AD NUMBER

AD844983

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; NOV 1968. Other requests shall be referred to Rome Air Development Center, Rome, NY.

AUTHORITY

RADC ltr, 4 May 1972

AD 844983

RADC-TR-68-280
Final Report

RELIABILITY PREDICTION AND DEMONSTRATION FOR GROUND ELECTRONIC EQUIPMENT

Dwight Q. Bellinger
Gerald M. Pittier
Robert E. Shelton
et al

TRW, Inc., TRW Systems Group

TECHNICAL REPORT NO. RADC-TR-68-280
November 1968

This document is subject to special export controls and each transmittal to foreign governments, foreign nationals or representatives thereto may be made only with prior approval of RADC (EMERR), GAFB, N.Y.

Rome Air Development Center
Air Force Systems Command
Griffiss Air Force Base, New York

231

When US Government drawings, specifications, or other data are used for any purpose other than a definitely related government procurement operation, the government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded, by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Do not return this copy. Retain or destroy.

RELIABILITY PREDICTION AND DEMONSTRATION FOR GROUND ELECTRONIC EQUIPMENT

Dwight Q. Bellinger
Gerald M. Pittler
Robert E. Shelton
et al

TRW, Inc., TRW Systems Group

This document is subject to special export controls and each transmittal to foreign governments, foreign nationals or representatives thereto may be made only with prior approval of RADC (EMERR), GAFB. N.Y. 13440.

FOREWORD

This technical report presents the results of a study conducted by TRW Systems, One Space Park, Redondo Beach, California under Contract F30602-67-C-0247, Project 5519, Task 551902, with Rome Air Development Center, Griffiss Air Force Base, New York. TRW Task No. is 6232, Report No. is 68.6373.3-146.

This project, performed between 24 April 1967 and 24 May 1968, was under the guidance of Harry S. Powell of the System Engineering and Integration Division and study efforts were supervised by Dwight Q. Bellinger, Head of the Systems Analysis Section. Principal authors of the report are Dwight Q. Bellinger, Gerald M. Pittler, and Robert E. Shelton, with technical contributions by Harold J. Bailey, Franz N. Kanaga, and Gene A. Spears.

Acknowledgement is made of technical information and data supplied by the following agencies: ESD Field Office, Bedford, Massachusetts; HQ, ADC, Colorado Springs, Colorado; Burroughs Corporation, Paoli, Pennsylvania; Mitre Corporation, Colorado Springs, Colorado; Philco-Ford Corporation, Willow Grove, Pennsylvania; and Radio Corporation of America in Cocoa Beach, Florida, Cinnaminson, New Jersey, and Moorestown, New Jersey.

TRW Systems wishes to express appreciation for the cooperative assistance, guidance, and technical reviews of the RADC Program Monitor, Anthony J. Feduccia, EMERR, and of Lester J. Gubbins, also of EMERR.

Distribution of this report is restricted under the provisions of the U.S. Mutual Security Acts of 1949.

This Technical Report has been reviewed and is approved.

Approved:
ANTHONY J. FEDUCCIA
Reliability Engineering Section
Reliability Branch

Approved:
WILLIAM P. BETHKE
Chief, Engineering Division

FOR THE COMMANDER:
IRVING J. GABELMAN
Chief, Advanced Studies Group

ABSTRACT

This study evaluates the accuracy of established reliability prediction techniques applied to a cross section of ground electronic equipment. Pre-design and stress analysis prediction methods were evaluated, including those on the revised RADC Reliability Notebook, Volume II, dated September 1967.

The study objectives were to measure and improve the accuracy of existing predesign and stress analysis reliability prediction techniques, and to apply the results to the development of a recommended reliability demonstration approach.

Prediction accuracy was determined by obtaining measured reliability data from field experience for comparison with new reliability predictions prepared for the same equipment in accordance with the established prediction techniques. Special studies and correlation analyses were performed to identify and establish relationships significant to the identification and correction of factors responsible for inaccuracies in the prediction techniques. Program-related factors were evaluated and a quantitative program rating system was developed for correlation with prediction accuracy values.

Sensitivity studies were performed to determine the degree to which stress, temperature, and quality grade factors influence the stress analysis reliability predictions for a variety of equipment types. The behavior of equipment failure rates during extended field operations was determined and evaluated for a variety of equipment functional types. Design approach categories, and functional categories, were established and applied to identify equipment groups having common characteristics resulting in distinct ranges of prediction accuracy.

Reliability demonstration techniques for ground electronics equipment were reviewed and a recommended demonstration approach was established.

EVALUATION

1. The objectives of this study were to measure and improve the accuracy of existing pre-design and stress analysis prediction techniques on ground electronic equipment. The study also called for a review of reliability demonstration techniques and the development of a recommended demonstration approach, which utilizes a prior prediction, for ground equipment.

2. These objectives were satisfactorily accomplished. Modifiers, which enhance the accuracy and precision of present prediction methods, were developed, and a proposed demonstration approach, using the reliability prediction as a baseline, is presented. Section VI is of special interest because it includes a comprehensive analysis of integrated circuit failure rate data and an evaluation of the relative accuracy of the RADC and EIA integrated circuit prediction models.

3. Although the prediction modifiers developed in this study improve the accuracy of existing techniques, the results of this study also clearly indicate the need for major improvements in the prediction process. For example, it is evident that separate techniques are required for digital and analog equipments, and that consideration should be given to items such as multilayer printed circuit boards which are not included in present predictions. Future RADC studies in reliability prediction will be directed towards the elimination of these deficiencies and others which were discovered in this effort.

Anthony J. Feduccia

ANTHONY J. FEDUCCIA
Reliability Engineering Section
Reliability Branch

CONTENTS

CONTENTS (Continued)

CONTENTS (Concluded)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Concluded)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Concluded)

SECTION I

INTRODUCTION

This study had the primary objective of evaluating and improving the accuracy of pre-design and stress analysis reliability prediction techniques applied to a variety of functional types of ground electronic equipment.

Emphasis was placed upon the recently revised (September 1967) stress analysis prediction technique of the RADC Reliability Notebook, Volume II, RADC TR-67-108.

A secondary objective was to develop a reliability demonstration approach. This involved the investigation of demonstration methods, reliability assurance techniques, and program characteristics which can serve to diminish or eliminate the need for formal demonstration testing. Also included were the investigation of reliability program attributes, reliability program ratings, and other program variables which are known to contribute to the control and elimination of design weaknesses and part failures, thereby increasing confidence in the achievement of reliability objectives.

The technical approach employed and the tasks performed to achieve these objectives are described in Section II, "Summary," which follows.

SECTION II

SUMMARY

This section supplements the information presented in the "Abstract" in order to provide a more detailed description of the technical approach and the tasks performed during the study. The principal tasks included the following:

- o Collection of observed reliability data, and equipment baseline configuration data for the preparation of reliability predictions.
- o Preparation and evaluation of stress analysis and pre-design reliability prediction techniques.
- o Improvement of reliability prediction techniques.
- o Collection and analysis of integrated circuit design, operation, and failure data.
- o Performance of special studies to investigate significant areas pertinent to the evaluation and improvement of stress analysis and pre-design reliability prediction techniques.
- o Evaluation of reliability test and demonstration approaches for ground electronics equipment.

The technical approach emphasized the comparative analysis of predicted and observed failure rates, using a variety of fixed ground electronics equipment representing a cross section of the types currently in the Air Force inventory. Statistical analyses were performed at all indenture levels of equipment, from the system through the part level, to evaluate relationships between prediction accuracy and such factors as:

- o Strength of reliability program
- o Design approach
- o Function
- o Prediction method
- o Stress, temperature, and part grade
- o Parts technology
- o Design complexity

This report presents the results of these tasks and analyses in the sections which follow. Each analytical section is introduced by a subsection presenting the objectives of the analysis. Conclusions are presented in the summary portion in each section.

SECTION III

DATA USED IN STUDY

1. INTRODUCTION

This section presents a tabulation of the data employed in performing this study. The data tabulated under III 2 "Candidate Equipments" were used throughout the study except for Special Studies No. 1 and No. 5 of Section VIII. The data utilized in Section VIII, Special Studies No. 1 and No. 5 are tabulated under III-3 "Data for Special Studies No. 1 and No. 5."

2. CANDIDATE EQUIPMENTS

The data from thirty-seven pieces of electronic equipment, operating in a fixed-ground environment, were selected for utilization in this study (except for Section VIII, Special Study No. 1 and Special Study No. 5). The selected equipments encompass the full spectrum of ground electronic equipment types (e.g., radars, receivers, displays, computers, etc.). The design dates of the equipment vary from 1959 through 1967 and include all types of electronic components (e.g., tubes, transistors, and integrated circuits). The selection of these equipments was made considering the following criteria, but not necessarily in the order of listing:

- o Availability of equipment parts lists
- o Availability of contractor prediction on equipment
- o Availability of operating failure data on the mature equipment
- o Established failure reporting system (e.g., AF66-1, contractor reporting, etc.)
- o Validity of data for desired analysis techniques.

In Table I "Ground Electronics Study Equipment Parts Breakdown," the equipments are listed by code numbers, total parts, and percentage of total parts for each part type. This table is very useful in reflecting the distribution (i.e., parts mix) of parts in ground electronic equipments.

3. DATA FOR SPECIAL STUDIES NO. 1 AND NO. 5

a. Summary

The data tabulated in this section is used in Special Studies No. 1 and No. 5. The data are field data on ground electronic equipment taken over a calendar period of seven years, ending in 1965. The equipments are broadly categorized as either transmitter type, receiver type, computer type, or display type equipment. The equipment was maintained by contractor personnel and USAF agencies and exhibited a constant duty cycle.

TABLE I GROUND ELECTRONICS STUDY EQUIPMENT PARTS BREAKDOWN

CODE NUMBER	TOTAL PARTS	PERCENT OF TOTAL PARTS									
		CAPACITORS	RESISTORS	DIODES	TRANSISTORS	TUBES	MAGNETICS	RELAYS	CONNECTORS	SWITCHES	INTEGRATED CIRCUITS
1	4,336	4.0	39.5	30.6	15.4	---	6.6	---	3.7	0.1	---
2	303	9.2	38.9	14.9	28.1	---	2.0	0.3	3.3	---	---
3	318	8.2	25.5	10.1	18.9	---	2.5	---	28.3	---	---
4	1,855	16.4	52.2	12.7	13.7	---	2.2	---	2.6	---	---
5	832	21.9	48.7	8.9	13.5	---	2.5	---	4.1	---	---
6	6,400	6.5	32.2	19.8	7.9	---	---	---	---	---	33.5
7	2,068	10.5	51.6	24.2	8.1	---	---	---	---	---	5.5
8	2,616	22.9	22.0	31.5	14.6	---	---	---	---	---	9.0
9	494	34.0	30.8	11.7	14.2	---	---	---	---	---	9.3
10	2,119	6.7	39.9	17.2	36.1	---	---	---	---	---	---
11	3,818	16.3	54.7	19.1	9.8	---	---	---	---	---	---
12	2,410	16.8	54.3	12.7	0.3	4.2	3.4	4.8	2.2	0.2	---
13	6,320	23.1	45.6	7.7	2.9	4.4	9.2	1.0	5.5	0.3	---
14	15,295	14.0	52.2	20.7	9.0	0.6	0.5	0.8	1.9	0.2	---

TABLE I GROUND ELECTRONICS STUDY EQUIPMENT PARTS BREAKDOWN (CONTINUED)

CODE NUMBER	TOTAL PARTS	PERCENT OF TOTAL PARTS									
		CAPACI-TORS	RESIS-TORS	DIODES	TRANSIS-TORS	TUBES	MAG-NETICS	RELAYS	CONNEC-TORS	SWITCHES	INTE-GRATED CIRCUITS
15	3,398	4.9	53.0	19.1	12.7	0.4	0.9	3.6	4.1	0.3	---
16	554	26.9	29.2	3.6	---	3.4	17.0	4.7	7.0	2.5	---
17	1,243	8.8	41.3	22.4	5.9	1.0	2.6	3.2	4.8	6.8	---
18	10,480	14.4	39.3	31.2	11.6	0.1	0.6	0.7	1.9	---	---
19	22,652	13.9	38.2	34.9	11.5	---	---	---	1.5	---	---
20	43,762	14.3	36.5	34.2	13.5	---	0.1	---	1.4	---	---
21	3,277	17.2	36.4	22.8	10.6	0.9	2.5	4.4	4.3	0.1	---
22	27,956	20.4	44.1	15.7	15.1	0.2	1.9	0.3	2.0	---	---
23	13,343	14.1	43.3	24.2	12.5	0.2	1.0	1.2	2.1	0.6	---
24	12,687	22.3	40.1	20.4	11.7	0.1	0.9	1.1	2.9	0.2	---
25	413	16.7	44.3	19.4	14.8	---	2.7	---	1.5	---	---
26	317	20.2	38.2	16.7	15.5	---	6.3	---	0.3	0.3	---
27	270	1.9	36.7	33.7	8.1	---	1.1	6.7	0.7	0.7	---
28	478	3.4	52.5	20.3	13.0	---	3.1	---	4.8	---	---

TABLE I GROUND ELECTRONICS STUDY EQUIPMENT PARTS BREAKDOWN (CONCLUDED)

CODE NUMBER	TOTAL PARTS	PERCENT OF TOTAL PARTS									
		CAPACITORS	RESISTORS	DIODES	TRANSISTORS	TUBES	MAGNETICS	RELAYS	CONNECTORS	SWITCHES	INTEGRATED CIRCUITS
29	611	8.2	43.7	30.9	13.1	---	0.3	2.1	1.2	---	---
30	624	10.4	42.3	29.3	10.7	---	2.6	3.2	1.3	---	---
31	196	1.0	34.7	37.8	12.3	---	---	---	0.5	1.5	---
32	32,086	22.2	37.7	23.3	13.2	---	0.3	0.6	2.9	0.1	---
33	103,192	1.6	3.9	93.1	1.4	---	---	---	---	---	---
34	4,797	11.4	47.6	16.4	13.8	---	1.6	1.5	4.5	0.8	---
35	3,693	8.6	32.6	32.7	13.3	---	0.1	2.3	2.8	---	---
36	860	1.0	4.6	29.6	1.6	---	7.0	10.5	6.0	6.9	---
37	34,491	17.7	37.1	28 2	13.0	---	0.4	0.4	3.0	---	---
38	120,393	14.2	48.7	23.5	10.1	---	0.2	---	2.6	0.7	---

The failure definition used in this study includes all failures that caused a downtime or interruption to the operational performance of the equipment excluding externally caused failures, such as power outages. Therefore, removal and replacement actions were not associated with all failure events. All equipment was in the steady-state operating portion of the equipment life cycle (i.e., all equipment had accumulated approximately 8-10,000 hours of operating time). Thus, the data excludes the debugging and installation phases of the equipment life cycle. A summary of the accumulated unit operating hours included within each equipment type, is given below.

Type Equipment	Operating Hours
o Transmitter	527,060
o Receiver	1,792,680
o Display	543,544
o Computer	887,003

b. Qualitative Discussion of the Field Data

All the data analyzed in this section of the report were obtained from summarized field reliability reports on the particular equipments. The reports discussed the causes of some of the failures that occurred, including failures due to the following causes:

(1) Design Inadequacies

Even during this period of maturity in the life cycle a number of design inadequacies became evident during the operation of the equipment. After recommended corrective action was taken, the equipment failure rate showed a decrease, in some cases, which might be attributed to the action taken.

(2) Parts Deficiencies

Deficiencies in some parts characteristics are indicated to have contributed to equipment failure rates in several instances. However, the extent of the contribution could not be quantitatively established, and could not always be clearly distinguished from the category of design inadequacies. Examples of the types of parts deficiencies which are known to be present in all fielded systems include: quality control deficiencies, deficiencies due to shipping and handling, and deficiencies caused by stresses incurred during installation and checkout activities. This category also includes part failures due to configuration control problems.

(3) Maintenance and Operational Policies and Practices

Like all other systems, these equipments were subject to the influence of changing maintenance and operational policies and practices. These changes result in both increased and reduced downtime and part replacement. To the extent that changes are made, equipment failure rates are indicated to be a function of these changes.

(4) Part Wearout Failures

Certain parts, such as tubes, relays, motors and certain moving mechanical components, have known wearout mechanisms. When these parts wear out, they are reported as field failures and are included in the equipment failure rate.

(5) Catastrophic Failures

The above four categories described failures, both catastrophic and non-catastrophic which are traceable to the effects of time and/or causes. This category differs from the above in that the failures are random in time and may be considered random in cause. These failures are not attributed to a design deficiency, part deficiency or maintenance or operating policy.

It is recognized that all of these failure categories are represented in all field data covering extended time periods. However, current prediction techniques are primarily based on catastrophic failures, although wearout failures are recognized in the RADC stress analysis method. The other failure classes are not represented in the prediction techniques. However, for some equipments during selected periods, failures in these other classes can represent the bulk of the total equipment failures.

As discussed, the prediction techniques generally yield higher than observed failure rates. This inaccuracy is accentuated for those equipments whose failure rate is decreasing with time. The predictions would appear even more inaccurate if the failures due to causes not included in the prediction process could be deleted from the observed data.

The contribution to prediction inaccuracy of failure classes not represented in the prediction techniques could be assessed if it were possible to determine the extent to which these failures contribute to the total equipment failure rate. To accomplish this requires more information and analysis than is currently available from any field reporting system. Therefore, all of the reported failures have been accepted as representative reliability statistics, applicable to the purposes of this study.

c. Equipment Analyzed

Tables II through V list the equipment which forms the baseline for this study. Each table lists the number of equipments in each category, total operating hours, total equipment hours, and the total number of failures. It will be noted from the tables that all equipments were placed into one of four broad functional categories, based upon their functional application. Within each category, equipments were divided into subgroups having identical characteristics.

The transmitter type equipment included 28 individual equipments (e.g., transmitters) grouped into four subgroups (T-1 through T-4). In each subgroup, the individual equipments each operated for a period of from 17,640 hours to 19,310 hours.

The receiver-type equipment comprised 92 distinct operational equipments (e.g., receivers, local oscillators, intermediate frequency equipment, active filters, etc.). These were grouped into eight subgroups (R-1 through R-8), in each of which the individual equipments operated for an average of from 19,340 hours to 19,530 hours.

The computer equipment consists of two complete computer equipment groups including core memory (C-2 and C-7), a total of four computers, an individual central processor (C-11), its associated memory core (C-12) and a set of magnetic tape units (C-15). Additional computer type equipment consisted of computer interface units (C-1, C-3, C-6, C-8, C-14), a display console controller (C-13) and four master timing units (C-4, C-5, C-9, C-10). The failures of the magnetic tape units are classified as electrical and mechanical since these two general classes of failures are expected to exhibit different failure rate versus time characteristics.

The display equipment consists exclusively of display consoles (D-1 thru D-7) and camera projection equipment (D-8, D-9). The latter equipment was used to provide a large screen dynamic display for one of the systems analyzed. Only 5,994 hours were reported on this equipment, representing a small segment of the equipment life. The remaining 34 display consoles accumulated 537,550 hours, an average of 15,800 hours per display unit.

This data is analyzed in detail in Special Studies No. 1 and No. 5.

TABLE II

TRANSMITTER TYPE EQUIPMENT

Equipment	Quantity	Total Operating Hours (Per Equipment)	Total Equipment Hours	Total Failures
T-1	6	17,640	105,840	2179
T-2	10	19,310	193,100	3126
T-3	4	18,750	75,000	1470
T-4	8	19,140	153,120	2365
TOTAL	28		527,060	9140

TABLE III

RECEIVER TYPE EQUIPMENT

Equipment	Quantity	Total Operating Hours (Per Equipment)	Total Equipment Hours	Total Failures
R-1	18	19,530	351,540	371
R-2	16	19,530	312,480	247
R-3	13	19,530	253,890	37
R-4	14	19,500	273,000	371
R-5	11	19,370	213,070	327
R-6	10	19,340	193,400	23
R-7	6	19,530	117,180	8
R-8	4	19,530	78,120	14
TOTAL	92		1,792,680	1398

TABLE IV

COMPUTER TYPE EQUIPMENT

Equipment	Quantity	Total Operating Hours (Per Equipment)	Total Equipment Hours	Total Failures
C-1	14	19,530	273,820	100
C-2	2	19,530	39,060	295
C-3	2	19,530	39,060	167
C-4	2	19,430	38,860	13
C-5	3	19,530	58,590	21
C-6	11	19,440	213,840	86
C-7	2	19,530	39,060	210
C-8	2	19,530	39,060	29
C-9	2	19,530	39,060	4
C-10	2	19,530	39,060	43
C-11	1	11,158	11,158	16
C-12	1	11,158	11,158	36
C-13	1	11,912	11,912	9
C-14	1	11,389	11,389	27
C-15(Elec)	14	--	11,158	97
C-15(Mech)	14	--	11,158	130
TOTAL	60		887,003	1283

TABLE V

DISPLAY TYPE EQUIPMENT

Equipment	Quantity	Total Operating Hours (Per Equipment)	Total Equipment Hours	Total Failures
D-1	6	19,480	116,880	40
D-2	4	19,530	78,120	55
D-3	3	17,360	52,080	5
D-4	4	19,530	78,120	37
D-5	3	19,530	58,590	74
D-6	3	10,850	32,550	1
D-7	11	11,110	122,210	370
D-8	1	1,830	1,830	28
D-9	1	3,164	3,164	9
TOTAL	36		543,544	619

SECTION IV

IMPROVEMENT OF STRESS ANALYSIS PREDICTION TECHNIQUES

1. OBJECTIVES

The primary objectives of this section are the assessment of the accuracy of the different stress analysis prediction techniques, and the development of a more accurate prediction method for ground electronic equipment.

2. SUMMARY

The development of an improved stress analysis prediction technique is predicated on the conclusions from this investigation. That is, a definite difference exists between digital and analog equipments. A modifier to the RADC Volume II Stress Analysis prediction technique could enhance the accuracy of the prediction.

The improved prediction technique is the application of a modifier to the RADC, Volume II Reliability Prediction. A separate modifier was developed for both digital equipments and analog equipments. The modifiers were developed by eliminating, from the analog and digital equipments, those equipments with tube components and determining a least-squares curve fit to the remaining equipment. The least-squares fit determined that a linear curve of the type

$$y = \alpha + \beta X, \qquad (1)$$

where

$y \equiv$ the observed MTBF,

$X \equiv$ the RADC Volume II Predicted MTBF, and

α, β, are regression coefficients,

sufficiently models the data for both types of equipments.

The regression coefficients determined for the digital equipments are

$$\alpha = 3.14$$

$$\beta = 0.14$$

Hence, to obtain an adjusted prediction for digital equipments the following linear expression was used:

$$y = 3.14 + 0.14X,$$

where

y ≡ the adjusted prediction, and

X ≡ the original RADC, Volume II prediction.

Table VI "Adjusted Prediction Accuracy Ratios vs RADC, Volume II Prediction Accuracy Ratios-Digital Equipments" compares the accuracy of the two prediction techniques for each equipment utilized in establishing the modifier.

TABLE VI
ADJUSTED PREDICTION ACCURACY RATIOS VS RADC VOLUME II
PREDICTION ACCURACY RATIOS - DIGITAL EQUIPMENTS

Equipment Code No.	RADC Ratio	Adjusted Ratio
1	1.7	0.4
5	6.1	3.8
6	3.8	1.1
7	7.0	3.7
8	3.8	1.7
10	2.1	1.0
29	1.3	0.8
32	11.4	0.9
37	7.1	1.0

The mean for the RADC Volume II prediction accuracy ratios is 4.9 and the mean for the adjusted prediction accuracy ratios is 1.6 (i.e., a reduction of more than 200 percent in the inaccuracy). The standard deviation for the RADC Volume II prediction accuracy ratios is 3.54 and the standard deviation for the adjusted prediction accuracy ratios is 1.36 (i.e., a reduction of 160 percent in the imprecision). Hence, the adjusted prediction technique will not only result in more accurate predictions, but will also result in more precise predictions.

The analog equipments included eleven equipments. The least-square curve fit produced the following correlation coefficients for these equipments.

α = 1.2

β = 0.42

The adjusted predictions were obtained from

$$y = 1.2 + 0.42 X,$$

where

$y \equiv$ the adjusted MTBF, and

$X \equiv$ the original RADC Predicted MTBF.

Table VII, "Adjusted Prediction Accuracy Ratios vs RADC Volume II Prediction Accuracy Ratios - Analog Equipments" shows a comparison between the two prediction techniques.

TABLE VII
ADJUSTED PREDICTION ACCURACY RATIOS VS RADC VOLUME II
PREDICTION ACCURACY RATIOS - ANALOG EQUIPMENTS

Equipment Code No.	RADC Ratio	Adjusted Ratio
2	26.5	12.5
3	13.4	7.1
4	0.8	0.5
11	3.8	2.3
25	0.5	4.2
26	10.2	7.0
27	0.5	0.3
28	0.9	0.5
30	1.5	1.0
31	0.9	1.1
34	2.3	1.0

The mean for the RADC Volume II prediction is 5.6 with a standard deviation of 8.2. The mean for the adjusted prediction is 3.5 with a standard deviation of 3.9. Thus, the adjusted predictions represent a 60 percent increase in accuracy and a 110 percent improvement in precision for the analog equipments.

In summary, the results of this study have shown that:

- o The various prediction techniques have a high degree of linear correlation.
- o The prediction techniques, generally, do not correlate with the observed data.
- o The prediction techniques indicated good correlation with the observed data for digital equipments.
- o The MTBF ratios exhibit a log-normal distribution.
- o The different prediction techniques resulted in equal variances but different means which indicates that a difference in accuracy exists between techniques but there is no difference in precision.
- o The analog and digital equipments were not of the same log-normal population (i.e., the means and variances were not equal).
- o The technique for predicting digital equipment reliability should be different from the technique used for predicting analog equipment reliability.
- o Stress analysis predictions produce lower-than-observed MTBF's for almost all equipments in the digital design approach category.
- o Power equipment demonstrated characteristically a higher than desired (i.e., >1.0) prediction accuracy ratio.
- o Control equipment exhibited the widest range of prediction accuracy ratios.
- o Vacuum tube equipments were characterized by a lower than desired (i.e., <1.0) prediction accuracy ratio.
- o A relationship was indicated to exist between the accuracy of reliability predictions for large systems, and the effects of program factors (e.g., strength of reliability programs). System prediction modifiers and program rating criteria were established.
- o A linear function provides the modifiers to improve the RADC Volume II predictions for both digital and analog equipments. These modifiers improve both the accuracy and the precision of the predictions.

3. DETAILS

a. Technical Approach

This portion of the study is an attempt to assess the accuracy of the stress analysis prediction techniques, isolate the factors which contribute to the inaccuracies of the technique, and develop a more accurate prediction technique.

The solution to the prediction inaccuracy problem was approached by selecting a group of electronic equipment, operating in a fixed ground environment and establishing predicted reliability values (i.e., RADC Volume II, upper and lower grade parts, MIL HDBK 217A, and Original Contractor predictions) for each of the selected equipments.

The stress analysis prediction techniques were evaluated to determine their correlation with each other and with the observed data, the degree of accuracy of the individual techniques, and the probability distributions formed by the ratio of observed mean-time-between failure ($MTBF_o$) to the predicted mean-time-between failure ($MTBF_p$) for each equipment. The new prediction technique was validated by comparison of prediction accuracy ratios between the new technique and the RADC Volume II technique.

The evaluation of stress analysis prediction techniques required the establishment of predictions which utilized the techniques. Therefore, predictions were prepared for thirty-eight equipments using both the methods of the RADC Reliability Notebook, Volume II and MIL-HDBK-217A.

The stress analysis prediction techniques require a knowledge of numerous design and operating factors which influence the failure rates of parts within the equipment (e.g., temperature, stress, environment, part quality, etc.). Therefore, information relative to the operating characteristics of the equipment were obtained from the following sources:

- System Environmental Specifications
- Environmental Control System Project Engineers
- Equipment Designers
- Contractor Reliability Prediction Reports

Utilizing the above information, a standard set of prediction factors and operating conditions was established for use in preparing all RADC Volume II type stress analysis predictions as listed below.

- The equipment operates in a fixed ground environment.
- The part quality level is consistent throughout the equipment (i.e., upper grade or lower grade).

The general equation used for establishing a part failure rate for the RADC Volume II prediction is

$$\lambda_p = \lambda_b \times \Pi_M \div \Sigma_E, \tag{2}$$

where

λ_p ≡ the part failure rate,

λ_b ≡ the base failure rate established for temperature, stress, and part quality,

Π_M ≡ the application modifiers, and

Σ_E ≡ the environment modifiers.

b. Correlation Analysis

This study evaluated the correlation of Mean-Time-Between-Failure (MTBF) values predicted by each of the stress analysis prediction techniques with observed values and each other. The purpose of this study was to statistically evaluate the relationships of prediction techniques for a variety of equipment, and to determine if any combinations of techniques and equipment exhibited relationships significant to the evaluation and improvement of prediction accuracy, precision, or repeatability. The study also attempted to identify and isolate any significant statistical differences which might exist.

The test for simple linear correlation was performed for three equipment categories:

o All equipments (34 equipments),

o Analog equipments (20 equipments), and

o Digital equipments (14 equipments).

The correlation coefficients obtained for the different prediction techniques are shown in Table VIII, "Simple Linear Correlation Coefficients Between Stress Analysis Prediction Techniques."

TABLE VIII

SIMPLE LINEAR CORRELATION COEFFICIENTS

BETWEEN STRESS ANALYSIS PREDICTION TECHNIQUES

Equipment Type		RADC Upper Grade	RADC Lower Grade	MIL-HDBK-217A
All	RADC Upper Grade	--	0.913	0.896
	RADC Lower Grade	0.913	--	0.909
Analog	RADC Upper Grade	--	0.923	0.986
	RADC Lower Grade	0.923	--	0.917
Digital	RADC Upper Grade	--	0.958	0.722
	RADC Lower Grade	0.958	--	0.829

The foregoing table shows relatively high degree of linear correlation between the stress analysis prediction techniques (i.e., the results of all stress analysis prediction techniques are quite similar). Although this correlation provides no insight into the accuracy of the techniques, it shows that the precision of the individual techniques is essentially the same for all.

The correlation analyses conducted between the observed data and the several stress analysis prediction techniques are illustrated in Table IX, "Correlation Coefficients Between Observed Data and Stress Analysis Prediction Techniques."

The table shows a significant correlation between predicted and observed values for digital equipment, but very little correlation between the predicted and observed values for analog equipments. This implies that a significant difference exists between analog and digital equipment which is not compensated for in the prediction techniques.

TABLE IX

CORRELATION COEFFICIENTS BETWEEN OBSERVED DATA

& STRESS ANALYSIS PREDICTION TECHNIQUES

Equipment Categories	RADC Upper Grade	RADC Lower Grade	MIL-HDBK 217A
All Equipments	0.520	0.336	0.208
Analog Equipments	0.269	0.192	0.192
Digital Equipments	0.963	0.868	0.604

The high correlation (0.963) between the RADC Volume II upper grade prediction and the observed data for the digital equipment precipitated a least-squares curve fit to determine what curve would best fit the observed data. The curves used in the least-squares curve fit are:

- $y = \alpha + \beta x$,
- $y = \alpha e^{\beta x}$,
- $y = \alpha x^{\beta}$,
- $y = \alpha + \frac{\beta}{x}$,
- $y = \frac{1}{\alpha + \beta x}$, and
- $y = \frac{x}{\alpha + \beta x}$,

where

$y \equiv$ the observed MTBF,

$x \equiv$ the predicted MTBF, and

$\alpha, \beta \equiv$ the least-squares coefficients.

The results of the least-squares curve fit are shown in Table X, "Least Squares Curve Fit, Digital Equipment". This Table shows that the linear curve is the best fit (i.e., the linear curve has the highest index of determination). However, the negative value of α is undesirable. The curve where y is a power function (i.e., $y = \alpha x^{\beta}$) is the second best fit. In fact, this curve indicates that a multiplier of approximately 0.32 would make the RADC Volume II upper grade prediction very close for digital equipments.

TABLE X

LEAST-SQUARES CURVE FIT

DIGITAL EQUIPMENTS

Curve	Index Of Determination	α	β
$y = \alpha + \beta x$	0.93	-14684.9	7.09
$y = \alpha e^{\beta x}$	0.59	1937.7	0.0001
$y = \alpha x^{\beta}$	0.90	0.32	1.25
$y = \alpha + \beta/x$	0.13	66144.8	-2.0×10^{-7}
$y = 1/\alpha+\beta x$	0.15	0.0014	-5.0×10^{-8}
$y = x/\alpha+\beta x$	0.69	0.84	-6.2×10^{-5}

Using the least-squares curve fi[illegible] [illegible]fficients from Table X for the power function curve, new predictions were made for the fourteen digital equipments. The equation for the new prediction is:

$y = \alpha x^{\beta}$,

where

$y \equiv$ the new prediction value,

$x \equiv$ the old RADC Volume II upper grade prediction value, and

$\alpha, \beta \equiv$ the least-squares coefficients (Table X).

Table XI, "Digital Equipment Prediction From Least-Squares Coefficients", shows the results of predictions for the digital equipments utilizing the least-squares curve fit coefficients.

TABLE XI

DIGITAL EQUIPMENT PREDICTIONS

FROM LEAST-SQUARES COEFFICIENTS

Equipment Code No.	Prediction ($y = \alpha x^{\beta}$)	Observed / L.S. Pred.	Observed / RADC Pred.
37	254.8	4.2	7.1
20	389.3	0.5	0.9
32	432.5	4.2	11.4
23	654.3	0.9	1.8
19	1510.3	0.2	0.7
18	3164.5	0.3	1.7
1	6854.5	0.7	1.7
6	7632.1	1.6	3.8
8	24207.8	1.2	3.8
10	32493.1	0.6	2.1
7	37906.6	2.1	7.0
5	46071.6	1.7	6.1
29	51808.3	0.4	1.3
9	230061.0	1.5	7.3
		$\bar{x} = 1.4$	$\bar{x} = 4.0$

The ratios of the observed MTBF to the new predicted MTBF were obtained. These ratios indicate, when compared with the ratios of observed MTBF to RADC Volume II upper grade predicted MTBF, that the least-squares coefficients give a more accurate digital equipment prediction (i.e., $\bar{x}$ is closer to one) but do not improve upon the precision of the prediction (i.e., the range of variability between the ratios for all equipments is essentially the same).

c. Analysis of MTBF Ratios

(1) Introduction

The ratios of observed MTBF to predicted MTBF were calculated for thirty-four equipments using various stress analyses prediction techniques. These ratios are shown, by equipment numbers, in Table XII, "Ratio of Observed MTBF to Predicted MTBF."

It is desirable to know the underlying probability distribution of the ratios of observed MTBF to predicted MTBF.

If the probability distribution can be determined, then it becomes possible to:

- determine if the prediction techniques produce equal means and variances. That is, is any one prediction technique either more accurate or more precise than any other technique?
- determine if all types of equipment can utilize the same prediction technique. That is, do all types of equipment have the same type of probability distribution and if so, are they the same distribution?

Thus, the analysis of the MTBF ratios is accomplished in the following manner:

- Determine the underlying probability distributions for the different types of equipments (i.e., digital, analog, and all equipments) via "goodness of fit" tests.
- Determine, for the different equipment types whose ratios have the same type of probability distribution, if they are, indeed, from the same distribution via tests for equal means and equal variances. That is, the MTBF ratios from two or more equipment types might exhibit a normal distribution, but also have different means and variances and hence, would not be members of the same normal distribution.

(2) Goodness of Fit Tests

These tests are performed to determine the underlying probability distributions of the MTBF ratios.

The categories of equipment considered in the MTBF ratio analysis are:

- Digital (14 equipments)
- Analog (20 equipments)

TABLE XII

RATIO OF OBSERVED MTBF

TO PREDICTED MTBF

Equipment Code Number	MIL-HDBK 217A Prediction	RADC Upper Grade Prediction	RADC Lower Grade Prediction	Original Contractor Prediction
1	8.8	1.7	10.8	---
2	51.4	26.5	255.0	8.0
3	34.4	13.4	111.6	7.2
4	2.7	0.8	5.4	---
5	17.8	6.1	53.8	---
6	120.2	3.8	50.5	---
7	57.5	7.0	53.9	---
8	50.7	3.8	36.0	---
9	91.5	7.3	71.3	---
10	52.2	2.1	24.6	---
11	19.9	3.8	25.4	---
12	0.2	0.06	0.13	0.16
13	0.15	0.09	0.23	0.11
14	1.8	0.9	4.1	0.4
15	1.0	0.4	3.4	0.5
16	0.18	0.05	0.15	0.31
17	0.14	0.05	0.27	0.10
18	11.4	1.7	12.8	3.2
19	5.8	0.7	6.2	1.6
20	6.9	0.9	8.1	1.5
21	2.5	0.9	7.1	1.5
22	1.4	0.4	3.0	0.7
23	5.0	1.8	12.3	3.7
25	1.6	0.5	4.0	0.9
26	50.7	10.2	56.2	8.8
27	1.4	0.5	2.0	0.4
28	1.9	0.9	3.2	1.5
29	4.6	1.3	6.5	1.4
30	4.9	1.5	10.5	3.6
31	2.9	0.9	5.9	2.3
32	36.3	11.4	111.4	2.9
34	4.8	2.2	18.3	2.2
36	0.3	0.08	0.4	0.1
37	27.0	7.1	67.9	1.4

o All equipments (34 equipments).

Having prior knowledge that these ratios might be either normally or log-normally distributed, Chi-Square and Kolmogorov-Smirnov "Goodness-of-Fit" tests can be applied to the data to determine the underlying probability distributions. Therefore, a chi-square goodness-of-fit test is first applied to the ratios.

The hypothesis to be tested, at the 0.05 significance level, is whether the ratios of observed MTBF to predicted MTBF for any or all of the three equipment categories have an underlying probability distribution which is either normal (Gaussian) or log-normal.

Table XIII, "Chi-Square Goodness of Fit Test for Normal Distribution", shows the results of the Chi-Square test for a normal distribution of the ratios.

TABLE XIII
CHI-SQUARE GOODNESS OF FIT TEST
FOR NORMAL DISTRIBUTION

Equipment Category	Sample Size	ν= D.F.	MIL-HDBK-217A			RADC Upper Grade		
			χ_0^2	$\chi^2_{.05,\nu}$	Significant	χ_0^2	$\chi^2_{.05,\nu}$	Significant
All Equip.	34	6	12.7	7.82	yes	2.71	7.82	no
Analog Equip.	20	1	5.95	3.84	yes	9.29	3.84	yes
Digital Equip.	14	1	4.67	3.84	yes	0.330	3.84	no

From Table XIII, we reject the hypothesis that the ratios of observed MTBF to predicted MTBF are normally distributed when the prediction is made via the MIL-HDBK-217A technique. Also, we reject the hypothesis for the analog equipments when the prediction is formed via the RADC Volume II technique. We are unable to state that the ratios for digital and all equipment categories are not normally distributed for the RADC predictions. However, it is obviously the strong influence of the digital equipment which prevents the "all equipments" category from being significant (i.e., rejected) at the 0.05 level.

Table XIV, "Chi-Square Goodness of Fit Test for Log-Normal Distribution", illustrates the results of the Chi-Square test for a log-normal distribution of the ratios.

TABLE XIV
CHI-SQUARE GOODNESS OF FIT TEST FOR
LOG-NORMAL DISTRIBUTION

Equipment Category	Sample Size	ν= D.F.	MIL-HDBK-217A			RADC Upper Grade		
			χ_0^2	$\chi^2_{.05,\nu}$	Significant	χ_0^2	$\chi^2_{.05,\nu}$	Significant
All Equip.	34	6	4.59	7.82	no	2.47	7.82	no
Analog Equip.	20	4	1.53	3.84	no	1.02	3.84	no
Digital Equip.	14	4	0.084	3.84	no	0.323	3.84	no

In Table XIV it is shown that we cannot reject the hypothesis that the ratios of any of the equipment categories (i.e., all, analog, or digital) are log-normally distributed whether the prediction utilizes the MIL-HDBK-217A or the RADC technique.

The Kolmogorov-Smirnov goodness of fit test was applied to the ratios of the same equipment categories as the Chi-Square test to ascertain whether the ratios by equipment categories were normally or log-normally distributed. The Kolmogorov-Smirnov Test is given by the expression

$$D_{\alpha,\nu} = MAX|F_{o_i} - S_{n_i}|;\ i = 1,2,\ldots,n = \text{number of cells,} \quad (3)$$

where

F_{o_i} ≡ the theoretical cumulative frequency distribution up to and including the i^{th} cell,

S_{n_i} ≡ the observed cumulative frequency distribution up to and including the i^{th} cell,

α ≡ the significance level,

ν ≡ the degrees of freedom, and equal to the total number of observations.

Table XV, "Kolmogorov-Smirnov Test For Normal Distribution," illustrates the results of this test by equipment categories.

