	x	x	x	x	x	x	x
6.1.16	Provide segregation of in-process materials							P	R	A				x	x	x	x	x	x	x	x
6.1.17	Provide data system for collection, analysis, and feedback				R			S	R	P				x	x	x	x	x	x	x	x
6.1.18	Assure corrective action in process control		S	R	S	S		S	S	P				x	x	x	x	x	x	x	x

6.2 STANDARDS OF PERFORMANCE FOR PROCESS CONTROL FUNCTIONS

6.2.1 PROCESS SPECIFICATIONS

Many manufacturing processes are such that discrepancies arising from the process cannot be detected by subsequent non-destructive tests. As these manufacturing discrepancies are a basic cause of early and random failure and because many of them are difficult to eliminate by inspection, high reliability requires that everything possible be done to minimize the number of these discrepancies which are inadvertently "built" into the product. Much can and should be done to convert organized knowledge of causes of unreliability into formal and mandatory process specifications for use within the Company's fabrication and assembly plants. Manufacturing techniques should be selected which will eliminate or reduce the human errors in the manufacturing and assembling operation. The process specification should be compatible with product quality requirements. Process specifications should be reviewed as part of the Design Review discussed in Section 4.2.11.

6.2.2 WORKMANSHIP AND QUALITY STANDARDS

The actual workmanship that goes into fabrication and assembly is a major factor in building reliability into the product. Each production worker should be made to feel that he is carrying a responsibility for reliability which is no less important than that of the designer. To facilitate this work, standard operating procedures or process standards should be prepared to supplement process specifications. These should include special instructions relative to: fabrication, assembly, material handling, house-keeping, tooling, uniform construction methods, use of automatic equipment, special precautions, standard methods of construction or assembly, and visual quality standards.

6.2.3 PROCESS CONTROL

To assure that products will continue to meet reliability requirements and that the inherent design reliability will not be degraded during the manufacturing process, special controls should be established. These controls should be placed as close as possible to the source of potential variation. Process control procedures should be prepared by the design

nated Process Control Group and should prevent the unwarranted manufacture of discrepant products. Such a procedure would be aimed at the early detection of an "out-of-control" process and provide an efficient means of instituting corrective action. Process controls should be established where it is necessary to control outgoing quality at some point prior to final inspection, to prevent the production of excess defective items, and to locate the causes of unreliability for special studies.

Procedures should be prepared for in-process controls and should include:

- a. Sampling and inspection.
- b. Characteristics to be inspected.
- c. Frequency of inspection.
- d. Inspection equipment required.
- e. Records and/or reports required.
- f. A means for effecting corrective action.

6.2.3.1 Steps in Process Control

To establish the required process controls, the following steps must be taken:

- a. Determine the product or process variables to be controlled. These variables are sometimes obvious or are known by technical, manufacturing, or quality control personnel. In other cases, however, the cause and effect relationships between process variables and product defects may need to be determined through the use of statistically designed exploratory experiments.
- b. Determine the acceptable quality level and acceptable reliability level.
- c. Design the proper control procedure based upon the quality or reliability standard and the knowledge of the process variability.
- d. Establish a procedure for corrective action based upon the control program established.

Process control may consist of audits, use of monitoring or automatic control equipment, 100% inspection or screening, sequential sampling

plans, control charts, etc. MIL-STD-105 and MIL-STD-414 should be used as applicable. The process control program should provide sufficient testing of production items to provide a measure or estimate of product reliability. It should include laboratory investigation and analysis of failures and malfunctions during production or service. In shops, where the work is primarily on a job shop basis, controls should be installed on the processes or equipment rather than on the product itself. Process controls should include measures to detect the reliability of the product as well as its quality.

6.2.4 PROCESS CAPABILITIES

Process capability studies are useful to the designer in establishing design tolerances. They are also imperative from the reliability standpoint, as it is impossible to produce a reliable product with equipment or personnel not having the necessary reproducibility capability.

6.2.5 PILOT RUNS

A formal pilot production run subsequent to product design, but prior to large scale production, is very desirable from the standpoint of reliability since it gives final proof of the design adequacy for producibility. If it is feasible to carry out sufficient tests of the products produced, the pilot run also provides a measure of the degree to which the design conforms to the contractual performance requirements.

Pilot runs should be performed on production equipment with production operators. They should be part of a joint program between the Design Engineering Staff, Manufacturing, and Process Control. A plan for the pilot run should be prepared by the Process Control Group indicating the number of products to be manufactured. This number of parts would be manufactured by the Manufacturing Department using the materials, processes, and methods described in the product design. The Process Control Group should monitor the program to make sure that the products produced conform to the design. The products (or a sampling) produced should be tested to ascertain that:

- a. The manufacturing is carried on exactly in accordance with design standards.
- b. The resultant products meet the performance requirements.

If the design standards, methods of processing, and product performance are not compatible, appropriate corrective action should be taken.

6.2.6 PROCESS EQUIPMENT

One of the principal causes of degradation of reliability during manufacturing results from damage caused by process equipment during fabrication and assembly of the product. All new or repaired equipment should be checked out prior to use by direct inspection or immediately after initial use by inspection of the first parts of the process. Process control should be established on critical and major parts to monitor machine-operator capability. A sound calibration program should be maintained for production tools used in the more critical operations.

6.2.7 INSPECTION AND TEST EQUIPMENT

Adequate inspection and test equipment should be provided by the Process Control Group for controlling the manufacturing process.

6.2.8 WASTE CONTROL

As part of the overall economy program, a waste control program should be conducted. This should include segregation of discrepant products and process scrap and maintenance of waste cost records. Process control charts should be used for maintaining this record and out-of-control points should be investigated and corrective action taken as necessary.

6.2.9 CERTIFICATION OF SPECIAL PROCESSES

When government approval or certification of special processes, equipment, or personnel is required under the contract, the Company shall be certain that all are fully qualified before requesting government approval. Special training programs should be conducted to assure a sufficient number of people capable of performing special processes. A record of certified personnel should be maintained.

6.2.10 ORIENTATION AND TRAINING

(See Section 2.2.10)

6.2.11 CONTROL OF MEASURING DEVICES

(See Section 2.2.11)

- 6.2.12 ACCEPTANCE INSPECTION METHODS AND PROCEDURES
(See Section 5.2.14)
- 6.2.13 ACCEPTANCE OR REJECTION OF IN-PROCESS MATERIALS
(See Section 5.2.15)
- 6.2.14 IDENTIFICATION OF IN-PROCESS MATERIALS
(See Section 5.2.16)
- 6.2.15 CONTROL OF DISCREPANT IN-PROCESS MATERIALS
(See Section 5.2.17)
- 6.2.16 SEGREGATION OF IN-PROCESS MATERIALS
(See Section 5.2.18)
- 6.2.17 SYSTEM FOR DATA COLLECTION, ANALYSIS AND FEEDBACK
(See Section 2.2.12)
- 6.2.18 CORRECTIVE ACTION
(See Section 2.2.13)

6.3 RELIABILITY METHODS FOR PROCESS CONTROL

Reliability methods and other guides developed for application to the process control program are presented in the following Aerojet-General Corporation documents: Volume II of this handbook, the Quality Control Standards Manual, the Quality Control Policies and Procedures Manual, and Book Standards.

SECTION 7

PRODUCT CONTROL

Product Control is a management control which is exercised to assure that all products as delivered to the Company's customer meet acceptable quality standards. Information fundamental to this control is presented in this section according to the following outline:

- 7.1 Product control functions and suggested assignments of responsibilities
- 7.2 Standards of performance for product control functions
- 7.3 Reliability methods for product control functions

LEGEND FOR SECTION 7.1

DEGREE OF AUTHORITY AND RESPONSIBILITY

- P = Prime authority = Has responsibility for satisfactory completion of task
- A = Approval authority = A series function - may accept or reject work or action of (P)
- R = Review authority = Reviews and requests corrective action from (P) when required
- S = Supporting services = Provides requested services for (P)

TIME OF PERFORMANCE BY PRODUCT MATURITY

1. Detailed design study
2. Preprototype (design 95% complete)
3. Prototype (design firm)
4. Preproduction demonstration (PFRT)
5. Demonstration of service readiness (qualification tests)
6. Service evaluation (flight tests)
7. Full scale production (acceptance tests)
8. Demonstration of major product improvement

7.1 PRODUCT CONTROL FUNCTIONS

Suggested Assignments of Responsibility

														Time-Phase							
														1	2	3	4	5	6	7	8
7.1.1	Provide acceptance inspection equipment				S	S	S	R	P							x			x		
7.1.2	Inspect and test product					S		R	P					x	x	x	x	x	x	x	x
7.1.3	Design packaging				P		S	A	R	A				x	x	x	x				
7.1.4	Perform packaging testing							R	P							x	x	x			
7.1.5	Prepare packaging procedures				S	P		R	R	A						x	x	x			
7.1.6	Prepare shipping instructions				S	P		R	R	A						x	x	x			
7.1.7	Perform warehouse and shipping inspection							R	P	R								x	x	x	
7.1.8	Pack and handle outgoing product				S	P	S	R	A	R								x	x	x	
7.1.9	Provide orientation and training (final inspectors, shippers, packers, handlers, etc.)			P			S				S							x	x	x	
7.1.10	Calibrate acceptance inspection equipment					S	S			P						x	x	x	x	x	
7.1.11	Prepare acceptance inspection methods and procedures				S	S			P							x			x		
7.1.12	Accept or reject product						S	S	P						x	x	x	x	x	x	x
7.1.13	Provide identification of product						S	S	P							x	x	x	x	x	x
7.1.14	Provide control of discrepant product	A			A			A	P							x	x	x	x	x	x
7.1.15	Provide for segregation of products					P			A									x	x	x	x
7.1.16	Provide system for data collection, analysis, and feedback				R		S	R	P									x	x	x	x
7.1.17	Assure corrective action in product control		S	R	S	S	S	S	P									x	x	x	x

7.2 STANDARDS OF PERFORMANCE - PRODUCT CONTROL FUNCTIONS

7.2.1 ACCEPTANCE INSPECTION EQUIPMENT

Acceptance inspection equipment includes all inspection gages, test instrumentation and equipment, and any other equipment necessary to accept or reject the final product. It is the responsibility of Quality Control to assure that adequate equipment is available for this purpose, and that this equipment is maintained in good condition. Assistance may be obtained from other departments for the design, manufacturing, and procurement of such equipment. There should be a systematic calibration and check of test equipment as indicated in Section 2.2.11.

