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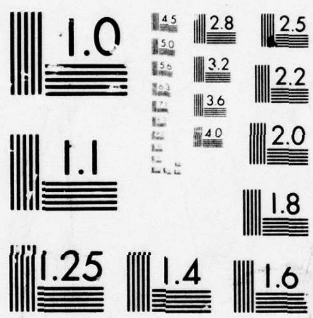

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PROGRAM MANAGEMENT COURSE
INDIVIDUAL STUDY PROGRAM

A PRACTICAL GUIDE TO RELIABILITY

STUDY PROJECT REPORT
PMC 76-2

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Major USA

FORT BELVOIR, VIRGINIA 22060

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DEFENSE SYSTEMS MANAGEMENT COLLEGE

STUDY TITLE:

A PRACTICAL GUIDE TO RELIABILITY

STUDY PROJECT GOALS:

To develop an illustrated booklet which serves as a general introduction to the basic concepts of reliability and how it is achieved during the system acquisition process.

STUDY REPORT ABSTRACT:

Most reliability references place heavy emphasis on the mathematics of measuring reliability and relatively little emphasis on the actions which contribute to a product's reliability. This ~~50 page~~ booklet emphasizes how reliability is achieved during the military systems acquisition process. It is aimed at those involved in project management and others who require an introductory reference of reliability principles and practices. After a brief discussion of reliability definitions and concepts, the booklet traces reliability program efforts beginning with the setting of realistic requirements and continuing through design, development, and production. Each page of discussion is accompanied by a page of illustrative curves and figures.

KEY WORDS: RELIABILITY; HANDBOOK; GUIDE; RELIABILITY TESTING

NAME, RANK, SERVICE	CLASS	DATE
EDWARD M. LEE, JR. MAJOR, US ARMY	76-2	17 November 1976

A PRACTICAL GUIDE TO RELIABILITY

Study Project Report

Individual Study Program

Defense Systems Management College

Program Management Course

Class 76-2

by

Edward M. Lee
Major USA

November 1976

Study Project Advisor
CDR Jerry Chasko, USN

This study project report represents the views, conclusions and recommendations of the author and does not necessarily reflect the official opinion of the Defense Systems Management College or the Department of Defense.

Executive Summary

A PRACTICAL GUIDE TO RELIABILITY

Assorted military handbooks and other detailed references abound for the specialist in the field of reliability. However, most of the references are too detailed and too mathematical to be useful as an introduction to reliability for students of project management and for others who seek only a familiarity with basic principles. For these individuals, there is a need for a brief discussion of what reliability is and how it is achieved during the systems acquisition process. This booklet is an attempt to fill that need.

ACKNOWLEDGEMENTS

I wish to thank the many people who contributed information for this booklet. Special thanks go to my wife Brenda for her long hours of graphic work; to Sylvia Spencer for her invaluable last minute typing; and to Mr. Carl Wigginton of Naval Air Systems Command whose many references, rich experience, and freely given time really made this endeavor feasible.

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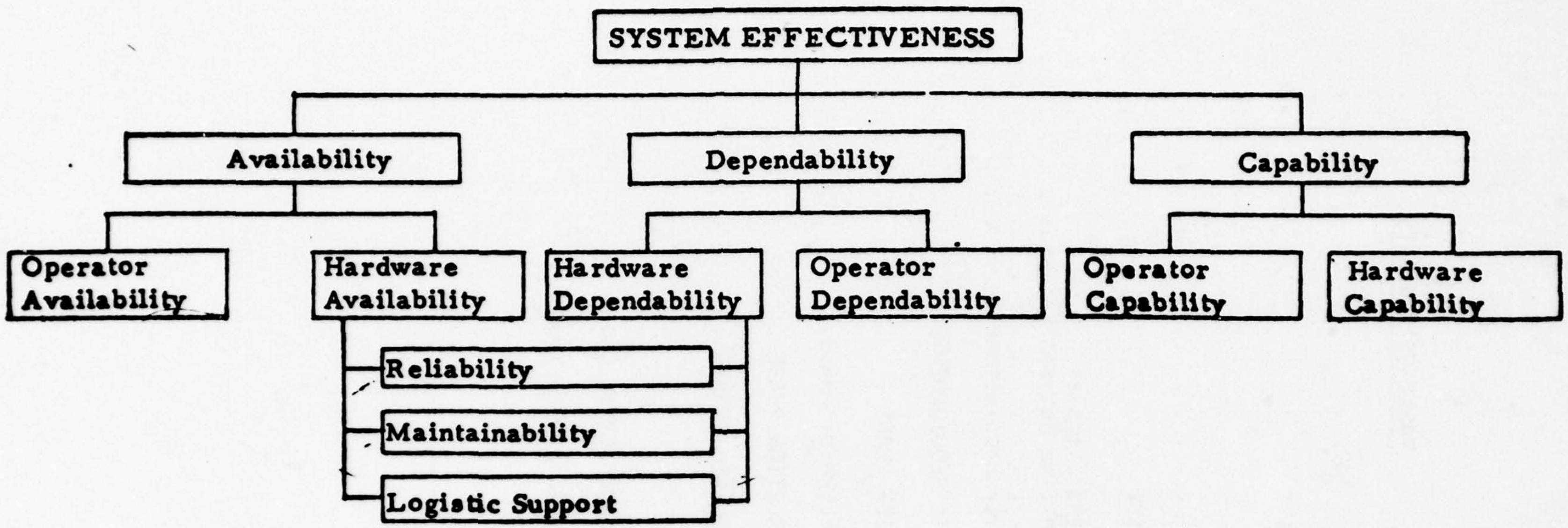

SYSTEM EFFECTIVENESS
Availability
Dependability
Capability
Operator Availability
Hardware Availability
Hardware Dependability
Operator Dependability
Operator Capability
Hardware Capability
Reliability
Maintainability
Logistic Support

Fig. 1

INTRODUCTION

Reliability as a formal discipline in design and production is relatively new; yet the concept is old. The designers of the first steam ships were concerned about the ability of the boilers and engines to withstand the long transocean crossing; therefore, they provided redundancy in the form of sails. Long after electric starters became standard equipment on American automobiles, hand cranks were still provided to insure reliable starting. In the past, designers were concerned with the same questions which are raised today in connection with reliability: Will the device work when it is needed? Will it work long enough to perform its intended function? What are the costs (both monetary and opportunity) associated with a failure? The concern today is even greater, because the consequences of unreliable weapons and equipment are graver--in terms of cost, in terms of safety, and in terms of accomplishing the mission.

Assorted military handbooks and other detailed references abound for the specialist in the field of reliability. However, most of the references are too detailed and too mathematical to be useful as an introduction to reliability for students of project management and for others who seek only a familiarity with basic principles. For these individuals, there is a need for a brief discussion of what reliability is and how it is achieved during the systems acquisition process. This booklet is an attempt to fill that need.

SYSTEM EFFECTIVENESS

A discussion of reliability should begin by relating it to the overall measure of a system's *utility:* system effectiveness. The effectiveness of a system can be viewed as a combination of three factors, availability, dependability, and capability (figure 1).

Availability - Is the system ready to operate when called on?

Dependability - Will the system continue to operate properly for the required duration of the mission?

Capability (Performance) - If the system performs as designed, is it capable of accomplishing the mission?

Figure 1 is an oversimplification of system effectiveness because it omits a host of other factors which affect availability, dependability, and capability. However, the figure emphasizes three of the most important of these factors; reliability, maintainability and logistical support. In fact these three factors are so vital and so interrelated to availability and dependability (which is really synonomous with reliability) that they are usually taught and discussed together under the heading of RAM (reliability, availability, maintainability). This booklet focuses only on reliability partially for simplicity of presentation and partially because of the compelling logic that improvements in reliability ought to significantly decrease the need for maintenance and its associated logistic support.

HOWITZER RELIABILITY VS. MISSION LENGTH

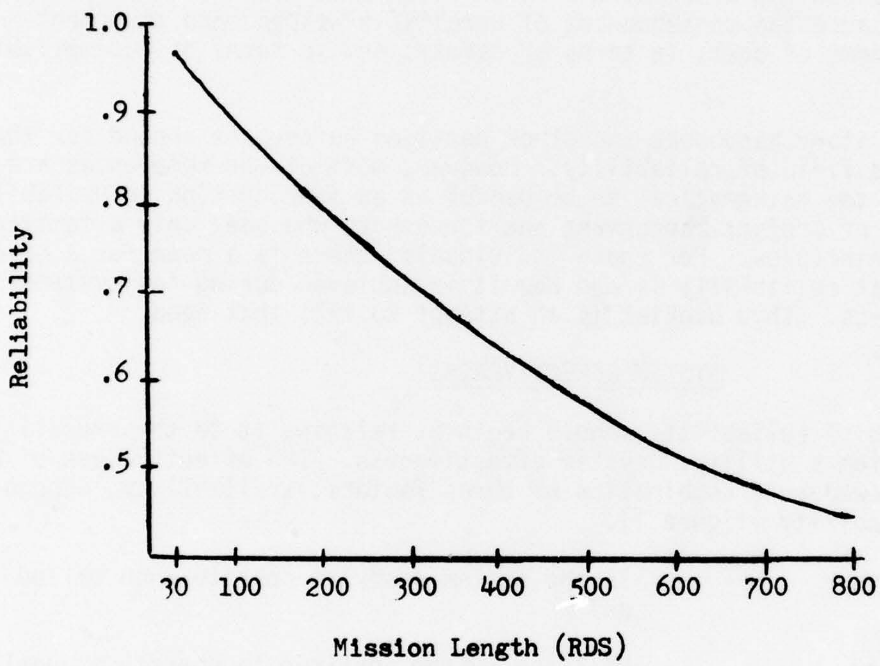


Fig. 2

DEFINITION OF RELIABILITY

Reliability is a quantitative concept. It is the probability that if an item is put to use under specified operating conditions, it will perform its intended function for a specified interval. (The interval can be time, miles, cycles, rounds, etc.)

How is reliability computed? To answer that question, let us consider the meaning of "probability." If an experiment is performed under identical conditions N times, and a particular result occurs A times, the probability of A's occurrence, P(A), is defined as the limit of the ratio A/N as N becomes infinite.

$$P(A) = \lim_{N \to \infty} \frac{A}{N}$$

In practice we perform the experiment some reasonably large number of times and use the resulting ratio, A/N, as an estimate of the true probability to predict the outcome in the future. To see how probability relates to reliability we will look at two examples. The first is an artillery piece example for which the specified reliability interval is consecutive rounds fired. The second example is electronic components, for which the specified interval is operating time.

Example #1. Artillery Howitzer. Consider the development of a new type of artillery howitzer. We would like to estimate the probability that the howitzer will fire a round in 125°F weather without misfiring or jamming. If we test 10,000 rounds and observe only 10 misfires (failures), we could estimate that the probability of firing any single round successfully is:

$$P(\text{success, 1 round}) = \frac{9990}{10{,}000} = .999$$

Now, an artillery officer might ask the question: what is the probability that the howitzer can fire 30 consecutive rounds during a mission without any failures? According to the laws of probability, the probability of any number of independent events occurring consecutively is equal to the product of the probabilities of occurrence for each single event. Thus, the probability that all of the 30 consecutive rounds will fire successfully is:

$$(.999)(.999)(.999)........(.999) = (.999)^{30} = .97$$

After this calculation, we have now specified all of the elements of reliability: a probability (.97), an operating condition (125°F), a function (firing), and an interval (30 rounds). Under these conditions, the reliability of completing the mission is .97. If we repeat the probability calculation for various numbers of rounds and plot the results, (figure 2), we can show how reliability varies for missions of from 30 to 800 rounds in length.

Another useful way to express the reliability of this howitzer is by its mean rounds between failure (MRBF). For this example, the mean rounds between failure is computed as:

$$MRBF = \frac{\text{Total Rounds Fired}}{\text{Total Number of Failures}} = \frac{10{,}000}{10} = 1000 \text{ rounds}$$

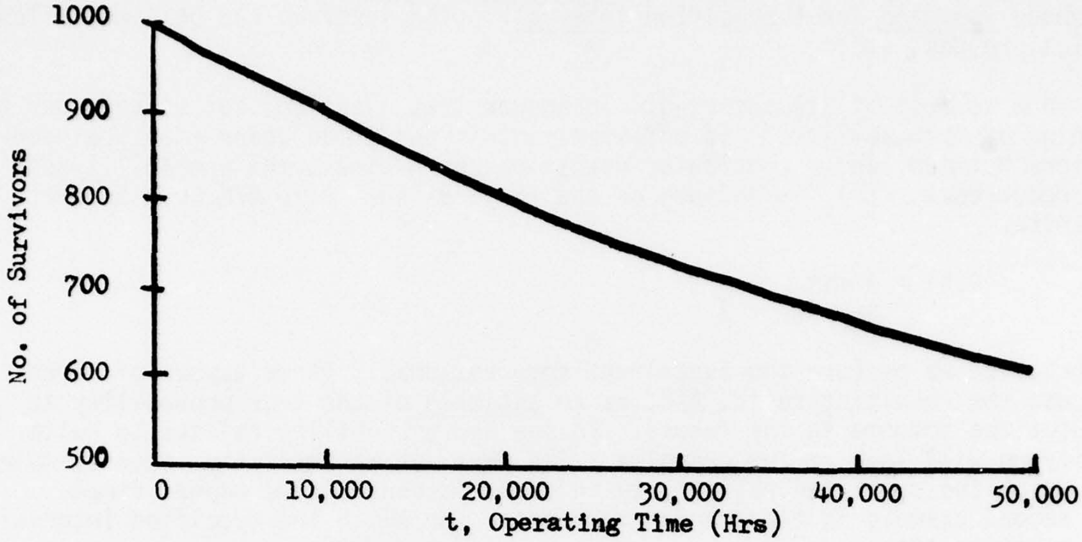

1000
900
800
700
600
500
No. of Survivors
0
10,000
20,000
30,000
40,000
50,000
t, Operating Time (Hrs)

Fig. 3a

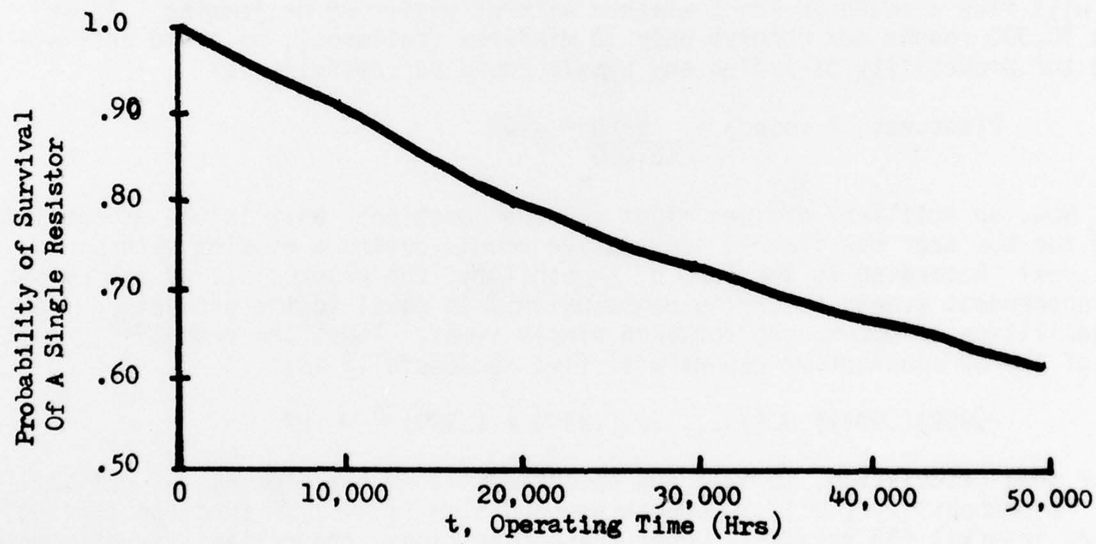

1.0
.90
.80
.70
.60
.50
Probability of Survival
Of A Single Resistor
0
10,000
20,000
30,000
40,000
50,000
t, Operating Time (Hrs)

Fig. 3b

In the first example, time was not a factor. There was little difference whether the mission was accomplished in two hours or ten hours (assuming the operating conditions were unchanged, of course). However, for most items of hardware, mission success is related to time or some time-dependent variable such as miles or cycles. The next example illustrates this for the case of an electronic component.