TABLE XV

KOLOMOGOROV-SMIRNOV TEST

FOR NORMAL DISTRIBUTION

Equipment Category	Sample Size	$\nu =$ D.F.	MIL-HDBK-217A			RADC Upper Grade		
			D_0	$D_{.05,\nu}$	Significant	D_0	$D_{.05,\nu}$	Significant
All Equipments	34	34	0.254	0.23	yes	0.261	0.23	yes
Analog Equip.	20	20	0.361	0.294	yes	0.319	0.294	yes
Digital Equip.	14	14	0.181	0.349	no	0.094	0.181	no

From Table XV we can reject the hypothesis that either of the categories of "all equipment" and "analog equipment" are normally distributed regardless of the prediction technique. However, we cannot reject the hypothesis that the digital equipment is normally distributed.

The results of the Kolmogorov-Smirnov test for the log-normal distribution are shown in Table XVI, "Kolmogorov-Smirnov Test For Log-Normal Distribution".

TABLE XVI

KOLMOGOROV-SMIRNOV TEST FOR
LOG-NORMAL DISTRIBUTION

Equipment Category	Sample Size	$\nu =$ D.F.	MIL-HDBK-217A			RADC Upper Grade		
			D_0	$D_{.05,\nu}$	Significant	D_0	$D_{.05,\nu}$	Significant
All Equipments	34	34	0.079	0.23	no	0.091	0.23	no
Analog Equip.	20	20	0.091	0.294	no	0.085	0.294	no
Digital Equip.	14	14	0.054	0.349	no	0.109	0.349	no

From Table XVI, we can observe that we cannot reject the hypothesis that the ratios for equipment categories have log-normal distributions regardless of the prediction technique.

It appears from both the Chi-Square and the Kolmogorov-Smirnov test that the log-normal distribution is the better fit for the ratios of observed MTBF to predicted MTBF.

(3) Tests for Equal Variances and Means

Since there appears to be a difference between the digital and analog equipments which may require different prediction techniques for the two equipment types, further tests were employed to determine if the equipments were part of the same log-normal distribution. These tests are:

- o Bartlett's Number (a test for the equality of variances).
- o "F" Ratio Test (a test for the equality of means).
- o "t" test (a test for the equality of means).

Prerequisites for the analog and digital equipments to be members of the same log-normal population, are that their means and variances be equal. Hence, the first step was to determine if the variances are equal. A useful test for determining if the variances are equal, especially when more than two variances are involved, is the "Bartlett's Test". The Bartlett's test is a comparison between the arithmetic average of the sample variances and the geometric average of those variances. The geometric average is less sensitive to extreme values than is the arithmetic average. Hence, a ratio of the arithmetic average to the geometric average produces a large value when the variance is non-uniform, and conversely, the ratio produces a small value when the variances are uniform.

The computed Bartlett's number is compared, at the appropriate confidence level ($1-\alpha$), with the Chi-Square variate whose degrees of freedom are the number of sample variances less one. If the computed Bartlett's number exceeds the Chi-Square variate, then one may conclude that the variances are not equal.

The standard deviations were determined and used to compute the Bartlett's number for six cases. These six cases were designed to test between the variances of the ratios within the three equipment categories, and also test between the variances of the ratios between equipment categories. The six cases and the results of these tests are presented in Table XVII, "Bartlett's Test for Equality of Variances."

TABLE XVII

BARTLETT's TEST

FOR EQUALITY OF VARIANCES

Equipment Category	No. of Sample Variances (k)	Bartlett's Number	$\chi^2_{.05,k-1}$	Test Case Number	Significant
All Equipment	4	5.26	7.82	1	No
Analog Equipment	4	2.41	7.82	2	No
Digital Equipment	4	5.65	7.82	3	No
All vs Analog	8	7.83	14.07	4	No
All vs Digital	8	30.72	14.07	5	Yes
Analog vs Digital	8	28.36	14.07	6	Yes

From the above table, it is evident that the variances within the three equipment categories may be considered equal. In addition, the variances between the all equipment category and the analog equipment category may be considered equal. However, the variance associated with the digital equipment category is different from the variances of the other equipment categories.

The next step in determining if the log-normal populations are one and the same for analog and digital equipments, is to determine if the means of the populations are equal. The test for the equality of population means is based on the analyses of variance technique. This technique (the F ratio test) is based on the assumption that the population variances are equal.

The value of F which is calculated is tested against a tabular value of F with K-1 and N-K degrees of freedom (K is the number of means under test and N is the sum of the observation for each sample.) and at the desired confidence level. If the calculated value exceeds the tabular value of F, one may conclude with $(1-\alpha)$ percent confidence that the means are unequal.

The F ratio test was performed on the three equipment categories where the variances within equipments were equal. The results of the F ratio test are shown in Table XVIII,"F Ratio Test For The Equality of Means".

TABLE XVIII

F RATIO TEST

FOR THE EQUALITY OF MEANS

Equipment Category	F_0	$F_{05;K-1,N-K}$	Significant	$F_{01;K-1,N-K}$	Significant
All Equipments	10.47	2.68	Yes	3.94	Yes
Analog Equipments	3.66	2.73	Yes	4.06	No
Digital Equipments	21.21	2.82	Yes	4.25	Yes

From the above Table, we recognize that we can reject the hypothesis of equal means for all three equipment categories with 95 percent confidence. Also, the hypothesis of equal means within the equipment categories can be rejected with 99 percent confidence for all categories except the analog equipment category. This indicates that different log-normal distributions exist in each case.

Since the test for equal variances between equipment categories showed a definite difference between the analog equipment variance and the digital equipment variance, the F ratio test could not be utilized to determine the equality of the means between these two equipment categories. Hence, a Student's "t" test was used to test the hypothesis of equal means between analog equipment and digital equipment.

The computed value of "t" is compared with a tabular value of "t" at the desired confidence level and the appropriate degrees of freedom. There were four comparison cases determined between the means of analog and digital equipments (i.e., MIL-HDBK-217A, RADC Volume II Upper Grade, RADC Volume II Lower Grade, and Original Contractor predictions). The results of these tests are shown in Table XIX, ' "t" Test For The Equality of Means.'

TABLE XIX

"t" - TEST FOR

EQUALITY OF MEANS

Prediction	D.F.	t_0	$t_{.01}$	Significant	$t_{.05}$	Significant
MIL-HDBK-217A	32	4.49	2.75	Yes	2.04	Yes
RADC Upper Grade	29	3.00	2.76	Yes	2.05	Yes
RADC Lower Grade	28	5.35	2.76	Yes	2.05	Yes
Original Contractor	22	2.31	2.82	No	2.07	Yes

From the above table, it can be noted that we reject the hypothesis of equal means between analog and digital equipment ratios for all prediction techniques with 95 percent confidence. However, we cannot reject the hypothesis of equal means between analog and digital equipment ratios for the original contractor prediction with 99 percent confidence. The above indicates that in all cases the analog and digital equipments are from different log-normal distributions. Thus, if accuracy is to be increased in prediction techniques, then analog and digital equipments require different techniques.

The reliability prediction (i.e., RADC Volume II upper grade parts) were divided into categories (i.e., high MTBF, low MTBF, close agreement to observed MTBF, and those for which insufficient observed data are available). The following tabulations evaluate the divisions of the equipments. (See Table XX - Table XXII)

TABLE XX

EQUIPMENTS

WITH HIGH MTBF RATIOS

Equipment Code Number	Ratio $MTBF_o/MTBF_p$	Analog or Digital	Function	Percent Active Elements
2	26.5	Analog	Power	43.0
3	13.4	Analog	Power	29.0
5	6.1	Digital	Control	23.4
6	3.8	Digital	Computer	61.2
7	7.0	Digital	Amplifier	37.8
8	3.8	Digital	Control	55.1
9	7.3	Digital	Control	35.2
10	2.1	Digital	Computer	53.3
11	3.8	Analog	Power	28.9
26	10.2	Analog	Power	32.2
32	11.4	Digital	Computer	36.5
34	2.2	Analog	Display	30.2
37	7.1	Digital	Computer	41.2

There were eight digital equipments and five analog equipments whose MTBF ratios were high (i.e., >2.0). The five analog equipments contain four equipments whose function is power (e.g., power supply) and of these four power equipments there were three equipments with extremely high ratios (i.e. >10.0). In fact, these three equipments were on the extreme end of the high MTBF scale. Also, the table indicates that more digital equipment predictions under-estimate the equipment MTBF's than analog equipment predictions. Predominant functional groups are computers and control equipments (seven of the eight digital equipments). There is no evident relationship between the percent of active elements and the MTBF ratios.

There were nine equipments whose MTBF ratios were low (i.e., < 0.5) These nine equipments were all analog equipments. Table XXI "Analog Equipments with Low MTBF Ratios," lists these nine equipments, their MTBF ratio, function, and percent of active elements.

TABLE XXI

ANALOG EQUIPMENTS

WITH LOW MTBF RATIOS

Equipment Code Number	MTBF Ratio	Function	Percent Active Elements
12	0.07	Control	17.2*
13	0.09	Receiver	15.2*
15	0.40	Control	31.2
16	0.06	Control	7.0*
17	0.06	Test	29.3*
22	0.40	Control	31.0
25	0.50	Control	34.2
27	0.46	Control	41.8
36	0.08	Test	31.2

* Approximately 5 Percent Tubes

The above table indicates a gross relationship between the incidence of active elements (tubes) and the very low (i.e., < 0.1) MTBF Ratio. The four tube type equipments have the lowest ratios and the lowest percent active elements. However, because of the small sample, a definite conclusion on the relationships could not be established. From Table XX, "Equipments with High MTBF Ratios", and Table XXI above, it is evident that the MTBF ratios for equipments with the control function vary across the spectrum of variability. This indicates that the prediction technique for control equipment exhibits a wide range of variation.

Table XXII, "Equipments with Accurate MTBF Ratio", show the twelve equipments whose MTBF Ratios were accurate (i.e., close to the observed value).

TABLE XXII

EQUIPMENTS WITH ACCURATE

MTBF RATIOS

Equipment Code Number	MTBF Ratio	Analog or Digital	Function	Percent Active Elements
1	1.71	Digital	Computer	46.0
4	0.76	Analog	Control	26.4
14	0.88	Analog	Control	29.7
18	1.68	Digital	Control	42.8
19	0.69	Digital	Control	46.4
20	0.88	Digital	Control	47.7
21	0.92	Analog	Control	33.4
23	1.78	Digital	Computer	36.7
28	0.93	Analog	Display	33.3
29	1.34	Digital	Power	44.0
30	1.47	Analog	Power	40.0
31	0.94	Analog	Test	50.1

From Table XXII, it is again evident that no correlation exists between MTBF ratio and percent of active elements. Also, the digital and analog equipments are equally represented.

SECTION V

IMPROVEMENT OF PRE-DESIGN PREDICTION TECHNIQUES

1. OBJECTIVES

The objectives of the study effort concerned with improvement of pre-design prediction techniques are listed below:

- o Research existing pre-design prediction techniques to determine areas wherein improvement should be made.
- o Measure the accuracy of existing pre-design prediction techniques.
- o Through the use of operational data, develop functional modifiers which can be used to provide a more accurate prediction.

2. SUMMARY

Two functions were developed, which will improve the accuracy of pre-design prediction techniques for analog power and control equipments. No function was found to have a sufficiently high correlation coefficient to enable improved pre-design prediction techniques to be developed for digital electronic equipment and display equipment.

The two techniques which were developed to improve the pre-design predictions are modifier functions to the MIL-STD-756A prediction, and are shown below for each category of analog equipment.

Power

$$\widehat{MTBF} = 1958\ (MTBF)^{0.73}$$

Control

$$\widehat{MTBF} = (MTBF)/(.0124 + .00037\ MTBF)$$

Where

$\widehat{MTBF}$ = Modified MTBF prediction

$MTBF$ = MIL-STD-756A Predicted MTBF

The percent difference of observed to improved MTBF predictions are shown in Table XXIII. All improved predictions are considered better than the original MIL-STD-756A prediction with one exception; namely, equipment number 16, where the modified prediction is comparable to the MIL-STD-756A prediction, but less accurate. The predictions for power equipment are more accurate than those for the control equipment, with all predictions within one hundred percent accuracy.

TABLE XXIII

PERCENT DIFFERENCE OBSERVED TO IMPROVED
MTBF PREDICTION FOR ANALOG EQUIPMENT GROUPS

Type	Code Number	MIL-STD-756A
Power	2	- 3.7
	3	- 19.8
	11	19.3
	26	56.3
	30	- 30.5
Control	4	353.4
	12	6.3
	15	1.8
	16	- 66.6
	21	38.4
	22	- 0.4
	25	696.5
	27	399.9
	36	60.7

In summary, the following conclusions were made as a result of the analysis of pre-design prediction techniques:

- o All pre-design techniques predict lower-than-observed MTBF values for most electronic equipment.
- o Equipment in the digital and analog design approach categories exhibited distinctly different ranges of prediction accuracy ratios.
- o The digital design approach category exhibited a positive correlation between prediction accuracy ratios based on the MIL-STD-756A, prediction technique.
- o The analog design approach category failed to show any significant correlation between the prediction accuracy ratios of the prediction techniques.
- o Significant differences in the range of prediction accuracy ratios were established between functional categories of analog equipment.
- o Prediction accuracy can be improved for the pre-design prediction techniques for selected functional categories of analog equipment, by the use of a functional modifier.
- o When the analog equipment is subdivided into power, control, and display groups, a positive correlation exists between the MTBF values produced by the pre-design prediction techniques and measured values for each group.

3. DETAILS

a. Technical Approach

The establishment of improvements in current predesign prediction techniques for ground electronic equipment, involved an analysis of the characteristics of the prediction techniques. This included investigations of the areas where the techniques were valid, and an identification of the weaknesses of the techniques. MTBF predictions for the candidate equipments were made, using the existing predesign prediction techniques. The accuracy of the predictions was evaluated and compared to the observed equipment MTBF, using the ratios of observed MTBF's to predicted MTBF's. To determine whether any technique could be improved to more accurately predict the observed MTBF values, it was necessary to determine whether or not the technique produced values having a fundamental relationship to the observed values. For this purpose, a regression analysis was performed on the predicted and observed MTBF values to obtain a functional fit of the predicted to observed MTBF values. Six functions, listed below, were evaluated in making the best fit. The correlation coefficient was used to indicate the goodness of fit for each function.

- $Y = A + BX$
- $Y = Ae^{BX}$
- $Y = AX^{B}$
- $Y = A + (B/X)$
- $Y = 1/(A + BX)$
- $Y = X/(A + BX)$

The function identified as having the best fit was used to obtain new predicted MTBF values for each equipment. The new MTBF values were compared to the observed values and a distribution analysis of the ratios of observed to predicted MTBF was performed. The analyses were used to identify and isolate factors causing prediction inaccuracy, and to determine distribution parameter values so that measures of the inaccuracy of selected prediction techniques could be determined.

b. Pre-Design Reliability Prediction Techniques

(1) Introduction

Current reliability prediction techniques are used during the predesign phase of the development cycle. These techniques are based upon established relationships between equipment reliability values (e.g., MTBF) and selected equipment characteristics such as:

(1) Equipment function,

(2) Active element group count,

(3) Power consumption, and

(4) Number of CRT tubes.

Each of the techniques evaluated is discussed in the sections below.

(2) Prediction by Function - Federal Electric Method

The prediction by function technique developed by the Federal Electric Corporation was based upon radar, communication, and Electronic Data Processing (EDP) central processing functions operating in a fixed ground environment.

The communication function is characterized in three separate sub-functions as follows: "receive," "transmit," and "multiplex." For these sub-functions, respectively, MTBF can be predicted as a function of Noise Figure (DB), Power Gain (DB) and the number of voice channels utilized, using the following expressions:

$$MTBF_{receive} = (2889)\ e^{-.136\ N_F}$$

$$MTBF_{transmit} = (6769)\ G^{-.624}$$

$$MTBF_{multiplex} = (783)\ e^{-.0178C}$$

Where,

N_F = Noise figure (in decibels) i.e.,

$$\frac{\text{Signal-to-Noise power ratio of ideal receiver}}{\text{Actual Signal-to-Noise power ratio of receiver output}}$$

G Power gain (in decibels) i.e.,

$$\frac{\text{Typical average power output of final amplifier}}{\text{Input power required to drive final amplifier}}$$

C = Number of Communication Channels

The EDP central processor prediction technique predicts MTBF as a function of the ratio of word size (in bits) to add time (in microseconds). The equation for the EDP central processor MTBF prediction is:

$$MTBF_{central\ processor} = (524)\ e^{-.135\ W/A}$$

where,

W = Word size in bits

A = Add time in microseconds

The radar function is characterized in two separate sub-functions: "receiver," and "transmitter." For these sub-functions, failure rates per active element are obtained through the following functions:

$$\lambda_r = 4.17\ (P)^{.32}$$

$$\lambda_t = 9.06\ (P)^{.36}$$

where,

λ_r = Receiver failure rate per active element group

λ_t = Transmitter failure rate per active element group

P = Peak power in kilowatts.

An active element group is defined as a tube and associated circuitry, or a transistor or diode and its associated circuitry. The FEC radar prediction by function has an alternate predictor which combines the two sub-functions of receive and transmit into a single equation as follows:

$$\lambda_{r-t} = 6.3(P)^{.3}$$

where,

λ_{r-t} = failure rate per active element group for the radar receive-transmit function.

For the range of parameter values represented for radar, communication and central processor equipment, the maximum and minimum MTBF values and their respective parameters for the six predictors are shown in Table XXIV. The functional parameter values represent the range of values for which the FEC predictors hold.

TABLE XXIV

MINIMUM AND MAXIMUM PREDICTION

PARAMETER AND MTBF VALUES

Predictor Function	Function Parameter	Parameter Value		MTBF Prediction	
		Minimum	Maximum	Maximum	Minimum
Communication Receive	Noise Fig	1 db	11 db	2500 hrs	600 hrs
Communication Transmit	Power Gain	15 db	75 db	1300 hrs	500 hrs
Communication Multiplex	# Voice Channels	5	45	750 hrs	350 hrs
EDP Central Processor	Word Size / Add Time	.1 bit/μSec	9 bit/μSec	580 hrs	160 hrs
Radar Receiver	Peak Power	1 KW	5000 KW	240,000*	13,000*
Radar Transmitter	Peak Power	1 KW	5000 KW	125,000*	5,000*

*MTBF per active element

(3) Prediction by Function - ARINC Research Corporation Methods

The prediction by function developed by ARINC was developed by grouping all the data into one group, in contrast to the three separate groups of the FEC technique, discussed previously. Three separate functional relationships were developed, using functions such as power, active element count, voltage, and the number of display tubes. The first, (and only one that includes the active element count) applicable to all equipments of the type used in the ARINC study, is indicated to be the preferred technique. The second and third equations are used for radiating or non-radiating systems, respectively. The ARINC equations are given below for similar, radiating, and non-radiating equipment, respectively.

- $\text{Ln } \hat{\theta} = 8.6859 - 0.5632X_a - 0.2556X_b - 0.0858X_c$
- $\text{Ln } \hat{\theta} = 6.4408 - 0.2055X_b - 0.1597X_c - 0.5120X_d$
- $\text{Ln } \hat{\theta} = 7.2612 - 0.5089X_d - 0.1123X_e$

where,

$\hat{\theta}$ = Predicted MTBF in hours

X_a = Ln (Adjusted count of active elements)

X_b = Ln (Power consumption in kw)

X_c = Number CRT's

X_d = Ln (Max dc voltage in kv)

X_C = Ln (highest frequency in mcs)

The major drawback of this technique, as with the FEC technique, is that there is a limited range of electronic equipment functions to which the technique can be applied and the state of the art changes in equipment design tend to make the data obsolete.

(4) MIL-STD-756A

The MIL-STD-756A technique is a prediction by series active elements through the use of a nomograph. The reliability values produced by this method have been shown (reference 2) to be dependent upon the functional block level to which the equipment reliability model is subdivided. This dependency is illustrated, for some selected ground electronic equipments, in Figure 1 "Ground Electronic MTBF Predictions - First and Second Indenture."

The dashed line in Figure 1 represents the predicted MTBF to the first indenture level for the selected equipments while the circled points are the predicted MTBF values to the second indenture level. The second indenture level predictions assumed a series relationship between the functional black boxes, and were plotted in Figure 1 using the total number of series active elements in the equipment so as to provide a first indenture level comparison.

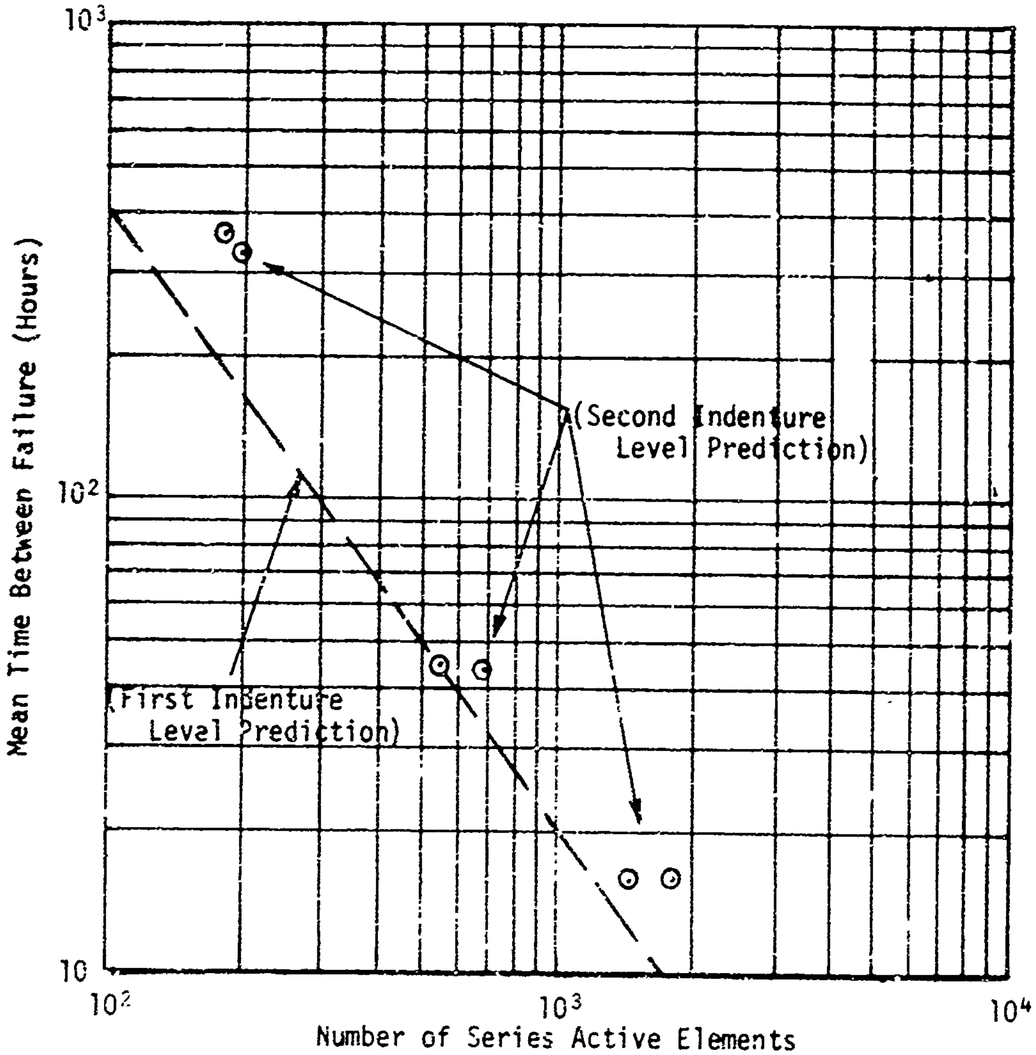

Figure 1. Ground Electronics MTBF Predictions First and Second Indenture

To apply the prediction technique, one must first break the system up into functional groups, count the number of series active elements in each group, enter the reliability nomograph and read off the functional group MTBF. The system MTBF is determined through the system reliability model. The active elements are defined as tubes, transistors, diodes and their associated circuitry, except that for a digital computer application, one tenth the number of diodes should be used. An additional indenture anomaly for an assembly which is on the border of being classed a computer arises when some of its subassemblies will not be so classified. In this case, a third prediction would result. Since the MIL-STD-756A technique can be applied for all functional classes of electronic equipment, this is a tool for providing a consistent set of predesign prediction techniques, provided predictions are made to the same functional level.

c. Candidate Equipments

The equipments in the predesign prediction analysis are the same equipments as were used in Section IV, "Improvement of Stress Analysis Prediction Techniques." The selection criteria used for the stress analysis were also used, as pertaining to predesign predictions in this section, and augmented to include predesign prediction requirements. The augmented list is given below

- o Availability of equipment parts lists.
- o Availability of predesign prediction parameters on equipment.
- o Availability of operating failure data on the mature system.
- o Established failure reporting system (e.g., AF 66-1, contractor reporting, etc.).
- o Validity of data for desired analysis techniques.

d. Correlation With Observed Reliability

Comparisons of observed to predicted MTBF's were made, using predictions formulated by each of the pre-design techniques. Since the prediction by function techniques are not applicable to the entire class of ground electronic equipment, not all the equipment having predictions formulated by the parts count prediction method were used in the prediction by function analysis. Furthermore, it was determined that results having a more general application could be obtained from the predesign prediction analysis, if the bulk of the analysis were performed by the MIL-STD-756A Method, which is applicable to the entire class of ground electronic equipment. Therefore, the ratios of observed to predicted MTBF's for the ARINC and FEC predictions are shown for information purposes in Table XXV, "Ratios of Observed to Predicted MTBF for Selected Ground Electronic Equipment - Prediction by Function."

TABLE XXV

RATIOS OF OBSERVED TO PREDICTED MTBF FOR SELECTED GROUND ELECTRONIC EQUIPMENT - PREDICTION BY FUNCTION

CODE NO.	ARINC	FEC
6	7.06	21.97
24	8.03	17.09
33		.97
35		.48

The ratios of observed to predicted MTBF's for MIL-STD-756A are shown in Table XXVI. The first thirteen equipments are in the digital design approach category while the twenty remaining equipments are in the analog design approach category. The MIL-STD-756A technique, in all but one case, predicted MTBF values which are lower than the observed, and in some cases predicted considerably lower MTBF values. When the equipments were divided into the two sub-sets of digital and analog, the MIL-STD-756A method exhibited more accurate predictions for digital equipments than for analog.

Six functional relationships listed in paragraph 3.a above, of predicted to observed MTBF were developed for each of the following three equipment categories and subcategories:

TABLE XXVI. RATIOS OF OBSERVED TO PREDICTED MTBF FOR GROUND ELECTRONICS - PARTS COUNT PREDICTIONS

Digital		Analog	
Code Number	MIL-STD-756A	Code Number	MIL-STD-756A
1	138.0	2	1542.0
5	437.0	3	412.0
6	424.0	4	304.0
7	2003.0	11	1068.0
8	1629.0	12	2.6
9	1112.0	13	2.9
10	621.0	14	45.1
18	129.0	15	55.0
19	302.0	16	.58
20	360.0	17	2.7
23	70.0	21	70.0
29	147.0	22	76.0
32	1998.0	25	71.0
		26	625.0
		27	31.7
		28	32.8
		30	416.0
		31	199.0
		34	147.0
		36	6.5

o All ground electronic equipment

o All analog electronic equipment

- Power
- Controls
- Display

o All digital electronic equipment

The correlation coefficients for each functional fit were calculated to determine what, if any, functional relationships existed between the predicted and observed MTBF's. From the correlation coefficients, it was determined that the best fit of the general categories was provided by the function:

$$Y = AX^B \quad (4)$$

Where,

X = The Parts Count predicted MTBF

Y = Adjusted MTBF

A = Shaping parameter

B = Shaping parameter

This function, of all the general category functional relationships tested, provided correlation coefficient values ranging from a low of .608 to a high of .867.

The correlation coefficients for the functional relationship $y = AX^B$ are listed in Table XXVII for all general categories.

TABLE XXVII

CORRELATION COEFFICIENTS FOR THE FUNCTIONAL RELATIONSHIP $Y = AX^B$ - PREDICTED TO OBSERVED MTBF

Equipment Category	MIL-STD-756A
All Equipment	.608
Analog Equipment	.622
Digital Equipment	.867

For digital equipment, the correlation coefficient was not considered to be sufficiently high to enable the development of adjustment modifiers to modify MTBF predictions of digital equipment to be more in line with the observed MTBF values. Further subdivision of the digital equipment was not possible, so no improved prediction technique for digital equipment was developed.

For analog equipment the correlation coefficient was not as high as for the digital, however, analog equipment could be subdivided into three subcategories of power, control, and display. For each subcategory the six functions discussed in paragraph 3.a were again fitted. This produced a noticeable increase in the resultant correlation coefficients. Table XXVIII lists the correlation coefficients, and the shaping parameters for those functions which were found to have sufficiently high correlations. The power and control subcategories had a correlation coefficient sufficiently high to use the fitted function in adjusting predesign predictions.

TABLE XXVIII SHAPING PARAMETERS AND CORRELATION COEFFICIENTS FOR SELECTED PREDICTION MODIFIERS - ANALOG EQUIPMENT

Equipment Category Prediction Technique Fitted Function	A	B	Correlation Coefficients
Power MIL-STD-756A $Y = AX^B$	1958.0	.73	.951
Control MIL-STD-756A $Y = X/(A+BX)$	.0124	.00037	.986

SECTION VI

INTEGRATED CIRCUIT FAILURE RATES

1. OBJECTIVES

The objectives of this portion of the study included the following:

- o Measure the accuracy of existing techniques for predicting the reliability of equipment using integrated circuits (IC's);
- o Identify and evaluate major sources of prediction inaccuracy; and,
- o Establish failure rates and related data useful for improving the accuracy of reliability predictions for equipment using IC's.

2. SUMMARY

The results of the investigation show that IC's generally exhibit failure rates that are lower that those predicted by two different prediction models. The low failure rates appear to be the result of increasing achievement of production, design and "Hi-Rel" requirements. These same factors, when applied to discrete parts, also result in observed failure rates which are lower than can possibly be predicted by the most optimistic stress analysis prediction technique of the RADC Notebook Volume II. The observed failure rates for discrete parts in general show more deviation from the predicted rates than do IC's. This large deviation from predicted to observed still exists at the equipment level, even though parts such as multilayer printed circuit boards are not included in the prediction and contribute up to 20% of the observed failure rate. If these parts were included in the prediction there would be a greater difference between predicted and observed equipment failure rates.

Prediction techniques which have limiting factors, such as the Σ_E modifier of the RADC Notebook, prevent predicted failure rates from decreasing to reflect improvements in production, design, or in the general state of the art. The limiting factor for the part failure rate should be the inherent failure rate of the part, that is, the failure rate associated with a part which has no quality defects and is applied within the design limits.

The quality modifier should be a continuous type of function instead of establishing a few discrete points. This is also brought out by the rating studies which show that the ratios of predicted and observed equipment failure rates reflect definite differences between systems having different quality programs. For the IC's, the Notebook uses four levels of quality, as compared to two for other parts. This may be one reason why the predictions for IC's are closer to the observed than the other parts.

3. DETAILS

Review of available literature shows that failure rates used in reliability predictions for integrated circuits (IC's) can vary by a factor of 100 - depending upon the manufacturer, the environment, and the user. This wide range of variation in failure rates is due to the fact that IC's are characterized by a very high inherent reliability and a rapidly changing state of the art, both of which result in a relative scarcity of standardized failure data.

This section presents an analysis of failure rate data and evaluations of the relative accuracy of several prediction techniques applied to a variety of IC's. Failure rate information is obtained from the operation of these IC's in a fixed ground environment for a total of nearly eight billion hours. Since IC's are always used in conjunction with discrete parts, data on the predicted and observed reliability of these related items are also included in the analysis.

a. Analytical Techniques for IC Reliability Prediction

Table XXIX presents a summary of the techniques applicable to the prediction and assessment of IC reliability, which were reviewed during this phase of the study. The table also presents conclusions applicable to each technique.

Since there are no pre-design techniques applicable to the prediction of IC reliability at this time, stress analysis techniques were used in developing reliability predictions for analysis and comparison with observed data. Two different prediction methods were selected as follows:

(1) The RADC Reliability Notebook, Volume II Method; and,

(2) The EIA (Electronics Industry Association) Method.

The models used by these techniques are illustrated in Table XXX Details on the RADC method are contained in the Notebook Volume II. Details of the EIA model are discussed below.

The EIA prediction model referred to herein is the model developed by the EIA microelectronic device group (MED 4.3). The EIA model assumes the existence of a mixed IC population comprised of two (2) major subsets. One subset contains potential failure modes related to inherent (design-oriented) factors which are by definition non-screenable. The other subset contains potential failure modes related to quality assurance factors which are by definition controllable and/or screenable. The basic prediction equation is of the form:

TABLE XXIX

ANALYTICAL TECHNIQUES FOR I.C. RELIABILITY PREDICTION AND ASSESSMENT

Technique	Application	Output	Conclusions
Classical Stress Analysis (based on circuit elements - i.e., resistors, transistors, etc.)	1. The circuit elements of the IC are the units of concern. 2. Electrical stress ratios. 3. Thermal stresses. 4. Environmental stresses.	1. Element λ as a function of stresses. 2. IC λ as the summation of element λ's.	1. Series reliability model is inapplicable due to interaction. 2. Circuit element of IC is not an appropriate unit of concern and stress data are difficult to define.
Worst Case Analysis	1. The IC is the level of application	1. Circuit λ as a function of worst case conditions.	1. Data are difficult to define. 2. Circuit transfer equations and interaction are complex.
Prediction by Function	1. Functional class (amplifier, oscillator, etc.) 2. Functional characteristics (power output level, etc.).	1. $\lambda = A_1C_1 + A_2C_2 + A_mC_m$ where the A's are constants and the C's are measures of critical characteristics.	1. Present data indicates little correlation to circuit function for IC's.

TABLE XXIX (Continued)

ANALYTICAL TECHNIQUES FOR I.C. RELIABILITY PREDICTION AND ASSESSMENT (Concluded)

Technique	Application	Output	Conclusions
Reliability Improvement Techniques	1. Design tasks, including selection of parts, integrating design work, interpretation of actual mission requirements. 2. Production tasks. 3. Operating procedures, including effects of operator, maintenance and administration personnel.	1. λ = (Contribution from each participating design, production, operating group) minus (deficiencies removed by analysis and corrective action).	1. Necessary for use in an IC prediction model, e.g., the "π_Q" factor from RADC Notebook.
Time Dependent Reliability Models	1. Time expended in screening and testing. 2. Number of failures that have occurred. 3. Operational time.	1. Debugging λ = f (time, number failures, screening program). 2. Normal life λ = constant. 3. Normal life = f (quality level).	1. Present data indicates 5:1 ratio between first-year failure rates and later year failure rates.

TABLE XXX

COMPARISON OF FORMULAS FOR IC PREDICTION MODELS

EIA	RADC Notebook Volume II
$\lambda_U = (\lambda_I + P_E P_U \lambda_Q)\ K_H K_T K_S K_A$	$\lambda_p = \lambda_b \times \pi_C \times \pi_P \times \pi_E \times \pi_Q$
$\lambda_I = \lambda_D + \lambda_m$ -- Design + Material Failure Rate -- Value .02 F/M hours. Fixed: or use of existing data.	λ_b -- Base Failure Rate varies as temperature from .0044 to .0305 F/Mili hours.
$P_E P_U \lambda_Q$ -- Added Failure Rates due to screen tests both vendor and user.	π_Q -- Screening Factor
K_H -- Handling Factor .8 to 1 less at comm. grade	Not Used
K_T -- Temperature Factor	Covered by base failure rate
K_S -- Stress Factor Assumed to be 1	Not Used
K_A -- Environmental Factor Not considered Not Considered	π_E -- Environmental Factor π_C -- Complexity Factor π_P -- Packaging Factor

$$\lambda_U = [\lambda_I + P_E \lambda_Q] K_A, \qquad (5)$$

where,

λ_U denotes the failure rate seen by the user

λ_I denotes inherent failures (non-screenable)

λ_Q denotes QA-related failures (controllable/screenable)

P_E is the probability of escape past the screen

K_A denotes application (environmental) factors

In theory, the term λ_I is a variable dependent upon several design factors, including a factor for device complexity. In practice, however, the design factors cannot be isolated and quantified to distinguish between design variations. Therefore, a constant λ_I failure rate of .002%/1000 hours is used for predictions on standard devices. Also in theory, the terms P_E and λ_Q are functions of individual producers where the QA-related failures are a function of the individual producer's process technologies, and the probability of escape (P_E) is a function of the effectiveness of individual screening programs. In practice, however, the available data allows only for a broad classification which relates these factors to general classes of programs (i.e., commercial, military, and hi-rel). For all except the most rigid high-reliability programs, the term $P_E \lambda_Q$ is much larger than the term λ_I.

One "failing" of the EIA model is the assumption of a constant failure rate. In practice, studies have demonstrated that the IC system failure rate initially decreases, due to continuation of screening at the black box level (in-house operation and checkout), and due to expending of failures in the QA related subset. In theory, the failure rate then reaches a low stable level and later increases as devices age. In practice, however, the available data does not demonstrate the aging effect. A comparison of the effects caused by the numeric modifiers of the EIA and the Notebook Volume II is presented in Table XXXI.

b. Description of IC Data Sources

All IC data were obtained from devices operating in a fixed ground environment under controlled conditions of temperature and humidity. Ambient temperature for all devices was controlled within a range which was not permitted to vary beyond 21°C to 37°C. Humidity for

TABLE XXXI

COMPARISON OF NUMERIC MODIFIERS FOR IC PREDICTION MODEL

Factor	EIA (Vendor) (Screens)	EIA (Vendor & User) (Screens)	RADC Notebook Volume II
1. Screening Factor Effect			
Commercial	100	111	*
Military	14.9	17.2	
Hi-Rel	1	1	
2. Temperature Factor Effect			
(T_J) 25°C	1	1	1
50°C	2.2	2.2	1.61
75°C	3.8	3.8	3.02
125°C	12.5	12.5	6.93
3. Basic Failure Rate With Temperature (parts per million hours)			
(T_J) 25°C	.12	.045	.0044
50°C	.26	.098	.0060
75°C	.46	.172	.0133
125°C	1.5	.563	.0305
4. Environmental Factor			
Lab.			1.0
Sat. Orbit	0.7	0.7	1.5
Gd. Fixed	1.0	1.0	2.0
Gd. Mobile	1.2	1.2	5.0
Gd. Portable			7.0
Airborne Inh.	1.7 to 3	1.7 to 3	5.0
Airborne Unh.			7.0
Sat Launch			8.0
Missile	10	10	10.0

* For the RADC Notebook, the values are: Lower Grade - 30; Average - 15; Upper - 2; and, Optimum - 1.

devices in an unsealed container was controlled with a maximum of 60% RH at 27°C under normal conditions. The remainder were operated within a hermetically sealed container.

These devices were operated in the following types of functional units: control assembly, amplifier assembly, computer, and a signal data converter.

The circuits were of the monolithic epitaxial construction. The cases were either Kovar gold or ceramic 1/8" by 1/2" flatpacks with up to fourteen external leads. The seal on the metal package was weld and the seal on the ceramic was glass frit. There were different metalization interconnects and internal wire systems with a predominance of gold-gold and aluminum-aluminum. The internal wire bonds for the gold-gold systems were "ball bonds" and on the aluminum-aluminum were "wedge bonds." Stress conditions were controlled at less than 50% of maximum rated power and temperature. Each circuit had a preseal visual inspection and a minimum electrical burn-in time of 250 hours. Many manufacturers were represented. However, one manufacturer supplied more than fifty per cent of the total parts. This exact amount was impossible to determine. All circuits were manufactured under similar specifications, processes, and quality controls.

c. <u>Analysis of Data</u>

Table XXXII lists the IC's used in the equipment by device type. The table includes for each device: the number of primary field failures, accumulated hours and the best estimate failure rate, using the ratio of total failures to total hours. Table XXXIII includes the best estimate failure rate for each device type by equipment.

To further analyze the failure rates in Table XXXII a distribution of the failure modes was considered. This is shown in Table XXXIV which indicates that 73.4% of the failure modes could not be identified due to the fact that failure mode data were not available. This was due to causes such as: mishandling, "retested good after removal," or electrical overstresses. The indicated "handling problems" accounted for approximately 25 per cent of the unknown failures. This suggested that handling errors may be a major cause of IC failures, i.e., good IC's may be damaged while a failure is being removed or replaced. For those IC's which were acceptable on retest, the possibility of incorrect removal action in the field was indicated. If not all of the listed IC failures were due to part defects (as opposed to other errors) the overall failure rate for IC's in this system would be much less than indicated.