Because of rapid advances in technology, some measurements must be made more accurately than has been customary, and new measurement methods and standards must be developed. However, since the precision of reliability estimates is closely correlated with the accuracy of test data, test equipment accuracy must be maintained. As a rule of thumb, the ratio between the test equipment accuracy and the tolerance limit permitted by the specification should be ten to one.

7.2.2 ACCEPTANCE INSPECTION

Acceptance inspection is the final inspection and testing of a product prior to delivery to the customer. All products which are deliverable to the customer either for test or operational use must meet all inspection and test requirements prescribed in the design standards. All products which deviate from these standards should be sent to the Material Review Board, where disposition should be made as indicated in Section 5.2.17. If all reliability requirements are a part of the design standard, as they should be, the acceptance inspection will include reliability testing as well as quality testing. Testing may include:

- a. Functional testing either on a sampling basis or 100% as required.
- b. Screening tests for critical reliability characteristics.
- c. Environmental tests on samples.
- d. Reliability demonstration tests.

For the important reliability requirements, testing should be done to acceptable levels of both reliability and quality.

Quality testing determines the compliance to a set of requirements at a particular point in time. Such tests do not guarantee that the characteristics exhibited at the time of final inspection will prevail and be stable for any future time when the product is used.

Reliability testing is aimed at determining the probability of success at the time the product is actually used. For certain types of products, this may be determined by testing all items. In other cases, non-destructive testing must be performed, requiring the use of statistical sampling plans. In many cases life testing or test to failure will be required. It is the responsibility of the design engineers to include reliability and life requirements in the test specifications and methods, and it is the responsibility of the Product Control Group to assure that this is accomplished.

7.2.3 PACKAGING DESIGN

An important part of the design standards is the design of packaging. Packaging design should be performed by Design Engineering and should be reviewed according to the regular design review procedure.

7.2.4 PACKAGING TESTING

Packaging should be tested for the type of transportation and handling in environmental extremes as indicated by the Company's customer. The designer must know the time, type, and environment of storage, handling and transportation, and the packaging must be tested accordingly.

7.2.5 PACKAGING PROCEDURES

Packaging procedures should be prepared as part of the design standards and should be consistent with the methods of handling, storage, and transportation. The Product Control Group should inspect to assure that packaging meets all design standards and that packaging procedures are followed. Packages should be properly identified, and important handling or storage instructions should be stenciled on the package.

7.2.6 SHIPPING AND STORAGE INSTRUCTIONS

Adequate procedures for control of supplies stored for the government or to be applied to government contracts should be provided to ensure preservation and treatment in accordance with applicable requirements. Similarly, procedures should be prepared for methods of shipping the product in order to prevent degradation of reliability. Procedures for protecting the quality of the products during transit must be in accordance with government requirements. Procedures should indicate the type of inspection that should be performed at scheduled intervals to assure compliance with these procedures.

7.2.7 WAREHOUSE AND SHIPPING INSPECTION

Adequate studies and tests to determine the effects of storage on the reliability of a product should be conducted and included in the specifications and instructions. Retesting of parts in stock should be accomplished as necessary to assure that reliability is not being degraded in storage. Procedures should be prepared for eliminating parts which show poor reliability. Shipments should be inspected to make sure that the shipping instructions are properly carried out, and that the product reliability will not be degraded during the shipment process.

7.2.8 PACKING AND HANDLING

The contractor will evaluate his packing and handling procedures to prevent degradation of reliability during handling and shipping.

7.2.9 ORIENTATION AND TRAINING

(See Section 2.2.10)

7.2.10 CONTROL OF ACCEPTANCE INSPECTION MEASURING DEVICES

(See Section 2.2.11)

7.2.11 ACCEPTANCE INSPECTION METHODS AND PROCEDURES

(See Section 5.2.14)

7.2.12 ACCEPTANCE OR REJECTION OF PRODUCT

(See Section 5.2.15)

- 7.2.13 IDENTIFICATION OF OUTGOING PRODUCTS
(See Section 5.2.16)
- 7.2.14 CONTROL OF DISCREPANT PRODUCTS
(See Section 5.2.17)
- 7.2.15 SEGREGATION OF PRODUCTS
(See Section 5.2.18)
- 7.2.16 SYSTEM FOR DATA COLLECTION, ANALYSIS AND FEEDBACK
(See Section 2.2.12)
- 7.2.17 CORRECTIVE ACTION
(See Section 2.2.13)

7.3 RELIABILITY METHODS FOR PRODUCT CONTROL

Reliability methods and other guides developed for application to the product control program are presented in the following Aerojet-General Corporation documents: Volume II of this handbook, the Quality Control Standards Manual, and the Quality Control Policies and Procedures Manual.

SECTION 8

FIELD CONTROL

Field Control is a management control which is exercised to assure that the delivered product is not degraded during field storage, handling and use. Information related to this control is presented in this section according to the following outline:

- 8.1 Field control functions and suggested assignments of responsibilities
- 8.2 Standards of performance for field control functions
- 8.3 Reliability methods for field control functions

LEGEND FOR SECTION 8.1

DEGREE OF AUTHORITY AND RESPONSIBILITY

- P = Prime authority = Has responsibility for satisfactory completion of task
- A = Approval authority = A series function - may accept or reject work or action of (P)
- R = Review authority = Reviews and requests corrective action from (P) when required
- S = Supporting services = Provides requested services for (P)

TIME OF PERFORMANCE BY PRODUCT MATURITY

1. Detailed design study
2. Preprototype (design 95% complete)
3. Prototype (design firm)
4. Preproduction demonstration (PFRT)
5. Demonstration of service readiness (qualification tests)
6. Service evaluation (flight tests)
7. Full scale production (acceptance tests)
8. Demonstration of major product improvement

8.1 FIELD CONTROL FUNCTIONS

		Customer or Cust. Rep.										Time-Phase							
		Contract Adm. or Sales	Director R. & Q./Staff	Plant Manager	Project Engineering	Test	Material	Manufacturing	Reliability Engineering	Quality Control	Technical Services	1	2	3	4	5	6	7	8
8.1.1	Prepare operating manuals and procedures				A			R	P						x	x			
8.1.2	Prepare field maintenance procedures				A			R	P						x	x			
8.1.3	Monitor all field operations								P							x	x		
8.1.4	Perform preflight inspection or testing	P				S			S							x			
8.1.5	Investigate and report field failures and customer complaints				R			R	R	P						x	x		
8.1.6	Obtain information on usage environments				R			R	R	P						x	x		
8.1.7	Provide technical assistance to customer or customer representative				S	S		S	S	P						x	x		
8.1.8	Assure delivery of all contractor furnished support equipment				S	S	S	S	S	P						x			
8.1.9	Provide spare parts				S	S	S	R	A	P						x	x		
8.1.10	Perform failed parts analysis (field)	R			P			R	R	S						x	x		
8.1.11	Perform field testing	P			R			R	R	R							x		
8.1.12	Provide orientation and training (field service and customer personnel)			S	P	S		S	S	S					x	x	x		
8.1.13	Calibrate field equipment							R	R	P					x	x	x		
8.1.14	Prepare acceptance inspection methods and procedures				S	S		S	P	R					x	x	x		
8.1.15	Accept or reject product in field	P							R	R						x	x		
8.1.16	Control discrepant product in field	P							R	R						x	x		
8.1.17	Provide system for data collection, analysis, and feedback	S	S		R	S	S	R	R	F						x	x		
8.1.18	Assure corrective action in field control	S	S	R,S	R	S	S	S	S	P						x	x	x	

8.2 STANDARDS OF PERFORMANCE FOR FIELD CONTROL FUNCTIONS

8.2.1 OPERATING MANUALS AND PROCEDURES

To maintain product performance and reliability during use, a procedures manual should be prepared indicating best methods for transporting, handling, storage, inspecting, assembling, installing, and using the product in the field. The manual should include the theory of operation of the product in the field. It should include the theory of operation of the product and a check-off list to make sure that all procedures are followed. It should also include educational material for operator training, instructions for feedback of malfunction information and precautionary measures to prevent potential difficulties.

8.2.2 FIELD MAINTENANCE MANUALS AND PROCEDURES

To prevent malfunctions in the field, maintenance methods, procedures, and instructions should be available to field personnel. This should include methods of checking, adjusting, aligning, calibrating, replacing, or repairing products or their parts. A preventive maintenance program should be included, as well as methods of fault location or troubleshooting in cases of trouble. Instructions for major overhaul, marginal testing, re-testing and age control of parts should be included also. Symptoms of failure should be described together with recommended corrective action.

As part of the contracting procedures or as a part of the field control activities, information as to maintenance requirements must be determined. This includes degree of maintenance desired, type and number of maintenance personnel available, and established maintenance procedures including preventive maintenance.

This information should be used to determine the contents of the maintenance manual, the need for replaceable subassemblies or modules, and the repair parts to be shipped with the equipment.

Moreover, field control personnel should maintain a log of fault locating time, repair time, total down time, mean time between failures, and other information which can be used by the designer to improve the maintainability of the design and consequently the availability of the product.

8.2.3 MONITORING OF FIELD OPERATIONS

The reliability inherent in the product or equipment at time of shipment can be realized in service only if it is not degraded during transportation, installation, maintenance, storage, and use in the field. Consequently, field control personnel should participate, insofar as project funds will allow, in the use phase of the product. In addition to the preparation of operating and maintenance manuals, field control personnel should make first-hand observations of service and storage conditions and the human factors involved, and should inform the using personnel concerning the proper care and use of the product. Formal training courses should be held as indicated in Section 2.2.10 of this handbook.

