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RELIABILITY PROGRAMS FOR NONELECTRONIC DESIGNS

Eagle Technology, Inc.

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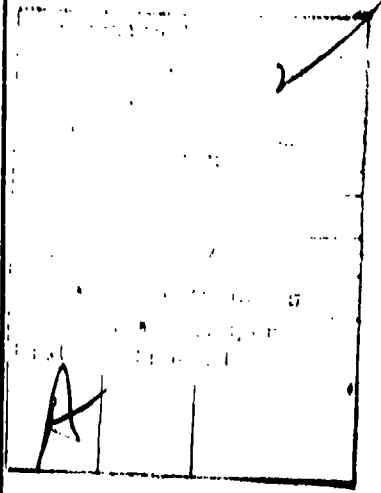
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applications experience, quantity of equipment to be produced and many other factors. To help identify these characteristics and formulate a set of criteria on which to base recommendations, the Rome Air Development Center distributed over 400 questionnaires throughout the Department of Defense and related industries.

Volume I of this report summarizes the results of the survey on reliability programs for nonelectronic designs. Contents include a description of the questionnaire; response to the survey in terms of analysis and testing tasks and program requirements; and the degree of correlation between analysis results, testing data and field performance.

Comments from respondents of the survey reflect considerable experience and knowledge on reliability programs and techniques as applied to nonelectronic designs. Recommended reliability tasks in Volume II of this report were prepared from opinions expressed by respondents combined with results of a literature search and an investigation of ongoing and past reliability programs. Volume II emphasizes the distinguishing characteristics of nonelectronic designs and provides guidelines for tailoring current reliability documents to nonelectronic designs with consideration given to mission criticality, development phase, program dollars, development time and other program constraints.

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RELIABILITY PROGRAMS FOR NONELECTRONIC DESIGNS
VOLUME II: RELIABILITY TASKS

SUMMARY

Current military standards for reliability programs, reliability predictions and qualification testing were written primarily for electronic equipment where component standardization and the valid assumption of an exponential failure rate permit their direct application. These electronic systems, however, often contain nonelectronic assemblies that are critical to operational readiness, mission success or logistic support. Examples of such nonelectronic assemblies include antenna positioning mechanisms, tape and disk drives, and printers.

Typical tasks imposed in existing contracts require a reliability program in accordance with MIL-STD-785, a reliability prediction in accordance with MIL-STD-756 and MIL-HDBK-217 and reliability testing in accordance with MIL-STD-781. These documents were prepared primarily for electronic equipment and the underlying assumptions and philosophies reflected therein do not always apply to a particular nonelectronic development program.

Analytical techniques, testing procedures and program controls can be made more cost effective by tailoring current standards to a particular nonelectronic development program. The extent of tailoring depends upon the type equipment being developed. Previous experience with applicable standards, the quantity of equipments to be produced, budget constraints, and many other factors contribute toward an engineering decision as to the extent which current standards can be applied to a particular non-electronic design. To help identify these characteristics and formulate a set of criteria on which to base recommended reliability program tasks,

a questionnaire on "Reliability Programs for Nonelectronic Designs" was developed by the Rome Air Development Center (RADC). Four hundred of these questionnaires were distributed throughout the Department of Defense and related industries, and over one hundred completed questionnaires were returned. Volume I of this report contains a detailed description of the survey and a compilation and statistical summary of questionnaire responses.

Results of the survey indicated that the characteristics which distinguish electronic from nonelectronic reliability programs can be concentrated in the areas of reliability analysis and reliability demonstration tests. The reliability tasks as included in MIL-STD-785 are sometimes applicable to a total system containing both electronic and nonelectronic designs. Individual nonelectronic equipments or total mechanical systems will require a unique approach to planning the analysis and/or testing program. The purpose of this Volume II report is to recommend guidelines for establishing analysis and testing requirements for nonelectronic designs and to describe analysis and testing methods which are unique to nonelectronic designs.

The guidelines contained in this report were prepared from opinions expressed by respondees of the survey combined with results of a literature search and an investigation of ongoing and past development programs. Comments from respondees of the survey reflect considerable experience and knowledge on reliability principles and practices, and the purpose of this report is to present the opinions expressed by respondees in the form of applications oriented guidelines for the reliability engineer who has the responsibility for specifying or performing reliability tasks and interfacing with mechanical designers and stress analysts.

This report emphasizes the distinguishing characteristics of non-electronic designs which require tailoring of established specifications

and standards. The guidelines consider such trade-offs and program constraints as mission criticality, program dollars and available development time. A brief mention or total absence of a particular reliability task in this report should not be interpreted as though that task is not important. MIL-STD-785 and supporting documents provide the necessary requirements to perform reliability tasks for electronic and nonelectronic equipments and these documents should be used as the basis for design of any reliability program. This report emphasizes those tasks which require significant differences in approach between electronic and nonelectronic reliability programs. Any recommended tasks contained in this report are intended to support those contained in MIL-STD-785 and supporting documents with consideration given to the unique requirements imposed by nonelectronic designs.

MIL-STD-785 partitions reliability tasks into three distinct sections including Task Section 100, Program Surveillance and Control; Task Section 200, Design and Evaluation; and Task Section 300, Development and Production Testing. This report has been subdivided in a similar manner. Section 1 of this volume contains some recommended approaches for establishing reliability programs and controls to be developed by the procuring activity prior to release of a Request For Proposal (RFP) and by the contractor in preparing the reliability program plan. The reliability engineer encounters a great deal of difficulty in predicting reliability of a nonelectronic design and must interface with a number of specialists. The mechanical designer has detailed knowledge of material and lubrication properties, clearance requirements and many other design related factors which influence equipment reliability. The stress analyst can provide knowledge of fatigue life, crack growth potential and other specialized information needed for the reliability prediction. The second section of this volume presents some of the information requirements to be obtained from these specialized sources for the design evaluation of nonelectronic designs. Section three provides guidelines for developing test programs for nonelectronic equipment.

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SECTION 1

RELIABILITY PROGRAM PLANNING AND CONTROL

1.1 INTRODUCTION

Planning and control of a reliability program includes the selection of reliability tasks to be conducted during a development program and the determination of methods for surveillance and control to assure that reliability requirements are being met. MIL-STD-785 is the most commonly used guidance document to establish planning and control requirements for equipment development and production reliability programs. This standard includes five tasks for program surveillance and control which are to be tailored to individual programs.

- Task 101, Reliability program plan
- Task 102, Monitor/Control of subcontractors and suppliers
- Task 103, Program reviews
- Task 104, Failure reporting, analysis and corrective action system
- Task 105, Failure review board

Tasks 102 through 105 are designed for control of a reliability program and applied in a similar way for both electronic and nonelectronic designs. Conversely, the planning of a reliability program will require some distinctions to be made for nonelectronic designs. This section describes the unique characteristics of nonelectronic designs and the special considerations to be incorporated in the program planning effort.

A reliability plan describes the efforts to be performed for evaluating the design, reliability controls to be established and tests to be performed. MIL-STD-785 emphasizes the selection of independent program elements and standardized procedures to be applied in the planning of reliability programs. For example, reliability estimates of electronic equipment during conceptual and validation phases can be

made without many design details being available and independently from other analysis and testing tasks. These preliminary estimates of reliability can be generated with the use of MIL-HDBK-217 and expected to be sufficiently precise so that reliability apportionment can be initiated. Also, MIL-STD-781 has been prepared for electronic equipment and the statistical test plans contained therein can be used to select an effective and efficient testing procedure for the entire equipment without a great deal of dependency on the results of reliability predictions, Failure Mode, Effects and Criticality Analysis (FMECA) or any other analysis task.

Nonelectronic equipments on the other hand often consist of one-of-a-kind component designs. Consequently, development programs for nonelectronic designs may be characterized by limited experience data for reliability analyses, a short supply of equipment samples and/or test time for reliability testing, and a need to rely on component test results for analysis data and demonstration of total equipment reliability. The lack of performance data and adequate testing time is caused by unique characteristics of nonelectronic equipment and will require special methods for reliability program planning. The unique characteristics of nonelectronic equipment and their effect on program planning can be summarized as follows.

● Reliability predictions of nonelectronic designs depend to a large extent on internally generated fatigue and component life test data. This closed analysis/testing loop is caused by the fact that: (a) nonelectronic components are not standardized to the extent that reliability information from previous experience with similar equipment can be directly applied to a new design at higher indenture levels, (b) the effects of derating are not quantitatively available for nonelectronic designs in predicting reliability and (c) published failure rates for nonelectronic components do not contain information on material properties or operational stresses which affect times to failure such as fatigue behavior, axial or side loading history, thermal stress

cycles or physical alignment of parts. Therefore, analysis and testing tasks for nonelectronic development programs must be planned so that internally generated test data can be used to the extent possible for reliability predictions. If external sources of reliability data such as the Nonelectronic Reliability Notebook or the Nonelectronic Parts Reliability Data Publication (NPRD-2) are used for reliability predictions they must be done so with these unique characteristics considered.

- Operational environment and utilization rate are much more critical in the analysis and testing of nonelectronic equipment because of direct interface with operator and environment. Equipment definitions in the analytical process must be very precise and test plans for non-electronic equipment must reflect this sensitivity. Human factors reliability must be included as part of the nonelectronic reliability program to describe the machine-operator interface.

- Individual nonelectronic components such as power transmission devices and clutch assemblies often perform more than one function and failure data for a specific application are difficult to obtain. Each function must be individually analyzed to predict component reliability. Test time requirements can also be increased because of the multi-functional characteristics of a particular component. The additional time requirements to analyze and test each component function must be considered in the planning of reliability program tasks.

- Definitions of failure for nonelectronic designs depend upon equipment application causing uncertainties in the use of published failure data. Many failure modes such as "loose" hardware, "noisy" bearing or "excessive" wear reflect a degraded condition of the component rather than a catastrophic failure. A definition of failure for nonelectronic equipment must specify the point at which the degraded component must be repaired or replaced. This failure definition for the

intended component application will aid in utilizing published failure data for reliability predictions and establishing accept/reject criteria for the testing program.

- Time-to-failure of a particular nonelectronic component may be dependent upon material wear properties not described by a constant failure rate distribution and the test plan may have to be based on procedures other than those contained in MIL-STD-781. Internally generated data must include times-to-failure of individual components in addition to total system operating hours and total failures.

- Reliability qualification testing can not always be performed "in accordance with MIL-STD-781" because of the small sample sizes available and the length of time required to detect deterioration type failure modes. It may be necessary to use results of an FMECA to maximize use of equipment samples and available test time. Accept/reject criteria must be carefully considered in the reliability program planning effort to include the effects of fatigue and other stress related factors and the accelerated testing environment or loading conditions. Care must be exercised in evaluating results of a long duration test to distinguish failures which are random from those caused by a wear out failure mode.