Example #2. Electrical Resistor. Consider a particular type of electrical resistor. We would like to know the possibility that this type of resistor will be able to operate continuously at 50°C for 50,000 hours (about 6 years) without failing. We could estimate this probability by applying our earlier definition of probability, A/N, i.e., performing an experiment N times and observing the number of times (A) the resistor specimen was still in operation after 50,000 hours. There is no reason why we could not conduct all of the experiments concurrently, if we insured that each resistor operated independently. Starting with 1000 perfect[1] resistors (N), we might expect the results to look like figure 3a. As time passes resistors begin to faily one by one, the failures occurring randomly over time. The resistor failures are caused by a complex set of internal physical and chemical changes which result from applied stresses and the effects of time. After 50,000 hours, there are 607 resistors still operating (A). Therefore A/N = 607/1000 = .607 is our experimental estimate of the probability that any resistor of this type can operate for at least 50,000 hours.

By repeating the calculation for earlier values of time and corresponding numbers of still operational resistors, we can estimate the probability that for any given length of time, t, a resistor of this type would operate without failing. These probabilities are represented by the curve at figure 3b. Once again all of the elements of definition of reliability are present: probability, specified interval (time), function (operate), and conditions (50°C). Therefore, the curve in figure 3b is also a reliability curve for this type of resistor.

---

[1]By "perfect" resistors, we mean that there are no defective units or partially defective units which might have failed early in the test. Also, we must assume that this type of resistor does not significantly deteriorate or wear out within 50,000 hours. Similarly, example #1 assumes that even the longest mission length (800 rds in figure 2) does not exceed the wearout life of the howitzer.

Time (hrs)	No. Of Resistors Still Operating	No. Of Failures	Avg. No. Operating During t	Failure Rate
1000	990	10	985	$\frac{10/985}{1000\ hrs} = 1.015 \times 10^{-5}$
2000	980			
35,000	705	7	701.5	$\frac{7/701.5}{1000\ hrs} = .998 \times 10^{-5}$
36,000	698			
50,000	607	6	604	$\frac{6/604}{1000\ hrs} = .993 \times 10^{-5}$
51,000	601			

Fig. 4a

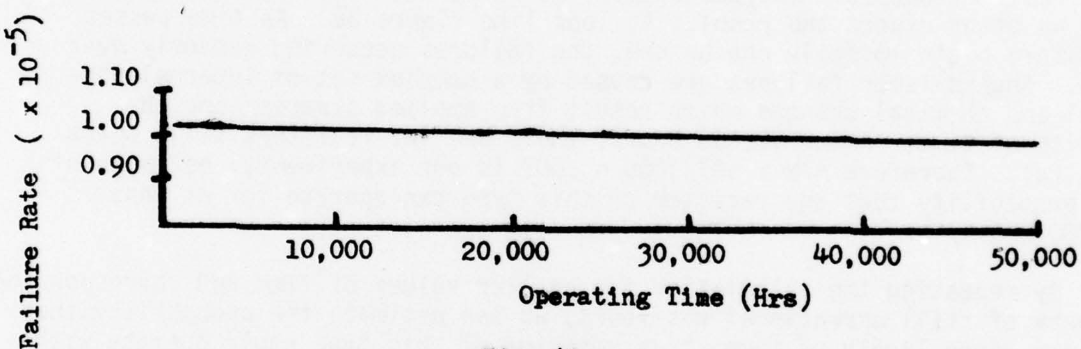


Fig. 4b

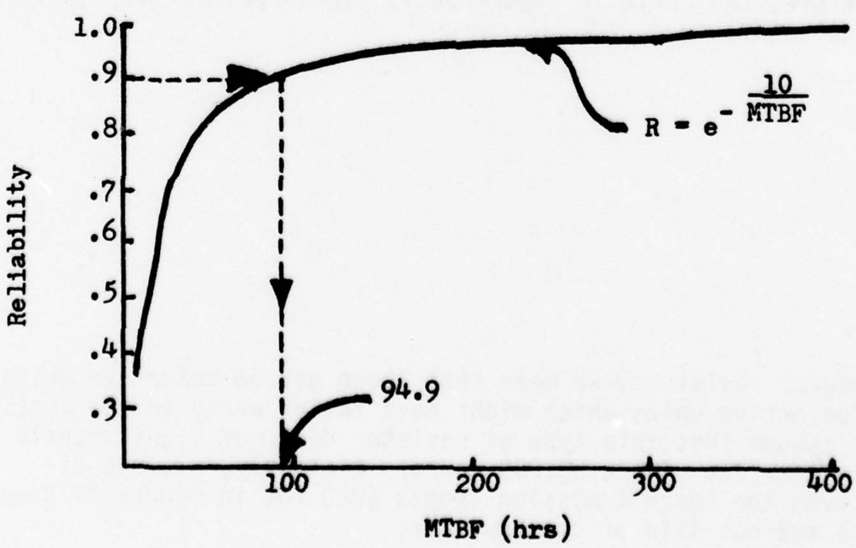


Fig. 4c

Failure Rate

Next, we need to discuss a key reliability parameter: failure rate. Failure rate is a measure of the number of failures experienced per unit of time, i.e., failures per hour or failures per 1000 hours, etc. When a number of units are being tested, the failure rate is computed by dividing the number of failures during some small time interval, t, by the average number of units under test during t, and then dividing again by t.

$$\text{Failure rate} = \frac{\text{No. of Failures in t/Average No. of units under test in t}}{t}$$

Defined this way, failure rate is relative rate, i.e., its dimensions are failures per unit under test per increment of time. If we looked at the detailed records for our resistor experiment, we could develop the matrix at figure 4a.

Note that for three separate time intervals, the computed failure rate was approximately constant. In fact, if we picked a number of time intervals from the hypothetical records, the computed failure rate would remain approximately constant, as shown in figure 4b. When this constant failure rate occurs in nature, it leads to a mathematical expression for reliability called an exponential function. For a constant failure rate, λ, the reliability, R, for any mission time, t, is given by the function $R = e^{-\lambda t}$. The curve in figure 3b represents this exponential reliability function for our resistor's constant failure rate of $\lambda = .00001$.[1]

Mean Time Between Failures (MTBF)

Another much used reliability parameter is the mean time between failures (MTBF). For items which have an exponential reliability function, i.e., constant failure rate, MTBF is the reciprocal of failure rate. For our resistor example, the MTBF is:

$$\text{MTBF} = \frac{1}{\lambda} = \frac{1}{.00001} = 100{,}000 \text{ hours per failure of a particular unit}$$

When referring to the reliability of a system or a piece of equipment, MTBF is useful because it relates readily to mission length. For example, consider a system which has a typical mission length of 10 hours and a tentative reliability requirement of .9. We would like to know (1) how large the MTBF for this system should be, and (2) how sensitive mission reliability is to variations in MTBF. If our piece of equipment has an exponential reliability function, then we know that:

$$\text{Reliability} = e^{-\lambda t} = e^{-t/\text{MTBF}} = e^{-10 \text{ hrs}/\text{MTBF}}$$

Solving this equation for MTBF gives us:

$$\text{MTBF} = \frac{-10}{\ln .9} = 94.9 \text{ hrs}$$

We could also have found the answer graphically by referring to the curve of $R = e^{-10/\text{MTBF}}$, shown in Figure 4c. The curve also indicates that to improve system reliability much above .9 requires a large improvement in MTBF; this might not be worth the cost and effort.

[1]In practice, today's resistors have failure rates which are 100 to 1000 times better than the figure used in our example.

COMPONENT LIFE CYCLE

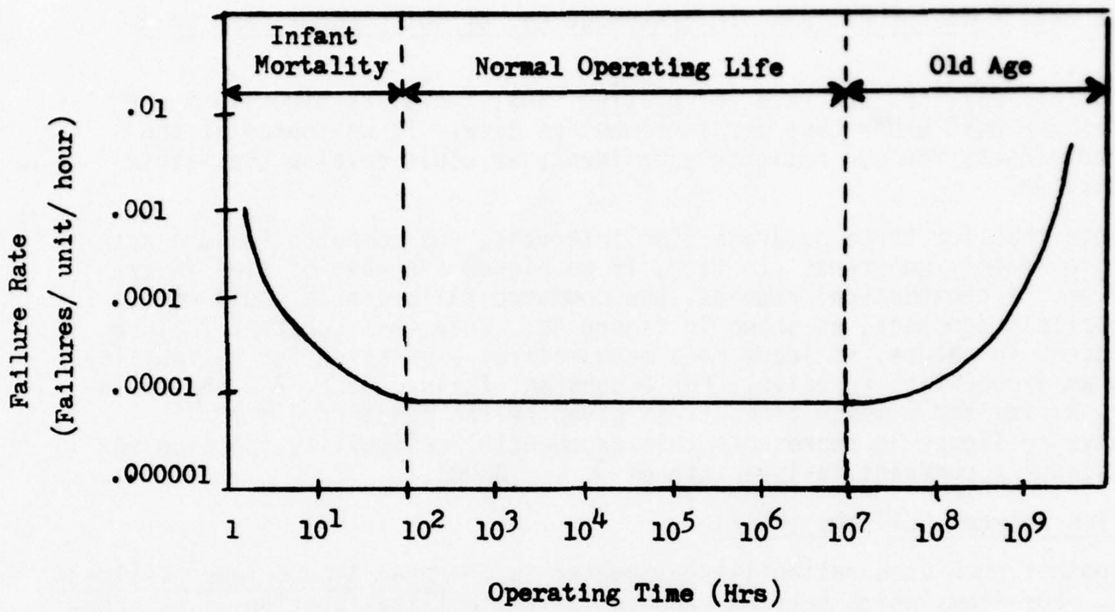


Fig. 5

The "Bathtub" Curve

In developing the discussion of the hypothetical resistor experiment, we stressed that the 1000 test resistors were "perfect", i.e., free from defects which would cause early failures. In reality, this is never the case. Due to the variability in manufacturing process and the fallibility of quality control inspections, any population of components will contain some defective or weak units. If the defect is serious enough to render the component inoperable initially (zero time defects) it would naturally be eliminated before it is put to use. However, many latent defects are not obvious until after power is applied and heat is generated. These "latent" defects contribute to a relatively high failure rate during the early stages in the life of component population.

If we were to use a real population of components in our resistor experiment, the actual curve representing the variation of failure rate with time would look like figure 5. During the first several hundred hours, the failure rate would be relatively high as the defective or weak components failed one by one. This period is referred to as the infant mortality or burn-in period. After the weak components are weeded out, the population failure rate settles down to a nearly constant level sometimes referred to as the "base" failure rate. This period is called the useful life period, because it is here that components are used to their greatest advantage. Had we continued our experiment beyond 50,000 hours, we would have reached the third typical period in life of components, the old age or wearout period. During this period the failure rate climbs as components begin to deteriorate rapidly.[1]

Limitations of the Exponential Reliability Function

Not all items exhibit failure rates which are constant over some portion of their life. Electrical components and some other parts usually do; and the exponential reliability function which results is very convenient to handle mathematically. But many items exhibit failure rates which increase or decrease with time because of some physical process such as gradual wearing, corrosion, or work hardening. When the failure rate is not approximately constant, the exponential expression for reliability is inapplicable. In such cases other mathematical functions such as the Weibull, the Normal, the Log-Normal, and the Extreme Value must be used. Most reliability texts contain detailed discussions of these reliability laws.

---

[1] As the operating time for a piece of equipment approaches the wearout time of one of its components, the component or part must be replaced during planned maintenance in order to avoid subsequent failures at inopportune times.

Item No.	Description	Failure Rate
1	Resistor	1.0×10^{-5}
2	Capacitor	5.0×10^{-5}
3	Resistor	1.0×10^{-5}
4	Diode	1.5×10^{-5}
5	Diode	1.5×10^{-5}
	Total	10.0×10^{-5}

Fig.6a

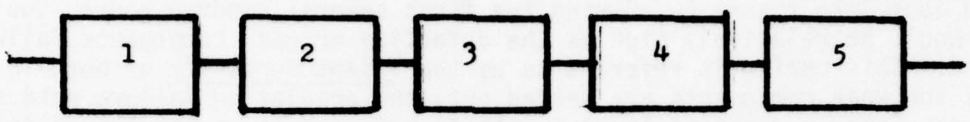


Fig. 6b

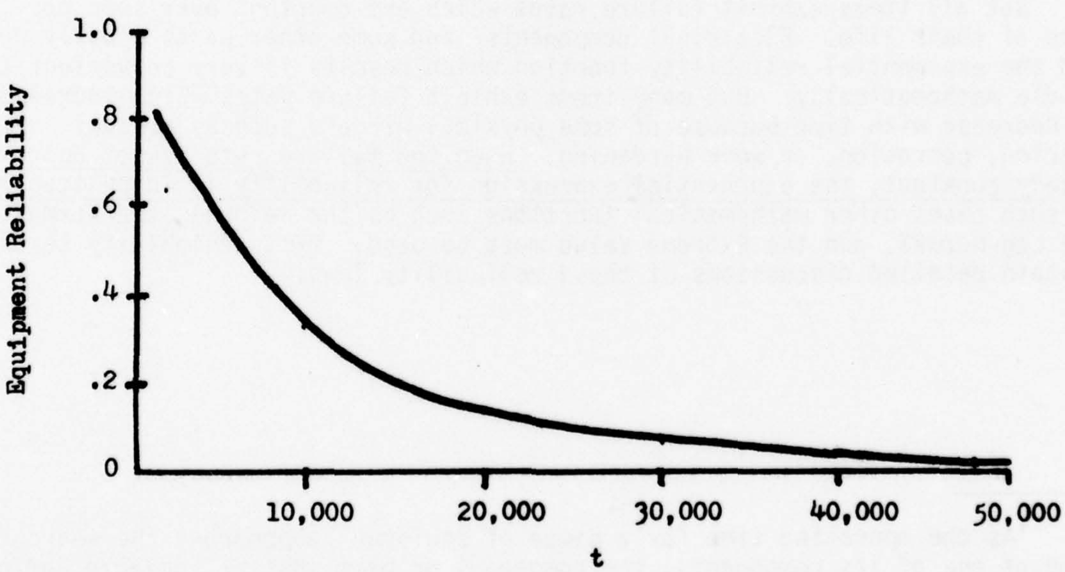


Fig.7

Hardware Reliability Prediction

Assume we build a small item of hardware using one of our resistors and four other electrical components. Assume we have tested each type of component to determine its failure rate and the results are at figure 6a. Further, assume we have connected the components in a series fashion such that failure of any one of them will cause a failure of our piece of hardware. Given a mission length, t, how do we calculate the reliability of the hardware item?

