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AN

INTRODUCTION

TO THE

EVALUATION OF RELIABILITY PROGRAMS

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Foreword

The project-support role of the reliability assurance program makes it necessary to tailor each such program to the nature and requirements of the individual project. This situation creates a natural variation in the degree of sophistication and proportioning of effort in each reliability program. In an effort to respond to this need for flexibility, there is frequently a tendency to lose sight of the primary need that each reliability program task, regardless of its level of sophistication, must contribute meaningfully to project decisions. This deficiency can be combatted effectively by astute management of the reliability assurance function, and one essential element in this management process—the subject of this publication—is the conduct of a continuous organized effort by the customer to monitor and evaluate the effectiveness of the reliability programs of the contractor and his subcontractors.

Consistent with the objective of describing a project-wide and mission-wide perspective of the assurance effort, the degree of detail in discussion of method in this publication has been kept at a moderate level.

The subject matter is presented here principally in the context of NASA project situations, particularly in chapter 4. However, the treatment of reliability program objectives, the criteria for judging task effectiveness, and the approach to evaluating the various tasks for meaningful accomplishment are essentially technical and are directed toward fundamentals. Thus, for the most part, this publication may be considered generic in its applicability.

The authorship of this document has been a joint effort of D. S. Liberman of this office and A. J. Slechter of the ARINC Research Corporation. However, effort in constructively reviewing and commenting on the document has been expended by numerous personnel of NASA program offices, NASA field installations, ARINC Research Corporation, and contractors to this office. This effort and the helpful suggestions offered by these reviewers are gratefully acknowledged. Special appreciation is expressed to the Jet Propulsion Laboratory of the California Institute of Technology for the use of its failure reporting system documents as supporting exhibits.

It is expected that this publication will be of great usefulness as introductory material for NASA personnel new to the reliability assurance area. However, in view of its fundamental approach to the subject, it can serve a much wider use as a communication tool.

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CHAPTER 1

Introduction

PURPOSE

This document presents a basic orientation to the task of evaluating the effectiveness of a reliability program. Although evaluation methodology is treated to some extent, primary emphasis is devoted to discussing the assurance task as it relates to project requirements and resources and to describing the factors which determine effectiveness in program implementation. The objective is to present an efficient general approach on which reliability assurance personnel can superimpose their own knowledge and initiative to adapt it for making timely and perceptive evaluations in their specific project situations.

BACKGROUND

Assuring the reliability of space-system hardware is a complex and difficult task. Basically, reliability must be built into the hardware during its design and fabrication, and degradation of that reliability must be prevented in the succeeding steps leading to the hardware's end use. One helpful technique in accomplishing this is the conduct of reliability and quality assurance programs. Because of the high levels of reliability required and the degree of complexity of space systems, policies and procedures have been developed to require contractors to plan and implement reliability and quality-assurance programs as a part of the design, fabrication, and utilization of major space-system hardware.

Effective reliability and quality assurance programs require foresight, timely planning, and vigorous pursuit by both the customer and the contractor. In the reliability area, the program is based on a reliability program plan which must be implemented by the contractor and monitored by the customer. Generally similar procedures apply to quality assurance programs, but detailed discussion of that area is outside the scope of this document.

Monitoring is particularly important to the effective management of the reliability program. Because the reliability effort is a support function which must continually readjust to unforeseen changes in the project program, continuous surveillance and assessment are necessary to assure that it does so effectively as the project progresses.

CHAPTER 2

Foundations of Reliability Program

PURPOSE OF RELIABILITY PROGRAM

The basic purpose of the reliability program is to contribute to the project in a supporting role, so as to increase the reliability of the hardware and systems produced. Often in the past, the contribution of the reliability program in this respect has been either small in comparison with its cost or too difficult to identify, or the program has been too isolated. Hence, the attitude of both industry and government as to the value of reliability programs has often been a negative one.

Unfortunately, reliability personnel in many cases have fallen short of taking the necessary positive action to assure the proper planning, execution, and management of their own program area. Further, because of the attitude which had resulted from weak past performance, even many sound recommendations from reliability personnel for improvements in their area often were not supported by management.

This trend is now reversing, to a great extent through a general recognition of the need for effective control disciplines to combat the failure potential resulting from increased mission severity and increased hardware complexity. However, this improved attitude toward reliability programs cannot be expected to endure unless it is demonstrated in practice that the reliability program is truly effective in supplying this control discipline.

As a basic rule in achieving its objective, it must be recognized that the reliability program performs its function effectively only as long as it supports the objectives and requirements of the project. Functions beyond this extent (unless specifically required by the contract for a stated secondary purpose) are academic and an unjustified use of resources. Therefore, reliability program management must take the initiative to ensure that the program is kept highly responsive to specific project needs, that it is staffed by adequate numbers of well-qualified personnel, and that it is conducted as an integral part of the project program. Operated in this manner, the reliability program can offer an important contribution to project success.

RESPONSE TO PROJECT CHARACTERISTICS

General

The principal project-situation factors that dictate differences in initial approach to the reliability program are:

(1) Mission criticality
(2) System complexity
(3) Type of mission
(4) Relationship to state-of-the-art
(5) Number of items produced
(6) Proportion of hardware developed on subcontract
(7) Use of existing hardware (including follow-ons)
(8) Project status at inception of reliability program

The following paragraphs discuss each of these factors as it affects the makeup of the reliability program.

Mission Criticality

Possibly the most basic indicator of mission criticality is the cost of failure—that is, the ultimate cost (in terms of human life, dollars, and time) of loss of the mission which a given hardware item is required to perform. Frequently, the cost of the hardware itself is a good indicator of the magnitude of such loss. However, in many cases (such as standard launch vehicles) unreliability of the hardware item of immediate concern can be responsible for far greater losses in the cost of payloads or even the costs of crippling delays in, or total loss of, a payload program.

The degree of criticality of a particular project will have a significant effect on shaping the efforts of the attendant reliability program. For the highly critical project, the reliability program must be conducted with greater thoroughness, tighter discipline, and somewhat more formality in documentation than is required for lesser projects. This emphasis would pervade almost all the reliability program areas and would dictate a need for increased manpower and greater dollar expenditures for reliability assurance. This is not to say that reliability program expenditures must be directly proportional to the potential failure cost, but, where potential failure cost is high, there is ample justification for adequate funding of appropriately more thorough reliability efforts.

System Complexity

The general relationship between the order of system complexity and the risk of failure is well known. High orders of system complexity require much more extensive overall testing programs and place a heavy demand on the reliability program to help minimize the effect of the greatly increased number of error sources (more components, more hardware interfaces, more organizational units, and more communications links). The general effect will be to require not only more technical effort in all reliability task areas but also a larger and more demanding reliability program management effort.

Type of Mission

The type of mission to be performed by the hardware system is an important factor in determining the orientation and content of the reliability program. A fairly broad breakdown of mission type may be made on the basis of the hardware classification, i.e., ground equipment, launch vehicles, or spacecraft. However, in considering the effect on the reliability program, a more appropriate classification can be made based on a further consideration of differences in basic mission characteristics such as:

(1) Manned or unmanned
(2) Mission significance (importance of mission to the space program)
(3) Mission life
(4) Environmental stresses
(5) Repairability of hardware during mission use
(6) Extent and difficulty of data acquisition and tracking requirements
(7) Extent of need for communication with, and command from, Earth

It is difficult to make a single general statement on the overall effect of all these factors on a reliability program. However, for any specific project, the appropriate areas for reliability program emphasis can be ascertained without great difficulty by considering these factors one by one.

Relationship to State-of-the-Art

Many NASA projects have certain mission obligations that approach the boundaries of the state-of-the-art either in design or in operational techniques. Often, in fact, the advancement of the state-of-the-art is the primary reason for the project in that future program planning is dependent on the breakthrough.

The effect of such conditions on the risk of failure places significant demands on the reliability program. Whereas reliance on proven techniques in design and fabrication is one of the basic methods by which high system reliability is achieved in the usual project situations, the project aimed at advancing the state-of-the-art must deliberately expose itself to risks in the area of the untried. Accordingly, in these cases, the reliability program must emphasize planned surveillance of the design, fabrication, and test cycle, with particular attention being devoted to the areas of design review, design-proof testing, and new component development associated with the advanced portions of the system.

Number of Items Produced

Whether a given project covers delivery of a large, as opposed to a small, number of copies of the hardware item being developed can materially affect the shape of the reliability program required. The larger project will experience a true production phase, with an opportunity for using more test items in the development cycle. In cases of this type (assuming equal orders of unit cost per item), the funding of a thorough reliability program can be more readily justified since the cost of the reliability effort can be amortized over a larger number of end items.

On the other hand, the project which produces only a few copies of the hardware item must evaluate the capability of the hardware with fewer test specimens; as a result, the reliability program is more difficult to fund, but it is even more necessary in order to place all possible project emphasis on careful and thorough planning and analysis (throughout the design and preliminary development phases) to try to eliminate all possible failures on paper or in model testing prior to a commitment to flight-type hardware.

Proportion of Hardware Developed on Subcontract

Where a system procurement relies heavily on subcontracting, and particularly where a relatively large number of subcontractors are involved, the reliability program problems multiply in much the same way that system management problems do. Effective reliability efforts by subcontractors are very important to overall mission success but are often difficult to obtain. Therefore the prime contractor's reliability program management effort must be particularly strong, and in the technical reliability program areas care must be exercised to see that subcontractors use compatible methodologies, that effective two-way communication is maintained to emphasize to the subcontractor the need for effective reliability effort, and that heavy emphasis is placed on those program areas which assure the adequacy of the "interfacing" of the prime contractor's efforts (see also par. 2.6 of NPC 250-1 (ref. 1)).

Use of Existing Hardware

Frequently, a system design will rely heavily on the incorporation of subsystems developed under previous projects. The incorporation of government furnished property (NPC 250-1, par. 2.7) is one case of this type. In all such cases, the reliability program must emphasize those areas which serve to ascertain the capabilities and limitations of the previously developed elements of hardware ("shelf items") under the new conditions of use, so as to determine adequately what requirements for reliability achievement must be placed on those elements which will involve new design work. As development proceeds, added emphasis must also be placed in the reliability evaluation area to assure that the shelf items are being integrated into the system without adversely affecting overall system reliability.

A very special case of the use of existing hardware is the follow-on contract which embodies partial modification of an existing system to give additional mission capabilities or to improve its present operation. Since a reliability program will usually have been implemented previously for the original hardware, the reliability planning for the follow-on effort must be based on examining the previous reliability program and reviewing the available reliability data and documentation to determine their applicability to the follow-on program. The new reliability program should then limit itself to the scope and depth necessary to support the follow-on development.

Project Status at Inception of Reliability Program

There are cases in which extensions of contracts are negotiated while development is in midprocess. In these cases the existing reliability program often is a poor one, and one of the requirements to be imposed with the contract extension is the incorporation of a more effective reliability program.

In such cases, particular care must be exercised to assure that the extent to which each reliability task is invoked is appropriate for providing useful support to the project effort as of its current state of evolution and that the reliability task cost will not be disproportionate to its expected impact on the project.

Summary

The foregoing factors roughly dictate the shape of the reliability program in that they describe most of the basic project characteristics to which a reliability effort must respond. The more specific determination of the reliability program scope must be made in light of project management's decision as to the risks it is willing to accept and the resources it is able to devote to reliability assurance after consideration of the project characteristics and of the economic constraints.

Once the project is roughly categorized, pertinent economic factors should be taken into account and a determination made as to (1) where emphasis must be placed, (2) whether the complete list of reliability assurance tasks is applicable, and (3) whether there are any apparently unique problems which must be overcome. This process of ascertaining project needs does not end with the establishment of a reliability program at the beginning of a project. It also applies to evaluation of changes in reliability assurance needs after the project is well underway.

NASA GUIDELINES AND PROCEDURES

NASA has developed its policies and procedures in full recognition of the project support role of the reliability function and of the need for flexibility in designing reliability programs to fit a diversity of project needs. Two basic documents govern reliability programs for NASA procurements. One of these is NPC 400, (ref. 2) "NASA Procurement Regulations," of which Part I, Subpart 51, is entitled "Integration of Reliability Requirements into NASA Procurements." The other document is NPC 250-1, (ref. 1), "Reliability Program Provisions for Space System Contractors." Essentially, NPC 400 (ref. 2), part I-51, prescribes the assignment of responsibilities within NASA for assurance of reliability and gives procedures for establishing and managing reliability assurance efforts on contracts, and NPC 250-1 prescribes a generally applicable program of assurance tasks to be employed by contractors. These documents lay the procedural foundations for the reliability programs which are the concern of this text); therefore, a discussion of their essential features is considered important in putting the evaluation process on a sound footing. Such a discussion is given in the following sections.

Reliability Requirements in NASA Procurement Procedures

The policy and outlook of NASA in regard to the area of reliability assurance are reflected in NPC 400, I-51. Among the important features of that regulation are those which show the basic attitudes of the agency in this area and which form the pattern for the evaluation philosophies and approaches contained in this text. Some of these features are as follows:

(1) Reliability assurance is defined as a systematic pattern of all actions necessary to provide adequate confidence that a space system, or portion thereof, will perform reliably in actual operation. The pattern of actions referred to is further described in the definition by identification of appropriate actions in the various steps of the processes of program and project planning, procurement planning and execution, and use of the item. Among these are the actions to be taken in the planning and execution of contractor reliability programs, as well as in the government monitoring and guidance of such programs.

(2) It is made clear that the intent of NASA policy as to the application of reliability program requirements (NPC 250-1, ref. 1) to projects of various types is that the reliability program be tailored to the requirements and state of evolution of the project.

(3) It is made clear that the primary responsibility for the assurance of reliability for any project lies with the project manager, but it is intended that this responsibility be implemented with the advice and support of appropriate reliability-assurance specialists.

(4) NASA responsibility for defining clearly in procurement documents the extent of applicability of NPC 250-1 to a given procurement is stated, and a number of reliability program task areas where this is particularly necessary are identified.

The reliability program evaluator must understand the logic and intent of the regulations fully and completely. This is essential to his making sound interpretations of that intent when judging a contractor's reliability program.

Reliability Program Provisions for Contractors

NASA reliability publication NPC 250-1 furnishes a general guideline adaptable as a basic structure for reliability programs that fit project situations of various types. It presents the reliability effort as an organized program of diverse tasks managed from a central point. The tasks themselves are functionally of two broad types: Those to be accomplished by reliability personnel and those to be accomplished by personnel of other project areas (i.e., basic design disciplines) but monitored as a part of the reliability program. The common denominator of all the tasks is their basic role in the planning and controlling of a sound design-development effort, wherein reliability status is periodically determined, timely inputs to design trade-off decisions are provided, and engineering discipline is maintained over the fundamental steps and milestones in the design and hardware evolution process. In Chapter 5 of the present text each reliability program element of NPC 250-1 will be treated in detail, and evaluation guidelines for each will be given. However, some of the key features and philosophies of that document are of particular interest here because they are fundamental to the evaluation effort; they are highlighted as follows:

(1) It clarifies the relationship of the reliability program to other project requirements and gives positive guidance for eliminating duplication of effort (par. 1.3).

(2) It spells out the requirement for accessibility to and visibility of all project data to NASA and its representatives, including independent reliability assessment contractors (par. 1.4). Also, in order to provide for most convenient accessibility, not only for NASA but also for the contractor's own personnel, it prescribes the use of a central unified file (or data center) for all reliability and quality data (par. 5.1).

(3) It requires the conduct of the reliability effort as a formally organized program with central management, a documented program plan, and a separate accountability for reliability program resources (pars. 2.1, 2.2, and 2.4). Moreover, it underscores the need for negotiating the reliability program together with the negotiation of the overall contract (rather than after contract execution). Also, it gives detailed procedures for this negotiation which provide for a realistic, three-step effort to delineate scope and cost of the reliability program and to develop the program plan (par. 2.2).

(4) It requires periodic reviews of the reliability program and provides for a revision of the Reliability Program Plan (RPP) to accommodate changes found to be necessary as a result of the reviews (par. 2.3). Since these reviews are jointly conducted by NASA and the contractor, they serve as one ideal means of implementing the recommendations of the reliability program evaluation effort.

(5) It requires that the prime contractor control the reliability of system elements obtained from subcontractors and that he determine the effect of reliability of system elements provided as government-furnished property on the reliability of the overall system (pars. 2.6 and 2.7).

(6) It requires that the project be covered by one integrated test program instead of by separately managed testing programs in each of the various project areas (par. 4). This requirement helps prevent both duplications and omissions in testing and also provides a single test baseline, alongside of which the closely interrelated program of reliability assessment should be conducted. This approach emphasizes the intimate tie-in of the reliability assessment effort with the requirements of the project and underscores its role as an input to the various project decision points.

CHAPTER 3

Keys to Effective Implementation

The implementation of any task, whether in a reliability program or elsewhere, must satisfy certain basic criteria in order to be considered effective. The net effect of these criteria must be to determine whether the program, task, or other item serves a recognized need in a meaningful way. This section will discuss such effectiveness criteria. These criteria may also be thought of as "evaluation tests" to which each element of the program should be subjected. Within the context of project needs, the evaluator should think in terms of the requirement that each program element must either satisfactorily pass each of these "evaluation tests" or undergo corrective action.

Because of the complex and variable nature of the situations which a reliability program evaluator will face, it may be quite difficult (if indeed possible) to establish quantitative measurements of adequacy which are completely objective. The judgment of the evaluator, therefore, must be the dominant factor in determining whether the program element in question adequately satisfies the evaluation criteria. However, if it is assumed that the evaluator is properly qualified, the absence of an objective quantitative yardstick does not impair the worth of the evaluation, since the very act of quantification in judgment-type situations is, in itself, highly subjective. The basic criteria for evaluation of any program task are:

(1) Quality of performance
(2) Timeliness
(3) Cost in relation to need

The effort put forth in each reliability program element must be of adequate quality, but not over-elaborate, for the actual project need; the output must be produced in time to have a positive effect on the project; and the amount of resources necessary to produce the output must be justified by its value to the project. Perceptive application of these three tests to each element under evaluation would fairly assess whether the reliability program is efficiently providing a usable output to the project.

However, the determination of effectiveness cannot end with a determination of the basic soundness of the planning and implementation of the reliability program tasks. It must also consider whether "usable" outputs are actually being used. This question then dictates that two additional test criteria be applied to determine effectiveness; these are:

(4) Attitudes of project personnel
(5) Impact on project

These last two factors, indicate the willingness and the ability of the project personnel to integrate effectively the reliability program outputs into the design and development process.

In the following sections these criteria are discussed in further detail.

QUALITY OF PERFORMANCE

Quality of performance is one of the primary evaluation considerations. It can be simply stated: If the quality of the work within a program element is poor, there will be either little effect on the project or, worse, a degrading effect. However, quality of performance cannot be meaningfully evaluated by itself. In considering "quality" in connection with a reliability program task, it is necessary to be keenly aware that the objective of the task is to provide basic data, or otherwise to support a project decision, at some project decision point or milestone. When viewed in this light, the necessity of evaluating quality within the constraints of timeliness and cost effectiveness becomes plainly apparent.