TABLE XXXII

INTEGRATED CIRCUITS
FIELD OPERATION DATA

Device Type	Number of Failures	Total Accumulated Hours	Best Estimate Failure Rate %/10^3 Hours*
1) Flip Flop	41	907,737,130	.00452
2) Triple Nand Gate	11	486,755,549	.00226
3) Clocked 7 Input Nand Gate	17	779,175,724	.00218
4) Clocked Dual Nand Gate	15	1,278,504,823	.00117
5) Input Network	3	45,120,650	.00665
6) Output Driver	9	218,112,541	.00413
7) Matrix Switch	0	98,170,498	.00101
8) Low Level Switch	6	147,255,732	.00407
9) Read Preamplifier	3	79,081,782	.00379
10) Demodulater Chopper	4	84,535,698	.00473
11) Power Switch	20	338,142,792	.00621
12) Unclocked Dual Nand Gate	28	2,376,656,832	.00118
13) Triple Non-Resistive Nand Gate	1	38,177,412	.00262
14) Input Network Low Current	4	183,308,153	.00218
15) One Shot Multivibrator	0	16,361,748	.00611
16) Level Detector	3	76,354,824	.00393
17) Write Switch No. 2	0	170,757.908	.00059
18) General Purpose Amplifier #1	7	292,134,787	.0024
19) General Purpose Amplifier #2	3	122,713,110	.00244
20) General Purpose Amplifier #3	0	5,453,916	.0183
21) Driver Switch	2	136,993,966	.00146
	177	7,881,505,565	.00225

*Assume one failure if none

TABLE XXXIII

INTEGRATED CIRCUITS
OBSERVED FAILURE RATES BY EQUIPMENT **

Device Type	EQUIPMENT NUMBER					
	8	9	10	11	12	TOTAL
1 Flip Flop	.00436	.0122*	.00667	-	.00295	.00452
2 Triple Nand Gate	.00130	.0183*	-	-	.00404	.00226
3 Clocked 7 Input Nand Gate	.00249	.0122*	-	-	.00112*	.00218
4 Clocked Dual Nand Gate	.00101	.00917	.00916	-	.00137	.00117
5 Input Network	.0110	-	-	-	.00560*	.00565
6 Output Driver	.00180	-	-		.0116	.00413
7 Matrix Switch	.00102	-	-	-	-	.00101
8 Low Level Switch	.00407*	-	-	-	-	.00407*
9 Read Preamplifier	.00379	-	-	-	-	.00379
10 Demodulator Chopper	-	-	.00407	.00917	-	.00473
11 Power Switch	.0200	.00136	.00444	.00407*	-	.00621
12 Unclocked Dual Nand Gate	.00126	-	.00367*	-	.00082	.00118
13 Triple Non-Resistive Nand Gate	.00262	-	-	-	-	.00262
14 Input Network Low Current	.00179	.0183*	-	-	.00303	.00218
15 One Shot Multivibrator	.00611*	-	-	-	-	.00611*
16 Level Detector	.00393	-	-	-	-	.00393
17 Write Switch No. 2	.000621*	.0367*	-	-	.0140*	.00059*
18 General Purpose Amplifier #1	-	.000748*	.00579	00333	.0033	.0024
19 General Purpose Amplifier #2	-	-	.00147	.00367	-	.00244
20 General Purpose Amplifier #3	-	-	-	.0183*	-	.0183*
21 Driver Switch	-	.00153*	.00349	-	.007*	.00146

*NO FAILURES

** FAILURE RATES ARE %/1000 HOURS

TABLE XXXIV

INTEGRATED CIRCUIT FAILURE MODES

FAILURE MODE	TOTAL NUMBER PER EQUIPMENT				
	EQUIPMENT NUMBER				
	8	9	10	11	TOTALS
Not Available	53	2	5	1	61
Retest Good	23	0	2	1	26
Analysis Pending	9	0	0	0	9
Electrical Overstress	10	0	7	1	18
Holes in Oxide	6	0	6	0	12
Oxide Defect	1	0	1	0	2
Surface Contamination	1	0	0	0	1
Non-Hermetic Seal	1	0	0	0	1
Foreign Material	2	0	0	0	2
Cracked Die	4	0	1	0	5
Faulty Diffusion	1	0	0	0	1
Poor Adhesive	1	0	0	0	1
Faulty Bond	0	0	1	0	1
Internal Lead Misrouted	1	0	0	0	1
Internal Lead Lagging	1	0	3	0	4
Internal Lead Damage	0	0	1	0	1
Poor Mask	1	0	0	0	1
Corrosion	6	0	2	0	8
TOTALS	121	2	29	3	155 *

* FAILURE MODES FOR IC FAILURES OF EQUIPMENT NUMBER 12 NOT AVAILABLE

The failure modes which could be attributed to the IC are process-oriented. A list of observed process-oriented failure modes and percentage distribution is given in the table below:

TABLE XXXV

PROCESS-ORIENTED FAILURE MODES

(Total Number 41)

Failure Mode	% of Total Process Failures	Failure Mode	% of Total Process Failures
Oxide Defects	34.1	Poor Metal Adhesion	2.4
Surface Contamination	2.4	Faulty Bond	2.4
Non-Hermetic Seal	2.4	Internal Lead Misrouted	2.4
Foreign Material	4.9	Internal Lead Sagging	9.8
Cracked Die	12.2	Internal Lead Damage	2.4
Faulty Diffusion	2.4	Poor Mask	2.4
Corrosion	19.5		

The table above indicates that quality control factors play a very important role in the failure rates of the IC's. At one extreme, the high reliability IC has a failure rate of about .002%/1000 hours. At the other extreme, when all of the unknown failure modes represented in the first four categories in Table XXXIV and 50 per cent of process Q. C. errors are censored out, the achievable IC failure rate could be less than .0005%/1000 hours.

The failure rate data presented in Table XXXIII was analyzed to determine if the failure rates of individual devices were considered statistically different from the expected failure rate of 0.00225%/1000 hours. The chi-square test was used to determine statistical equivalence. For each device the observed number of failures per billion part hours was compared to the expected number of failures per billion part hours (22.5 failures per billion part hours) estimated from the data. Devices where the failure expectation per cell was less than five failures were grouped so that the assumptions underlying the test were not violated. This resulted in 12 cells for the test.

If the failure rates for all devices were determined to be statistically equivalent, this would be significant to the validation of such elements of the RADC Volume II prediction method as the complexity factor. It would also be significant from the standpoint of determining the sensitivity of IC failure rates to circuit application and to equipment function.

The value of chi-square that was obtained is 146.0, which is greater than the value of chi-square in the statistical tables (10 degrees of freedom, 99% confidence level). Thus, at a confidence level exceeding 99%, it is concluded that at least one of the devices in the table exhibits a device failure rate which is not equal to .00225%/1000 hours.

d. <u>Accuracy of IC Prediction Models</u>

When using the two failure rate prediction methods, major considerations are utilized; accuracy at the part level, and the effect of the prediction at the equipment level. Data which were used to verify accuracy at the part level are the accumulated results of Table XXXII Table XXXVI presents a comparison of the observed and predicted failure rates for each device, based on predictions formulated by the Notebook Volume II and EIA prediction methods. To determine the accuracy of the prediction methods, the following steps were taken:

(1) Predictions were prepared, using two junction temperatures, 30°C and 60°C. These temperatures represent the maximum and minimum junction temperatures which the devices experienced in actual operation. This given range of temperature is a necessary feature of the prediction, because the data concerning junction temperature was available only as a range.

TABLE XXXVI

COMPARISON OF OBSERVED DATA WITH PREDICTIONS PER THE RADC NOTEBOOK VOL. II AND THE EIA METHOD*

	DEVICE TYPE	λ %/10^3 HRS. BEST ESTIMATE	RADC NOTEBOOK VOL. II				E.I.A.		
			π_C COMPLEXITY FACTOR	λ PRED $T_j=30^0C$	λ PRED $T_j=60^0C$	ERROR FACTOR	λ PRED $T_j=30^0C$	λ PRED $T_j=60^0C$	ERROR FACTOR
1	Power Switch	.00621	1	.002	.004	1.55	.005	.011	0
2	Clocked 7 Input Nand Gate	.00218	1	.002	.004	0	.005	.011	-2.29
3	Unclocked Dual Nand Gate	.00118	1	.002	.004	-1.69	.005	.011	-4.24
4	Clocked Dual Nand Gate	.00117	1	.002	.004	-1.71	.005	.011	-4.27
5	Low Level Switch	.00407	1	.002	.004	1.02	.005	.011	-1.23
6	Input Network	.00665	1	.002	.004	1.66	.005	.011	0
7	Input Network Low Current	.00218	1	.002	.004	0	.005	.011	-2.29
8	Output Driver	.00413	1	.002	.004	1.03	.005	.011	-1.21
9	Level Detector	.00393	1	.002	.004	0	.005	.011	-1.27
10	Driver Switch	.00146	1	.002	.004	-1.37	.005	.011	-3.42
11	Triple Nand Gate	.00226	2	.004	.008	-1.77	.005	.011	-2.21
12	Triple Non-Resistive Nand Gate	.00262	2	.004	.008	-1.53	.005	.011	-1.91
13	Write Switch No. 2	.00059**	2	.004	.008	-6.78	.005	.011	-8.47
14	Matrix Switch	.00101**	2	.004	.008	-3.96	.005	.011	-4.95
15	Demodulator Chopper	.00473	2	.004	.008	0	.005	.011	-1.11
16	Flip Flop	.00452	2	.004	.008	0	.005	.011	-1.10

* Failure Rate at %/1000 hours.

TABLE XXXVI (CONCLUDED)

COMPARISON OF OBSERVED DATA WITH PREDICTIONS PER THE RADC NOTEBOOK VOL. II AND THE EIA METHOD*

	DEVICE TYPE	λ %/10^3 HRS. BEST ESTIMATE	RADC NOTEBOOK VOL. II				E.I.A.		
			πC COM-PLEXITY FACTOR	λPRED T_j=30°C	λPRED T_j=60°C	ERROR FACTOR	λPRED T_j=30°C	λPRED T_j=60°C	ERROR FACTOR
17	One Shot Multi-vibrator	.00611**	3	.006	.012	0	.005	.011	0
18	General Purpose Amplifier #1	.0024	8	.016	.032	-6.67	.005	.011	-2.08
19	General Purpose Amplifier #2	.00244	8	.016	.032	-6.56	.005	.011	-2.05
20	General Purpose Amplifier #3	.0183**	8	.016	.032	0	.005	.011	1.66
21	Read Preamplifier	.00379	10	.02	.04	-5.28	.005	.011	-1.32

RADC MODIFIERS

$\pi P = 2$
$\pi E = 2$
$\pi Q = 1$
$\lambda b\ (30^oC) = .0005$
$\lambda b\ (60^oC) = .001$

E.I.A. MODIFIERS

$K_S = 1$
$K_A = 1$
$K_H = 1$
$P_U = .25$
$P_E = 0.1$
$\lambda_Q = 1.0$

$\lambda_I = .002$
$K_t\ (30^oC) = 1.1$
$K_t\ (60^oC) = 2.4$

* FAILURE RATE AT %/1000 HOURS

** NO FAILURES

NOTE: The maximum and minimum junction temperature is used. If the prediction falls within the range, it is considered a reasonable prediction.

(2) If the observed failure rate fell within the range of failure rates established by the predictions from the two junction temperatures, the prediction was considered reasonably accurate and the error factor was equal to zero.

(3) If the observed failure rate was greater than the predicted at T_j max (underestimate), the error factor was formulated as follows:

$$\lambda obs/\lambda pred\ (T_j max)$$

(4) If the observed failure rate was less than the predicted at T_j min. (overestimate) the error factor was formulated as follows and identified in the tables by a minus sign (-).

$$-\lambda pred\ (T_j min)/\lambda obs$$

The analysis of the error factor gives an insight into the accuracy of the prediction models:

(1) The Notebook Volume II has seven values of zero: the EIA has three.

(2) The Notebook Volume II overestimates ten times and underestimates four times. The EIA overestimates seventeen times.

(3) The Notebook Volume II has an average error factor for underestimation of 1.32 and -3.73 for overestimation. The EIA average for overestimation is -2.70.

(4) The error factors of the Notebook Volume II's prediction for linear circuits is significantly different than those for lower complexity. The EIA methods show no significant difference.

There are five device types which have large error factors greater than 2.0 when using the Notebook Volume II model. They are the write switch, the matrix switch and three linear amplifiers. The reason that the write and matrix switches have lower failure rates than predicted is not discernible from analysis of available data. The quality and complexity factors could account for inaccuracy in the predictions for these "Hi-Rel" parts. The reason for the amplifiers' high error factors is due to the influence of the complexity factor on the predicted values. With "Hi-Rel" screening, these linear amplifiers did not show any significant increase in failure rate over the digital type of devices. This does not mean that linear amplifiers which are manufactured under normal screening will exhibit the same failure rate as digital devices which are screened in the same manner. The complexity modifier may need to be further developed as a function of quality factors. Unfortunately, only one quality level is represented in the data. If the complexity factor for all devices with "Hi-Rel" screening had been equal to "one", then there would be only one error factor over 2.0. There would also be an equal distribution between underestimation and overestimation of the failure rates. However, when complexity reaches a medium scale integration, i.e., around 30 gates, the effect of complexity on the increase in the number of failure modes may not be offset by "Hi-Rel" screens.

The EIA model has the largest error factor and overestimates for 90% of the devices with one underestimation. The model gives a range, 0 to -4.95, for the error factors when omitting the one large factor. This is less than the range of 1.66 to -6.78 for the Notebook Volume II. This indicates distribution of error is smaller for the EIA model. However, with the modifiers and base failure rates, the model cannot predict less than .0045% per 1000 hours for these devices.

e. Distribution of Equipment Prediction Errors

To identify the sources of prediction error for the equipments using IC's, the contribution of the various parts to the predicted and observed failure rates was studied. Tables XXXVII through XLI present the contribution of each generic part type to the predicted from the Notebook Volume II and observed failure rates for the five equipments in terms of percent per 1000 hours and percent of the total failure rate. The Notebook Volume II was used because other prediction methods had less accuracy for these equipments. Observation of the tables showed that:

(1) The prediction accuracy for IC's and capacitors was better than for resistors, diodes and transistors.

(2) The relative contribution to the observed failure rate of IC's and capacitors is greater than predicted, and the relative contribution is subsequently lower for diodes, transistors, and resistors.

(3) The influence of multilayer printed circuit boards is high compared to the number of boards used. The best estimate observed failure rate for the multilayer printed circuit boards is .058%/1000 hours. The Notebook Volume II does not, at present, include a method to make a prediction for printed circuit boards. For some systems, therefore, the Notebook Volume II will not identify a component which is one of the major sources of failure.

For four of the equipments a further breakdown of specific parts failures is possible. Tables XLII through XLV present the total accumulated hours, number of failures, and a best estimate failure rate for specific parts by equipment. One failure is assumed if none are observed. Table XLVI gives the best estimate failure rate for specific parts, using the combined total from the previous four tables.

TABLE XXXVII

FAILURE DISTRIBUTION OF GENERIC PARTS*
EQUIPMENT NUMBER 8

COMPUTER

PART TYPE	TOTAL NUMBER OF FAILURES	CONTRI-BUTION TO λ PRED	%CONTRI-BUTION TO λ PRED	CONTRI-BUTION TO λ OBS	%CONTRI-BUTION TO λ OBS	RATIO OF λ PRED TO λ OBS
INTEGRATED CIRCUITS	121	7.72	23.8	4.44	52.7	1.74
TRANSISTORS	29	12.7	39.2	1.06	12.6	12.0
DIODES	21	6.64	20.5	.77	9.13	8.62
RESISTORS	2	4.68	14.4	.073	.86	64.1
CAPACITORS	17	.66	2.07	.623	7.39	1.06
MULTILAYER PRINTED CIRCUIT BOARD	28	**	0	1.03	11.89	--
MASTER INTERCONNECT BOARD	12	**	0	.440	5.21	--
	230	32.4	100.00	8.43	100.00	3.84

* FAILURE RATES ARE %/1000 HOURS
** NOT USED IN PREDICTION

TABLE XXXVIII

FAILURE DISTRIBUTION OF GENERIC PARTS*
EQUIPMENT NUMBER 9
AMPLIFIER ASSEMBLY

PART TYPE	TOTAL NUMBER OF FAILURES	CONTRI-BUTION TO λ PRED	% CONTRI-BUTION TO λ PRED	CONTRI-BUTION TO λ OBS	%CONTRI-BUTION TO λ OBS	RATIO OF λ PRED TO λ OBS
INTEGRATED CIRCUITS	2	.407	4.51	.073	5.70	5.58
TRANSISTORS	2	2.82	31.3	.073	5.70	38.6
DIODES	1	2.55	28.3	.037	2.89	68.9
RESISTORS	0	2.99	33.1	0.000	0.00	--
CAPACITORS	30	.256	2.83	1.100	85.80	.233
	35	9.02	100.00	1.28	100.00	7.05

* FAILURE RATES (λ) ARE %/1000 HOURS

TABLE XXXIX

FAILURE DISTRIBUTION OF GENERIC PARTS*
EQUIPMENT NUMBER 10
CONTROL UNIT

PART TYPE	TOTAL NUMBER OF FAILURES	CONTRI-BUTION TO λ PRED	%CONTRI-BUTION TO λ PRED	CONTRI-BUTION TO λ OBS	%CONTRI-BUTION TO λ OBS	RATIO OF λ PRED TO λ OBS
INTEGRATED CIRCUITS	29	.846	6.55	1.06	31.1	.798
TRANSISTORS	20	5.82	45.1	.733	21.5	7.94
DIODES	18	4.23	32.8	.660	19.4	6.41
RESISTORS	1	1.17	9.06	.037	1.08	31.6
CAPACITORS	25	.843	6.52	.917	26.9	.919
	93	12.91	100.00	3.41	100.00	3.79

* FAILURE RATES ARE %/1000 HOURS

TABLE XL

FAILURE DISTRIBUTION OF GENERIC PARTS*
EQUIPMENT NUMBER 11
ACCESSORY ELECTRONICS

PART TYPE	TOTAL NUMBER OF FAILURES	CONTRI-BUTION TO λ PRED	%CONTRI-BUTION TO λ PRED	CONTRI-BUTION TO λ OBS	%CONTRI-BUTION TO λ OBS	RATIO OF λ PRED TO λ OBS
INTEGRATED CIRCUITS	3	.166	7.75	.110	37.5	1.51
TRANSISTORS	2	1.04	48.6	.073	24.9	14.2
DIODES	0	.290	13.6	0	0	--
RESISTORS	0	.318	14.9	0	0	--
CAPACITORS	3	.325	15.2	.110	37.5	2.95
	8	2.14	100.00	.293	100.00	7.56

* FAILURE RATES ARE %/1000 HOURS

TABLE XLI

FAILURE DISTRIBUTION OF GENERIC PARTS*
EQUIPMENT NUMBER 12
SIGNAL DATA CONVERTER

PART TYPE	TOTAL NUMBER OF FAILURES	CONTRI-BUTION TO λ PRED	%CONTRI-BUTION TO λ PRED	CONTRI-BUTION TO λ OBS	%CONTRI-BUTION TO λ OBS	RATIO OF λ PRED TO λ OBS
INTEGRATED CIRCUITS	22	1.93	18.9	1.23	25.3	1.57
TRANSISTORS	16	3.85	37.7	.896	18.4	4.30
DIODES	10	1.86	18.2	.56	11.5	3.32
RESISTORS	0	2.26	22.2	0	0	*
CAPACITORS	21	.281	2.75	1.18	24.2	.238
MULTILAYER PRINTED CIRCUIT BOARD	17	* *	0	.952	19.5	*
MASTER INTERCONNECT BOARD	1	* *	0	.056	1.14	*
	87	10.2	100.00	4.87	100.00	2.09

* FAILURE RATES ARE %/1000 HOURS
** NOT USED IN PREDICTION

TABLE XLII

FAILURE DISTRIBUTION OF DISCRETE PARTS
EQUIPMENT NUMBER 8
COMPUTER

PART TYPE	NUMBER OF FAILURES	TOTAL ACCUMULATED HOURS	BEST ESTIMATE FAILURE RATE %/10^3 HOURS*
Capacitor			
Tantalum Foil	0	40,904,370	.00244
Tantalum Wet Slug	16	654,469,920	.00244
Glass	0	43,631,328	.00229
Ceramic	1	395,408,910	.000253
Resistor			
Wirewound Accurate	2	349,050,624	.000573
Film-Precision	0	3,711,389,838	.0000269
Power Wirewound	0	1,565,273,892	.0000639
Diode			
Silicon General Purpose	20	3,048,739,044	.000656
Silicon Power	1	409,043,700	.000244
Transistor			
Silicon General NPN	17	719,916,912	.00236
Silicon General PNP	4	406,316,742	.000984
Silicon Power NPN	6	54,539,160	.0110
Germanium General NPN	0	106,351,362	.000940
Germanium General PNP	2	95,443,530	.0000210

* ASSUME ONE FAILURE IF NONE

TABLE XLIII

FAILURE DISTRIBUTION OF DISCRETE PARTS
EQUIPMENT NUMBER 9
AMPLIFIER ASSEMBLY

PART TYPE	NUMBER OF FAILURES	TOTAL ACCUMULATED HOURS	BEST ESTIMATE FAILURE RATE $\%/10^3$ HOURS*
Capacitor			
Tantalum Foil	0	19,088,706	.0052
Tantalum Wet Slug	29	46,358,286	.0626
Ceramic	0	50,994,146	.00196
Polystyrene	1	19,088,706	.00524
Resistor			
Wirewound Accurate	0	730,824,744	.000136
Precision Film	0	1,783,430,532	.0000561
Power Wirewound	0	398,135,868	.000251
Diode			
Silicon General	1	1,308,939,840	.0000764
Silicon Power	0	57,266,118	.00175
Transistor			
Silicon General NPN	1	302,692,338	.000330
Silicon General PNP	0	16,361,748	.00611
Silicon Power NPN	1	139,074,858	.000719

* ASSUME ONE FAILURE IF NONE

TABLE XLIV

FAILURE DISTRIBUTION OF DISCRETE PARTS
EQUIPMENT NUMBER 10
CONTROL UNIT

PART TYPE	NUMBER OF FAILURES	TOTAL ACCUMULATED HOURS	BEST ESTIMATE FAILURE RATE %/10^3 HOURS *
Capacitor			
Paper	0	19,088,706	.00524
Tantalum Wet Slug	24	886,261,350	.00271
Glass	0	62,720,034	.00159
Ceramic	1	662,650,794	.000151
Polystyrene	0	5,453,916	.0183
Resistor			
Wirewound	1	13,634,790	.00733
Precision Film	0	1,079,875,368	.0000926
Power Wirewound	0	474,490,692	.000211
Diode			
Silicon General	18	2,094,303,744	.000859
Silicon Power	0	152,709,648	.000655
Transistor			
Silicon General NPN	6	670,831,668	.000894
Silicon General PNP	10	286,330,590	.00349
Silicon Power NPN	4	84,535,698	.00473

*ASSUME ONE FAILURE IF NONE

TABLE XLV

FAILURE DISTRIBUTION OF DISCRETE PARTS
EQUIPMENT NUMBER 11
ACCESSORY ELECTRONICS

PART TYPE	NUMBER OF FAILURES	TOTAL ACCUMULATED HOURS	BEST ESTIMATE FAILURE RATE %/10^3 HOURS *
Capacitor			
Tantalum Foil	0	81,808,740	.00122
Tantalum Wet Slug	3	122,713,110	.00244
Glass	0	10,907,832	.00917
Ceramic	0	234,518,388	.000426
Polystyrene	0	8,180,874	.0122
Resistor			
Wirewound Accurate	0	19,088,706	.00524
Precision Film	0	286,330,590	.000349
Power Wirewound	0	109,076,320	.000917
Diode			
Silicon General	0	158,163,564	.000632
Transistor			
Silicon General NPN	1	111,895,278	.000894
Silicon General PNP	1	79,081,782	.00126

* ASSUME ONE FAILURE IF NONE

TABLE XLVI
TOTAL ACCUMULATED DATA
FOR DISCRETE PARTS

PART TYPE	NUMBER OF FAILURES	TOTAL ACCUMULATED HOURS	BEST ESTIMATE FAILURE RATE %/10^3 HOURS*
Capacitor			
Paper	0	19,088,706	.00524
Tantalum Foil	0	141,801,816	.000705
Tantalum Wet Slug	72	1,709,802,666	.00421
Glass	0	117,259,194	.000853
Ceramic	2	1,343,572,238	.000149
Polystyrene	1	32,723,496	.00306
Resistor			
Wirewound Accurate	3	1,112,598,864	.000270
Precision Film	0	6,861,026,328	.0000146
Power Wirewound	0	2,546,978,772	.0000393
Diode			
Silicon General Purpose	39	6,610,146,192	.000590
Silicon Power	1	619,019,466	.000162
Transistor			
Silicon General NPN	25	1,803,246,196	.00138
Silicon General PNP	15	788,090,862	.00190
Silicon Power NPN	11	278,149,716	.00396
Germanium General NPN	0	106,351,362	.000939
Germanium General PNP	2	95,443,530	.00210

*ASSUME ONE FAILURE IF NONE

When comparing the observed part failure rates with the Notebook Volume II predictions, these "hi-Rel" parts generally experienced lower failure rates than the "upper quality grade" parts, except for the tantalum wet slug capacitor and those parts without enough accumulated hours. Table XLVIII compares the observed failure rate with the Notebook Volume II predictions. The table shows that:

(1) Almost all parts have a lower observed than predicted failure rate.

(2) The germanium NPN transistor failure rate was less than that for silicon transistors. This is contrary to the generally accepted belief that silicon transistors exhibit failure rates lower than germanium. The lower failure rates are believed to be due to the effects of "hi-Rel" screens and low power dissipation (less than 50% of maximum rated power capabilities).

(3) The tantalum wet slug capacitor is the only type of part which has a higher observed failure rate than the predicted. The high failure rate is due to an application problem.

(4) The observed resistor and diode failure rates are less than the upper grade additive failure rate (Σ_E) derived from the Notebook Volume II formula (λpart = λbase X π modifiers + Σ_E). The Σ_E factor, determined by environment and part quality grade, becomes the limiting factor for the failure rate of these parts. In other words, the predicted part failure rate cannot be less than the Σ_E factor. Examples are shown in Table XLVII below.

TABLE XLVII

COMPARISON OF OBSERVED FAILURE RATES AND Σ_E FACTOR VALUES

Part Type	Failure Rate %/1000 Hours	
	Observed	Σ_E*
Resistor		
Accurate Wirewound	.00027	.002
Precision Film	.0000146	.001
Power Wirewound	.0000393	.0015
Diodes		
Silicon General Purpose	.00059	.001
Silicon Power	.000162	.001

* Derived from RADC Notebook Volume II using fixed ground environment and upper grade quality

TABLE XLVIII

COMPARISON OF OBSERVED AND PREDICTED FAILURE RATES* FOR DISCRETE PARTS

Part Type	λ Observed	λ Predicted**	λ Predicted / λ Observed
CAPACITOR			
Paper	.00524	.00005	***
Tantalum Foil	.000705	.005	7.09
Tantalum Wet Slug	.00421	.002	.475
Glass	.000853	.0001	***
Ceramic	.000149	.0007	4.70
Polystyrene	.00306	.008	2.61
RESISTOR			
Accurate Wirewound	.000270	.007	25.9
Precision Film	.0000146	.0005	34.2
Power Wirewound	.0000393	.0054	138
DIODE			
Silicon General Purpose	.000590	.005	8.47
Silicon Power	.000162	.007	43.2
TRANSISTOR			
Silicon General NPN	.00138	.013	9.42
Silicon General PNP	.00190	.017	8.95
Silicon Power NPN	.00396	.025	6.31
Ge General NPN	.000939	.098	104.4
Ge General PNP	.00210	.065	31.0

* Failure Rates are %/1000 Hours.

** Predicted for Notebook Volume II.

*** No observed failures and insufficient data.

SECTION VII

RELIABILITY DEMONSTRATION APPROACH

1. OBJECTIVES

This section presents a comparison of four general approaches to reliability demonstration for ground electronic equipment, as follows:

- o Formal Reliability Demonstration
- o Field Reliability Demonstration
- o Reliability Verification Testing
- o Reliability Demonstration by Prediction

The advantages and limitations of each approach are listed, and based on these comparisons, a suggested reliability demonstration approach, incorporating features of the above approaches, is formulated.

Also included are results of studies and analysis relating to the question of reliability demonstration. Specifically, the results of Special Study No. 5 and Special Study No. 1 of Section VIII are included, as these studies bear directly on the question of reliability demonstration. Finally, a discussion of Bayes Theorem is included, describing a methodology whereby prior subjective reliability estimates can be merged with test data to obtain reliability estimates of assemblies and equipments.

2. SUMMARY

The suggested reliability demonstration approach consists of three parts, as follows:

(1) Initially employ reliability predictions to form an equipment reliability baseline.

(2) Develop and implement a reliability verification test program designed to assure that failure mechanisms are identified and corrective action is implemented.

(3) Perform a formal, in-service reliability demonstration test to verify equipment reliability under use conditions. Apply a formal accept/reject criteria to the test.

This suggested approach to reliability demonstration is designed to gain maximum assurance that the equipment does possess a reliability level which meets (or exceeds) developed equipment reliability requirements. However, in performing a formal reliability demonstration test, care must be exercised to assure that the basic statistical assumptions employed in formulating the test are not violated, specifically, the assumption of a constant failure rate. Special Study No. 5, and Special Study No. 1 of Section VIII indicate that the assumption of constant failure rate may not be generally applicable, and that reliability prediction techniques may not be sufficiently accurate such that meaningful demonstration requirements can be established, based on these predictions.

Considering the equipment represented in Table LXXVI, "Percentage Failure Rate Change" (Special Study No. 5, Section VIII), 51.7% had a decreasing failure rate vs time, 34.5% had a constant failure rate vs time, and 13.8% had an increasing failure rate vs time. Thus, 65.5% of the equipment had failure rate vs time characteristics which were in variance with the statistical model assumed. Decisions on whether the equipment passed or failed the test may not necessarily be valid. For example, it is possible that an equipment exhibiting an increasing failure rate vs time could pass a fixed time test simply because, during the test, the total number of failures observed did not exceed the allowable number of failures defined by the statistics of the test. Equipment operation for a slightly longer period of time may alter the conclusion. Likewise, an equipment which exhibits a decreasing failure rate vs time may fail the demonstration test, but may, in fact, have an adequate failure rate, as may have been demonstrated if the test had not been terminated. Only if the equipment failure rate is actually constant can valid conclusions be drawn concerning the demonstrated failure rate and the validity of the demonstration test.

A second inference that can be drawn from the results of Special Study No. 5, Section VIII, is that decreasing failure rates vs time can be expected in, perhaps, up to 50% of the equipments. The implication is that, under the exponential failure assumptions these equipments would pass the test. This would be true in general if the failure rate calculated during the early part of the test equaled the expected value of the failure rate. The demonstrated failure rate would then be greater than the actual failure rate of the equipment since the failure rate would be decreasing. Thus, reliability demonstration tests would yield pessimistic estimates of the reliability of the equipment. If the failure rate were increasing with time, an optimistic estimate of the failure rate would result.

A third inference may be drawn from the results of Special Study No. 1, Section VIII. When early reliability predictions are used as the basis for establishing quantitative reliability demonstration requirements, the probability and range of possible error should be considered. Table LIV , "Comparison of Predicted and Observed Failure Rates" (Special Study No. 1, Section VIII), shows that 84.6% of the observed failure rates differed from the predicted failure rates by greater than plus or minus 100%. In 65.4% of the cases, the predicted failure rate over-estimates the observed failure rate by a factor exceeding two. Therefore, in these cases it would be expected that the equipment would easily pass the reliability demonstration.

Statistical reliability demonstration techniques would not be appropriate for most of these equipments because reliability demonstration models assume constant failure rates and, 72.9% of the equipment exhibit failure rates which are not constant with time (See Table LXXV, "Equipment Failure Rate Characteristics vs Time," Special Study No. 5, Section VIII).

3. DETAILS

a. Introduction

This section of the study presents a brief review of the current demonstration approaches, their advantages and limitations, and a recommended approach. For the purposes of this discussion, reliability demonstration is viewed as a means of obtaining assurance that the equipment will perform the required functions in the specified environment without failure for a specified period of time. Current approaches to reliability demonstration, under this definition, include:

- o Formal test of the equipment for the purpose of determining whether the equipment meets a specified reliability requirement. The test results are analyzed employing statistical analysis techniques. This is generally accomplished at the contractor's facility.

- o In-service equipment demonstration in the field once the equipment has been installed and debugged. This type of testing results in an estimation of "use" reliability. Generally, the test results are analyzed, employing statistical techniques, but the test may lack the formality of the formal demonstration test. The emphasis is placed upon measuring the achieved equipment reliability rather than formally demonstrating a specified reliability requirement, although field testing has been employed for formal demonstration of equipment reliability.

- o Reliability verification tests, designed to gain assurance that the equipment will operate as specified in a reliable manner. This type of testing includes qualification or environmental testing. This type of testing does not result in a formal assessment (in the statistical sense) of equipment reliability.

- o Reliability demonstration by prediction. The reliability prediction is accepted as the demonstration of equipment reliability.

Each of these demonstration techniques is discussed in more detail in the following sections. The features of each type of test, the advantages, and the limitations of each approach are presented.

b. Formal Demonstration Tests

The formal reliability demonstration test determines whether the equipment meets a specified reliability requirement by accumulating operating time and failure data on one or more equipments under specified environmental and operational conditions in accordance with a statistical test plan. The results of the test statistically determine whether, within stated confidence limits, the required reliability was demonstrated. The underlying equipment failure model generally assumed is the exponential time to failure distribution and the accept/reject criteria are based upon the

Poisson distribution. The demonstration test is usually conducted at the contractor's facility by contractor personnel under the cognizance of customer representatives.

The demonstration test is a formal procedure characterized by strict operational rules, rigidly defined result statements, considerable expense, and long test times measured in multiples of the required MTBF. The demonstration test plan consists of four parts:

- o Procedure rules
- o Decision rules
- o The experimental outcome
- o Statements of results

The procedure rules are a priori statements of the test procedure, and include:

- o The type of test; fixed time, fixed number of failures, sequential or other applicable testing approaches.
- o The specific decision rules, accept/reject criteria, and definitions of failure and degradation.
- o The number of equipments to be employed during the test and the test time for each equipment.
- o Rules under which procedures for unforeseen circumstances or questions will be determined.
- o The penalties if the equipment fails the test and the rewards if the equipment passes the test.

The decision rules depend upon the type of test and the specific reliability specification which is applied to the program, but in general will be composed of an accept/reject criteria based upon the appropriate statistics and statistical distribution assumptions inherent in establishing the test. The decision rule will associate the number of failures, test times, penalties and rewards with the decision to accept/reject.

The experimental outcome is the set of data which becomes available as a result of the test. These data are analyzed, using the decision rules and employing suitable statistical analysis techniques. Determination is made as to whether the equipment has passed or failed the test. This determination is the statement of the results of the test, and once the results are verified, the test is completed. Further courses of action are then pursued, based upon the procedure and decision rules established prior to the test. Advantages and limitations are as follows:

-ADVANTAGES-

- Provides a formal demonstration of equipment reliability at a stated confidence level.

- Provides definite penalties and rewards, based upon the results of the demonstration test, which act as powerful incentives to reliability achievement.

- Permits early assessment of reliability which allows the identification and correction of problems before equipment is shipped to the field.

-LIMITATIONS-

- The cost, test time, and number of equipments required to demonstrate statistically a required reliability may be excessive.

- Since the formal demonstration cannot fully duplicate or simulate the actual field environment, the results are questionable.

- The statistical assumptions used to formulate the test may not be valid; e.g., the exponential failure distribution model is not applicable. (See Special Study No. 5, Section VIII)

- The test articles often are not representative of the final product, due to changes in production processes, design, and materials.

- Difficulty is encountered determining courses of action under unforeseen circumstances, even though provision is made for these type occurrences; i.e., all failure and degradation modes cannot be defined in advance.

- It may not be feasible to perform a formal demonstration test, due to the size of the equipment or the operations which are required to be simulated.

c. Field Reliability Demonstration

The field type of reliability demonstration has many features which are similarto the formal demonstration test. The basic test also accumulates operating hours and failure data on the equipment in accordance with a statistical test plan. Statistical techniques are employed to analyze the data. The underlying failure model that is assumed is exponential.

Procedure rules and decision rules are formulated for the test. Generally, contractor personnel perform the test under the cognizance of customer personnel.

However, despite these similarities there are substantial differences in the field demonstration test and the formal demonstration test. The major difference is that the equipment is tested in the actual operating environment. The actual stress and environmental conditions that will be present during the life of the equipment are present during the demonstration test.

A second major difference is that the effects, on equipment reliability, of the in-service operational and maintenance policies and procedures will influece the test results. For example, improper operational or maintenance practices could be reflected by an increased equipment failure rate. Also, the effects of logistics support policies and diagnostic techniques can be significant to the results of this test. (These policies and techniques will influence the mean time to repair (MTTR) of the equipment rather than the mean time to failure. On ground electronic equipment, the MTTR is a significant parameter, contributing to system availability.)

A third major difference that generally exists between the two testing concepts is that a formal accept/reject criteria, including appropriate penalties and rewards, is not established. Instead, the test is run to determine the level of reliability that is achieved and to pinpoint problem areas that require corrective action. The test then becomes an assurance/corrective action test rather than an accept/reject test. If the equipment reliability demonstrated is below a desired or required level, the only recourse available to the customer is to require that corrective action be implemented on those areas where a high defect rate was observed. But, on the other hand, if the equipment performs up to or exceeding expectations, the customer has gained assurance that the equipment performs reliably in the actual operating environment. This assurance is gained without the requirement to pay an incentive fee.

Recently, field reliability demonstration tests with definite accept/reject criteria and associated penalty and rewards, have been proposed, and at least one such test is in progress today. This test requires the demonstration of a specified minimum MTBF. If the MTBF is not achieved, the contractor will incur a financial penalty. If the MTBF is achieved or exceeded, the contractor will gain an incentive fee. Thus, this in-service test is an in-service, formal demonstration test of the equipment. Advantages and limitations are listed below.

-ADVANTAGES-

o The test eliminates the cost and inaccuracies which result, when the environment is simulated, since it is conducted under the actual operating environment of the equipment.

- The test cost is minimized by the use of existing operating personnel and facilities, in lieu of requiring special test personnel and facilities solely for formal demonstration purposes.
- Earlier delivery schedules are achieved since no additional calendar time need be expended after production acceptance tests for the purpose of reliability demonstration.
- The test may identify significant areas for the improvement of the effectiveness of the operational, maintenance, and logistic areas.

-LIMITATIONS-

- Field operational and maintenance policies and practices are beyond the control of the contractor and the customer. This can totally invalidate the test results.
- If equipment fails, it may be too late to incorporate the necessary changes to correct the fault, for economic or tactical reasons.
- It is simply not practical or feasible to monitor and measure the reliability of many types of equipments in the field (e.g., because of short duty cycles, inaccessible points of use, delays in field deployment schedules, etc.).

d. <u>Reliability Verification Tests</u>

Reliability verification testing represents a substantial departure from the formal or field approaches to demonstration testing. In this approach, the emphasis is not on demonstrating a specific reliability but to verify that there are no major sources of unreliability. Tests are conducted both at the complete equipment level and the level of individual parts or assemblies. The general procedure is to operate the equipment at stress levels in excess of operating levels to induce degradation in operating parameters, identify significant failure modes, and pinpoint design features requiring optimization for the improvement of reliability and/or operating characteristics.

The equipments to be tested, using the verification testing technique, are selected by employing one of the following criteria:

- High risk designs, either state-of-the-art assemblies or assemblies which have a past history of a high failure rate.
- Items which possess known failure or wearout mechanisms; batteries, tube design, etc.

- Items which, based on a failure modes and effects analysis, have unresolved potential failure mechanisms which require investigation.

A sample of each of these equipments are placed on test for a period sufficient to verify the existence or non-existence of the suspected failure mechanisms. During the test, special subtests, such as temperature cycling, vibration, and shock would be performed to simulate assembly stress under actual use conditions and to perhaps accelerate the suspected failure mechanism. The test would be concluded when sufficient data was obtained to verify the failure mechanism or to adequately demonstrate that the assembly was suitable (from a reliability and performance standpoint) to incorporate on the final equipment. No attempt is made, generally, to test a large sample for a long test time, such that sufficient data suitable for statistical analysis would be obtained. However, if the verification test required that a large sample be tested for a substantial period, statistical data analysis would be possible. The analysis technique would not require the assumption of exponential time to failure, particularly when a wearout mechanism was under investigation.

-ADVANTAGES-

- Relatively inexpensive to integrate within the standard qualification test program.

- Less time-consuming than either of the previously described approaches.

- Designed to pinpoint failure mechanisms and design inadequacies for early corrective action. The emphasis is placed upon elimination of potential failure mechanisms and upon understanding of other failure causes (such as wearout).

- When statistical data analysis is possible it allows freedom in selection of the most appropriate failure distribution which more accurately describes phenomena under study.

- Aimed at building reliability into the equipment. Other testing approaches only identify weak areas in the equipment. This approach requires corrective action to be incorporated in the design.

-LIMITATIONS-

- Requires considerable engineering manhours, scheduling and funding to support program.

- Provides no accept/reject criteria.