8.2.4 PREFLIGHT INSPECTION OR TESTING

For certain critical components or systems, an inspection or non-destructive test may be required in the field before installation in the weapon system to assure that no damage occurred during shipment. Inspection may be also desirable after long periods of storage or after major repairs. Occasionally, retrofit programs are required and should be supervised. Final checkouts are often required prior to product use. All readiness inspection or tests of this kind should be under the supervision of the field control personnel. Inspection, test, or engineering personnel should be borrowed from the appropriate division when required.

Adequate inspection and test procedures should be included as part of the operating or maintenance manual.

8.2.5 FIELD FAILURES AND CUSTOMER COMPLAINTS

Field control personnel should investigate all customer complaints concerning company products, and should provide failure reports on all product failures. For guidance here, product failure is defined as the inability of any item to perform its function during operation within the limits of its intended use. Also see Section 10 for definitions of critical, major, and minor failures.

It is recognized that the amount of evaluation testing that can be performed and the simulation of operating conditions that can be

achieved in the plant prior to shipping the product is inadequate. Consequently, the fullest possible use of field operating experience must be made. The reliability of complete weapon systems under actual or simulated tactical conditions is the obvious end point of the whole reliability program. Therefore, contract proposals should include coverage for participation of field control personnel in field operations to the extent necessary for adequate evaluation and reporting of all field failures.

Field reports and analysis operations should:

- a. Provide information necessary to determine equipment reliability under operating conditions,
- b. Delineate significant problem areas, and
- c. Contribute information needed for management controls and corrective action.

The exact form of a failure report must be determined for each project, but should include certain standard information such as identification of the failed item, identification of failure, mode of failure, cause of failure, severity of failure, classification of failure as to type and source, operating time to failure, symptoms of failure, fault location time, repair time, total down time, corrective action taken, and extenuating circumstances.

Failure classification should include sources of failure such as design error, manufacturing error, material failure, mishandling, misapplication, poor installation, secondary failures, poor maintenance, lack of preventive maintenance, personnel deficiencies, and inadequacy or inaccuracy in instruction manuals.

Field control personnel should follow-up on the effectiveness of corrective action for all field failure reports in order to minimize the number of recurring failures. Copies of failure reports should be sent to the cognizant company organizations such as Design Engineering, Reliability Engineering, Manufacturing, Purchasing, and Quality Control.

8.2.6 OBTAIN INFORMATION ON USAGE ENVIRONMENTS

Field control personnel should obtain information on environ-

mental and operational conditions under which the product is used in the field and provide this information to engineering personnel. Such information should include transportation, handling and storage conditions, maintenance procedures, environmental extremes at firing site or test base, time in readiness or standby state, manner of installation, readiness checkouts, manner of replacing components or parts, type and number of composite system or compatibility tests, and other information which would be useful to the designer for design improvements or for the creation of new designs.

The designer can use this information not only for improvement in the design, but also for determining the need for replaceable sub-assemblies, throw-away modules, number of spares, and instruction manuals.

8.2.7 TECHNICAL ASSISTANCE TO CUSTOMERS AND CUSTOMER REPRESENTATIVES

Technical assistance should be provided to the customer to assure that company products are used in the proper manner and that the customer is satisfied with company services. Such assistance might include the services of design engineers, reliability specialists, test engineers or technicians, quality engineers or inspectors, package engineers, or maintenance engineers, etc. Special assistance should be arranged when required by the field control personnel. Sufficient contract funds should be provided for these services.

8.2.8 SUPPORT EQUIPMENT

Field control personnel should ascertain that all field support equipment which is to be furnished by the company is designed, tested, manufactured, and delivered to the proper use site. All inspection and test equipment should be properly calibrated as outlined in Section 2.2.11.

8.2.9 SPARE PARTS

Field control personnel should make sure that the proper quantity of spare parts are available at the test or operational sites and that these parts are in satisfactory condition for use when required. The number and type of replaceable subassemblies or components should be determined by the requirements for maintenance time and the skill of maintenance personnel. At those operating sites where the cost of supporting spares is high and/or storage space is critical, consider the following:

a. The number of times the subassembly is used in the equipment.

b. The number of times the subassembly is used in other equipment supplied with spare parts from the same location.

8.2.10 FAILURE ANALYSIS

Failure reports should be reviewed and an analysis made by the responsible engineer. The failed part should be returned to the Company and reinspected as required. The purpose of the failure analysis is to determine the mode and cause of failure and to determine the corrective action required. Failure analysis reports should be submitted to the Company's customer as required by contract, and also to the several control groups who are responsible for following up on corrective action.

8.2.11 FIELD TESTING

The only true measurement of product reliability comes from the field use testing program, provided of course, that the field testing closely simulates true operational conditions. Field tests should be witnessed by field control personnel whenever possible to assure that the proper data and information may be obtained and fed back to the cognizant departments through the designated control groups. A further discussion of field testing is given in Section 4.2.16 of this handbook.

8.2.12 ORIENTATION AND TRAINING

(See Section 2.2.10)

8.2.13 CALIBRATION OF FIELD MEASURING DEVICES

(See Section 2.2.11)

8.2.14 ACCEPTANCE INSPECTION METHODS AND PROCEDURES

(See Section 5.2.14)

8.2.15 ACCEPTANCE OR REJECTION OF PRODUCT IN THE FIELD

(See Section 5.2.15)

8.2.16 CONTROL OF DISCREPANT PRODUCT IN THE FIELD

(See Section 5.2.17)

8.2.17 SYSTEM FOR DATA COLLECTION, ANALYSIS, AND FEEDBACK

(See Section 2.2.12)

8.2.18 CORRECTIVE ACTION

(See Section 2.2.13)

8.3 RELIABILITY METHODS FOR FIELD CONTROL

Reliability methods and other guides developed for application to the field control program are presented in the following Aerojet-General Corporation documents: Volume II of this handbook, the Quality Control Standards Manual, the Quality Control Policies and Procedures Manual, and Field Quality Control Instructions Manuals as issued by the individual plants.

SECTION 10

GLOSSARY

ACCEPTABLE QUALITY LEVEL (AQL) - A nominal value expressed in terms of percent defective or defects per hundred units as specified for a given group of defects of a product. It is a measure of quality or the fraction defective which will be accepted some preassigned percentage of the time by a sampling plan.

ACCEPTABLE RELIABILITY LEVEL (ARL) - A measure of reliability which will be accepted some preassigned percentage of the time by a reliability sampling plan.

ACCEPTANCE CRITERIA - The standards used as a basis for determining whether or not contract requirements are met.

ACCEPTANCE INSPECTION - Examination and testing to determine conformance of material or processes to required standards.

ACCEPTANCE NUMBER (either "ac" or "c") - The largest number of defectives (or defects) permitted in a sample for acceptance of the inspection lot.

ACCEPTANCE SAMPLING - Procedures whereby decisions are made to accept or reject lots or processes based upon the inspection of samples.

ACCEPTANCE SAMPLING PLAN - A specific plan which states the sample sizes, and the criteria for acceptance, rejection, or taking another sample.

ACCEPTANCE TESTS - Tests to determine conformance to design standards which are part of the acceptance inspection program.

ACCURACY - The closeness of computations, measurements, or estimates to the exact or true values.

ASSEMBLY - A number of parts or subassemblies or any combination thereof joined together to perform a specific function.

ASSIGNABLE CAUSE - An identifiable reason for a change in product quality due to usual and predictable (non-chance) causes.

ASSOCIATE CONTRACTORS - Suppliers who have direct contracts with a customer but are coordinated by a prime contractor.

ASSURANCE - Certainty of obtaining a specified result. When used as a function, it is the act of ascertaining that a specified result is obtained.

ATTRIBUTE - A characteristic or property which can be appraised only in terms of whether it does or does not exist.

ATTRIBUTES INSPECTION - Inspection wherein certain characteristics of the sample units are inspected to specified requirements and classified simply as conforming or not conforming. The degree of nonconformance may be further categorized through the use of classifications such as critical, major, and minor.

AVAILABILITY - The probability that the equipment is operating or capable of operation at a given time instant. This can be estimated by the fraction $\frac{MTBF}{MTBF + MDT}$, where MTBF is "mean-time-between-failures", and MDT is "mean-down-time."

AVERAGE LIFE - See Mean Life.

AVERAGE OUTGOING QUALITY (AOQ) - The long run average quality that may be expected from a given sampling plan if rejected lots are 100% inspected and all defectives found are corrected or replaced with acceptable units.

AVERAGE OUTGOING QUALITY LIMIT (AOQL) - The upper limit on outgoing quality (percent defective) that may be expected in the long run when all rejected lots are subjected to 100% inspection, with all defective articles corrected or replaced by good articles.

AVERAGE SAMPLE NUMBER (ASN) - The average number of sample units inspected per lot when reaching a decision to accept or to reject.

AVERAGE TOTAL INSPECTION (ATI) - The average number of units inspected per lot, including all units in rejected lots (applicable when the procedure calls for 100% inspection of rejected lots).

BALLISTIC MISSILE - Any missile which is guided through part of its trajectory, especially the early part, but becomes a free-falling body in the latter stages of its flight through the atmosphere. Although the missile may contain guiding devices, it is distinguished from a guided missile in that it becomes a free-falling body subject to ballistic reactions as it descends through the atmosphere. Currently, the term has a strong connotation of a missile designed to travel outside, or in the outer reaches of the atmosphere, before plunging toward its target.

BREADBOARD MODEL - An assembly of detailed parts and subassemblies to prove the feasibility of a device, circuit, equipment, system, or principle in rough or breadboard form, without regard to the eventual over-all design or form of parts.

BUDGET CONTROL - A reliability assurance function which sets and assures conformance with budget requirements for all reliability control functions.

CALENDAR AGE - Age measured in terms of time since the object was manufactured.