It follows that the highest achievable quality of performance is not always justifiable. It is necessary that there be no compromise of validity, competence, or accuracy (the term "compromise" refers to accepting a standard below a technically responsible level). However, careful judgment must be applied to avoid unnecessary or unwarranted levels of precision, elaborateness, refinement, or thoroughness.

The best general approach to evaluating quality of performance might be to consider first the particular project decision point for which a given reliability task output is to be used. Normally, this will give an insight into the order of elaborateness, accuracy, and precision required. Next, the evaluator should consider the practical ease (and cost) of attaining the required level of quality. Lastly, he should consider whether an adequate reliability task output can be reasonably produced within these constraints and whether the performance he observes is adequate within this frame of reference.

TIMELINESS

Timeliness is perhaps the single most important factor in differentiating between effective and ineffective implementation of a reliability program task. Since the purpose of the reliability program is to support the project, it is essential that the reliability program tasks be conducted integrally with the other project tasks and provide usable inputs at project decision points. Otherwise, the reliability input, whether it be analytical or of a monitoring nature, degenerates to an academic function or a historical documentation process, instead of actively contributing to the improvement of hardware reliability.

In evaluating timeliness of a reliability program task, it is essential to consider the nature of the design and development process itself. In essence, this process is an iterative one. It begins with conceptual studies which form the basis for selecting the overall design approach. This, in turn, provides the general point of departure for formulating concepts and designing subsystems and components. As the design and development process proceeds, the definition of the subsystems and components that will perform the system's mission functions becomes progressively clearer. At intervals throughout this process, engineering assessments must be made of the effect of one subsystem or component on the others or of the need to cope with technical problems not previously anticipated. This is particularly true in such areas as demands on the power or weight budgets or on limitations in attainable performance of one element, which place the burden for achievement of overall performance goals on other elements of the system. In addition, management assessments must be made where cost, schedule, and performance factors were examined.

The purpose of all these assessments is to determine where and how the course of the project must be corrected to provide the optimum chance (both technical and managerial) of attaining overall project goals — in short, to guide project-directing decisions. These assessments must be made at all major milestones, and a formal design review is usually a part of them. This type of activity is not confined to the system level; it must also occur at the subsystem and component level, where the same iterative assessment/decision process takes place to conform with the design and development milestones that occur at the lower levels of assembly.

The objective of the tasks in the contractor reliability program is to support the decision-making process. Analytical tasks provide a picture of relative (or estimated) reliability status, or they identify or quantify sources of potential failure. On the other hand, the monitoring tasks assure the decision maker that the progress accomplished at that point in time is soundly based and within the accepted bounds of the technical discipline. If the reliability program task (for either of these types) fails to provide usable information for the decision maker at or before the decision point, then it has made no contribution to that project decision.

Obviously, it is not practical for every reliability task to make a strong contribution to every project decision point. Some must be planned to impact only selected decision points. In either case, the output of the reliability task may sometimes slip its schedule and thus not be available at the decision point for which it was originally planned. Whenever a reliability task effort falls behind in this manner, the decision on whether to continue it will depend, in each particular case, on the probability that the task can "catch up" and contribute at a subsequent project decision point.

COST IN RELATION TO NEED

A trade-off between the cost and the comprehensiveness of a task is mandatory in almost every program situation. Reliability program functions are certainly no exception. In fact, because these functions may frequently be considered a "soft spot" for cost trimming, the reliability program managers must be constantly alert and assume the initiative in maintaining the cost-effectiveness aspect of all parts of their own program.

In general, the evaluation must diligently pursue all reliability-assurance tasks to determine whether the contractor is using "gold-plated" approaches in areas where only limited effort is required. The interrelated factors of quality and timeliness, covered in the preceding paragraphs, bear heavily on this. However, in addition to these, the appropriateness of the current scale of task implementation—or, simply, "currentness"—deserves particular mention in the area of cost management. The evaluator must bear in mind that the level of effort assigned to a given task area at the time of initial reliability program planning is a "best estimate" as of the time at which it was made. Realism demands that these estimated levels be reexamined at the time of the reliability program evaluation to determine whether they have responded to the fluctuations in need dictated by the exigencies of the project. Frequently, originally planned levels of effort may later prove to be too "comfortable" in light of a reduced need later in the project (although sometimes the reverse may be just as true). Therefore, each time the reliability program is evaluated, the evaluator must review his earlier judgment of whether the scale on which each reliability program task is implemented is still appropriate to the potential benefit of the task output to the project. These judgments should be used as a prime criterion for evaluating the efficiency of implementation of each reliability task, as well as that of the overall reliability program.

ATTITUDES OF PROJECT PERSONNEL

The success of the reliability program in supporting the design and development process is contingent upon effective working relationships between the reliability personnel and all other project personnel. An important part of this is a mutual agreement from the start as to what is expected of the reliability program. Although the careful planning of reliability tasks to provide timely and useful outputs to the project provides the foundation for a successful reliability program, it is vital that the various user groups in engineering and manufacturing recognize and accept that a worthwhile support function is being competently performed by qualified personnel.

As previously discussed in the section entitled "Purpose of Reliability Program," there has been a negative attitude by project personnel in many quarters toward reliability inputs; this attitude has largely resulted from the failure of many past reliability programs to make effective or efficient project contribution. It is not reasonable to expect in-line project personnel to respect a support function which not only appears to generate "useless" information but which also seems, in their eyes, to impede project progress. Therefore, it is extremely important that the reliability personnel strive not only to produce a worthwhile output in an efficient manner but also to demonstrate through their daily performance that the reliability tasks are of material use to the project in an integral support role.

Although it is the responsibility of reliability personnel to earn and maintain respect through good performance, company management must accept the basic responsibility for, and take the initiative in, developing positive attitudes toward the reliability function. Management must ensure strong staffing (in quality, if not in numbers) of the reliability function and give it appropriate organizational stature. It should also see that the reliability function (both analytical and monitoring tasks) is performed and recognized as an integral part of the design and development process. When such support is given by management, and when this support is augmented by appropriate training of the engineering staff in the general application of reliability techniques, the necessary understanding and attitudes can be developed to promote effective program implementation.

The item of attitude of nonreliability personnel will more frequently be encountered on a program-wide or on an individual-person basis rather than task by task. However, the evaluator should be alert to this item on any basis, since it will provide important insight for his overall task.

IMPACT ON PROJECT

The final and most important test of the effectiveness of any reliability program task is its impact on the project. Even if a task output is of adequate quality, is timely, is done efficiently, and is respected by in-line project personnel, it is not effective unless it has a constructive effect on the project. Such effects might be categorized as (1) direct support to improvement of hardware reliability, (2) providing confidence in the probability of achieving project success, or (3) indirect contribution to project success through increasing the consciousness of the need for good project discipline and in motivation of personnel.

Although motivational contributions are very hard to identify and evaluate, the functions of providing direct support or of providing confidence are evidenced in the use of reliability program outputs in the making of project decisions. In the area of direct support, the contributions might concern detection of points of weakness or sources of unreliability; or, more frequently, they might provide guidance as to the relative magnitude of risks from more than one potential failure source to help support a trade-off decision. The evaluator's task of trying to detect the contribution of the reliability program to project decisions is a difficult one indeed. Although some direct indication can be obtained by observing the design review program, most of the bases for evaluation are indirect, and some require a subjective judgment based on candid indications of the true attitude of both working level and key in-line project personnel.

CHAPTER 4

Evaluation Process

AIMS AND REQUIREMENTS

The previous sections have discussed in depth the philosophy behind employing reliability programs and have specified the general criteria governing the establishment and effective implementation of such programs. With this foundation, one can now begin responding in detail to such questions as:

(1) How is a reliability program evaluation best accomplished?
(2) What type of personnel and resources are required, and where are they best deployed?
(3) What is the most effective organizational approach to the evaluation problem?
(4) How are reliability program weaknesses detected and corrected?

In providing the guidelines for answering these and other queries, one must first answer the more basic question: "What is the purpose behind the monitoring and evaluation effort?"

Few would question the appropriateness of monitoring a contractor's efforts as a general principle of contract management, and many would quickly equate monitoring to assessing the adequacy of compliance with contractual requirements. However, the problem is, "How does one define adequate compliance?" Despite the fact that the reliability program tasks are defined in detail in the reliability program plan (RPP), the complexity of many of these tasks makes it extremely difficult to describe each element comprising each task in sufficient depth to define clearly what constitutes adequacy (or inadequacy). As a result, the evaluation which is oriented to compliance alone is likely to be ineffective in most project situations.

A preferable approach is that of using the "compliance" criterion as one of the broader aspects of the evaluation, but to make the primary aim of the evaluation a search for those areas of the reliability program which require improvement; the purpose is to discover the weak areas in sufficient time to make the needed improvements (or eliminate activities which are wasted effort). This objective, the prompt correction of inadequacy, is the only immediately constructive reason for determining that an area of noncompliance exists (even if noncompliance can be clearly established). The other reason, assessment of penalties, normally comes well after the fact and, in any case, offers cold comfort to those whose primary interest is to prevent mission failures.

The evaluation effort should be particularly concerned with determining:

(1) Adequacy of the reliability program in meeting current project needs
(2) Effectiveness of reliability program implementation in terms of input to, and impact on, the overall program.

This approach emphasizes the need for reliability program flexibility in keeping abreast of important changes in the project. Its principle, furthermore, is recognized in reliability publication NPC 250-1 (ref. 1) (par. 2.3), which requires periodic review of the reliability program to determine the need for, and to make appropriate changes to, that program. Finally, this approach is designed to help identify ineffective reliability program elements that offer only an external appearance of adequacy, since it recognizes "compliance" in terms of effective compliance.

Obviously, the evaluation effort cannot and should not assay to achieve a "one-for-one" coverage on all technical output under the contractor's reliability program. Instead, its objective should be to selectively sample and evaluate enough of the various technical items to ascertain whether each is reasonably satisfactory for its purpose and whether the contractor's reliability management group is doing an adequate job.

ORGANIZATION OF EVALUATION EFFORT

To be effective, reliability program evaluation should be conducted as an orderly process. It should be managed in a positive, planned, and scheduled manner that effectively uses readily available resources and promptly identifies for correction those problems encountered in the evaluation process itself.

As a first step in planning the evaluation effort, a careful review should be made of all the elements of the contract reliability program and the inputs to, and outputs from, each. These inputs and outputs should then be characterized as to form, degree of formality, ease of accessibility, physical location, milestone "time," and, most important, the effort and degree of technical and management competence required to evaluate them intelligently.

The next basic step should be a review and careful evaluation of the resources available to conduct the evaluation process. A complete listing of potential resources is given below, although there are many programs in which available evaluation help is far more limited.

(1) Personnel of the NASA center itself
(2) NASA representatives resident in the contractor's plant
(3) Resident in-plant representatives of other government agencies
(4) Periodic visit surveys by a task group
(5) Use of independent reliability assessment contractors

Few programs exist in which any one of the above-listed resources can effectively satisfy the complete evaluation function. However, each has qualifications and location advantages which enable it to perform best certain portions of the total task. Note that each of these resources can vary widely from one project situation to another in such respects as motivation, availability of manpower, levels of capability, and distribution of technical specialties. These attributes must be carefully appraised for the particular situation at hand during the planning of the reliability evaluation program.

After fully assessing the job to be done and the means available to do it, the manager of the reliability program evaluation effort can then divide the overall task into parcels appropriate for taking maximum advantage of the available evaluation resources.

The remainder of this chapter will further discuss the management and execution of the evaluation and monitoring program by describing the role of the NASA center, the functions which can be served by various monitoring delegates, and the basic task-evaluation technique.

THE NASA CENTER

The cognizant NASA center must be the focal point of the reliability program evaluation process. It is the project reliability assurance function at the NASA center that is responsible for general direction and motivation of the system contractor in the reliability area. This function must also interpret reliability policy and provide program guidelines to definitize general NASA requirements to meet the specific needs of the project. Included in this responsibility is the requirement for monitoring and evaluating the contractor's reliability program.

As brought out in the preceding section, the evaluation and monitoring of the contractor's reliability program should be organized and systematic — in effect, a program in itself. The project reliability assurance function at the NASA center must accept the responsibility for planning and managing this evaluation program. Normally, those responsible for this function will also participate heavily in the technical evaluation work itself. These activities are discussed in the following sections.

Planning and Management

Initial Planning

Planning the evaluation and monitoring effort is a challenging task. Not only must one face the normal array of uncertainties that most planning functions encounter, but one must also deal with the problem of deciding what work can be delegated and who of the potential delegates can and will accomplish it properly. In addition to these difficulties, the demanding job of planning the monitoring and evaluation effort occurs during the same time frame as other basic reliability assurance tasks. Among these are the negotiation of the reliability program and the initial shaping of the formal RPP. The NASA reliability assurance personnel should resist any temptation to classify mentally the monitoring and evaluation effort as something of secondary importance or something which can be "taken care of later." The basic elements of planning the evaluation effort tie in very closely with the detailed development of the contractor's RPP, which NASA must approve. In particular, the selected scheme of monitoring and evaluation should have a significant bearing on the documentation requirements under the RPP. Also, the point of acceptance or "Review" of certain contractor actions can sometimes be constructively delegated if the resident NASA representative's office is adequately staffed and willing to accept these responsibilities. Further, the decision on the need for contractual assistance in the evaluation effort should be made as early as possible to enable the study contract effort to be initiated early in the hardware contract cycle.

Apportionment of Effort

In general, all monitoring and evaluation effort must be either delegated, contracted (as supporting studies), or performed by the reliability assurance personnel of the cognizant center itself. It is vital that the center be as realistic as possible in dividing this effort so that the program will be one of active and useful evaluation and will not degenerate into uninformed and uninspired "onlooking" and "sightseeing."

The proper sequence of decision in the apportionment process should normally be as follows:

(1) What potential government-type delegates are available, and which tasks they can be assigned.

(2) Of the remaining evaluation tasks, what can be handled by reliability personnel at the NASA center (including temporary duty at the contractor's plant).

(3) What complementary areas can be covered reasonably by visiting "survey" groups.

(4) What is not adequately covered. Areas in this category can sometimes be handled effectively by the use of the reliability study contract. These contracts are discussed under that heading (p. 21).

Technical Participation

The basic technical task to be accomplished by reliability assurance personnel at the NASA center is the overall technical supervision of the evaluation process. This task includes integration of the inputs from all the various monitoring sources so that a composite evaluation picture of the contractor's reliability program can be built. This function may be broken down broadly into the following areas:

(1) Evaluating report inputs
(2) Planning and conducting periodic surveys
(3) Special on-site evaluations
(4) Overall evaluation and followup

Evaluating Report Inputs

The report inputs that the NASA center evaluator must be concerned with will be of two kinds: (1) The technical and management reports generated by the contractor as an output of the reliability program itself and (2) the monitoring reports received from the various monitoring and evaluation delegates. The evaluation of these reports will serve to provide a picture of the effectiveness of both the evaluation effort and the contractor's reliability program. Each report should be evaluated both as a separate information item and with a view toward identifying inconsistencies in the overall picture due to the failure of seemingly adequate individual items to fit together properly. Thus the evaluation of these reports not only can reveal the degree of adequacy of performance but also can guide the apportionment of further evaluation effort to determine causes of identified weakness, to clarify doubtful areas, and to resolve areas in which conflicting data are received from different sources. In particular, the information obtained from evaluation of report inputs can be most valuable in the planning of surveys.

Normally, monitoring reports will be submitted to the NASA center by the delegates as a task of their overall evaluation routine. However, the extent to which technical reports will be submitted depends on the terms of the contract. Where these are not required to be submitted by the contractor, the evaluator must take the initiative to obtain them. He should sample the technical reports in the various reliability task areas throughout the program to the extent he finds necessary to maintain adequate surveillance.

The evaluation of individual technical report inputs obviously requires technical competence in the specialty areas being reported. However, this by itself is not enough, since quality and degree of sophistication of the report should depend on its intended use. Therefore, the evaluator must also have a firm appreciation of the use context of the particular item he is evaluating.

Thus, the evaluation of report inputs can provide indications of many aspects of the contractor's reliability program and of the effectiveness of various aspects of the evaluation effort itself. However, it must be reemphasized that the obtaining of a really good "reading in depth" demands a broad competence and astuteness on the part of the evaluator.

Periodic Surveys

As used here, the term "survey" implies an orderly and organized evaluation visit to a contractor's facility by a task group of customer representatives. The periodic survey of the contractor's reliability program serves several important functions in the overall evaluation process.

By utilizing a formal and perceptive approach, the survey helps to stress to the contractor the customer's vital interest in a well-managed reliability assurance program. For the evaluator, it can be a means to obtain a complete overview and broad indication of the efficiency of the reliability program in a short period of time. However, most importantly, the survey performs the function of complementing the other facets of the evaluation program by directing specific attention to the resolution of questionable items identified through those other program facets and by obtaining a nonresident viewpoint.

Generally speaking, the survey should be used in the overall evaluation scheme on a fairly regular schedule. However, the frequency will vary with a number of factors, the most important of which are need, as evidenced by events in the contract situation at hand, and the resources of time and manpower available from the center to conduct the surveys.

It is not within the scope of this text to treat the conduct of surveys in intimate detail. There are other sources, both within NASA and outside, which provide specific instruction on the conduct of reliability program surveys. However, it is appropriate here to cite some of the fundamentals for planning and conduct of the survey.

The survey contributes most meaningfully to the overall evaluation program when it is planned as a complement to other monitoring and evaluation activities. This is far more effective than using it as an independent evaluation mechanism. The formulation of survey objectives should, therefore, be based on indications received from these other evaluation sources (technical and management reports both from delegates and the contractor; see preceding section). Normally, unless this is done, the survey either will end up trying to exceed its resources or will otherwise spend its effort unproductively; the net effect will be to accomplish little more than a show of interest to the contractor. Survey results that are vague and cursory will have little value in formulating a meaningful overall reliability program evaluation.

The proper planning and conduct of a survey will include the following:

(1) Formulation of objectives and establishment of scope
(2) Selection of a team
(3) Advanced team preparation
(4) Conduct of survey visit
(5) Utilization of findings

These elements are discussed in the succeeding paragraphs.

(1) Objectives and Scope.—The objectives and scope of the survey may vary widely, depending on the overall project situation in question. However, if a balanced evaluation effort is assumed, one of the most self-defeating

errors a survey can make is to try to cover a broader scope of investigation than its resources (time and manpower) can support. Careful consideration should be devoted to selection of objectives. In so doing, it is perhaps better to plan to limit the scope of investigation to permit the vital areas of current question to be covered thoroughly at the expense of some desirable-but-not-essential areas than to plan a scope of effort that will cause the team to be pressed for time. In the former case, at least the immediate objectives of the survey can be assured, while, in the latter, the result may well be a "diluted" coverage which fails to achieve the desired insight into the essential problem areas.