The above characteristics of nonelectronic designs necessitate some unique reliability program requirements that will ensure extensive coordination of analysis and testing efforts throughout the development program. The interrelationships of analysis and testing tasks are shown in Figure 1-1. Additional front-end planning over and above that required by MIL-STD-785 should be accomplished prior to issuance of a Request For Proposal (RFP) or initiation of reliability tasks. This section describes the elements of a nonelectronic reliability program which must be considered by the procuring activity prior to release of an RFP, and by the contractor in preparing a reliability program plan. Section 1.2 provides recommendations for the procuring activity to include in the RFP considering available program funding and time

constraints. Section 1.3 provides procedural methods for the contractor who is developing a reliability program plan for a nonelectronic design.

1.2 RELIABILITY PROGRAM REQUIREMENTS IN THE RFP

The reliability analysis of nonelectronic equipment may consist of any number of individual tasks such as reliability allocation, prediction, FMECA, Fault Tree or Reliability Centered Maintenance analysis. To accomplish any of these tasks the equipment must first be defined in terms of its operational environment. Next, reliability models or block diagrams must be established and, finally, quantitative values of reliability must be determined from detailed analysis/testing results. A reliability program for nonelectronic designs will include the accumulation of component test results as an input to the analytical process. Designing a reliability demonstration test for nonelectronic equipment will require a similar analytical process of defining the equipment to be tested, establishing block diagrams, identifying failure modes of multi-functional components and determining which component functions require life tests to be performed. As shown in Figure 1-1, integration of analysis and testing tasks will be required to successfully plan a reliability program. The planning process should be initiated during preparation of the RFP.

The contractor will be expected to generate a reliability program plan for coordinating reliability tasks. If the contractor is to establish a meaningful reliability program plan, the procuring activity must provide certain minimum information in the RFP. One item which requires special emphasis for the development of a nonelectronic design is a description of the equipment to be developed in its operational environment. Another item to be included in the RFP for nonelectronic designs is a definition of reliability tasks to be performed and the purpose of each task. The two subsections which follow provide guidelines for including these items in the RFP.

1.2.1 Define the equipment in its operational environment

Obtaining meaningful results from reliability tasks requires contractor understanding of the environment under which the equipment to be developed will be operated, maintained, transported and stored. Component parts of the equipment can not be effectively evaluated or failure rates determined without a knowledge of operational environment. This information must be supplied by the procuring activity and is particularly applicable to nonelectronic equipment because of the direct exposure of nonelectronic equipment to operator handling and environmental extremes.

An example of the different environment that exists between electronic and nonelectronic equipment is the modern electrostatic duplicating machine where the electronic components are installed on printed circuit cards and somewhat protected in a card cage from direct contact by the operator or the elements. On the other hand, nonelectronic components such as sorting mechanisms, paper loading bins and front panel controls are often directly exposed to the operator and may be subject to detrimental handling procedures. Defining the operating environment is probably the most important and difficult task in preparing an RFP.

Equipment definition includes design requirements and operational characteristics, such as intended use, operational procedures, environmental envelope, failure definition and maintenance philosophy. Nonelectronic equipment is usually designed for more than a single mode of operation and may be active at different times during the day or mission. Therefore, functional variations and equipment requirements for each operational mode and mission phase must be considered in preparation of the RFP. It is imperative that the procuring activity include all mission environments in the RFP that are to be considered by the contractor for the reliability program. The contractor will further define the equipment and its requirements in the reliability program plan by breaking the system down into major functional parts, displaying these parts as functional diagrams, and describing the function of each part and the interfaces between the parts.

Fatigue is one of the key factors affecting equipment reliability. The designer realizes that a provision of adequate strength is no guarantee that equipment subjected to varying loads will meet required reliability. The procuring activity must realize that the soundness of a design is no better than the soundness of fatigue load information. Operational scenarios must be made available to the designer so that loading actions can be accurately defined.

Numerical reliability requirements in the RFP may be based on probability of mission success, mean time to failure (MTTF), mean time between failures (MTBF), life expectancy or any other reliability term which specifies equipment reliability requirements. It is important that these requirements be based on information at the total system or mission level so that the contractor can identify equipment requirements and consider all mission factors such as logistics, operational environment, operator interface and maintenance in the reliability program. Simply stating an equipment MTBF in the RFP without tying this requirement to operational and maintenance profiles does not answer the contractor's need to design his reliability program plan around total mission or system reliability requirements.

The amount of detail required to define the equipment in the RFP will vary to a considerable extent with equipment complexity and uniqueness of function. The basic elements of an equipment definition shown in Table 1-1 must be considered by the procuring activity in preparing an RFP. Many details will be missing in the RFP and the equipment definition will require refinement and updating as more information becomes available during the development program.

Each of the components listed in Table 1-1 must be included in the RFP so the contractor can establish a roadmap for conducting reliability tasks in his response to the RFP. Well structured requirements in the

RFP will avoid delays in the development program caused by misunderstandings of schedule, budget, available resources and expected results of the reliability program.

**TABLE 1-1
COMPONENTS OF AN EQUIPMENT DEFINITION
TO BE INCLUDED IN THE RFP**

- Design requirements
- Mission or operational requirements
- Equipment utilization for each operating cycle
- Maintenance philosophy
- Environmental profiles
- Failure definitions
- Numerical reliability requirements

1.2.2 Identify reliability tasks to be performed and their purpose

The second element to be included in the RFP is a listing of reliability tasks to be performed and an identification of their intended use. It is particularly important for nonelectronic designs that the contractor establish the interrelationship between tasks because of their dependency upon one another as shown in Figure 1-1. Most tasks in MIL-STD-785 are applicable to both electronic and nonelectronic equipment. Two tasks which require some special considerations in the RFP for nonelectronic designs include reliability analysis and reliability testing. The following paragraphs provide guidelines for specifying the intended use of analysis and testing results with consideration given to funding and scheduling constraints. The guidelines will be separated into two parts:

- (a) reliability analysis considerations in the RFP, and
- (b) reliability testing considerations in the RFP.

(a) Reliability analysis considerations in the RFP

For a reliability analysis task to be cost effective it must fulfill one or more of the specific objectives listed in Table 1-2. The procuring activity should address the desired utilization of analysis results in the RFP.

**TABLE 1-2
TYPICAL OBJECTIVES OF AN ANALYSIS TASK**

Task Objective	Task	Relative Cost
● Allocate subassembly reliability requirements	Allocation	Moderate
● Rank the criticality of potential failure modes	Criticality analysis	Expensive
● Compare alternate designs in terms of life expectancy or reliability	FMECA	Moderate
● Determine the effects of a proposed design change on equipment performance	FMECA	Moderate
● Serve as an input for design reviews	FMECA	Moderate
● Identify high failure rate items for spares provisioning	FMECA	Expensive
● Predict the frequency of maintenance actions as an input to maintainability analysis	FMECA	Expensive
● Predict equipment reliability as a starting point on the growth curve	Reliability prediction	Expensive
● Determine contractual compliance with numerical requirements	Reliability prediction	Expensive

Some of the objectives for an analysis effort listed in Table 1-2 are in terms of a relative evaluation of reliability while others require a quantitative assessment. Comparing designs, allocating spares and projecting the number of failure mode occurrences for design tradeoff decisions all depend upon an estimate of reliability, the precision of which is not the most important criteria, but rather the detection of potential design related problems. Performing a reliability prediction to generate a number does not usually serve any useful purpose unless a high degree of confidence based on past experience with similar equipment or published failure rate data can be demonstrated. Applications such as estimating contractual compliance to reliability requirements or determining if reliability goals are achievable with a new design will not generally warrant the cost of the exercise for nonelectronic equipment because the prediction will not be sufficiently accurate for engineering design decisions. In summary, merely placing a requirement in the contract to perform a reliability prediction in accordance with MIL-STD-756 seldom results in a meaningful analytical effort. The application of a reliability prediction should be well defined before such a task is placed in the RFP.

MIL-STD-756 is commonly referenced in an RFP for the performance of reliability predictions. This standard provides for a compilation of component failure rates from a handbook or other source of failure rate information in order to predict system level reliability. The approach works well for electronic equipment where component standardization has permitted the development of MIL-HDBK-217, a very good source of failure rate data for electronic components.

Sources of failure rate data for nonelectronic components such as the Nonelectronic Reliability Notebook are excellent for a feasibility type prediction, but because failure rate data from alternate sources reflect

such a wide dispersion of operational and environmental conditions of use, the contractor will have difficulty in performing a prediction with sufficient confidence to meet all of the typical expectations of a reliability prediction as listed in Table 1-2. When compared to the task of predicting electronic equipment reliability, nonelectronic equipment involves greater difficulty and expense due to specialized designs, non-standardization of components and the need to perform a more detailed analysis of stress levels.

Recognizing the potential lack of confidence in a reliability prediction for nonelectronic designs, the RFP should emphasize the location of overstressed components, evaluation of alternative designs and reliability growth. The tradeoff between cost of the analysis task and potential benefits to be derived must be evaluated prior to issuing the RFP. For many nonelectronic designs a detailed stress analysis will have to be performed for the reliability prediction to be sufficiently precise to meet the objectives of an analysis task listed in Table 1-2. This is an expensive procedure if performed on all detail parts. A more economical approach is the combined FMECA/stress analysis. The FMECA is a very powerful tool for evaluating nonelectronic designs through the identification of potential failure modes and their effects on system performance. The FMECA can be used to identify those critical areas where a stress analysis should be performed and eliminate the expense of performing a stress analysis for all parts. Section 2 of this volume describes the procedures for combined analysis tasks when applied to nonelectronic designs.

The criticality analysis is part of the FMECA and requires a determination of the frequency of occurrence for each failure mode. This process requires many of the same methods as required for performing a

reliability prediction. As stated previously, reliability predictions for nonelectronic designs require a stress analysis of critical failure modes which have been identified by the FMECA. Because of the interdependency of reliability predictions and FMECAs, a reliability prediction should not be included in the RFP for nonelectronic equipment without a FMECA requirement. Therefore, if funding or time constraints exist a FMECA will be more cost effective than a reliability prediction toward achieving reliability growth.

If both a reliability prediction and a FMECA are to be performed, the combined FMECA and reliability prediction effort may be a more cost effective input for engineering trade-off decisions and project control. The FMECA can be used to identify those critical areas of a design where a stress analysis is required, such as a component requiring extended maintenance time or a large quantity of spare parts or a component that is critical to mission success. Non-critical areas can rely on other less costly prediction methods utilizing data from similar equipment comparisons, NPRD-2 or the Nonelectronic Reliability Notebook. The reliability analysis must, however, be performed with emphasis on design evaluation rather than an exercise to generate reliability numbers. In any event, the procuring activity should not expect a great deal of precision or place a great deal of confidence in reliability prediction results for nonelectronic equipment. The procuring activity must formulate the intended use of analysis results and the RFP should reflect one or more of the objectives listed in Table 1-2 so the contractor can generate a roadmap of analysis and testing tasks accordingly.