Since each component makes a contribution to the overall failure rate of the piece of hardware, we can simply add the individual failure rates to give a combined hardware failure rate.[1]

$$\text{Failure rate } (\lambda_h) = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5$$

$$\lambda_h = 1.0 \times 10^{-5} + 5.0 \times 10^{-5} + 1.5 \times 10^{-5} + 1.5 \times 10^{-5}$$

$$\lambda_h = 10.0 \times 10^{-5}$$

Now, using the hardware failure rate, we can compute the hardware reliability. from $R = e^{-\lambda_h t}$. This is plotted in figure 7 for any t.

Note how the reliability of the combination (figure 7) has been degraded compared to the reliability of our single resistor (figure 3b). The culprits were: (1) the fact that we had to use more components, all of which contributed to the unreliability of the system and (2) Item 2, which had a failure rate significantly higher than the other components. Imagine adding up the failure rates of the thousands of series components contained in some of our military systems: It is plain to see why two primary objectives of any reliability program are: (1) minimize the number of parts, and (2) choose the most reliable parts available within the constraints of cost, schedule, and space.

---

[1] In this example, adding failure rates is mathematically equivalent to multiplying individual reliabilities because we have an exponential expression for reliability:

$$R(\text{hardware}) = e^{-\lambda_h t} = (e^{-\lambda_1 t})(e^{-\lambda_2 t})(e^{-\lambda_3 t})(e^{-\lambda_4 t})(e^{-\lambda_5 t})$$

EFFECT OF MISSION LENGTH ON RELIABILITY

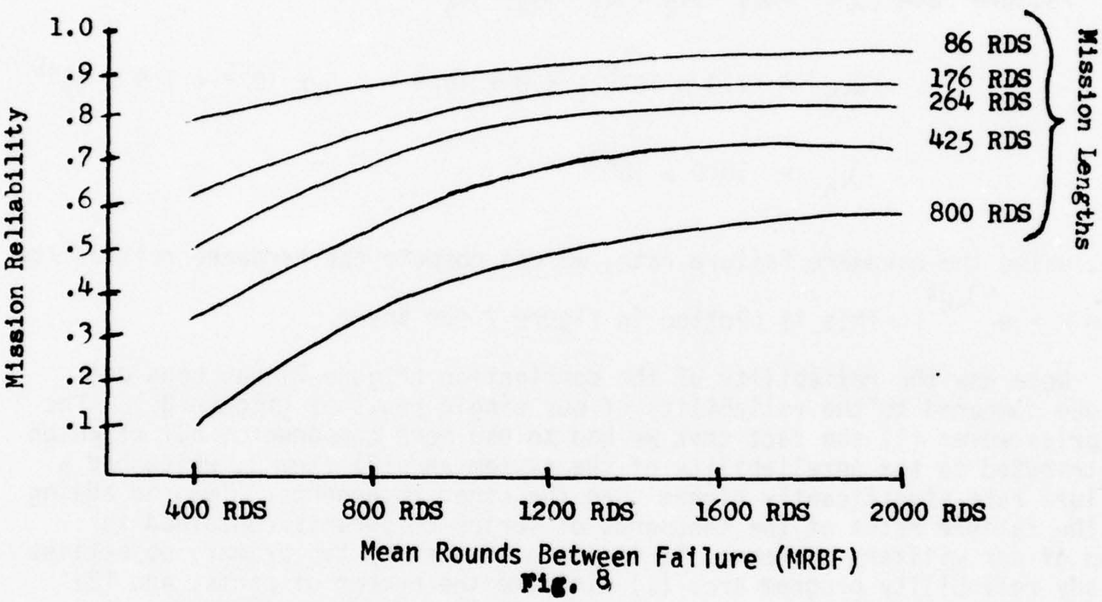


Fig. 8

A RELIABILITY PROGRAM

How are reliability requirements established? What steps does a contractor take during design, development, and production to enhance reliability? How does the government contract for reliable products and effectively manage a reliability program? What are some of the major obstacles and problems? These are the questions which the remainder of this booklet will address.

ESTABLISHING RELIABILITY REQUIREMENTS

Reliability begins with a realistic, achievable requirement. For military hardware, the requirement is established jointly by the military user and the military developer in the following manner.

The first step is to evaluate the reliability of systems currently in the field. This evaluation indicates the status of current reliability levels and the trends of reliability improvement.

The second step is to conduct a thorough systems analysis involving trade-offs between reliability levels, mission performance, and logistical factors. This analysis will indicate the reliability level which is actually needed and appears affordable. Figure 8 shows for a typical artillery piece an example of the sensitivity of reliability to mean rounds between failure (MRBF) with various assumed mission lengths.[1]

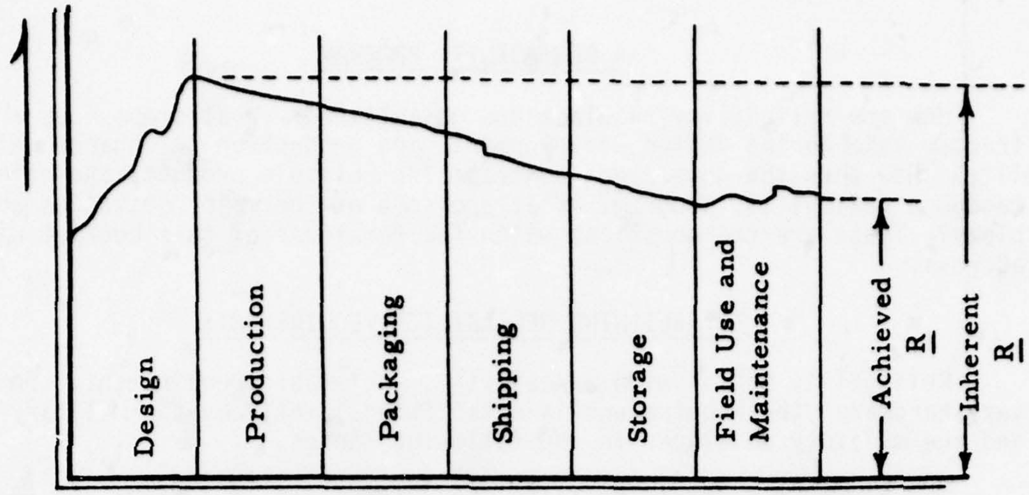
The third step is a technical assessment of the tenative requirement. This considers the technical feasibility of attaining the desired reliability goal, the schedule implications of striving for that goal, and such factors as the ability to determine by testing whether or not the equipment has reached its reliability goal.

The final result is a reliability requirement which is usually stated with two values: <u>a specified value</u>, which is the value the developer will use as a design requirement and a <u>minimum acceptable value</u>, which represents the least operational capability the user can tolerate.

---

[1]Probably the most crucial part of setting reliability requirements is developing a complete and accurate system definition. Figure 9 illustrates one of the major difficulties: what is a typical mission? 86 rounds? 425 rounds? or 50 rounds? Obviously, there can be a number of "typical" missions depending on the situation. In the case of aviation systems, the definition becomes even more difficult. Is an aircraft performing an intercept mission, a ground support mission, or a reconnaissance mission? Is an air-to-air missile flying for the first time or the tenth time? Clearly, different missions and operating modes may require different reliability requirements.

A complete definition of the mission must also include the anticipated environmental conditions in which the item may operate (levels of temperature, humidity, vibration, shock, salt spray, altitude, etc.) and the length of time in each.



Reliability During System Life

Fig. 9

TYPICAL MISSION PROFILE

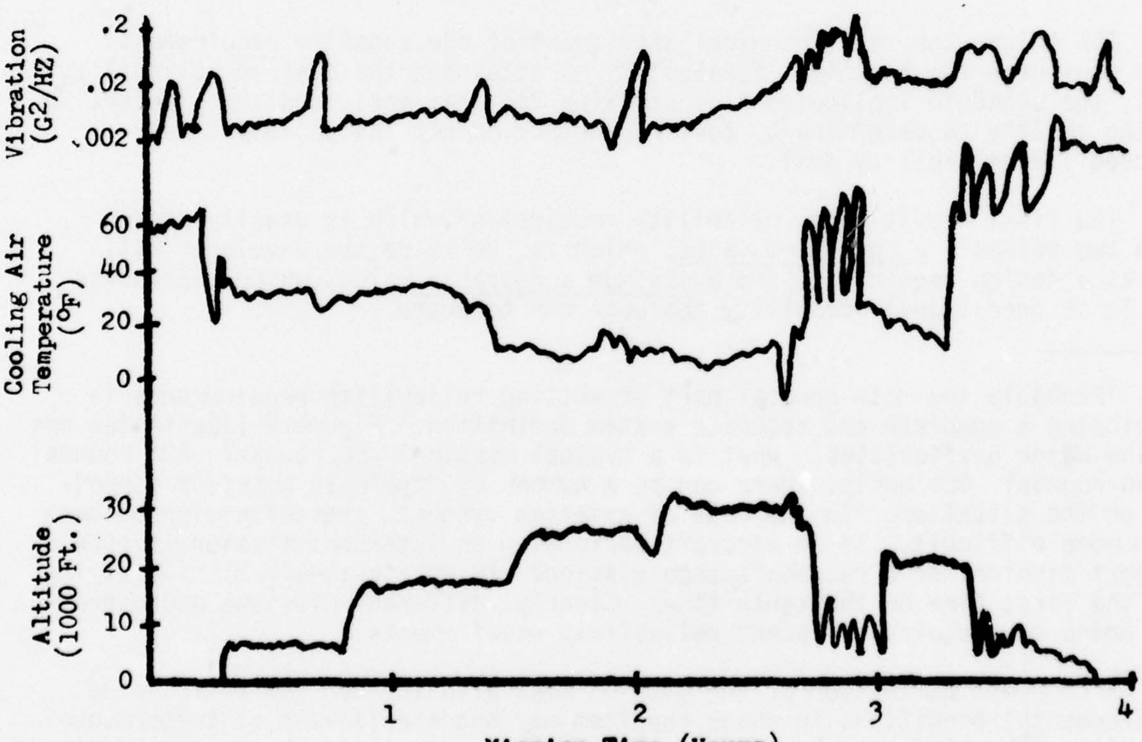


Fig. 10

RELIABILITY IN THE DESIGN PHASE

The reliability of a product depends primarily on its design. The best manufacturing techniques and the most thorough testing cannot improve an item's reliability beyond that which is inherent in its design. It is here that the designer must make tradeoffs with performance and use special techniques to enhance reliability (figure 9).

The following list summarizes some basic techniques which are used during the design phase.

1. Know the True Environmental Conditions
2. Keep the Design Simple
3. Develop an Accurate Model.
4. Select Reliable Parts
5. Apply Parts Properly in the Design
6. Conduct Thorough Design Reviews

These techniques are not employed strictly in the order listed because the process is very iterative. (Analysis discovers problems which require redesign using different parts and so forth.) A brief discussion of each technique follows.

Know the True Environmental Conditions

Overall environmental conditions are well known even before the design phase begins. However, the environmental conditions so defined are more descriptive of the whole system rather than of its elements. The designer must determine the appropriate levels of temperature, vibration, etc. for each location within the system. Detailed environmental profiles may identify local extremes which dictate relocation of sensitive items to a more environmentally benign location. Figure 10 shows a typical profile for three elements of the environment during a four-hour aircraft mission.

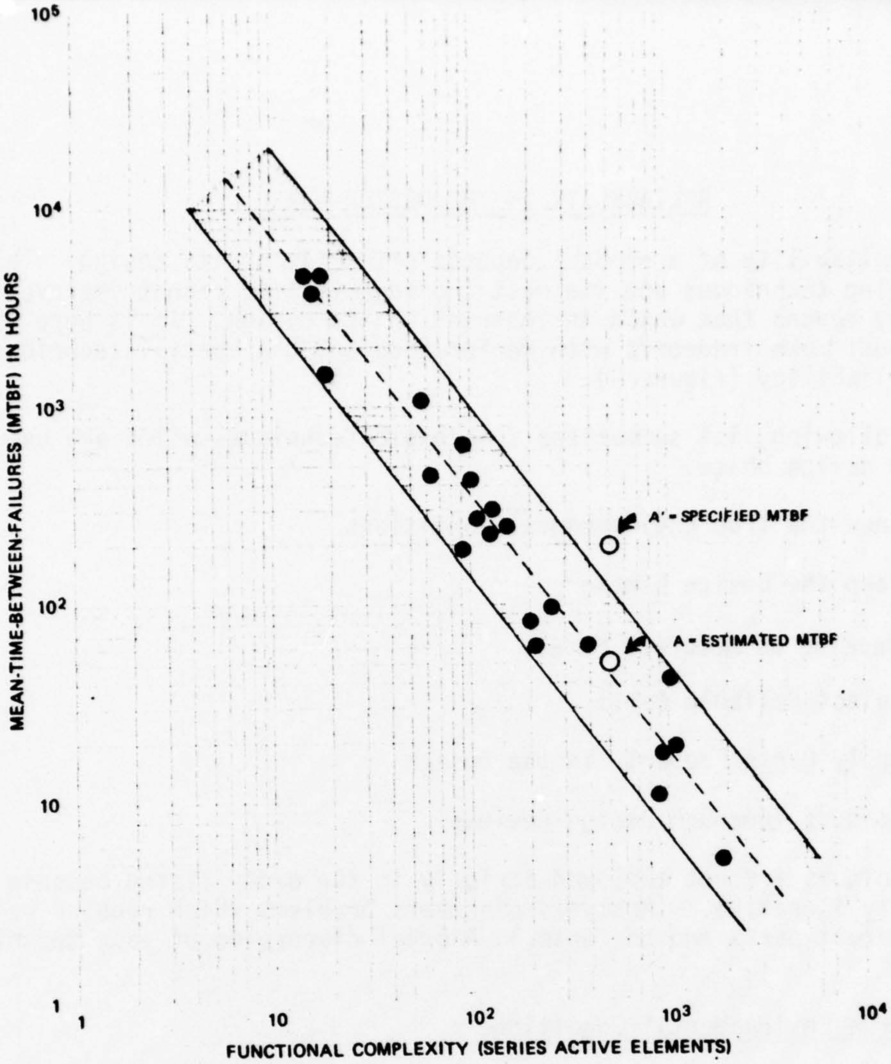


Fig. 11

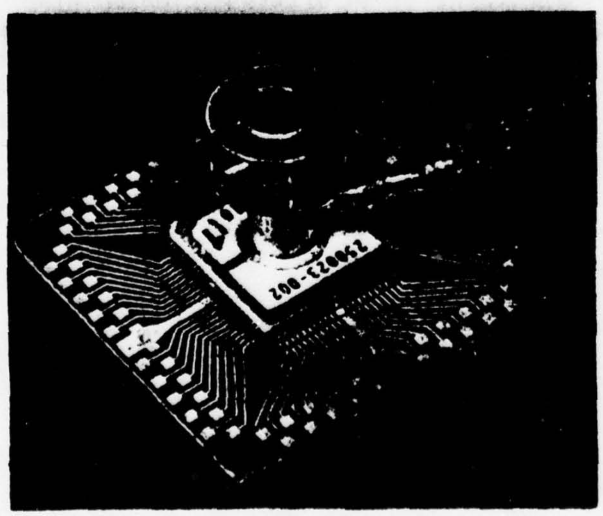


Fig. 12
Integrated Circuit With Finned Stud For Cooling

Keep the Design Simple

The need for simplicity is as important to reliability as it is to so many other aspects of our complicated lives. Yet, the demands of complex mission performance requirements and the natural inventiveness of engineers can act as powerful forces to undermine simplicity. Field records show unmistakable correlation between poor reliability and unnecessarily complex designs utilizing parts which do not have a proven track record of reliable performance.