CALIBRATION - The control, adjustment, or scaling of a measuring device so that its accuracy and precision will be within specified tolerances.

CAPABILITY - In general pertains to the nature and quality of performance. In a weapon system, it pertains to the damage inflicted upon the target when the weapon functions as intended.

CATASTROPHIC FAILURE - A sudden change in the operating characteristics of an item resulting in a complete lack of performance.

CENSORED SAMPLE - A censored sample is one in which measurements are not made on items whose values are greater or less than some known value or values.

CHANCE FAILURE - A chance failure is a failure which occurs at random or which is not economically feasible to identify. In electronics, the chance failure is normally considered a failure which occurs within the operational time of an equipment after all efforts have been made to eliminate design effects and unsound components and before wearout becomes predominant.

CHANGE CONTROL - A system assuring adequate control of changes to drawings, specifications, and other engineering design documentation.

CHARACTERISTIC - An individual trait or property of a unit of product.

CHECKOUT - A test or procedure for determining whether a device is capable of performing a required operation or function. A checkout usually consists of the application of a series of operational and calibrational tests in a certain sequence, with the requirement that the response of the device to each of these tests be within a predetermined tolerance.

CIRCULAR PROBABLE ERROR (CPE) - In missile fields, a probable error used as a factor in determining the probable damage to a target expressed in terms of the radius of a circle which would include half of the missile strikes of missiles aimed at the center of the circle.

CLASSIFICATION OF DEFECTS - The enumeration of possible defects of the unit of product classified according to the seriousness of the effect on the mission of the product.

CLASSIFICATION OF FAILURES - The enumeration of possible failures classified according to the seriousness of the effect on the mission of the product.

COMPLEXITY - The figure of merit or measure of quantity of related parts or circuits. The total number of parts (n) is often used as the measure. Complexity units are sometimes used as a preliminary and approximate measure.

COMPONENT - A self-contained combination of parts, subassemblies, or assemblies, which perform a distinctive function in the overall operation of an equipment.

COMPONENT STRESS - The stresses induced in component parts as a result of the external and internal environments encountered by the system during its life and use cycle.

CONDITIONING - Conditioning is the exposure of sample units or specimens to a specific environment for a specified period of time (or successively to two or more specific environments, each for its specific period of time) to prepare them for subsequent inspection.

CONFIDENCE INTERVAL - A range of values estimated from a random sample which will encompass the true value of a sought-for parameter of the parent population a given percentage of times if the sampling process were to be repeated many times.

CONFIDENCE LEVEL - The probability that an interval estimated from a test or series of tests, will contain the parameter tested. For example, from a sample, the interval $R_L \leq R \leq R_U$ is determined at the 90% confidence level.

This implies the mathematical probability is 90% that the interval will contain the intrinsic reliability. The point estimate lies within this interval.

CONFIDENCE LIMITS - Statistical limits placed upon an estimate of a parameter such that there is a given probability that the true value of the univariate parameter lies between these limits a given percentage of the time.

CONSUMER'S RELIABILITY RISK - The risk of the consumer that a product will be accepted by a reliability test when its reliability is actually below a specified minimum level.

CONSUMER'S RISK (Beta) - The probability of acceptance by sampling of a lot of material of objectionable quality. (Beta is usually set at 10%.)

CONTINUOUS SAMPLING PLAN (CSP) - A type of inspection wherein units or samples are taken directly from a continuous flow of product without forming inspection lots. The desired outgoing quality is maintained by adjustment of the percentage of inspection to the quality of material being produced.

CONTINUOUS VARIABLE - A variable that may assume any value within a defined range.

CONTRACT - An agreement between supplier and purchaser regarding an item to be purchased.

CONTRACT CONTROL - A management control which assures (1) a valid and realistic contract containing clear statements of the customer's requirements and contractor's obligations, and (2) the contractor's full and efficient compliance to these requirements.

CONTRACT REQUIREMENTS - All obligations agreed to by the contractor on acceptance of a contract. Includes requirements for performance, reliability, storage, packaging, proof of compliance, documentation, etc.

CONTRACTOR - An individual or organization entering into a contract to furnish specified products or services in accordance with the terms of the contract.

CONTROL - The observation and regulation of an operation within prescribed limits in order to achieve an objective.

CONTROL CHART - A graphic chart with a central line and upper or lower control limits on which data from a series of samples or subgroups are plotted.

CONTROL LIMITS - Limits on a control chart which are used as criteria for action or for judging the significance of variations within or between samples or subgroups. Any plotted points falling outside control limits are presumed to indicate the presence of assignable causes. (See Statistical Control Limits.)

CONTROL LOOP - The path that data feedback and corrective action take in eliminating reliability problems throughout the life cycle. (See Product Life Cycle Chart (Fig. 1) at the end of this handbook.)

CONTROLLED PROCESS - A process which yields samples whose characteristics vary randomly within the control limits of a Control Chart.

CORRECTIVE ACTION - Action taken to isolate and eliminate usual and predictable causes of discrepancies and prevent manufacture and shipment of nonconforming material, and to eliminate causes of unreliability.

CORRELATION - The relationship of one variable with another; the amount of similarity in direction and degree of variations in pairs of observations of two variables; also, the relationship of one variable with two or more variables.

CRITICAL CONTRACT REQUIREMENTS - Contract requirements which are considered extremely important and difficult to meet at the specified level of reliability, and which should receive priority in research and development.

CRITICAL PARTS - Parts whose achieved or estimated reliability is significantly lower than the reliability goal.

CURTAILED INSPECTION - Sampling inspection which is discontinued because a definite decision has been reached. For example, if the rejection number for defectives is reached in sampling a lot, the decision is certain and further inspection is unnecessary. (Note: A first sample is always completed for the purpose of estimating process average.)

DEBUGGING - A process of "shakedown operation" of each finished equipment which is performed prior to placing it in use. During this period, "weak" system elements are expected to fail and be replaced by elements of normal quality which are not subject to early failure. This process exposes the equipment to all field operational stresses. The debugging process is not, however, intended to detect inherent weaknesses in system design. These should have been eliminated in the preproduction stages by appropriate techniques.

DEFECT - Any imperfection, deficiency, flaw, lack of completeness, or other condition at variance with technical requirements. A unit of product may contain more than one defect.

DEFECT, CRITICAL - A critical defect is one that judgment and experience indicate could result in hazardous or unsafe conditions for individuals using or maintaining the product; or, for major end item units or product, such as ships, aircraft, or tanks, a defect that could prevent performance of their tactical function.

DEFECT, MAJOR - A major defect is a defect, other than critical, that could result in failure, or materially reduce the usability of the unit of product for its intended purpose.

DEFECT, MINOR - A minor defect is one that does not materially reduce the usability of the unit of product for its intended purpose, or is a departure from established standards with no significant bearing on the effective use of operation of the unit.

DEFECTIVE UNIT - A unit of product containing one or more defects.

DELIVERY - Includes all operations after fabrication and assembly until an item is transferred to the customer.

DEMONSTRATION OF MAJOR PRODUCT IMPROVEMENT MONITORING POINT - At this point the reliability and overall value of major product improvements are demonstrated and may be approved for incorporation into the weapon system.

DEMONSTRATION OF SERVICE READINESS MONITORING POINT - Here the contractor is required to show that the weapon system which is usually built under the limited (or pilot) production program has reached the reliability objectives, and that the system can be produced in quantity without significant loss in performance or reliability.

DEMONSTRATION TESTS - Tests performed to prove compliance of the product with contract performance requirements at the specified reliability level.

DEPENDABILITY - A function of reliability and maintainability quantitatively estimated by the ratio of the mean operating time between failures and the mean down time.

$$D = \frac{MTBF}{MDT}$$

DERATING - The purposeful use of a component or part at a load level below its designed maximum allowable stress level.

DESIGN - The specification and configuration of an item.

DESIGN CONTROL - A management control which assures that the design conforms to contract requirements.

DESIGN CRITERIA - Contract requirements expressed in terms of design inputs.

DESIGN DOCUMENTATION - See Design Standards.

DESIGN EVALUATION - An evaluation of prototype hardware to determine whether the design of a product meets the design criteria which has been established as necessary to provide a product which will meet the needs of the purchaser of that product.

DESIGN PARAMETER - Product characteristic inherent in a given design.

DESIGN REVIEW - A critical survey of all design standards conducted at specified points during the life cycle of a product for the purpose of increasing effectiveness and reducing cost.

DESIGN STANDARDS (DESIGN DOCUMENTATION) - All documentation, such as drawings and specifications, which describe the product and the parts and materials of which it is composed, including specifications for processing, testing, packaging, shipping, and storage.

DESIGN STUDY - An early engineering phase resulting in the determination of specific performance and reliability requirements necessary to achieve weapon system requirements.

DESIGNED EXPERIMENT - See Statistically Designed Experiment.

DESTRUCTIVE TEST - An inspection test resulting in destruction of the particular test specimen.

DETAILED DESIGN STUDY MONITORING POINT - This phase begins with the contract award and ends with a design report that includes studies of system and subsystem reliability that encompass the entire weapon system design and includes an assessment of reliability using prediction techniques wherever feasible.

DEVELOPMENT MODEL - A model designed to meet performance requirements of a specification or establish technical requirements for production equipment. This model need not have the required final form or necessarily contain parts of final design.

DEVELOPMENT TESTING - An integrated series of evaluation tests conducted during the research and development of a product to assure that the product, with any necessary modifications during the tests, will meet the contract requirements.

DISCRETE VARIABLE - A quantity that may assume any one of a number of individually distinct or separate values.

DISTRIBUTION - See Frequency Distribution and Probability Distribution.

DISTRIBUTION FUNCTION - The (cumulative) distribution function of a variate X is the total frequency of members with variate values less than or equal to X . Ordinarily the total frequency is taken to be unity so that the distribution function is the proportion of members having values less than or equal to X .