(b) Reliability testing considerations in the RFP

For a reliability testing program to be cost effective it must fulfill one or more of the specific objectives as contained in Table 1-3, which were derived from MIL-STD-785.

**TABLE 1-3
TYPICAL OBJECTIVES OF A DEVELOPMENT
TESTING PROGRAM**

- Disclose deficiencies in the equipment design, materials and workmanship
- Provide measured reliability data as an input to other analysis tasks
- Determine compliance with quantitative reliability requirements
- Determine requirements for environmental stress screening (ESS) tests
- Determine requirements for the production reliability acceptance test (PRAT) program

Fulfillment of these objectives requires some specialized test plans for nonelectronic equipment. The procuring activity should include the intended use of test results from this list in the RFP so the contractor can formulate his test plan accordingly.

The contractor is expected in his test plan to fully describe the test methods for compliance to requirements. The accomplishment of test program objectives requires a determination as to the extent of testing and the environment under which the tests should be run. Test requirements are not well defined for nonelectronic equipment in any published standard. Significant differences must be considered for establishing test requirements in an RFP for electronic versus nonelectronic equipment. For example, specifying a test "in accordance with MIL-STD-781" may not be practical because of limited sample sizes and testing time.

In addition to outlining objectives of the testing program, the procuring activity must include a description of test program requirements in the RFP as listed in Table 1-4.

**TABLE 1-4
REQUIREMENTS FOR A TEST PROGRAM
TO BE INCLUDED IN THE RFP**

- | |
|---|
| <ol style="list-style-type: none">(1) Tests to be performed(2) Degree of test realism(3) Definition of test failure(4) Degree of confidence for the qualification test program |
|---|

The following paragraphs provide a brief summary of these test program requirements and Section 3 contains recommendations for developing the test plan.

(1) Tests to be performed - Integrated testing programs are designed to detect potential design related problems, assure system design integrity, estimate achievable reliability and verify that a system is ready for the next phase of development or for production. Several development type tests to achieve these goals are included in MIL-STD-785 and are listed in Table 1-5. These tests as applied to nonelectronic designs are described in Section 3.

TABLE 1-5
DEVELOPMENT TEST PROCEDURES
FOR NONELECTRONIC DESIGNS

- o Reliability engineering tests
 - Reliability development/growth tests
 - Environmental stress screening (ESS)
- o Reliability accounting tests
 - Reliability qualification test
 - Production reliability acceptance test (PRAT)

Reliability engineering tests are performed to determine basic design capabilities and functional characteristics, detect failure modes, and determine wear rates and other time dependent failure mechanisms so that design improvements can be effected and the life expectancy of components verified. ESS or run-in testing is intended to detect manufacturing defects by stressing the equipment under test.

Reliability accounting/qualification tests are intended to provide assurance that minimum acceptable reliability requirements are being met prior to starting production of the equipment. Qualification tests are formal acceptance tests, performed in an operationally realistic environment and are statistically designed to provide estimates of demonstrated reliability. Ideally these are formal tests, conducted under strict environmental and operational profile conditions, with maintenance performed in accordance with specified access for repairs.

(2) Degree of test realism - An RFP must contain requirements which will result in tests as realistic as possible in relation to actual operational and environmental conditions. This is particularly true for nonelectronic equipment which usually interfaces with the operator and environment more directly than does electronic equipment. For example,

many switches and actuator assemblies come in direct contact with an operator whereas electronic components mounted on a printed circuit board are somewhat "protected" from an operator or other failure inducing environment. The more realistic the test in terms of simulating operational and environmental profiles the greater the chance of detecting design deficiencies and defects caused by manufacturing processes that otherwise could be discovered only after the equipment is placed into service. Nonelectronic equipment is often subjected to direct handling by the operator and therefore tests must be more operationally oriented than for electronic equipment. The large physical size of many nonelectronic equipments and the long testing time required for each mode of operation may require some specially prepared procedures to achieve a high degree of test realism. The RFP should require the contractor in his response to propose the operational and environmental profiles to be simulated.

(3) Definition of test failure - Just as important as realism in test planning is realism in defining a failure, a difficult task for nonelectronic equipment because many component failures are subjective. Terms such as "noisy", "binding", or "leaking" are legitimate failure modes but not easily quantified. It is imperative that these types of failures be defined in the equipment specification included with the RFP and reflect realistic operational environments.

It is customary during electronic testing procedures to operate the equipment until a failure occurs, shut down the equipment for repairs and then operate the equipment until the next failure. For nonelectronic equipment this approach may not be practical because of the longer test time required for small sample sizes. A more efficient testing operation is required and long periods of shut down can not be afforded. Differences between critical and minor failures must be defined in the RFP so that the test need not be stopped for minor failures. However, the test

will have to be interrupted briefly at predetermined times for measurements of wear, critical clearances and other time-dependent parameters.

(4) Degree of confidence for the qualification test program - Reliability is a time and stress dependent parameter for nonelectronic equipment as shown in Figure 1-2 and there is no way to verify reliability without extensive test data and sufficient testing time to establish a confidence factor. The problem that the contractor will have in designing qualification tests for nonelectronic equipment is the fact that specialized designs in small quantities limit the number of units available for test. MIL-STD-781 contains some high risk test plans for small sample sizes but very often only one unit is available for qualification test. For nonelectronic equipment, test data must be accumulated from piece part testing, component evaluation tests and any other available source. The key to using this data for evaluating reliability is the maintenance of exact records on bench testing and prototype testing in the very early design stages that includes test time and operational environment. Some of the failure rate data for individual components can be applied toward the reliability demonstration test if the test records contain not only accept/reject data but also time dependent information such as mechanical wear, crack size and fatigue data. The procuring activity must identify in the RFP the degree of confidence required for the testing program and the type of tests required for reliability demonstration while recognizing the potential restriction of test time.

1.2.3 Summary of RFP requirements

Section 1.2 provided some general guidelines for including in the RFP the necessary reliability requirements for nonelectronic designs. These guidelines are not intended to be all inclusive but rather present special nonelectronic design considerations for tailoring existing reliability documents and achieving a cost effective reliability program. Requirements to be considered in preparing an RFP for nonelectronic designs are summarized in Table 1-6.

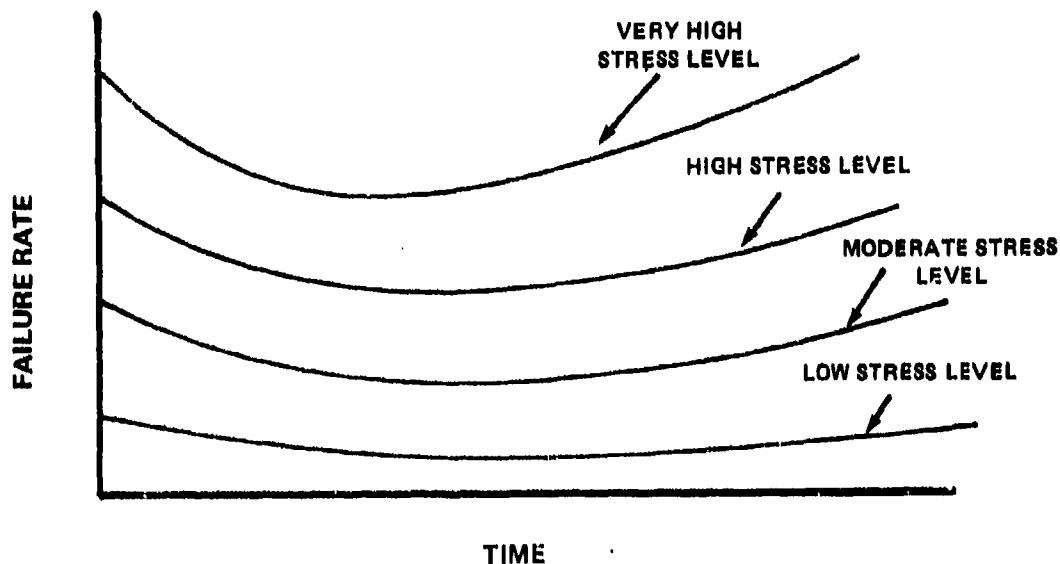


FIGURE 1-2. EFFECT OF TIME AND STRESS LEVELS ON FAILURE RATE FOR NONELECTRONIC EQUIPMENT

1.3 RELIABILITY PROGRAM PLAN

Just as the procuring activity must establish certain minimum requirements in the RFP for developing a reliability program, so must the contractor establish his roadmap for conducting reliability tasks. A reliability program plan describes the coordinated effort of all reliability tasks to be accomplished and includes the methods to perform the tasks as required by the contract. The procuring activity in reviewing the program plan can assure that cost effective plans and controls are established for the development effort. This section describes the unique aspects of the reliability program as it applies to nonelectronic equipment.

The reliability program plan generated by the contractor must contain an equipment definition and a procedure for each reliability task. A listing of reliability program tasks is included in MIL-STD-785 and such

TABLE 1-6
SUMMARY OF RFP REQUIREMENTS
PARTICULAR TO NONELECTRONIC DESIGNS

- Equipment definitions must be precise to the extent possible in describing multi-functional operating environments, failure criteria and numerical reliability requirements.
- An evaluation of analysis objectives must be made prior to citing compliance to reliability specifications.
- Reliability predictions should not be specified without an FMECA.
- Care must be exercised in specifying MIL-STD-781 for nonelectronic equipment because the qualification test may be completed prior to the detection of time dependent failure mechanisms and therefore provide a false indication of reliability. The RFP should require the contractor to establish test methods in the program plan which will establish confidence factors through the accumulation of testing data at lower equipment levels.
- Test, Analyze And Fix (TAAF) programs are designed to achieve operational reliability consistent with contractual requirements through failure detection, failure analysis and the incorporation and verification of design changes to prevent recurrence of failure. TAAF programs should be emphasized in the RFP.

documents as Data Item Description DI-R-3533. These lists should be reviewed for each program. Planning efforts requiring particular attention for nonelectronic designs are listed in Table 1-7.

**TABLE 1-7
PLANNING EFFORTS REQUIRING PARTICULAR
ATTENTION FOR NONELECTRONIC DESIGNS**

- Construction of roadmaps for reliability tasks to be performed
- Description of how each reliability task will be performed
- Identification of known reliability problems to be solved, their impact and proposed solution
- Development of reliability growth procedures
- Development of reliability qualification procedures

One of the problems the contractor encounters in establishing a reliability plan for a particular nonelectronic development program is the determination of the type analyses to be performed for a given phase. For example, a contractual requirement to perform an FMECA in accordance with MIL-STD-1629 does not necessarily result in a cost effective or even useful FMECA. The contractor may perform a top-down functional FMECA, a bottom-up hardware FMECA or combination thereof. The contractor may perform an FMECA with a qualitative or quantitative criticality analysis. Depending on the analysis objectives as described in the RFP, the contractor structures the analysis tasks so they will be completed at a time when they can contribute measurably to system reliability. Sometimes a less detailed analysis performed early in the development phase will be more cost effective than a more detailed analysis completed too late to affect design improvements.