- Does not test the complete equipment for a period of time sufficient to demonstrate reliability.

- Does not simulate the actual operating environment.

e. Demonstration By Prediction

Equipment demonstration by prediction simply means that the reliability prediction is accepted as verification that the equipment possesses a satisfactory reliability level. This technique does not require any testing, either at the equipment or assembly level, but may use data obtained from such testing to validate predictions.

The procedure for performing this type of demonstration is to formulate a reliability prediction in the accepted manner. The contractor develops a mathematical model representing the reliability characteristics of the equipment. The model divides the equipment into assemblies or subassemblies. Next a reliability estimate is generated for each of the assemblies and subassemblies, using any one of several acceptable prediction techniques. These include stress analysis prediction techniques, prediction by similarity or other appropriate methods. The reliability of each of the assemblies is combined by use of the appropriate mathematical expressions and an estimate of the equipment reliability is generated. The entire process is monitored and subject to approval by the customer to insure adequate consideration is given to all factors which influence the equipment reliability. The applicability and acceptability of failure rate data incorporated in the prediction is the key issue.

-ADVANTAGES-

- Major program cost reductions are achieved by eliminating test requirements.
- Immediate corrective action response capability is achieved.
- Program delivery schedules are shortened.

-LIMITATIONS-

- Established prediction inaccuracies introduce large risk factors.
- Accept/reject criteria for the prediction procedure are difficult to establish and may require extensive negotiation.
- The effects of the field environments-including operational and maintenance factors-cannot be measured.
- The prediction employs a model which is only an approximation of actual equipment operational conditions

f. Bayesian Approach to Reliability Assessment (References 3, 4, and 5)

(1) Introduction

The Bayesian approach to reliability assessment is an approach which can be applied to reliability demonstration, since it attempts to incorporate all information that is available to develop an estimate of the reliability of the equipment under analysis. This information includes engineering estimates (predictions) made early in the design cycle and test data or operational data collected during the test or operation of the equipment. The predictions are sometimes labeled "subjective prior estimates" as they cannot be expressed in relative frequency terms (e.g., ratio of total successes to total trials). The test data are termed "objective data" as they are expressed in relative frequency terms. The Bayesian approach to reliability assessment develops a rationale which permits the incorporation of subjective prior estimates with objective test data to obtain an estimate of the reliability of the equipment, at appropriate statistical confidence levels.

The Bayesian approach combines the early reliability assessment with test data to develop early estimates of equipment reliability. Early in a development program, when test data are not available on a particular design, the major assessment tool is the reliability prediction. As the program continues, sufficient test data may be accumulated such that an accurate estimate of equipment reliability can be obtained based solely on the test data. This point usually occurs late in the development cycle. Therefore, it is natural to develop a method where both the prediction (subjective estimates) and objective data (test results) can be combined in a common framework. This can be accomplished using the Bayesian approach. The following discussion will develop the Bayesian approach, with no attempt to advocate superiority of the approach to classical techniques. Also, a discussion of the soundness of combining subjective and objective information will not be included. Final proof of the applicability of the Bayesian approach will be obtained through field experience.

(2) Bayes Theorem

Bayes Theorem is an analysis technique designed to bridge the gap between prior knowledge and statistically conclusive data. The approach permits combination of prior knowledge with test data making use of all the available information in arriving at an estimate of equipment reliability. The application of Bayes to reliability assessment is generalized by considering the following quantities.

γ = The total estimate of the reliability

A = The reliability of the equipment based on test data

B = All prior information concerning the equipment reliability

Using these terms, Bayes theorem can be written:

$$P(\gamma/AB) = \frac{P(\gamma/B)\, P(A/\gamma B)}{P(A/B)} \tag{6}$$

$P(\gamma/AB)$ = Probability that the equipment reliability is γ, based on prior estimates and test data. This is the desired result.

$P(\gamma/B)$ = Probability that the equipment reliability is γ, based on all prior information.

$P(A/\gamma B)$ = Probability of duplicating the test data when the equipment reliability is known, along with prior information. This term is the estimate of equipment reliability based on assumption of an underlying statistical distribution, (the underlying distribution which is assumed is typically Poisson or Binomial).

$P(A/B) = \int_{\text{All } \gamma} P(A/_{\gamma}B) \cdot P(\gamma/B)\, d\gamma$

= Probability of duplicating test data when equipment reliability is unknown.

Bayes Theorem is then:

$$P(\gamma/AB) = \frac{P(\gamma/B)\, P(A/\gamma B)}{\int_{\text{All } \gamma} P(\gamma/B)\, P(A/\gamma B)\, d\gamma} \tag{7}$$

The next step in the formulation process is to select suitable prior distributions. There exist no explicit rules for selecting a specific prior distribution [P (γ/B)]. The following criteria can be established.

o The prior distribution must adequately reflect what is known before test data is available.

o The prior distribution should not imply any assumptions about unknown information concerning the reliability of the component.

o The prior distribution should "go together" with the existing data but allow sufficient variety of choice so that any reasonable prior belief can be represented by the prior distribution.

o The resulting expression should be mathematically tractable.

Although the above criteria are general, two cases of specific interest to reliability analysis techniques are being considered.

- o If the sample test data is Poisson distributed, a Gamma distribution is a convenient prior. A Gamma distribution will be obtained as a posterior distribution.
- o If the sample data is binomially distributed, a Beta distribution is most conveniently selected as a prior. A Beta Distribution will result as a posterior distribution.

Both of these situations will be discussed in the analysis.

(3) Bayesian Approach - Gamma Prior Distribution

The Gamma distribution is used as a prior distribution when the test data is considered to be Poisson distributed. The Gamma prior is:

$$P\ (\gamma/B) = \frac{\tau e^{-\gamma\tau}\ (\gamma\tau)^{\phi-1}\ d\gamma}{(\phi-1)!} \tag{8}$$

The test data is Poisson distributed:

$$P\ (A/\gamma B) = \frac{e^{-\gamma t}\ (\gamma t)^{f}}{f!} \tag{9}$$

$$P\ (A/B) = \int_{0}^{\infty} \frac{\tau e^{-\gamma\tau}\ (\gamma\tau)^{\phi-1}\ e^{-\gamma t}\ (\gamma t)^{f}}{(\phi-1)!\ f!}\ d\gamma \tag{10}$$

After suitable mathematical manipulation P (γ/AB), the estimate of the equipment reliability considering all information is:

$$P\ (\gamma/AB) = \frac{(\tau+t)^{\phi+f}\ [e^{-(\gamma\tau+t)}\ \gamma^{\phi+f-1}]\ d\gamma}{(\phi+f-1)!} \tag{11}$$

t = Accumulated test time

τ = Pseudo test time

f = Actual failures

ϕ = Pseudo failures

The pseudo test time and pseudo failures can be considered parameters of the prior Gamma distribution.

The posterior distribution has the same form as the prior distribution. The initial parameters, ϕ and τ are replaced by ϕ+f and τ+t. The mean and standard deviations of the distributions are given by:

Prior	Posterior
$\gamma_0 = \frac{\phi}{\tau}$	$\gamma_0 = \frac{\phi + f}{\tau + t}$
$\sigma(\gamma) = \frac{\sqrt{\phi}}{\tau}$	$\sigma(\gamma) = \frac{\sqrt{\phi + f}}{\tau + t}$

The resulting posterior Gamma distribution includes the test data (t and f) and the initial estimate (ϕ and τ). The Gamma distribution can be used to obtain confidence limits for γ, based on prior estimates and test data.

(4) Bayesian Approach - Beta Prior Distribution

The Beta Distribution is used as a prior distribution when the test data is considered to be Binomial distributed. The Beta prior is based on a probability P

$$P\ (P/B) = \frac{(\nu-1)!\ P^{\rho-1}\ (1-P)^{\nu-\rho-1}}{(\rho-1)!\ (\nu-\rho-1)!} \quad (12)$$

$0<p<1$

$\nu, \rho > 0$ where ρ is pseudo successes and ν is pseudo trials.

The test data is based on s successes in n trials, and is binomially distributed.

$$P\ (A/pB) = \frac{n!\ p^s\ (1-P)^{n-s}}{s!\ (n-s)!} \quad (13)$$

$$P\ (A/B) = \int_0^\infty \frac{(\nu-1)!\ n!}{(\rho-1)!(\nu-\rho-1)!\ s!\ (n-s)!}\ p^{\rho+s-1}\ (1-p)^{\nu-\rho+n-s-1}\ dp \quad (14)$$

Finally,

$$P\ (P/AB) = \frac{(\nu+n-1)!}{(\alpha+s-1)!\ (\nu-\alpha+n-s-1)!}\ p^{\alpha+s-1}\ (1-p)^{\nu-\alpha+n-s-1} \qquad (15)$$

This too is a Beta distribution. The mean and variance are:

Prior	Posterior
$p = \frac{\alpha}{\nu}$	$p = \frac{\alpha + s}{\nu + n}$
$\sigma^2(p) = \frac{\alpha\ (\nu-\alpha)}{\nu^2\ (\nu-1)}$	$\sigma^2(p) = \frac{(\alpha+s)\ (\nu-\alpha+n-s)}{(\nu+n)^2\ (\nu+n-1)}$

The Beta distribution can be used to determine confidence level for p, based on prior estimates and test data.

(5) Selection of Pseudo Test Time and Failures

The previous discussion demonstrated the procedure by which prior estimates of equipment reliability can be combined with test data to estimate the reliability of the equipment. These subjective estimates were called pseudo failures and test time (ϕ and τ). It is necessary to assign values to each of these quantities and care must be exercised when this is done. If ϕ/τ = .1 and values of ϕ = 10 and τ = 1000, were used, the subsequent test data may not be sufficient to minimize the effects of the prior. This would be particularly undesirable if the prior estimates and the test data lead to different estimates of the true failure rate. In this case, it is desirable that the prior estimate is eliminated or "washed out" by the actual test data.

It is desired then to establish prior estimates that are "washed out" by the test data as more data is accumulated, particularly if the test data and prior estimates lead to substantially different estimates of the failure rate. One procedure is to establish an uncertainty factor, U:

$$U = \frac{\sigma^2}{\gamma} = \frac{\phi/\tau^2}{\phi/\tau} \qquad (16)$$

$$= \frac{1}{\tau}$$

The establishment of U fixes τ, which then fixes ϕ, since a prior estimate of γ is assumed.

A second approach would be to select τ such that it represented a fraction of the actual test time that is expected to be accumulated. Then, as the test time is accumulated, the prior estimate, if different from the test results, will "wash out". If the prior estimate and test data are compatible then this will lead more quickly to an estimate of the failure rate. If a Beta distribution was assumed as a prior distribution, then v would be selected as a fraction of the total number of the expected test trials. As test data is accumulated the estimate is either reinforced or "washed out" depending on the accuracy of the prior estimate and the test results.

(6) Conclusions

The Bayesian approach is designed to supplement early test data to develop estimates of equipment reliability. Later in the program, when sufficient test data are available, the test data will provide the necessary means by which the equipment reliability can be estimated. The initial estimates, if in error, will be "washed out" by the test data and the reliability estimates will be based upon the test data alone. To be assured of this situation the estimates of pseudo time (τ) and pseudo failures (ϕ) should be selected such that τ is selected to be only a fraction of the expected test data. Thus, τ is selected in terms of assurance that it will not be a factor in the estimate of equipment reliability, if the prior estimate proves to be in variance with the test data.

The advantages of the Bayesian approach are as follows. In the early stages of a test program, many components have few test hours and no failures. By using the prior estimate of the component reliability, it is possible to develop reliability estimates on each component. Each of the estimates, if no failures were observed, would result in reduction of the equipment failure rate, in terms of both the prediction and the test data. As the test program continues and more data is accumulated, the weight of the test data will be the determining factor in predicting the equipment reliability. If the prior estimate is compatible with the test data, the effect would be to more quickly obtain failure rate estimates, as each type of information contributes to the total failure rate estimate. If the prior estimate is in variance with the test data, the prior estimate would "wash out," by virtue of the procedure used to determine the prior estimate. Thus, early estimates, which may be incorrect, will not be a significant factor in determining the final component failure rates.

The degree which the early predictions or prior estimates are "washed out" is a function of the accuracy of the early predictions and the degree which they duplicate the test data. If the predictions favorably compare with the ultimate test results, the Bayesian approach will allow more rapid estimates of the reliability to be developed. If the predictions and the ultimate test data are in variance, the prior will almost "wash out" completely and the final reliability estimates will be based on the test data.

g. Matrix Comparison of Four Demonstration Techniques

This section presents a comparison in matrix form, (Table XLIX) of the four demonstration techniques discussed in the previous section. The four techniques are qualitatively rated in accordance with:

- Cost - Cost of running the test,
- Timeliness - When a program test is performed and whether increase in schedule is required, and
- Assurance Gained - Degree of assurance that results of test accurately depict equipment reliability under service conditions.

These parameters are considered the most significant, from a comparison standpoint. Since the Bayesian approach involves all techniques, it is not included in the matrices.

h. Proposed Demonstration Approach

Based upon the demonstration technique matrix and the preceding discussion, the following reliability demonstration approach is suggested:

- Employ reliability predictions to form an equipment reliability baseline. Continually update the predictions as new data becomes available from the predesign phase through the period of field operation and maintenance.
- Develop a reliability verification test program. Define assemblies which require reliability verification testing. Implement this testing to minimize and eliminate failure mechanisms. In the cases where components exhibit known mechanisms which limit the life of the component, test the component to better understand the particular mechanisms involved.
- Perform a formal in-service reliability demonstration to determine reliability under use conditions, including the effects of maintenance policies and logistics support. Include formal accept/reject criteria and associated penalties and rewards.

TABLE XLIX DEMONSTRATION TECHNIQUES MATRIX

Demonstration Technique	Cost	Timeliness	Assurance
Formal demonstration testing	Highest cost - in terms of schedule, manpower, and test equipment involved.	Occurs at end of manufacturing cycle. Requires schedule increase to the extent that delivery is delayed.	Moderate assurance, however, the degree of correlation of demonstration test results with actual in-service reliability is not high.
Field demonstration testing	Low cost - test can be performed with existing manpower and test equipment.	Occurs when equipment enters service. Affects schedule only if equipment fails.	Most assurance - accurately depicts actual reliability under service conditions.
Verification	Moderate to high cost - depending on the scope of test program.	Usually no increase in schedule occurs prior to or during equipment manufacture.	Indefinite - depends upon the individual test program. Does not evaluate total equipment or equipment interfaces. May select wrong assemblies for testing.
Demonstration by prediction	Least cost	No increase in schedule. Is concurrent with design schedule.	Variable assurance - depends on accuracy of model and prediction accuracy.

The suggested reliability demonstration approach incorporates features of the demonstration by prediction, verification testing, and in-service testing techniques, but does not include the formal in-plant demonstration technique. The formal in-plant demonstration technique is excluded because it will generally be the most costly approach, require a longer schedule, and the results will have dubious correlation with the actual in-service measured reliability.

In the suggested approach, the reliability prediction is used as a baseline to establish the initial estimate of the equipment reliability. This estimate is performed at the system level and defines the expected level of reliability. This estimate is not accepted as proof of reliability, but only serves as a starting point in the demonstration process. As the program progresses, the prediction will be continually updated, incorporating design and testing information that is generated, thereby increasing confidence in the prediction.

Concurrent with the equipment prediction, a list of components and assemblies is identified containing candidates for verification testing. For each component, the quantity to be tested, test conditions and test time is determined. These components will be selected based on at least one of the following criteria:

- o High design risk

  State of the art design
  Known history of high failure rate on similar designs

- o Known failure mechanisms

- o Known wearout mechanisms which are imperfectly understood

- o Designs which, based on a failure modes and effects analysis, possess critical failure mechanisms

Tests will be conducted on each of the selected components and assemblies aimed at determining and eliminating the failure mechanisms. In the situations where the components exhibit known wearout mechanisms, these components will be tested to obtain a better understanding of these mechanisms. The tests will be conducted under varying degrees of stresses, to more accurately simulate the actual operating environment. If a sufficient sample and test time is required for the tests, statistically meaningful data will be generated. This data will be reduced and updated estimates of component and assembly failure rates will be obtained. These will be incorporated in the updated predictions.

After the equipment is installed and debugged in the field, the formal in-service demonstration test will commence. This test would be performed concurrently with performance and evaluation tests. The test would be performed under the cognizance of contractor and customer personnel and would be designed to formally establish the achieved reliability of the equipment, including the effects of environment, operation, maintenance, and logistic policies. The results of the test will provide a formal proof of equipment reliability under use conditions.

SECTION VIII

SPECIAL STUDIES

1. INTRODUCTION

The prediction-by-function technique established that relationships exist between observed reliability and selected functional parameters for a number of types of electronic equipment. In addition, studies (1) have shown that prediction accuracy varies between functional types of equipment. Therefore, classification and grouping of equipment, in accordance with its function, was a necessary consideration in the study of reliability prediction techniques.

In addition, it was observed that, when equipments are divided into functional groupings, they can exhibit a wide range of possible design approaches to a given function. Also, within any one design approach, a wide variety of part technologies can be represented (e.g., CRT tubes, integrated circuits, solid state devices, and conventional electronic parts). Therefore, it was also necessary to establish design approach categories and part technology groupings for consideration.

Equipments were divided into broad functional categories (e.g., receiver, transmitter, display, and computer types). These categories proved useful for such purposes as analyzing the distribution of equipment failure rates over long periods of time, and for comparing observed and predicted failure rates for functional types. (See Special Study No. 1.) In addition to broad classifications, categorization by sub-functions (e.g., control, power supply, synchronizer) was also found to be a necessary and useful method of analysis (see Special Study No. 2).

Several methods for categorization of design approaches were investigated. The initial method attempted to align design approach categories with equipment functions, since some functions (e.g., digital computers and pulse-doppler radar transmitters) imply established design characteristics. However, because so many functions can be accomplished through the use of a wide variety of designs and basic hardware, this method was not used. Furthermore, many functions involve a hybrid structure in terms of the various part technologies which are used in the design.

Therefore, a second method considered for the categorization of design approaches was based upon the predominant part technology used for the design, (e.g., solid state, vacuum tube, integrated circuit, electromechanical, magnetic, etc.). However, correlation analyses failed to establish the general utility of these categories. Nevertheless, it was indicated that they are useful as sub-categories.

Evaluation of prediction accuracy, measured in terms of the ratio of the observed to predicted MTBF values (using stress analysis prediction techniques) showed two distinct groupings of equipment. One group exhibited a predominant number of high ratios, while the other showed a predominant number of low ratios. The design approach categories which characterized these groups represented "digital and analog" equipments. Within the analog group, the power equipments constituted a distinct subset, i.e., five out of the six high-ratio equipments were power types. However, within the digital and analog groups, there were no other distinct subsets. Further analysis of prediction inaccuracy factors failed to indicate any further relationships traceable to design approach. Therefore, the categories of digital and analog were established as the only design approach categories.

The Special Studies also were concerned with the evaluation of many other factors pertinent to the accuracy of the reliability prediction process. These included, but were not limited to, the following:

- o The impact of major prediction method variables such as stress, temperature, and part grade (see Special Study No. 3);
- o The impact of program-related factors and the rating of these factors (see Special Study No. 4);
- o The effects of time and field operations upon equipment reliability (see Special Study No. 5).

2. SPECIAL STUDY NO. 1: "COMPARISON OF OBSERVED AND PREDICTED FAILURE RATES"

a. Objectives

The objectives of this Special Study are:

- o Determine if the ratio of predicted to observed failure rate (λ_p/λ_o) could be categorized for particular types of equipment (i.e., transmitter, receiver, computer and display type equipment). That is, does the ratio λ_p/λ_o for a particular type equipment possess any specific, distinguishing characteristic?
- o Define a possible statistical distribution of λ_p/λ_o.
- o Determine a method that could be employed, using the data, to improve the accuracy of predictions. The technique used in this Special Study was to determine a division factor for λ_p, such that the ratio of λ_p/λ_o would be either within plus or minus 100% of $\lambda_p/\lambda_o = 1$, or

$$0.5 \leq \lambda_p/\lambda_o \leq 2.0$$

The division factor (or factors) which resulted in the maximum number of equipment failure rate ratios lying in this range would be selected as representing factors, by which the predicted failure rate could be divided, resulting in "more accurate" equipment predictions.

b. Summary

In summary, the salient results of this Special Study are:

- o The failure rate ratios for transmitter equipments analyzed in this study (λ_p/λ_o) are all less than 0.5. A possible implication is that predictions for transmitter equipment tend to be optimistic. Failure rate ratios for the remaining equipment types show that, generally, predictions are pessimistic.

- o The probability plot of failure rate ratios is not log normally distributed. A normal distribution more closely fits the data.

- o If the predicted failure rates were divided by a constant factor in the range of 3.0 to 4.5, (excluding the transmitter and camera display equipments), a more accurate prediction would have resulted. Accuracy is defined as the predicted failure rate deviating from the observed failure rate by no more than plus or minus 100 percent, which can be expressed in the following form:

$$0.5 \leq \lambda_p/\lambda_o \leq 2.0$$

- o Specifically, if a factor of 4.0 were used as a divisor of the predicted failure rate, 81 percent of the failure rate ratios lie within $0.5 \leq \lambda_p/\lambda_o \leq 2.0$ (The transmitter and camera equipment are excluded. In fact, a multiplying factor of 4.0 would be appropriate for these equipments.)

c. Details

(1) Comparison of Observed and Predicted Failure Rate - Data Presentation

The predicted failure rate for each equipment was obtained from field reports and generally represents the early contractor's predictions. The prediction techniques used by the contractors include prediction by similarity and prediction by parts count. The predictions employed in the study varied and did not all employ the same techniques (i.e.; not all predictions used the stress analysis methods described in MIL-HDBK-217A). The observed failure rate was obtained from field data taken after the equipment had been in operation in the field approximately one year.

Tables L through LIII present a comparison of contractors' predicted failure rates to observed failure rates. The comparison is made at two points in time: (1) at the end of a 12 month period; and, (2) at the end of 27 months (except where otherwise indicated). All comparisons are made on the basis of failures per 1000 hours per equipment type. Failure rates are average failure rates for an individual unit per equipment type. That is, for T-1 the failure rate listed is the average failure rate of the six transmitter units of that equipment type.

TABLE L

TRANSMITTER TYPE EQUIPMENT - FAILURE RATE COMPARISON

Equipment	Predicted Failure Rate (λ/1000 hours) λp	Observed Failure Rate at 12 Months (λ/1000 hours)	Observed Failure Rate at 27 Months (λ/1000 hours) λ_o	Ratio λ_p/λ_o
T-1	9.4	28.2	20.5	0.46
T-2	5.4	24.0	16.2	0.33
T-3	9.4	16.2	19.4	0.48
T-4	5.4	19.2	15.5	0.35

Table L shows that all four of the observed failure rates exceed the predicted failure rate by substantial margins. These four equipments are high power transmitters and the primary contributors to the transmitter failure rate are the power tubes used in the transmitter.

TABLE LI

RECEIVER TYPE EQUIPMENT - FAILURE RATE COMPARISON

Equipment	Predicted Failure Rate (λ/1000 hours) λ_p	Observed Failure Rate at 12 Months (λ/1000 hours)	Observed Failure Rate at 27 Months (λ/1000 hours) λ_o	Ratio λ_p/λ_o
R-1	7.6	1.4	1.1	6.9
R-2	3.2	0.8	0.8	4.0
R-3	0.6	0.15	0.15	4.0
R-4	7.6	1.5	1.4	5.4
R-5	3.2	1.4	1.5	2.1
R-6	0.6	0.11	0.12	5.0
R-7	1.9	0.4	0.4	4.7
R-8	1.9	0.6	0.7	2.7

The comparison between the observed and predicted failure rate shows that the predicted failure rate exceeds the observed failure rate in all cases. The ratios of predicted failure rate to observed failure rate range between 2.1 and 6.9, with an average of 4.35. Table LI shows these results.

TABLE LII

COMPUTER TYPE EQUIPMENT - FAILURE RATE COMPARISON

Equipment	Predicted Failure Rate (λ/1000 hours) λ_p	Observed Failure Rate at 12 Months (λ/1000 hours)	Observed Failure Rate at 27 Months (λ/1000 hours) λ_o	Ratio λ_p/λ_o
C-1	Not Available	0.35	0.36	--
C-2	18.2	7.5	7.6	2.40
C-3	Not Available	5.6	4.3	--
C-4	Not Available	0.5	0.34	--
C-5	1.8	0.5	0.4	4.5
C-6	Not Available	0.5	0.4	--
C-7	18.2	5.2	5.4	3.37
C-8	Not Available	1.5	0.75	--
C-9	Not Available	0.12	0.10	--
C-10	1.8	1.8	1.1	1.64
C-11	Not Available	1.4	1.5 *	--
C-12	Not Available	2.3	3.2 *	--
C-13	5.0	1.1	0.9 *	5.5
C-14	2.5	3.1	2.5 *	1.0
C-15	Not Available			
Elec.		0.6	0.6 *	
Mech		0.6	0.6	
C-16$^{\Delta}$	91	20.5	21.5	4.2

* 18 months

Δ C-16 = C-11 + C-12 + 14 (C-15); where there are 14 units of equipment C-15.

The predicted failure rate was only available for six of the fifteen computer type equipments, which represent approximately 20% of the computer equipment hours accumulated, but approximately 45% of the total failures accumulated. In all the cases, the predicted failure rate was greater than the observed, by a factor that ranges from 2 to approximately 5.

A prediction was performed by the contractor for the computer complex which includes C-11, C-12 and C-15. This is shown as C-16. This predicted failure rate is considerably higher than the observed, after combining the appropriate data. Table LII,"Computer Type Equipment - Failure Rate Comparison," presents the data on all the computer equipment.

TABLE LIII

DISPLAY TYPE EQUIPMENT - FAILURE RATE COMPARISON

Equipment	Predicted Failure Rate (λ/1000 hours) λ_p	Observed Failure Rate at 12 Months (λ/1000 hours)	Observed Failure Rate at 27 Months (λ/1000 hours) λ_o	Ratio λ_p/λ_o
D-1	1.75	0.53	0.34	5.15
D-2	4.65	1.3	0.70	6.65
D-3	Not Available	0.15	0.10*	--
D-4	1.75	0.35	0.50	3.50
D-5	4.65	2.0	1.3	3.57
D-6	Not Available	0.04	0.03**	--
D-7	5.70	3.1	3.0 ***	1.90
D-8	1.15	15.6	--	0.07@
D-9	7.40	4.2	--	1.76@

* 24 months
** 15 months
*** 18 months

@ Calculated using failure rate at end of 12 months.

The observed failure rate, in every case but one, was less than the predicted failure rate. This case was D-8, the camera equipment which had components with known reliability limitations. This is shown in the above table.

(2) Failure Rate Comparison - Predicted vs. Observed - Results

Table LIV presents the results of the failure rate comparisons by equipment type as shown in the four preceding tables. It was possible to obtain predicted failure rates on 26 of the 36 equipments. These predictions were performed by contractor early in the development cycle. Therefore, they represent the initial estimates of the equipment failure rate. The prediction methods included a prediction by similarity method and a parts count method. The observed failure rate included failures due to all causes including design anomalies, wearout, maintenance policies and random failures in time.

TABLE LIV

COMPARISON OF PREDICTED AND OBSERVED FAILURE RATES

	RATIO OF PREDICTED FAILURE RATE TO OBSERVED FAILURE RATE $\frac{\lambda_p}{\lambda_o}$					
EQUIPMENT TYPE	0.05-0.5	0.51-1.00	1.01-2.00	2.01-5.00	5.01-10.00	$\geq$10.01
Transmitter	4	0	0	0	0	0
Receiver	0	0	0	6	2	0
Computer	0	1	1	4	1	0
Display	1	0	2	2	2	0
TOTALS	5	1	3	12	5	0
PERCENTAGE OF TOTAL (26 Equipments)	19.2	3.8	11.6	46.2	19.2	0

The table presents the ratio of the predicted failure rate to the observed failure rate for the 26 equipments per equipment type. The table further subdivides the ratio into six groups, ranging from predictions which were one-twentieth of the observed failure rate to predictions which were ten times the observed failure rate. Considering the equipment types as one group, 15.4% of the ratios fall between plus and minus 100% of the observed failure rate. The remaining 84.6% are either less than 0.5 ($\lambda_p/\lambda_o \leq 0.5$) or are greater than 2.0 ($\lambda_p/\lambda_o \geq 2.0$). None of the ratios exceeded 10.0. Figure 2 shows the cumulative plot of the ratio on log probability paper. If the distribution of λ predicted/λ observed were log normal, this plot could be fitted by a straight line. However, as can be seen, a straight line would be a poor fit.

The chi-square goodness of fit test was applied to the logarithms of the data to determine if the hypothesis that the data could be fitted with a log normal distribution could be accepted. Chi-square calculated to be 8.56 with one degree of freedom. The value of chi-square at one degree of freedom at the 99% confidence level is 6.635. The calculated value of chi-square exceeds this value and it can be concluded that the data points do not fit a log normal distribution. Hence the hypothesis that the log normal distribution is an adequate fit for these points is rejected.

The chi-square test was then applied to the actual ratios to test the hypothesis that the ratios could be fitted by a normal distribution. All data were included except the camera equipment. The value of chi-square calculated from the data, with one degree of freedom is 1.25. This does not exceed the value of chi-square in the table, 3.84, at 95% confidence and one degree of freedom. Thus, the normal distribution cannot be rejected as a fit for the data. Figure 3 plots the data on normal probability paper.

Table LIV shows that the observed failure rates for all four high power transmitters were greater than the predicted failure rates by more than 100%. Only one other equipment displayed this behavior, a camera projection equipment in the display group. For the receiver type equipment, all the equipment had predicted failure rates that exceeded the observed failure rates by a factor of at least two, and 33.3% of the equipment had predicted failure rates that exceeded the observed failure rates by a factor of at least five. For the computer equipment, 71.4% of this group had predicted failure rates which exceeded the observed failure rates by a factor of at least two times the observed failure rate. For the display equipment, discounting the camera projector, 67% of the equipment had predicted failure rates which exceeded the observed failure rates by a factor of two ($\lambda_p/\lambda_o \geq 2.0$).

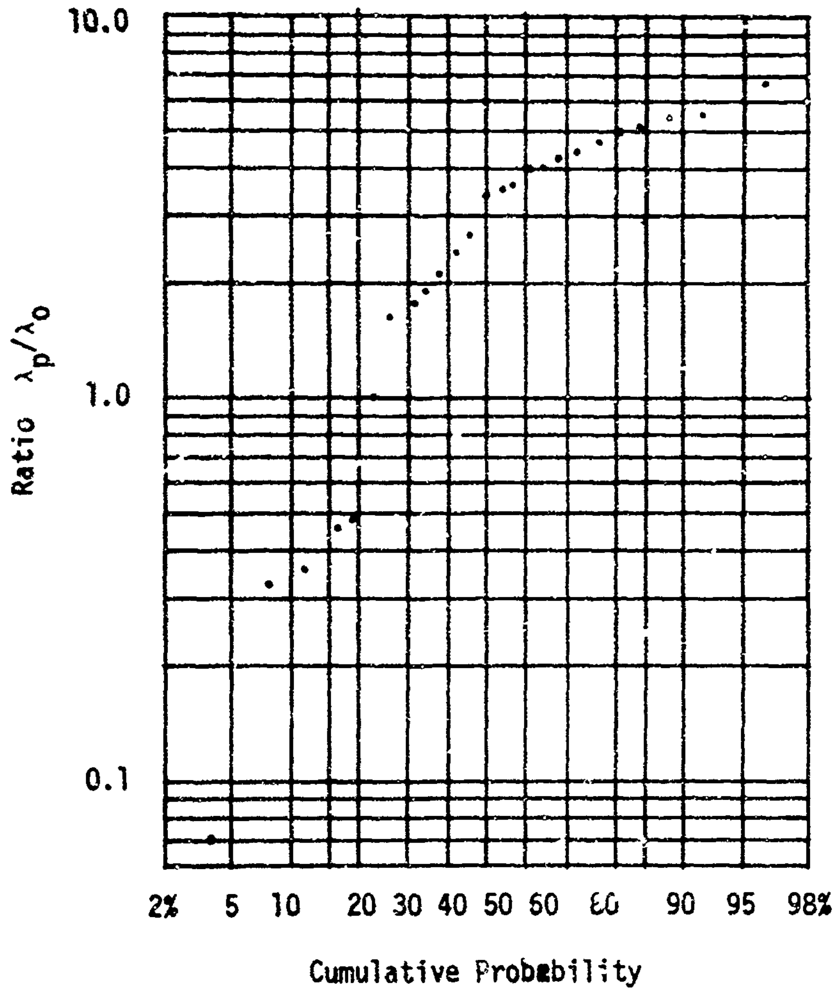

Figure 2. Log Normal Probability Plot of Ratio λ_p/λ_o

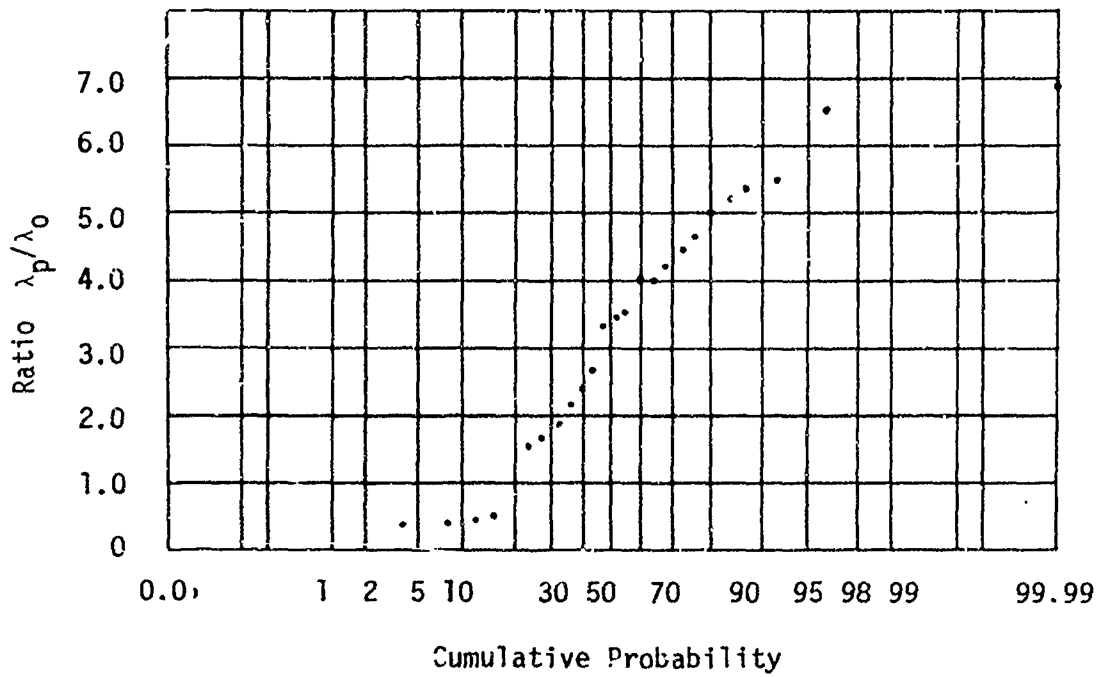

Figure 3 Normal Probability Plot of Ratio λ_p/λ_o

Table LIV shows that 46.2 per cent of the equipment failure rate ratios (λ_p/λ_o) lie in the range of 2.01 to 5.00. This suggests that a factor could be applied to the predicted failure rate such that the prediction would better approximate the observed results. To determine the acceptability of this factor, an acceptability criteria is required. In this study, the acceptability criteria is established as follows: If the ratio λ_p/λ_o is between .5 and 2.0, the prediction is defined as an acceptable estimate of the true failure rate. Mathematically:

$$.5 \leq \lambda_p/\lambda_o \leq 2.0$$

The technique employed in the study is to divide the predicted failure rate by a constant and recompute λ_p/λ_o. As a larger number of these ratios fall within the acceptable range defined above, the prediction is judged to be more acceptable. Figure 4 shows the relationship between the division factors, ranging from 2.0 to 7.0, and the number of equipment failure rate ratios which fall within the defined acceptable range.

Discounting the four transmitter and the camera display equipments, (since division of λ_p by a constant would result in a more erroneous ratio) 85.6 percent of the equipment failure rate ratios lie within 0.5 to 2.0 when division factors of 3.0 or 3.5 are applied. If a division factor of 4.0 is used, then 81.0 percent of the equipment failure rate ratios lie within the range defined above. If a division factor of 4.5 is used, 76.4 percent of the equipment failure rate ratios lie within this range. Thus, the prediction accuracy for this equipment could be improved if a division factor between 3.0 and 4.5 were used as a divisor for the predicted failure rate originally developed.

Table LV is developed using a dividing factor of 4.0. All the failure rate ratios now lie between 0.02 and 2.00. Discounting the transmitter and camera equipments, all failure rate ratios lie between 0.25 and 2.0.

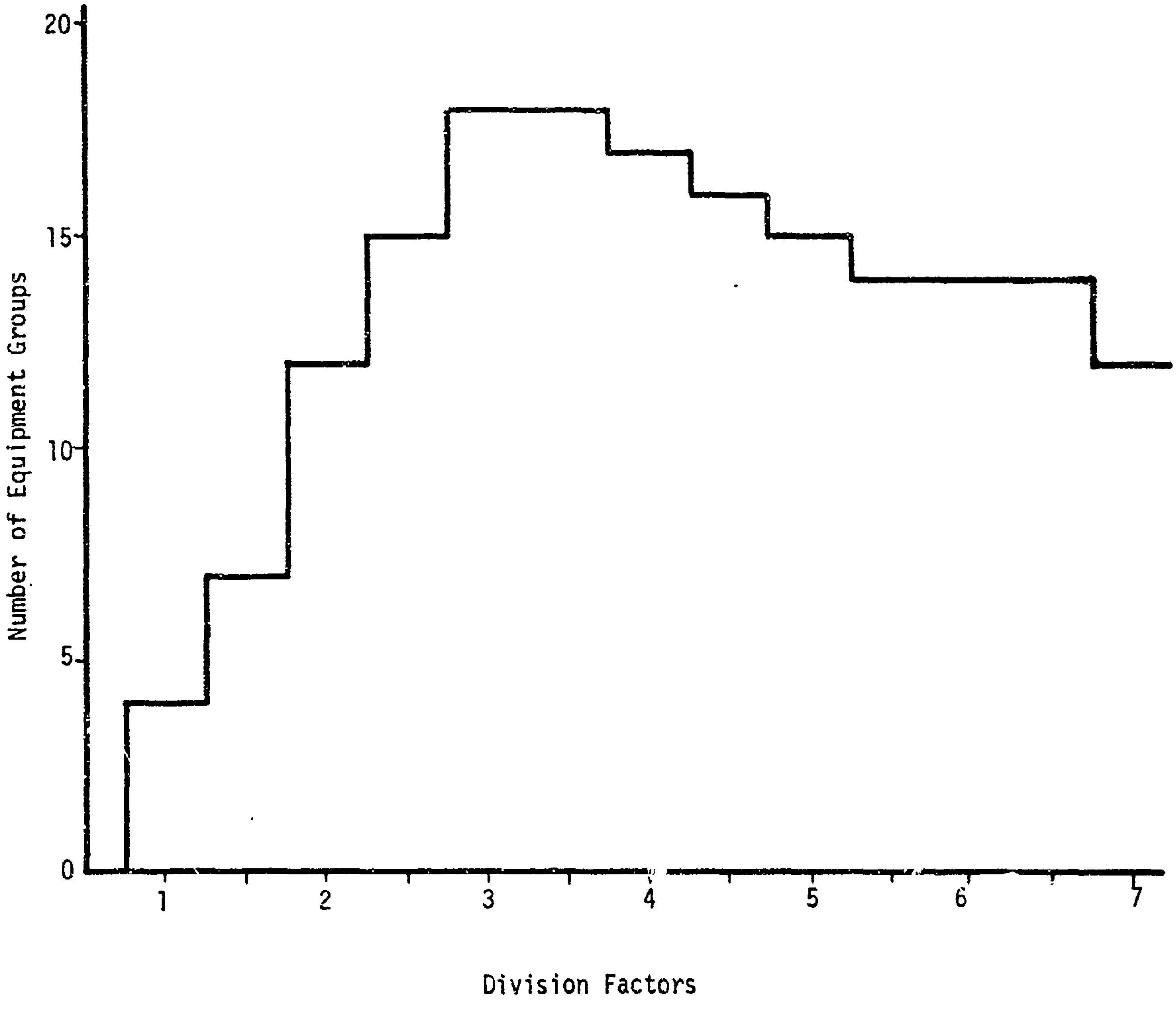

Figure 4. Number of Equipment Groups Falling in Failure Rate Ratio Range of $0.5 \leq \lambda_p/\lambda_o \leq 2.0$

TABLE LV RATIO OF PREDICTED FAILURE RATE DIVIDED BY FOUR, TO OBSERVED FAILURE RATE

	Ratio of Predicted Failure Rate Divided by 4 To Observed Failure Rate $\lambda_p/4\lambda_o$					
Equipment Type	0.02-0.5	0.51-1.00	1.01-2.00	2.01-5.00	5.01-10.00	> 10.00
Transmitter	4	0	0	0	0	0
Receiver	0	4	4	0	0	0
Computer	2	2	3	0	0	0
Display	3	2	2	0	0	0
Totals	9	8	9	0	0	0
Percentage of Total (26 Equipments)	34.6	30.8	34.6	0	0	0

3. SPECIAL STUDY NO. 2: "ANALYSIS OF PREDICTION INACCURACY FACTORS"

a. Objectives

The objectives of this study were the identification and analysis of prediction inaccuracy factors inherent to the following categories:

- o Design Approach
- o Equipment Function
- o Program - Related Factors
- o Parts - Mix
- o Prediction Method

b. Summary

The analysis of the prediction inaccuracy factors resulted in the following observations:

- o The design approach categories (i.e., digital and analog) exhibit different prediction accuracy ratios and part of this difference can be ascribed to design characteristics.
- o The equipment function categories (i.e., power, test and display, control, and computers) have different prediction accuracy ratios, and part of these differences can be attributed to function and active element content.
- o The reliability program factors cannot be isolated as contributions to individual equipment prediction accuracy.
- o The prediction accuracy ratio of an equipment is influenced by the types of parts predominant in the design.
- o An error in selecting either stress, temperature, or part quality values in the prediction process could contribute significantly to prediction inaccuracies.
- o The semiconductor application factor (π_A) is a significant contributor to prediction inaccuracy.

c. Details

(1) Introduction

The analysis of prediction inaccuracy factors was performed for each of the following categories:

o Design Approach

o Equipment Function

o Program - Related Factors

o Parts-Mix Factors

o Prediction Method Factors

For purposes of this study, prediction accuracy is defined as the ratio of the observed MTBF to the RADC Volume II upper grade part predicted MTBF. Obviously, the most desirable prediction accuracy value is 1.0. The analysis performed on the above factors and the results of the analyses are contained in the following subsections.