DOUBLE SAMPLING - Sampling inspection in which the results of inspection of the first sample may be inconclusive, and inspection of a second sample may be required to determine acceptability. A double sampling plan provides first and second sample sizes with associated acceptance and rejection criteria.

DOWN TIME - The time in which the system is not in condition to perform its intended function.

EARLY FAILURE PERIOD - That period of time following initial turn-on during which failures occur at a higher than normal rate.

EFFECTIVENESS - A function, roughly proportional to the product of capability and reliability of a system. In a weapon system, it pertains to the results obtained from attempts to use the weapon.

END USE - The purpose for which the ultimate consumer employs a device.

ENVIRONMENT - The aggregate of all the conditions and influences which affect the operation of equipments and components.

ENVIRONMENTAL TESTS - Tests conducted under actual or simulated environmental conditions to determine effects of various environmental factors on product performance or reliability.

EQUIPMENT - A combination of assemblies which is capable of operation by itself.

ESTIMATE - The expected value of a characteristic of a universe determined from observations on samples taken from the universe.

EXPECTATION - Mean value, over the population of all possible values.

EXPERIMENTAL DESIGN - The combination of conditions and sequence of tests making up an experiment.

EXPERIMENTAL ERROR (TESTING ERROR) - The variation inherent in repeat measurements obtained under similar test conditions.

EXPERIMENTAL MODEL - See Developmental Model.

FABRICATION - The construction and assembly of an item.

FABRICATION TOLERANCE - In the construction and assembly of an equipment or portion thereof, the maximum variation in the characteristics of a component which, when related to the defined variations of the other components comprising this equipment, will permit operation of the equipment within specified limits.

FAILED PARTS ANALYSIS - The reinspection of failed parts to determine cause and mode of failure. (See Failure Analysis.)

FAILURE - Inability to perform required function during operation within limits of intended use.

FAILURE, CRITICAL - Failure, or performance degradation in excess of tolerance limits, which prevents the product from satisfactorily completing its intended task or mission, or which creates a safety hazard requiring premature destruction of the product or discontinuance of the test.

FAILURE, MAJOR - A failure which in itself does not cause an abortive malfunction or safety hazard, but which might have done so under different operating conditions.

FAILURE, MINOR - All failures other than critical or major which have no significant effect on the ability of the item to perform in the manner intended and hence would not be counted against reliability.

FAILURE ANALYSIS - The investigation of modes of failure in order to gain information leading to corrective action and increased reliability.

FAILURE CODES - A numerical code to classify discrepancies into comparatively simple groups for ease in data processing.

FAILURE DATA - Information relating to modes, causes, and frequency of failure.

FAILURE RATE - The frequency of failure occurrence expected or observed over a specified time interval. In the case of exponentially distributed times to failure, the failure rate per unit time is the reciprocal of mean time to failure.

FAILURE REPORT - A published record of failure data originating during test or use, in the plant or in the field. Includes analysis and summarization of the data for pertinent reliability information.

FEASIBILITY STUDIES - Those studies conducted to determine the possibility of incorporating a new material, process, or product into project weapons systems, supporting systems, subsystems, components, or operational support equipment, or to explore the possibility of using present weapon systems, etc., in new operational environments.

FIELD CONTROL - A management control which assures that the product is not degraded during field storage, handling and use.

FIRST ARTICLE INSPECTION - Detailed inspection of the first unit(s) produced by new, repaired, or revised manufacturing operations, processes, or tooling to determine their capability to produce acceptable product.

FIRST PART INSPECTION - See First Article Inspection.

FRACTION DEFECTIVE (p) - The ratio of the number of defective pieces to total number of pieces inspected, expressed as a decimal fraction. (Note: Percent defective = 100 x fraction defective.)

FREQUENCY DISTRIBUTION - A tabulation showing the frequencies of the values of a variable with the values arranged in order of magnitude, either by size of individual observations or by grouping into classes.

FULL SCALE PRODUCTION MONITORING POINT - The primary aim at this stage is to insure that the level of reliability designed into the system is maintained during production.

FUNCTIONAL PERFORMANCE - Operation within specified limits.

FUNCTIONAL PERFORMANCE TIME - The time during which an item is performing a specified function.

GRAND AVERAGE OR GRAND MEAN ($\bar{\bar{X}}$) - The arithmetic mean of a group of averages.

GROUND HANDLING EQUIPMENT - That equipment which is used to accomplish a prime mover function, e.g., gantry crane.

GROUND OPERATING EQUIPMENT - That ground equipment which is peculiar to the weapon system or support system and which is operated with the prime vehicle in the performance of the latter's mission as the major operational element of the weapon system or support system. This term does not include those items which are defined as ground support equipment.

GROUND SUPPORT EQUIPMENT - Any or all non-airborne implements or devices which are required to inspect, test, adjust, calibrate, appraise, gage, measure, repair, overhaul, assemble, disassemble, transport, safeguard, record, store, actuate, or otherwise perform a function in support of the airborne vehicle and guidance station equipment during both the research and development and operational phases of the weapon system. Test GSE is that ground support equipment used to support the missile test program which also may be identified as test support equipment (TSE). Ground operational equipment (GOE) is that nonmobile equipment used in support of the Operational Weapon System.

HETEROGENEITY - A state or condition of dissimilarity of nature, kind, or degree.

HETEROGENEOUS PROCESS - A non-homogeneous process; one that is not accomplished under continuously similar conditions and exhibits evidence of assignable causes for product variation.

HISTOGRAM - A block diagram of a frequency distribution.

HOMOGENEITY - A state or condition of similarity of nature, kind or degree.

HOMOGENEOUS PROCESS - A process wherein units were produced under essentially the same conditions.

HUMAN ENGINEERING - Consideration of a complex equipment as a man-machine system for the purpose of increasing its effectiveness by treating it as a unified system.

HYPOTHESIS - A tentative theory provisionally adopted to explain certain observations or occurrences and to guide in the investigation of other observations or occurrences.

IMPORTANCE FACTOR - The importance factor of an equipment is the relative importance of the particular system to the total mission effectiveness. It is defined as the ratio of the number of mission failures due to the equipment failing to the total number of failures of the equipment.

INCOMING MATERIAL CONTROL - A management control which assures that incoming materials conform to design standards at the optimum cost.

INDEPENDENT FAILURES - Those failures which occur or can occur without being related to the malfunctioning of associated items.

INDUCED ENVIRONMENT - The shocks, vibrations, temperatures, accelerations, pressures and so forth which are imposed upon the system due to the operation or handling of the system.

INFANT MORTALITY - Premature catastrophic-type failures occurring at a rate substantially greater than that observed during subsequent life prior to wearout.

INSPECTION - That phase of quality control which, by means of examination and test, determines the extent of conformance of supplies or services to established requirements.

INSPECTION LEVEL - A term used to indicate the relative number of sample units for a given amount of product applied for a particular sampling plan. All other things being equal, a higher inspection level entails a lower risk of acceptance of a lot of inferior quality, and vice versa.

INSPECTION LOT - A collection of units of product of a single type, grade, class, size, or composition manufactured or processed under substantially the same conditions and offered for inspection at one time during a fixed period of time.

INSPECTION LOT SIZE - The number of units of product in an inspection lot.

INSPECTION STRINGENCY - The level of inspection applied for a particular AQL, e.g., normal, reduced, or tightened as given in MIL-STD-105B. Inspection stringency depends upon the process average of similar material previously inspected.

INTERCHANGEABILITY, COMPLETE - The ability to interchange without restriction like equipments, or portions thereof in manufacture, maintenance, or operation.

INTERCHANGEABILITY, SELECTED - Exists when all components manufactured to the same general specifications are not completely interchangeable. When this is the case the component parts are often placed in classes so that there will be complete interchangeability in each class.

ITEM - A general term used to denote one of a number of similar units, objects, test pieces, etc.

KILL PROBABILITY - The probability that a target will be destroyed as a result of a direct hit or a near miss.

LAUNCHER - A specific facility for launching a missile. It includes all the installed and ground support equipment necessary for missile countdown.

LEVEL OF SIGNIFICANCE - A preselected probability of occurrence at which a decision to reject a null hypothesis will be made.

LIFE CHARACTERISTIC - Operating life as a function of failure rate. Usually plotted showing three parts: (1) an infant mortality or debugging part; (2) a normal operating (constant λ) part; (3) a wear-out portion, i.e., the relationship which holds between the failure rate of equipment and operating or test time.

LIFE CYCLE - The complete life of the system from the first operational planning through contracting, research, development, testing, procurement, fabrication, assembly, inspection, packaging, shipping, storage, maintenance and use.

LIFE DISTRIBUTION - The distribution of the life under a specified environment of a number of similar products. This usually is the operating life distribution.

LIFE TESTING - Testing conducted at specified stress levels for either a predetermined time or until a predetermined number of failures have occurred for the purpose of estimating mean life.

LOGISTICS - That activity that provides for the necessary support of a weapon system by providing for supplies, equipment, transportation, maintenance, construction and operation of facilities, movement and evacuation of personnel, and other like services, so as to render the weapon efficient and effective in both combat and noncombat operations.

LONGEVITY TESTS - This is a term generally applied to tests of small quantities of equipments to determine a typical safe useful life. The longevity test is not a life test in the sense that only those wearable parts which can be replaced in preventative maintenance are damaged. The equipment subjected to longevity test is not necessarily expended. It may be serviced and shipped.

LOT - See Inspection Lot.

LOT QUALITY - The ratio of the number of units defective to the total number of units comprising the lot.

LOT SIZE (N) - The number of units offered for inspection and acceptance at any one time.

LOT TOLERANCE PERCENT DEFECTIVE (LTPD) - An unsatisfactory quality level for submitted lots, expressed in percent defective, for which the probability of acceptance (consumer's risk) should not exceed a given percent (usually set at 10%).

MAINTAINABILITY - The probability that when specified maintenance is taken, the system can be restored to a satisfactory operational condition in a given period of time in a specified maintenance environment.