A fundamental goal of every designer should be to minimize the total number of parts, either by clever design, by combining several parts into one, or by assigning several functions to one part. Until recently, one could demonstrate a rather accurate inverse mathematical relationship between the number of discrete "active" electronic elements in a design and the inherent reliability of the resultant piece of hardware (figure 11). In recent years, more widespread use of integrated semi-conductor circuits (figure 12) has brought about such improvement in the reliability of electronic components, that this relationship is no longer strictly applicable, but the fundamental principle of low parts count is.

Curiously, as integrated circuits have reduced the physical space required to package electronics, more space has been created to pack in additional electronics. Thus, the battle to minimize the parts count is a never-ending one for the designer and the reliability engineer.

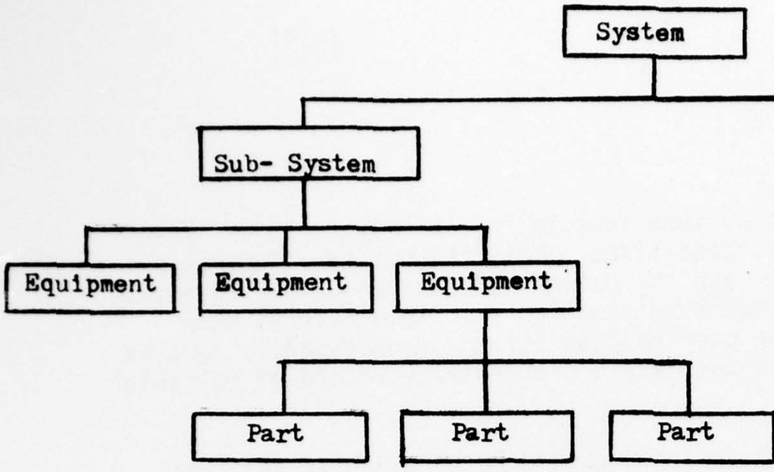
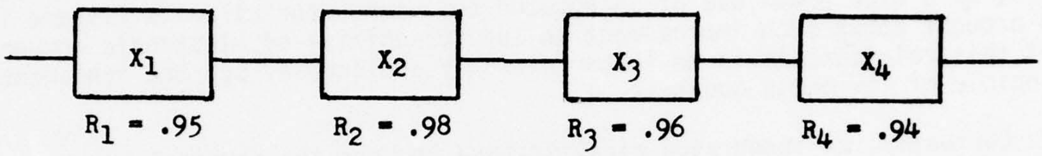
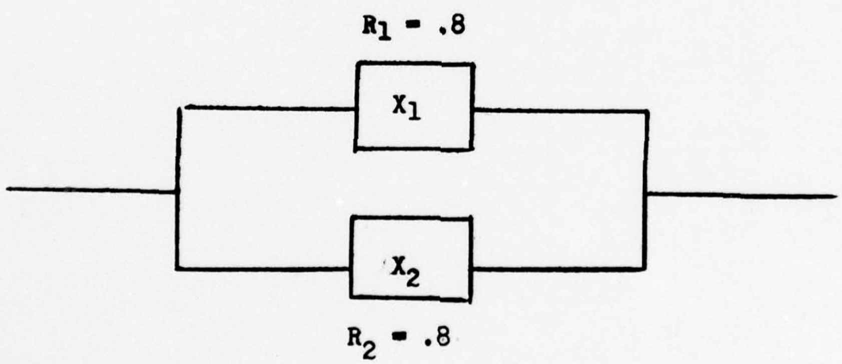


Fig. 13 a



$$
\begin{aligned}
R_s &= (R_1)\ (R_2)\ (R_3)\ (R_4) \\
&= (.95)\ (.98)\ (.96)\ (.94) \\
&= .84
\end{aligned}
$$

Fig. 13 b



$$
\begin{aligned}
R_s &= (R_s \text{ if } X_1 \text{ works})\ (\text{Prob. } X_1 \text{ works}) + (R_s \text{ if } X_1 \text{ fails})\ (\text{Prob. } X_1 \text{ fails}) \\
&= (1.0)\ (R_1) + (R_2)\ (1 - R_1) \\
&= .8 + (.8)\ (.2) \\
&= .96
\end{aligned}
$$

Fig. 13 c

Develop A Good Model

Developing a good reliability model actually begins in the conceptual phase. The first step is to completely define the system in terms of its various subsystems and items of equipment. This is essentially constructing a work breakdown structure of the hardware-related items (sometimes called a "system tree".) Figure 13a is a simplified example of such a system tree.

The second step is to construct a functional block diagram which indicates the functional relationship of all items in the system tree and the sequence in which they must perform for the system to operate successfully. This block diagram becomes very complicated, but it is constructed of combinations and modifications of just two basic model building blocks: the series block and the parallel block. In the series block, the failure of any one element causes a block failure. The reliability of the block is equal to the product of the individual element reliabilities (figure 13b). In a simple parallel block (simple redundancy) the failure of any one element does not affect the function which the block performs. Reliability of the parallel block R_S is found by repeated application of the following equation:

$$R_S = (R_S \text{ if } X_1 \text{ works})(\text{Probability } X_1 \text{ works}) + (R_S \text{ if } X_1 \text{ fails})(\text{Prob } X_1 \text{ fails})$$

Figure 13c illustrates the application of this equation for a two element parallel building block. Building on these basic series and parallel blocks, one then develops a mathematical equation which expresses overall system reliability in terms of the reliability levels of subsystems and pieces of equipment. This is the reliability model. (MIL-HDBK 217B has detailed discussion of modeling.)

How reliable must each subsystem and piece of equipment be in order to provide a desired overall system reliability? The first cut at answering this question occurs during the conceptual phase. Starting at the top of the system tree, reliability levels are allocated or apportioned among the various subsystems.[1] Assumptions are made about the degree of reliability one can realistically expect, given the state of the art and the reliability of similar items in current use. The allocation process is repeated at successively lower levels in the system tree until, as a rule, every item down to the equipment or equipment module level has been allocated a reliability goal or "budget".

During the development phase, design engineers begin selecting detailed parts and applying them in specific circuit designs. Reliability engineers assess the suitability of the design by calculating reliability predictions. The predictions are based on established or assumed failure rates for each component part and estimated part stresses such as voltage, power, temperature, etc. The reliability predictions build from the bottom of the system tree upward until an estimate for the system is predicted. At all levels, predictions are compared with previous allocations. Differences are resolved by redesign or re-allocation of the reliability budget. This iterative process is repeated throughout the design phase to insure that reliability is "designed in."

---

[1]The prudent designer usually starts with a design reliability goal which is at least 125% of the requirement, expressed in terms of MTBF. This provides an overall "safety factor."

RELIABILITY OF ELECTRONIC COMPONENTS

Classification	Reliability	Typical Uses	Cost Factor	Sources
Commercial/ Industrial	Varies by type and vendor	- TV, Hi-fi - Expensive Consumer Goods - Military ground support equip.	1	Any Vendor
Military Standard (MIL-STD)	5 - 10 X Commercial	- Tactical missiles - Tactical Commo Equip	2 - 3 X Commercial	Qualified Sources Only
High Reliability (HIGH REL) ER - Capacitors & Resistors JANTX/JANTXV - Diodes/ Transistors Class A - Micro-circuits	5 - 10 X MIL-STD	- Avionics - Satellites - Strategic Missiles - "Wooden Rounds"	5 - 10 X Commercial 2 - 3 X MIL-STD	Qualified Sources Only (Limited Number)

Fig. 14

Select Reliable Parts

Parts vary greatly in their reliability. A 100 ohm resistor used in a portable television may have a tolerance of ± 10%, a failure rate of 1 per ten thousand hours, and a cost of 8¢, while a 100 ohm resistor in a strategic missile probably has a tolerance of less than ± 1%, a failure rate of less than 1 per million hours, a cost in excess of $1. Choosing reliable electronic components depends not only on the required tolerances and basic failure rates, but also on the degree to which infant mortalities must be eliminated from the population.

Electronic components are generally classified into three reliability categories (figure 14).

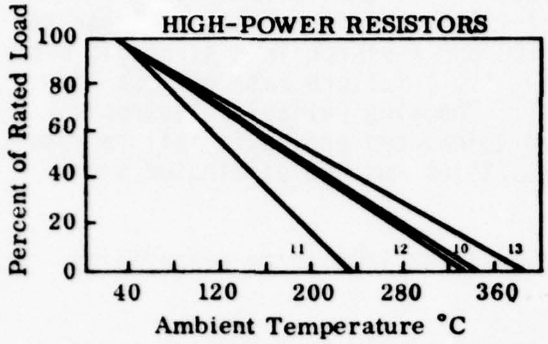
1. Commercial or Industrial. These are generally good quality parts which any vendor can design and manufacture to whatever reliability level is dictated by his market. These parts are typically used in such applications as television, hi-fi, radio, expensive consumer goods and some military ground support equipment.

2. Military Standard. These are higher grade parts available only from qualified sources who have manufactured and tested them according to strict military quality standards. They are roughly 5 - 10 times more reliable than commercial parts and are used in such items as tactical missiles, communication equipment, and vehicles.

3. High Reliability. "HIGH REL" components are the highest grade--roughly 5 - 10 times more reliable than MIL-STD parts. In addition to undergoing inspections after almost every step of the manufacturing cycle, these parts are subjected to an array of very stressing environmental tests. The objective is to screen out all units with latent quality defects--the infant mortalities. Applications such as aircraft avionics, satellites, strategic missiles, and "wooden round" tactical missiles generally require HIGH REL components.

If reliability is to be designed into a system, the reliability of the individual components must be known or at least estimated. Extensive testing of MIL-STD and HIGH REL parts has led to the development of standardized tables for base failure rates under varying conditions of temperature and voltage stress. By referring to these tables (or other lists of preferred parts), a designer can choose a part which has a proven failure rate consistent with the apportioned reliability goals for the article under design. Usually he cannot afford the luxury of calling out all HIGH REL parts. Due to the rigorous control under which they are manufactured and the relatively low percentage of parts which pass subsequent screening tests, the cost of HIGH REL parts is 2 - 3 times MIL-STD parts, and 5 - 10 times commercial equivalents. A further limitation is that there are a limited number of qualified suppliers and their output is limited.

MIL-HDBK-217 RESISTOR DERATING



Number	Style		Curve
26C	RW	Temp. V, Y	10
11804C	R		11
22A	RP	< 100 watt	12
		> 100 watt	13

Fig. 15

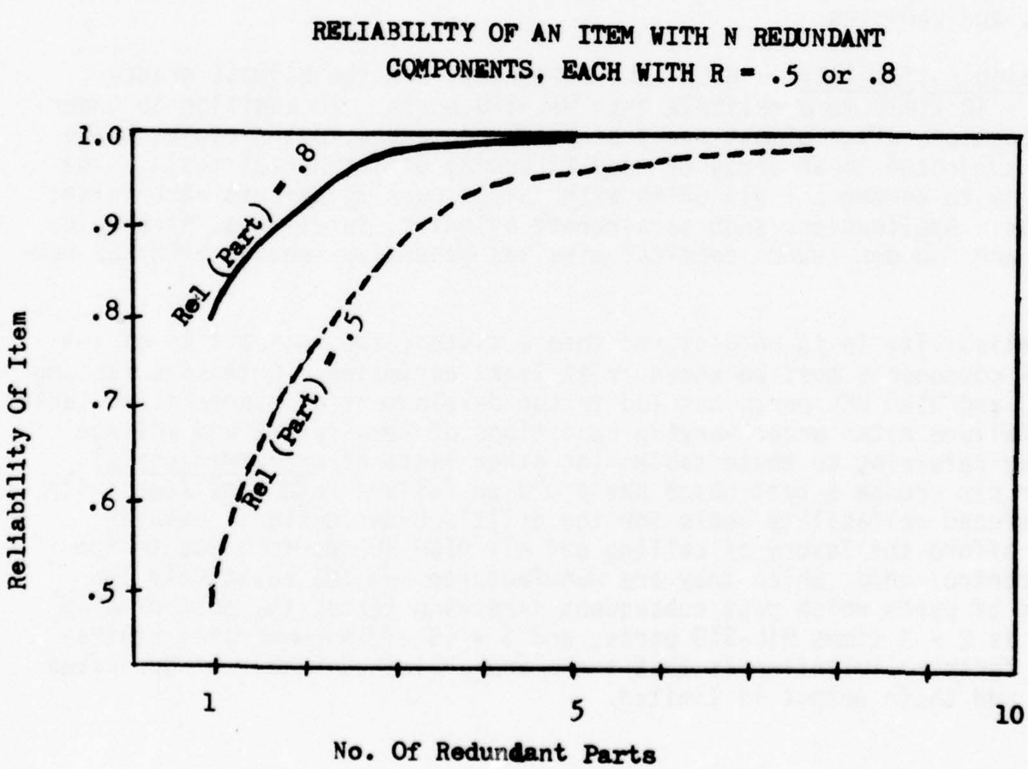


Fig. 16

Apply Parts Properly

After selecting reliable parts with (preferably) known failure rates, one must insure that their inherent reliability is not degraded by interactions within the design, such as excessive surges of electrical current or damaging heat generated from surrounding components. A number of analysis techniques are used to pinpoint potential problems. Several of them are:

- Worst Case Analysis, which evaluates design performance under all possible extremes of electrical and physical environment.