(2) Design Approach Categories

The design approach analysis considered variations in prediction accuracies which exist between the two design approach categories discussed in VIII 1. above, i.e., digital and analog equipments. The distributions of prediction accuracy ratios for the 14 digital and 20 analog equipments, which were utilized, are shown in Figure 5, "Prediction Accuracy Ratio Distributions for Analog and Digital Equipment."

For the digital equipment group, the mean of all the prediction accuracy ratios is 4.1, with a standard deviation of 3.2. The range of the digital prediction accuracy ratios is from 0.7 to 11.4 (i.e., about 16.5 to 1). There are only two digital ratios below the desired 1.0 value (i.e., 0.7 and 0.9). All other digital ratios exceed the desired 1.0 value.

The analog equipment group prediction accuracy ratios have a mean of 3.2, a standard deviation of 6.5, and range from 0.06 to 26.5 (i.e., about 442 to 1). Fourteen analog equipments ratios were less than the desired 1.0.

From the above it is concluded that digital equipments predominantly have low predicted MTBF's when compared with the observed values, and analog equipments predominantly exhibit high predicted MTBF's when compared with the observed values. Some of the design characteristics which account for these anomalies are:

o Digital equipments operate on a low power requirement while analog equipment power requirements extend over a large range,

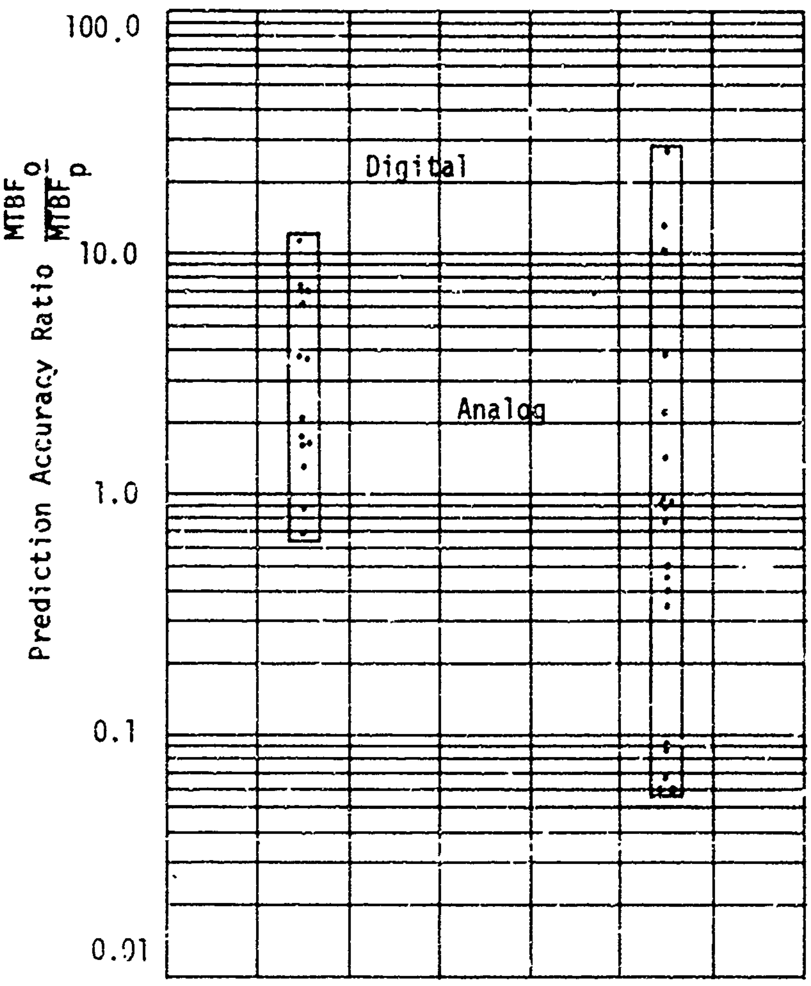

Figure 5. Prediction Accuracy Ratio Distributions for Analog and Digital Equipment

o Digital equipments are bi-stable, i.e., operate at one of two levels or states.

o Analog equipments operate continuously over an infinite range and are thus susceptible to additional failure modes, e.g., drift sensitivity, etc.

(3) Equipment Function

In assessing the relationship of functional characteristics to prediction accuracy, the equipments were divided into four groups: power, control, computer, and test and display. There were six power equipments, seventeen control equipments, five computer equipments, and six test and display equipments.

The six power equipments have prediction accuracy ratios ranging from 1.3 to 26.5. That is, all the MTBF predictions are low when compared to the observed values. The six power equipments are, basically, all power supplies. However, two equipments have test functions as part of their operation. These two equipments also have the best prediction accuracy values (i.e., 1.3 and 1.5).

The mean of the prediction accuracy ratios for all the equipments is 3.5, whereas the mean for the six power equipments is significantly higher, 9.5 (i.e., almost 1000 percent above the desired value). However, there is no evidence that the high prediction accuracy ratios can be ascribed to other factors such as: parts count, active elements, or derating. Therefore, in these cases the prediction inaccuracy was ascribed to unidentified factors associated with the configuration of power function equipment.

The seventeen control equipments have prediction accuracy ratios ranging from 0.06 to 11.4 with a mean of 2.8. Although this mean is closer to the desired prediction accuracy of 1.0 than the mean for all equipments (3.5), eleven of the control equipments have prediction accuracy values of less than 1.0. In fact, only four of the seventeen equipments are close (0.7, 0.7, 0.8, and 0.9) to the desired value. Four of the equipments exhibited extreme inaccuracies of 1000 percent or better (i.e., 0.07, 0.09, 0.09, and 11.4). The eleven control equipments which have prediction accuracy values less than the desired value of 1.0, and the six which had ratios above 1.0, were investigated separately and collectively to determine if such factors as part count, active element count, and solid state part count contributed to their inaccuracy. No significant correlation was found between any of the above factors and the prediction accuracy ratios. However, it was noted that all 3 equipments using integrated circuits had high ratios whereas all 5 equipments using vacuum tubes had low ratios. Thus, approximately half of the control function equipment inaccuracy was determined to be part-related. The remainder was attributed to other unidentified factors associated with the control equipments.

The five computer type equipments have prediction accuracy values of 1.7, 1.7, 1.8, 2.1, and 3.8. The equipment with the highest prediction accuracy ratio (3.8) includes a parts complement of 33 percent integrated circuits and 27 percent other active element devices. Also, the equipment with the prediction accuracy value of 2.1 includes a parts complement of over 50 percent active element devices. The other three equipments contain less than 50 percent active element devices. Hence, there is an evident relationship between high prediction accuracy ratios and the active element content of computer type equipments.

The six test and display equipments have prediction accuracy ratios of 0.06, 0.09, 0.09, 0.9, 0.9, and 2.2. The three equipments with the extremely low prediction accuracy ratios have a lower active element mix than the other three equipments. The active elements in the three lowest valued equipments include vacuum tube components. Thus, low active element ratios were significant contributors to prediction inaccuracies for the test and display functional types.

(4) Program-Related Factors

The investigation of inaccuracies in the prediction techniques which are program-related is contained in the rating studies in Special Study No. 4, Section VIII. The rating studies indicated that the programs with rating values higher than 3.55 had system prediction accuracy ratios greater than 1.0. Hence, if all the program factors were maximized, the prediction techniques would result in a higher prediction accuracy ratio. However, it was also shown in the rating studies that a prediction modifier could be established which would improve the accuracy of a system prediction but would not improve the accuracy for the individual equipment. Therefore, the effects of program-related factors are not discernible in the analysis of individual prediction accuracy ratios.

(5) Parts-Mix Factors

The inaccuracies of the prediction technique were analyzed to determine if relationships existed with respect to:

o Part Count

o Active Element Count

o Part Type Factors

The active element count expressed as the ratio of total transistors, diodes, and vacuum tubes to total part count, was correlated with prediction accuracy ratios. The correlation analysis was performed for three equipment categories (i.e., all 34 equipments, digital equipment and analog equipment). The results of this analysis is shown in Table LVI, "Correlation of Active Elements versus the Prediction Accuracy Values."

TABLE LVI CORRELATION OF ACTIVE ELEMENTS VS PREDICTION ACCURACY VALUES

Category	Correlation Coefficient (R)	Index Of Determination (R^2)
All Equipment	0.48	0.232
Digital	0.56	0.314
Analog	0.43	0.186

The table shows that meaningful correlation does not exist between the active element components and the prediction accuracy ratios. Hence, it is concluded that all the prediction inaccuracies are not assignable to the active element components.

Similarly, correlation analyses were conducted for the same three equipment categories between the equipment part count and the prediction accuracy ratios. The results indicated that no relationships existed (i.e., less than 0.2 for all three categories).

The part type analysis attempted to relate the inaccuracies of the prediction technique to the types of part predominant in the design. The following types of parts were investigated:

- Tubes
- Capacitors
- Resistors
- Diodes
- Transistors
- Integrated Circuits

The equipments were ordered by prediction accuracy ratios (highest order first), and by content of the individual part types. The order of the prediction accuracy ratios was compared with the order of the part type content. From this comparison the following conclusions were established:

- Tube type devices contribute significantly to a lower-than-desired prediction accuracy ratio.

- Capacitors do not contribute significantly to any variation of the prediction accuracy ratios.
- Diodes and resistors contribute to lower-than-desired prediction accuracy ratios.
- Transistors and integrated circuits contribute to a higher-than-desired prediction accuracy ratio.

(6) Prediction Method Factors

Factors in the RADC stress analysis prediction technique were evaluated to determine if the accuracy of predictions for individual equipments could be related to:

- Part quality grade
- Stress effects
- Temperature effects
- Failure rate modifiers

Special Study No. 3, Section VIII evaluated the effects of stress, temperature, and part quality by creating prediction variability envelopes representing a range of influence for these factors on the variability of prediction techniques. By comparing the data with these envelopes, it was determined that 19 of the 34 equipments had observed values which were within the range of their variability envelopes. Fifteen observed values were outside the range. However, if new variability envelopes are prepared, using the extreme values of stress and temperature from the RADC Notebook, Volume II, the observed values for 29 of the 34 equipments will fall within the range of the prediction technique. Therefore, under worst-case and best-case conditions, it would be possible for the prediction technique to encompass the observed values for all but five equipments.

However, since these extremes of stress and temperature are definitely not present in the equipments, only the original variability envelopes warrant consideration. Thus, based on the sensitivity study, it is possible that the prediction inaccuracies associated with 19 equipments could be due to the effects of errors in estimating stress, temperature, and part quality grade.

However, other factors in the prediction technique must also be considered. The effects of the application factor (Π_A) on transistor and diode failure rates in digital and analog equipment were evaluated to determine their contribution to the total equipment failure rates. The effect of this factor on digital equipment is to cause a decrease in the total equipment failure rate by an amount to be determined by the quantity of semiconductors of each type and the ratio of their failure contribution to the total equipment failure rate. Predictions for samples representing a range of analog and digital equipments were evaluated to determine the impact of this factor upon the total equipment failure rate. The results are summarized in the following Table LVII, "Impact of Semiconductor Application Factor (π_A) on Equipment Predictions."

TABLE LVII

IMPACT OF SEMICONDUCTOR APPLICATION

FACTOR (π_A) ON EQUIPMENT PREDICTIONS

Equipment Code Number	Equipment Type	Total Part Count (1000's)	Per Cent Semiconductors	Per Cent Increase (+) or Decrease (-) in Failure Rate
3	Analog	.3	30.0	-39
11	Analog	3.8	28.9	-29
22	Analog	28.0	30.8	-75
37	Digital	35.0	41.2	+106
1	Digital	4.3	46.0	+109
10	Digital	2.1	53.3	+ 92

The table shows that the failure rates of analog equipment would decrease by from 29 to 75 percent if this factor was applied. However, the prediction accuracy ratios indicate the predicted failure rates are generally too low without this factor. The digital equipment failure rates would approximately double if this factor was not applied. However, the prediction accuracy ratios indicate that the predicted digital equipment failure rates are already too high in almost all cases - i.e., the application factors are also too high. Therefore, it was concluded that the application factor was a significant source of prediction inaccuracy for digital equipment. For analog equipment, an application factor which increases the failure rate would offer a potential for improvement in prediction accuracy.

4. SPECIAL STUDY NO. 3: "SENSITIVITY STUDY"

a. Objectives

This study was performed to evaluate the relative impact of major elements of the RADC Reliability Notebook, Volume II stress analysis prediction technique upon the variability of reliability predictions for a variety of equipment types. Principal objectives were:

- Determine the amount of variation in predicted failure rates contributed by the prediction elements of stress, temperature, and part grade.
- Determine if the differences between observed equipment failure rates and predicted failure rates fall within a range of variation in predicted values resulting from the effects of stress, temperature and part grade.

b. Summary

The study showed that the prediction element, part quality grade, provided the most significant single contribution to prediction variation. For both digital and analog equipments, this factor could account for approximately 90 percent of the total range of prediction variation. In addition, the study also showed that the part grade factor can affect the combined effects of both temperature and stress in a prediction. That is, the use of the upper grade parts - even under the worst-case conditions of stress and temperature - produces a lower predicted equipment failure rate than is achieved using the lower grade parts under the best-case conditions of stress and temperature.

At the equipment level, the difference in predicted failure rates between lower and upper grade parts was observed to be approximately ten to one, over the range of temperature and stress values studied.

The distribution of observed failure rates for the 34 equipments was examined with respect to the total range of variability in predicted failure rates due to temperature, stress, and part grade for each equipment. This comparison indicated that, for the sample studied, the prediction technique is too sensitive (i.e., predicts too high a failure rate) to the effects of temperature, stress, and part grade for all digital equipment and most analog equipment. This conclusion is based upon the following observations:

- Only 19 equipments had observed failure rates within the range of prediction variability. All but one of these fell near the lower limit of the range.

- Almost all observed failure rates (30 out of 34) fell either near, or below, the lower limit of the range.
- Only the analog equipment (four of 19) showed observed failure rates near, or above, the upper range of predicted failure rates.

The sensitivity of individual equipment failure rates to part quality, stress, and temperature was markedly different between equipments within both the analog and digital design approach categories. However, the sensitivity to part quality generally increased as temperature and stress values increased.

c. <u>Details</u>

This study exercised the latest RADC stress analysis prediction technique (RADC Reliability Notebook, Volume II) on 34 ground electronic equipments to develop a range of reliability predictions (prediction variability envelopes) for selected levels of stress, temperature, and part quality grade. These levels were selected to represent a range of temperature and stress values extending beyond the limits of most ground electronic equipment design criteria.

The prediction variability envelopes were constructed from predicted equipment failure rates obtained for seven points on the applicable part failure rate temperature/stress curves. Upper and lower grade parts, per RADC Volume II, were represented in separate prediction envelopes. The seven points used to develop the failure rates are:

- 0.1 Stress, 60°C Temperature
- 0.3 Stress, 60°C Temperature
- 0.6 Stress, 60°C Temperature
- 0.3 Stress, 40°C Temperature
- 0.1 Stress, 20°C Temperature
- 0.3 Stress, 20°C Temperature
- 0.6 Stress, 20°C Temperature

The Π_E and Σ_E values for a fixed ground environment were utilized for each part. The values used for the longevity factor and Π_{S2} (secondary electrical stress) were 1.0 in all cases. The above data were processed by a computer program (PRG-1, Appendix II) which utilized the following equation to obtain the prediction variability envelopes:

$$\lambda_T = \sum^{N} Q(\lambda_b \cdot \Pi_p \cdot \Pi_E + \Sigma_E), \tag{17}$$

where,

λ_T ≡ the failure rate prediction for an equipment at a specified temperature/stress level,

N ≡ the number of part types,

Q ≡ the quantity of a part type,

λ_b ≡ the basic failure rate at the selected temperature/stress level,

Π_p ≡ the product of the application factors, excluding Π_E,

Π_E ≡ an environmental factor, and

Σ_E ≡ an additional environmental factor.

The equipment level failure rate data outputs from the computer program were used to plot the prediction variability envelopes for each equipment. Since the shapes of the envelopes were essentially the same for all 34 equipments, individual charts are not included. A typical example of the prediction variability envelopes is shown in Figure 6, "Prediction Variability Envelope (Typical)."

To evaluate the effects of temperature, stress, and part quality, the total variability for each equipment was established (i.e., the difference between the failure rate for upper grade parts at 20°C and 0.1 stress and the failure rate for lower grade parts at 60°C and 0.6 stress). The total variability for each equipment was used as an index of variability for that equipment. That is, the total variability was considered to include 100 percent of the prediction variability inherent to that equipment due to stress, temperature, and part quality. The index was used to measure the change, in percent, due to a change in part quality at selected levels of temperature (20°C, 40°C, 60°C) and stress (0.1, 0.3, 0.6). For example, for equipment No. 2 at 20°C temperature and 0.1 stress, the difference in failure rates between upper grade parts and lower grade parts is 83.2, and the total variability is 1382.0; therefore, the percent of failure rate change due to part quality for equipment No. 2 is 6.0. These calculations were performed for all 34 equipments and these data are shown in Tables LVIII and LIX, "Percent of Failure Rate Change Due to Part Quality" for digital and analog equipments respectively.

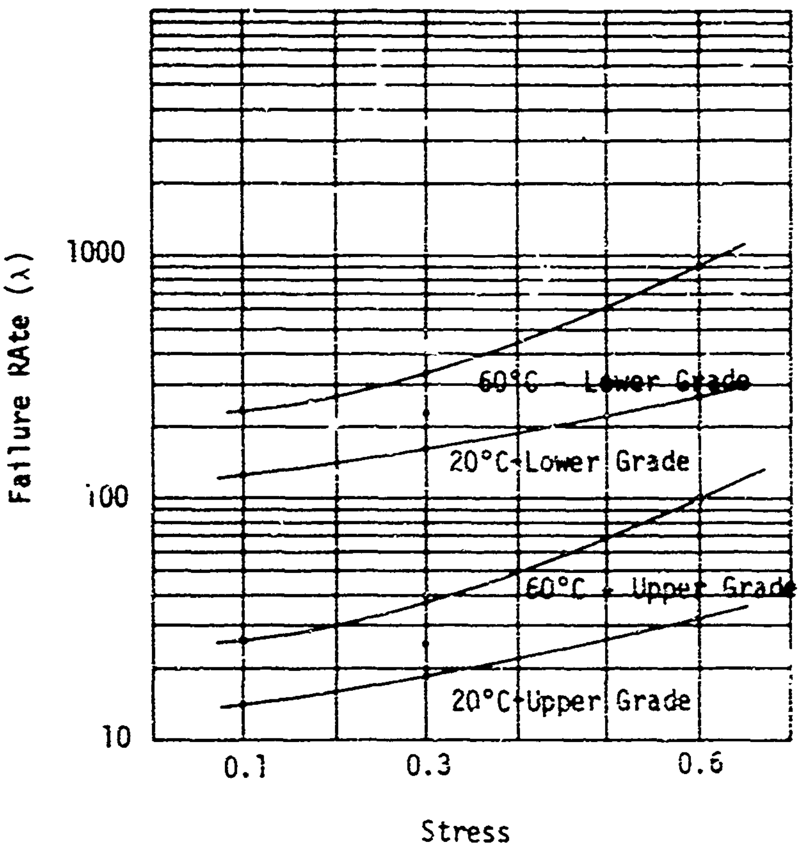

Figure 6. Prediction Variability Envelope (Typical)

TABLE LVIII PERCENT OF FAILURE RATE CHANGE DUE TO PART QUALITY (DIGITAL EQUIPMENTS)

Equipment Code Number	0.1S 20°C	0.3S 20°C	0.6S 20°C	0.1S 60°C	0.3S 60°C	0.6S 50°C	0.3S 40°C
1	13.0	16.9	27.5	23.2	33.5	90.4	22.7
5	8.4	10.2	17.6	17.1	26.5	90.3	15.3
6	22.3	24.8	34.4	42.0	50.3	92.1	38.6
7	24.7	31.5	50.0	38.4	50.0	89.7	41.1
8	24.0	30.5	49.6	38.2	49.6	90.8	40.4
9	24.4	31.1	51.5	40.0	51.1	91.1	42.2
10	29.4	35.1	50.2	51.6	60.7	91.9	50.2
18	6.5	8.7	14.9	15.5	25.1	93.7	13.7
19	5.9	7.9	13.8	14.7	23.6	89.4	12.7
20	5.9	7.9	13.8	14.8	23.6	89.6	12.6
23	6.4	8.6	14.8	16.6	24.6	90.1	13.5
29	25.0	31.9	50.0	36.1	48 6	88.9	38.9
32	6.2	8.4	14.6	15.4	24.5	90.1	13.4
37	5.9	7.9	13.9	15.0	24.0	89.9	12.8

TABLE LIX PERCENT OF FAILURE RATE CHANGE DUE TO PART QUALITY (ANALOG EQUIPMENTS)

Equipment Code Number	0.1S 20°C	0.3S 20°C	0.6S 20°C	0.1S 60°C	0.3S 60°C	0.6S 60°C	0.3S 40°C
2	6.0	8.2	14.4	15.4	24.5	90.5	13.2
3	6.4	8.6	15.0	16.0	25.2	90.6	13.6
4	22.2	28.9	45.6	33.3	45.0	90.6	35.0
11	23.0	30.5	53.6	32.3	44.7	88.6	37.1
12	21.4	24.5	33.7	33.7	39.8	82.7	28.5
13	15.0	18.1	26.9	24.8	33.9	87.8	23.0
14	7.8	9.8	16.4	16.5	25.6	89.1	14.6
15	6.2	8.3	14.4	15.5	24.6	90.3	13.3
16	40.7	43.1	45.5	51.7	57.8	84.4	47.3
17	10.5	12.8	19.5	19.6	28.8	89.9	17.9
21	6.7	8.8	15.4	16.4	26.5	90.3	14.0
22	6.6	8.9	15.6	15.9	25.0	90.1	13.9
25	22.2	30.5	49.9	33.5	46.7	90.9	37.2
26	24.2	32.6	51.6	35.8	48.6	90.8	39.2
27	26.2	33.4	49.8	37.7	49.8	88.5	40.7
28	23.4	31.5	49.1	35.5	48.3	90.7	38.5
30	20.0	28.5	47.4	32.1	44.9	89.6	35.4
31	20.5	28.8	47.2	32.3	45.4	90.4	36.2
34	6.4	8.6	15.1	15.9	24.9	90.5	13.7
36	12.3	14.4	20.5	21.5	29.9	89.4	19.1

Tables like the foregoing were prepared for stress and temperature failure rate changes. From these tables it was noted that at the upper limit (i.e., 0.6 stress and 60°C temperature), part quality could account for approximatly90 percent of the total inherent variability of the prediction.

The observed reliability values for all the equipments were compared with their prediction variability envelopes to determine if the variability inherent in the prediction technique could account for the inaccuracy of the predictions. Tables LX and LXI "Variability Envelope Extremes Versus Observed Failure Rates," for analog and digital equipments, respectively, were made for comparison of the observed data with the prediction variability envelopes. These tables illustrate the equipments' predicted failure rates at the lowest and highest points on the envelopes (i.e., 0.1 stress, 20°C temperature, upper grade parts and 0.6 stress, 60°C temperature, lower grade parts, respectively) and the observed failure rates for each equipment.

The tables show that for the analog equipments, 8 out of 20 fell outside the prediction variability envelope and for the digital equipment, 7 out of 14 fell outside the prediction variability envelopes.

The prediction variability limits were established for upper and lower grade parts, analog and digital equipments. The PVL's were established, in each case, as follows:

- o The upper PVL is the maximum quotient of the ratios of maximum predicted failure rate to midpoint predicted failure rate.
- o The lower PVL is the minimum quotient of the ratios of minimum predicted failure rate to midpoint predicted failure rate.

As shown in Figure 7, "Prediction Variability Limits, Digital Equipments," the PVL's for both upper and lower grade parts are 0.4 for the lower limit and 7.1 for the upper limit. The ratios of predicted failure rates (upper and lower grade parts) to the observed failure rates for all equipments were plotted to ascertain if the variability of the prediction technique could accout for inaccuracies which exist between the predicted and observed values. For the upper grade part predictions on digital equipment, eleven of the fourteen ratio values lay within the PVL's; for the lower grade parts, two of the fourteen values lay within the PVL's.

Figure 8, "Prediction Variability Limits, Analog Equipments," is a plot of the PVL's and the ratios of predicted failure rates to observed failure rates for the 20 analog equipments. The upper grade PVL's are 0.5 and 6.6, lower and upper respectively. The lower grade PVL's are 0.5 and 6.7, lower and upper, respectively. For the upper grade part predictions, ten out of twenty of the ratio values lay within the PVL's, and for the lower grade part predictions, seven out of twenty of the ratio values lay within the PVL's.

TABLE LX VARIABILITY ENVELOPE EXTREMES VERSUS OBSERVED FAILURE RATES - ANALOG EQUIPMENTS

Equipment Code Number	λ Lower 0.1S, 20°C, UG (%/1000 Hours)	λ Upper 0.6S, 60°C, LG (%/1000 Hours)	λ Observed (%/1000 Hours)
2	10.0	1392.1	0.81
3	4.8	505.4	0.70
4	5.9	185.8	13.81
11	11.7	302.4	4.93
12	27.1	125.2	498.0
13	65.9	801.9	1242.0
14	406.1	14087.7	633.0
15	35.3	3914.3	172.0
16	5.3	26.4	114.0
17	17.5	532.2	437.0
21	36.0	3176.6	71.63
22	154.5	16651.2	873.0
25	1.5	52.1	5.25
26	2.9	58.5	0.40
27	2.7	33.2	8.08
28	2.8	65.1	10.51
30	2.4	76.5	2.83
31	1.0	23.9	1.62
34	44.7	5724.6	48.73
37	297.3	43615.6	92.61

TABLE LXI VARIABILITY ENVELOPE EXTREMES VERSUS OBSERVED FAILURE RATES - DIGITAL EQUIPMENTS

Equipment Code Number	λ Lower 0.1S, 20°C, UG (%/1000 Hours)	λ Upper 0.6S, 60°C, LF (%/1000 Hours)	λ Observed (%/1000 Hours)
1	14.6	891.8	20.72
5	3.9	395.6	1.27
6	17.2	1005.3	8.43
7	5.7	151.5	1.28
8	7.0	279.3	3.41
9	1.2	46.0	0.29
10	5.8	216.4	4.87
18	51.4	5963.9	70.42
19	109.4	14346.7	331.0
20	227.7	31587.4	556.0
23	125.5	13946.2	179.5
29	4.9	76.9	5.25
32	163.7	22297.7	55.6
36	7.7	43615.6	92.6

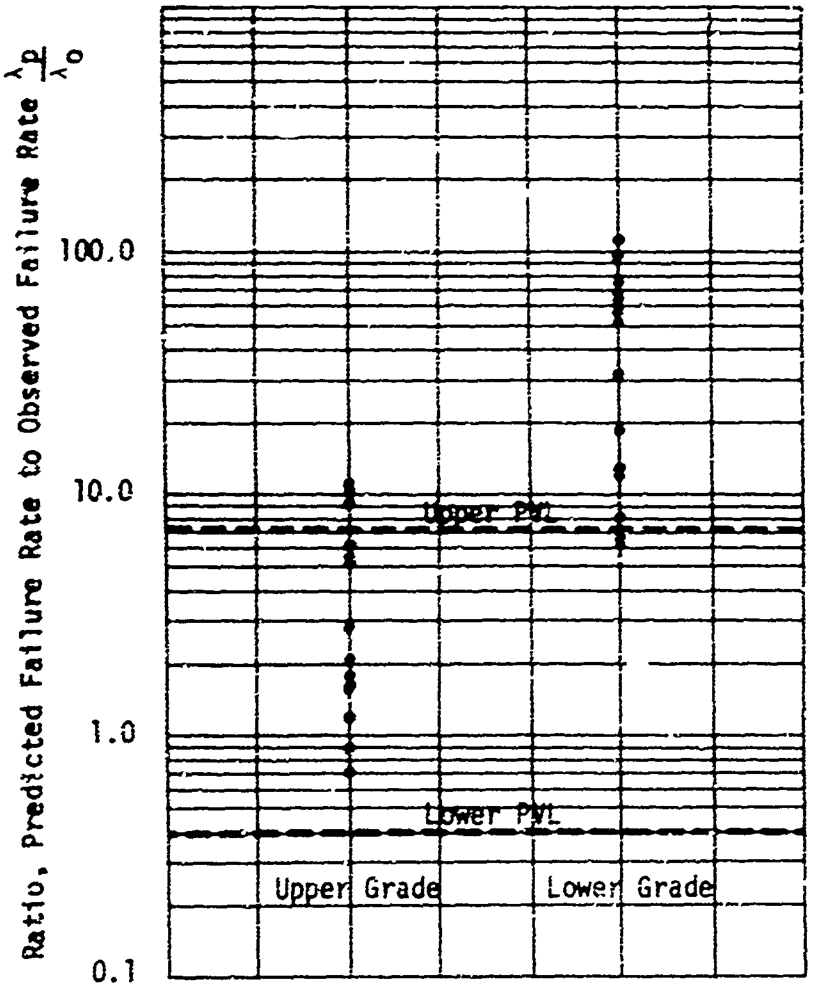

Figure 7. Prediction Variability Limits - Digital Equipments

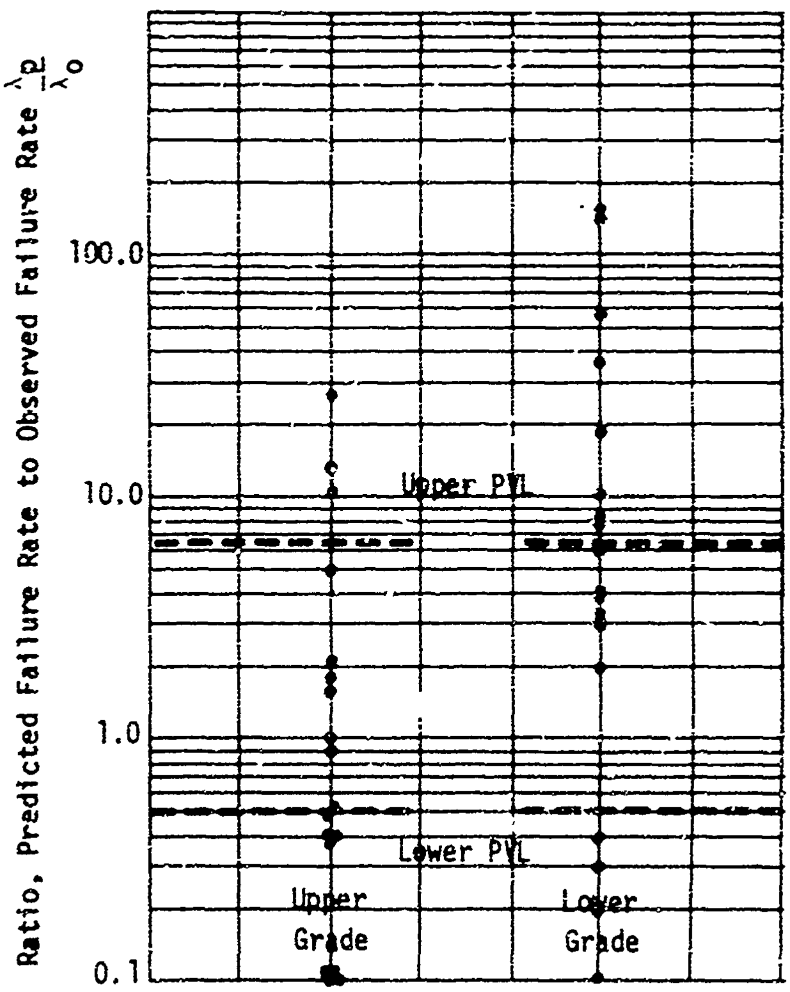

Figure 8, Prediction Variability Limits
Analog Equipments

5. SPECIAL STUDY NO. 4: "PROGRAM FACTOR RATING STUDIES"

a. Objectives

The rating studies were designed to determine if statistical relationships could be established between prediction accuracy, using the RADC Reliability Notebook, Volume II, stress analysis prediction method, and program factors which are likely to influence the level of achieved reliability. The major objectives of this special study were:

- o Determine if statistical correlations exist between prediction accuracy and the quantitative ratings of the program factors.
- o Identify program factors which are significant to reliability achievement.
- o Establish modifiers for use in prediction models, based on the rating criteria and established coefficients, to increase prediction accuracy.
- o Obtain information for use in other areas of this study.

b. Summary

The program factor rating studies developed the use of a program rating grade which can be used with the RADC Reliability Notebook, Volume II, stress analysis prediction to ascertain the expected MTBF that will be observed on a particular program with a particular rating grade.

c. Details

A set of 50 program-related factors which were believed to be significant to reliability was developed and grouped into eight categories. These are shown in Tables LXII through LXIX. A rating scale, based on the relative strength of the factors, was employed to quantify the strength of each factor (e.g., strong = 5, average = 3, and weak = 1).

The programs utilized in the rating studies were chosen on the basis of available knowledge concerning the 50 program factors, availability of observed reliability data and availability of parts information sufficient for making a stress analysis prediction. All equipments for each program were rated for each of the program factors. Individual equipment characteristics were not permitted to influence the ratings since the primary purpose of the study was to establish whether or not program-related factors influence the level of achieved reliability. There were three programs, containing thirty equipments, with sufficient information for rating evaluation. Table LXX, "Program Reliability Measurements" shows the program rating grades established, range of dispersion and the mean of the ratios of observed MTBF to RADC, Volume II, predicted MTBF (i. e., the prediction accuracy ratios) for each of the three programs.

TABLE LXII PROGRAM-RELATED FACTORS:

VARIABLES	QUALITATIVE STRONG	
1. Degree of Standard Parts Usage	Parts of standard, proven design are selected.	Sc Th p
2. Complexity	Most parts require a single action-reaction to provide a desired single function, such as voltage build-up on a capacitor in response to a charging current.	S s
3. Difficulty of Function	Parts encompassing routinely achievable functions are selected.	S e a c
4. Sensitivity	Part functions are achieved by a relatively wide range of stimuli, such as a wide range of currents to actuate a relay.	S l

TED FACTORS: PARTS MIX AND SENSITIVITY

LITATIVE CATEGORY		
	AVERAGE	WEAK
	Some parts are relatively new versions of standard items. The new versions provide enhanced performance of selected parameters, such as greater gain or lower leakage.	Some parts utilize new and unproven design concepts.
ired	Some parts require complex action to provide a function, such as switching through a stepping switch.	Many complex parts.
ed.	Some parts, such as potentiometers and connectors, encompass functions which are relatively difficult to achieve (electrical continuity through low pressure contacts)	Many parts encompass functions which are difficult to achieve.
y.	Some parts, such as microwave elements, operate at low signal levels.	Many parts operate at low signal levels.

B

TABLE LXIII PROGRAM-PELAT

VARIABLE	QU
	STRONG
1. Worst Case Analysis	Analysis methods (ECAP, etc.) indicate that circuits will function with worst case combinations of part parameters.
2. Monte Carlo Analysis	Permissable circuit outputs (high and low) encompass ± 4 sigmas of the calculated output distribution.
3. Number of Adjustments	Use of trimmer circuit elements (potentiometers, etc.) is avoided. Temperature compensating circuitry and feedback (stabilization) loops are employed.
4. Test Points	Test points provide for monitoring of all critical circuitry.

A

M-RELATED FACTORS: DRIFT SENSITIVITY

QUALITATIVE CATEGORY

	AVERAGE	WEAK
	No analysis performed. Some circuits would probably fail a worst case test.	No analysis performed. Most circuits would probably fail a worst case test.
	No analysis performed. Permissable circuit outputs would probably encompass ± 3 sigmas of a calculated distribution.	No analysis performed. Permissable outputs would probably encompass ± 2 sigmas of a calculated distribution.
	Trimmer elements are commonly employed as "factory adjustments."	Trimmer elements are commonly employed as 'field adjustments.'
ry.	Test points provide for monitoring of critical portions of output circuitry.	Few test points are employed.

TABLE LXIV PROGRAM-RELATED FAC

VARIABLES	QUALITATIVE CATEG	
	STRONG	
1. Electrical Derating	Worst case electrical stresses are less than 50% of ratings	No Wo
2. Vibration Damping	Worst case vibration at part level is less than part ratings.	No rat
3. Thermal Design	Thermal paths provide for low temperature rise at part levels even under worst case conditions.	Th Ov
4. Humidity Protection	Use of seals and coatings prevent moisture condensation on sensitive parts even under worst case conditions.	Se co un

A

PROGRAM-RELATED FACTORS: DERATING

TATIVE CATEGORY		
	AVERAGE	**WEAK**
tings	Nominal stresses are less than 50% of ratings. Worst case stresses occasionally exceed ratings.	Nominal stresses are less than 75% of ratings. Worst case stresses frequently exceed ratings.
ratings.	Nominal vibration at part level is less than part ratings. Worst case vibration often exceeds ratings.	Resonance exist which allow vibration at part level to reach 3-5 times ratings.
	Thermal paths are minimal, allowing some parts to overheat under worst case conditions.	Thermal paths are minimal, allowing some parts to overheat under nominal conditions.
on on	Sensitive parts are partially protected by seals and coatings, but are affected by long duration exposures under high humidity conditions.	Sensitive parts lack protective coatings.

B

TABLE LXV PROGRAM-RELATED FACTORS: D

VARIABLES	QUALITATIV	
	STRONG	
1. Procedures	Procedures, detail data recording, findings factored into higher tier tests as well as design. Parameters to be tested are determined in part by paper analysis activities such as worst case analysis.	Informal p test parame
2. Environments	Tests to all environments judged to be critical to system performance.	Test envir parameters.
3. Hardware Levels	Engineering model through pre-production, prototype hardware.	Selected p
4. Environmental	Greater than spec. requirements with assurance that individual component limitations are not exceeded for all significant environments.	Maximum sp vironments.
5. Input/Output Parameters	Multiple variables measured and recorded, i.e., output parameters measured with minimum, maximum, and nominal inputs applied, and output load variations.	Attribute t tolerance w testing
6. Production Testing	100 % of sub-assemblies tested, or lot samples selected to an equivalent level of confidence for production units throughout the period of manufacture.	Sampling, c provides an
7. Hardware Level	All levels, comprehensive test characteristics at each level	All systems at each lev

A

ELATED FACTORS: DEVELOPMENT TEST PROGRAM

QUALITATIVE CATEGORY

	AVERAGE	WEAK
higher s de- st case	Informal procedures prepared by designer as tests progress, with test parameters selected from engineering judgment.	Informal procedures.
	Test environments equal to spec. requirements at least on critical parameters.	Test environment on critical parameters only.
are.	Selected pre-production hardware.	No pre-production test.
idual t en-	Maximum spec. requirements tested at least for most critical environments.	Maximum spec. requirements on few critical environments.
rameters d, and	Attribute type testing, (i.e., nominal plus or minus specified tolerance with nominal input.) supplemented by limited variables testing	Attribute testing only.
o an ghout	Sampling, or 100% testing for limited characteristics, which provides an intermediate level of confidence.	Insufficient testing to assure conformance to principal specification requirements.
vel	All systems and most subassemblies on principal characteristics at each level	System and limited testing at other levels - Does not include all principal characteristics.