If available resources will not give even adequate coverage to all areas considered essential, a trade-off decision must be made wherein some of the less vital of these "essential" areas should be deferred for a future survey. The benefits to be derived in being thorough in the most vital areas will usually make this course worthwhile. On the contrary, a survey effort that is "spread too thin" will often fail to identify both the obvious program weaknesses and those that the contractor may be attempting to gloss over.

(2) Survey Team Selections.—The manning of the reliability program survey team will vary with a number of considerations, the limiting factor in most cases being the availability of required personnel. This constraint will place a natural ceiling on both survey team size and practically achievable survey frequency. However, the limitation of team size, by itself, is not particularly detrimental if the personnel used are of the proper levels of competence. This competence not only must cover the particular technical specialties required, but the members must also be well grounded in the fundamentals of the research and development (R&D) process and astute in recognizing application of these fundamentals in the day-to-day workings of an industrial organization engaged in sizable R&D aerospace projects.

This background is essential for enabling the surveyor to know where to look for objective evidence of the manner of accomplishment of a program task and is the foundation for the insight necessary to recognize the true signs of an effective or ineffective effort. It follows, therefore, that in the selection of personnel for the survey team greatest emphasis should be placed on this overall competence rather than on the job title of the individual's position. Assuming that appropriate basic technical specialists are not left out, the composition of the team may include personnel from quality, test, project engineering, etc. in addition to reliability assurance personnel.

(3) Survey Preparation.—In order to provide for fully productive use of the time spent by the survey team in the contractor's facility, it is essential that a thorough job of preparation be accomplished before the team sets out. The individual team members should have a firm grasp of all pertinent background information including the following:

(a) Contract requirements for reliability and quality assurance (R&QA)

(b) Pertinent task requirements in the original and the current RPP

(c) The manning of the tasks and the organizational interrelationships of personnel responsible for their accomplishment

(d) The content and status, as practicable, of the contractor's technical reports on the particular task areas in question

(e) The content of reports by resident monitoring personnel on the task areas in question

(f) Pertinent project factors or developments (funding, schedules, priorities, special problems, etc.) which result from or bear on the reliability program.

Each member should then chart his own survey plan to obtain the information desired in the areas selected for his special investigation, and either the chairman or the team as a whole should lay specific plans for obtaining required data on overall aspects of the program. This specific planning should include consideration of what areas and data will be observed, which individuals (by job assignment) will be contacted, and what lines of questioning (and, to some extent, which specific questions) will be pursued. To this end, the team member may make up his own checklist or may modify some standard checklist to his purpose. Most of the task area treatments in chapter 5 of this text contain pertinent questions. In addition, other documents, such as references 3 and 4, include, among other things, checklist questions from which the surveyor may draw. However, in the case of any checklist question, judgment type answers to the questions are meaningless unless the surveyor is in fact competent to make a sound judgment in the particular area in question. Accordingly, where there is doubt, the surveyor may elect to orient parts of his own survey solely to the collection of facts which can be better evaluated and judged later in connection with findings of other members of the survey team.

(4) Conduct of Survey Visit.—An intensive discussion of conduct of the survey in such aspects as detailed planning, psychology of interviewing, operational detail (security clearance, physical routing within the plant, etc.), entrance and exit interviews, and specific formal reporting is beyond the scope of this text. However, some basic considerations are worth mentioning.

It is of paramount importance that the survey be conducted in a well-organized fashion to obtain the information it seeks in a thorough but efficient manner. This not only facilitates an effective survey effort but also ensures that the survey team causes the minimum practicable interference with the contractor's project effort, consistent with survey objectives. To this end, the survey itself should be scheduled, and effort should be made to adhere to the schedule by avoiding "interesting," though not directly applicable, digressions—particularly those suggested by the contractor. However, schedule adherence should never be used as an excuse for stopping the pursuit of pertinent data if this is found to require more time or effort (within reason) than originally anticipated.

(5) Utilization of Findings.—In a number of respects, the proper utilization of survey results must be a corollary to the basic function of the survey and its initial planning. It should suffice here to state that the survey has the primary purpose of aiding in the evaluation of the contractor's reliability effort (to guide corrective action where appropriate). It also serves a secondary purpose of detecting where the reliability monitoring and evaluation effort requires reorientation, further study, or strengthening. Accordingly, the results of the survey should be reports that document findings and recommend appropriate actions.

Special On-Site Evaluation Studies

In the overall evaluation program it will be necessary to make a detailed study of one or more aspects of the contractor's reliability program or of some of the tasks which the reliability program monitors. Examples of such areas are the failure-reporting system, the design specifications, the failure mode, effect, and criticality analyses (FMECA), and qualification status of hardware. Normally, a study of this type is primarily done to assist the contractor in putting the area in question in good order, rather than being limited to fact-finding and evaluation. Frequently, these studies will require a temporary residence in the contractor's facility for several weeks or a longer overall period involving time at both the plant and the NASA center.

This type of effort concentrates on correcting weaknesses and on showing the contractor how he himself can conduct a better task or program. It should therefore be strongly favored by the evaluation group wherever applicable. Personnel involved need not be solely from the reliability assurance area; where manpower is limited, the use of contract effort by an independent study team may be considered to augment the special study team.

Evaluation and Followup

The final form of evaluation participation by the personnel at the NASA center is both technical and managerial. It involves not only the integration of all the reliability inputs into a coherent picture and the judgment of the extent to which that picture fits current project needs, but also the more difficult judgment and recommendation to the NASA project manager of the appropriate action to take. Many of the factors involved in these functions are discussed at various places throughout this text, but these can only serve as guides to the overall evaluation. Assuming reasonable resources and support, the ultimate success of the evaluation effort will depend primarily on the effectiveness of those directing it and their realism, astuteness, and industry in approaching the evaluation of the reliability program in terms of the overall project situation.

DELEGATION OF EFFORT

All reliability program evaluation effort must either be performed by the NASA center, be contracted, or be delegated. Although delegation of efforts may possibly be debatable from a theoretical viewpoint, practical requirements of most contract situations will make it advantageous to delegate as much of the evaluation effort as can be done meaningfully. This last qualification—that it be meaningful—is an essential one. Delegation beyond this extent is one of the chief causes of a poor overall evaluation effort.

Potential delegates fall into three broad categories:

(1) On-site field representatives of government agencies other than NASA
(2) NASA plant representatives
(3) Independent study contractors.

The status of the first of these differs rather sharply from that of the last two in that the latter are under close control of the NASA center, while control of the former is a much more formal matter. There is also a general difference in the levels and types of personnel, but this may be less true in some specific cases. The net effect of these factors is that they will strongly influence the number and types of tasks that can reasonably be given to each type of delegate.

The basic rule for delegation of reliability program evaluation tasks is that no group should be given an assignment beyond its technical capability, manning ability, or willingness to execute as delegated. Other considerations are duration of prior residence, spectrum and levels of technical talent available, nature of prior functions as an organization, motivation and astuteness of individuals, and a willingness not only to accept, but to perform delegated functions as required for NASA purposes. Because of this variability, the only valid guide for reliability program monitoring delegations is to make a thorough prior investigation of the case at hand and judge on that basis what can be delegated beneficially and to whom it should be delegated.

Liaison

One of the basic considerations in delegating tasks under the reliability program evaluation effort is that the delegate becomes, functionally speaking, a member of the NASA team. Although his function may not be a very large one in the overall team effort, it is an important one. To make him aware of this and to obtain maximum benefit from his services, it is necessary to establish a close rapport between him and the central NASA evaluation management. It is therefore important, when planning the delegation of any effort, to plan for the manner of liaison with the delegate. This also applies to individuals from the NASA center who may be on extended detail duty in the contractor's plant.

The importance of this liaison is much greater than is generally realized because it is the only effective defense (except reassignment) against the tendency to "go native," that is, the tendency to sympathize unconsciously to a progressively increasing (and inappropriate) degree with the contractor's problems and point of view as the period of residency in the plant extends. This is in no way a reflection on the integrity of these resident personnel, but an observation on the usual human reaction to a physically remote situation as compared with the reaction to the problems close at hand. A thorough program of liaison, with appropriate emphasis on the true dependence of the overall evaluation effort on a thorough and objective job by the delegates will serve both to keep their sense of identification with the "team" and to make them plainly aware of their importance in the evaluation effort.

NASA Plant Representatives

At first thought, one might view the NASA representatives who are resident in the hardware contractor's plant as the preferred group to handle all delegated reliability monitoring and evaluation tasks. This group is responsive to the NASA point of view, knows the project and contract effort intimately, and normally includes a number of technical personnel of respectably high levels of professional competence.

However, in practice it is rarely appropriate to try to assign all on-site evaluation functions to the NASA plant representative's office. In fact, except under special circumstances, only a limited number of reliability evaluation functions should be assigned to this group, and these should be carefully selected. The reason for this is the nature and perspective of the resident group's basic job, which relates primarily to functions of on-site contract management in those cases where delegation of these functions has been considered and found to be inappropriate. This normally dictates that they perform both business-type functions and certain technical tasks, the orientation of both being to act for the cognizant NASA center in matters involving the day-to-day operations of the contract effort where prompt on-site NASA participation is essential to smooth overall pursuit of that effort. Therefore, any reliability assurance tasks delegated to this group should normally fit the description of the basic mission of the resident representative's office. Delegated reliability functions outside this scope will frequently have to be relegated to a low-priority status, with the result that they cannot be accomplished in the keen manner required for purposes of the reliability program evaluating effort.

The foregoing general discussion of the resident NASA plant representative's office reflects the usual case for major contracts. For lesser contracts, there may well not be a resident representative's office, or it may not be able to justify more than a very few technical men on its staff. However, there are special cases in which, for sound management reasons, the resident function has been staffed in depth. Under such circumstances it is usually within the objectives of expansion of the resident representative's function, and very much in the interest of the NASA project reliability assurance function at the center, to include reliability and quality assurance specialists among the personnel of the NASA resident group. The number and extent of reliability program evaluation functions which should be delegated to this group will vary with circumstances. However, a good basic principle to observe in use of these personnel is to assign them the more vital of the delegatable evaluation functions. These might include reviewing some of the "for NASA review" documentation generated by the contractor (see NPC 250-1 ((ref. 1)), par. 1.6) or other tasks where higher levels of technical and project-oriented judgment are required. It should be borne in mind, however, that whenever project "emergencies" arise these personnel must perform as project men first and reliability assurance men second. Therefore, some flexibility should be provided by the cognizant Center both in avoiding assignment of too heavy a workload and in providing alternative evaluation support during emergency periods.

On-Site Government Agency Field Representatives

As used here, the term "on-site government agency field representative" means a government employee who is employed by an agency other than NASA to perform contract administration functions in a resident capacity in the contractor's facility. These government field representatives are probably the most universally available of all the potential reliability program monitoring sources. Normally, they handle a number of contract administration tasks, including inspection functions associated with the quality assurance effort. Their use as NASA delegates, in general, is established in basic government policy agreements, and there are detailed mechanisms and procedures for this use (see also NASA PRD 65-9, ref. 5). In the area of quality assurance functions, the use of these groups is governed by NASA quality publication NPC 200-1A (ref. 6). Many of the requirements and some (but not all) procedures of that publication for quality assurance functions should reasonably be considered as also applicable to the delegation of certain reliability program monitoring tasks to those agencies. Since that information is already available to the reliability program evaluator, this text will limit its scope to discussing the principal advantages, disadvantages, and necessary cautions attendant to the effective use of these groups.

Monitoring Functions

The principal area in which the government agency field groups can assist the reliability program evaluation effort is in monitoring of task outputs which are highly specific in nature. The variety of tasks in the reliability program will usually call for a sizable number of individual outputs. Although many of these outputs are not required to be delivered to the customer, each is needed for the program and must be completed on schedule (relative to other project events) to be fully useful. The government agency group is very well situated to monitor this area and can report on whether items were issued and whether they were issued on time. They can also report on whether review meetings were held, who participated, and whether reports were generated within prescribed time limits.

Other assignments might include (1) monitoring of testing, (2) monitoring of proper maintenance of equipment logs (which may come under the quality assurance delegation), or even (3) judging adequacy of some reliability task outputs if a standard which clearly describes the demarcation between adequacy and inadequacy can be provided.

There are also other areas in which the advice of the delegate on appropriate aspects of the contractor's reliability effort is valuable as one of the inputs to the overall evaluation. However, much of the technical evaluation of a contractor's reliability effort must involve NASA project trade-off decisions and is therefore not appropriate to delegate. Other items which are basic NASA responsibility and which should not be delegated include final judgment on acceptability of program plans, test proposals, or other cost-type items.

Reliability Study Contracts

One rather versatile means of augmenting the evaluation of the contractor's reliability program is the reliability study contract. Although the study contractor cannot be used as a monitor of contract compliance as such, he can be used to make studies, in-plant observations, and analyses in the role of an advisor and consultant.

In order to perform the functions envisioned here, the contractor must be a bona fide independent study organization, that is, one which is not affiliated with an aerospace hardware contractor. Although extenuating circumstances have permitted the existence of a few exceptions, it is an almost mandatory rule that selection be limited to independent contractors in order to preclude conflict-of-interest problems.

One basic approach for the reliability contract study is to direct it toward analysis of the design, essentially as a basis for an independent reliability assessment. Another approach is to use it as an independent search for sources of unreliability through analysis either of the design itself or of the integrity of the procedures and controls used in the design and development of the hardware. The study contract must be oriented toward predefined objectives and tasks which fill a specific need identified in early planning of the reliability program evaluation effort. Also, although it will normally be performed within the hardware contractor's facility, it should be conducted with minimum interference with the hardware effort.

The study effort may be used in part to assist the hardware contractor to improve his reliability program or to assist the NASA evaluator in specific areas. However, it should not be used as a roundabout means of obtaining extra personnel to fill needs "as they arise" or as a substitute for a properly managed reliability program evaluation effort.

Depending on program needs and the objectives of the study, the "search-for-unreliability" type of contract might study one or several of the following areas:

- Reliability and quality assurance programs
- Design
- Fabrication
- Test and checkout
- Handling and shipping
- Launch operations

Sources of potential unreliability within these areas with which the study might be concerned include:

- Mission profile factors
- Potential failure modes
- Procedures and interfaces
- Other human-error sources
- Implementation of procedures
- Program and configuration controls
- Program communication and feedback

Usually, when the study is oriented toward searching out potential sources of unreliability it is highly desirable to utilize a rapid, informal reporting method to facilitate the initiation of early corrective action where weaknesses are found.

Some advantages of using reliability contract studies are listed below:

(1) Reliability contract studies enable the evaluation effort to buy the services of a team of specialists in the required areas on short notice and for a definite period of need. Thus, where specific reliability-critical problem areas requiring technical study in depth can be identified, the reliability program evaluation function can use the study to obtain proper coverage when NASA center specialists cannot be spared for the job.

(2) Once the contract has been executed and the contractor's charter is clearly established, he is in a position to study, observe, evaluate, and report directly and promptly to the contract supervisor with a minimum of organizational red tape within either the organization of the customer or the hardware contractor.

(3) Usually, the study contractor's self-concern for maintaining his reputation motivates him to perform to high standards of objectivity and competence.

The use of study-contract assistance has its attendant problems. Some of these are as follows:

(1) Contractors must be selected very carefully. Not only must the contractor be well qualified as a firm, but the team of specialists he provides must be well qualified and well managed. Otherwise the advantages of the contractual study are largely negated.

(2) The study contract is a cost item that must be financed with project funds. It must, therefore, be justified in advance and must compete with other project needs for its funding.

(3) Contractual assistance in advisory areas must be used cautiously. The NASA evaluator must be careful to employ the contractor's findings as one of the inputs to the overall NASA evaluation rather than simply to let them become the complete evaluation.

The final decision as to the use of a study contractor, like so many of the other elements of reliability program evaluation, must be based on a trade-off of considerations involved in the situation in question. However, the study contract approach does merit consideration wherever it appears that the sum of the other available evaluation resources cannot effectively cover all necessary areas of reliability program evaluation.

RELIABILITY EVALUATION IN SMALLER PROGRAMS

The foregoing paragraphs in this section have presented the uses of all potential evaluation resources and described a rather complete and sophisticated organization of the evaluation effort. The intent has been to show a relatively complete catalog from which the evaluator of any specific reliability program can select or adapt items to fit his program requirements and resources.

It should be recognized that for smaller projects and for some of intermediate size the total range of evaluation resources described here is seldom available. Further, many projects of this type do not have available at the NASA center reserves of reliability personnel and other technical specialists as large as those implied by some of the descriptions of NASA center evaluation functions. In such situations the evaluator must revise the approach to make maximum use of evaluation methods that have the most benefit on a day-to-day basis, with a limited use of the more formal and sophisticated approaches which require large levels of effort at periodic milestones. This revised approach should be extended directly, as much as possible, to the evaluation of subcontractors as well as of the prime contractor. Otherwise, the lack of resources to mount a large-scale formal evaluation effort may permit reliability program problems, particularly at the subcontractor level, to persist too long without detection.

CHAPTER 5

Reliability Program Elements and Their Evaluation

Chapter 3 provided a foundation for general criteria to be used in evaluating reliability programs. Chapter 4 gave detailed guidelines for NASA participation in, and monitorship of, these programs and provided an insight into a general technique for evaluating contractor operations. With such a basis, it is now appropriate to elaborate in some detail on the ingredients of an adequate reliability program and to discuss the application of these general evaluation principles in assessing the individual tasks of contractor reliability programs.

This chapter describes the character of individual elements that should be considered for implementation in contractor reliability programs. Each reliability program element is discussed in terms of its contribution to the the project, the responsibilities of the contractor in providing the element, and how and to what level the evaluation must be carried in order to make a satisfactory judgment of effective contractor implementation.

In applying this information to particular projects, the NASA evaluation personnel must be cautioned to treat this material as guideline information which shows the thought process necessary to develop a sound evaluation technique; it is not a substitute for adequate specific interpretation of project requirements.

5.1 RELIABILITY PROGRAM AND ITS ELEMENTS

Relationship to System and Mission

The overall objective of the reliability program is to help improve the capability of the system hardware (and software) to accomplish successfully the space mission for which it is developed. Therefore, one of the prime concerns in each reliability program task area is the assurance not only of the adequacy of performance of each component and subsystem as a separate unit but also of the integrity of the functioning of all of them together as a complete system. Further, the system concept cannot be limited to the consideration of launch vehicle, spacecraft, and associated ground and test equipment (of an immediate nature); it must also extend to the area of mission operations wherein the spacecraft (and to a lesser extent, the launch vehicle) is tracked, commanded, and controlled from earth, and data are received and reduced. This latter area involves its own equipment, much of which is not limited in its use to the support of any one project or mission. It also involves heavily the use of operations personnel and software (computer programs and various procedures).

Obviously, hardware, communications, or human failures in the mission operations system can conceivably be as fatal to accomplishment of the space mission as failure of the spacecraft itself. Therefore, the reliability program must operate with an awareness of the mission system as a whole (flight hardware system and mission operations system). Although the flight hardware contractor may not have responsibility for building or operating the mission operations system, his project effort, including his reliability program, must be planned and conducted to take into account the capabilities and limitations of that system. Moreover, the project personnel (including reliability personnel) at the NASA center must give particular attention and support to this vital interface, and the reliability program evaluation effort must give appropriate attention to this aspect in the evaluation of the contractor's reliability program.