- Tolerance Analysis, which evaluates the build-up effect of individual part tolerances, each of which may be allowable, but the sum of which may cause unacceptable conditions.

- Failure Modes and Effects Analysis (FMEA), which predicts the most likely cause of failure for each part and then evaluates the impact of that failure on the remaining system. This produces a clear picture of likely failure patterns and critical parts.

Extensive design analysis will indicate the need to select different parts, or employ other design techniques to improve reliability. Three of these techniques are particularly important: derating, redundancy, and local environmental protection.

- Derating. Derating is simply applying a safety factor. For a mechanical part, it means choosing or designing the part to bear a larger mechanical load than the part is expected to encounter. For electronic components, it means limiting the use of a component to electrical loads which are less than those for which the part is designed or rated--thus, "derating." The degree of derating depends on factors such as operating temperature, power consumption, and other indices of stress. A sample derating chart for resistors is shown in figure 15.

- Local Environmental Protection. Local environmental conditions which are too severe to correct by relocation or derating may require special design features such as: fins to conduct heat away, seals to exclude humidity, or stiffeners to dampen vibration.

- Redundancy. Redundancy can be an effective way to improve the reliability of a critical part. Figure 13c showed how double redundancy increased the reliability of a component from .8 to .96. The solid curve of figure 16 demonstrates the further improvement possible by adding more redundant components.

The dotted curve of figure 16 illustrates one of the limitations of redundancy: if you don't start with a fairly reliable part, it takes a lot of redundancy to reach the .99 level. Other limitations which prevent the use of redundancy as a panacea include: (1)parts count goes up with correponding increases in heat, cost, and the number of individual part failures which must eventually be repaired; (2) redundant elements sometimes introduce additional failure modes; and (3) more sophisticated maintenance and test equipment and test circuitry are required to discern partial failures of a redundant element.

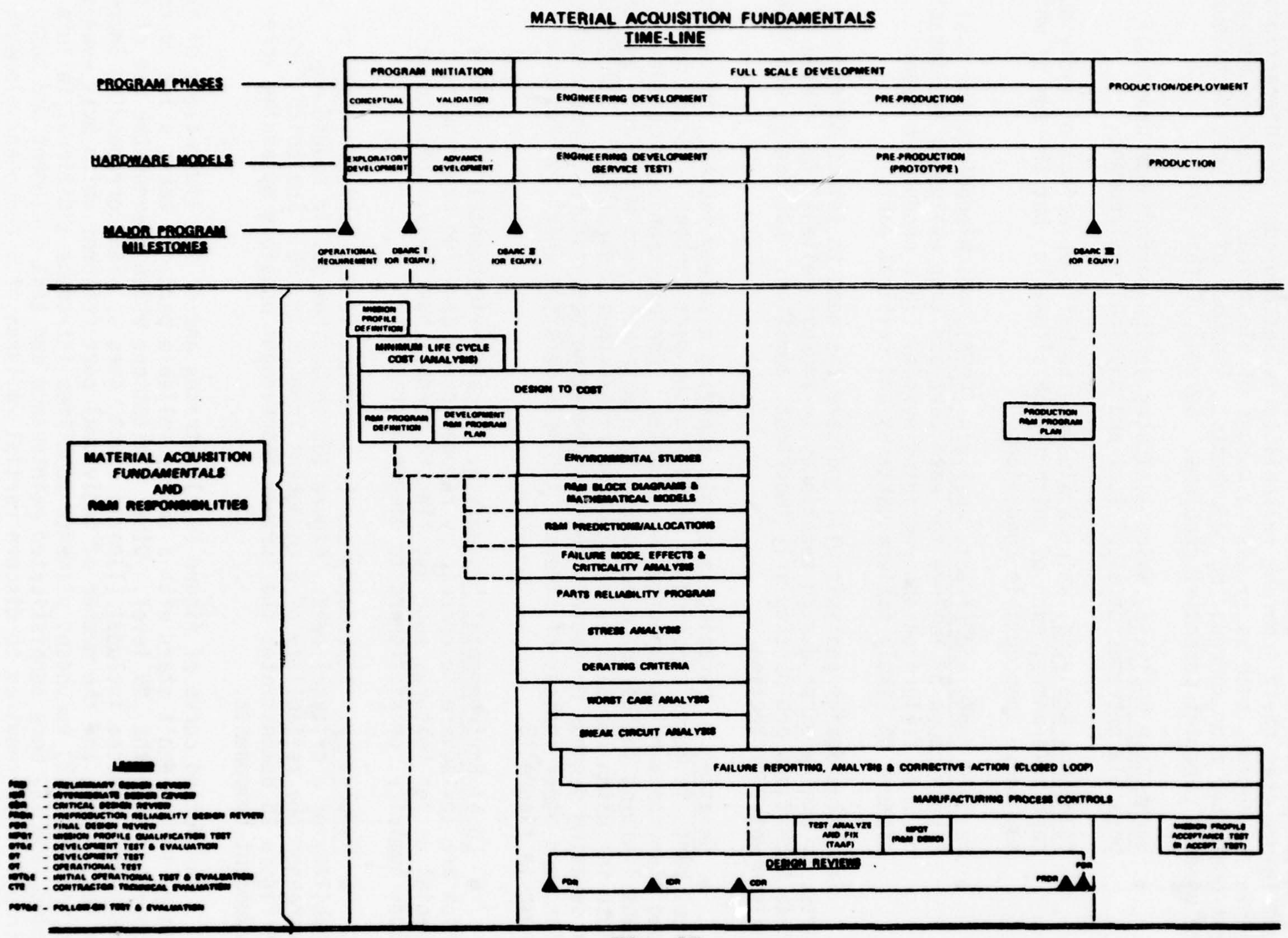

MATERIAL ACQUISITION FUNDAMENTALS
TIME-LINE
PROGRAM PHASES
PROGRAM INITIATION
CONCEPTUAL
VALIDATION
FULL SCALE DEVELOPMENT
ENGINEERING DEVELOPMENT
PRE-PRODUCTION
PRODUCTION/DEPLOYMENT
HARDWARE MODELS
EXPLORATORY DEVELOPMENT
ADVANCE DEVELOPMENT
ENGINEERING DEVELOPMENT (SERVICE TEST)
PRE-PRODUCTION (PROTOTYPE)
PRODUCTION
MAJOR PROGRAM MILESTONES
OPERATIONAL REQUIREMENT
DSARC I (OR EQUIV)
DSARC II (OR EQUIV)
DSARC III (OR EQUIV)
MATERIAL ACQUISITION FUNDAMENTALS AND R&M RESPONSIBILITIES
MISSION PROFILE DEFINITION
MINIMUM LIFE CYCLE COST (ANALYSIS)
DESIGN TO COST
R&M PROGRAM DEFINITION
DEVELOPMENT R&M PROGRAM PLAN
PRODUCTION R&M PROGRAM PLAN
ENVIRONMENTAL STUDIES
R&M BLOCK DIAGRAMS & MATHEMATICAL MODELS
R&M PREDICTIONS/ALLOCATIONS
FAILURE MODE, EFFECTS & CRITICALITY ANALYSIS
PARTS RELIABILITY PROGRAM
STRESS ANALYSIS
DERATING CRITERIA
WORST CASE ANALYSIS
SNEAK CIRCUIT ANALYSIS
FAILURE REPORTING, ANALYSIS & CORRECTIVE ACTION (CLOSED LOOP)
MANUFACTURING PROCESS CONTROLS
TEST ANALYZE AND FIX (TAAF)
MPQT (R&M DESIGN)
MISSION PROFILE ACCEPTANCE TEST (R ACCEPT TEST)
DESIGN REVIEWS
PDR
IDR
CDR
PRDR
FDR
CRITICAL DESIGN REVIEW
FINAL DESIGN REVIEW
MISSION PROFILE QUALIFICATION TEST
DEVELOPMENT TEST & EVALUATION
DEVELOPMENT TEST
OPERATIONAL TEST

Fig. 17

Conduct Thorough Design Reviews

Unfortunately, not all designers have the experience and attitude necessary to systematically consider every aspect of a design at the time it is being developed. Under the stress of time and pressure to meet performance requirements, other important areas often are neglected or compromised excessively. The next best thing to a design without errors is a design review which corrects the errors before they become "cast in hardware," so to speak.

Design reviews provide formalized periodic appraisal of the design to evaluate its progress in meeting all objectives--performance, reliability, maintainability, safety, etc. They bring specialized talent to bear on specific problem areas. The review team typically consists of one or two senior design engineers, several project engineers, a reliability engineer, a maintainability engineer, a value engineer, and other specialists such as metallurgists, human factors engineer, etc. as they are required. The optimal review team size is 10 - 15.

Prior to the review, each member is furnished with a data package and copies of applicable analyses to study. To insure that all important design considerations are reviewed, a comprehensive checklist is invaluable. A sample checklist is at Appendix A. Problems must be expected and frankly discussed by both designer and reviewer. The reviewer should not expect a finished, perfect product or else the designer will be forced to cover up problems to present a rosy picture, and the review concept will be of little use. Problems which cannot be solved on the spot are assigned as action items to specific individuals for resolution by a given time. The design review is not complete until all action items are resolved.

Within the DOD weapons system acquisition process, there are four broad categories of design reviews:

- Preliminary Design Review
- Interim Design Review
- Critical Design Review
- Production Design Review (or Final Design Review)

The approximate timing of these reviews in relation to other design activities is shown by figure 17. The actual number of design reviews held by military development agencies will depend on the number of critical decision points in a given program and the philosophy of the program management team.

Some often cited problems with government design reviews are: (1) they are omitted or shortened due to the pressure of time and money, (2) they are attended by an insufficient number of qualified people, particularly from the specialty disciplines whose criticism of the design later in the program is so costly and painful, and (3) follow-up on items requiring government action is inadequate and too slow.

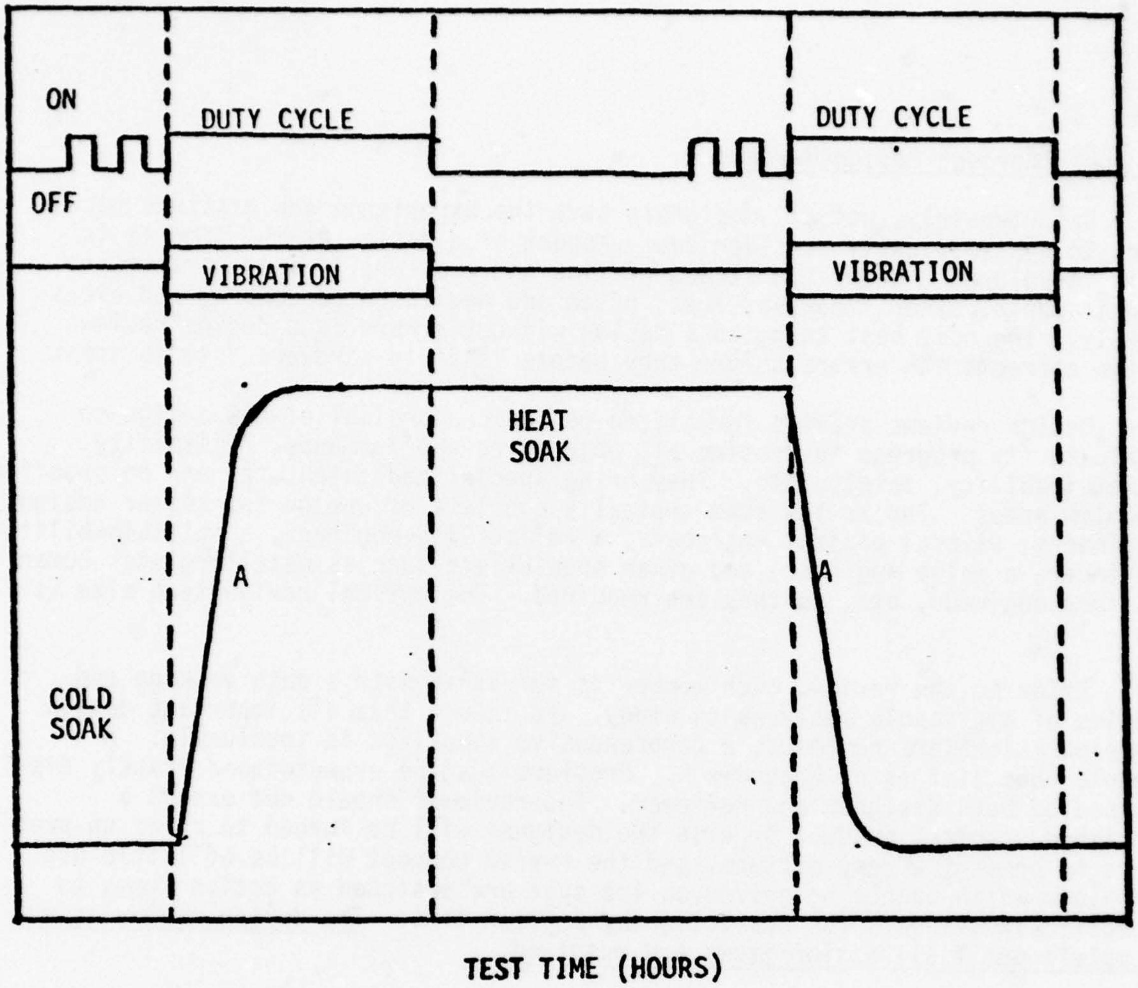

ON
OFF
DUTY CYCLE
DUTY CYCLE
VIBRATION
VIBRATION
HEAT
SOAK
A
A
COLD
SOAK
TEST TIME (HOURS)

Fig. 18

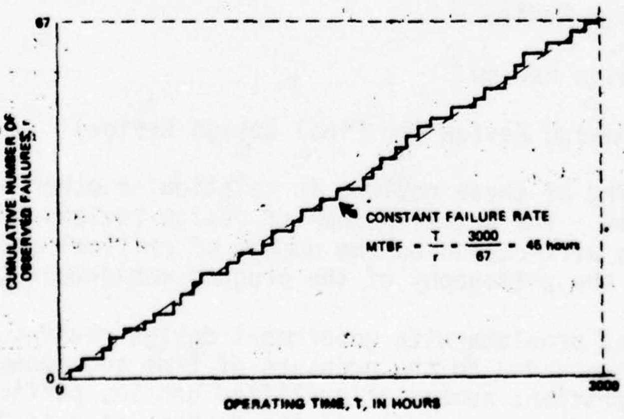

67
CUMULATIVE NUMBER OF OBSERVED FAILURES, r
CONSTANT FAILURE RATE
MTBF = T/r = 3000/67 = 45 hours
0
0
3000
OPERATING TIME, T, IN HOURS

Fig. 19

RELIABILITY IN THE DEVELOPMENT PHASE

When the design is complete on paper and it has been judged satisfactory, the construction of engineering models begin. These models are used for extensive testing to insure that the design meets all of its specified requirements--both performance requirements and reliability requirements. Tests are designed so that as much as possible, one test will provide data for several different purposes. For example, a test designed primarily to evaluate the performance of a radio under extremes of temperature could also yield valuable reliability data by indicating the effect of temperature on electronic module failures modes. This is an example of integrated testing, and it is a very important aim of all test planning.