MAINTENANCE - All actions necessary for the retaining of material in, or restoring it to, a serviceable condition, modifying or improving equipment, in use or in storage, to meet programmed operational requirements, installation-engineering and installation of equipment and facilities. Maintenance also includes the function of servicing, trouble shooting, manufacturing, rebuilding, testing, reclaiming and the condition status classification of material.

MAINTENANCE PROCEDURES - Established techniques for effecting immediate repair of failed equipments.

MALFUNCTION - A general term used to denote the occurrence of failure of a product to give satisfactory performance. It need not constitute a failure if readjustment of operator controls can restore an acceptable operating condition.

MANAGEMENT CONTROL - A function which involves setting standards for satisfactory performance in an area of responsibility, determining conformance with these standards, and initiating corrective action whenever standards are not met.

MANUFACTURE - The procurement, fabrication, and delivery of a product to the customer.

MARGINAL TESTING - Testing employing non-destructive measurement techniques to identify units which will exhibit submarginal performance or reliability in service. May involve severity testing.

MATERIAL REVIEW - A system involving the review of all discrepant materials and products in order to determine proper disposition. Usually includes representatives from engineering, manufacturing and when necessary, customer or military representatives.

MEAN-CYCLES-BETWEEN-FAILURE - The average number of cycles between successive failures, i.e., the total number of cycles under specified conditions divided by the number of failures (the mean-cycles-between-failure is the reciprocal of the failure rate per cycle).

MEAN DOWN TIME - The expected value of the total time required to restore an equipment or system to a satisfactory operational condition measured from the moment when it is judged unsatisfactory for normal service.

MEAN LIFE - The mean of a life distribution.

MEAN TIME BETWEEN FAILURES (MTBF) - The expected value for elapsed time between successive failure occurrences in a unit or in the mean time to failure after a maintenance and repair action. Estimated from total operating time between failures of several units divided by the number of failures.

MEAN TIME TO FAILURE (MTTF) - The expected value for elapsed operating time of a unit before failure occurs. Associated with non-repairable equipment of systems. Estimated from total operating time of several units divided by the number of failures.

MEAN TIME TO FIRST FAILURE (MTTFF) - The average time to first failure of several equipments. Used to determine the apparent approach of the equipment life characteristic to its random failure rate. Usually accomplished during the manufacturing phase of a program.

MEASUREMENT STANDARDS - Reference standards calibrated through secondary and primary plant levels to the National Bureau of Standards.

MINIMUM RELIABILITY LEVEL - An unsatisfactory value for product reliability for which the probability of acceptance (consumer's risk) should not exceed a given percent. See Reliability Operating Characteristic Curve.

MISSION TASK - The specified purpose for which a device is to be used.

MISSION TIME - The period of time in which a device must perform specified mission task in a specified environment.

MODES OF FAILURE - The physical description of the manner in which a failure occurs, and the operating condition of the equipment or part at the time of the failure.

MODULE - A combination of components, contained in one package or so arranged that they are common to one mounting, which provides a complete function or functions to a system and/or subsystem in which they operate. Synonymous with out-moded term "black box".

MONITORING - See Reliability Monitoring.

MONITORING POINTS - See Reliability Monitoring Points.

MOVING AVERAGE - (r item moving average). The average of each r consecutive measurements, recalculated after each measurement.

MULTIPLE SAMPLING - Sampling inspection in which results of the inspection of one or more successive samples from an inspection lot may be inconclusive and the inspection of several samples may be required to determine its acceptability. A multiple sampling plan consists of three or more sample sizes with associated acceptance and rejection criteria.

NATURAL ENVIRONMENT - Aggregate of all natural external conditions and influences such as time, temperature, humidity, pressure, solar radiation, rain, snow, hail, wind, and so forth which are imposed upon a system.

NON-DESTRUCTIVE TESTING - Testing of any nature which does not materially affect the life expectancy of the item tested.

NORMAL INSPECTION - The degree of sampling inspection required when the estimated process average for the lots remains within the limits of the process average for the AQL used.

NORMAL OPERATING PERIOD - The normal operating period of an equipment is that period of equipment life during which the equipment failure rate remains essentially constant.

OBSERVATION - A single measurement of a single characteristic.

ONE HUNDRED PERCENT INSPECTION - Inspection where every unit of product is individually accepted or rejected for the characteristic(s) on which inspection is being performed.

OPERATING CHARACTERISTIC CURVE - The curve of a sampling plan which shows the relationship between the quality of submitted inspection lots and the percentage of such inspection lots which may be expected to be accepted on the basis of that sampling plan.

OPERATING EQUIPMENTS - Equipments of a system whose operational function is a part of the overall system operation.

OPERATING INSTRUCTIONS - Information intended to assist in the operation of an equipment or type of equipment.

OPERATING LIFE - The total time an equipment will operate prior to wearout.

OPERATING TIME - The time period between turn-on and turn-off of an equipment or system.

OPERATIONAL READINESS - The probability that a system will perform satisfactorily at any point in time.

OUTGOING PRODUCT CONTROL - A management control which assures that all products as delivered to the customer meet acceptable quality standards.

OUT OF CONTROL - The terminology used when some characteristic of an operation is not within its normal range of variability. See Process Capability.

PARAMETER - The true value of any measurable characteristic of a universe such as mean, standard deviation, correlation coefficient, etc.

PART - The least subdivision of a system. An individual piece having an inherent functional capability but unable to function without the interaction of other parts or forces and ordinarily not subject to disassembly without destruction.

PERCENT DEFECTIVE (p) - The ratio of the number of defective pieces to the total number of pieces inspected, multiplied by 100.

PERFORMANCE FAILURE - A detected change in performance beyond the limits established for satisfactory operation.

PILOT PRODUCTION - Production of a limited quantity of an item using the same tooling, methods, and inspection techniques as will be used in the full production at production rates.

POPULATION - See Universe.

PRECISION - The degree to which repeated observations of a class of measurements conform to their mean.

PREDICTION TECHNIQUES - Methods by which future behavior of a system is forecast on the basis of knowledge of its components and their inter-relationships.

PREFERRED PRODUCTS LIST - A list of those products which have been tested and found satisfactory from the reliability standpoint.

PREPRODUCTION DEMONSTRATION MONITORING POINT - At this point the production design of the weapon system is essentially complete and the missile or missile system is considered ready for production. A demonstration of the reliability achieved during this stage provides one of the bases for assessing the system's readiness for full scale production.

PREPRODUCTION MODEL - See Prototype Model.

PREPRODUCTION TESTS OR INSPECTION - Tests performed on first production equipment using factory type tooling and methods to insure that processes and methods are capable of producing satisfactory product.

PREPROTOTYPE MONITORING POINT - Here the initial system design is nearly complete, and many component parts and assemblies have undergone some developmental testing. This point may be identified by some such phrase as "95 percent of engineering released", "design engineering inspection", or "the time at which initial design is essentially complete".

PREVENTIVE MAINTENANCE - A procedure of periodically reconditioning a system in accordance with specific instructions and schedule to prevent or reduce the probability of failure or deterioration while in service.

PRIMARY FAILURE - That portion of a system which fails first, which may or may not result in another failure.

PROBABILITY - The likelihood that an event or group of events will occur, expressed as a fraction between 0 and +1.

PROBABILITY DISTRIBUTION - A mathematical model, displayed in graphic, tabular, or equation form, which presents the probabilities for all of the possible values a given random variable may take.

PROBABILITY LIMITS - Upper and lower limits assigned to estimated value to indicate the range within which the true value is supposed to lie according to some statement of a probabilistic character. Examples: control chart limits, confidence limits.

PROBABILITY OF ACCEPTANCE (P_a) - The chance that a lot of a given quality p will be accepted under a given sampling plan.

PROCESS - Procedure or technique followed in the production of a product.

PROCESS AVERAGE - The average quality from a given process. The process average is estimated from the results of inspection of a preceding quantity of product. It may be expressed either in percent defective or in defects per hundred units.

PROCESS CAPABILITY - The normal range of variability in a characteristic resulting from a manufacturing process in a state of statistical control.

PROCESS CONTROL - A management control during fabrication to optimize the conformance of a product to design and process requirements and to minimize costs.

PROCUREMENT - All functions connected with obtaining reliable supplies from sub-contractors consistent with the design standards at the optimum cost.

PRODUCER'S RISK (α) - The probability of rejection by sampling of a lot of the specified acceptable quality level. (α is usually set at 5%.)

PRODUCIBILITY - The degree of compatibility between design requirements and production capabilities.

PRODUCT - The physical item called for by a contract and may be a part, component, equipment, subsystem, or system.

PRODUCT ASSURANCE - An integrated overall management control program embracing the final performance of the product in the field and all related characteristics such as reliability, quality, maintainability, availability, systems integration, operability, value, cost, etc. Assures the maximum military effectiveness at the optimum cost.

PRODUCT CONTROL - See Outgoing Product Control.

PRODUCT IMPROVEMENT - Design changes which have a beneficial effect on performance, reliability, and cost.

PRODUCTION MODEL - A unit of product made in accordance with production design specifications using production tools and methods.

PRODUCTION TESTS (VERIFICATION) - Tests performed on samples of production equipment at periodic intervals during production to insure that it complies at all times with standards previously established.

PROOF OF COMPLIANCE - The final action on the part of a contractor to show that all requirements of the contract have been fulfilled. It is a final accounting of the contracts execution and deliveries, indicating all approvals and waivers received.

PROTOTYPE (PREPRODUCTION MODEL) - A model suitable for complete evaluation of design and performance. It shall be of final form, employ approved parts, and be completely representative of final equipment.

QUALIFICATION - Formal assurance and approval that an article used in the product meets all operational and reliability requirements under all conditions of expected environmental conditions.

QUALIFICATION INSPECTION AND TESTS - An examination and testing of a product to determine whether or not it conforms to all qualification requirements of the applicable specification.

QUALITY - The degree of conformance of material to: (a) design standards (drawings, purchase specifications, etc.), and (b) customer requirements of performance, reliability, and cost.