Elements of Reliability Program

Although a proper evaluation of the contractor's reliability program must take an overall system and mission viewpoint, the evaluation is most feasibly approached through consideration of the separate elements and interfaces of the hardware and the treatment of these and their synthesis in separate reliability program tasks or elements. These tasks are divided here as follows:

(1) Reliability program management
(2) Training and indoctrination
(3) Subcontractor and supplier control
(4) Design specifications
(5) Reliability prediction and estimation
(6) Failure mode, effect, and criticality analyses (FMECA)
(7) Human engineering and maintainability
(8) Design review program
(9) Failure reporting and correction
(10) Standardization of design practices
(11) Parts and materials program
(12) Equipment logs
(13) Testing and reliability evaluation.

Documentation of the reliability program is not considered here to be a separate element of the program as such. Rather, it is recognized that each of the elements listed above requires documentation for transmitting the results of work performed in the element, for technical record purposes, and as an internal tool for the project. Some factors to be regarded concerning the proper perspective for viewing and evaluating the function of program documentation are given in the concluding section of this chapter.

The attributes of effective implementation of each of the above-listed elements will be discussed in the succeeding sections, along with the principles for the monitoring and evaluation of each element by the customer. Incorporation of these details into a general program-evaluation approach, staffed and managed in accordance with the principles discussed in the preceding chapter, should result in an effective reliability program evaluation.

5.2 PROGRAM MANAGEMENT

Management Structure and Responsibilities

Where complex hardware systems are being developed, a loosely organized reliability effort is inadequate for obtaining successful reliability assurance. Therefore, it is necessary to organize all reliability support functions into a coherent program and to provide that program with its own control and management. The function of reliability program management, as with any management function, is basically as follows:

(1) To develop the necessary program planning
(2) To establish, operate, and control the organization responsible for implementing the program
(3) To monitor and ensure effectiveness of the program.

Since the purpose of the reliability program is to support the project, the reliability program management function will normally report directly to the overall project management. In this way it can best provide timely inputs for effective project decision-making. The responsibilities and authority of reliability program management should be clearly specified in authoritative project management directives and in a reliability program plan (RPP). Ideally, the RPP should be issued as a formal project instruction and clearly cited as the governing document for reliability program implementation. Elaboration of the responsibilities of the reliability program management element is as follows:

(1) Planning—the establishment of a workable reliability program plan, including the budgeting of manpower and resources, and scheduling of program support outputs in accordance with the anticipated best utilization by the project.
(2) Operation and Control—the development of an organization to implement the program plan, and control of the scope and procedures of that organization through program directives, meetings, and other techniques.
(3) Program Monitoring—the continuous monitoring of reliability program costs and effectiveness, and feedback of results of this monitoring effort to ensure that the program is providing maximum support in proportion to the resources available.

Normally, a management structure will have been agreed upon by NASA and the contractor during contract (or reliability program) negotiation. Revisions to the original reliability program management structure may be required as the program progresses and as project situations demand changes in program emphasis. At all times the management setup should be one that will provide best control of the program and maximum input to the project management, rather than one dictated by less practical considerations (regardless of how good they may seem in theory).

Regardless of its structure, reliability management must take the initiative in providing status information to project management; it must keep current with the effectiveness of its support program and must transmit information to the project with appropriate authority when hardware conditions or operations that have an adverse effect on mission reliability are detected. Above all, the reliability program covers a wide diversity of tasks, many of which are not under the direct control of the reliability program manager; it is therefore all the more important that the reliability program management be as strong and astute as possible to cope with those demanding responsibilities.

Evaluation of Management

Evaluation of effectiveness of reliability program management in steering the program and providing useful inputs to project management will normally be derived from evaluation of the individual reliability tasks. Such management weaknesses as lack of control or lack of sufficient backing by project management for important reliability support functions will be evident to the evaluator in his monitoring of the implementation of other reliability program tasks. Seldom can the evaluation be effectively accomplished by separating the management element from the reliability program and performing an independent assessment based on what theoretically comprises satisfactory management practice.

The evaluator should, however, ensure that the basic management framework of planning, control, and monitoring activities discussed in the previous section is specified in an RPP or project directive. He should review this plan (if he has not already been closely associated with its content) and determine the following:

(1) Whether the management responsibilities are clearly defined. Any vague general statements that prevent clear understanding should be documented and corrected.

(2) Whether a schedule of reliability program outputs keyed to major project-decision points has been established. This is the first step in maintaining a program that is oriented to project needs rather than one that operates independently as a mere academic exercise.

The contents of the RPP will then guide the investigation of each program element. During the evaluation of these elements, the evaluator should look for the following types of evidence to obtain a measure of management's effectiveness:

(1) Has management established all program elements called for in the RPP? If not, are the discrepancies between the RPP and established organization explainable by a proven lack of need at the time or by a lack of funds or personnel?

(2) Does the lack of any particular element constitute a recognizable loss of effectiveness of the program?

(3) Is reliability management making an effort to keep the program focused toward areas of maximum project need?

(4) Is there any indication that management has issued timely directives to revise procedures and responsibilities where a lack of program impact has been noted?

(5) Does it appear that reliability management lacks sufficient voice to project management in pointing out reliability problems? Is there a lack of recognition by project management of reliability problems, as compared with other trade-off and decision-making information at their disposal?

(6) Is there evidence that the various reliability subgroups lack a clear understanding of their interface with each other and with other contractor functions? Reliability management should provide a proper definition of responsibilities and establish communication links through meetings, memos, and informal personal contact.

(7) Do the personnel in supervisory positions maintain full schedule consciousness in all tasks within their responsibility? It may be necessary in many instances to lower the level

of detail of certain tasks in the interest of providing important information to the project when hardware decisions must be made. More specific details can often be added later.

(8) Is there a lack of formal or informal status reporting within the reliability organization by which reliability management can maintain close contact with all current hardware problems ?

(9) Has reliability management succeeded in creating an attitude that the reliability support function has value to offer to the project ? This attitude must, to a large extent, grow out of the daily performance of the reliability groups, but it is the overall responsibility of management. Techniques for creating this attitude through training and motivation are discussed in the following section.

This type of subjective evaluation obviously requires a continuous monitoring and appraisal, but it is the best approach for determining the real value of management operations from the standpoint of quality of performance, timeliness of action, and program impact.

It is difficult to measure management quantitatively in relation to cost effectiveness. While other reliability program functions can be eliminated when they are unproductive, a management function must always exist. Its value cannot be related to cost (except when it is obvious that an unwieldy, top-heavy reliability management structure exists). Rather, it must be continuously evaluated for its ability to project the importance of reliability into project operations and to direct the reliability assurance efforts toward providing maximum project support. When the reliability management function is effectively discharging this responsibility, its cost is justified.

5.3 TRAINING AND INDOCTRINATION

General Considerations

Reliability training is normally less dependent on project factors and is more a function of management decision by the customer than any other element in the program. The general NASA requirement for training, stated in NPC 250-1 (ref. 1), recognizes in principle a government responsibility to bear the cost of training in reliability problems peculiar to the project. However, in practice, a wide range of training efforts is encountered, largely because contracts are awarded on the basis of many factors, of which reliability management qualification is only one. When the selected contractor is considered weak in some areas of reliability program capability, customer project management will often elect to fund the cost of strengthening these areas through appropriate training or to sponsor motivational indoctrination.

Accordingly, the reliability program evaluator must guide his judgment of the contractor's training effort primarily on the basis of the following:

(1) Determining the scope of training requirements stated in the contract

(2) Determining whether effort expended within that scope is effective and efficient

(3) Recommending changes in that scope based on very clear indication of training needs evidenced by overall reliability program performance (or the need to prune an ineffective training effort from the reliability program).

Training Program Requirements

The training element of the reliability program is one that falls in the category of a management function in that it is separated from the mainstream of project planning and control activities. It should be directed toward educating appropriate employees in special techniques in the technical disciplines involved in performing reliability tasks and educating other appropriate employees to recognize the potential benefits of the reliability program to the project. It should also be directed toward motivating all program personnel in the importance of designing and manufacturing reliability into the hardware. Because of the varying groups of personnel and disciplines within the contractor's facility, this activity must be approached on a fairly broad front, with each facet of the training program specifically tailored for the group involved. It should be emphasized, however, that a training program must be both selective in the number and type of trainees involved and cost effective in the value received from the total training expenditure. The approaches to training of the principal groups are discussed in the following sections.

Systems Engineers

Training of systems engineers (and project engineers) should focus primarily on the use of the reliability program as a means of effecting discipline from a system-wide technical management viewpoint. It should emphasize those tasks and aspects which contribute to (1) basic system planning (e.g., reliability review of mission profile studies and design specifications; FMECA), (2) control of interfacing between units, (3) system trade-off decisions, and (4) analysis and assurance of the design from the viewpoints of the system and mission as a whole.

Design Engineers

Training of design engineers should cover briefly the same areas as that for system engineers. However, it should place primary stress on the benefits to be derived from proper integration of reliability task outputs into the design-development effort, particularly at the hardware unit levels. By recognizing the past lack of acceptance by design personnel of some support-group inputs to the design function, the training should aim at showing graphic and convincing ways in which the reliability task output can be of material assistance to the design effort. (Such areas as FMECA and proper parts application are of particular interest here.) It should also be quite frank about the limitations of the usefulness of these outputs.

Reliability Engineers

The training for reliability engineers should be aimed at teaching the use of new or special techniques required by the project in such areas as mathematical modeling, reliability block diagramming, redundancy analysis techniques, circuit design analysis, or failure mode, effect, and criticality analysis. It should not be directed toward teaching so-called specialists the rudiments of their own area. This training may be designed around existing text material, if such is available, or around manual material especially written for the project at hand. This should be augmented with instruction by reliability engineers experienced in application of these new techniques in order to enable the trainees to absorb and apply them promptly.

The selection of participants in this training should be limited (in most cases) to employees actively engaged in reliability engineering and, furthermore, should be directed to those of lesser experience who can be expected to benefit from it. In some cases, design engineers working directly with reliability problems might also be included, particularly in such areas as failure mode, effect, and criticality analysis.

Management and Administrative Personnel

For the contractor's management personnel and for select administrative personnel in pertinent functional areas, the reliability indoctrination approach should stress the same areas as for design and systems engineers. However, the treatment should be more concise and less technical. It should also emphasize economic aspects and the contributions of the reliability program to, and its interfaces with, other areas of the contract effort as a whole.

Motivational Material

The motivational material must provide an effective message to all plant personnel, both production workers and those in the various professional activities, emphasizing the role of each in helping to assure project success. Typical techniques include a program of movie and slide presentations, periodic lectures, periodic leaflet handouts, and posters. To be effective the motivational program must be dynamic. The material (particularly posters) must be frequently changed to provide a continuously fresh outlook on the reliability problem, in order to focus attention on situations applicable to the project while generally retaining an air that reliability is everyone's job.

Evaluation of Reliability Training

The evaluator should be concerned from the outset with determining whether the training program is providing a useful service to the project. The reliability educational and motivational program can be a valuable asset if it aims a particular message to the groups of people most in need of being informed.

It is important to the efficiency of the reliability training effort that selection of personnel for training be made properly, particularly that of those to be exposed to technical reliability engineering material. The evaluator should carefully examine the contractor's trainee selection technique and ascertain that the candidates for technical training are of the following types:

(1) Personnel performing or utilizing results of a reliability engineering task
(2) Personnel of lesser experience in the application of the reliability discipline who will derive maximum benefit from exposure to the training program.

These qualifications are cited to emphasize to the evaluator the inappropriateness of training programs in which trainess are already uniquely qualified in the conduct or use of reliability support work or where they are selected for technical reliability training even though their project areas do not interface with the reliability support effort.

In summary, the basic elements of the assessment of the reliability training effort are determinations of the following:

(1) Are the contractor employees receptive to the training material or do they seem to take it very lightly? What are their attitudes?
(2) Does some of the course material appear to be more valuable than some other? Attempt to rank the value. Are some important subjects being overlooked? Are others overemphasized?
(3) Do the employees appear to have benefitted from the training; that is, is there any apparent difference in attitude toward usefulness of the reliability tasks or in job proficiency between "trained" and "untrained" personnel of an otherwise comparable level?
(4) Has the contractor selected personnel for formal reliability training based on their need for further education?
(5) Is the contractor providing the best program at minimum cost, or are some needless efforts being expended?

After making these judgements, the evaluator should determine if modifications can be made, considering the time remaining and the contribution of such modifications to program improvement. Budget, of course, is always to be considered; it may prevent changes that would provide improvement. However, decisions based on budget alone should ultimately be made at a higher management level.

5.4 SUBCONTRACTOR AND SUPPLIER CONTROL

Contractor Requirements

Because of the large number of subcontractor-supplied components and subsystems that accompany nearly all space programs, the prime contractor's reliability program must provide controls for assuring adequate reliability of this "bought" hardware. Reliability assurance in this area is exercised through the following:

(1) Selection of subcontractors from the standpoint of demonstrated capability to produce a reliable product
(2) Development of adequate design specifications and test requirements on the subcontractor-produced product
(3) Development of proper reliability and quality program requirements to impose on each subcontractor
(4) Establishment and maintainence of close day-to-day technical liaison with the subcontractor (both in design and reliability areas) in order to minimize communication problems and to facilitate earliest identification and correction of design problems of an interface or interrelation nature
(5) Continuous review and assessment to assure that each subcontractor is implementing his reliability and quality assurance programs effectively.

Reliability assurance requirements must be imposed on subcontractors and suppliers on the basis of criticality of the hardware item being supplied. Similarly, the depth of these requirements should govern the amount of effort expended by the contractor to assure that the subcontractor is performing his reliability assurance function adequately.

Where suppliers of major components and subsystems are concerned, the prime contractor must evaluate each subcontracted item independently to determine the extent and type of reliability program needed. He should then impose appropriate reliability program requirements on each subcontractor so as to provide reliability assurance in these areas of need.

Each major subcontractor is required to submit a reliability program plan, and the contractor must monitor the subcontractor's implementation to assure compliance with the plan and to assess the timeliness and adequacy of individual tasks as the project advances. The subcontract must contain surveillance entrees to permit this. This procedure places the contractor reliability group in a situation very similar to that of the NASA center with regard to monitoring and evaluating reliability program performance. Therefore, the methods and procedures described in other subsections of this section, with regard to the manner of performing the monitoring and evaluation of various program elements, apply to the contractor-subcontractor relationships in the same way that they apply to NASA evaluation of the contractor's program.

The assurance of reliability of parts and components not formally classified as "major" must rely on the controls imposed through the contractor's quality assurance program. Decreased emphasis in this area is dictated by obvious economic considerations.

Evaluation Techniques

In assessing the contractor-subcontractor relationship, the NASA evaluators must proceed in view of the similarity of this relationship to the NASA-contractor interface. Their evaluation of the contractor's effort in this area should be concerned with four basic items:

(1) The appropriateness of the reliability and quality requirements imposed on each subcontractor in light of the significance of the hardware item being procured

(2) The degree of (informal) technical communication existing between contractor and subcontractor counterpart personnel

(3) The contractor's program to monitor and evaluate subcontractor reliability efforts, with particular emphasis on the apportionment of the contractor's effort within this area

(4) The contractor's procedure for monitoring and evaluation of the subcontractor

Although item (1) will usually have been agreed to in basic form in the NASA approval of the contractor's Reliability Program Plan, it should not be dismissed in the evaluation, since misjudgments sometimes occur in initial planning and other factors may also dictate changes.

Item (2) is of particularly great importance, since a constructive effort here of adequate scope can do much to preclude, or at least minimize, the seriousness of deficiencies in items (3) or (4).

With regard to item (3), the evaluation can adapt and use the basic guides presented in chapter 4 as they would apply to a contractor-subcontractor relationship.

Finally, the NASA evaluator should ascertain that the contractor is monitoring and evaluating each subcontractor reliability program element in a manner similar to that specified in the various portions of this section. Where there is doubt of the effectiveness of the prime contractor in guiding and monitoring the reliability efforts of his subcontractors, particularly of major subcontractors, the NASA evaluation program should give consideration to a first-hand evaluation of the subcontractors in question (assuming that adequate entrees exist).

It is important to recognize that the evaluation of reliability assurance effort on subcontracted items must be made in the perspective of a net project-oriented trade-off rather than as a distinctly separated "reliability" activity. The reliability program evaluator must, therefore, consider his immediate evaluation to be of greatest significance as one of the inputs to the NASA project management evaluation of the overall subcontractor area. Its contribution to the evaluation of the contractor reliability effort, by itself, is secondary.

5.5 DESIGN SPECIFICATIONS

Contractor Requirements

For the ultimate achievement of a reliable system it is imperative to assure the proper specification of all design parameters, such as environment, performance, and operation, as well as reliability requirements, at the earliest possible date. These must be specified first as they apply to gross mission functions at the spacecraft, launch vehicle, and mission operations levels; these are usually given in project definition documents. They must then be specified within each gross mission function (e.g., spacecraft) to spell out the functions of its subelements. It is at these levels (subsystem and black box) that design specifications as such must be generated to provide detailed design criteria for guidance to (1) contractor design groups and (2) major subcontractors. These specifications are the primary documentary link between the establishment of a mission and the design of system hardware. A design specification is the detailed interpretation of the mission in terms of characteristics that define the requirements the hardware must meet. Improper or poorly defined specification requirements can lead to a system that is incapable of performing the intended mission. Normally, poor specifications will result in redesign or "patch-up" of subsystems, a less-than-optimum design configuration, probable over-complexity, and subsystem interfaces that are inconsistent. In general, they will result in low reliability, not through limitations of design capability, but through failure to define the design problem.

Because of the vital role design specifications play in providing the basis for the design of reliable hardware, it is important that they be reviewed systematically by a group that is independent of those responsible for generating them. Ideally, the reliability group should have the system engineering and design engineering talent necessary to perform this function. However, in the many situations where it does not, the specification review task may rightfully be delegated to some other independent group possessing the necessary talent. Regardless of who is assigned this function, it is the responsibility of the reliability group to ascertain that an adequate specification review is performed. When the technical aspect of the review task is delegated, the reliability group should at least retain the role of monitoring and auditing to assure that an adequate set of specifications is being generated and updated as trade-offs are made at various project decision points.

Evaluation Considerations

The preceding discussion indicates that the NASA evaluation should determine that the reliability group is:

(1) Performing an adequate specification review and critique, or

(2) Monitoring the effort of a group that has been delegated the specification review responsibility.

Either method is acceptable if it results in adequate determination that each design specification is complete and is kept current and that the set of these specifications covers the entire system and its interfaces without omission.