B

TABLE LXVI PROGRAM-RELATED FACTORS: PROD

VARIABLE	QUALITATIVE CATEGO	
	STRONG	AV
1. Control of Production Equipment, Tools, and Processes	All production processes, tooling, jigs, fixtures, and machinery have proven capabilities, demonstrate repeatability, and are subject to scientifically established process controls, calibration, and maintenance schedules. All changes in processes and equipment are carefully proven out prior to break-in to production and closely monitored after break-in. Process and equipment capability studies are conducted and statistical/engineering analyses are continually performed to ensure and improve process capability and assure reliability. Periodic calibration and inspections are performed. Responsibility and authority for process control are firmly established.	Processes and equipmen capability, but change closely controlled. after-the-fact, to corr production process. R consideration in proce are established by the based on experience to process control are di quality, design, and p
2. Control of Production Operators	Operators are skilled, well-trained, have above-average understanding of work instructions and workmanship standards. Plant working conditions and facilities are designed to provide optimum operator performance. Work instructions are explicit, current, and provided with each order. Quality and quantity of work are traceable to the individual production operator and strong emphasis is placed by management on maintaining a high level of individual operator performance.	Operator training, skil standards are average. facilities are average. are not usually traceab Management places a mod performance.

FACTORS: PRODUCTION RELIABILITY CONTROL

ATIVE CATEGORY

AVERAGE	WEAK
sses and equipment are generally of proven ility, but changes are not full evaluated or ly controlled. Normal controls are established, -the-fact, to correct problems arising from the ction process. Reliability is not a significant deration in process control. Formal controls established by the Quality Control organization, on experience to date. Responsibilities for s control are divided between manufacturing, ty, design, and production engineering.	No adequate process control program exists. All controls center on the product. Operators may supply their own tools. Calibration and service cycles are informally established. Changes in processes are incorporated on an uncontrolled basis.
tor training, skill, and knowledge of workmanship rds are average. Working conditions and ities are average. Quality and quantity of work ot usually traceable to the individual operator. ement places a moderate emphasis on individual rmance.	Below-average operator training and skill levels. Working conditions and facilities contribute to a reduction in the quality or quantity of work performed by operators. Management does not motivate operators to stress quality of work for the individual and quality of work is seldom traceable to the operator.

TABLE LXVI (CONTINUED) PROGRAM-RELATED FACT

VARIABLES	QUALITA	
	STRONG	
3. Control of Incoming Parts and Materials	Inspection and test of incoming parts and materials are accomplished in accordance with current formal instructions and controlled equipment. These instructions focus attention upon the critical characteristics which are significant to the reliability and quality of the item during the production and use cycles, as established thru engineering analysis. Most features of the Q.C. program in this area are at optimum levels for reliability purposes. Laboratory analyses are performed periodically to verify the conformance of materials.	Inspection and te using a mixed syst and/or the discret acteristics inspec to the reliability production and use program in this ar levels for reliabi
4. Control of Product Quality	Inspection and test operations are established at all strategic points in the production process. They exercise complete control of all production factors significant to product quality and reliability. Characteristics to be inspected and tested, related procedures, tools, and equipment are selected, developed and controlled within a unified quality program which is based upon a detailed engineering knowledge, analysis, and evaluation of the sensitivity of the product to the production process, and all applicable product specifications and requirements. Complete program documentation, records, and procedures exist and are kept current. Effective change control procedures are enforced. Statistical analyses of quality trends, defect rates and distributions of defect types for each product type, production department, and inspection operation are continually performed with feedback to cognizant manufacturing and engineering areas to initiate corrective/preventive action. Failure analyses are performed and heavy emphasis is placed on defect prevention and optimization of the total Q.C. program.	Inspection and te insure that produ by the production the contract and basis for selecti tested and inspec are generally ade is not incorporat planning or opera

-RELATED FACTORS: PRODUCTION RELIABILITY CONTROL

QUALITATIVE CATEGORY	
AVERAGE	**WEAK**
spection and test of incoming items are accomplished ing a mixed system, based upon formal procedures d/or the discretion of inspection personnel. Char- teristics inspected are not necessarily significant the reliability and quality of the item during the oduction and use cycles. Most features of the Q.C. ogram in this area are at something less than optimum vels for reliability purposes.	Inspection and test operations have a limited scope and employ procedures and records which are generally inadequate to insure the relia- bility and quality of the item during the production and use cycle. Some features of the Q.C. program in this area exhibit signifi- cant deficiencies.
spection and test operations are established to sure that product quality is not adversely affected the production process. Specifications governing e contract and the product are used as the primary sis for selection of the characteristics to be sted and inspected. Documentation and records e generally adequate. A dynamic "systems approach" not incorporated in the total quality program anning or operation.	Limited inspection and test operations are per- formed to achieve a minimum (or lesser) compli- ance with contractual quality control require- ments. The quality program is "inspection- oriented," with little or no emphasis on defect prevention and no adequate recognition of the need for quality engineering.

B

TABLE LXVI (CONCLUDED) PROGRAM-RELATED FACTOR

VARIABLES	QUALITAT	
	STRONG	
5. Lot Control	A comprehensive system of product identification or marking is established to accomplish traceability of production units in a unique manner to reflect all significant factors in the production process (e.g., order of production, production line, material lot, process changes, date of production, serial number, etc). The system extends to all significant indenture levels.	Production units are associated paperwork system of lot contro significant factors major process change include all signific
6. Handling, Storage and Packaging	Material is carefully handled from points of receiving inspection through final packaging. Material is protected from damage by well-designed conveyors, jigs, containers, fixtures, etc. Storage conditions prevent contamination, deterioration, and damage. Packaging for storage and shipment insures serviceability and preservation. Standards and procedures to insure full compliance with all safeguards necessary to prevent damage or deterioration are enforced, and verified by tests and engineering analyses.	Material handling, s and procedures equal tices, and usually c invoked by contract. equipment and contai production workers o to equipment. Littl effectiveness of the accomplished.
7. Material Review	Procedures and practices insure that all defective material is promptly identified, segregated, and that disposition is accomplished in accordance with review procedures. These provide for escalation of analyses and corrective action in response to the significance of the defect(s). Procedures for processing and controlling variations are effective, and documentation is current and complete. The backlog of corrective action, and the quantity and type of deficiencies, give evidence of an optimum system which insures follow-up on all major problems.	Generally good contr accomplished, using practices. Engineer and disposition inst do not always escala or potential impact adequate, repetitive incomplete correctiv an adequate system t problem areas.

A

QUALITATIVE CATEGORY	
AVERAGE	**WEAK**
roduction units are serialized, date coded-or ssociated paperwork is identified-under a limited ystem of lot control which does not include all ignificant factors in the production process (e.g., ajor process changes are not reflected) and does not nclude all significant indenture levels.	Serialization or lot identification may exist, but is not meaningful or useful in most cases, (e.g., lot sizes are too large, identification is not changed to reflect significant variations in processes, materials, etc.).
aterial handling, storage, and packaging standards nd procedures equal or exceed good commercial pracices, and usually comply with the applicable MIL-STD's nvoked by contract. Design of production handling quipment and containers, and handling practices of roduction workers occasionally present some hazards o equipment. Little or no verification of the ffectiveness of these standards and procedures is ccomplished.	Material is not carefully handled at some points in the production process. Production handling equipment, jigs, storage facilities, packaging methods, and/or containers subject the equipment to adverse conditions or hazards to an extent which reflects significant deficiencies in design, planning, or management.
Generally good control over defective material is accomplished, using adequate procedures and standard practices. Engineering review, corrective action, and disposition instructions are usually good, but do not always escalate in response to the magnitude or potential impact of the deficiency. Records are adequate, repetitive deficiencies and a backlog of incomplete corrective action exist. There is not an adequate system to insure follow-up on all major problem areas.	Procedures and practices loosely control defective material. They do not insure that the disposition, analysis, and corrective action will be commensurate with the significance of the defect. Documentation review gives evidence of an inadequate system. There is no evidence of follow-up on major problems.

B

TABLE LXVII PROGRAM-RELATED FACTORS: DESIGN

VARIABLES	QUALITATIVE CATEGOR	
	STRONG	
1. Simplicity of Design Logic	Relatively few building blocks (amplifying stages, electromechanical items, etc.) are employed to achieve required functions.	A fe confi isti
2. Circuit Sensitivity to Part Failure/ Degradation	Significant circuit designs will tolerate failure or degradation of principal parts (e.g. through built-in redundancy or added capacity at the part level) without significant failure or degradation of circuit performance.	Signi degra
3. Unit Sensitivity to Circuit Failure/ Degradation	Significant unit designs will tolerate failure or degradation of principal circuits (e.g. Through built-in redundancy or safety margin on input/output values) without loss of primary function.	Signi degra
4. System Sensitivity to Degradation and Wearout	No limited-life items are used in any function necessary for system performance.	Limi syst
5. Design vs State of The Art (SOA)	All functions are easily achieved using established, proven technology throughout the design, with capability and performance well above standards.	Most curr from use

A

ED FACTORS: DESIGN FEATURES AND DEGRADATION

TATIVE CATEGORY

	AVERAGE	WEAK
	A few building blocks are added to the basic (simple) configuration to enhance selected performance characteristics, or to add supplementary functions.	Many "extras" are added.
e.	Significant circuit designs will tolerate failure or degradation of principal parts to a limited extent.	No attempt to compensate for part failure or degradation in any circuit design.
	Significant unit designs will tolerate failure or degradation of principal parts to a limited extent.	No attempt to compensate for part failure or degradation in any unit design.
	Limited life item usage does not significantly affect system reliability, but may cause some failures.	Limited life items are a principal source of system failure.
ven	Most functions are readily achieveable within the current SOA, but some designs are close to marginal from a performance standpoint, or involve limited use of new technology not yet proven in service.	Very difficult for the design to achieve all functions within SOA. New, untried technology may be used extensively.

B

TABLE LXVIII PROGRAM-RELATED FA

VARIABLES	QUALITA	
	STRONG	
1. Parts Standardization	The procuring activity maintains a strong components standards organization which exercises effective control over parts specification, standards, procurement, qualification, acceptance, source selection and application. Parts specialists regularly consult with designers on parts application, and work closely with procurement, quality engineering, reliability, and production to insure optimum parts management. Formal procedures effectively limit/control the use of non-standard parts.	Par Des exe to
2. Specifications	Procuring Agency establishes and controls part and test specifications in excess of MIL requirements specifications.	Mil
3. Source Selection	By an impartial scientific process which insures selection of a reliable source.	By (e.
4. Qualification Testing (Source or Procuring Activity)	A comprehensive qualification test program, requiring proof of part acceptability, is provided with respect to all mission environments. Periodic retesting is accomplished. Test levels are frequently higher than mission requirements.	Qua Ret
5. Screening/Burn-in/TX Program	Parts screened for parameter drift or subject to 100% conditioning or burn-in prior to acceptance and assembly.	Part
6. Acceptance Testing (Source or Procuring Agency)	Parts are tested 100% with respect to numerous parameters at levels which exceed MIL-SPEC requirements.	Acc sam
7. Established Parts Reliability	If part reliability is not established by use of ER Specs then suitable data in large samples are used to demonstrate part failure rates.	.Lim

...-RELATED FACTORS: PARTS PROGRAM

QUALITATIVE CATEGORY

	AVERAGE	WEAK
...ndards ...s ...cialists ...d work ...ty, and ...ocedures	Parts of standard proven design are generally selected. Design standards exist but the individual designer exercises independent control over parts selection, subject to limited surveillance by other engineering disciplines.	No effective standards organization, program, or documentation exists.
...ons.	Military specifications and test requirements are used.	Vendor specification sheets or catalogs are used.
...on of	By a process which sometimes but not always insures (e.g. QPL listing) reliability of sources.	Purchasing selects source without reliability constraints
...oof ...d. ...nts.	Qualification testing per MIL-STD-202 is accomplished. Retesting is occasionally performed.	Qualification testing, per MIL STD-202, may be accomplished, but is less than adequate.
...y.	Part burn-in is accomplished during assembly or unit test.	No screening or burn-in.
...s at	Acceptance tests, per military specifications, and sample tests of critical parameters.	Acceptance tests are frequently omitted.
...s then ...art	Limited life tests are performed.	No program and parts data.

TABLE LXVIII (CONCLUDED) PROGRAM-RELATED

VARIABLES	QUALITATIVE CATEG	
	STRONG	
8. Parts Improvement Programs and Failure Analysis	None is needed (Or: an effective program was provided).	Fail to a
9. Source Surveillance	Procuring Agency performs QA audits, may arrange to have a resident inspector at the source, and maintains a vendor-rating system or equivalent feedback of test data analysis.	Peri
10. Change Control	Vendor must submit and procuring agency must approve major process and drawing changes.	Chan is a

PROGRAM-RELATED FACTORS: PARTS PROGRAM

IVE CATEGORY		
	AVERAGE	WEAK
	Failure modes are identified, evaluated, and minimized to a moderate degree.	Needed but not provided or no part failure analysis program.
ting	Periodic audits per MIL-Q-9858A are performed.	No audits, no feedback other than rejection reports.
	Changes are controlled only when part interchangeability is affected or when Procuring Agency discovers problem.	No control over part vendor

B

TABLE LXIX PROGRAM-RELATED FACTORS:

VARIABLE	QUALITAT	
	STRONG	
1. Program Management (Reliability Manager)	Reports to Vice-President or General Manager	Reports
2. Procuring Agency Program Review	Monthly, with specific task status review	Quarterl
3. Reliability Math Models, Predictions and Estimates	Task conducted during: Pre-design Paper Design Breadboard Design Pre-Prod Hardware Operational Hardware	Task con Pre-d Paper
4. Failure Mode Analysis	Comprehensive failure mode, effects, and criticality analysis by Reliability Engineers	Provide ability)
5. Reliability Trade-Off Analysis	Reliability is major trade-off factor	Reliabil
6. Reliability Design Requirements	Reliability department stipulates and enforces design constraints in the areas of derating, environmental requirements, redundancy, parts/material application. Worst case design, etc.	Reliabili enforce t

RELATED FACTORS: RELIABILITY PROGRAM

QUALITATIVE CATEGORY		
	AVERAGE	**WEAK**
	Reports to Chief Engineer	Reports to Project Engineer or other
	Quarterly with general task status review	No Procuring Agency Review
	Task conducted during: Pre-design Paper design	Task conducted during: Paper design
is	Provide failure rates to other organizations (such as maintainability) and review other organization output	No failure mode analysis
	Reliability is minor trade-off factor	Reliability trade-off analysis not performed
raints dancy,	Reliability department stipulates design constraints but does not enforce them	No design constraints

TABLE LXIX (CONCLUDED) PROGRAM-RELATED FACT

VARIABLE	QUALITATIV	
	STRONG	
7. Design Review	Reliability department takes active role in design reviews and may organize and chair the review. Reviews consist of System Design Review (pre-design) Preliminary Design Review (initial paper design) Critical Design Review (final paper design, Technical Acceptance Review (Engineering Model) First article Configuration inspection (Production)	Reliabilit Critical
8. Test Program	Reliability department is instrumental in test planning and has approval authority of test documentation.	No reliab
9. Failure Reporting, Analysis and Corrective Action	Reliability department establishes and controls program that ensures a closed loop system for analysis of each failure event.	High perce conducted

ROGRAM-RELATED FACTORS: RELIABILITY PROGRAM

QUALITATIVE CATEGORY		
	AVERAGE	**WEAK**
and tem ial cle	Reliability department attends design review meetings, usually a Critical Design Review (initial paper design) is the only one held.	No Design Review
d has	No reliability effort	No reliability effort
nt event.	High percent of failure events are documented, but analysis is conducted only on known problem areas.	Many failure events go unreported. Analysis is conducted by other than reliability department.

TABLE LXX

PROGRAM RELIABILITY MEASUREMENTS

Program	Equipment Code Numbers	Rating Grade	Range of Dispersion ($MTBF_0/MTBF_p$)	Mean ($MTBF_0/MTBF_p$)
I	12,13,14,15,16, 17,18,19,20,21, 22,23	3.3	0.06 to 1.8	0.66
II	25,26,27,28,29, 30,31	4.0	0.5 to 10.2	2.26
III	1,2,3,4,5,6,7, 8,9,10,11	4.8	0.8 to 26.4	6.94

The distribution of the equipment ratios are shown in Figure 9, 10 and 11 "Distribution of Prediction Accuracy Ratios", (Programs I, II and III respectively). It is noted from Table LXX that the range of dispersion is consistent between programs regardless of the rating grade, but the means of the ratios increase as the program rating grades increase. That is, there is no correlation between the precision of the prediction for individual equipments and the program rating grade but definite correlation exists between the accuracy of the program prediction and the program rating grade.

The RADC Reliability Notebook, Volume II recognizes the existence of two part quality levels (upper and lower) but implies that intermediate levels may exist and, in fact, be continuous from the very low level to the very high level. It appears from the rating studies, that a continuous part quality grade does exist and may be applied as a modifier at the program level.

To illustrate the existence of a program modifier based on the rating grade established for the program, Figure 12, "Program Rating Grade vs Prediction Accuracy Ratios," was prepared. This figure was formed by plotting the program means of the ratios of observed MTBF to predicted MTBF versus the program rating grade (i.e., the mean of the program prediction accuracy ratios). The plotted means were connected with a straight line. This line defines the program mean for a population of programs with varying rating grades between the range of 3.3 and 4.8. This will allow the use of a rating grade modifier for more accurate program predictions via RADC Volume II.

For example, given a program with a rating grade of 3.8 and an RADC Volume II prediction of 1000 hours MTBF for the program, what is the expected ratio of observed MTBF to predicted MTBF (i.e., the prediction accuracy ratio)? From Figure 12, the expected prediction accuracy ratio for the program is 1.48. Hence, when the RADC Volume II prediction for the program is multiplied by 1.48, the prediction accuracy ratio for the program is reduced to 1.0, the desired value. Looking at this in another way, Figure 12 can be used to determine what observed MTBF can be expected in the field. Having determined that the expected prediction accuracy ratio is 1.48, and knowing this to be the ratio of observed to predicted MTBF, then (1.48) (1000) = 1480 hours is the expected, observed MTBF in the field for equipment having a rating grade of 3.8. The above results are based on the data from only 3 programs. However, due to the potential significance of these results it is felt that further effort in this area is warranted.

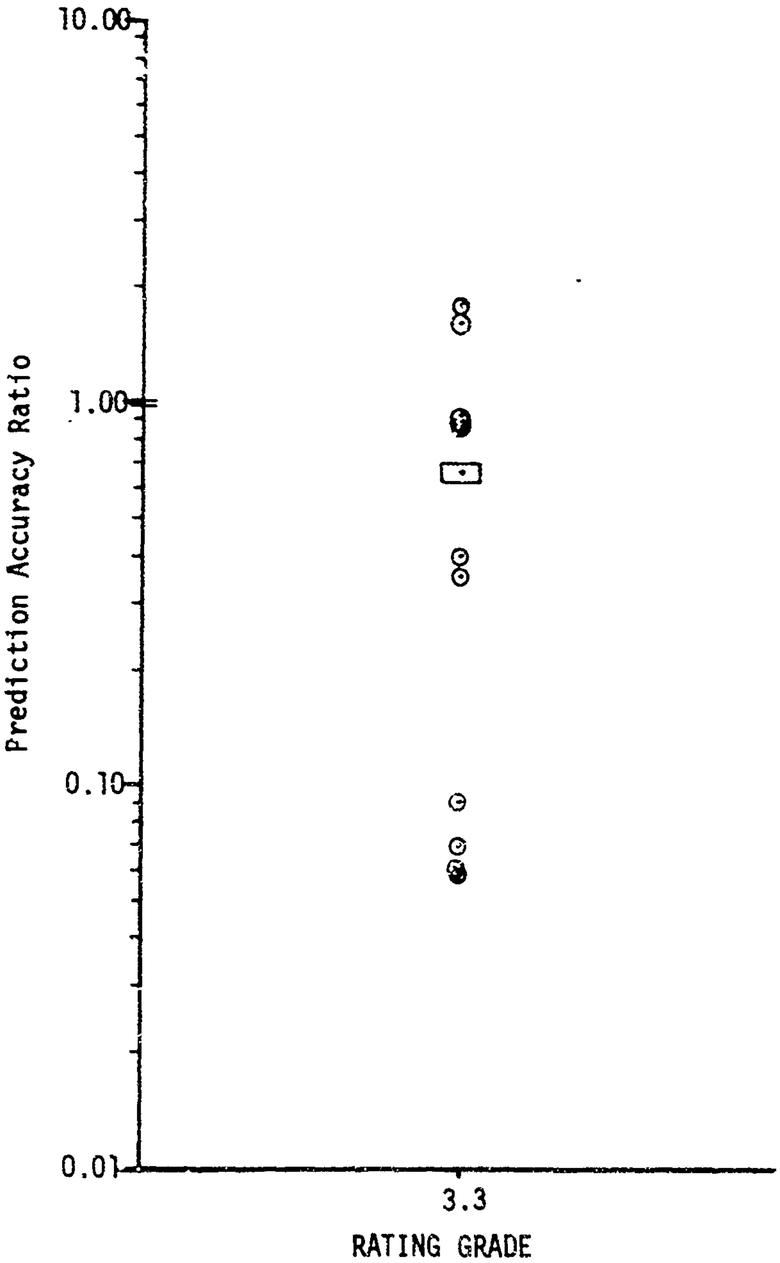

Figure 9. Distribution of Prediction Accuracy Ratios Program I

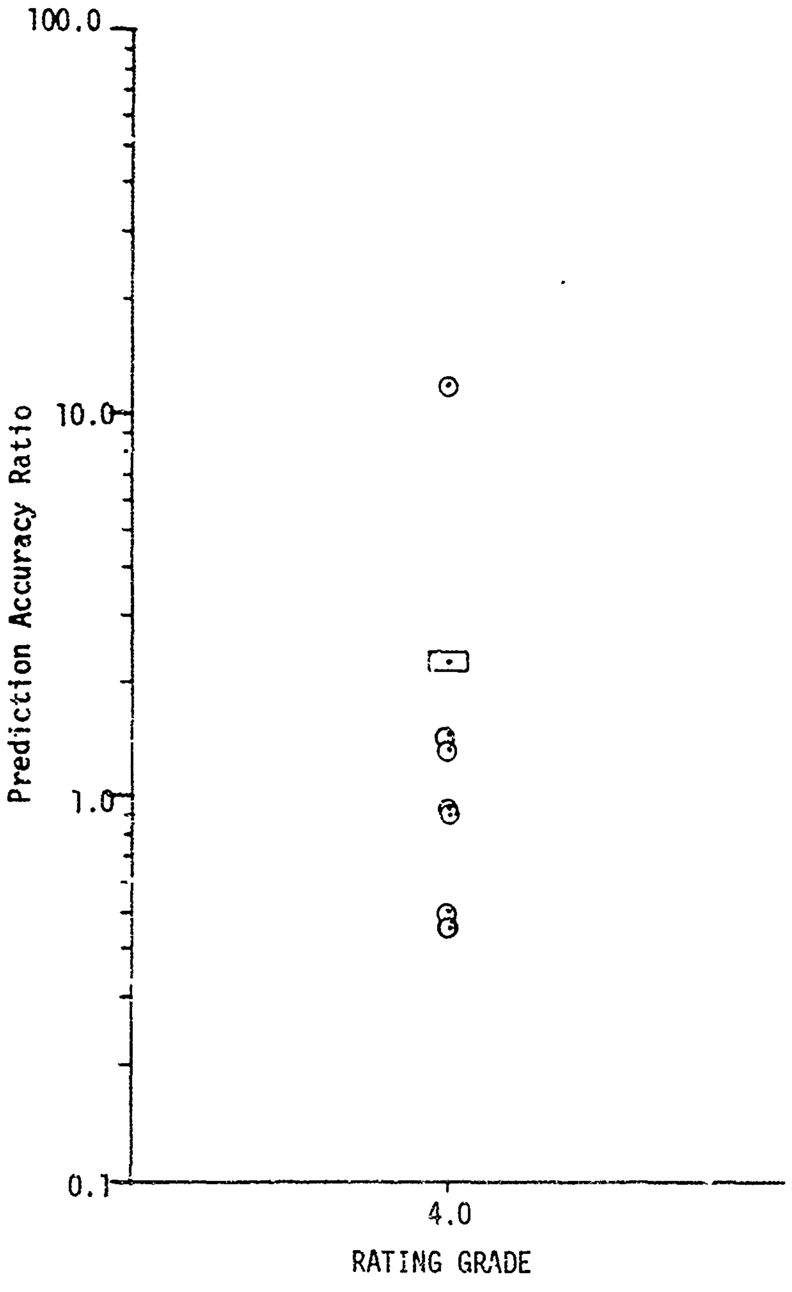

Figure 10. Distribution of Prediction Accuracy Ratios Program II

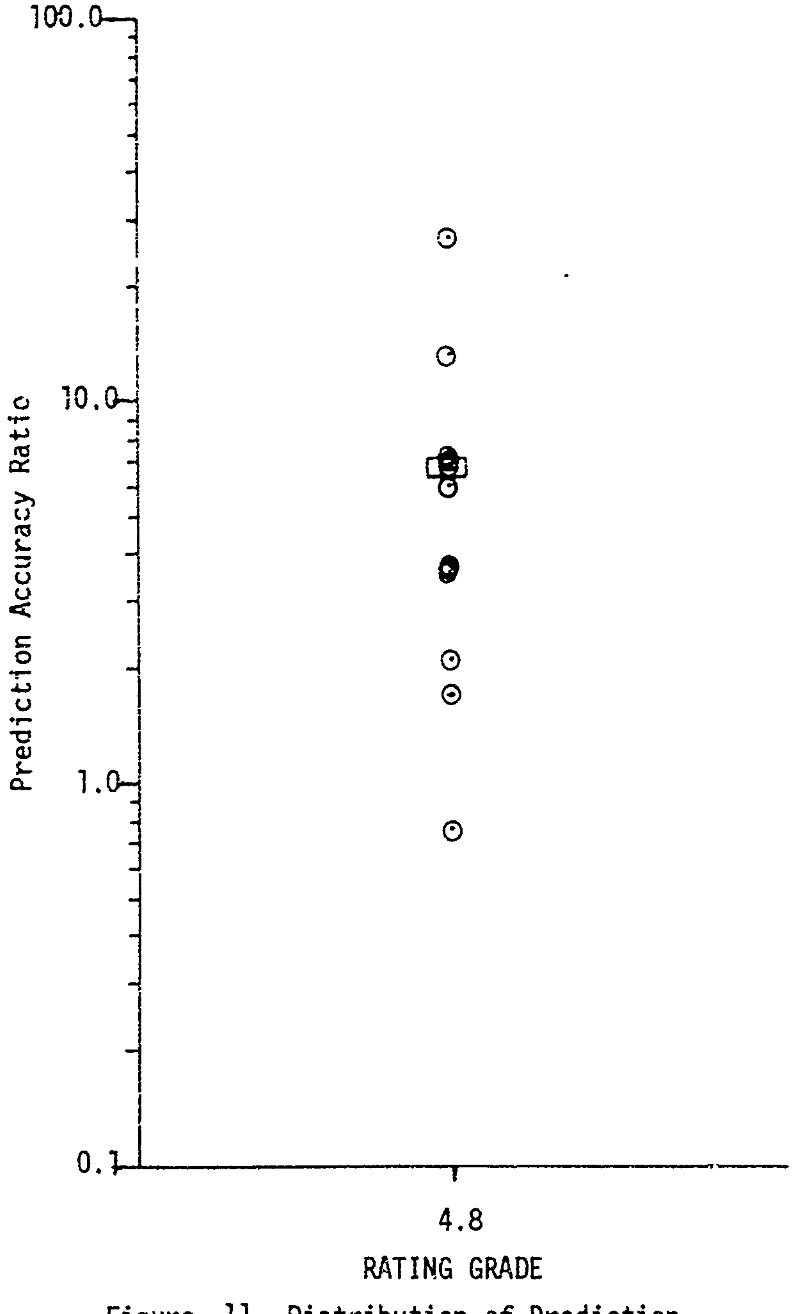

Figure 11. Distribution of Prediction Accuracy Ratios Program III

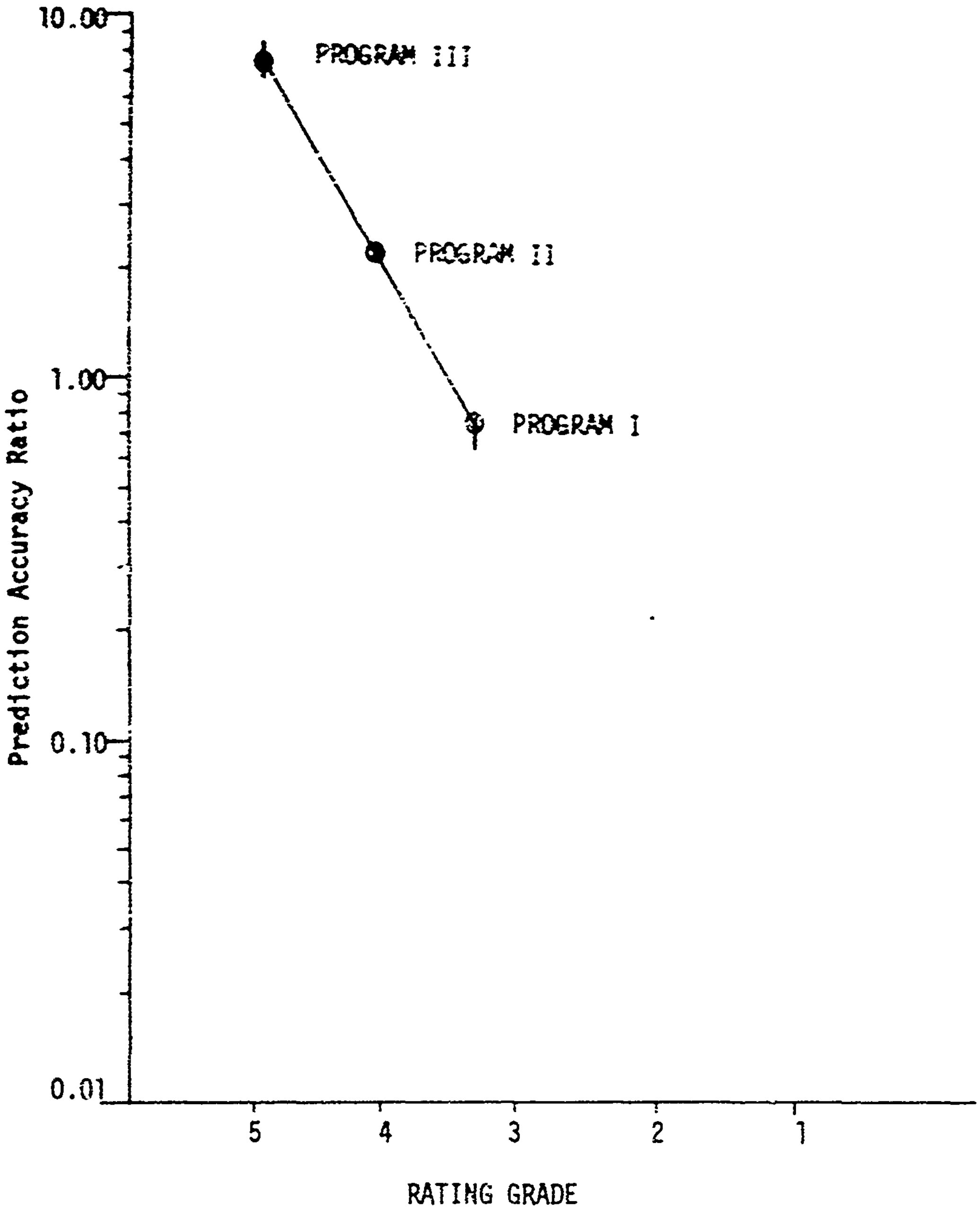

Figure 12. Program Rating Grade vs.
Prediction Accuracy Ratios

6. SPECIAL STUDY NO. 5: "FAILURE RATE VERSUS TIME"

a. Objectives

The latest revision of the RADC Reliability Notebook indicates that part failure rates are not constant with time. This study was conducted to evaluate the relationships between failure rates at the equipment level and accumulated operating time for a variety of ground electronic equipment. The study examines failure rates versus time for approximately forty types of fixed ground electronic equipments.

Plots of failure rate versus time are developed based on quarterly intervals to eliminate short-term variations introduced by monthly anomalies. Each equipment plot presents three views of the data:

- o The actual number of failures per 1000 hours per period.
- o The cumulative failure rate versus time for the total period.
- o The one-year moving average of failures per 1000 hours. This moving average was used to reflect the influence of later data and to provide more positive trend indications.

b. Summary

The following conclusions can be drawn from the analysis of failure versus time characteristics of the equipment.

- o In 72.9% of the equipments analyzed, failure rates are not constant with time. For the equipment where the failure rate is decreasing with time, the minimum failure rate decrease was 20% and the maximum decrease was 940%. Eighty percent of these equipment experienced failure rate decrease between 20% and 165%. For the equipments where the failure rate is increasing with time, the equipments showed failure rate increases of 145%, 80%, 20% and 0.0%. Equipment C-1 had a failure rate versus time pattern that was definitely increasing, even though the year to year estimates were identical.
- o Receiver and computer type equipment are more likely to exhibit constant failure rates versus time than transmitter and display equipment.
- o Failure rate changes from year to year are greater than plus or minus 50% in 48.4% of the equipments analyzed.
- o A positive correlation exists between failure rate versus time characteristics and percent failure rate change.

c. Details

(1) Failure Rate Versus Time - Statistical Analysis

This section presents a discussion of the failure rate versus time data derived from the field reports. The first consideration is to determine if the failure rate is increasing, decreasing, or can be considered constant. This determination can be reached by examining the curves to observe the general shape and to perform statistical tests on the data. The statistical test used was the chi-square test. The fundamental theorem underlying the test is that: given 2 sets of observed outcomes and a matching set of expected outcomes for the possible outcomes of an experiment that is performed many times; then as the number of observations become large, the distribution of

$$\sum_{i=1}^{K} (o_i - e_i)^2/e_i \qquad (18)$$

approaches a chi-square distribution with k-1-ℓ degrees of freedom, where:

o = number of observations (failures per unit time) per time interval k.

e = expected number of observations (failures per unit time) per time interval k.

k = number of time intervals considered (number of quarters).

ℓ = number of parameters estimated from the data.

The number of observations equals the number of failures per 1000 hours per quarter. The expected number of observations equals the average number of failures per 1000 hours times the hours per quarter.

$$e = \frac{\text{Failures}}{\text{1000 Hours}} \times \frac{\text{Hours}}{\text{Quarter}} = \text{Failures/Quarter}$$

A statistical test of hypothesis is established for the data as follows:

H_0 : Failure rate is constant with time

H_1 : Failure rate is not constant with time

A statistical significance level is established for the test. If the calculated value of chi-square exceeds the value of chi-square in the chi-square table at the desired significance level, the initial hypothesis (H_0) is rejected and H_1 is accepted. In this analysis, acceptance of H_0 means the hypothesis of a constant failure rate cannot be rejected. The acceptance of H_1 means that at least one of the equipments in the subgroup has a failure rate that is not constant with time.

In performing the chi-square test, the restriction that the expectation (expected number of failures) per cell should exceed five was observed. If this was not the case for a particular equipment, cells were combined such that the requirement was satisfied. Thus, if no cells were combined and since 9 quarters were involved, the maximum number of degrees of freedom is $9-1-\ell = 7$. For this formulation $\ell = 1$, as the expected number of failures is estimated from the data requiring that one degree of freedom be subtracted. If the number of quarters of data is less than 9, or cell combination was required, the number of degrees of freedom was reduced correspondingly.

TABLE LXXI

TRANSMITTER TYPE EQUIPMENT - CHI-SQUARE COMPARISON

Equipment	Chi-Square at 95% Confidence	Calculated Value of Chi-Square
T-1	14.1	338.5
T-2	14.1	1023.2
T-3	14.1	335.2
T-4	14.1	670.7

All calculated values of chi-square exceed the 95% significance value of chi-square listed in the above table. (Seven degrees of freedom were used for all equipments). This means one or more of the units per equipment group has a measured failure rate that could not be considered constant in time. In fact, for the four equipments, the chi-square value would reject the hypothesis at greater than the 0.995 confidence level (the limit of the available table).

TABLE LXXII

RECEIVER TYPE EQUIPMENT - CHI-SQUARE COMPARISON

Equipment	Chi-Square at 95% Confidence	Calculated Value of Chi-Square
R-1	14.1	68.4
R-2	14.1	43.6
R-3	6.0	11.5
R-4	14.1	26.6
R-5	14.1	11.2
R-6	3.8	0.1
R-7	--	--
R-8	--	--

In four of the six cases, the hypothesis of a constant failure rate was rejected. For R-6, one of the cases where chi-square was not significant, only one degree of freedom was available due to data grouping requirements. Most of the calculations show chi-square to be significant at greater than the 0.995 confidence level. (R-1, R-2, R-3, R-4). The chi-square test was not performed for equipments R-7 and R-8 since the failure expectancy was not sufficient.

TABLE LXXIII

COMPUTER TYPE EQUIPMENT - CHI-SQUARE COMPARISON

Equipment	Chi-Square at 95% Confidence	Calculated Value of Chi-Square
C-1	14.1	44.7
C-2	14.1	9.0
C-3	14.1	84.7
C-4	--	--
C-5	3.8	2.0
C-6	14.1	26.1
C-7	14.1	10.7
C-8	6.0	32.0
C-9	--	--
C-10	5.0	54.9
C-11	--	--
C-12	3.8	47.6
C-13	--	--
C-14	9.5	9.2
C-15		
a) Electrical	9.5	8.0
b) Mechanical	9.5	40.9

For the computer equipment chi-square calculations could be performed for 11 of the 15 equipments. On the other four equipments, cell merging requirements prohibited use of the chi-square test. Of the equipments tested, 7 showed rejection of the constant failure rate hypothesis; for the remainder the hypothesis was not rejected. For equipments where the hypothesis was not rejected, two were the large computers (C-2 and C-7), one was the electrical components of the magnetic tape units (C-15), one was an interface equipment (C-14) and one was a timing unit (C-5). Four other interface equipments and three other timing equipments chi-square test resulted in rejection of the constant failure rate hypothesis.

TABLE LXXIV

DISPLAY TYPE EQUIPMENT - CHI-SQUARE COMPARISON

Equipment	Chi-Square at 95 % Confidence	Calculated Value of Chi-Square
D-1	6.0	15.5
D-2	14.1	47.0
D-3	--	--
D-4	6.0	6.3
D-5	14.1	48.0
D-6	--	--
D-7	9.5	3.1
D-8	6.0	9.7
D-9	--	--

Chi-square tests were performed on 6 of the 9 display equipments and 5 of these 6 showed significance.

(2) Graphs of Failure Rate Versus Time

This section presents the plots of failure rate versus time for each of the equipment groups. Each plot presents the average unit failure rate per 1000 hours per quarter, (designated by a dot (.)); the cumulative failure rate versus time, (designated by a triangle (Δ)); and a one-year moving average failure rate versus time, (designated by a circle (O)). Accompanying each plot is a discussion of the data.

In the discussion for each equipment, the calculated value of chi-square is presented. Also, failure rate estimates for all the equipments per equipment group for the first year, the second year, and overall (cumulative failure rate) are listed. For example, referring to transmitter equipment T-1, each point per quarter is obtained by dividing the total failures by the number of equipments. (In this case six transmitters are included in the equipment group.)

The failure rate estimate for the first year is obtained by dividing the total operating hours for the six transmitters for the first year by the total number of failures, and adjusting the value to the base of failures per 1000 hours. A similar procedure was used to obtain the estimate of failures per 1000 hours for the second year. The cumulative or overall failure rate is obtained by dividing the total number of hours by the total failures, and adjusting to the failure rate base of failures per 1000 hours.

Finally, it should be noted that on all charts, the abscissa is broken to indicate that data are not shown for the time interval between the equipment IOC (Initial Operational Capability) date and the beginning of the first quarter represented in the data

Transmitter Equipment T-1

The point estimates of the failure rate per quarter and the cumulative failure rate decrease with time. The value of chi-square is 338.5, highly significant. The point estimate of the failure rate for the first year is 169/1000 hours, for the second year is 109/1000 hours, a decrease of 35.5%, and an overall failure rate of 123/1000 hours for 27 months of operation. Hence, it is concluded that the failure rate of this equipment is decreasing with time. Figure 13 plots the average failure rate for the six transmitters.