QUALITY CHARACTERISTICS - Those properties of an item or process in the population domain which can be measured, reviewed, or observed and which are identified in the drawings, specifications, or contractual requirements.

QUALITY CONTROL - A set of management control functions which assures that all quality characteristics, including reliability, serviceability, maintainability, attractability, performance, and cost, conform to customer expectations.

QUALITY STANDARD - Any accepted or established rule or model for defining a quality characteristic.

RANDOM FAILURE - Any chance failure whose probability of occurrence with time is unpredictable. May in some cases include those failures uneconomically feasible to identify.

RANDOM SAMPLE - Units taken from a lot in such a manner that every unit in the lot has an equal and independent chance of being included in the sample.

RANDOM VARIABLE - A variable -- either discrete or continuous -- which may assume any one of a number of values, each of which has a fixed probability of occurrence.

RANDOMNESS - An equal chance for any of the possible outcomes.

RANGE (R) - The arithmetic difference between the largest and smallest value in a sample.

RATIONAL SUBGROUPS - Groupings of observations chosen so that variations within the subgroups are least likely to be due to assignable causes and so that extra variations between subgroups are likely to be the result of assignable causes. Rational subgrouping is an essential technique in discovering the existence of assignable causes.

READINESS TIME - The length or time required to obtain a stabilized system ready to perform its intended function. (Readiness time includes warm-up time.) The time is measured from the point when the system is unassembled or uninstalled to such time as it can be expected to perform as accurately as at any later time. Maintenance activity time is excluded from readiness time.

RECEIVING INSPECTION - Acceptance inspection of incoming material.

REDUCED INSPECTION - A reduction in inspection stringency when records for prior material indicate that the process is well stabilized and producing appreciably better than the anticipated lower limit of the process average (e.g., see MIL-STD-105B for typical special requirements.)

REDUNDANCY - The existence of more than one means for accomplishing a given task, where all means must fail before there is an overall failure to the system. Functional redundancy applies to systems where two or more means are working at the same time to accomplish the task when less than the total number is necessary. Standby redundancy applies to a system where there is one or more alternate means of accomplishing the task that is switched in by a malfunction sensing device when the primary means fail.

REJECT - To certify that material is not to be used for its intended purpose and that it will be returned to the supplier or referred to Salvage for disposition.

REJECTION NUMBER - The smallest number of defectives (or defects) in the sample or samples under consideration that will require the rejection of the inspection lot.

RELEASE - To clear tested materials from impound by means of formal acceptance.

RELIABILITY - The probability that a product will perform its intended function for a specified period of time when used under specified environmental conditions.

RELIABILITY, ACHIEVED - The reliability demonstrated by a product under actual operational conditions at any given time in the life cycle of the product.

RELIABILITY, EQUIPMENT, INHERENT (R_e) - The probability that an equipment or product will perform properly when operated under contractually stated operational conditions utilizing supporting equipment and procedures in the manner intended. It is the reliability potential of an equipment or product after manufacturing, but prior to any degradation in use. Hence,
 $R_e = R_d \times R_m$.

RELIABILITY, MANUFACTURING (R_m) - The probability that there will be no degradation of the inherent design reliability during manufacturing.

RELIABILITY, MINIMUM REQUIREMENT - A value less than desired which must be demonstrated on or before specified date.

RELIABILITY, OPERATIONAL (R_o) - This is the reliability actually achieved in operational use and is the value with which we are most concerned.

$$R_o = R_e \times R_u = R_d \times R_m \times R_u$$

RELIABILITY, USE (R_u) - The probability that there will be no degradation of inherent equipment reliability during use.

RELIABILITY ANALYSIS - A thorough review of all reliability data and information available for a given product in order to prepare a current prediction or assessment of operational reliability.

RELIABILITY APPORTIONMENT - The assignment of reliability goals or requirements to subsystems, equipments, components and parts using approved reliability techniques.

RELIABILITY ASSESSMENT - The establishment of the value of achieved product reliability based on a reliability analysis.

RELIABILITY ASSURANCE - The overall coordination of all reliability activities to assure product conformance to contract reliability requirements.

RELIABILITY CONTROLS - All of the management controls necessary to assure achievement of reliability goals. These consist of contract control, design control, incoming material control, process control, outgoing product control, and field control.

RELIABILITY DATA - Data originating from reliability tests used to prevent product failures by creating preventative techniques in the basic design and to monitor the product reliability throughout the life cycle.

RELIABILITY DEGRADATION - The decrease in system reliability from that inherent in the design due to manufacturing and/or use. Inherent design reliability minus degradation due to manufacturing gives inherent equipment reliability.

RELIABILITY DEGRADATION FACTOR - The ratio of (a) the loss in system reliability due to degradation and (b) the system's inherent design reliability. For example, $(R_d - R_o)/R_d$ is the reliability degradation factor for the interval from end of design through field use.

RELIABILITY DEMONSTRATION - Proof of the conformance to reliability requirements using contractually specified methods.

RELIABILITY DESIGN, INHERENT (R_d) - The reliability potential of the design prior to any degradation in manufacture or use.

RELIABILITY ENGINEER - An engineer specializing in the analysis and prevention of reliability problems through the application of appropriate statistical methods and reliability techniques.

RELIABILITY ENGINEERING - A management control function which assures that the product design conforms to contract reliability requirements.

An engineering specialty in the same sense as Stress Analysis, Materials Engineering, Systems Engineering, etc.

RELIABILITY ESTIMATE, EXPERIMENTAL (R_{exp}) - An estimate of product reliability based on tests of that product simulating actual conditions of operational use.

RELIABILITY ESTIMATE, INFERENTIAL (R_{inf}) - An estimate of reliability based on a mathematical composite of available information such as reliability data on parts or components based on field tests, factory tests or data interchange, acceptance inspection data, reliability data from similar products, etc.

RELIABILITY GOAL - The numerical reliability desired for a product at a specified time in its development or use cycle. This value may or may not be a firm contract requirement.

RELIABILITY GROWTH CURVE - The increase in reliability through a system's life cycle. It may be hypothesized or based on achieved reliability.

RELIABILITY MEASUREMENT - The observed proportion of successes out of a definite number of trials made under operational conditions.

RELIABILITY METHODS - Techniques for contracting and designing reliability into the product, preventing degradation during manufacturing and use, and for monitoring reliability during the product life cycle.

RELIABILITY MONITORING - The quantitative specification, apportionment, estimation, prediction, assessment or measurement of reliability at predesignated times, or monitoring points during the life cycle of a product.

RELIABILITY MONITORING POINTS - Predesignated points at which reliability is monitored during the life cycle of a product.

RELIABILITY OPERATING CHARACTERISTIC CURVE (ROC) - The operating characteristic of a reliability acceptance test which shows the relationship between the reliability of submitted lots and the percentage of such lots which may be expected to be accepted by the reliability acceptance test plan.

RELIABILITY PLAN - A specified plan including a reliability analysis, task assignment, methods, and budget.

RELIABILITY PREDICTION - An estimate of the reliability at some future time based on reliability information presently available.

RELIABILITY PROGRAM - An organized approach assuring the achievement of the reliability requirements of the weapon system as established by the procuring activity and incorporated in the contractual documents. It is not a separate effort but an integral part of the overall problem of systems management and engineering.

RELIABILITY REQUIREMENT - A level of reliability expressed in an equipment specification as a design requirement.

RELIABILITY SYNTHESIS - See Reliability, Inferential.

RELIABILITY TESTS - Tests and analyses, in addition to other type tests, which are designed to evaluate the level of reliability in a product and the dependability or stability of this level with time and use under various environmental conditions.

REPAIRABILITY - A function of mean time to repair (MTR) and the mean down time (due to corrective maintenance) and is a parameter of the maintainability function. It can be used to derive the availability of a system in a manner analogous to the use of mean time between failures to derive the reliability.

REPAIR TIME - Repair time is time measured from the beginning of correction of malfunction to the completion of such correction. It is assumed that the cause of malfunction is known, i.e., the time actually required to replace defective items and insure satisfactory operation. This time should not include delays due to shortages of parts, transportation, or other non-related factors.

REPRODUCIBILITY - The ability of a measuring device to repeat measurements under specified conditions. This includes both accuracy and precision.

RETROFIT - Replacement of parts on existing products due to design changes or improvements.

RISK - The probability of making an incorrect decision.

SAFETY FACTOR - Ratio of the ultimate strength of a component part and the maximum stress to which it will be exposed in use.

SAFETY MARGIN - Difference between the mean strength of a population of component parts and the maximum stress to which all parts will be exposed in use, expressed in units of the standard deviation of the strength distribution.

SALVAGE ACTION - To dispose of non-conforming material to the best advantage.

SAMPLE - One or more units selected at random from a quantity of product to represent the quality of product for inspection purposes.

SAMPLE SIZE (n) - The number of units in a sample. Also used in the sense of the number of observations in a sample.

SAMPLE UNIT - A unit of product selected without regard to its quality, to be part of a sample.

SAMPLING METHODS - Procedures used for the efficient collection of data relating to a population. These are generally based on statistical principles and optimize the statistical analysis and interpretation of the data.

SAMPLING PLAN - A plan used in determining the acceptability of an inspection lot. A sampling plan consists of a statement of both the sample size or sizes to be used and the associated acceptance and rejection criteria.

SCRAP - Material in such condition that it has no reasonable prospect of being used or sold except for the recovery value of its basic material content.

SCREENING - 100% inspection of specific characteristics of the balance of a lot after sampling.

SECONDARY FAILURE - A cessation of ability of an item to perform its required function due to the malfunction of another item, i.e., a dependent failure. A second failure is one which occurs as a byproduct of another failure.

SEQUENTIAL SAMPLE THEORY - The theory developed for sampling or decision making where the number of observations is a random variable. After each sample or trial it is possible to make one of three decisions: (1) to accept the hypothesis H , (2) to reject the hypothesis H , (3) to continue by taking an additional sample or observation.

SEQUENTIAL SAMPLING - See Multiple Sampling.