Initial reliability performance is usually only a fraction of that predicted during the design phase. The reasons are many: unforeseen circuit interactions, unexpectedly large environmental stresses, poor quality parts, and so on. Improvement comes through long hours of testing, thorough analysis of all failures, and fundamental solutions to problems--in short, test, analyze, and fix (TAAF).

Testing

In terms of basic methods, there are generally two types of reliability testing: environmental testing and longevity testing.

o Environmental testing subjects equipment to a host of environmental extremes such as temperature, shock, vibration, fog, salt water spray, fungus, mud, etc. The purpose of this testing early in development is to assess the sensitivity of operating parameters to various environmental stresses and to detect unexpected failure modes. Later in development, environmental testing is used to demonstrate that a major subsystem or equipment is unaffected by specified environmental stresses. A typical environmental test profile (one cycle only) for temperature, vibration, and on/off switching is shown in figure 18.

o Longevity Testing evaluates MTBF trends over extended periods of operating time. The earlier described test of resistors was a form of longevity testing for component parts. Unlike a component, a piece of equipment is a repairable item. When a part fails, it is replaced and the test continues. MTBF is determined by (1) operating the equipment continuously, (2) repairing failures as they occur, (3) noting the total number of failures during the entire test period, and then (4) dividing the total test time by the total number of failures.[1] Figure 19 illustrates this procedure for a complex weapon control system which experienced 67 failures during a 3000 hour test.

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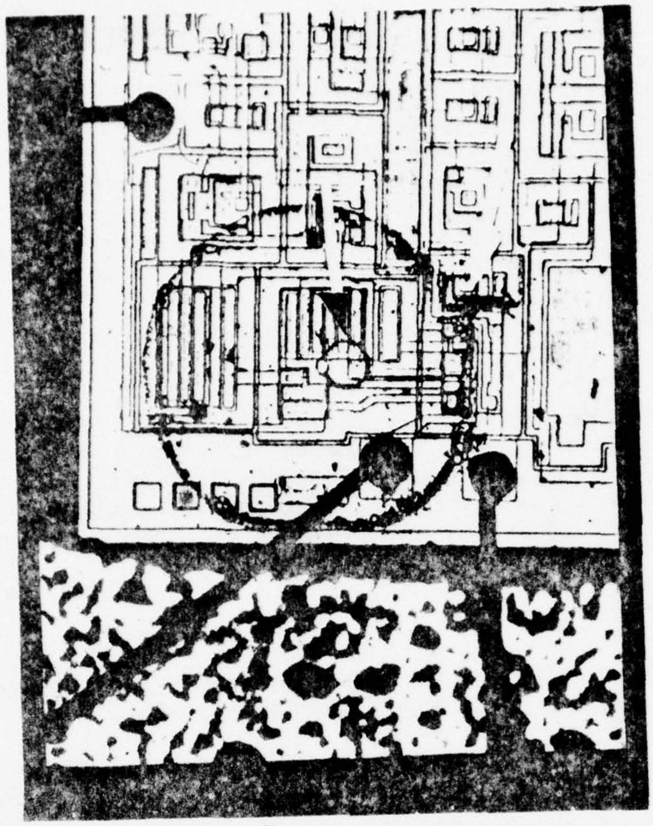
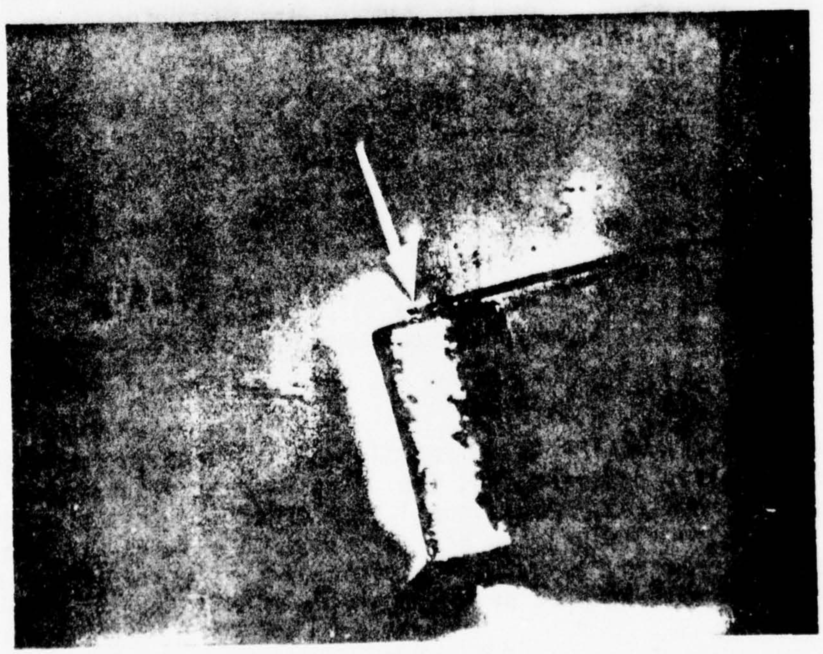
[1]This calculation of MTBF is valid only when the equipment follows an exponential reliability distribution, i.e., the rate at which failures occur must be reasonably constant. Additionally, in order for this procedure to give a true indication of MTBF, the design must remain fairly stable during the test. For this reason, longevity tests are not very meaningful during the early "breadboard" stages of development.



Bottom

Fig. 20



Bottom

Fig. 21

Failure Analysis

Testing alone does not improve reliability. It merely confirms what has been designed into the product. Every test failure must be recorded along with the prevailing test conditions and painstakingly analyzed. First, the apparent cause of failure must be isolated. To isolate a failure, the reliability engineer employs a range of electrical, mechanical, and chemical tests, chemical solvents, and optical techniques as sophisticated as the scanning electron microscope. He literally disassembles the failed item down to basic raw materials, if necessary. Figures 20 and 21 illustrate typical electronic component failures. Figure 20 pictures (75X) the lower left corner of an integrated circuit which was contaminated with a small drop of some chemical (dark arrow). After power was applied during operation, heat caused the chemical to spread until it caused a partial short circuit (light arrow). Figure 21 shows (also 75X) a transistor post from which the lead became separated after power was applied.

When the apparent failure has been isolated, the analyst must be sure he has found the root cause of the problem. Sometimes a part fails for a reason entirely unto itself. Other times a part begins to deteriorate, but as it fails, it induces a failure in a second part. (Reliability specialists euphemistically differentiate these types of failures as "suicides" and "murders.")

Corrective Action

Once the failure mechanism is thoroughly understood, the reliability engineer and the designer work together to provide a fundamental solution to the problem. The solution may be simple or it may require partial redesign. If the problem is a component quality problem, the solution may be to require the vendor to change his manufacturing process or institute tighter quality control on his current process; or the solution may be to use a different vendor. As a recent example, repeated test failures of a particular diode used in electronic modules were suspected to be linked to the plastic material used to encapsulate or "pot" the module. The encapsulating material, which was injected into the module under pressure and heat, was suspected of causing an excessive mechanical load on the diode. The problem was greatly reduced without redesign or a change in materials, merely by adding a soft plastic sleeve around the diode to cushion some of the load.

MISSILE RELIABILITY GROWTH
BY MODEL

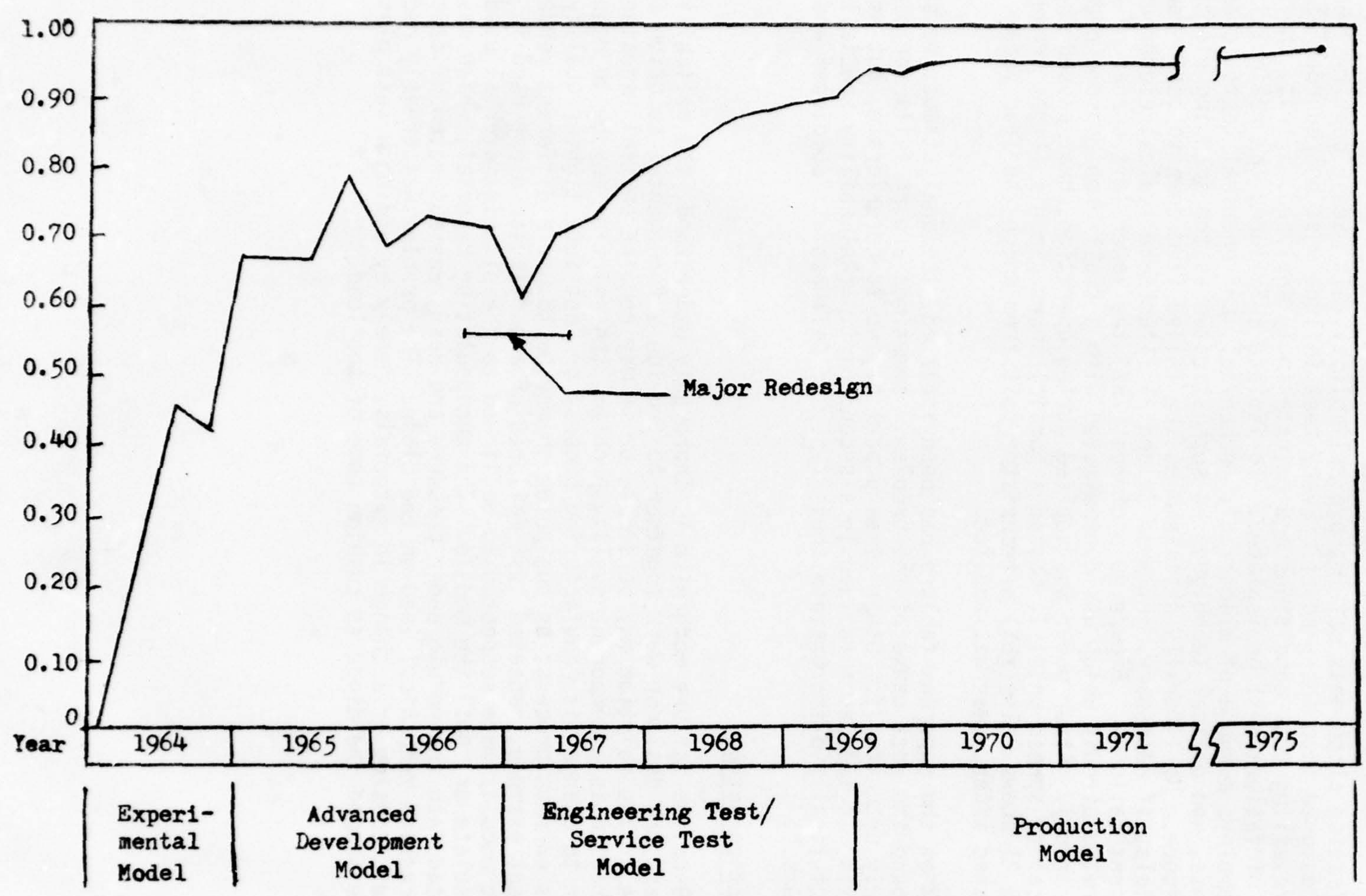


Fig. 22

Reliability Growth

If a development program has a vigorous reliability effort supported by extensive testing, analyzing, and correcting, the reliability of the product will continue to improve.[1] This is illustrated in Figure 22 for a typical tactical missile development. Testing commences in early development with small items and progressively builds up to major items of equipment and sub-assemblies. Restrictions of money and time sometimes force elimination of some step-by-step testing at lower levels. However, long experience has shown that solving problems at lower levels is much easier and less costly in the long run than discovering problems during major equipment or sub-assembly level testing.

Reliability testing during the development phase usually culminates in a formal reliability demonstration test. The sole purpose of the reliability demonstration test is to determine before award of a production contract, whether or not the hardware meets the specified minimum reliability requirement. Ideally, this test employs hardware which has been built using production tooling, test equipment, processes, and personnel. In practice, a formal reliability demonstration test is sometimes omitted if previous testing has sufficiently demonstrated reliability and if the tooling and test equipment used during final development are judged to be sufficiently similar to the production items. However, there are obvious risks associated with this approach.

Qualification of Parts

Concurrent with the development of a piece of hardware, a contractor develops a list of vendors who have demonstrated that they can provide piece parts which conform to all specifications--including reliability specifications. This is usually referred to as vendor qualification. To become qualified, a vendor usually must subject his parts to an extensive test program which includes both environmental testing and longevity testing. For some parts, particularly high-use electronic components, one or more vendors will be qualified already.[2] For other, non-standard parts, a contractor must develop and monitor a qualification test program by which the vendor demonstrates the conformance of his product. If a contractor decides to make a part in-house, he too must subject his part to a qualification test program.

Generally, every reasonable effort is made to have more than one source for each part. Many programs have suffered substantial delays and cost penalties when the sole qualified source for a critical part experienced difficulty. The process of qualifying a new supplier is both lengthy (6-12 months) and expensive ($10,000-$100,000).

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[1]Selby and Miller (reference 23) observed that for a fixed level of reliability engineering effort, the improvement in reliability, as measured by MTBF, was proportional to the square root of the total cumulative test time.

[2]Formal government lists of qualifed vendors exist for some products by type and are referred to as "Qualified Products Lists" or QPL.