The evaluator should be wary of a meaningless response to the requirement for a review function. One of the primary signs of such a response is the project situation in which the magnitude of the technical review task far exceeds the time and level of effort available. This type of situation usually forces a meaningless concurrence with the contents of the documents in the interest of meeting the project schedule. Use of unqualified personnel will provide a similar result. Additional evidence of this situation will be seen in a lack of any constructive critiques and recommendations from the reviewing group.

A distinction should be made, however, between the deliberately poor or indifferent response and difficulty encountered in a truly conscientious effort to keep up with a demanding task under heavy time schedule pressure. Normally, the dynamic project situation will not afford a "comfortable" amount of time for the review. It will therefore be imperative that adequate coordination be maintained between the specification initiator and reviewing group so that early drafts or portions of the specification will be made available for beginning the review early in the specification draft period.

The original subsystem design specifications can be expected to require revision, particularly during the early development phase as initial design decisions and trade-offs are made. Difficulties may arise in providing the originally established outputs of one subsystem within required design tolerances; this would necessitate revisions to the specifications for the interacting subsystems. Similarly, weight and volume trade-offs between subsystems are common and should result in specification revision. The evaluator should look for evidence of specification updating during the development period, particularly at major design decision points.

It must be remembered that the responsibility for final determination of technical adequacy of the contractor's design specifications is normally assigned to the systems engineers or design personnel in the NASA project manager's organization. This responsibility would include responsibility for judgment of the levels and tolerances specified for such parameters as signal levels, gains, mechanical stresses, and power requirements. The reliability program evaluator must rely on the systems engineers for assistance in judging suspected weakness in the detailed content of design specifications.

Additional points to pursue in the evaluation of the contractor specification review activity are:

(1) Is the contractor using qualified personnel to review and evaluate design specifications? This question can often be answered through personal contact between the NASA evaluator and the personnel in question.

(2) Does the specification review group follow an organized approach to its tasks (e.g., schedules and informal status reporting)?

(3) Is a design specification of sufficient detail drafted for every subsystem and major component (black box)? Does the specification properly state the inputs available to the subsystem, the output requirements, the environmental conditions under which it must operate (including overstress), other system interfaces, reliability goals, and maintainability goals (if applicable)?

(4) Do the review personnel take the initiative to consult with the design specification group in the early draft stage? Do the review personnel have an orderly method of consultation?

(5) Is there recognition by other project personnel that the specification review is worthwhile?

(6) Is there an effective means by which the project takes action as a result of nonconcurrence by the reviewing group?

(7) Is the review function responding adequately within the time constraints imposed by project schedule, assuring that the specifications contain current information in accordance with project developments and are updated as required by system trade-offs or mission revisions?

(8) Does the complete set of subsystem and component specifications describe adequately all the mission functions in the system in terms of environmental and performance parameters? (Or do significant omissions exist?)

5.6 RELIABILITY PREDICTION AND ESTIMATION

Contractor Program

The analytical reliability prediction from which numerical estimates of hardware reliability are made is one of the basic tools of the reliability program. However, this task can degenerate into a totally ineffective expenditure of effort—or even a serious liability to the reliability program—if the prediction results are not supplied to the project in a timely manner, if they are poorly done, or if they are improperly used.

Basically, reliability prediction provides quantitative estimates of the reliability of the system and its individual subelements. These "numbers" are largely based on a process of mathematical synthesis of failure probabilities from the subelements of that assembly, usually starting from the part level and continuing up to the system level. This buildup (model synthesis) takes many steps, each of which involves assumptions. Assumptions are also heavily utilized in adapting generic failure-rate data to a specific project and mission (to apply in the model). As a result, the numerical prediction of system reliability provides only a broad estimate of the reliability of system elements.

On a comparative basis, however, the numerical indices can usually be quite useful in determining the reliability of one system element relative to that of another or in determining the reliability status of the system at one time in the project cycle relative to status at a different time. Because predictions can identify weak areas of the design and, furthermore, can quantify the weakness of one system element relative to that of another, they can serve a number of functions, some of which are:

(1) Helping to guide the selection of one design approach over another (at the conceptual phase)

(2) Guiding apportionment of corrective design effort

(3) Serving as one important criterion for the decision on the extent to which it is necessary to employ redundancy in the design

(4) Determining the need for additional test information, changes in test procedure, and changes to test intervals.

As input data to the prediction become more refined and more confidence can be placed in the actual quantitative prediction results, the prediction can acquire usefulness as a decision-making tool for higher-level decisions such as whether to commit the system to launch.

One of the most important keys to effectiveness of the prediction task is timeliness. Since the design-development process for the hardware is basically iterative in nature (see the section entitled "Timeliness" in chapter 3), the reliability prediction process must also be iterative to support each of the decision points in the design-development process. Furthermore, the prediction must be updated periodically, not only to reflect design trade-offs made at each decision point but also to replace generic and estimated failure-rate data with specifically applicable data as they are evolved from the project testing program.

The reliability prediction for all parts of the system, including those procured under subcontract, should use compatible prediction techniques; that is, the same basic ground rules must be used for selection of such data as part and component failure rates, environmental and stress factors, and mathematical modeling approaches. The use of compatible ground rules is necessary for the prediction results for each system element to be compared with those for the other elements on a common basis.

The contractor's reliability program plan should call for early initiation of the reliability prediction and estimation element, with an initial schedule for periodic updating based on the initial schedule of decision points in the development process; and these prediction schedules should be revised as changes in project schedules occur. Furthermore, prediction efforts should be performed in synchronization with design progress. Not only should the prediction results be provided formally prior to the design reviews, but the reliability personnel should work closely with design personnel informally on a person-to-person basis when making them. Recommendations for system modification to improve reliability can thereby be available for consideration at the time of trade-off decisions, instead of being too late to be of significant value.

Evaluation Considerations

Since the key factor in measuring the effectiveness of the prediction effort is timeliness, the evaluator should first look for a formal prediction schedule in the reliability program plan that is keyed to the overall project development schedule in such a way that prediction results will be available in time for consideration at major design-decision milestones. He should be careful to recognize the situation in which prediction tasks are being performed according to a schedule in the original RPP that has subsequently become obsolete because of changes in overall project schedules or because of unforseen problems.

Not only must the evaluator be concerned that the contractor is conforming to a schedule of prediction efforts and that this schedule is kept current but he must also determine whether the comprehensiveness of each separate prediction is appropriate to its intended use. Since early predictions are tools for assessing gross weaknesses in the design, it is not necessary at the early prediction stage to make elaborate analyses (such as performing detailed calculation of those failure modes considered to have minor effect on mission success or waiting for data to provide unnecessarily accurate failure rates and environmental and stress factors). Instead, a gross prediction will often suffice as a preliminary design decision input and may be necessary to enable it to be used (because of schedule pressure). It will at least result in early determination of the most unreliable subsystems and suggest those areas which bear further immediate investigation. The evaluator should look for this type of early program prediction effort. An attempt to provide the completely comprehensive prediction at the outset is often the reason for untimely outputs and is a natural result of poor coordination between design and reliability groups.

Where the necessary reliability/design coordination does exist, there should be indications that reliability engineers are accomplishing the following:

(1) Obtaining engineering drawings before their official release
(2) Sitting in, as necessary to their function, on early design meetings
(3) Providing early advice on areas where reliability can be improved
(4) Obtaining a feel for the depth of analysis required at the next decision point.

This kind of evaluation can best be accomplished by interviewing reliability and design engineers separately with questions such as those given below which depend on existing project status.

Questions for the reliability engineer are:

(1) Are you making (or have you made) a reliability prediction on the "blank" subsystem? Can I obtain a copy of the prediction analysis for the most recent milestone?
(2) Was the original design concept within the preliminary reliability allocation? If not, what recommendations were made for improvement?
(3) Was your prediction considered in the preliminary design review, and were design changes made as a result of it? With the understanding that trade-off decisions may result in no reliability improvement changes being made, what were the reasons for your recommendations not being incorporated, if such was the case?
(4) Are you continuing to review design changes for their effect on the latest prediction?
(5) Is there coordination between the reliability and design personnel in advance of all design changes? Who is responsible for seeing that such contact is initiated?
(6) Do you review the final drawing change release to determine whether it contains the same change as discussed in advance?
(7) Did you deliver the required prediction results at the previous milestone?
(8) If the prediction is still in progress, will the results be available in time to be considered by project management in the next design-decision milestone (such as the next design review)?

Questions for the design engineer are:

(1) Has your subsystem design been analyzed by the reliability group and a prediction made? If not, is a prediction in progress?
(2) Does the prediction work include all the latest design changes?
(3) Were you given any recommendations by the reliability group as a result of earlier prediction efforts, such as the use of redundancy and changes in design technique and components?
(4) Has the reliability group provided recommendations that are both practical and in time to be of benefit in design decision? Are you continuing to coordinate with reliability engineering as changes are anticipated?

Note that the above questions are all aimed at determining the impact on the project of the reliability prediction element through its timely application of supporting analyses. The evaluator should be aware that existence of a planned prediction requirement does not in itself justify unusually large manpower expenditures. The levels of effort for prediction, as for any other task, must be commensurate with a justifiable need.

Where the evaluator finds that little effort or progress has been made in the prediction of system reliability, he must determine whether to recommend elimination or curtailment of the activity, or, if the project is still young enough, to suggest increased emphasis or selectivity in the prediction effort. The originally anticipated needs of the project may no longer apply to the existing project conditions. Where a change is to be recommended, time is the critical factor. Since reliability predictions of certain critical subsystems may still be beneficial rather late in the program—particularly in support of test program decisions such as frequency and level of tests—selected prediction effort may be the best alternative.

Nothing specific has been said here concerning the evaluation of the quality of the prediction work in terms of appropriateness of analytical techniques selected or adequacy of their implementation. These factors involve areas such as construction of proper block diagrams and mathematical models, application of justifiable environmental and stress factors, and failure rate determinations. This evaluation requires astute engineering judgment that is best obtained from evaluation personnel whose specialty is analytical prediction and who are familiar with the latest applicable part failure sources and are backed up with adequate competence in the component and system engineering design areas. Their assistance should be used to determine that there is a consistency of overall methodology by the prime contractor and all subcontractors, that failure rate sources are compatible, and that selection and employment of the specific methodology for each prediction reflects good judgment and is technically sound.

5.7 FAILURE MODE, EFFECT, AND CRITICALITY ANALYSIS

Contractor Requirements

Companion to the reliability prediction element is the requirement to perform failure mode, effect, and criticality analyses (FMECA) of the system hardware. This task is another that must be iterative in order to provide design guidance during the evaluation of the hardware configuration. Together with the reliability prediction, the FMECA should provide the primary analytical reliability information for design and system trade-off decisions at appropriate program milestones. Although it is the objective of FMECA to identify all modes of failure within the system, its first purpose is the early identification of all first-order or catastrophic failure possibilities so that they can be eliminated or minimized through corrective design action at the earliest possible time.

The contractor should provide in the reliability program plan for an FMECA effort that is time-phased to correspond with the decision points in the development of each system, subsystem, and component. Individual analyses should be initiated as soon as preliminary design information is available on the hardware element in question. In order to accomplish this overall purpose, the contractor's reliability engineers should work with the design personnel on a continuing basis in completing the following tasks:

(1) Identifying system, subsystem, and component failure modes

(2) Identifying the effects of potential failures on the mission of the system (and relating the effects to specific portions of the system, such as launch vehicle, spacecraft, crew, or ground support)

(3) Determining probability of occurrence of each potential mode of failure

(4) Recommending appropriate corrective features such as redundancy, fail-safe design features, backups, and selection of more reliable parts

(5) Assisting in the formulation of test criteria selected in light of identified critical failure modes.

Frequently, it may be necessary and quite proper for the design engineer to assume the primary role in this analysis at the component level because of his complete familiarity with the hardware configuration, its operation, and the design technology area of the component in question. The role of the reliability engineer in this case should be one of objective and constructive co-participation. He should provide support in use of reliability analysis technique and offer an independent point of view on the criticality of failure modes and the most effective means of lowering their probability of occurrence (including elimination of them) through suggested changes in design or mode of operation. When making analyses of the subsystem, system, and mission levels, the reliability group should participate in the FMECA with the cognizant system engineering group or, if necessary, assume the responsibility for accomplishing the task itself (coordinating with the systems engineers as necessary).

The results of the FMECA should provide a guideline for design reviews to highlight all critical first-order failure modes and corresponding proposed design corrections for scrutiny by the review team. For potential failure modes outside the first-order category, the probability-of-occurrence data should be useful to project management in making trade-off decisions on the extent of effort and time to be invested in corrective action. Finally, the FMECA results should provide criteria for use by the contractor's test personnel in planning and designing tests for the system, particularly in such aspects as testing depth, test intervals, and stresses.

Evaluation Considerations

Probably the greatest single criticism of past FMECA's has been the limited application of their results for the improvement of system hardware. The chief causes of this limitation relate to the general considerations of quality, timeliness, and cost effectiveness discussed in chapter 3. Some of the specific ways in which these appear are:

(1) Failure to recognize that the FMECA must be iterative in nature, to correspond with the iterations in the design process itself

(2) Failure of the RPP to schedule FMECA outputs to correspond with scheduled design decision milestones in the overall project program plan

(3) Failure to keep the FMECA schedules current

(4) Late FMECA reporting

(5) Lack of confidence of design engineers in the value of the analyses and consequent unwillingness to use them

(6) Overemphasis by reliability personnel on comprehensive analyses at the expense of timeliness

(7) Use of analysis methods either too simple or too sophisticated for the requirement

(8) Inadequate implementation of the analysis method selected, or an isolated effort by analytical specialists without adequate technical input by knowledgeable design personnel.

The evaluation should start with the FMECA portion of the RPP. Here the evaluator should look for a functional schedule (oriented to project milestones) of FMECA's. This should provide for an analysis of each element of hardware down to the component ("black box") level at each appropriate stage in its development. For each of these analyses, it should provide a clear-cut description of the depth of analysis, its purpose, and the planned use of its results. The word "appropriate," as applied to the number of analyses and their depth, will depend on the system element being analyzed, its criticality in the system, and the nature and requirements of the system as a whole. Where there is doubt in the evaluator's mind in judging this "appropriateness," it is usually best to lean in the direction of more, rather than less, effort because of the potentially high reliability-achievement contribution of the FMECA task.

In monitoring the implementation of the FMECA task, the evaluator should first ascertain whether the functional schedule of FMECA's is being maintained. This may be done by comparing calendar schedules (past and future) of the FMECA's with the calendar schedules of development milestone events for the corresponding hardware elements. Not only should the original dates and the revisions on the two schedules correspond, but evidence should be obtained (from project documents, such as memoranda) that the changes in the FMECA schedules track closely in date of revision with those in the hardware schedules. One very meaningful way to determine overall timeliness of FMECA output is to determine whether it was included in the input data package (and in what condition) for the corresponding design review.

The second important aspect of the evaluation of the FMECA task is to determine the manner and effectiveness of communicating the problem areas discovered in FMECA for early design attention. In practice, this determination will be closely allied to the schedule determination (and that of effectiveness). In the ideal case, the reliability engineer will perform the FMECA jointly with the component design engineer (or systems engineer for FMECA at higher assembly levels). In this situation, the communication of findings, the attitude of design personnel toward these findings, and the question of conscientious corrective response to them will offer little, if any, problem. However, in many cases the reliability engineer, himself, will have to conduct the actual FMECA, coordinating closely with the design engineer (or systems engineer) to obtain design and function information needed in the analysis. In these cases, the reliability engineer should take the initiative, both to obtain this assistance and to communicate his findings as expeditiously as possible to his design counterpart (but not in lieu of formal reporting). The character and effectiveness of this working relationship can be best evaluated through interviews of the principals, by review of memoranda between the two groups, and by determining (through any other means available) the points in time at which initial corrective design consideration is given to FMECA results. Frequently, a detailed discussion between the evaluator and cognizant NASA project personnel can provide much useful information on this.

A sound judgement of the technical quality of FMECA outputs is difficult at best because each must be judged in light of the nature and criticality of the hardware element in question and the design milestone which the analysis at hand is intended to support. Therefore, the evaluator may frequently find it useful or necessary to obtain additional judgment from qualified personnel at the NASA center. These personnel include design and systems engineers for the project and FMECA specialists, who will collectively have the background experience in the pertinent design technology area, the applicable analytical techniques, and the intimate specific knowledge of the hardware necessary for a complete judgment. These personnel should review at least a representative sample (and hopefully a large porportion) of the FMECA reports as they are generated and should provide comments to the evaluator on the contractor's performance.

The overall effectiveness of the FMECA task can best be assessed through observation and analysis of the test program (see section entitled "Contractor Requirements") and the design review program. However, this should be used as a complement to, but not a substitute for, other aspects of the evaluation of FMECA. The uses of design review as a vantage point for assessing timeliness of FMECA and for following up on corrective design action have been mentioned earlier in this section. The functional roles of the FMECA task and the design review task are closely allied. The FMECA, on the one hand, identifies first-order failure modes for vital corrective design action and gives probability-of-occurrence data to guide trade-off decisions on the correction of less critical potential failure modes. On the other hand, the design review program reviews the adequacy of these decisions and actions and the logic on which they are based. For this reason, the formal FMECA report at each milestone is particularly important as a design document. Also, when examined together with the design review report, it is a prime indication of effectiveness of the FMECA. The evaluator, should, therefore, devote appropriate attention to the formal as well as to the informal outputs of the FMECA task.

In summary, the FMECA task is potentially one of the most beneficial project contributions of the reliability program. To be effective it must (1) competently detect, analyze, and evaluate all significant failure modes at each pertinent hardware level and milestone, (2) report its findings in time and form to be of use at corresponding project decision points, and (3) be recognized for its value and be employed effectively in improving the mission system. The evaluator's concern will be to ascertain through evidence (or absence of evidence) the degree to which these functions are being performed.

5.8 HUMAN FACTORS AND MAINTAINABILITY

Contractor Requirements

One of the most significant areas for potential mission failure or performance degradation is the interface between people and machines. In order to provide for reliability assurance in this area, the contractor is required to give careful consideration to the elimination of human induced error, particularly in the areas of maintainability and serviceability, throughout his activities of design, development, and operational use of the hardware.

The extent of effort and sophistication of approach used in this area will vary with the significance and magnitude of the project and the nature of the hardware item (e.g., whether or not it is man-operated). However, the basic approach to assurance in this area is essentially the same in all cases:

(1) Break down the mission to be performed into functions.

(2) Select concepts of hardware to perform each function. In this process, decide which functions will be automated and which will be manned. Also, at this time establish basic maintenance and servicing concepts.

(3) As the design and development progresses through each stage, analyze further to bring the maintainability, serviceability, and other human factors requirements into sharper focus.

(4) As these requirements are identified, respond to each throughout the development effort by providing accessibility for maintenance and simplification of activities (operation or checkout) so that they can be performed with a minimum of stress or confusion to the operator, by designing equipment to reduce the opportunities to misuse or damage it, by devising procedures which are clear and effective in directing activities without error, and by using other measures of a similar nature.