SERVICEABILITY - Those properties of an equipment design that make it easy to service and repair in operation.

SERVICE EVALUATION MONITORING POINT - During this phase, the Military Service uses its own personnel to perform its own weapon system evaluation tests. If the weapon system is found to be operationally acceptable and is capable of being produced in quantity without significant loss in reliability or performance, approval of production for service use is usually given at this monitoring point.

SERVICE TEST MODEL - A model to be used for test under service conditions for evaluation of suitability and performance. It shall closely approximate the final design, have the required form, and employ approved parts or their interchangeable equivalents.

SERVICE TESTS - Government evaluation conducted in the field under service conditions to determine suitability of supplies and services for military use.

SEVERITY TESTING - Testing under conditions more extreme than expected or specified operationally.

SHELF LIFE - The length of time an item can be stored under specified conditions and meet specified requirements with a specified level of assurance.

SIGNIFICANCE LEVEL - See Level of Significance.

SIMULATION - A set of test conditions designed to duplicate field operating and usage environments as closely as possible.

SINGLE SAMPLING - Sampling inspection in which a decision to accept or to reject is reached after the inspection of a specified number of items in a single sample.

SPECIFICATION - A detailed description of the characteristics of a product and of the criteria which must be used to determine whether the product is in conformity with the description.

SPECIFICATION LIMITS - Upper and/or lower boundaries defining the amount of variation which is permissible in a specific characteristic for an item of product.

SPECIMEN - A fraction of a sample unit (or a whole sample unit) on which a single determination is made. The term "specimen" generally is used only in connection with inspection of basic characteristics such as chemical composition, specific gravity, or tensile strength.

SPOT CHECK - The act of selecting a sample or samples and evaluating the quality of the characteristic(s) in question to determine whether a radical change in an operation or process has taken place. (Note: Since this is not a formal sampling plan, it cannot be used to determine whether the desired quality level has been attained.)

STANDARDIZATION - An industrial function serving engineering, purchasing and manufacturing. Professional standards engineers establish and publish convenient reference data on preferred or standard materials and processes, finishes, and components. This relieves product design engineers of the repetitive burden of evaluating and selecting from wide varieties.

STANDARDS - Documents that establish engineering and technical limitations and applications for items, materials, processes, methods, design and engineering practices.

STATE OF THE ART - The current level of technical feasibility with existing knowledge, techniques, parts, and materials.

STATIONARY INSPECTION LOT - A collection of units of product offered for inspection at one time. All of the units of product in a stationary inspection lot are presented to the inspector at the time the sample is drawn.

STATISTICAL ACCEPTANCE TEST - A procedure designed to determine with prescribed accuracy whether a characteristic of a product is in conformity with acceptance criteria set forth for that point.

STATISTICAL ANALYSIS - The mathematical treatment and evaluation of statistical information.

STATISTICAL CONTROL - A condition of a process in which variations are attributable to a constant system of chance causes.

STATISTICAL CONTROL LIMITS - Limits calculated mathematically for control charts within which all, or nearly all, of the plotted points will fall if the variations in the process are the result of the operation of the chance mechanism only. (See Control Limits.)

STATISTICAL METHODS - Mathematical methods involving the collection, analysis, and interpretation of numerical data relating to an aggregate of individuals.

STATISTICALLY DESIGNED EXPERIMENT OR TEST PROGRAM - An experiment or test program developed by applying proven principles of statistical test design to program objectives. Test combinations are scientifically selected and arranged to give the maximum amount of useful information for a given cost. An objective method for analyzing the data and drawing conclusions is provided.

STATISTICALLY VALID - Verified by accepted statistical techniques.

STATISTICS - Numerical data relating to an aggregate of individuals; the science of collecting, analyzing, and interpreting such data.

STORAGE LIFE - The total time an equipment may be stored under a given environment without the degradation of reliability below specified requirements.

STRENGTH DISTRIBUTION - The distribution of frequencies or probabilities of failure occurrence along the scale of the characteristic. (See Frequency Distribution and Probability Distribution.)

STRESS DISTRIBUTION - The distribution of frequencies or probabilities of stress occurrence along the scale of the characteristic. (See Frequency Distribution and Probability Distribution.)

SUBASSEMBLY - Two or more parts which form a portion of an assembly, replaceable as a unit, but having a part or parts which are individually replaceable.

SUB-CONTRACTOR - Any manufacturer or processor performing work for a prime contractor or higher-tier subcontractor.

SUB-SYSTEM - A major division of a system consisting of one or more equipments that perform a certain function in the overall operational function of the system.

SUCCESS - Operation of a required function without failure.

SUITABILITY - See Human Engineering.

SUPPLIER - A distributor, manufacturer, etc., serving the function of vendor or subcontractor in providing material or performing work for a prime contractor or other subcontractor.

SUPPLIES - Any material, commodity, equipment, accessory, part, component, or assembly.

SUPPORT EQUIPMENT - Articles necessary for the operation and/or maintenance of the system which are not physically part of the system. (Test equipment, tools, cooling equipment, ground support items, etc.)

SURVEILLANCE PROGRAM - A systematic survey of stored product to determine effect of aging and/or obtain an up to date estimate of quality.

SYSTEM - An assemblage of objects united by some form of regular interaction or interdependence for the purpose of performing a specified operational function.

SYSTEM COMPATIBILITY - The ability of the equipments within a system to work together to perform the intended mission of the system. In a broader sense, system compatibility is the suitability of a system to provide the levels of field performance, reliability, and maintainability required by the military services.

SYSTEMS ANALYSIS - The preliminary selection of the systems configuration including the selection and application of parts to conform to contract requirements.

SYSTEMS ENGINEERING - Specifically, the process of applying science and technology to the study and planning of an overall system, whereby the relationships of the various parts of the system and the utilization of various subsystems are fully planned and comprehended prior to the time that hardware designs are committed.

TEST CONDITIONS - The complete environment under which a test is performed.

TEST EQUIPMENT - Equipment designed to assist in the inspection, servicing or maintenance of an equipment or type of equipment.

TEST PROGRAM - A series of tests performed to gain information about the performance and reliability of a system under specified conditions.

TEST TO FAILURE - Testing conducted on one or more items until a predetermined number of failures have been observed. Failures are induced by increasing electrical, mechanical and/or environmental stress levels, usually in contrast to life tests in which failures occur after extended exposure to predetermined stress levels. Under certain conditions, life test can be considered a test to failure using age as the stress.

TESTING - An element of inspection that generally denotes the determination by technical means of the various physical, chemical, and functional properties or elements of materials, supplies, or components thereof, involving not so much the element of personal judgement as the application of established scientific principles and procedures.

TIGHTENED INSPECTION - Inspection which is used when there is a significant evidence that the quality of product being submitted is poorer than specified requirements. A lot of inferior quality is more likely to be rejected when subjected to tightened inspection than it is when subjected to normal inspection.

TIME PHASE - Specific portions of the product life cycle.

TOLERANCE - The allowable variation in measurements, within which an item is judged acceptable.

TOLERANCE LIMITS - See Tolerance and Statistical Tolerance Limits.

TOTAL QUALITY CONTROL - Total quality control is a broad look at quality which includes aspects of designing for quality as part of quality assurance. This is synonymous with the term "Product Assurance".

TRADE OFF - A compromise usually involving design parameters and time schedules to obtain maximum military effectiveness at optimum cost.

TYPE TESTS - Tests performed on typical items to determine compliance with specification requirements.

UNIT OF PRODUCT - The entity of product inspected in order to determine its classification as conforming or nonconforming. The unit may be a single article, a pair, a set, a length, an area, a volume, etc., of the finished product or component thereof, or the entire finished product.

UNRELIABILITY - The probability of failure expressed numerically as 1 minus the reliability of the product.

UP-TIME - The time in which the system is in condition to perform its intended function.

USABLE TIME - Time during which equipments are capable of doing useful work. A part of this time may be used for preventive maintenance.

USAGE - See Use.

USAGE ENVIRONMENT - The environment affecting a product after delivery.

USAGE LIFE - The span of time from manufacture to wearout of an item.

USE - Includes everything happening to the product from time of delivery to the consumer until consumed. Includes logistics (handling, transporting, storage, check-out) as well as actual use.

USEFUL LIFE - The total operating time between debugging and wearout.

VARIABLE - A quantity that may assume either a number of individually distinct or separate values or any value.

VARIABLES, INSPECTION BY - Inspection wherein certain characteristics of the sample units are evaluated with respect to a numerical scale and are expressed as points along this scale. The distribution of the points, as established by measures of their central tendency and dispersion, is mathematically related to specified requirements to determine the degree of conformance to those requirements.

VARIABLES TESTING - Variables testing is a test procedure where the items under test are classified according to quantitative rather than qualitative characteristics.

VENDOR - A supplier who furnishes material to established standards. His material is ordinarily obtained through the use of purchase orders.

VENDOR CERTIFICATION - Formal approval of a supplier after qualification of his products.

WAIVER - Granted use of an article which does not meet specification requirements.

WARM-UP TIME - The length of time required, after power is applied to the system, before the system is stabilized and ready to perform its intended function.

WEAPON SYSTEM - An instrument of combat such as an air vehicle together with all related equipment both airborne and ground based, the skills necessary to operate the equipment, and the supporting facilities and services required to enable the instrument of combat to be a single unit of striking power in its operational environment.

WEAR-OUT - The point at which further operation is uneconomical.

WEAR-OUT FAILURES - Those failures which can be predicted on the basis of a known wear-out characteristic and thus prevented by appropriate preventive maintenance.

WEAR-OUT FAILURE PERIOD - That period of time after the normal operating period during which the equipment failure rate increases above the normal rate.

FIGURE 1
PRODUCT LIFE CYCLE

INNER CIRCLE = POLICY - METHODS - COORDINATION

MIDDLE CIRCLE = CONTROL = STANDARDS + CONFORMANCE + CORRECTIVE ACTION

OUTER CIRCLE = PRIME RESPONSIBILITY