MTBF, FIELD VS DEMONSTRATED DURING DEVELOPMENT

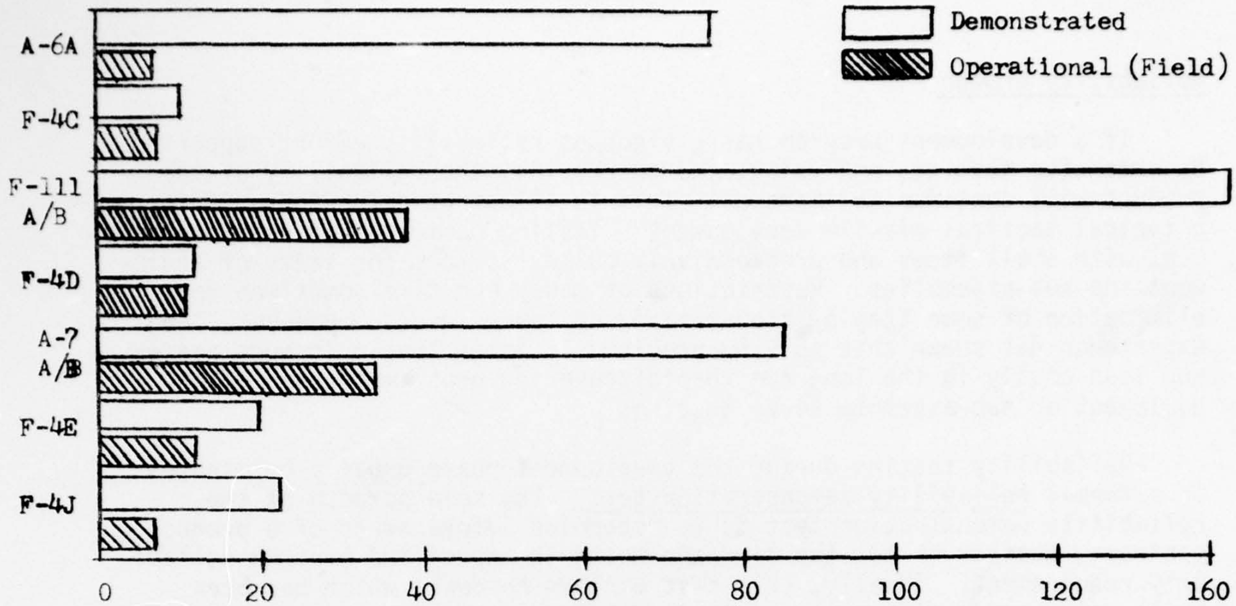

Fig. 23

VIBRATION LEVELS: FORWARD - LOOKING RADAR

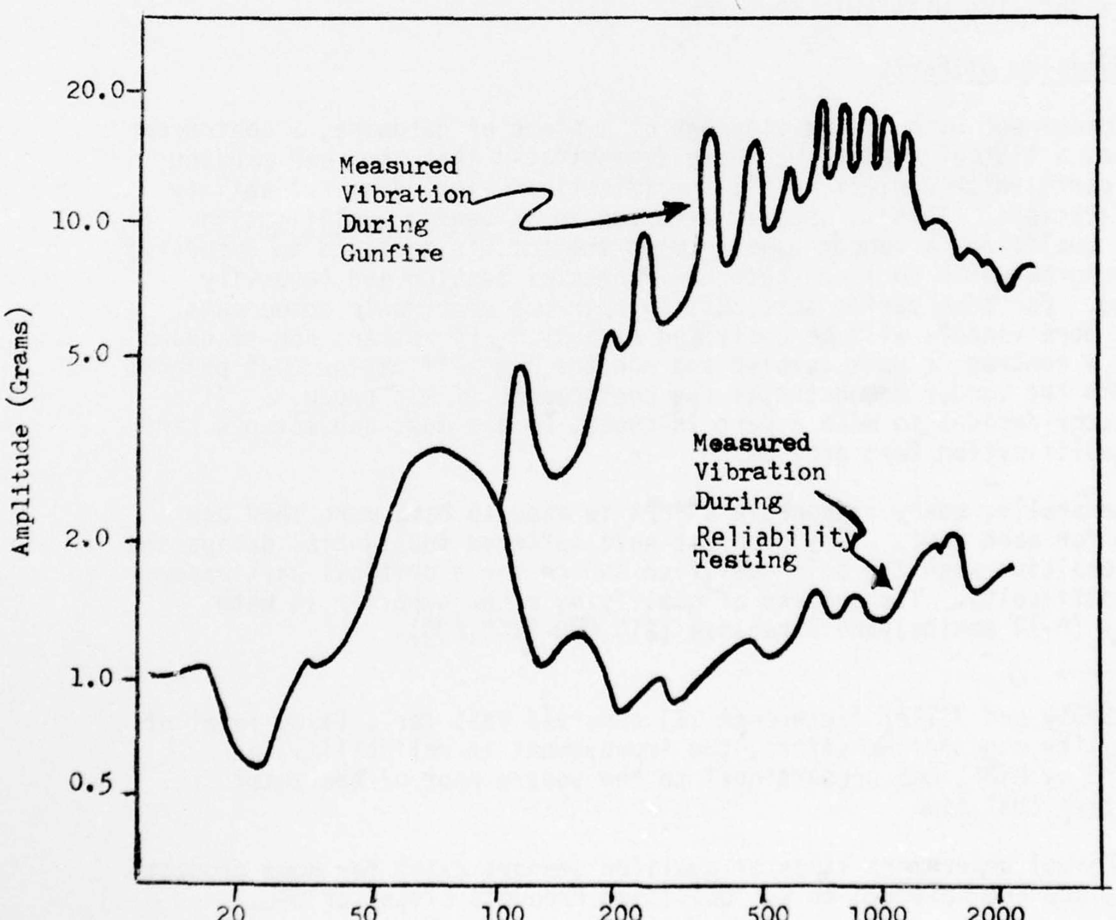

Fig. 24 Frequency (Cps)

A Major Problem: Demonstrated vs. Field Reliability

The ultimate objective of a reliability program is to develop, produce, and deploy a piece of hardware which meets a certain level of reliability under field conditions. The reliability demonstration test at the end of the development phase is intended to confirm that an acceptable level of reliability has been reached. Yet, the evidence suggests that demonstration testing does not adequately fulfill its intended function. Figure 23 illustrates the extent to which some typical system reliability levels under field conditions fall short of levels demonstrated at the end of development. It is common to find demonstrated MTBF to field MTBF ratios of 5 or 10 to 1. Why? What is wrong with the system? There are many reasons, but two major causes stand out: (1) failure to test to actual field environment, and (2) lack of uniformity in the definition of failures.

- Test Environments vs. Field Environments. Despite the designer's best efforts to incorporate in the design all aspects of the actual field environment, many details are overlooked or simply cannot be anticipated. Unless subsequent tests duplicate field environments, design shortcomings remain undetected throughout development. Unfortunately the military specifications and standards which prescribe test conditions do not currently provide an "automatic" test of all severe operational environments. The current standards were developed with heavy emphasis on standardization of test levels in order to economize on purchase of environmental test equipment. These standard test levels overtest in some areas and undertest in others.[1] For example, Figure 24 shows the vibration levels experienced by an aircraft forward-looking radar during demonstration testing. The upper curve shows the actual vibration levels experienced in field operation. The tremendous difference is due to vibration caused by firing of the plane's guns--a factor which certainly should have been tested during development. Help is on the way in this area. The test standards are currently being revised to improve tailoring of test conditions to equipment end use, e.g., airborne, missile, ground fixed or mobile, and shipboard. This will help the developer to systematically require testing which matches the most appropriate and most severe mission profile.

An equally serious shortcoming of development testing is the failure to adequately consider systematic failure modes caused by maintenance techniques. Over the years, gains in technology have been aimed primarily at increasing performance, with inadequate emphasis on designing products for ease of trouble-shooting and maintenance. As equipment grows increasingly complex, maintenance personnel under pressure to improve "operational readiness" resort to cannibalization and other "quick and dirty" maintenance techniques. The results are maintenance-induced faults, a large percentage of equipment removed which is later found to be without defects, and a reduction in field reliability. Improvement in this area can come only through increased recognition of the human environment, both during design and during testing. If an operator's judgement is the failure criterion in the field, then an operator should be included in demonstration testing.

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[1] Reference 27, p. 32.

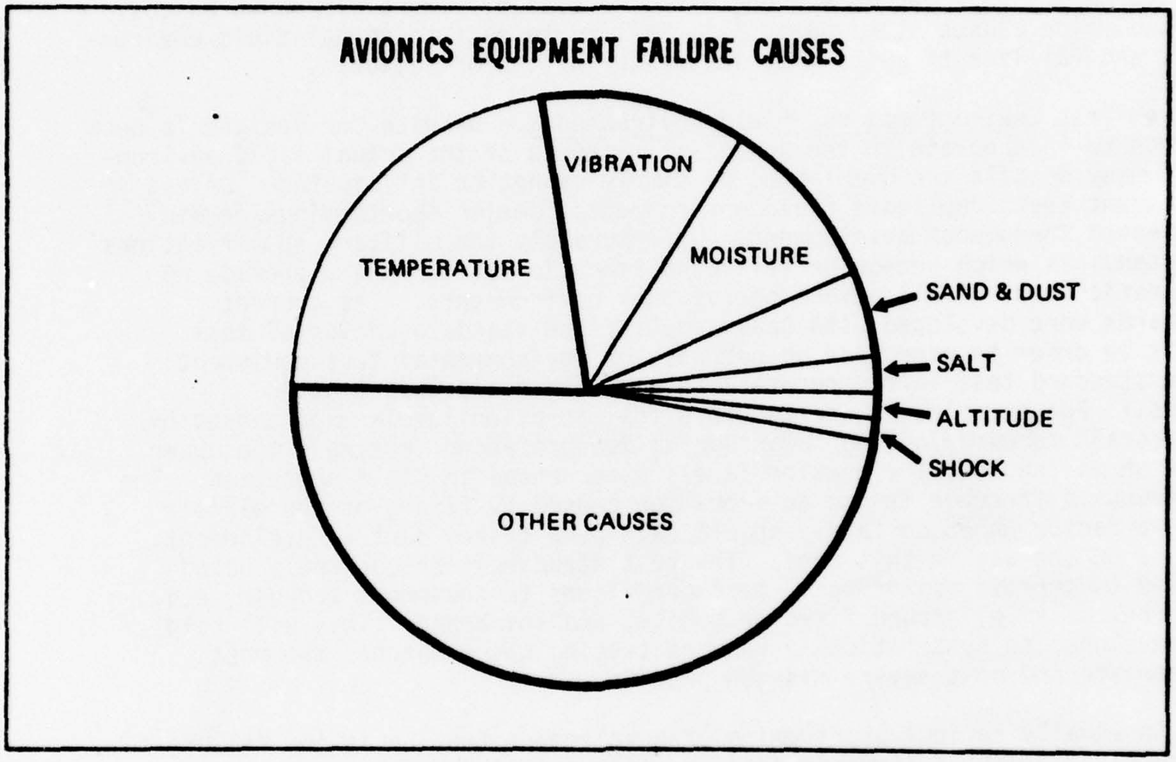
AVIONICS EQUIPMENT FAILURE CAUSES
VIBRATION
TEMPERATURE
MOISTURE
SAND & DUST
SALT
ALTITUDE
SHOCK
OTHER CAUSES

Fig. 25

o Test Failures vs. Field Failures (Relevant/Non-relevant). There is generally very little disagreement on the results of performance testing If, for example, a voltage output of 12 volts is required, there is little argument over whether or not it is achieved, because the definition of a "volt" is not debatable. With reliability demonstration testing, however, there is usually considerable disagreement over the number of failures experienced. The reason is that not all failures are counted as failures in the computation of MTBF. Failures which are caused by "a condition external to the equipment under test which is not a test requirement and not encountered in service,"[1] can be termed "non-relevant" and discounted. Non-relevant failures can stem from a variety of causes such as:

(1) Failures directly attributable to improper equipment installation in the test chamber.
(2) Failures of test instrumentation or monitoring equipment (other than built-in test equipment).
(3) Failures resulting from test operator error or test procedure error in setting up or testing the equipment (e.g., dropping test item).
(4) Failures clearly attributable to an overstress condition in excess of the design requirements (often user-induced, e.g., improper operation or maintenance in an operational test).

These exceptions are equitable and probably necessary, but with such a great latitude for interpretation, the final value of demonstrated reliability is usually made after considerable negotiation between the government developer and the contractor, both of whom are naturally interested in getting on with production. The result is a compromise which reclassifies many of the failures as non-relevant.

Of course the field environment has its own definition of a failure: a failure is a failure is a failure! In the field all failures are relevant, require maintenance effort, and reduce reliability. Figure 25 illustrates the results of a 1971 study on operational avionics equipment failures. Almost half of the failures were attributable to "other" causes, which would normally be considered non-relevant during demonstration testing.

There is no easy solution to this problem, but several actions can help:

(1) Setting reliability requirements which are reasonable and will not force the contractor to rely heavily on "testmanship."
(2) Insuring that contractor proposed corrective actions will actually correct the problem and not induce other failure mechanisms.
(3) Duplicating to a far greater extent during testing, the field physical and human environment, including data collection and analysis procedures.

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[1]Reference 22, para 5.5.1.(1)

QUALITY CONTROL IN MANUFACTURE OF A HIGH QUALITY TRANSISTOR

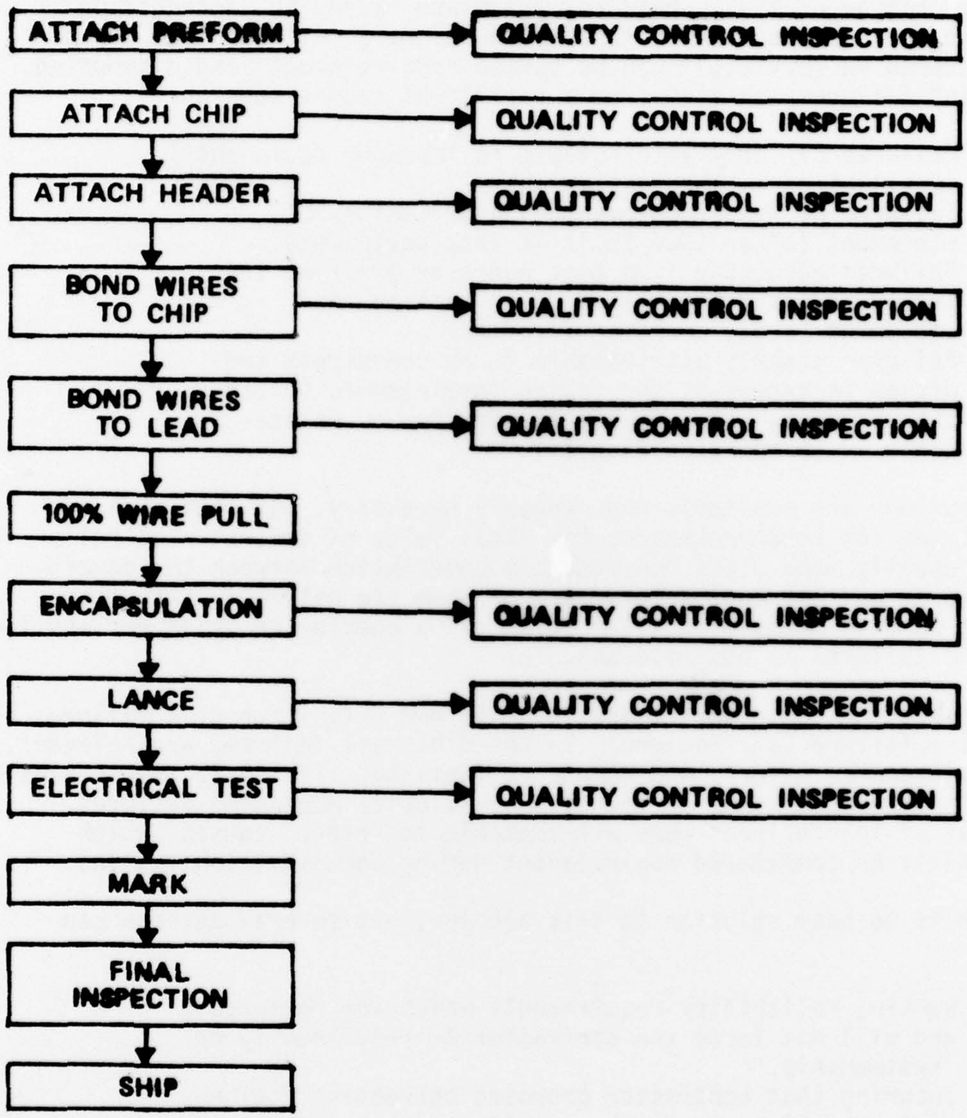

Fig. 26

RELIABILITY IN THE PRODUCTION PHASE

The principal objective of a reliability effort during the production phase is to insure that the reliability inherent in the design at the end of development is not degraded during the manufacturing process. This is accomplished primarily by assuring that incoming purchased parts and materials, manufacturing processes, and inspection procedures all conform to strict standards which allow no more than a very small percentage of defective items to pass any stage in the manufacturing cycle. This assurance effort actually comes under the heading of quality assurance, which involves assuring the quality of not only reliability but of all details contained in the product specifications.[1]

For this reason, many manufacturers adminster their reliability programs during production as part of the quality assurance program. However, there are several activites which are distinctly oriented toward reliability and which often support the existence of a reliability organization separate from the quality organization, especially in DOD programs. Two of the most important of these activities are (1) insuring the continued high reliability of incoming parts and materials, and (2)conducting a reliability demonstration test on the finished items of hardware.