The functions described above are likely to be encountered as distinct, separately identifiable efforts on large programs or on those where major system functions are performed by human operators. However, they must also exist, though possibly on a much simpler scale, in intermediate and small-size programs; here, instead of a separate formal effort manned by specialists, they may be performed variously by design, systems, test, and reliability engineers with little or no assistance from human factors or maintainability personnel. These functions are described in detail in a as yet unpublished paper entitled "Introduction to the Assurance of Human Performance in Space Systems."

Whatever the extent of human factors involvement in the design and development of flight hardware, the area of assuring human performance is vital in the mission operations system. This is particularly true during launch phase activities in general and for the entire mission sequence of lunar or interplanetary spacecraft, since there is a high probability of losing the mission if human errors in these situations are not identified and corrected immediately. Therefore, development and debugging of procedures and training to assure effective interfacing of these procedures with mission operations personnel and equipment are a major part of the mission operations system activity.

In summary, whether conducted full-time or part-time by specialists or conducted in the absence of specialists, the human factors effort must identify man-machine interfaces wherever they exist and provide appropriate design, instructions, and training measures to minimize chances for error. These efforts must be followed through in appropriate assurance activities including the design review program, and they should be monitored as necessary by the reliability management function.

Evaluation Considerations

The contractor reliability activity's role in assuring that maintainability and human factors are properly considered in the contract effort is basically a "checking" function. Therefore, the NASA evaluation must attempt to determine whether the reliability group is keeping up to date on the progress of human factors activities and whether those responsible for technical support in this area are providing it effectively. A full support effort is usually justifiable for manned spacecraft, man-rated launch vehicles, launch-critical ground support equipment, and mission operations equipment and functions (particularly for projects of high significance). Less emphasis can be expected on projects whose hardware interface with the human element is more limited and where mission criticality is not high.

The evaluator should ensure that someone in the reliability group has the responsibility for monitoring and assuring the adequacy of the human engineering and maintainability support efforts and that he has, in fact, established a means for accomplishing this task. Then, to determine the effectiveness of the human engineering and maintainability function in supporting the design/development process, the evaluator should check on the documented responsibility for this activity and how it operates; for example:

(1) Has the contractor planned a human factor and maintainability program commensurate with the overall requirements of the system?

(2) Does the contractor have specialized personnel (in-house or otherwise) to carry out the proposed program successfully, and are their responsibilities specified in a project or management directive? Is there an adequate

mechanism for assuring effective consultation between designers and these specialists?

(3) Does the designer coordinate early design information with the human engineering specialists prior to design release for manufacture? This should be accomplished both informally and formally prior to the prepackaging design review.

(4) As design changes are made, are they coordinated with the human engineering specialists (or functional equivalent) to assure proper consideration of maintenance and human factors?

(5) Do those responsible for the human factors effort regularly assess and report the status of actions being taken to cope with recognized problems in the human factors area?

(6) If no separate human engineering and maintainability specialists are available, how and by whom is this function being carried out?

(7) Are the steps of the program to eliminate human error sources actually being completed in a satisfactory manner?

The evaluator should carefully consider the needs of the project in question with regard to human factors support and seek expert opinion if necessary to identify effectiveness of activities and the efficiency of use of manpower for this function.

5.9 DESIGN REVIEW

Contractor Requirements

General

A means must exist within the project whereby the design progress of each system element can be periodically assessed by project management as the basis for confirming, reorienting, or rescheduling project effort. The contractor is therefore required to establish a program of design reviews applicable at the major component, subsystem, and system level and scheduled so as to review technical decision and trade-off information at major project milestones. Similar reviews should also be required of all major subsystem and component suppliers, and these should be monitored by the contractor (see section entitled "Subcontractor and Supplier Control."

The design review activity is basically a survey of each hardware segment, in which all design requirements are reviewed (basic functions, input-output parameters, environment conditions, reliability, maintainability, weight, volume requirements, etc.) and assurance is obtained for company and customer management that the design has been optimized to support these requirements. A complete design review should consist of (1) the necessary pre-meeting compilation of all design considerations (i.e., the design review "data package"), (2) the design review meeting, and (3) a formal report of all important results of the meeting. Project action items should be generated as a result of each review and each item should be assigned to a responsible group on the basis of priority of importance to the project.

This subject is treated at some length in an as yet unpublished paper entitled "Elements of Design Review for Space Systems." The five principal design review milestones described therein are:

(1) Preliminary: at the completion of initial formulation of a design concept, where it can be expected that several approaches to the design are feasible, and where circuit configuration decisions offer varied choices.

(2) Prepackaging: between the preliminary and prerelease reviews, where an interim review of critical parts and circuit selection and application can be of definite benefit.

(3) Prerelease: prior to release of the drawing and specification package to manufacturing (breadboard and early development test results are available).

(4) Postqualification: after completion of component qualification but prior to delivery of the qualification report. The purpose is to assure that all changes to the qualification units are incorporated in the delivered hardware and that all testing to date confirms the adequacy of the design including any revisions since design release.

(5) Acceptance review: a part of the buy-off procedure prior to government acceptance of the hardware to give assurance to the customer that the system is in accordance with specifications and mission requirements.

Effective design review is contingent upon (1) the delegation of review responsibility to personnel having both high technical qualifications and the ability to communicate their ideas effectively and (2) sufficient preparation prior to the review by all persons involved. All representatives must have a complete understanding of the requirements of the hardware under review that are applicable to their discipline. By the time of the review meeting, each should have studied the design review "input data package" and have prepared questions on this package and on the results of all previous informal reviews and critiques of individual segments of the hardware. Although the design review requires that the designer defend his hardware configuration, it should be conducted with sufficient objectivity that the designer is not placed "on trial" or in a position of personal defense.

The procedure for conducting the design review meeting may be oriented by a checklist or tabulation of pertinent items to be considered. However, whether a checklist is, or is not, used, the important point is that the meeting proceedings should be oriented to the following:

(1) The hardware design specification

(2) The latest mission profile requirements for the subsystem being reviewed and other related subsystems

(3) Questions on the input data package generated by each member of the design review team prior to convening the meeting.

The result of each design review should be a report that completely describes the design status at the time of review, documents the review discussion, explains the designer's means of meeting each requirement, lists any areas of nonconformance, discusses solutions to provide conformance, and points out trade-off considerations that would be involved in decisions to change the design. The design review report is the principal input for assurance to company and customer management that previously made technical decisions are valid, and it may recommend action required to achieve desired design improvements.

Reliability Group Responsibilities

As a support function to the project, the reliability group should actively participate in all design reviews from two standpoints. The first of these is to determine whether the design has completely responded to previously established reliability requirements and, if not, whether they have been given proper consideration in the trade-off decisions. The reliability representative should also assure that any previous reliability group recommendations (as a result of earlier reliability prediction or analysis) have been duly considered and implemented where feasible within other trade-off limitations.

The second reliability group function is to monitor the overall design review activity to ensure that adequate documentation of all problem areas is achieved, to follow up on action items, and to advise the chairman of the design review team (or project manager) of status and thoroughness of implementation of these follow-through activities. This support to the design review chairman (or project manager) falls in naturally with the reliability group's engineering monitoring activities overall.

Evaluation Considerations

NASA's concern with the contractor's design review program is much broader than the single aspect of evaluation and monitoring of reliability assurance with which this text is primarily concerned. Because the design review provides mid-program summations and analyses of design progress at significant program milestones, the NASA project management team should be acutely concerned with the review program. This concern will normally include close monitoring by NASA design and project engineering personnel of any hardware items within their individual areas of technical responsibility.

The reliability program evaluators should therefore coordinate with their design and project engineering counterparts and other supporting engineers in obtaining an overall assurance that the design review program is being implemented satisfactorily. In addition, to complete the evaluation, they should perform an independent assessment of the contractor reliability group's participation and of management's use of the design review outputs. From this latter standpoint, they should review the project design review planning documentation and ascertain that a design review program has been established which provides for reviews of all system elements down to the major component level, that the program includes subcontractor's design review activities, and that it adequately defines the participants and their responsibilities. Then the contractor reliability group participation can be evaluated by the checking of such details as the following:

(1) Does the reliability group have representation in all design review meetings?

(2) Is the reliability group supplying up-to-date reliability predictions and FMECA (see two previous sections) as part of "the input data package"?

(3) Is there a mechanism for assuring thoroughness of review documentation and follow-through on action items? If not otherwise assigned to one specific group, are these functions assigned to reliability?

(4) Is a reliability representative among those signing off on the final report, signifying concurrence in its content?

(5) Are the right personnel in attendance at each design review?

A vital factor is the importance which the contractor's top project management attaches to the design review program. In this area, the evaluation should concern itself with the answers to questions such as the following:

(1) To what extent is project management actively participating in the design reviews, and at what level (of personnel) does project management show an immediate interest in specific design review activities?

(2) Are design review outputs being employed as basic project guides, and is management issuing timely direction for action as a result of the reviews?

(3) How is the responsibility for monitoring subcontractor design reviews delegated? Are contractor representatives actually participating in these reviews and concurring in the resultant final reports? Where deficiencies are considered to exist, does the contractor project management have a means (and is he employing it) for frequent checkup on subcontractor progress to bring about a satisfactory solution? Such a means might be a contractor resident engineering group, the contractor quality assurance representative, or other contractor representatives reporting frequently to the project manager.

(4) Are subcontractor design review reports provided in accordance with project scheduling, and are they sufficiently detailed to assess the comprehensiveness of the review?

Since the results of other reliability assurance functions (predictions, FMECA, design standardization, parts and materials standardization, etc.) are all keyed to, or have a bearing on, the design review, this function provides a focal point for the evaluator at which he may assess not only that adequate design reviews are being conducted but that the outputs of these supporting reliability tasks are being furnished in a timely fashion; moreover, he may assess the extent to which they are impacting the project. For these reasons, the design review activity should be given top priority in the overall reliability program assessment.

5.10 FAILURE REPORTING AND CORRECTION

Contractor Requirements

The contractor is required to have a formalized system for the reporting of hardware (and software) discrepancies and nonconformance to design specifications. This system serves to document equipment discrepancies not only in quality and workmanship but also in performance of all system elements at various levels of testing. While data on the former type of discrepancy give a good indication of the manufacturer's capability to produce a quality product (and can serve as a check on the quality control operation), data on the latter are important to both the measurement and assurance of system reliability.

The primary purpose of the failure reporting system is to document accurately all discrepancies and to disseminate this information so that remedial action may be taken promptly and thoroughly, thereby preventing recurrence of the failure or anomalous condition. To serve this purpose adequately, the contractor must maintain a disciplined reporting system and an effectively managed corrective action scheme with sufficient followup to assure that the corrective actions are taken and that the problem condition is eliminated.

The reporting system not only must exist in the contractor's main plant, the subcontractors' plants, and all hardware test facilities (including the launch facilities), but it must also function at command and tracking facilities associated with the mission operations system; that is, it must encompass people, procedures, equipment, and communications associated with the data acquisition, tracking, command, and mission operational control of the launch vehicle and spacecraft. In cases where the contractor does not have responsibility for mission operations, the cognizant NASA center must assume the contractor's failure reporting assurance responsibilities in this area and coordinate this activity with that of the contractor.

In the subcontractor facilities and in the mission operations facilities, these organizations must be required to maintain a failure system, which, if not implemented with the identical paperwork format, at least provides for the recording of all failure information necessary to evaluate each hardware or software discrepancy effectively.

Because of the remoteness of some of these locations from the contractor's plant and the large volume of data that results from all locations, it is necessary that the contractor designate a group to be responsible for: (1) Assembling all failure reports, (2) determining the criticality of each failure and the priority for failure analysis, and (3) upon completion of such analysis, monitoring the progress of corrective actions. The group discharging this responsibility (frequently reliability or quality) should utilize the technical assistance, as required, of particular design or systems engineers. A description of a typical failure reporting system is included as a supplement to this text.

There are several "keys" that render the failure reporting and corrective action cycle effective. Some of these are:

(1) The discipline of the report writing itself must be maintained so that an accurate description of failure occurrence and proper identification of the failed items are assured.

(2) The proper assignment of priority and the decision for failure analysis must be made with the aid of cognizant design engineers and systems engineers.

(3) The status of all failure analysis must be known; it is of prime importance that the analysis be expedited as priority demands and that corrective action be implemented as soon as possible.

(4) There must be a means of tabulating the failure information for determining failure trends and the mean times between failures of individual system elements. There should also be a means for management visibility into the status of failure-report dispositions and corrective actions. Such a tabulation system may be either manual or part of an automatic data processing (ADP) system. For sizeable volumes of data, ADP is most helpful and should be utilized if the contractor has the capacity available.

(5) Lastly, an extremely valuable assurance mechanism is to provide for a high-level technical management sign-off, concurring in the results of failure analysis, the soundness of corrective action, and the completion of formal actions in the correction and recurrence prevention loop.

Evaluation Considerations

The aspects of performance quality and timeliness (as discussed in chapter 3) are particularly appropriate to the failure reporting and corrective action system. The NASA evaluation should be primarily concerned with the completeness of information contained in the failure reports and the time lag between the reporting of a typical failure and the implementation in hardware of a solution to the problem. The two significant items of information (the description of the trouble recorded at the time of failure and the information resulting from failure analysis) may be contained in a single document or in two separate documents. A number of systems exist for the actual recording process. A typical failure reporting format (employed by the Jet Propulsion Laboratory of the California Institute of Technology) with explanation of its use appears as a supplement to this text (pp. 51 to 67).

If a system of separate documents is in effect, a cross-reference numbering system should also exist. From these the evaluator should be able to determine the extent of the detail used in failure reporting and the depth to which the contractor performs analyses of particular failures. Instead of examining a random selection of failure reports, the evaluator should select several representative failures (major ones, minor ones, and some involving subcontractors in the loop); he should then check the paperwork, failure analysis, and corrective action through the complete closed loop, carefully noting periods of time required for action, apparent delays in communications, thoroughness of documentation, and any other evidence to ascertain whether sound system discipline and sound technical judgment characterize the implementation of the failure reporting system.

Coordination with a resident project engineer will usually uncover several suitable failure reporting examples to be put to the evaluation test. In following through each typical case, the evaluator should direct his investigation in part toward determining the following:

(1) Is the failure properly described in the failure report? Typical examples of poor notation are "no output," "doesn't work," "shorted," "broken," "no response." Preferable description of a failure would be, for example, "Output voltage of 7.5 V dc was recorded during step 29 of test procedure A12456. Tolerance is 8.2 to 9.6 V dc."

(2) Is the proper failed assembly recorded? One typical mistake is to identify a part or component as having failed when the failed item was actually another part or component in series.

(3) Who determines whether a formal failure analysis should be performed? This task should be performed by reliability engineers in conjunction with system engineers to assure that all potentially critical failures are analyzed.

(4) What is the time lag from the date of failure to that of the performance of failure analysis? Even in a well-executed program the time for analysis may be expected to vary with such factors as criticality of the failure, extensiveness of the analysis required, and whether the analysis must be done by a vendor. However, other programs may suffer from a lagging analysis effort because of "logjams" in paperwork, improper assignment of priorities, inadequate (or overcrowded) facilities, or simply inept management. The evaluator should examine these factors in judging what constitutes too great a lag and whether long delays are the rule or the exception.

(5) Is an adequate failure analysis conducted? Adequacy is usually recognizable in the failure analysis report by the completeness and detail of the description of the testing performed to isolate the failure and by a clear identification of the individual failure mechanism and probable cause. Failure analysis laboratories may also be visited for more information.

(6) Are useful corrective recommendations made? Again, the failure analysis report should show this. The individual responsible for the analysis should coordinate informally with the appropriate design group to discuss feasible solutions.

(7) What is the time lag from the date of recommendation to actual implementation of a design change? Such action should be taken on a priority basis, most critical failures being considered first.

(8) Check failure reports from outlying areas such as remote test facilities. Is there swift communication of critical failures from these areas to the main plant?

(9) Where launch site failures occur, is there a special means of reporting these back to the plant (e.g., by teletype) and obtaining prompt support for failure analysis and corrective action?

(10) Is the failure reporting system of each major subcontractor properly monitored by the contractor, and are all failures resolved in a timely fashion?

(11) What provisions are there for reporting, analysis, and corrective action in the mission operations system (including test and training)? Who is responsible, and how, in detail, does he perform these functions and coordinate them with the overall failure reporting system?

(12) Where a failure occurs in testing at the subsystem or system level, what provision exists to ensure that testing does not continue with the failed, but unanalyzed, black box still in the system? (I.e., is the failed black box removed and is system testing suspended until

either a replacement unit is obtained or the failed unit is analyzed, repaired, proofed, and reinstalled?)

(13) Are all critical failures reconciled prior to utilization of the system?

(14) Is there accountability for failure report forms; that is, are the blank forms serialized in printing and periodically accounted for to provide a check on whether filled out reports are being turned in promptly or are left lying about?

(15) Does technical management review and concur in corrective actions for closures of reported failures? Is there single-point responsibility for following and certifying the completion of all actions necessary to close a failure report?

(16) At what point in the life of an element of hardware does it become subject to formal failure reporting (i.e., at module or component level and at what phase of testing)? If failure reporting does not begin at the earliest stage of life and test of an identifiable item, what other mechanism exists for reporting of anomalous performance of the item prior to formal failure reporting?

(17) Does the contractor maintain and publish a rapid-reaction, continuously updated management report which summarizes the status of all open failure reports and provides full visibility on items such as date of initiation, a very brief description of failure, test where failure occurred, affected component, individual responsible for close-out action, and anticipated (or required) disposition date? Does this system cover failure reporting status for subsystems and components being tested (or already delivered) by major subcontractors?

(18) What are the requirements for closure of a failure report? Does closure require devising, test-verifying, and incorporating the "fix" into the immediate flight hardware, the drawings, and other items of hardware in the same configuration series?

Although there are other individual items worthy of checking in particular contractor operations, these questions form a good basis for the investigation of any failure reporting system and should be added to as the evaluation proceeds. Once the contractor has committed a design to manufacture, the failure reporting and corrective action system is the primary means of documenting design or manufacturing problems, and sufficient emphasis must be given to each step in the reporting cycle to assure resolution of all critical hardware and software problems prior to flight.

5.11 STANDARDIZATION OF DESIGN PRACTICES

Contractor Requirements

Hardware reliability is considerably enhanced when the design and manufacture are accomplished in accordance with a well documented and implemented standards system. By contrast, the lack of standardization of such practices causes excessive individualism of design and an increased burden to project support and checking functions (and management); in most instances, this results in a lack of firm control of the hardware development. Although the development of unique design and manufacturing techniques should not be discouraged, a system must exist by which such development may be controlled and the new methods tested and proved before becoming acceptable within the project.

The contractor will normally have a standards program in operation prior to contracting for the NASA project. Every effort should be made to utilize as much as possible of this existing standards program since such practice makes for better centralization of control within the contractor's facility and is an obvious cost saver. However, it is to be expected that these existing standards will reflect levels of refinement and process control commensurate with the type of hardware activity in which the contractor has been engaged. Therefore, in adapting to an R&D space system effort, it will be necessary to review these standards and practices to determine which among them require upgrading. This review should be the joint responsibility of the contractor's reliability and quality assurance personnel and should result in a program for upgrading by the standards group.