Analysis tasks and testing programs must be tailored to the non-electronic equipment being developed, the development phase and purpose of the analysis. The contractor must know why each task requirement is contained in the RFP. The contractor must then propose in his program plan which methods will be used to meet these objectives. After reviewing equipment definitions, reliability tasks to be performed and the purpose of each task, the contractor must establish ground rules and assumptions for performing the tasks. Each ground rule as shown in Table 1-8 requires special considerations for a nonelectronic design.

TABLE 1-8
GROUND RULES TO BE ESTABLISHED IN A
RELIABILITY PROGRAM PLAN

- (1) Equipment levels for analysis and testing
- (2) Environmental and operational requirements to be considered
- (3) Failure definitions
- (4) Criticality analysis
- (5) Threshold levels of criticality
- (6) Determination of data sources
- (7) Derating criteria to be used

(1) Equipment levels for analysis and testing - Establishing a ground rule for the equipment levels of the analysis is dependent upon the desired use of analysis results, availability of design information and program constraints of cost and calendar time. The following guidelines can be used to select the equipment levels between which the analysis will be performed:

- a. The lowest equipment level at which the analysis is effective is that level for which information is available to establish definition and description of functions. The lowest equipment level is influenced by previous experience. The greater the level of detail and number of failure possibilities considered, the greater will be the cost and the time required for the analysis. Less analysis detail can be justified for items having a good reliability, maintainability and safety record. Conversely, greater detail and a corresponding lower equipment level is indicated for items having a questionable reliability history for an unproven design or when the equipment is critical to mission success.

- b. The specified or intended maintenance and repair level may be a valuable guide in determining the lowest equipment level for the analysis. Results of the maintenance analysis will determine the lowest level at which maintenance will be performed and the lowest level of analysis is often defined as the equipment level immediately below this lowest level of maintenance. For example, the lowest replaceable assembly in a hydraulic system may be a valve assembly. The reliability analysis should therefore include the failure modes of O-rings, packings and other parts of the valve. This analytical process will assure the consideration of all contributing failure modes to each replaceable item. On critical items the analysis may be performed down to lower part levels to determine failure causes such as wear rate, contaminants and corrosion.

- c. Results of the analysis to select the initial equipment level are used to determine the requirements for the next and subsequent levels. Both the critical functional elements for which a detailed stress analysis is required and the non-critical functional elements that do not require further analysis are identified.

- d. During the conceptual phase, the top-down functional approach as described in MIL-STD-1629 or ARP 926 is effective in eliminating inadequacies of the design concept. In the validation phase, the more detailed bottom-up hardware approach may be more appropriate to identify critical failure modes.

(2) Environmental and operational requirements - Another ground rule to be established is the limit of acceptable performance and the environmental and operating conditions to be considered during the analysis. Assumptions should be made with respect to alternate modes of operation. Block diagrams serve as a point of reference throughout the analysis and the environmental and operational conditions assumed for the analysis should be listed on the appropriate block diagrams.

(3) Failure definitions - The next ground rule to be established includes general statements of what constitutes a failure of the equipment in terms of performance parameters and allowable limits for each specified output. These statements are amplified from those provided in the RFP and are established at progressively lower equipment levels. Excessive friction noise or leakage rate are examples of failures which must be defined in quantitative terms.

(4) Criticality analysis - A ground rule is required to establish the method of criticality evaluation best suited for the analysis being undertaken. The practical levels of quantification for the expected failure rate and severity level are determined. ARP 926 and MIL-STD-1629 contain criticality analysis procedures.

(5) Threshold levels of criticality - Depending on the purpose of the analysis, specific investigations are performed above a predetermined threshold for severity level and failure rate. For example, a maintenance oriented analysis will require an investigation of all failure modes having a high projected rate of occurrence regardless of the

associated severity level. Conversely, a safety or mission success oriented analysis will require an investigation of all failure modes having a high severity level regardless of the projected failure rate. This ground rule establishes the threshold levels for severity and failure rate above which specific investigation will be performed.

(6) Determination of data sources - The next step in performing a reliability analysis is the determination of data sources. Failure rate data sources must be reviewed in order to determine the acceptability of the data base in relation to the utilization of analysis results and the accuracy requirements of the analysis. The contractor has several choices in selecting a source of failure rate data as shown in Table 1-9. In utilizing test data, for example, it can not always be ascertained whether test data from an actuator is derived from impulse tests or cycling tests; yet, failure rates from the two tests could be significantly different. Another reason that failure rates listed in one source often vary considerably from those in another is because some data sources provide replacement rates rather than actual failure rates. Various failure rate tables have been derived with different degrees of precision, different operating environments and component utilization. Not all data bases include manufacturing techniques, quality control procedures or the time on the market of new components. Careful screening of available sources will provide optimum accuracy of analysis results.

Levels of precision for failure rates of electronic components published in MIL-HDBK-217 are relatively high and reliability estimates for electronic equipment can, as a result, be fairly accurate. Evaluating the reliability of nonelectronic equipment, however, is usually much more involved than for electronic equipment because the failure rate of a nonelectronic part is more dependent upon design configuration, equipment age, operational environment and application.

TABLE 1-9
TYPICAL SOURCES OF FAILURE RATE DATA

- Internal data base as established from similar equipment operating in a similar environment and similar operating conditions
- A set of prediction equations developed from finite element analysis or stress analysis results
- Engineering estimates at a very low equipment level
- Published failure rate data

In addition, nonelectronic parts are usually not standardized because of the need for a unique design to perform a multitude of functions. The first step in selecting a data source is the review of the analysis method or methods to be utilized, the intended use of the analysis and the resulting degree of accuracy required. The second task in selecting the data source is an analysis of available data. Several sources of failure rate data are available such as the Nonelectronic Reliability Notebook and NPRD-2. Many commercial firms maintain their own data base and many laboratories maintain data on particular parts. Table 1-10 includes the factors involved in selecting a data base.

If the contractor has no data base available to him that appears to be applicable to his design, his own analytical approach may be better than utilizing published data. However, a failure rate based on "engineering judgement" is not adequate. Some rationale for a derived failure rate must be provided by the contractor. For example, historical failure rate data from testing a similar design can be multiplied by a "K" correction factor to reflect the use of new materials. Although the "K" factor is still an engineering estimate it is based on strength of

TABLE 1-10
CONSIDERATIONS FOR SELECTING A SOURCE
OF FAILURE RATE DATA

- Availability of failure rate references (lab test data, field data, vendor data, similar parts, handbooks, etc.)
- The "acceptability" of the data base in terms of previous utilization and experience with the data
- Differences between failure definition used in the analysis and that obtained from data sources
- Type of equipment for which comparison is to be made and application (airborne, shipboard, etc.)

materials, new lubricants or other design improvements which can later be validated. Other guidelines for using available failure rate data are as follows:

- Avoid using MTBF figures that were collected from data where few failures occurred during short term tests of a relatively large number of test items.
- Use caution when applying the exponential reliability function to a model for a specific time period. Failures may not be caused by random high stress levels but rather due to component deterioration with respect to time.

(7) Derating criteria to be used - Derating is defined in MIL-STD-721 as (1) "the use of an item in such a way that applied stresses are below rated values" or (2) "the lowering of the rating of an item in one stress field to allow an increase in rating in another stress field". MIL-HDBK-217 is a data base of failure rates as a function of stress loads for electronic components which permits a trade-off determination between failure rate and stress level. Derating can be confirmed by stress analysis and the effects of more or less derating can be predicted in trade-off decisions. For example, designers can derate capacitors in terms of voltage or a transistor can be derated in terms of junction temperature. In each case a failure rate for the selected derating factor can be derived from MIL-HDBK-217. Derating information contained in this Handbook is based on extensive failure rate data where stress levels could be determined.

Nonelectronic components can not be derated so easily as voltage or junction temperature and some alternate procedures must be considered. First of all, each nonelectronic component quite often reflects an individual design and derating procedures must be tailored to that design. Secondly, a nonelectronic component will often be sensitive to more than one stress level and a review of derating procedures must be made from an operational and environmental system level perspective. A mechanical actuating arm for example is derated in terms of safety factor depending on a detailed analysis of material strengths, stress raisers, and mechanical stresses on the actuating arm. In addition to external conditions such as shock and vibration, design parameters affecting reliability include rotation rate and the resulting shock pulse at the end of actuator travel.

The design process involves the application of derating procedures to prevent failure and at the same time meet size and weight restrictions, and the designer is constantly confronted with decisions as to what safety factors to use for a design. For nonelectronic equipment the

derating exercise is usually more effectively accomplished through the designer's experience rather than any rigid mathematical or design evaluation process. The margin between operating stress levels and material strengths are estimated with consideration given to material properties and loading configuration. A typical derating procedure is conducted as shown in Table 1-11.

TABLE 1-11
TYPICAL DERATING PROCEDURE

- (1) Design and configuration specifications are examined and those failure modes which are sensitive to the design are determined
- (2) Material properties that are directly related to these failure modes are determined with consideration given to material cost and availability
- (3) Strength data for selected materials are obtained from literature or results of lab tests
- (4) Stress levels are determined from environmental and operational profiles
- (5) Stress/strength relationships are evaluated in terms of design constraints

The design review process outlined in Table 1-11 is enhanced by experience. The assessment of assumptions used in the stress analysis associated with design derating as well as the ability to anticipate which failure modes govern the design is presently not based on any standardized procedure but rather experience with the particular equipment involved. Handbooks are not generally available that provide

derating factors of nonelectronic components. Finite element techniques, NASTRAN and various computer programs are available to designers for structural type analyses and the reliability engineer must work with the stress analyst in deriving derating factors and equating these factors into a projected failure rate.

For nonelectronic equipment, derating procedures are often the main factor affecting reliability. Failures are often introduced by wear out mechanisms which in turn are related to loading. An evaluation of loading characteristics as well as stress is an essential element in any derating procedure. Because the identification and application of derating procedures are performed more on the basis of experience rather than methodology, it seems impractical for a reliability analyst to get involved to the extent necessary to affect design improvements. The reliability analyst's contribution should be in the area of providing operational and environmental information to the stress analyst, identifying failure modes and assisting to equate stress analysis results to failure rates.

1.3.1 Summary of reliability program planning requirements

Section 1.3 provides general guidelines for including the necessary elements for nonelectronic designs in the reliability program plan. These guidelines are not intended to be all inclusive but rather to present those special requirements for nonelectronic designs so existing reliability documents can be tailored for a cost effective reliability program. Figure 1-3 provides a typical list of tasks to be considered in formulating a reliability program plan. The conclusion to be reached from the interrelationship of tasks involved in a nonelectronic reliability program is that both the procuring activity and the contractor must recognize the need to coordinate analysis and testing tasks for nonelectronic designs.