Reliability of Incoming Parts

The reliability level of purchased parts will normally have been established prior to production by some sort of vendor qualification. But insuring continued high reliability is a never-ending vigil. Vendors habitually make some small change in their process or materials which affects a part's reliability--without informing the manufacturer. The slightly changed part usually still conforms to the drawing; therefore the change is undetected during incoming quality control inspections. Unless the change affects performance, it may remain undetected for some time, and the longer it takes, the more costly will be the repair and rework.

This problem is particularly acute in the case of electronic components. To protect against this, many manufacturers subject electronic components to an environmental screening process which screens out latent defectives. The mainstay of the screening process is a burn-in, i.e., operating the device at an elevated temperature for several hundred hours. Temperature accelerates aging of electronic devices. Therefore burn-in effectively operates devices through most of their infant mortality period and weeds out many latent defectives. Burn-in at the component level is not 100% effective, but by repeating the burn-in at the next higher manufacturing level (when components are attached to printed circuit boards), the number of defectives can usually be diminished to an acceptably low level.

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[1]Figure 26 shows how the quality control inspections are used during the manufacture of high quality transistors.

TYPICAL RELIABILITY TEST PLAN

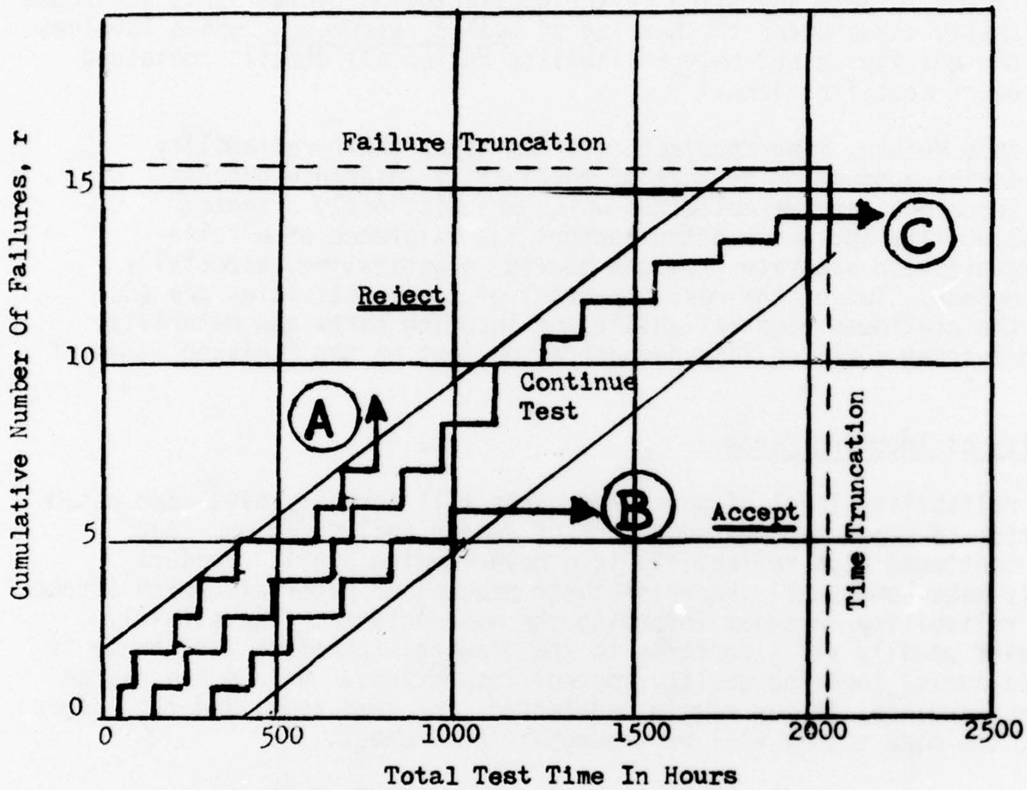

Fig. 27

Production Reliability Demonstration Tests

Reliability demonstration testing during production confirms that reliability has not suffered during the manufacturing process, and that the hardware is ready for the field. There are basicially two kinds of production reliability tests: (1) an extended MTBF test performed on a small sample from each production lot, and (2) a shorter screening test performed on all of the items in each production lot.

- Extended MTBF Test. This test is conducted on a small sample randomly selected from a production lot. The test articles are operated continuously while being subjected to environmental extremes; failures are repaired as they occur. In Figure 27 the "stairstep" plots of cumulative sample test times and failures illustrate three possible outcomes for a typical test of an item which has an MTBF requirement of 200 hours:

(A) The test was a failure and the lot rejected because sample failures occurred at too high a rate. The eighth failure occurred after approximately 200 hours of accrued test time and forced the cumulative plot across the reject decision boundary. This indicated an unacceptably large risk that many of the items in the lot would have an MTBF below the 200 hour requirement.

(B) The test was a success and the lot accepted because sample failures occurred at a sufficiently low rate. Only 6 failures had occurred when the cumulative plot crossed the accept decision boundary after about 1230 hours of accrued test time. This indicated only a small risk that many items in the lot would have an MTBF below the 200 hour requirement.

(C) The test was terminated with inconclusive results. After 2100 total test hours and 14 failures, the MTBF of the sample was neither good enough nor bad enough to reach an accept/reject decision. The lot was conditionally accepted, pending contractor correction of defects indicated by the sample testing.

Obviously, there are many variables in an MTBF test: sample size, level of risk, accept/reject thresholds, etc. Sample test plans for a wide range of situations are given in MIL-STD-781.

MTBF sample testing is very useful, but it has features which can be undesirable. First, the test lasts a number of weeks, during which the remainder of the production lot is either held in "bond" pending the outcome of the test or it is processed onward in normal fashion. (In this latter case, by the time a reject decision is reached, substantial quantities of hardware could already be fielded.) Second, if the sample passes the test, there is still a risk that some items in the lot will have MTBF's substantially below the requirement. These "lemons" could have a detrimental effect on field operations. Of course, every item in the lot could be subjected to an MTBF test, but the cost of this approach is usually prohibitive. A compromise is offered by the second kind of production reliability test, the "all equipment screening test."

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• All Equipment Screening Tests (sometimes referred to as "burn-in")

This approach subjects every item in a lot to a minimum amount of operating time under stressing environmental conditions. All failures are analyzed and repaired, and every item must have a certain period of failure-free operation in order to pass. A screening test acts as a "shake-down" to weed out defects not visible in normal quality control performance testing. It is similar to the screening performed on components to weed out infant mortalities.

Screening tests do have some shortcomings. Since the test time per item is much less than in extended MTBF tests, screening tests do not yield very confident estimates of MTBF. Additionally, screening tests can be more expensive because of the requirement for a large investment in test equipment. However, for many people, these disadvantages are outweighed by the very beneficial effect of subjecting 100% of all items to some kind of reliability testing.

RELIABILITY IN THE DEPLOYMENT PHASE

A reliability program does not stop when the product rolls off the production line. Field use invariably uncovers reliability problems which escape detection during even the best development and production testing. The problem may be a latent design deficiency or (more likely) an unanticipated failure mode which appears because of "green" operating and maintenance personnel. Some improvement in field reliability is usually possible through minor design modifications or changes in operating and maintenance procedures.

The military departments have active reliability improvement programs which emphasize collection and analysis of field data, identification of specific problems, and dedicated funding to engineer improvements. In some cases significant improvements have been made. For example, the Army increased the MTBF for its Vulcan Air Defense System from 30 hours to 100 hours, which will yield an estimated 10 year savings of $51 million. However, improvements such as this should not overshadow what is perhaps the fundamental principle of reliability: reliability is design in!

APPENDIX A

GENERAL DESIGN REVIEW CHECKLIST[1]

1. Review all basic parameters included in the data package for correctness and completeness.

2. Examine the subject design or component to determine if provisions for each functional requirement have been included in the design. Establish the feasibility of holding these to specified variability in manufacture and define the level of confidence that must be generated to assure that the variability is within limits.

3. Note any capabilities, features, accuracies or specified tests which are beyond the state-of-the-art or beyond the functional capabilities of the design facilities.

4. Examine the design approach to determine if the simplest possible means for obtaining the required function has been developed.

5. Determine if proven (by test or similar application history) components and parts have been used wherever feasible.

6. Check the stress analysis (including structural) of each component.

7. Compare the resistive strengths (and any established allowables) of each material, with the calculated load stresses expected. Indicate the ranges of variability.

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[1] Taken from reference 18

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8. Examine the possibility and effect of deflection under load of each component or part on the performance required. Estimate the effect of external shock and resonant vibrations on performance and life expectancy.

9. Determine the compatibility of materials and finishes in expected environments. If data is not available, estimate testing requirements.

10. Consider the possibility and effects of predictable wear on the maximum allowable tolerances, as related to the performance factors of the components.

11. Consider the possibility and the effects of adverse tolerance buildup on each part, including the effects of thermal expansion, vibration, and differential shock excursions.

12. Consider the producibility of each component or part under the manufacturing conditions in which it will be built.

13. Consider the related aspects of accessibility, repairability, maintainability (including lubrication) and operability under field conditions with the variabilities of skill and morale of personnel.

14. Consider the convenience, special tools and accuracy required for operational adjustments, and control instrumentation, from a human factors standpoint.

15. Consider the effects of associated random casualty and permanent shock effects on the performance characteristic of the total system.

16. Consider the compatibility of the components and parts with each other and with supporting services in the system.

17. Consider the installation criteria (handling, alignment, etc.) for the system, component, or part in the overall arrangement.

18. Review the overall evaluation, summarize, and conclude, noting:

a. The possible design deficiencies, including contract or specification deficiencies or conflicts.

b. The probable and possible modes of failure and the effect of these or both the component and overall system.

c. The tests deemed necessary to establish data for final reliability assurance.

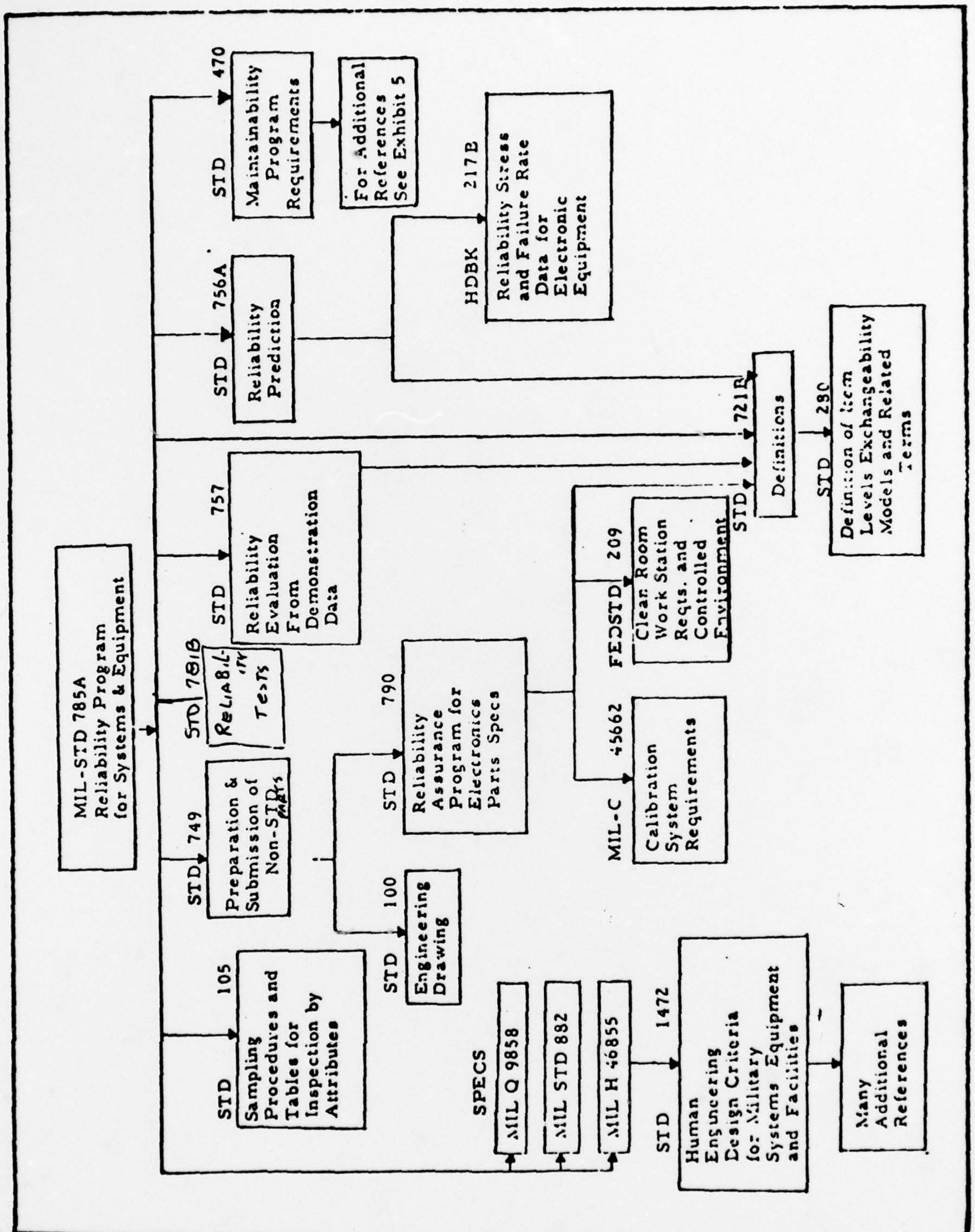
d. Any inspection procedures, either routine or special, which would help uncover most likely manufacturing and assembly errors.

e. The tests deemed necessary to fully evaluate performance vs. design, failure modes, and overload conditions.

f. For parallel components or other components that can fail without causing a detectable system malfunction, list the periodic inspection procedures that will monitor these potential failure points.

APPENDIX B

RELIABILITY REFERENCE TREE



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