The program of standard practices should include documentation of manufacturing process specifications; general design techniques for electrical, electronic, and mechanical applications; drafting guidelines; and installation techniques. Standardization of parts is also required; this will be discussed in the following section. The control of standard practices should be administered by a group specifically designated for this function.

Although there are obvious reliability implications imposed by standard practices, contractor quality assurance personnel must also monitor the generation of new practices and take the leading role in monitoring the implementation of standard techniques, particularly manufacturing processes, to assure that quality assurance requirements in the areas of process control procedures and environments are met. (See par. 7.5.4 of NASA quality publication NPC 200-2 (ref. 7).) This should include their being in the concurrence signature cycle of all standard procedures documentation. In the area of standard design practices, the concurrence of appropriate assurance groups should also be required.

Evaluation Considerations

The evaluation of the contractor's standards area should aim at the adequacy of the standards themselves and at the proper use of the standards in design and manufacturing. This includes determination of:

(1) Whether the process specifications being used represent acceptable practices and provide adequate controls in terms of needs of the space system in question

(2) Whether available standards are being properly utilized through drawing and specification callouts

(3) Whether the contractor's quality program is adequately enforcing proper implementation of manufacturing process controls.

Item (1) above requires an independent review of each standard process and practice with a view toward ease of manufacture, ability to control the process, and adequacy of contractor facilities. Item (2) can be evaluated through a periodic review of samples of drawings and specifications by either residents or other task team delegates and by giving this area consideration in design reviews.

Because of the importance of assuring that implementation of process controls is maintained at all times, item (3), a customer-monitoring effort is frequently appropriate to assure that the contractor's quality assurance function is performing adequately. Government agency representatives, if available, should be utilized for this task, and provisions for their employment for it is covered in NASA quality publication 200-1A (ref. 6). In this function, they should establish a schedule of monitoring to be carried out throughout the duration of the project. Their surveillance should include checking of control measurements performed during the process, review of all instrumentation calibrations, and a determination that contractor quality control personnel are maintaining tight control of each process in all other appropriate ways.

Other considerations for evaluation of the contractor reliability and quality assurance group's tie-in to the contractor standards effort are implied in the preceding section and are briefly restated as follows:

(1) Is there evidence of a planned, scheduled effort by contractor R&QA for early review of existing standard processes for applicability to the present space-system project?

(2) Has an orderly program of updating of process specifications been implemented?

(3) Is reliability assurance in the concurrence signature cycle for design practices?

(4) Is quality assurance in the concurrence signature cycle for all standard manufacturing processes?

(5) Does the contractor's quality assurance group execute a planned, periodic program of checking process implementation on the manufacturing floor?

5.12 PARTS AND MATERIALS PROGRAM

Contractor Requirements

In order to furnish support for the design and development effort, the contractor must conduct a program to control the selection and application of parts and materials. This program is one of the foundations of the development of reliable systems; as such, it must be systematically implemented with the respect its importance demands.

The contractor must establish a group to manage and execute this program as required by the project. Functions should include selecting, specifying (i.e., providing specifications), and qualifying parts and materials to result in a parts list for the project. This list must be maintained current with respect to parts availability and new project or mission requirements. This parts and materials group should provide consultation to design engineers to guide them in selecting parts appropriate for each application in terms of system performance and environmental requirements (utilizing suitable derating criteria and techniques). The parts group should also support the failure analysis activity in the analysis of failed parts. The reliability group should monitor the parts and materials function to ascertain whether it is supporting the project effectively in these areas.

It is important that the parts group be consulted by design engineers as early as possible during the formulation of basic subsystem designs so that applications for which no standard part exists can be identified in time to permit consideration of minor design changes which may eliminate the need for procurement of nonstandard items. When a nonstandard part must be used, adequate specifications must be drafted early to avoid delays in the procurement cycle. Consultation with parts specialists should be continued throughout the development period whenever additional parts application problems arise. The parts and materials group should sign off on design drawings to indicate their review of parts applications. Also, parts and materials application reviews should be conducted and documented as inputs to design reviews of the components and subsystems in question. (A detailed treatment of this review area is given in an as yet not published document entitled "Parts and Materials Application Review for Space Systems.")

Normally, the parts program will develop a preliminary parts list early in the project cycle, which will evolve through qualification and testing into an approved parts list (APL) as the final parts reference document for the design. The APL must include specifications as to which each part is qualified, the recommended application guidance for the part, and pertinent warnings of limitations on its usage. As additional parts are added to the parts list through qualification, these parts must be included on updated versions or in supplemental pages of the approved parts list.

The parts and materials group has the twofold responsibility of continuously monitoring progress in the industry in order to maintain up-to-date standard information for dissemination to the project and of consulting with project designers on the selection and application of parts and materials.

Evaluation Considerations

The above description of the contractor's requirements cites some of the principal factors to be considered in the evaluation. The organization of the parts and materials activity, as outlined in the contractor's planning documentation, should be reviewed by NASA center personnel. It should be determined that a separate, full-time responsibility has been delegated for the purpose of performing the functions cited in the preceding section. The official mission statement of the group should indicate an approval authority for all parts and materials selection, and the detailed schedules of the project should identify points in time for parts and materials applications review of each component design.

Detailed implementation of the parts and materials activity should be monitored by NASA residents and/or by the delegated survey group during periodic surveys of the reliability program operation. Some of the specific items to check are the following:

(1) To what extent do designers solicit parts and materials assistance from the parts group?

(2) Are the personnel in the parts group qualified? Interview them on an informal basis to determine whether the collective experience of the group encompasses electronic, electrical, electromechanical, and mechanical parts knowledge.

(3) Do the design personnel appear to respect the technical ability of this group? (Determined from evaluator's discussions with design personnel.)

(4) Does the parts and materials group make review of parts applications as a specific input to the design reviews of each component?

(5) Is there a preliminary parts list for the project? If the "drawing release" stage has been

reached, is there an APL, and is it under project drawing change control?"

(6) Is the parts group responsible for assisting in the specification of requirements for all parts (nonstandard and standard), and is there an accessible listing of these parts for possible use in other applications?

(7) Does the parts and materials group have approval authority over sources from which parts and materials are purchased?

(8) What means are used to ensure that parts for use on flight-critical hardware are obtained from approved vendors?

(9) Are any parts purchased from sources other than approved vendors? If so, for what use are they intended, and how are they controlled?

(10) What controls exist to ensure that any short-order system, by which designers purchase limited numbers of parts for breadboard or other informal testing, does not degenerate to side purchase of critical components for the sake of expediency?

(11) For projects where the formal failure reporting system does not cover breadboard or other testing prior to flight acceptance testing (FAT), what mechanism is used by the parts group to keep track of catastrophic part failures in early testing?

5.13 EQUIPMENT LOGS

As the development cycle progresses and the number and types of equipments of various configurations increase, the problem of hardware configuration control takes on major significance. The contractor must have a means of documenting the history of every manufactured item and must enforce discipline in all plant facilities to keep such documentation up to date at all times. Although this task is a natural requirement in the area of test and product quality control, it directly affects system reliability. Questions arise daily (particularly in test situations) concerning the latest incorporated changes to individual units, their most recent performance history, previous discrepancies, and conformance to specifications. This information must be readily accessible and accurately listed in an equipment log to allow for efficient test operations as the equipment progresses from one area to another and to provide a detailed record to support later failure analyses.

Section 3.10 of NPC 250-1 (ref. 1) provides a detailed listing of the items that should be included in the equipment log, and paragraph 14.2.4 of NPC 200-2 (ref. 7) prescribes additional logging requirements; these need not be repeated in this writing. Evaluation by the NASA contract monitoring team is also relatively straightforward since the referenced listings provide a detailed itemization of information of concern. The evaluation can only be performed practically as a matter of routine along with other daily duties, rather than by a wholesale review of all logs at one time.

To meet this requirement, the contractor may elect to record parts of the total data compilation in several documents rather than in a single log. Test results (in particular those recorded in real time by oscillograph or pen recorders) may only be referenced in the equipment log to another data file. Such a technique is satisfactory as long as all the data and references are recorded currently and are always readily available in a repository reasonably near the equipment.

The equipment log data are not only important to the efficient progress of the test activities but they become one of the key documents in the customer-contractor negotiation of system acceptance. Where discipline in recording the required data has not been maintained, the deficiency will become apparent and constitute an obstacle to confidence in the product at system acceptance. It is therefore important for the NASA reliability program evaluation to monitor the equipment logs for adequacy beginning as early as practical in the development phase.

5.14 TESTING AND RELIABILITY EVALUATION

Contractor Requirements

Once system development progresses to a stage where hardware is being produced, the emphasis of the reliability program must be on contractor activities that provide data for measurement and assessment of actual hardware capability. It is during this period that the analytical reliability engineering efforts are provided support in actual data, and previous analyses can be refined as a result of testing of the system at various levels of assembly.

In most projects, the size, scope, and technical skill levels required to carry out a successful test program dictate its being planned and conducted by a separate organization. However, it is the responsibility of reliability management to accomplish the following:

(1) Determine and require the test data necessary to support the analytical reliability assurance tasks.

(2) Assist in the planning of the test program.

(3) Provide (in conjunction with the quality assurance group) a monitoring effort to assure that the test program supplies the basic information required and that the data have been recorded under the conditions prescribed by applicable documentation.

The contractor must therefore provide in his reliability program plan a detailed description and schedule of the test activity as it interfaces with the reliability assurance program (reliability evaluation plan) and show how the data generated by the tests will be used to support the analytical reliability evaluation process.

In regard to the test monitoring function, the contractor reliability group, together with the quality assurance group, must closely follow the test program to assure that all testing is adequately performed and documented. This process should include review of test specifications and test procedures for adequate content, monitoring of the test implementation, and review of test reports. The reliability group should be actively engaged in the evaluation of all failures resulting from testing and should assure that adequate documentation of all operating time, cycles, and anomalous conditions is maintained (see preceding section). Further, the reliability group should compile all data on failure versus operating time to refine hardware failure rates and to verify previous system reliability predictions.

As part of the overall test plan, the contractor should perform reliability tests at the part, selected-component, and sometimes even higher levels. However, because of the cost of such testing on a large scale, the extent to which it is carried out should be established in contract negotiations. Factors cited in the section entitled "Response to Project Characteristics" in chapter 2 such as mission criticality, type, and cost have a direct bearing on the scope of reliability testing to be conducted on parts and components.

Additional verification of the capability of hardware to perform reliably is obtained through test results which:

(1) Verify performance capability at the component, subsystem, and system level

(2) Identify undefined subsystem interfaces

(3) Identify design weakness and defects in materials or workmanship

(4) Verify the performance of hardware when it is subjected to expected mission environments and durations

(5) Assure the required life (accelerated when necessary) of all critical system components

(6) Apply overstress to determine margins of safety of all components and subsystems

Each of the above segments of testing provides data which either verify adequate performance or identify areas requiring improvement, thus providing additional confidence in ultimate mission success.

Evaluation Criteria

The test program of any project interfaces with almost every group and discipline within the project. It is performed not only for the purpose of providing inputs to the reliability program but also to demonstrate design integrity, to prove the design is capable of qualifying to all mission environments, to determine compatibility of one subsystem with another, and to demonstrate readiness for acceptance by the customer. The information resulting from testing is therefore of vital interest to all NASA project personnel.

Although a significant NASA test program monitoring effort will, in most cases, be taking place in addition to the reliability program evaluation effort, the latter evaluation should focus upon the interface between the reliability program and the test program. The preceding section implies the major considerations to be determined from the standpoint of planning an integrated activity and providing the necessary reliability support data. Further questions to be answered are:

(1) Does the RPP adequately define the interface between the reliability program and the test program and specify the test data that must be provided for reliability assurance?

(2) Has the reliability group (in coordination with quality assurance) established a plan for test monitoring, and is the plan being implemented in an effective manner?

(3) Are all test procedures being reviewed and compared with the corresponding test specifications, and are inconsistencies discovered in this review being reconciled by feedback to the test group?

(4) Does the reliability group maintain a disciplined collection program for operating time and cycle data from all test areas?

(5) Are component failure rates updated by analysis of testing time versus failure data? Are these failure rates periodically applied in revising reliability predictions to obtain refined reliability assessments?

(6) Is the reliability test program for parts and components being implemented as established by contract, and is it progressing satisfactorily?

(7) Does the contractor have an organized process for maintaining control of failed items, and analysis of failure, and the followup for corrective action? Is this process meticulously carried out (see section entitled "Failure Reporting and Correction")?

(8) Is the contractor employing statistical test planning techniques to achieve maximum economy in testing?

(9) Is the reliability evaluation plan submitted initially as a part of (or at the same time as) the formal RPP?

(10) Does the reliability evaluation plan clearly show (preferably in matrix or other graphic form) tests conducted at each level of assembly which contribute to reliability assessments and does it show

(a) What each test contributes, with relative value of the contribution to the assessment

(b) Program milestones at which reliability data from each test will be available

(c) Estimate of cost of additional effort in each test to produce specific reliability data

While the reliability program monitoring and evaluation is proceeding, much of the day-to-day evaluation of the test program will usually be carried out by NASA project engineers because of the detailed technical decisions required between customer and contractor in this activity. However, the monitoring of testing to assure compliance with procedures, particularly at the component or subsystem level, will usually be delegated to government agency representatives (when available).

NASA reliability monitoring personnel and project engineers should be on the alert for indications of a poor test program. If the test program is not producing the necessary data for reliability assurance or the many other decision-making criteria that it must provide, a test program evaluation should be conducted to determine the weaknesses and how to correct them. This effort might include a study of all specifications, procedures, test implementation, test item configuration control, and review of test results. Consideration may be given to employing a consultant group to assist in this study (see section entitled "Reliability Study Contracts" in chapter 4).

5.15 RELIABILITY PROGRAM DOCUMENTATION

Much has been said on the subject of producing sufficient documentation to record all the significant inputs to, and outputs from, the reliability support effort. While it is true that a certain level of documentation is necessary to provide a basis for a well-managed project and as evidence of an adequately implemented program (in all areas), stated requirements for this should not be misconstrued as a requirement or encouragement for creating an excessive volume of paperwork as evidence of an adequately documented program. What must result from the contractor's efforts are documents that either satisfy an internal project purpose or are considered basic to the contractor-customer interface for proper management of the program. In this latter category are documents such as progress, management, and financial reports, and documents that provide direction to the project. All other documentation should have as a first purpose the dissemination of information, the recording of data necessary to the accomplishment of the project effort, or the documentation of underlying logic governing project decisions. Although internal project documentation must be available for review by the customer as deemed necessary to his overall monitoring activity, the generation of such technical documentation solely for the enlightenment of the customer is not appropriate.

It is particularly important to avoid duplications in reporting routine. Excessive documentation is self-defeating in that it tends to bring about first a confused, then an indifferent, attitude toward all documentation. It is also recognized as a typical means of masking unfavorable technical information amid an array of irrelevant documents.

Both the contractor and the customer evaluation activity should be conducted with an awareness of the primary purpose of the documentation effort. Beyond the recognized need to provide information for management decision, the documentation must provide technical support to the design, evolution, and use of hardware and to the accomplishment of mission.

Supplement—Spacecraft Problem/Failure Reporting System

The following exhibit describes the failure reporting procedure used by the Jet Propulsion Laboratory (JPL) of the California Institute of Technology. It has been selected as typifying most of the key features of the better failure reporting systems presently in use in the aerospace industry.

Most of the elements of this procedure, although tailored to the organizational structure of JPL, may be readily recognized as generic in their essence. However, in reading paragraph IB entitled "Scope," it should be borne in mind that the lowest levels of assembly and types of tests, the failures of which are to be covered by the reporting system, should be interpreted separately for each project to conform with the lowest levels at which (1) there exists a full formalized characterization of test conditions, procedures, and stress levels and (2) a formalized system of configuration control is in force.

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RP-1A
15 March 1966

jpl Procedure

P/FR

JPL RELIABILITY PROCEDURE

SPACECRAFT PROBLEM/FAILURE REPORTING SYSTEM

JET PROPULSION LABORATORY

PREPARED	SEC.	APPROVED	SEC.
F. F. Baran	153	F. H. Wright	153
		F. A. Paul	153

Editor ____________________

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CHANGES		
NUMBER	PAGES	DATE

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APPENDICES

DEFINITIONS

ECR	Engineering Change Requirement
FAILURE	Equipment performance outside the limits of applicable requirements. Term to include intermittent, cessation of performance, or failure of equipment to respond as commanded.
P/FR	Problem Failure Report
PROBLEM	Any anomaly requiring action for correction, or an occurrence which cannot immediately be explained.
PTM	Proof Test Model
SAF	Spacecraft Assembly Facility, Jet Propulsion Laboratory, Building 179

Procedure No. RP-1A

Page 1

I. INTRODUCTION

A. Objective

The objective of this Problem/Failure Report (P/FR) Procedure is to describe a method of systematically reporting, recording, and reviewing all actions upon failures and problems that arise in the design, fabrication, test, and operation of spacecraft and related Operational Support Equipment.

B. Scope

This procedure applies to all JPL personnel. It is utilized in reporting problems or failures on Lab or at the Eastern Test Range. (P/FR procedures for JPL Contractor's are contained in Reliability Procedure RP-2A). The Problem/Failure Report shall be used to record all failures and problems occurring during Type Approval and Flight Acceptance tests of PTM, flight systems and flight spares and any other testing of subassemblies, assemblies, subsystems, and systems, commencing with the first application of power.

II. RESPONSIBILITIES

The items listed below are those necessary to implement the JPL Problem/Failure Reporting System.

A. Personnel

The roles of the various personnel in the JPL in-house P/FR Reporting System are as follows:

1. Originator - The originator is anyone who believes a problem or failure has occurred or exists.

2. Processor - The JPL Reliability P/FR Group (Section 153).

3. Cognizant Engineer - That person who is responsible for the design and/or fabrication of an assembly or subsystem.

4. Cognizant Section Chief (Manager) - That person who is Section Manager for one or more cognizant engineers.

5. Reliability Coordinator - That person representing Section 153 on initiation, distribution, action, and closeout of P/FR activities.

6. Spacecraft System Engineer - That person responsible for the overall technical design of the spacecraft.

7. Reliability Project Representative or Reliability Manager - That person from the Reliability portion of Division 15 assigned to each specific project.

B. Applicable Documents

JPL Problem/Failure Report (P/FR) Form, JPL No. 1290, January 1964.

JPL Procedure RP-2A, JPL Contractor Problem/Failure Reporting, dated 1 April 1966.