RFP	CONCEPTUAL PHASE	DEMONSTRATION AND VALIDATION PHASE	FULL SCALE ENGINEERING DEVELOPMENT PHASE
<ul style="list-style-type: none"> • EQUIPMENT DESCRIPTION • ANALYSES AND TESTS TO BE PERFORMED • INTENDED USE OF ANALYSIS AND TEST RESULTS 	<ul style="list-style-type: none"> • REFINEMENT OF EQUIPMENT DESCRIPTION AND PROGRAM PLAN • PLAN FOR INDIVIDUAL COMPONENT TESTING • DEVELOPMENT TESTING • FMECA INITIATED 	<ul style="list-style-type: none"> • FMECA CONTINUED • RELIABILITY PREDICTION FROM SIMILAR EQUIPMENT • RELIABILITY ALLOCATION • DEVELOPMENT TESTS CONTINUED • TAAF INITIATED • QUALIFICATION OF COMPONENT PARTS 	<ul style="list-style-type: none"> • ENGINEERING STRESS ANALYSIS • FMECA UPDATED • RELIABILITY PREDICTION • TAAF CONTINUED • QUALIFICATION OF COMPONENT PARTS CONTINUED

FIGURE 1-3. TYPICAL REQUIREMENTS OF A RELIABILITY PROGRAM

SECTION 2 DESIGN AND EVALUATION

2.1 INTRODUCTION

Reliability analyses are performed during the conceptual, validation and engineering development phases of design to (a), identify potential problem areas for design review consideration and (b), provide an indication of the degree of success that a completed equipment is expected to have under established conditions of operational use, handling and maintenance. Standard procedures are available for some analysis tasks such as MIL-STD-756 in conjunction with MIL-HDBK-217 for reliability predictions and MIL-STD-1629 or ARP 926 for the FMECA. Procedures contained in these documents must be tailored to the individual analysis task. Possible tasks as referenced in MIL-STD-785 are listed in Table 2-1. Application of those tasks requires extensive tailoring for nonelectronic designs.

TABLE 2-1
TYPICAL DESIGN AND EVALUATION TASKS

- Task 201, Reliability modeling
- Task 202, Reliability allocations
- Task 203, Reliability predictions
- Task 204, Failure modes, effects, and criticality analysis
- Task 205, Sneak circuit analysis
- Task 206, Electronic parts/circuits tolerance analysis
- Task 207, Parts program
- Task 208, Reliability critical items
- Task 209, Effects of functional testing, storage, handling, packaging, transportation, and maintenance

Section 1 of this volume provides some guidelines for selecting the most appropriate analysis tasks for a new procurement or development effort. Regardless of the analysis tasks selected or imposed in the contract, certain basic procedures will apply as listed in Table 2-2.

TABLE 2-2
BASIC PROCEDURE FOR A RELIABILITY ANALYSIS

- Equipment definition
- Reliability models
- Identification of failure modes
- Detailed reliability analysis
- Failure mode criticality/reliability prediction
- Analysis summary

The tasks included in this section are intended to provide guidance for selecting the most appropriate method of analysis for the development program. Recommended tasks conform to MIL-STD-756, MIL-HDBK-217, MIL-STD-1629, ARP 926, and other procedural standards which may have been prepared primarily for the analysis of electronic equipment. The tasks are not intended to replace the requirements of standard procedures but should be tailored according to the reliability program plan and used in conjunction with and to support standard reliability procedures. Tasks included in this volume emphasize the distinguishing characteristics of performing an analysis of a nonelectronic design in relation to standard procedures. MIL-STD-756, MIL-STD-1629 and the other standards should be used for the actual analysis.

2.2 EQUIPMENT DEFINITION

The first step in conducting a reliability analysis is to define the equipment and equipment levels to be analyzed. Fulfilling the purpose

of and obtaining meaningful results from a reliability analysis depends upon a complete definition of the equipment to be analyzed.

Equipment definition includes design requirements and operational characteristics such as intended equipment use, operational procedures, environmental envelope, failure definition and maintenance philosophy. Defining the equipment and its requirements is accomplished by breaking the system down into major functional parts, displaying these parts on block diagrams, and describing the function of each part and the interfaces between parts. Nonelectronic equipment is usually designed for more than a single mode of operation and may be active at different times during the day or mission. Therefore, functional variations and equipment requirements for each operational mode and mission phase must be considered. It is imperative that the contractor include all mission environments in his equipment description.

Nonelectronic equipment often interfaces with the operator and environment more directly than does electronic equipment and defining this interface is very important to the effectiveness of reliability analysis tasks. Component parts of the equipment can not be effectively evaluated or failure rates determined without a knowledge of their operational environment. This part of the equipment definition is critical for nonelectronic equipment. Electronic components are commonly mounted on printed circuit boards within a card cage or are otherwise protected from external handling by the operator and direct contact with the elements. Nonelectronic components on the other hand often interface with the operator or outside environment. Defining an operating environment is probably the most important and difficult task of any analytical effort.

The amount of detail required to define the equipment will vary to a considerable extent with equipment complexity and uniqueness of functions. Table 1-1 listed the components of an equipment definition to be

included in the RFP. Many details of the equipment definition will be missing in the RFP and early development phase, and refinement and updating by the contractor will be required as more information becomes available.

Within the RFP the procuring activity has required the contractor to discuss some of these elements of equipment definition. The contractor in his response to the RFP includes his understanding of the requirement in greater detail. Further refinement of definition is required for the reliability program plan and each design and evaluation task. Some of the more important considerations are as follows.

(1) Design Requirements - One aspect of design requirements for the equipment to be analyzed includes a physical description of the equipment including its configuration and specific descriptions which define the physical composition. Also included in design requirements are the specifications for the equipment including its purpose, operational requirements and maintenance philosophy. Operational requirements include stand-by operation, normal operating characteristics of the equipment and operating life requirements in cycles or time. Although detailed and approved specifications will not normally be available in the early development phases, preliminary operational environment and maintenance parameters must be estimated. They can be revised later as approved specifications become available.

(2) Equipment utilization for each operating cycle - The intended utilization of the equipment, expected number of total operating hours or cycles in each mode of operation and the percent of total operating hours or cycles for each mode must be estimated. Each phase of operation is divided into time segments such as start up, idle, etc. If the operational mode is expected to change with time, such changes and their expected duration are defined.

During certain operations of the equipment a situation may arise that subjects the item to unique environments or loading conditions. These conditions are described for each mode of operation. During many operational modes, there is human contact with the equipment. Type of contact and potential handling are defined for the physical operation. Duration of the interaction is estimated and unique situations caused by unusual induced environments combined with human contact are defined.

(3) Operational parameters and environmental profiles - Temperature, pressure, humidity and climate are considered for each phase of operation. Variations in natural environments for various segments are defined by amplitude and duration. For example, the ambient temperature surrounding a solenoid actuator assembly may have a projected maximum of 85°C for five hours each 24 hour day and 20°C for 12 hours with the expected rate of change being 20°C per hour. Induced environmental factors such as velocity, acceleration, shock and vibration which may affect operation or accelerate degradation of the equipment item are then identified. A review is made to determine the effects of equipment operation in both the nonoperational mode and the operational mode on the external environment. The result of this particular task defines exhaust gases, sparks, noise and other by-products which may have an effect on the local environment.

(4) Failure Definitions - Conditions which constitute a failure of the equipment, considering maintenance strategies, spares concept and level of repair are described as part of the equipment item definition. For nonelectronic equipment such failure modes as friction noise, leakage, and roughness must be defined.

2.3 RELIABILITY MODELS

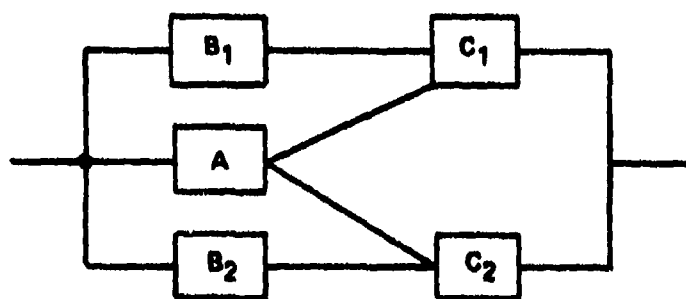
The second step of a reliability analysis is the development of reliability models which define the operations necessary for determining equipment or mission success. Block diagrams can be used to depict

Block diagrams can be produced only after a thorough system definition is achieved so characteristics and functions of the parts can be considered in performing the detailed analysis. However, block diagrams should be developed as soon as the program definition permits even though numerical data are not yet available.

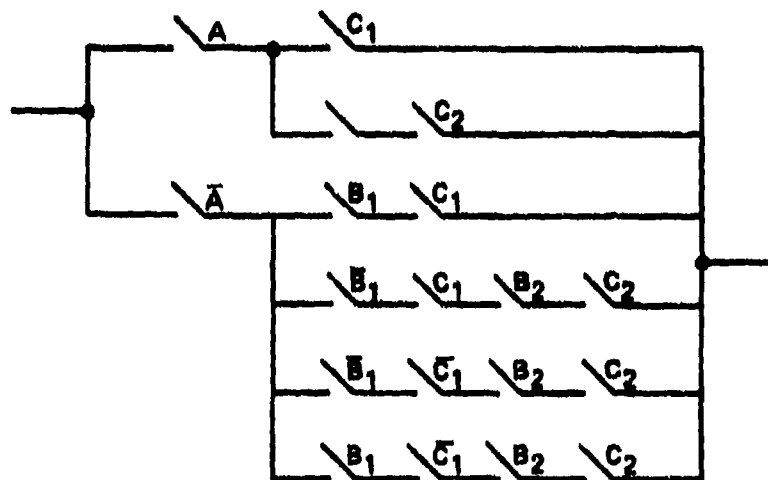
Development of logic diagrams, examples of which are shown in Figure 2-2, may be more cost effective than functional block diagrams for complex nonelectronic equipment. The simulation diagram is essentially a switching network, a closed contact representing equipment success and an open contact representing equipment failure. Each complete path of contacts represents an alternate mode of operation and each equipment item that is required for operation is identified by a contact along the path. All paths terminate at a single point (success). This approach is particularly useful for nonelectronic designs which often carry out more than one function for different operating modes.

The logic diagram approach lends itself to computer simulation for derivation of system reliability. The basic concept of the simulation approach is to reproduce equipment operation in a computer and then "operate" the equipment through increments of time. As operation continues, occurrence of failures is simulated by the generation of random numbers. Operation continues until total equipment failure occurs or until the mission is completed. A large number of equipment operations are simulated and reliability is equal to the percentage of successful missions. MIL-STD-756 contains a more complete description of logic diagrams.