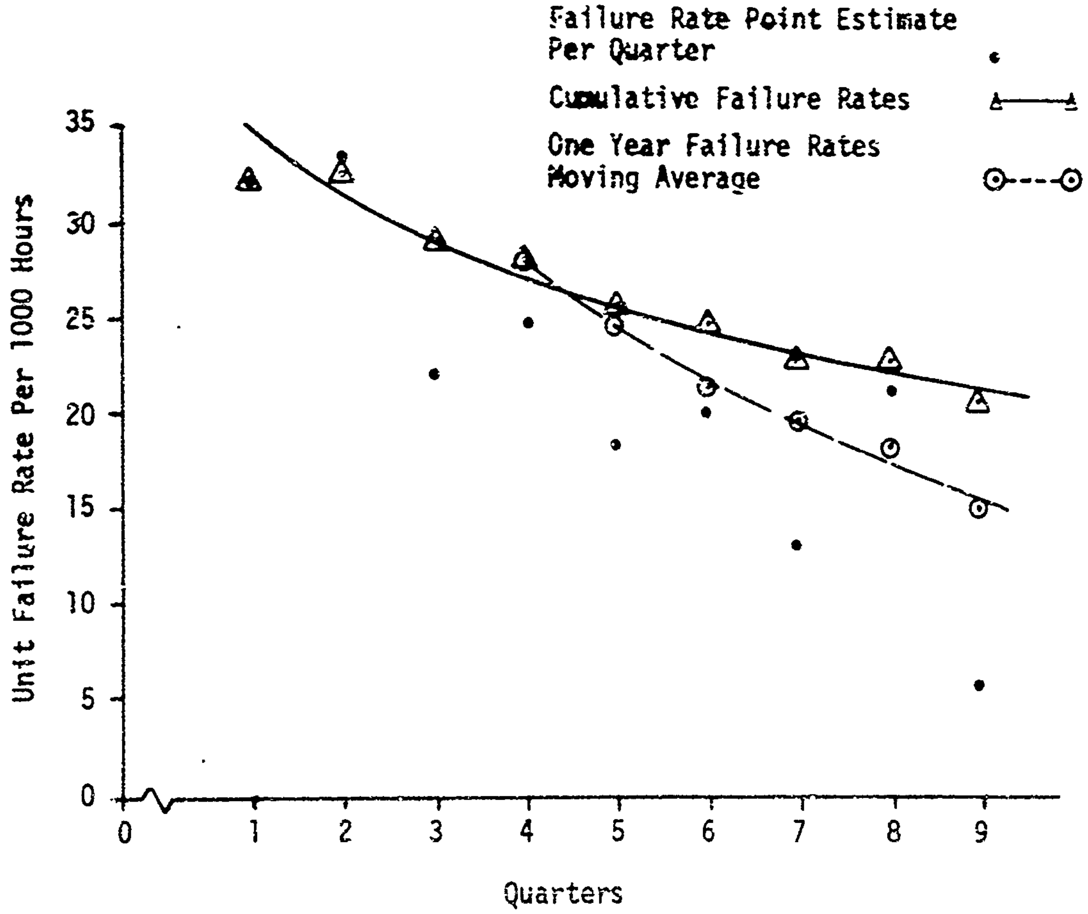

Figure 13. Failure Rate Versus Time - Equipment T-1

Transmitter Equipment T-2

The point estimate of the failure rate per quarter and the cumulative failure rate decrease versus time. The value of chi-square is 1023.2, highly significant. The point estimate of the failure rate for the first year is 240/1000 hours, for the second year is 114/1000 hours, a decrease of 52.4%, and an overall failure rate for 27 months of operation is 162/1000 hours. Hence, it is concluded that the failure rate of this equipment is decreasing with time. Figure 14 plots the average failure rate for the ten transmitters.

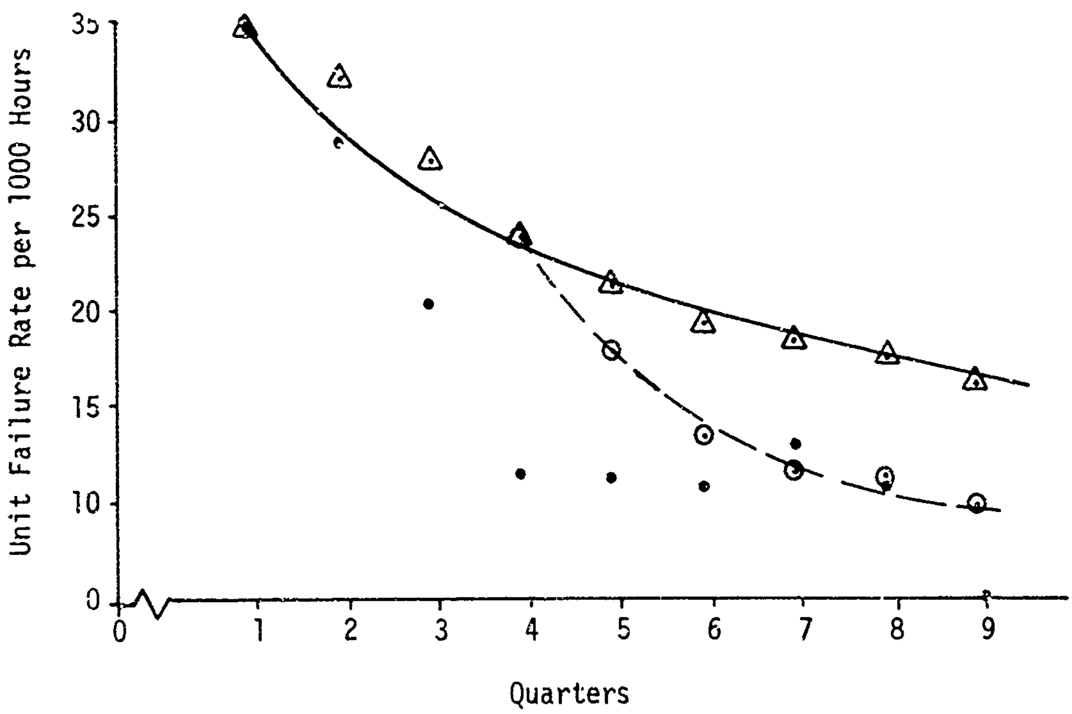

Figure 14. Failure Rate Versus Time - Equipment T-2

Transmitter Equipment T-3

This equipment is similar to transmitter equipment T-1, but the data are substantially dissimilar. The cumulative failure rate versus time initially decreases, reaches a minimum at 12 months, climbs substantially the next 12 months, and then shows a tendency to decline during the last quarter. The failure rate for the first year is 65/1000 hours, for the second year 104/1000 hours, with an overall failure rate of 78/1000 hours. Chi-square is highly significant at 335.2. Based on the data, at least one of the four transmitters must have had a failure rate that was increasing with time. Figure 15 shows the average results for the four transmitters.

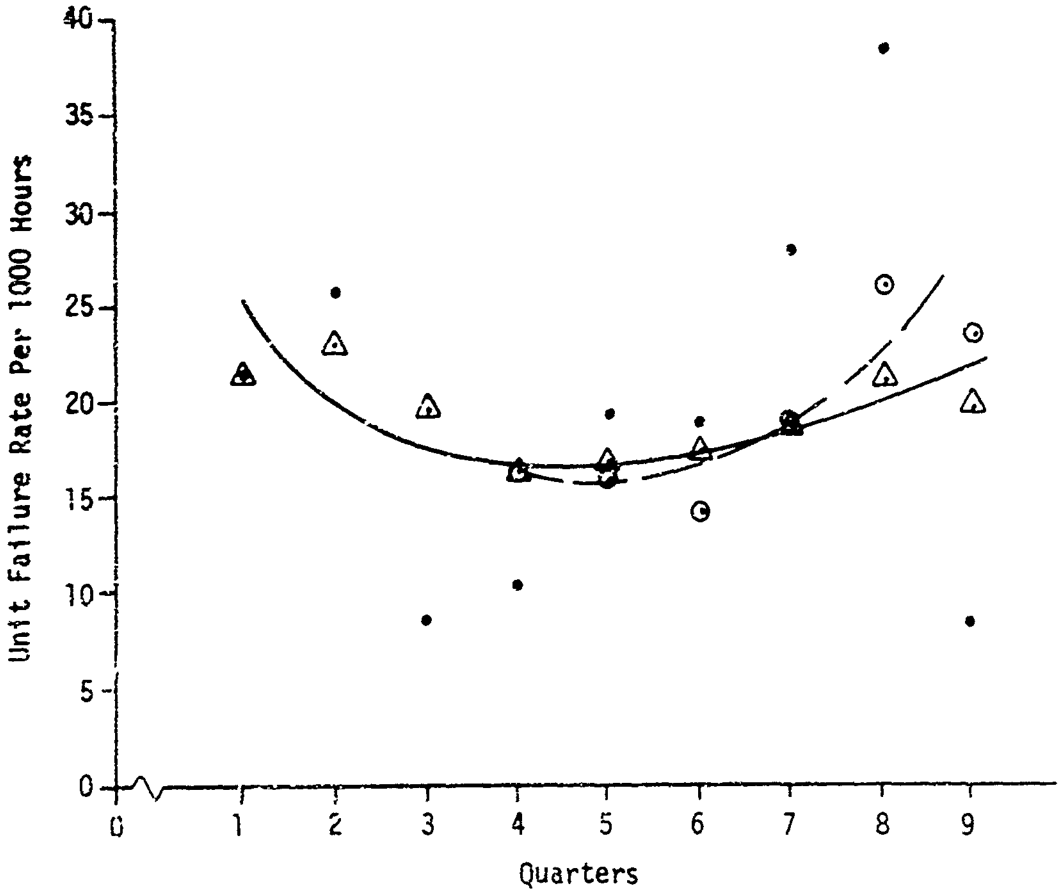

Figure 15. Failure Rate Versus Time - Equipment T-3

Transmitter Equipment T-4

This hardware is similar to transmitter equipment T-2. The cumulative failure rate decreases with time. The value of chi-square is 670.7, highly significant. The point estimate of the failure rate for the first year is 154/1000 hours, for the second year is 115/1000 hours, a decrease of 25.4%, and the overall failure rate for 27 months of operation is 124/1000 hours. Hence, it is concluded that the failure rate for this equipment is decreasing with time. Figure 16 plots the average failure rate for the eight transmitters.

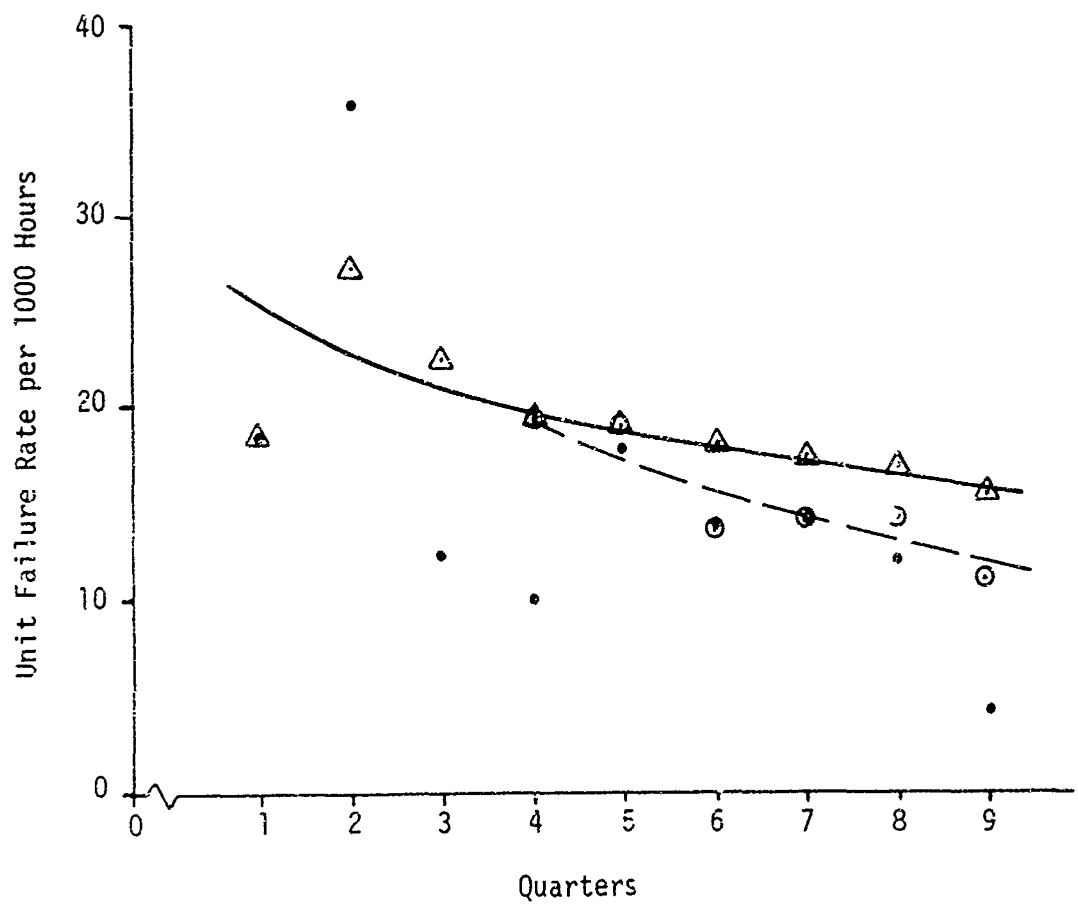

Figure 16. Failure Rate Versus Time - Equipment T-4

Receiver Equipment R-1

The cumulative failure rate and the moving average decrease with time for this equipment. The point estimate of the failure rate for the first year is 25.6/1000, for the second year is 13/1000, a decrease of 49.1%, with the overall failure rate of 19.1/1000 hours for 27 months of operation. The value of chi-square is 68.4, highly significant. The failure rate for this equipment is decreasing with time. Figure 17 plots the average failure rate for the 18 receivers.

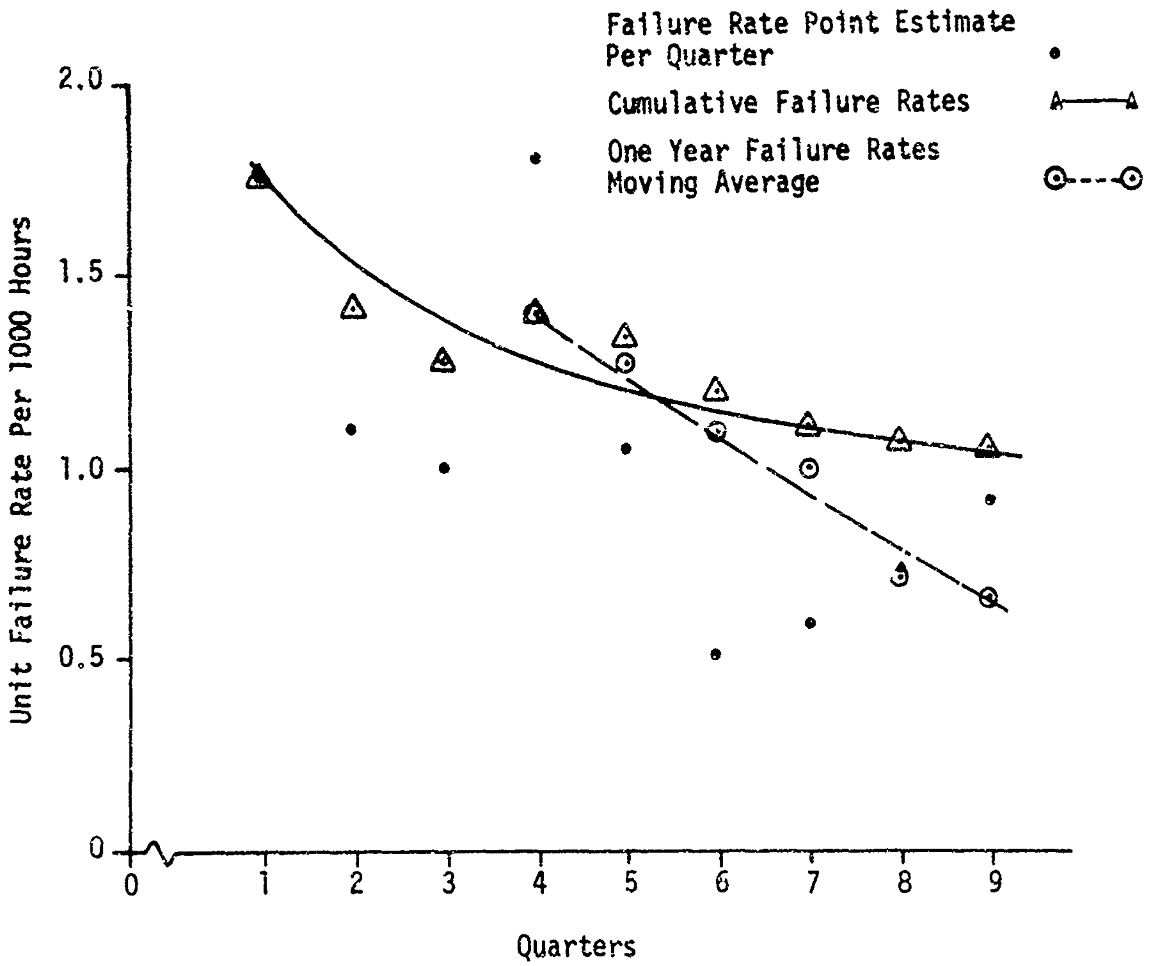

Figure 17 Failure Rate Versus Time - Equipment R-1

Receiver Equipment R-2

The failure rate versus time plot for this equipment is one of the most peculiar observed in the study. The point estimates of the failure rate per quarter form an oscillatory pattern, giving rise to an oscillatory cumulative failure rate plot. From this data, it appears that the equipment experienced, on a yearly basis, some problem that resulted in a high removal rate, and then was temporarily repaired. The point estimate of the failure rate for the first year is 12.5/1000 hours, for the second year is 10.8/1000 hours, with the overall failure rate for 27 months of operation of 12.7/1000 hours. Thus, on a yearly basis, the failure rate was constant. However, due to the unique slope of Figure 18, the only conclusion that is reasonable is that the failure rate for these 16 equipments is not constant with time.

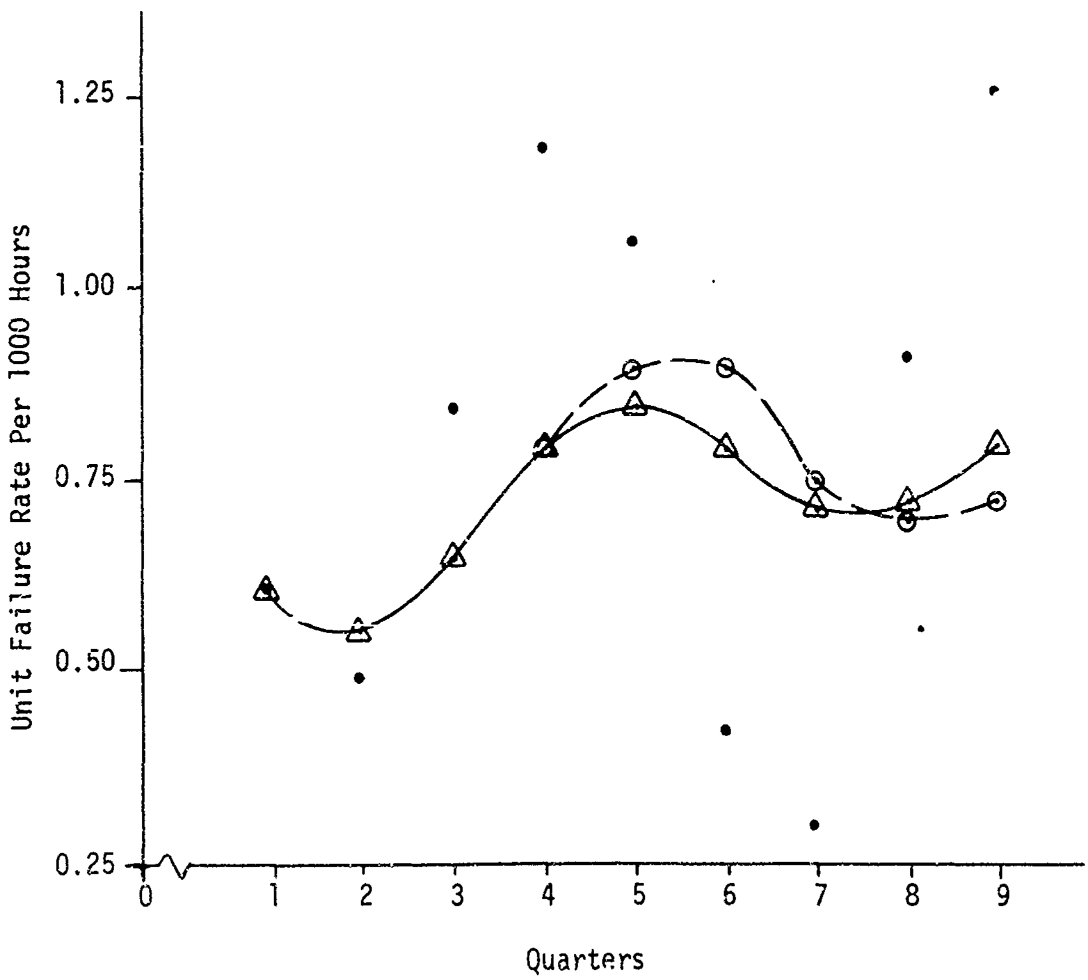

Figure 18. Failure Rate Versus Time - Equipment R-2

Receiver Equipment R-3

The cumulative failure rate and the moving average decrease with time. The point estimate of the failure rate for the first year is 3.0/1000 hours, for the second year is 1.1/1000 hours, a decrease of 63.4%, with an overall failure rate for 27 months of operation of 1.9/1000 hours. The value of chi-square is 11.5, highly significant. The failure rate for this equipment is decreasing with time. Figure 19 plots the average failure rate for the 13 receivers.

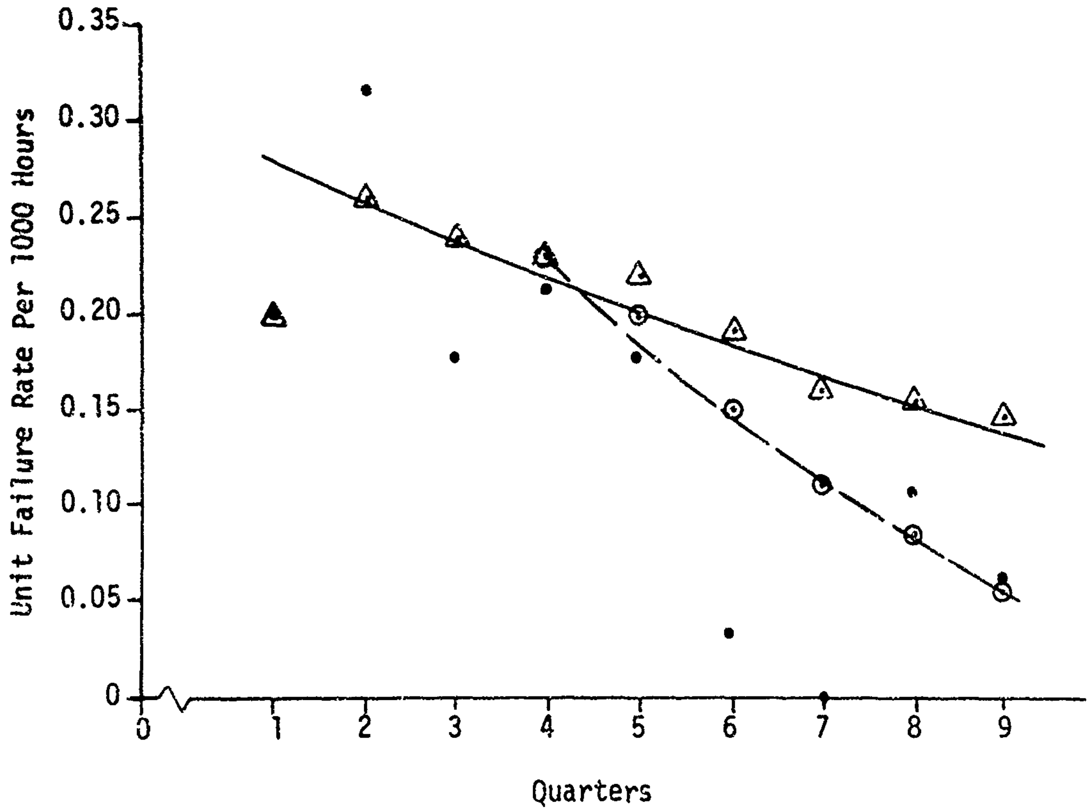

Figure 19. Failure Rate Versus Time - Equipment R-3

Receiver Equipment R-4

This hardware is similar to receiver equipment R-1. The cumulative failure rate and the moving average decrease with time. The point estimate of the failure rate for the first year is 21.9/1000 hours, for the second year 17.6/1000 hours, a decrease of 19.6%, with an overall failure rate for 27 months of operation of 19.2/1000 hours. The value of chi-square is 26.6, highly significant. The failure rate for this equipment is decreasing with time. Figure 20 plots the average failure rate for the 14 receivers.

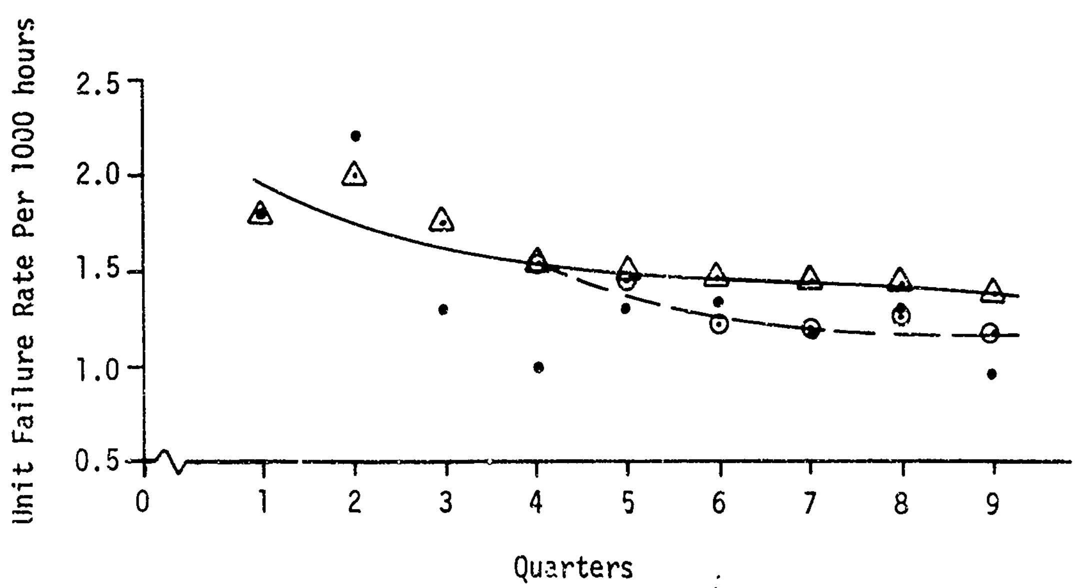

Figure 20. Failure Rate Versus Time - Equipment R-4

Receiver Equipment R-5

This hardware is similar to R-2, but the results are distinctly dissimilar. The number of failures per month and the cumulative failure rate versus time are nearly constant (with the exception of 19 failures in the fourth quarter compared to an average of 38.5 failures per quarter, excluding that quarter). The point estimate of the failure rate for the first year is 15.0/1000 hours, for the second year is 17.9/1000 hours, an increase of 19.3%, with an overall failure rate of 16.9/1000 hours for 27 months of operation. Chi-square is 11.2, not significant at the 95% confidence level. It is concluded that the failure rate for this equipment is constant with time. Figure 21 plots the average failure rate for the 11 receiver equipments.

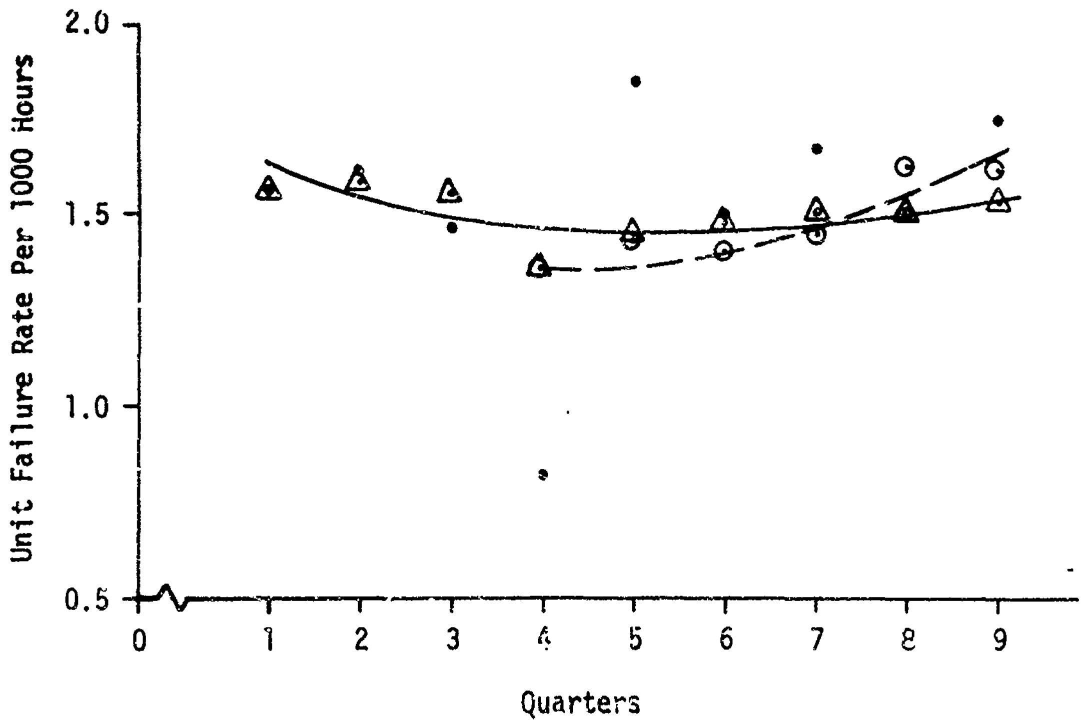

Figure 21. Failure Rate Versus Time - Equipment R-5

Receiver Equipment R-6

This hardware is similar to R-3. The point estimates of the failure rate per quarter appear to oscillate, but the cumulative failure rate versus time is nearly constant. Chi-square is 0.1, not significant. The total plot is based on 9 failures the first year, 12 failures the second year and two failures the last quarter. Hence, the individual points will appear to vary considerably, but this variation is due to the addition or subtraction of one failure. The point estimate of the failure rate for the first year is 1.1/1000 hours, for the second year 1.4/1000 hours, with an overall failure rate of 1.2/1000 hours. It is judged that the failure rate for this equipment is constant with time. Figure 22 plots the average failure rate versus time for the 10 equipments.

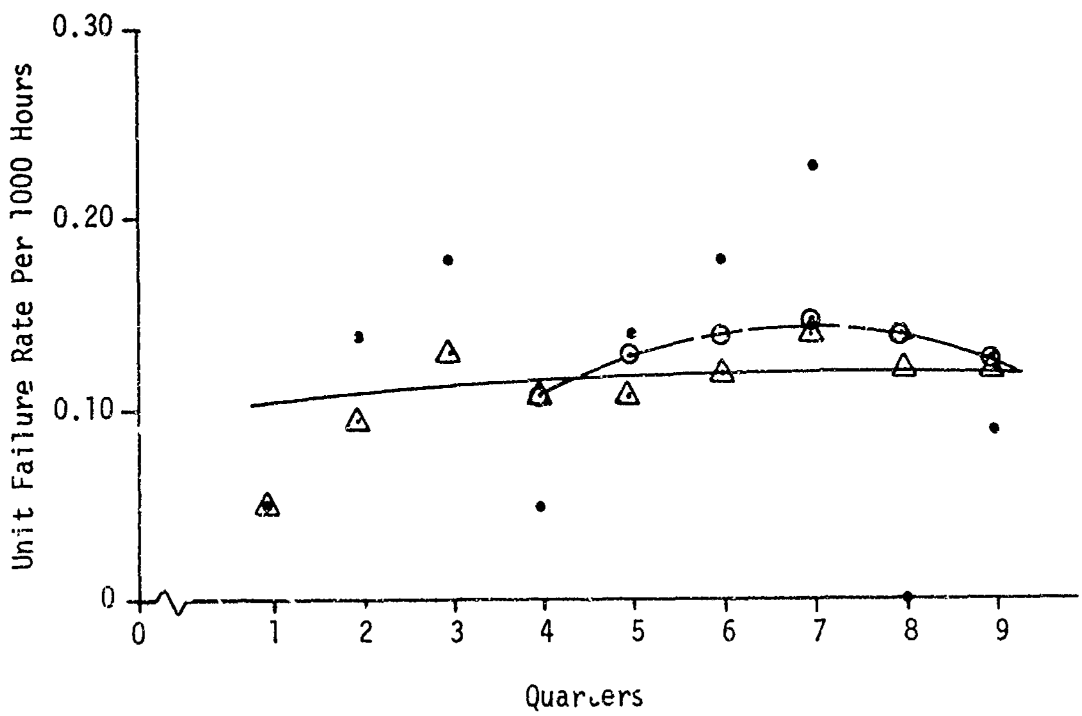

Figure 22. Failure Rate Versus Time - Equipment R-6

Receiver Equipment R-7

For this equipment, a total of eight failures in 19,580 calendar hours were experienced, with no more than two failures recorded per quarter. Failures were observed as follows: three failures the first year, four failures the second year and two failures the last quarter. The chi-square test was not performed, since the failure expectancy per cell, when grouped, is less than five. The failure rate for this equipment is increasing, but the trend would be reversed if no failures or one failure were observed the next quarter. Based on this data, it is judged that the failure rate for the equipment is constant with time. Figure 23 shows the average results for the six equipments.

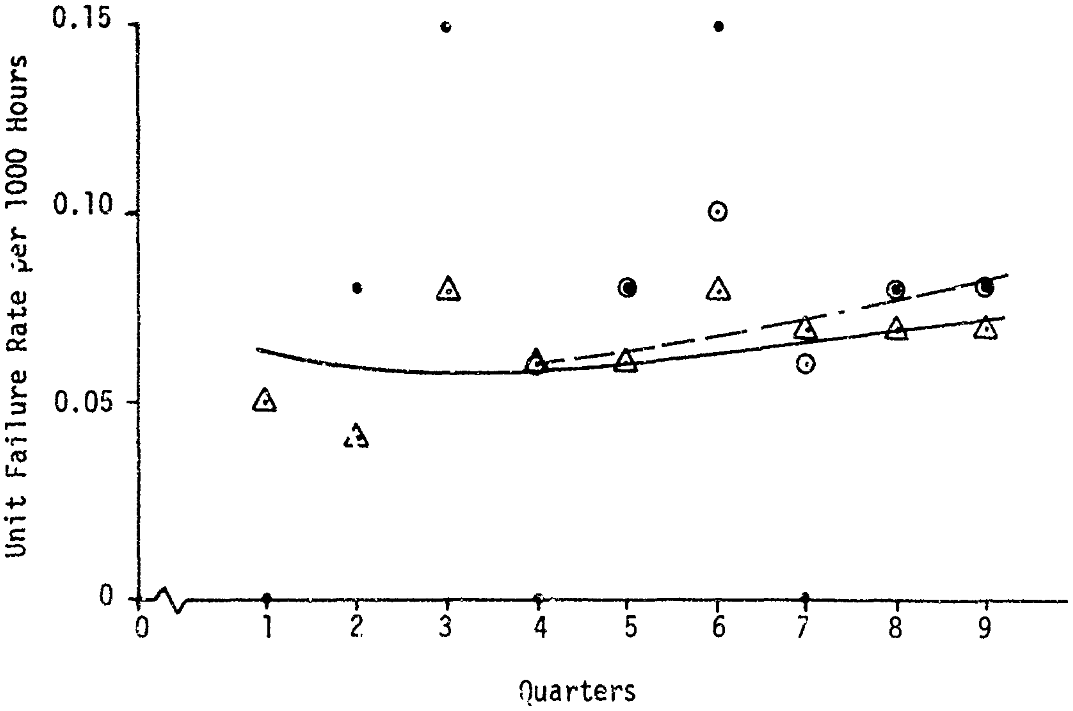

Figure 23. Failure Rate Versus Time - Equipment R-7

Receiver Equipment R-8

This hardware is similar to receiver component R-7. A total of 14 failures in 19,530 calendar hours of operation were experienced. Failures were observed as follows, five failures during the first year, nine failures during the second year, and no failures during the last quarter. Of the total number of failures, five of these were recorded during the eighth quarter (but none in the ninth quarter). The chi-square test was not performed since the failure expectation per cell, when grouped, is less than five. The cumulative failure rate is increasing with time. It is judged that the failure rate for this equipment is increasing with time, but that the trend could be reversed if subsequent operating quarters showed zero or one failure. Figure 24 plots the average failure rate for the four equipments.

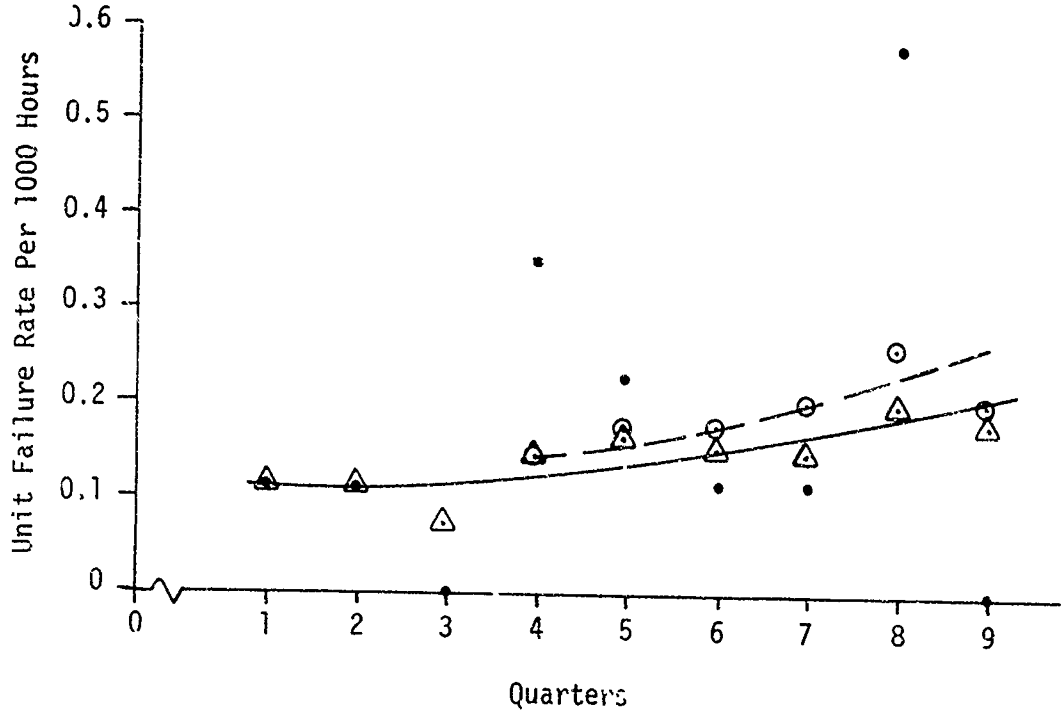

Figure 24. Failure Rate Versus Time - Equipment R-8

Computer Equipment C-1

The point estimates of the failure rate per quarter and the cumulative failure rate versus time increase with time. The value of chi-square is 44.7, highly significant. The point estimate of the failure rate for the first year is 4.8/1000 hours, for the second year 4.8/1000 hours with an overall failure rate of 5.1/1000 hours for the 27 months of operation. Even though the failure rate per year is constant, the failure rate per quarter is not, and it is judged that the failure rate of this equipment is increasing with time. Figure 25 plots the average failure rate of the 14 equipments.