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III. DETAIL PROCEDURE

Page 3

STEP	OPERATION
1	<u>Origination</u> <u>NOTE:</u> BE SURE TO PULL PROTECTIVE TISSUE WHEN FILLING OUT A P/FR AND REPLACE SAME WHEN DONE. A. The originator completely fills out Section I of the Problem Failure Report (JPL-1290) or a facsimile thereof (Appendices A and B give examples of how to properly fill out a P/FR) and gives it to: 1. The cognizant Quality Assurance (QA) representative for handling (if the P/FR originates at SAF, Building 144, Building 150, or the Eastern Test Range), or 2. The Cognizant Engineer for handling (if the P/FR originates from a bench test as a subsystem), or 3. The Reliability P/FR Group. <u>NOTE:</u> IN THE EVENT TWO OR MORE SUBSYSTEMS ARE INVOLVED, THE SPACECRAFT SYSTEM ENGINEER IS NAMED AS THE COGNIZANT ENGINEER. B. Next, in the case of 1 and 2 above, the entire P/FR (the dittomaster and colored copies), except for the hard copy, is sent to the Reliability P/FR Group, Section 153. If a failure, the hard copy remains with the failed part or assembly. If a problem, the hard copy remains with the Cognizant Engineer until the problem is analyzed, in case a failure is discovered during problem analysis.
2	<u>JPL 1290 Form Distribution (Initial)</u> A. Distribution of the Problem Failure Reports will be handled by the Reliability P/FR Group. (Quality Assurance may perform this service at the Eastern Test Range). Routing by the Reliability P/FR Group will be as follows: 1. The DITTOMASTER will be kept on file by the Reliability P/FR Group and copies of "open" P/FR's will be sent to appropriate personnel. Lists of such personnel will be supplied to the Reliability P/FR Group by the Reliability Project Representative. 2. The PINK copy will be sent to the Cognizant Engineer whose name appears in the lower right hand corner of Block 9 on the P/FR form. 3. The GREEN copy will be sent to the Spacecraft System Engineer.

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III. DETAIL PROCEDURE (contd)

STEP	OPERATION
	4. The HARD COPY (cardboard copy) will be kept with the appropriate Problem/Failure hardware.
	The Reliability P/FR Group will log in the dittomaster and, if necessary, will seek any information missing from Section I needed to describe the problem or failure.
3	<u>Verification, Analysis and Corrective Action</u>
	A. The Cognizant Engineer receives the Pink Copy and proceeds to investigate and analyze the problem/failure. His analysis and recommended action are recorded in Sections II and III. The cognizant engineer should complete all data on the pink copy left out by the originator such as Blocks 4A, B, C, or D. He should correct any errors that the originator may have made in Section I. The Cognizant Engineer makes the determination whether the occurrence is a problem or failure. If any further explanations for filling out these sections are needed, the Reliability P/FR Group or the Reliability Project Representative should be contacted.
	B. If a failed electronic or electromechanical part is involved, the Cognizant Engineer dispositions the part(s) to the Electronic Parts Engineering Section (Section 354) along with the hard copy. If the failed part(s) cannot be determined or removed from the subassembly without damage, Section 354 shall be contacted to determine the method to be used for the part's analysis. The cognizant engineer should retain the pink copy until the Parts Failure Analysis Report has been received from the Electronic Parts Engineering Section.
	C. If an ECR is required, the pink copy should not be forwarded to the Reliability P/FR Group until an ECR number has been assigned and effectivity established.
	D. The P/FR must be filled out such that it is self-explanatory and self-sufficient. Significant details should be reported in the analysis and corrective action blocks. Addenda and references may be used. The degree to which the analysis was performed should be indicated. The P/FR must contain sufficient information to allow an evaluation to be made of the problem, and its risk to the mission.
	E. If special tests are required to verify a failure or authenticate the adequacy of corrective action, the P/FR should be left open until the test work has been completed to the satisfaction of the Cognizant and the Spacecraft System Engineers.
	F. When all of the above has been completed satisfactorily, the Cognizant Engineer obtains his Section Manager's approval of his analysis

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III. DETAIL PROCEDURE (contd)

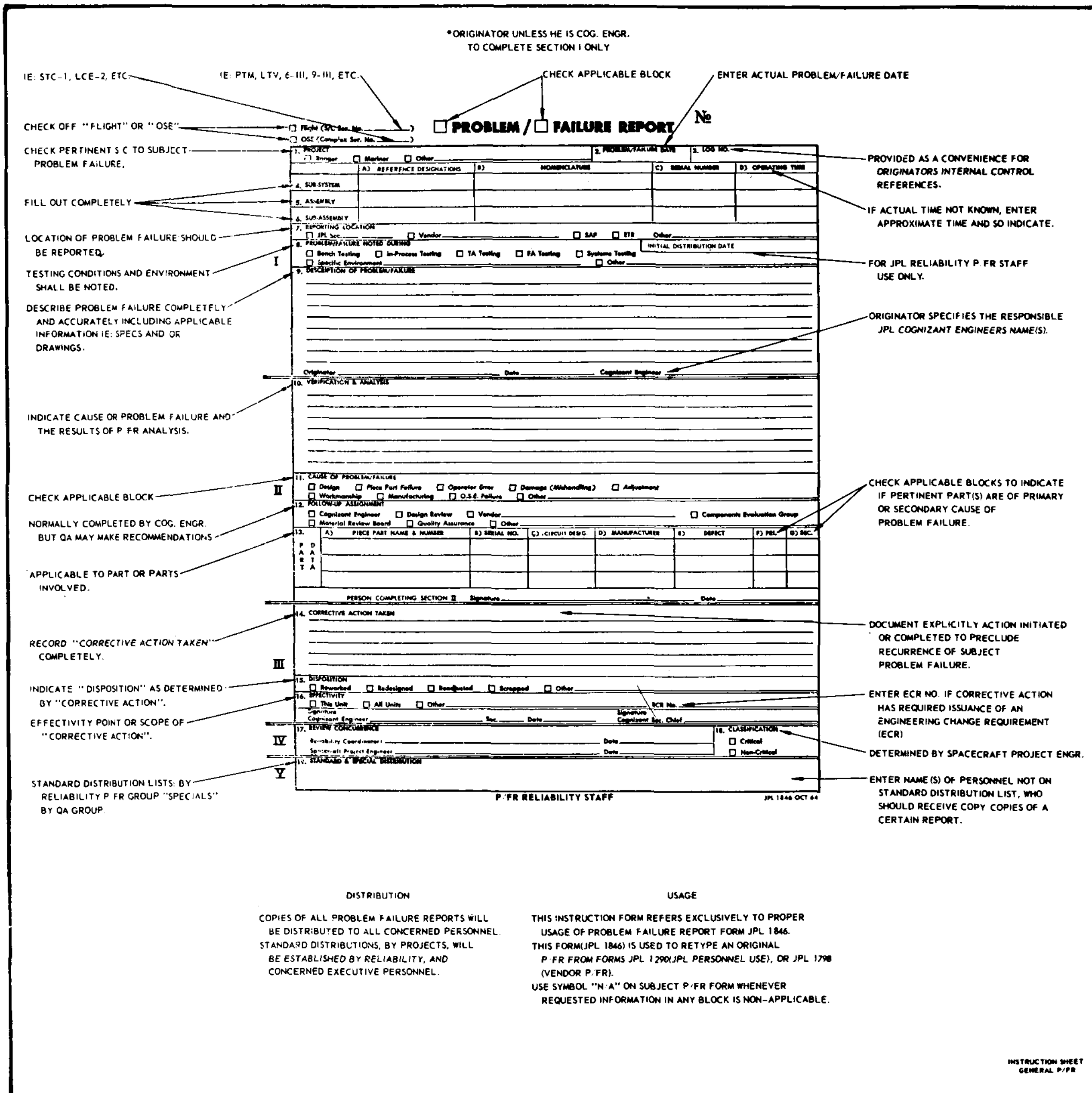
STEP	OPERATION
	and corrective actions and returns the completed pink copy to the Reliability P/FR Group as soon as possible after the initial distribution of the P/FR. The Section Manager signs for: (a) completeness, (b) adequacy, (c) definitive description, and (d) technical soundness of the analysis and corrective action defined on the P/FR.
4	Parts Failure Analysis*
	A. The hard copy or reasonable facsimile is kept with the lowest level of hardware responsible for a problem/failure. This is especially important in the case of an electronic or electromechanical part failure, wherein the failed part will be attached to the hard copy and sent to Section 354 for laboratory failure analysis.
	B. A parts analysis will be made by the Electronic Parts Engineering Section.
	C. The Electronic Parts Engineering Section will furnish the cognizant engineer with an interim or final Part Failure Analysis Report within seven calendar days after receipt of the failed part. A ditto-master of the final Part Failure Analysis Report will be forwarded to the Reliability P/FR Group for reproduction and distribution. Any recommendation(s) that the Electronic Parts Engineering Section may have where further action is suggested will list the person recommended for this action.
	* This section applies to failed electronic and electromechanical parts. In the case of failed or faulty connectors, the same general procedure should be followed, but the failed connector should be sent to Section 357.
5	P/FR Processing
	A. Upon receiving the pink copy from the Cognizant Section Manager, the Reliability P/FR Group will review the form for omissions. It will be the responsibility of the Reliability Project Representative to audit and evaluate the technical accuracy of the analysis or adequacy of the corrective action subject to closeout of the P/FR.
	B. The P/FR Group delivers the pink copy to the Spacecraft Systems Engineer for his acceptance and sign-off. The Spacecraft System Engineer reviews the reported description, analysis, and corrective action for effect on the spacecraft and its expected flight operation, marks Block 18 of the report (critical or non-critical), shows concurrence by signing the pink copy, and then returns the

Procedure No. RP-1A

III. DETAIL PROCEDURE (contd) Page 6

STEP	OPERATION
	pink copy to the Reliability P/FR Group where this information is transcribed onto the dittomaster. If the concurrence of the Spacecraft System Engineer is not obtained, the P/FR is expedited by the P/FR Group with comments to the Cognizant Engineer or Section Manager for further action.
	C. Return of the P/FR from the Cognizant Engineer starts the sign-off procedure again. If agreement cannot be reached, the matter is referred to the Spacecraft System Manager for arbitration.
	D. The Reliability Coordinator signs the pink copy when it is completed satisfactorily, and all addendum(s) have been received. The P/FR is now "closed."
6	Processing for Final Distribution
	A. A general distribution will be made from the "closed" P/FR dittomaster. The P/FR and any Parts Failure Analysis Report dittomasters, as well as the pink copies of each Problem/Failure will be stored in the files of the Reliability P/FR Group.
7	Management Visibility
	A. Monthly summaries of P/FR status will be developed, reprinted and distributed by Section 153. During critical Project review periods, more frequent distribution will be made of these P/FR summaries.

APPENDIX A


*ORIGINATOR UNLESS HE IS COG. ENGR. TO COMPLETE SECTION I ONLY
IE: STC-1, LCE-2, ETC.
IE: PTM, LTV, 6-III, 9-III, ETC.
CHECK APPLICABLE BLOCK
ENTER ACTUAL PROBLEM/FAILURE DATE
PROBLEM / FAILURE REPORT
№
CHECK OFF "FLIGHT" OR "OSE"
CHECK PERTINENT S/C TO SUBJECT PROBLEM FAILURE.
FILL OUT COMPLETELY
LOCATION OF PROBLEM FAILURE SHOULD BE REPORTED.
TESTING CONDITIONS AND ENVIRONMENT SHALL BE NOTED.
DESCRIBE PROBLEM FAILURE COMPLETELY AND ACCURATELY INCLUDING APPLICABLE INFORMATION IE: SPECS AND OR DRAWINGS.
INDICATE CAUSE OR PROBLEM FAILURE AND THE RESULTS OF P FR ANALYSIS.
CHECK APPLICABLE BLOCK
NORMALLY COMPLETED BY COG. ENGR. BUT QA MAY MAKE RECOMMENDATIONS
APPLICABLE TO PART OR PARTS INVOLVED.
RECORD "CORRECTIVE ACTION TAKEN" COMPLETELY.
INDICATE "DISPOSITION" AS DETERMINED BY "CORRECTIVE ACTION".
EFFECTIVITY POINT OR SCOPE OF "CORRECTIVE ACTION".
STANDARD DISTRIBUTION LISTS: BY RELIABILITY P FR GROUP "SPECIALS" BY QA GROUP.
PROVIDED AS A CONVENIENCE FOR ORIGINATORS INTERNAL CONTROL REFERENCES.
IF ACTUAL TIME NOT KNOWN, ENTER APPROXIMATE TIME AND SO INDICATE.
FOR JPL RELIABILITY P FR STAFF USE ONLY.
ORIGINATOR SPECIFIES THE RESPONSIBLE JPL COGNIZANT ENGINEERS NAME(S).
CHECK APPLICABLE BLOCKS TO INDICATE IF PERTINENT PART(S) ARE OF PRIMARY OR SECONDARY CAUSE OF PROBLEM FAILURE.
DOCUMENT EXPLICITLY ACTION INITIATED OR COMPLETED TO PRECLUDE RECURRENCE OF SUBJECT PROBLEM FAILURE.
ENTER ECR NO. IF CORRECTIVE ACTION HAS REQUIRED ISSUANCE OF AN ENGINEERING CHANGE REQUIREMENT (ECR)
DETERMINED BY SPACECRAFT PROJECT ENGR.
ENTER NAME(S) OF PERSONNEL NOT ON STANDARD DISTRIBUTION LIST, WHO SHOULD RECEIVE COPY COPIES OF A CERTAIN REPORT.
I
II
III
IV
V
P/FR RELIABILITY STAFF
JPL 1846 OCT 64
DISTRIBUTION
COPIES OF ALL PROBLEM FAILURE REPORTS WILL BE DISTRIBUTED TO ALL CONCERNED PERSONNEL.
STANDARD DISTRIBUTIONS, BY PROJECTS, WILL BE ESTABLISHED BY RELIABILITY, AND CONCERNED EXECUTIVE PERSONNEL.
USAGE
THIS INSTRUCTION FORM REFERS EXCLUSIVELY TO PROPER USAGE OF PROBLEM FAILURE REPORT FORM JPL 1846.
THIS FORM(JPL 1846) IS USED TO RETYPE AN ORIGINAL P FR FROM FORMS JPL 1290(JPL PERSONNEL USE), OR JPL 1798 (VENDOR P FR).
USE SYMBOL "N A" ON SUBJECT P/FR FORM WHENEVER REQUESTED INFORMATION IN ANY BLOCK IS NON-APPLICABLE.
INSTRUCTION SHEET GENERAL P/FR

APPENDIX B

[X] Flight (S/C Ser. No. MC-1 (PTM) [X] **PROBLEM /** [ ] **FAILURE REPORT** № 003486
[ ] OSE (Complex Ser. No. STC)

1. PROJECT [ ] Ranger [X] Mariner [ ] Other
2. PROBLEM/FAILURE DATE: 27 Apr 64
3. LOG NO.: SAF #186

	A) REFERENCE DESIGNATIONS	B) NOMENCLATURE	C) SERIAL NUMBER	D) OPERATING TIME
4. SUB-SYSTEM				
5. ASSEMBLY	11	Solar Panel Installation	PTM	N/A
6. SUB-ASSEMBLY				

7. REPORTING LOCATION [X] JPL Sec. 314 [ ] Vendor [X] SAF [ ] ETR Other

8. PROBLEM/FAILURE NOTED DURING [ ] Bench Testing [ ] In-Process Testing [ ] TA Testing [ ] FA Testing [X] Systems Testing [ ] Specific Environment [ ] Other

INITIAL DISTRIBUTION DATE

I

9. DESCRIPTION OF PROBLEM/FAILURE
After returning S/C to SAF from Thermo Control Test in 25 ft. chamber, many Mylar chips were found lying on upper Thermo Shields. They appear to be coming from Solar Panel Squib Harness and Solar Panel Arm Boots.

Originator T. Lanay Date 27 Apr 64 Cognizant Engineer B. Freeman/B. Carroll

10. VERIFICATION & ANALYSIS
The problem is caused by thermal and ultra-violet degradation of the aluminized 1/2 mil mylar material. The chips came from the brittle ultraviolet degraded portions of the sunlit solar panel squib harness wrapped with the mylar side exposed. Other sunlit areas of the harness and solar panel arm boots embrittled by thermal and UV degradation resulting from metallized coating being too thin to protect the mylar substrate from UV when material is stretched.

II

11. CAUSE OF PROBLEM/FAILURE [X] Design [ ] Piece Part Failure [ ] Operator Error [ ] Damage (Mishandling) [ ] Adjustment [X] Workmanship [ ] Manufacturing [ ] O.S.E. Failure [X] Other Misapplication

12. FOLLOW-UP ASSIGNMENT [ ] Cognizant Engineer [ ] Design Review [ ] Vendor [ ] Components Evaluation Group [ ] Material Review Board [ ] Quality Assurance [ ] Other

13. PART DATA

A) PIECE PART NAME & NUMBER	B) SERIAL NO.	C) CIRCUIT DESIG.	D) MANUFACTURER	E) DEFECT	F) PRI.	G) SEC.

PERSON COMPLETING SECTION II Signature B. Freeman Date 7/1/64

14. CORRECTIVE ACTION TAKEN
All exposed sunlit cables to be wrapped with 2 mil aluminized white pigmented Tedlar. ECI's governing the change are as follows: #9621 - Harness Hardware Installation, Planetary Science, #9622 - Attitude Control Gas System, #9616 - Cabling Integration Installation, #9644 and #9620 - Upper and Lower Ring Harness Installations; respectively.

III

15. DISPOSITION [ ] Reworked [ ] Redesigned [ ] Readjusted [ ] Scrapped [X] Other N/A

16. EFFECTIVITY [ ] This Unit [ ] All Units [X] Other All flight units ECR No. 7601

Signature Cognizant Engineer s/ B. Freeman Sec. 351 Date 7/15/64 Signature Cognizant Sec. Chief s/ C. Levoe

IV

17. REVIEW CONCURRENCE
Reliability Coordinator s/ T. Samuels Date 7/27/64
Spacecraft Project Engineer s/ J. Casani Date 7/21/64

18. CLASSIFICATION [X] Critical [ ] Non-Critical

V

19. STANDARD & SPECIAL DISTRIBUTION
MAR-C

THIS COPY ACCOMPANIES MATERIAL

JPL 1846 OCT 64

Notes on corrective action (block 14):

1. Tedlar has materially better ultraviolet resistance than mylar.
2. Pigmented film helps prevent wrapping with the wrong side out.
3. 2-mil Tedlar will stretch less in wrapping than ½-mil mylar.

References

1. Anon.: Reliability Program Provisions for Space Systems Contractors. NASA NPC 250-1.

2. Anon.: NASA Procurement Regulations. NASA-NPC 400.

3. Office of Manned Spaceflight Program Standards: Reliability Program Evaluation Procedures. NASA SP-6002, Aug. 1963.

4. Anon.: Apollo Contractor Reliability Plans and Performance Evaluation Manual. NASA-NHB 5320.2.

5. Anon.: Contract Management and Delegation of Contract Administration Services and Related Field Support Functions. NASA-PRD 65-9, Aug. 13, 1965.

6. Anon.: Quality Assurance Provisions for Government Agencies. NASA-NPC 200-1A.

7. Anon.: Quality Program Provisions for Space System Contractors. NASA-NPC 200-2.

NASA-Langley, 1967

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

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