A nonelectronic design may not conform to the constant failure rate assumption inherent in the use of exponential prediction models and a specific reliability model may be required to incorporate the increasing failure rate in relation to time. Distribution laws for individual parts which exhibit an increasing failure rate (aging) are determined so that



LOGIC BLOCK DIAGRAM



LOGIC SIMULATION DIAGRAM

FIGURE 2-2. EXAMPLES OF LOGIC DIAGRAMS

failure rates or probabilities of occurrence needed for other block diagrams, logic diagrams or other reliability models can be computed. Time dependent models, an example of which is shown in Figure 2-3, are developed by inserting part failure rate values into the model in the usual manner and applying the appropriate correction factors periodically in order to obtain predictions for the component as it accumulates operating time.

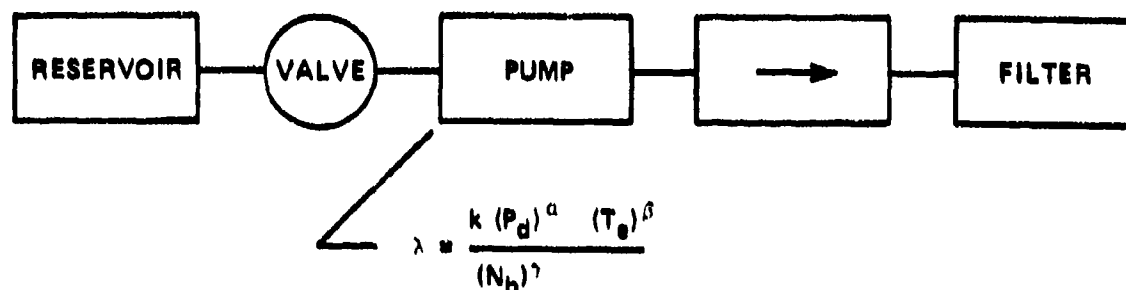


FIGURE 2.3. EXAMPLE OF A TIME DEPENDENT MODEL

The preceding paragraphs describe several approaches to diagramming nonelectronic equipment reliability. Other approaches to generating block diagrams or models can of course be established by the contractor and should be fully described in his reliability program plan. Upon complete evaluation of individual nonelectronic components, a reliability block diagram for the total system can be compiled. Examples of reliability block diagrams are contained in MIL-STD-756.

There are no concrete rules for the development of a particular reliability model at a given design phase. For example, much of the design information needed to develop a functional block diagram is not available during the preliminary design phase. The establishment of overall mission success diagrams developed from similar equipment already in existence is often a better approach to use at this stage of development. When complicated redundancies or maintenance considerations are involved, logic diagrams which can be developed for computer simulation of equipment performance may be the more cost effective approach.

2.4 IDENTIFICATION OF FAILURE MODES

The next basic step in the reliability analysis of nonelectronic equipment is the identification of failure modes. If a reliability prediction or allocation is desired, it is advantageous to first identify all failure modes for the nonelectronic design. Stress analysis can then be performed on those failure modes determined to be "critical". Procedures are presented in MIL-STD-1629 and ARP 926 for determining the criticality of failure modes. Basically, the criticality evaluation of a failure mode includes the following considerations:

- Failure mode resulting in loss of operational capability
- Failure mode resulting in expensive maintenance action
- Safety related failure mode
- High frequency of occurrence of a particular failure mode

Initially a top-down approach as defined in MIL-STD-1629 and ARP 926 is used to identify critical failure modes at the system level and to identify those assemblies which require a detailed stress analysis to be performed. This process is critical to nonelectronic equipment because it is impractical to perform a stress analysis on all parts.

2.5 DETAILED RELIABILITY ANALYSIS

A detailed stress analysis is performed on critical failure modes. A procedural outline for determining the rate of occurrence for critical failure modes is shown in Table 2-3.

TABLE 2-3
STEPS TO DETERMINE THE RATE OF OCCURRENCE OF
CRITICAL FAILURE MODES

- (1) Identify critical failure modes of each listed equipment item
- (2) Determine failure criteria
- (3) Develop evaluation criteria
- (4) Determine material properties and actual design strengths
- (5) Determine actual stress levels for critical failure modes
- (6) Determine degradation properties
- (7) Determine failure mode probabilities

(1) Identify critical failure modes of each listed equipment item - The first step in performing a detailed analysis is to determine the most critical components of the equipment and those failure modes or failure mechanisms which are critical to reliability or operational safety. Failure modes may be identified from a previously performed FMECA. Identification of critical failure modes depends on the design approach such as a safe-life or a fail-safe design and the resulting materials and processes selected. Failure modes should be identified in terms of degradation when applicable.

(2) Determine failure criteria - Failure criteria are the limits which, if exceeded, will cause equipment performance to be degraded below a specified level. Failure definitions are prepared in terms of performance parameters and allowable limits of the item.

(3) Develop evaluation criteria - Evaluation criteria for the equipment being analyzed need to be developed unless adequate failure rate data are available for manufacturing, operational and environmental conditions. The time period for evaluating equipment reliability is identified for those cases in which a constant failure rate can not be assumed. The following considerations are examples of evaluation criteria:

- X-ray, borescope, eddy current, ultrasonic and other non-destructive testing methods may be used to detect cracks and other detrimental flaws in structural equipment. Minimum detectable flaw size and the probability of locating such cracks based upon the method and frequency of inspection must be considered.
- Manufacturing operations which will be required during the production phase and residual stresses in an item as a result of the various manufacturing operations are considered in the degradation analysis.
- Failure effects from combined loading must be considered.
- Adequacy of the criteria includes the degree of error from assumptions made in developing the criteria.
- The effect of cumulative damage from degradation failures which go undetected without inspection.

(4) Determine material properties and actual design strength -

The mechanical fatigue and fracture properties of the materials used in each part should be determined. These properties include yield strength, ductility and toughness. Axial bending and torsion loading, surface finishing, stress concentration, fatigue strength, tensile strength, heat treatment, temperature and other modifying factors which affect strength of the item under analysis should be determined. Unit strength means and distributions are estimated from these considerations. Part strengths with appropriate statistical distributions are derived and expressed as a probability of failure. If distributions can not be derived, part strengths are expressed as the maximum stress which can be sustained for a specified number of cycles or hours without failure. MIL-HDBK-5 and various other design handbooks provide data on strength of materials.

(5) Determine actual stress levels for critical failure modes -

Those loads and loading conditions expected to be encountered during normal operations and the repetition of such loads and factors affecting the stress distribution for the useful equipment lifetime need to be determined. Those loads which may result from either natural or induced environments, and which most contribute to wear out or catastrophic failure are considered. Natural environmental loads are the result of extremes in temperature, radiation, salt spray and other adverse environmental conditions. Induced environments are those which result from operation or handling of the item including vibration, shock, acceleration and other adverse conditions.

(6) Determine degradation properties - The statistical data or maximum stress for material properties may be modified in accordance with expected degradation. The interaction of different operational environments such as the accelerating effects of salt and humidity on stress corrosion are considered in the determination of degradation properties.

(7) Determine failure mode probabilities - An evaluation of the stress/strength processes are made for each part analyzed. This evaluation may be entirely deterministic, entirely probabilistic, or a combination of the two depending on the criticality of evaluation results. This evaluation yields a quantitative estimate of failure rate for each failure mode. The bibliography contains some excellent sources of information on probabilistic design techniques.

Reliability data required to determine failure mode probabilities are not generally available from published handbooks. Reliability data for nonelectronic equipment must usually be derived from one or more of the following sources:

- Engineering stress analysis
- Published data on specific types of detail parts
- Test programs for specific parts and assemblies
- Tests conducted during previous development programs at the component and part level

Most of these sources of data are internally generated within the development program and are dependent to a large extent upon test programs for individual components and parts specifically designed to provide failure rate data.

2.6 FAILURE MODE CRITICALITY

If a criticality analysis is to be performed, the rate of occurrence of each identified failure mode is derived. Values of severity level and failure rate are used to insert failure mode identification numbers into a matrix indicating the distribution of failure mode criticality. MIL-STD-1629 and ARP 926 both contain procedures for conducting a criticality analysis. Several additional factors should be considered in determining the criticality of a nonelectronic design as follows:

- Principal failure mechanism - Those loads resulting from both natural and induced environments and which most contribute to wear out or catastrophic failure.
- Fundamental effect of failure mechanism - The effect of the failure mechanism on operation or function of the part under consideration including secondary effects. Where possible, effects are listed as a gross failure such as fracture, fatigue, deformation or instability.
- Failure distribution - An engineering judgement as to the nature of the failure distribution of each failure mechanism. Appropriate consideration of early mortality and mechanical wear in and wear out is addressed.
- Operational dependency - The critical elements of equipment dynamic operation which affect failure mechanisms such as RPM, compressive or tensile stress.
- Environmental dependency - The critical elements of the environmental envelope for the equipment which affect failure mechanisms of the failure modes such as high temperature or humidity.
- Production or life cycle dependency - The equipment time phase such as process, fabrication, design, storage, handling or operation which is most critical to the item quality and reliability.
- Loading factors - An analysis of loading factors on the part in relation to the principal failure mechanism.
- Margins of safety - Margin of safety or reliability margin between stress and strength for the principal modes of failure for each item. Safety factors can be obtained from design handbooks, detailed part analysis, actual measurement or mechanical/structural test data.

- Analysis life cycle - The time phase of the equipment life if the principal failure mechanism is assumed to be subject to wear out.

- Time between wear out events - The estimated time between component replacement in terms of cycles, impact or whatever describes the life characteristics.

- Failure detection method - The method of detection if component replacement is dependent upon preventive maintenance.

- Probability of failure detection - The probability of detecting the degraded equipment if replacement is dependent upon preventive maintenance or inspection.

- Component life rating - The projected component life as listed in manufacturing catalogs combined with engineering judgement, intended condition of use and experience with similar equipment.

2.7 RELIABILITY PREDICTION

If a reliability prediction is to be performed, one or more procedural methods will be involved. During the concept formulation phase when detailed design information is not yet available, the analysis is usually limited to a comparison with existing equipment having functional and operational requirements similar to those of the equipment being developed. The equipment similarity method of analysis compares the reliability of a mature system design with what may be expected in a new but similar system design. The reliability of the mature system is determined usually by field evaluations. This method of analysis is often used during the conceptual phase of design development. As more detailed part information becomes available, a parts listing is obtained and a stress analysis of critical parts is performed to keep the analysis current. It becomes essential in performing a reliability prediction to first perform some of the elements of an FMECA. Reliability data for nonelectronic designs is usually not available from universal data banks

and a stress analysis on critical failure modes as identified by the FMECA will be required.

Two prediction methods are recommended as basic to a reliability prediction of nonelectronic designs.

- (a) Stress analysis
- (b) Equipment similarity

Although the parts count prediction method utilized for electronic designs can be used for a feasibility study of a nonelectronic design, it is impractical to refine or update such a prediction during the later stages of design development. The parts count technique without a stress analysis is therefore not recommended for nonelectronic designs.

(a) Stress analysis

The stress analysis procedure for predicting reliability is often used for the final reliability prediction when detailed design information and the operational scenarios are available. A stress analysis is performed for each part or group of parts and the predicted failure rates are combined according to the reliability model to produce a total equipment failure rate. An initial analysis is made to assure that the occurrence of a failure is independent of another and that failure rates do not vary with time. A time dependent analysis may have to be made in some cases. The preliminary analysis also assures that failure distributions for individual assemblies not exhibiting a constant failure rate will have little or no effect if the constant failure rate distribution is assumed.

Determining stress involves an analysis of the actual loads to which the nonelectronic part will be subjected. A load is a function of factors external to the part, the factors being determined by functional requirements of the entire equipment. After the loads which will exist

on the part are evaluated, the adequacy of the part to withstand these loads without failure is determined.

The method of determining actual loads for a given part depends upon the model selected. The preferred technique recognizes that loads or stresses acting upon nonelectronic parts are not assigned specific values but have ranges of values with a probability of occurrence associated with each variable. To utilize the procedure, knowledge of the appropriate statistical stress distribution is required.

It is evident that a stress analysis is a necessary task to support a reliability prediction of a nonelectronic design. The stress analysis, however, depends to a large extent on inputs from an FMECA to determine the critical failure modes to be analyzed since it may be uneconomical to perform a stress analysis on each nonelectronic part. This interdependency creates a bond that connects the FMECA, reliability prediction and stress analysis. Stress analysis results are usually obtained from the design group and equated into failure rates for the reliability prediction jointly by the designer and reliability analyst. The relationship of a stress derating number or safety factor to failure rate can be estimated by comparison to field results of similar designs or lab test data.

(b) Equipment similarity

The equipment similarity method of analysis compares the reliability of a mature system design with what may be expected in a new but similar system design. The reliability of the mature system is usually determined by field evaluations. This method is often the only analysis that can be applied during the early phase of design development or feasibility determination but is applicable to any phase. The accuracy of the analysis depends upon the availability of part selection and derating policies and thermal and mechanical environments. The greater the design similarity and the better the failure documentation on the mature system design,

the better the basis of comparison and consequently the accuracy of the reliability prediction of the new system design.

2.8 ANALYSIS SUMMARY

For the reliability analysis to contribute to the development process, conclusions which strongly lead to design improvements or further testing must be clearly documented. These inputs to the total reliability program are very important for nonelectronic designs to provide probabilities of occurrence of critical failure modes and to predict total equipment reliability. Any shortage of failure rate data as pinpointed in the summary will trigger additional testing requirements for specific components. Components critical to system or mission reliability are also identified in the analysis summary with a discussion of the interaction between the factors which contribute to potential malfunction or accelerated wear out.

SECTION 3

RELIABILITY DEVELOPMENT TESTING

3.1 INTRODUCTION

Integrated testing programs are designed to detect design related problems, assure system design integrity, estimate achievable reliability, determine contractual compliance with reliability specifications and verify that a system is ready for the next phase of development or for production. Results of a testing program should provide reasonable assurance that equipment specification requirements can be fulfilled for identified operational environments. MIL-STD-785 provides some objectives of a development test program which were summarized in Table 1-3. The Standard emphasizes the importance of an integrated testing program combining performance, reliability and environmental stress testing to the extent possible.

To accomplish the test program objectives listed in Table 1-3, each development program requires a determination of the extent and environment of the tests to be run. These requirements are not well defined for nonelectronic equipment in any published standard and usable reliability data from which to derive test requirements on an individual basis is limited. There are several differences between electronic and nonelectronic equipment to be considered in establishing test programs and guidelines for developing test programs for nonelectronic equipment are contained in the following sections. Tests are divided into Reliability Engineering Tests and Reliability Accounting Tests.

3.2 RELIABILITY ENGINEERING TESTS

Reliability engineering tests are performed as part of the design effort on prototype and advanced development equipments and individual

components to verify basic design capabilities and functional characteristics. Tests are designed to detect failure modes which may have been overlooked in the analysis effort and provide reliability data for the revision of reliability predictions. As discussed in Section 2, the reliability analysis of nonelectronic equipment is usually based upon the identification of failure modes and an estimate of the frequency of occurrence for each failure mode. For reliability engineering test results of nonelectronic equipment to be usable for analysis efforts, good record keeping is imperative, it being necessary to record such things as materials used, clearances and surface finish. Also, as established in Section 1, the test program will to a large extent depend on analysis results to identify particularly sensitive components which need to be tested for specific functional reliability information. The interrelationship of reliability engineering tests and the analysis effort is shown in Figure 3-1.

Reliability engineering tests consist of two types of tests as described in MIL-STD-785.

- (a) Reliability development/growth tests
- (b) Environmental stress screening

(a) Reliability development/growth tests

Reliability development/growth tests are used to enhance system reliability through identification, analysis and correction of failures, the objective being to optimize reliability prior to production.

Development tests are performed during the conceptual and validation phases of design without accept/reject criteria and are intended to verify the design approach, identify potential failure modes, determine the effects of varying stress levels and environments on reliability, and provide data for analysis tasks. Tests are specifically designed to detect wear out failure modes, measure wear and determine component

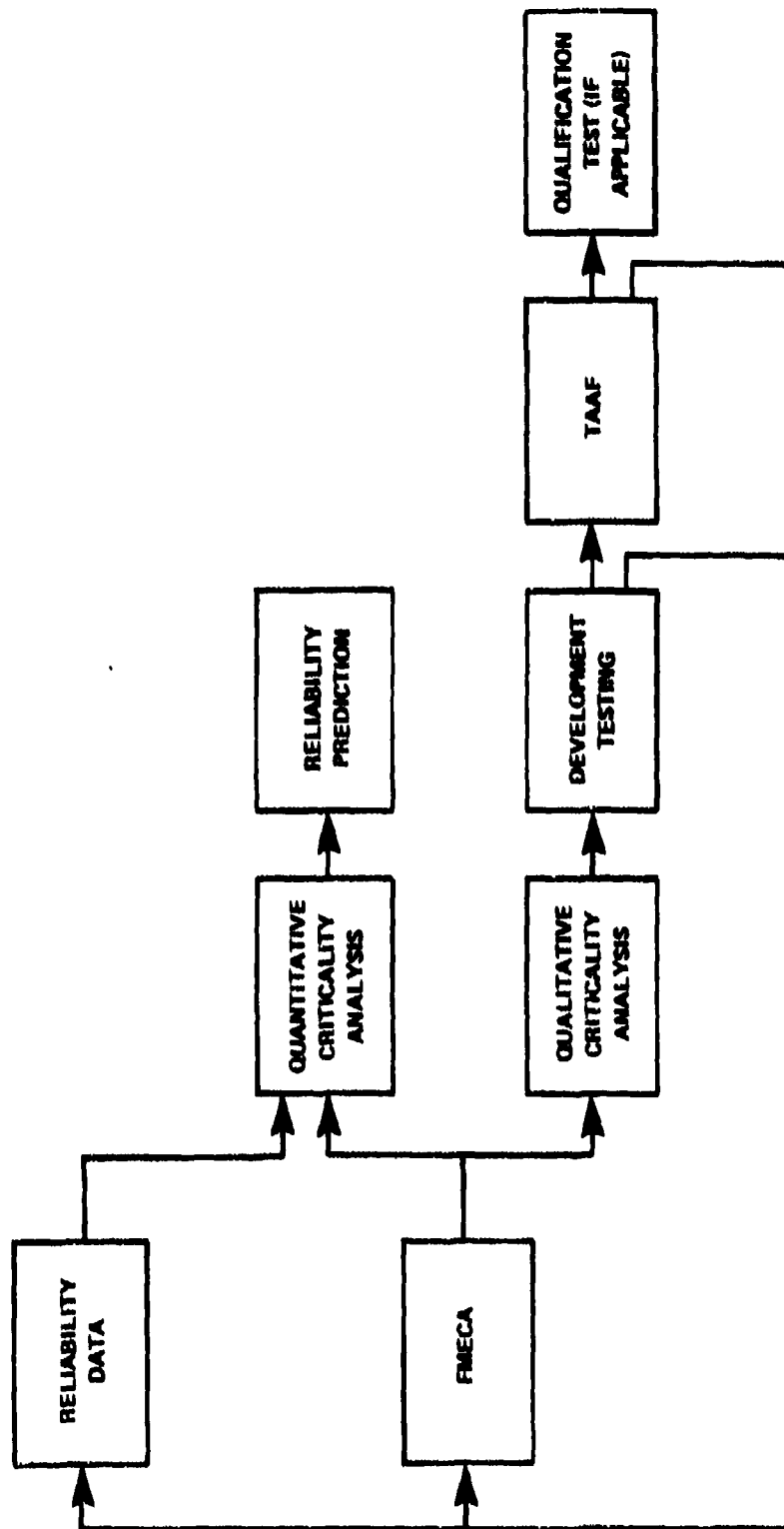


FIGURE 3-1. TYPICAL FLOW DIAGRAM OF ANALYSIS/TESTING PROCESS FOR NONELECTRONIC EQUIPMENT

life. Therefore, development tests are usually performed at component or subassembly levels. Each test unit should be scheduled for as many tests as are possible in order to secure a maximum of test experience and data from available units. The following examples are tests which may introduce new failure modes to be considered in design as well as generating test data.

TEST

Duty Cycle
Humidity
Temperature
Vibration
Durability

TEST MONITORING

Wear, Fatigue, Stability
Freeze-up, Corrosion, Contaminants
Binding
Fatigue, Alignment, Clearances
Degraded Performance

Test, Analyze And Fix (TAAF) programs are designed to achieve operational reliability consistent with contractual requirements through failure detection, failure analysis and the incorporation and verification of design changes to prevent recurrence of failures. The contractor should design his testing program for nonelectronic equipment around this growth process because qualification testing in accordance with the procedures of MIL-STD-781 is often impractical and dependency must be placed on the TAAF program to provide a qualitative assurance that reliability objectives are being met.

TAAF programs for nonelectronic designs must have two objectives. First, the tests must be designed to identify failure modes so that effective design changes may be incorporated. This is the primary objective of any TAAF program but, for nonelectronic equipment, another test objective must be considered: an indication of wear out failure modes and limited component life. Tests for wear out are destructive in nature and these tests must usually be accomplished at lower indenture levels where equipment is more available and less costly.

Data requirements for a quantitative indication of reliability necessitate TAAF programs to include assembly level as well as system level tests. Reliability data must be obtained from whatever sources are available because of the shortage of available equipment for official test programs. MIL-STD-785 combines the requirements for development tests and TAAF programs. For nonelectronic equipment the requirements for test planning and data recording of development tests and TAAF programs are more distinct than for electronic equipment. Degradation type failure modes must be detected early in the development program and tests to detect these failure modes must be performed at the lower equipment levels.

Reliability development tests are usually performed on parts, components and lower equipment levels to determine failure modes and such variables as life expectancy, wear rates of sliding and impacting parts and other time dependent failure mechanisms. TAAF programs on the other hand are performed at higher equipment levels to determine potential reliability.

It is customary during the TAAF program to operate the equipment until a failure occurs, shut down the equipment for repairs and then operate the equipment until the next failure. For nonelectronic equipment this approach may not be practical since the test time required for a small sample size is too long and nonessential interruptions can not be afforded. Specialized test plans must be developed for nonelectronic equipment. First, differences between critical and minor failures must be determined prior to initiating the test program so that the test need not be stopped for minor failures. Second, although the test must be interrupted at predetermined times to measure such parameters as wear rate, critical clearances and other time-dependent parameters, such interruptions must be minimized.

The purpose of a TAAF program is not only to obtain a measure of reliability but also to achieve reliability growth by testing, detecting design change requirements, and following up on corrective action to verify reliability growth. Only minor significance can be placed on the statistics of TAAF programs for nonelectronic designs. The cost benefit of testing programs designed to provide a quantitative value of reliability for nonelectronic equipment is questionable. Of greater cost effectiveness may be the process of detecting potential design problems and achieving the planned reliability growth, a determination of reliability being accomplished through a compilation of test results at lower equipment levels, past performance data with similar equipment, stress analysis results and other reliability data.

(b) Environmental stress screening

Reliability engineering tests specified by MIL-STD-785 to be conducted during the development phase include development tests and those tests as part of the TAAF program. Engineering tests are designed to detect failure modes and determine wear rates and other time dependent failure mechanisms so that design improvements can be effected and the life expectancy of components extended. Another task specified during the development phase by MIL-STD-785 is the Environmental Stress Screening (ESS) test. ESS or run-in testing is intended to stimulate relevant failures by stressing the equipment under test. MIL-STD-785 provides a procedure as shown in Table 3-1 for establishing an ESS test plan.

MIL-STD-785 also specifies that the results of ESS testing during development shall be analyzed and used as the basis for the ESS procedures to be specified for production. Prior to incorporating ESS requirements into the development program for nonelectronic equipment the total quantity of equipments to be fabricated during the development program must

TABLE 3-1
DEVELOPMENT OF ENVIRONMENTAL
STRESS SCREENING TESTS

- (1) Description of environmental stress types, levels, profiles, and exposure times to be applied
- (2) Identification of level (part, subassembly, assembly) at which testing will be accomplished
- (3) Identification of item performance and stress parameters to be monitored during ESS
- (4) Proposed test duration (failure free) interval and maximum ESS test time per item

be considered. If the quantity is on the order of several equipments or less, such a requirement may not be practical. ESS procedures for the production program should be prepared by the contractor during the development phase but these procedures may have to be prepared from development test results at a lower equipment level or from the TAAF program rather than from ESS development tests. The contractor must specify in his reliability program plan how ESS procedures for the production phase are to be developed.

3.3 RELIABILITY ACCOUNTING TESTS

A reliability qualification test is one accounting type test performed to demonstrate that design reliability specifications have been met. Ideally this is a formal test, conducted under strict environmental and operational profile conditions with maintenance performed in accordance with specified access or repair procedures. In many development programs for nonelectronic equipment, qualification testing is not possible simply because the quantity of equipments required to perform the test is not available.

A reliability qualification test is intended to provide assurance that minimum acceptable reliability requirements are being met prior to starting production of the equipment. Qualification tests are formal acceptance tests performed in an operationally realistic environment and are statistically designed to provide estimates of reliability. Formal procedures for conducting qualification tests contain a description of the item to be tested, the equipment operational specification and a statistical test plan with accept/reject criteria.

Reliability is a time-dependent parameter and there is no way to verify reliability without test data and sufficient testing time to establish a confidence factor. The problem with designing qualification tests for nonelectronic equipment is the fact that specialized designs limit the number of units available for test. MIL-STD-781 contains some high risk test plans for small sample sizes but very often only one nonelectronic equipment is available for qualification test. The problem is compounded by the fact that each nonelectronic design will have a multitude of operational modes and all design requirements can not be tested simultaneously. For nonelectronic equipment, testing time must be accumulated from piece part testing, component evaluation tests and whatever sources are available. The key to using this data for evaluating nonelectronic reliability is the maintenance of test results as a source of engineering data for such time dependent parameters as mechanical wear, crack size and material strength.

A clearly defined and closely monitored reliability qualification test is a necessary requirement at the completion of full scale development. It must be remembered by the procuring activity, however, that nonelectronic equipment contains time dependent failure modes, and it may not be possible to quantify equipment reliability from the test results. Qualification testing remains a necessary part of a test program as an equipment operational test prior to full scale production.

The procuring activity must require the contractor in his reliability program plan to provide estimated testing times for various critical components in developing qualification test procedures.

The other reliability accounting test as described in MIL-STD-785 is the Production Reliability Acceptance Test (PRAT). PRAT is intended to simulate in-service evaluation of the delivered item or production lot. Because of the limited test data achievable for many nonelectronic development programs, PRAT can be very useful in providing estimates of demonstrated reliability. The same problems of designing test plans for qualification test with small sample sizes and multi-functional equipment applications are encountered in designing a PRAT program.

SECTION 4 CONCLUSIONS

Current military standards for reliability programs, reliability predictions and qualification testing were written primarily for electronic equipment where component standardization and the valid assumption of an exponential failure rate permit their direct application. Reliability tasks as included in MIL-STD-785 are sometimes applicable to a total system containing both electronic and nonelectronic designs. The reliability of the nonelectronic equipment will, however, be much more dependent upon the operational environment than will electronic equipment because of the more direct interface with the operator and the environment. The individual nonelectronic equipments within the system will, therefore, require a unique approach to planning the analysis and testing program. Small sample sizes usually available for nonelectronic equipments and their multi-functional operational characteristics also necessitate a unique approach to planning a reliability program for nonelectronic equipments within a total electronic system and totally mechanical systems.

Reliability analyses for nonelectronic designs such as a failure rate prediction depend to a large extent on internally generated fatigue and component life test data because published failure rates are not generally applicable to the equipment being developed. An analysis of a nonelectronic design for reliability must, therefore, focus upon the location of overstressed components. The FMECA is the most powerful tool for evaluating nonelectronic reliability and should be applied very early in the design program for use in identifying those critical areas where a stress analysis should be performed. Early application of the FMECA can eliminate the expense of performing a stress analysis for all parts in the design.

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Application of reliability specifications depends upon the equipment being designed and a general rule of applicability for nonelectronic equipment is not possible. MIL-STD-785 states that a reliability prediction is generally applicable in the engineering development phase and that the FMECA is selectively applicable in the concept phase. For nonelectronic designs, the prediction will likely be delayed until internally generated testing data is available. Meanwhile, the FMECA should be initiated very early in the development program to identify critical failure modes and corresponding testing requirements. Typical application of these and other reliability tasks for nonelectronic development programs is shown in Figure 4-1.

Nonelectronic equipment usually dictates a testing program at lower component levels than does electronic equipment. Fatigue tests, wear tests and other evaluation type tests must often be performed on individual piece parts as part of the development effort. Small sample sizes of preproduction equipments will necessitate reliance on these design test results to provide a relative indication of total equipment reliability as compared to similar equipment designs. Procedures contained in MIL-STD-781 are sometimes not appropriate for nonelectronic equipments and results of the TAAF program combined with results of engineering development tests must be relied upon to provide an indication of reliability.

Another example of the difference in application of reliability specifications to electronic and nonelectronic development programs is the preparation of Environmental Stress Screening (ESS) procedures. MIL-STD-785 states that ESS is selectively applicable to the validation phase and generally applicable to the full scale engineering development phase. For nonelectronic equipment such requirements will not generally be applicable to the validation phase and only selectively applicable to the full scale development phase.

TABLE 4-1. TYPICAL APPLICATION OF RELIABILITY TASKS TO NONELECTRONIC DEVELOPMENT PROGRAMS

TASK	TASK TYPE	PROGRAM PHASE			
		CONCEPT	VALID	FBED	PROD
RELIABILITY PROGRAM PLAN	MGT	S	S	G	G
MONITOR/CONTROL OF SUBCONTRACTORS AND SUPPLIERS	MGT	S	S	G	G
PROGRAM REVIEWS	MGT	S	S	G	G
FAILURE REPORTING, ANALYSIS, AND CORRECTIVE ACTION SYSTEM (FRACAS)	ENG	NA	S	G	G
FAILURE REVIEW BOARD (FRB)	MGT	NA	S	G	G
RELIABILITY MODELING	ENG	S	S	G	G
RELIABILITY ALLOCATIONS	ACC	S	S	G	GC
RELIABILITY PREDICTIONS	ACC	S	S	S	G
FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)	ENG	G	G	G	GC
SNEAK CIRCUIT ANALYSIS (SCA)	ENG	NA	NA	NA	NA
ELECTRONIC PARTS/CIRCUITS TOLERANCE ANALYSIS	ENG	NA	NA	NA	NA
PARTS PROGRAM	ENG	NA	NA	S	S
RELIABILITY CRITICAL ITEMS	MGT	S	S	G	G
EFFECTS OF FUNCTIONAL TESTING, STORAGE, HANDLING, PACKAGING, TRANSPORTATION, AND MAINTENANCE	ENG	NA	S	G	GC
ENVIRONMENTAL STRESS SCREENING (ESS)	ENG	NA	S	G	G
RELIABILITY DEVELOPMENT/GROWTH TESTING (NOTE 1)	ENG	S/C	G/C	G	G
RELIABILITY QUALIFICATION TEST (RQT) PROGRAM	ACC	NA	S/C	S	G
PRODUCTION RELIABILITY ACCEPTANCE TEST (PRAT) PROGRAM	ACC	NA	NA	S	G

CODE DEFINITIONS

TASK TYPE

ACC - RELIABILITY ACCOUNTING
 ENG - RELIABILITY ENGINEERING
 MGT - MANAGEMENT

PROGRAM PHASE

S - SELECTIVELY APPLICABLE
 G - GENERALLY APPLICABLE
 C - APPLICABLE AT COMPONENT LEVEL
 GC - GENERALLY APPLICABLE TO DESIGN CHANGES ONLY
 NA - NOT APPLICABLE

NOTE 1: ALSO KNOWN AS TEST ANALYZE AND FIX (TAAF)

As indicated in Table 4-1, there are no specific rules for applying reliability tasks to nonelectronic development programs. Until such time that specific reliability specifications are prepared for the analysis and testing of nonelectronic equipment, the generation of analysis and testing plans unique to the nonelectronic equipment under development will be required.

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