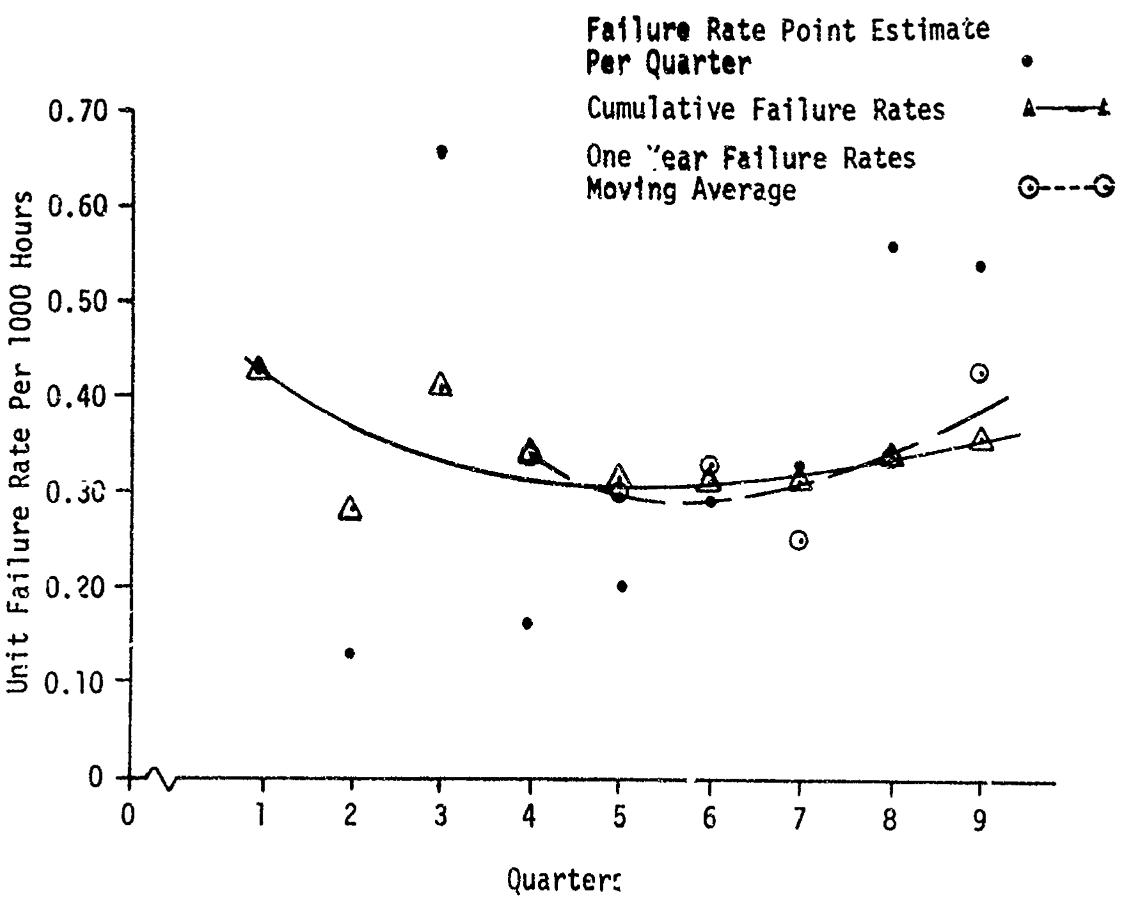

Figure 25. Failure Rate Versus Time - Equipment C-1

Computer Equipment C-2

The cumulative failure rate versus time for this equipment appears to be constant with time. The value of chi-square is 9.0, which is not significant at the 95% confidence level. The failure rate for the first year is 15.1/1000 hours, for the second year is 15.6/1000 hours, an increase of 3.3%, and the overall failure rate for 27 months of operation is 15.2/1000 hours. It is judged that the failure rate for this equipment is constant with time Figure 26 plots the average failure rate versus time for the two computers.

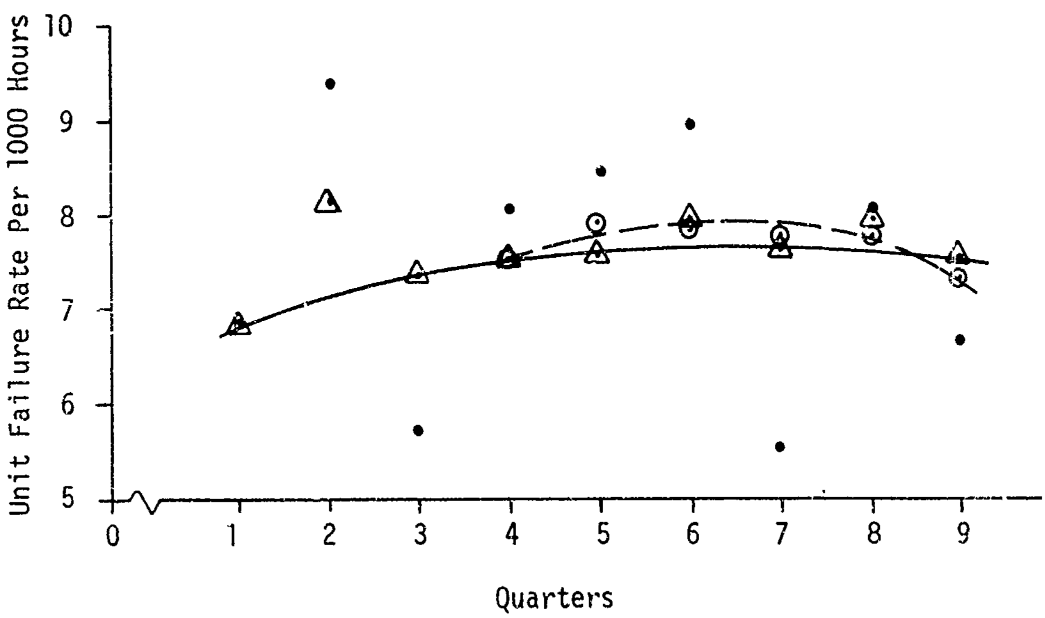

Figure 26. Failure Rate Versus Time - Equipment C-2

Computer Equipment C-3

This equipment exhibited an oscillatory failure rate per quarter, giving rise to the peculiar cumulative function. The failure rate for the first year is 11.1/1000 hours, for the second year is 8.1/1000 hours, and for the total 27 months of operation is 8.6/1000 hours. The only realistic conclusion is that the failure rate for this equipment is not constant. Figure 27 shows the average failure rate for the two equipments.

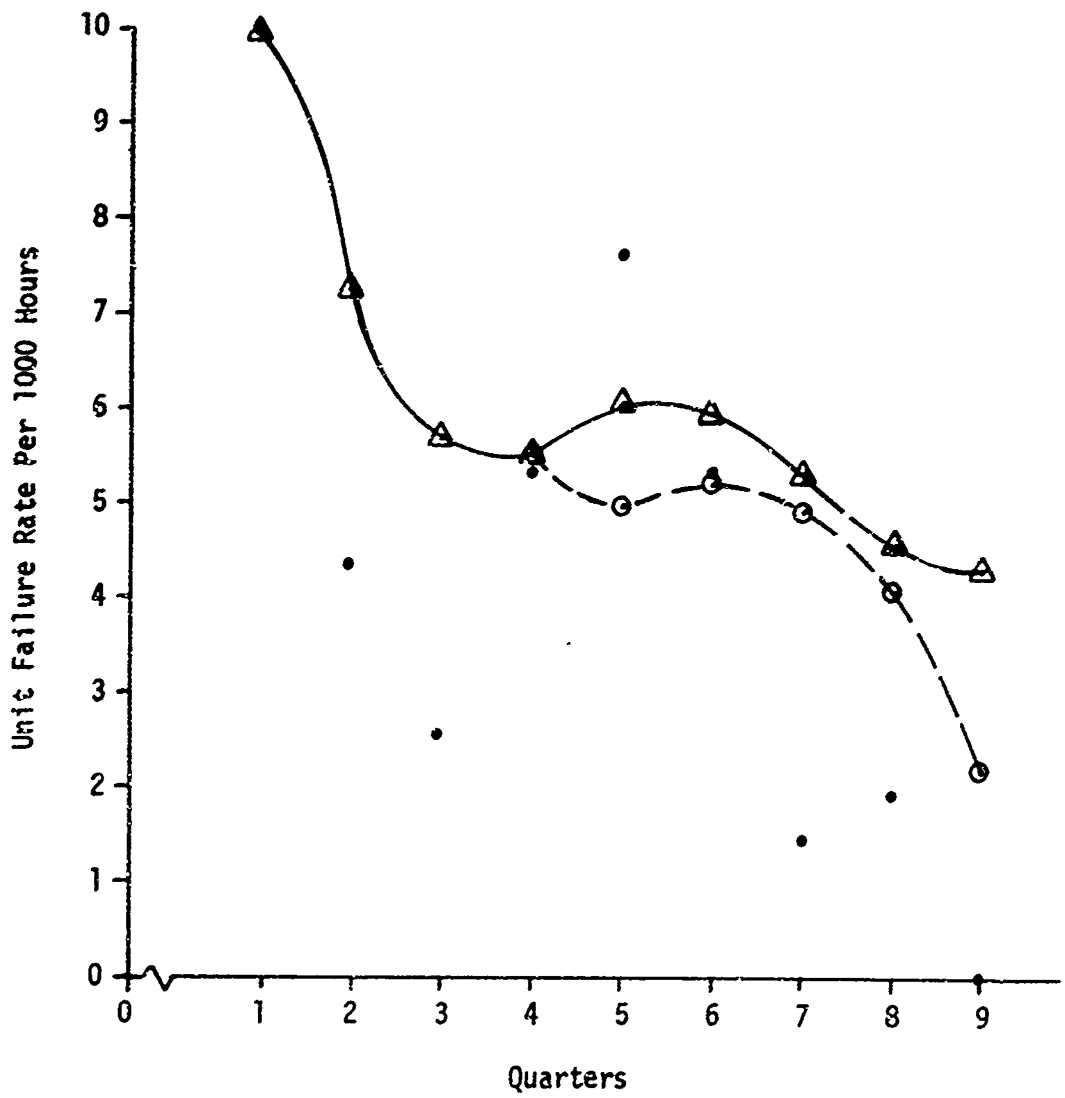

Figure 27. Failure Rate Versus Time - Equipment C-3

Computer Equipment C-4

For this equipment, a total of 13 failures in 19,530 calendar hours of operation were observed. The failures were divided as follows; nine the first year, four the second year and none the last quarter. The chi-square test was not performed since the failure expectancy per cell, when grouped, is less than five. Based on the observed cumulative failure versus time curve, it is judged that the failure rate of this equipment is decreasing with time. Figure 28 plots the average failure rate versus time for the two equipments.

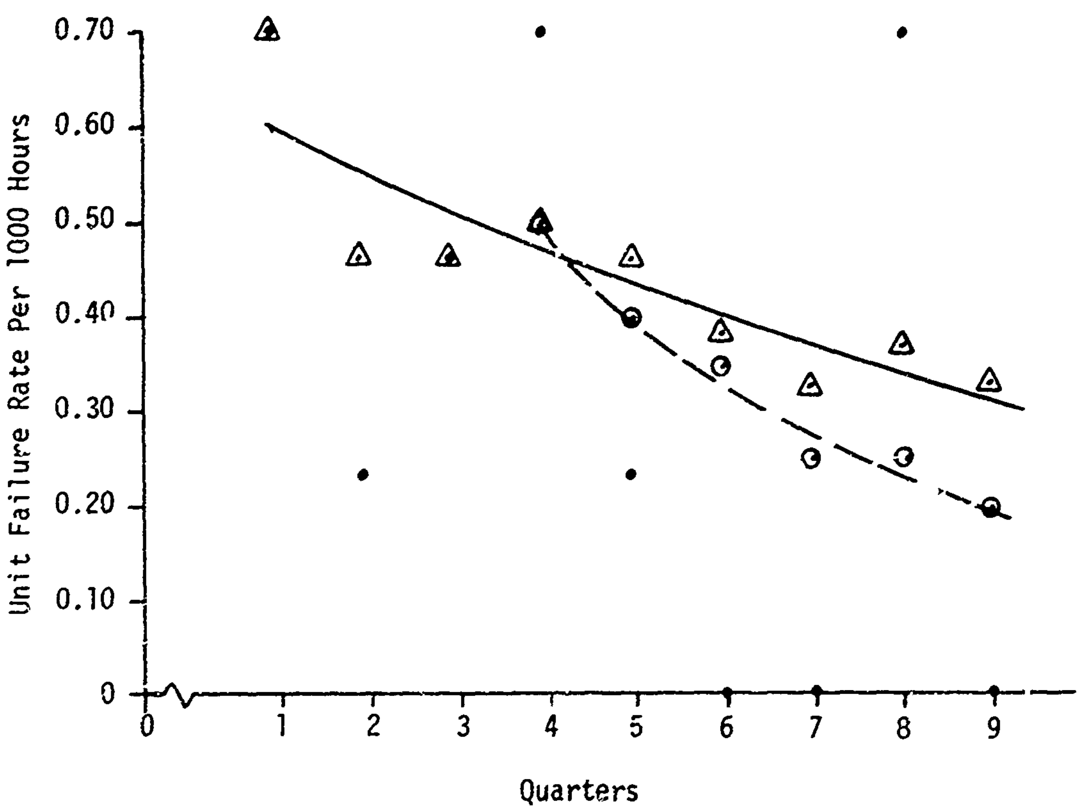

Figure 28. Failure Rate Versus Time - Equipment C-4

Computer Equipment C-5

There were a total of 21 failures measured on this equipment, 10 the first six months and 11 the last 18 months (none were recorded during the third quarter). During the last six quarters the failures were recorded as follows; one failure in each of two quarters, two failures in each of three quarters and three failures in one quarter. After the first six months of operation the failure rate appears to be constant. The value of chi-square of 2.0 (not significant) supports this judgement. Hence, it is judged that the failure rate for this equipment is constant with time. Figure 29 shows the average failure rate versus time for the three equipments.

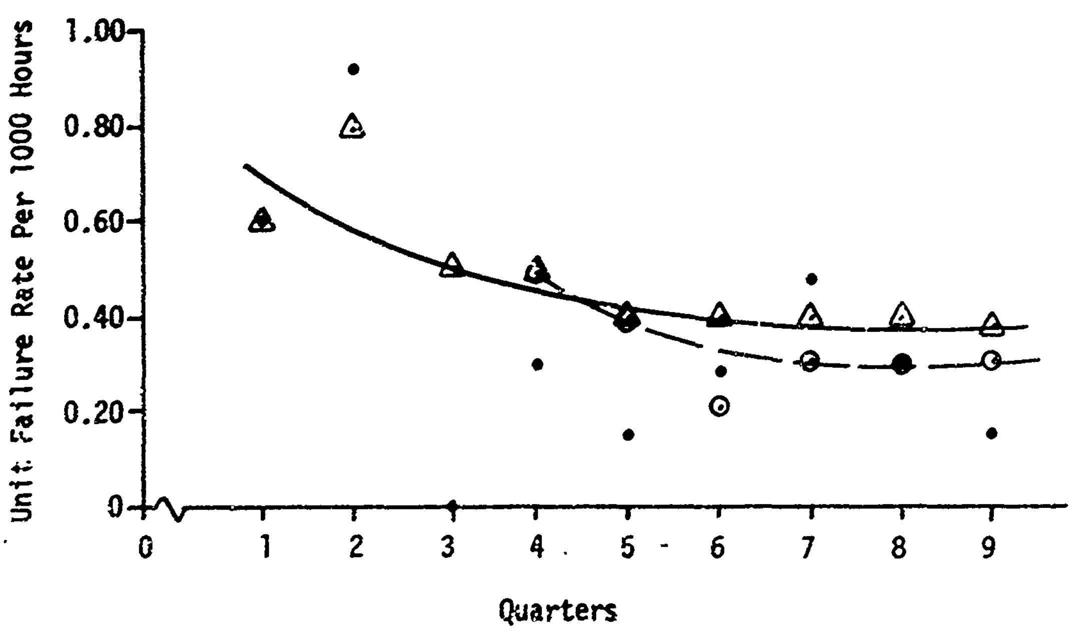

Figure 29. Failure Rate Versus Time - Equipment C-5

Computer Equipment C-6

This hardware is similar to equipment C-1. The point estimates of the failure rate and the cumulative failure rate are decreasing with time (with the exception of the last quarter). The point estimate of the failure rate for the first year is 5.7/1000 hours, for the second year is 2.7/1000 hours, a decrease of 52.7%, with an overall failure rate for 27 months of operation of 4.4/1000 hours. This failure rate was influenced by the data from the last quarter (14 failures compared to a total of 17 the previous three quarters). Chi-square was 26.1, highly significant. It is judged that the failure rate for this equipment is decreasing with time. Figure 30 plots the average failure rate for the 11 equipments.

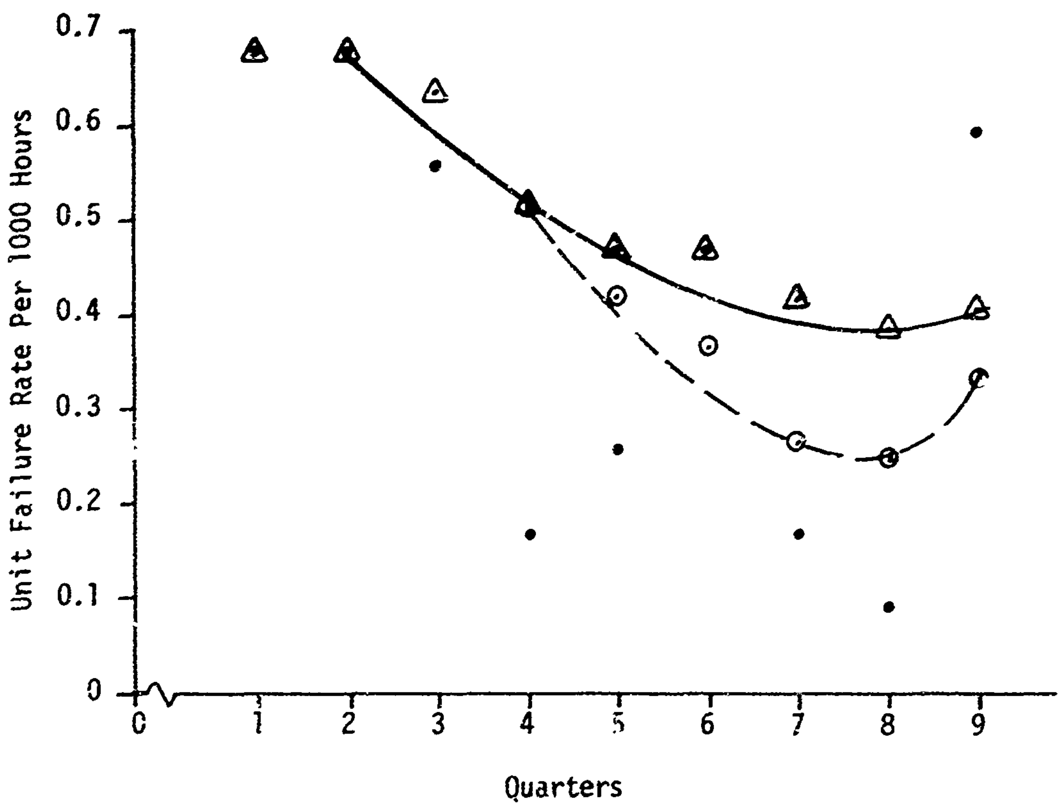

Figure 30. Failure Rate Versus Time - Equipment C-6

Computer Equipment C-7

This hardware is similar to equipment C-2. The cumulative failure rate appears to be constant with time. The value of chi-square is 10.7, which is not significant at the 95% confidence level. The failure rate for the first year is 10.4/1000 hours, for the second year is 10.1/1000 hours, a reduction of 2.9%, with an overall failure rate for 27 months of operation of 10.9/1000 hours. This increase is due to 32 failures the last quarter. It is judged that the failure rate for this equipment is constant with time. Figure 31 plots the average failure rate versus time for the two computers.

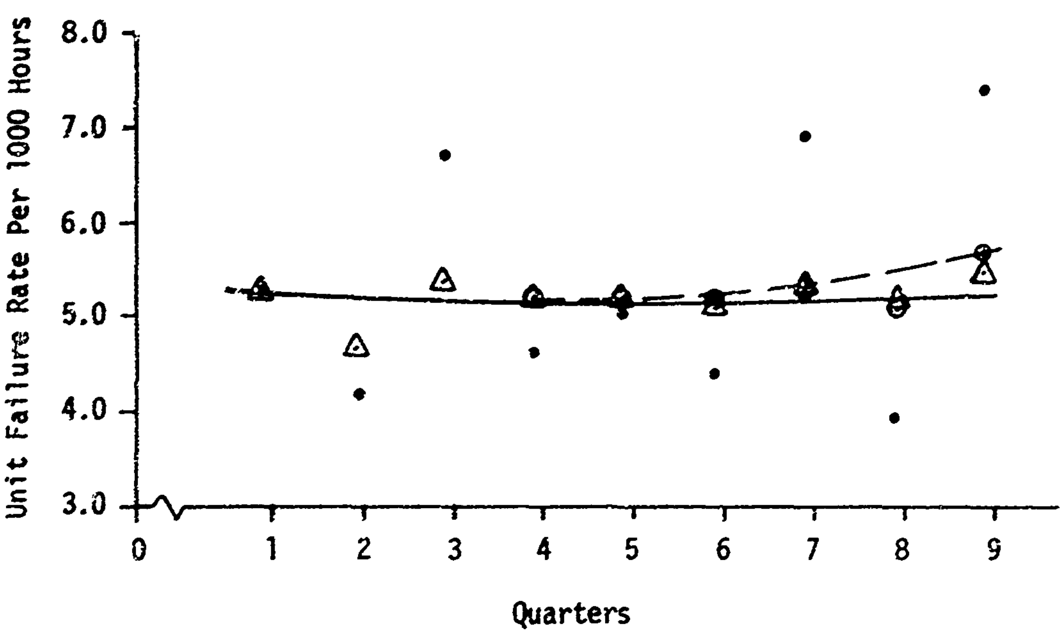

Figure 31. Failure Rate Versus Time - Equipment C-7

Computer Equipment C-8

This hardware is similar to C-3 but does not exhibit the oscillatory characteristics of that equipment. The point estimate of the failure rate and the cumulative failure rate are decreasing with time. The value for chi-square is 32.0, highly significant. The point estimate of the failure rate for the first year is 3.0/1000, for the second year is 0.35/1000, a decrease of 88.3%, with a cumulative failure rate for 27 months of operation of 1.5/1000 hours. It is judged that the failure rate for this equipment is decreasing as a function of time. Figure 32 plots the average failure rate for the two equipments.

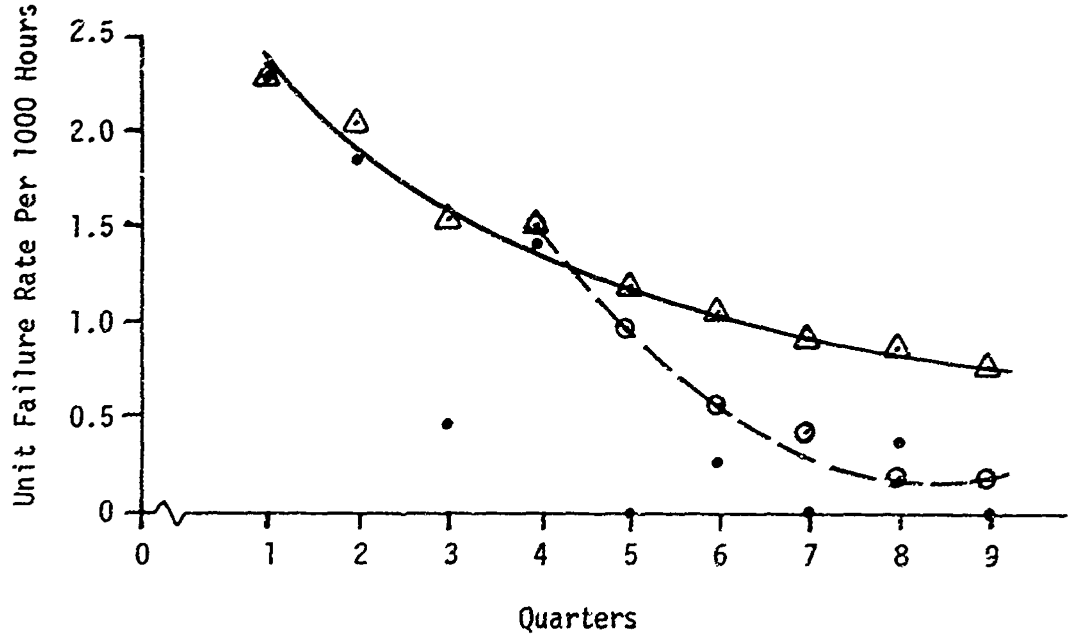

Figure 32. Failure Rate Versus Time - Equipment C-8

Computer Equipment C-9

This hardware is similar to equipment C-4. A total of four failures were observed, two during the first year, one during the s, ond year and one during the last quarter. The chi-square test is not appropriate due to the low failure expectation per cell. The failure during the first year is 0.23/1000 hours and for the last four quarters is 0.23/1000 hours. In six of the nine quarters, zero failures were observed. It is judged that the failure rate for the equipment is constant with time. Figure 33 plots the average failure rate for the two equipments.

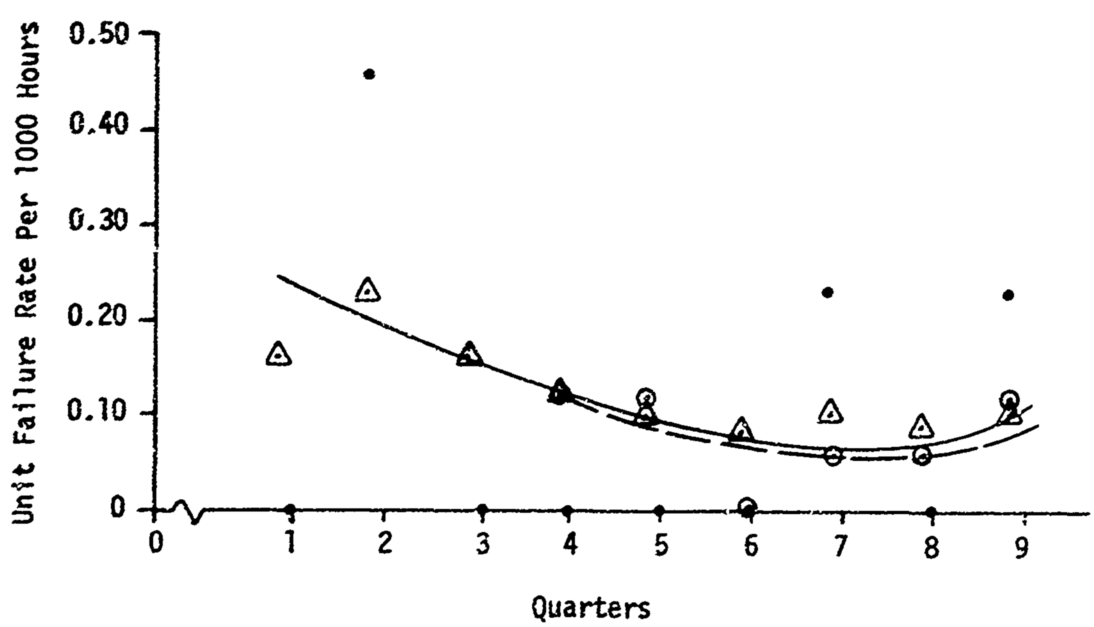

Figure 33. Failure Rate Versus Time - Equipment C-9

Computer Equipment C-10

This hardware is similar to equipment C-5. A total of 43 failures were observed, 26 in the second quarter and 11 in the fifth quarter. In the remaining six quarters, zero, one and two failures were observed in each of two quarters. Based on the two high failure quarters, chi-square was significant (54.9). It is judged that these two quarters represent anomalies in the data reporting process and that the appropriate estimate of the failure rate is that it is constant with time. Figure 34 shows the average failure rate for the two equipments.

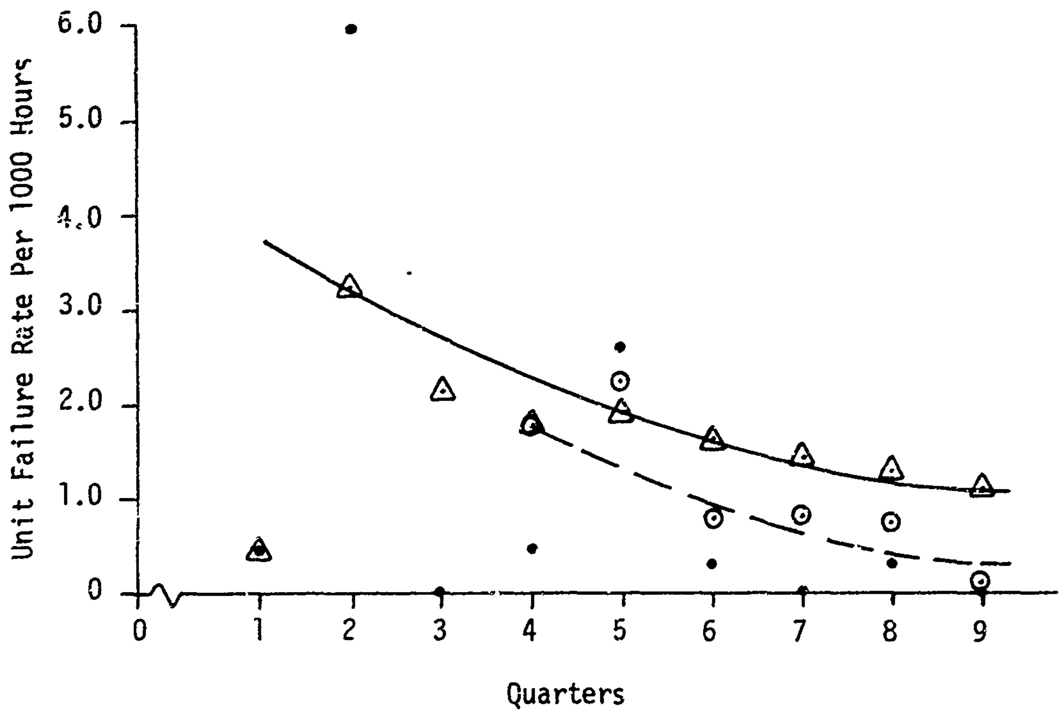

Figure 34. Failure Rate Versus Time - Equipment C-10

Computer Equipment C-11

A total of 16 failures were observed in 11,158 calendar hours of operating time (six quarters of operation). Four of these failures were observed the first three quarters and 12 failures during the last three quarters. The chi-square test was not performed since the failure expectancy per cell, when grouped, is less than five. The point estimates of the failure rate appear to oscillate, reaching a peak of six failures in the fourth quarter, and dropping to two failures in the sixth quarter. The only conclusion is that the failure rate is not constant. Figure 35 shows the average failure rate for the equipment.

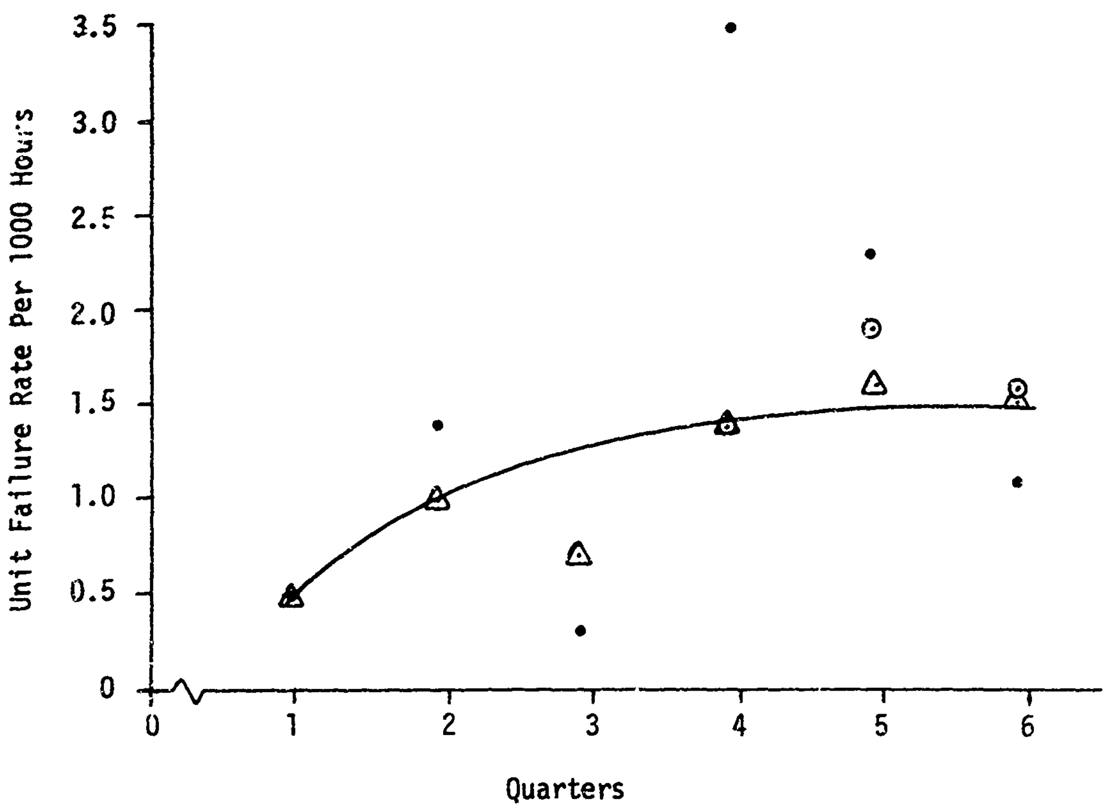

Figure 35. Failure Rate Versus Time - Equipment C-11

Computer Equipment C-12

A total of 36 failures were observed in 11,158 hours of operations (6 quarters), 16 in the first two quarters and 18 in the last two quarters. Thus, the point estimates of the failure rate form a 'V'. The cumulative failure rate curve forms a 'bathtub' shape curve with a minimum at one year. Based upon this behavior of the point estimates of the failure rate, it can be concluded that the failure rate is not constant with time. Figure 36 plots the equipment failure rate versus time for this equipment.

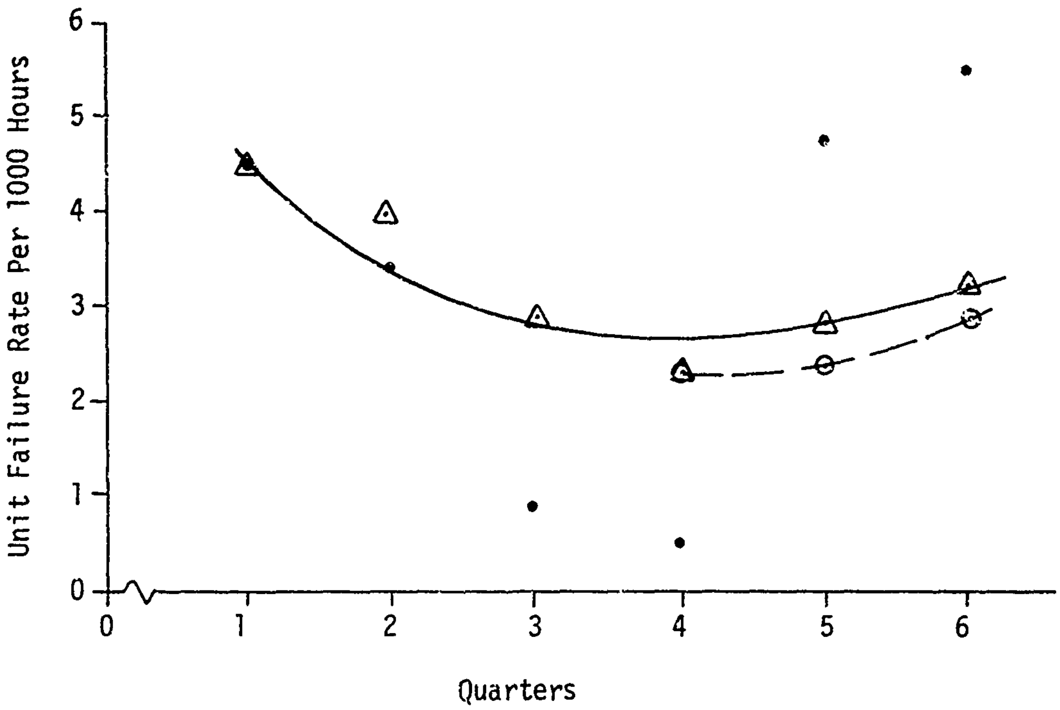

Figure 36. Failure Rate Versus Time - Equipment C-12

Computer Equipment C-13

A total of nine failures were observed in 11,912 hours of operation. During the first two quarters one and zero failures were observed, respectively. During the next four quarters, four, three, one and zero failures were observed, respectively. After the first six months the failure rate per quarter is declining. The cumulative failure rate curve increases from the first to fourth quarter and then begins to decrease. Based on the point estimates of the failure rate, it is judged that the failure rate is decreasing with time. Figure 37 plots the failure rate versus time for this equipment.

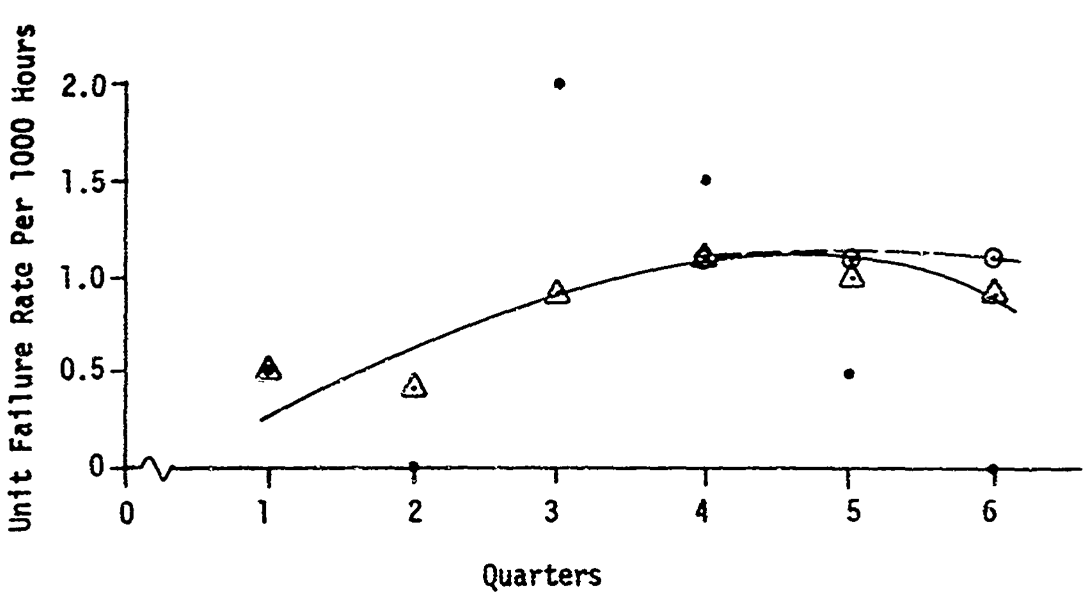

Figure 37. Failure Rate Versus Time - Equipment C-13

Computer Equipment C-14

The point estimates of the failure rate and the cumulative failure rate versus time are both decreasing. The value of chi-square is 9.2, which is not significant. The failure rate for the first three quarters is 3.7/1000 hours and for the last three quarters is 1.6/1000 hours, a decrease of 56.7%, with an overall failure rate of 2.5/1000 hours. The value of chi-square was not significant at the 95% significance level, but it is significant at the 90% level (chi-square at 90%, 4 degrees of freedom = 7.78). Based upon the general shape of the curve and the trend shown by the one year moving average, it is judged that the failure rate of the equipment is decreasing with time. Figure 38 shows the failure rate for the equipment.

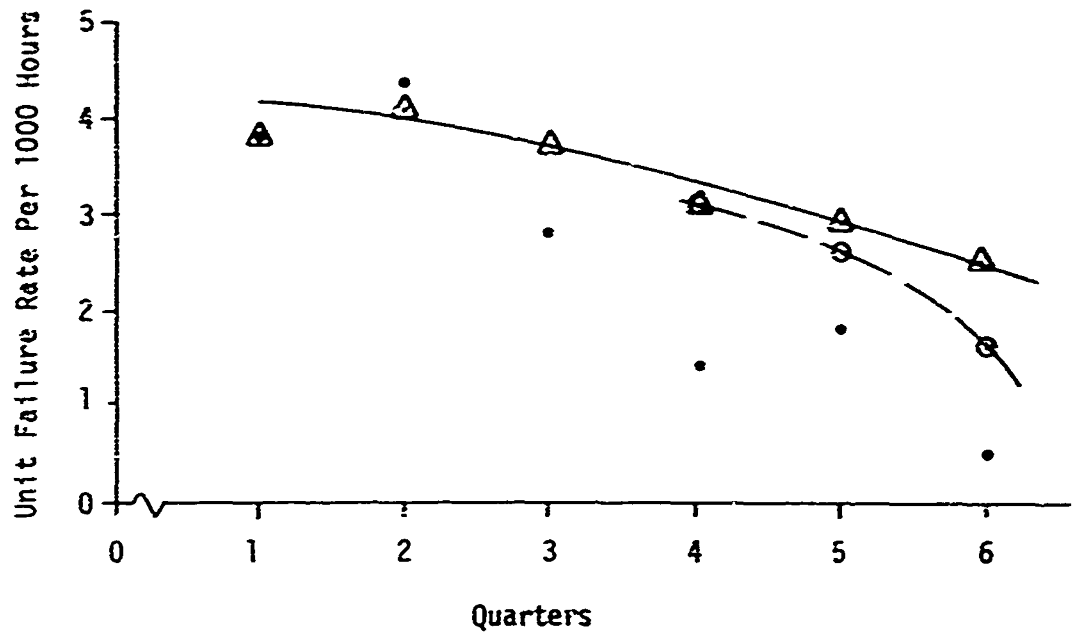

Figure 38. Failure Rate Versus Time - Equipment C-14

Computer Equipment C-15 (Electrical)

The magnetic tape unit failures were divided into electrical component and mechanical component failures. Figure 39 plots the electrical component failures for the equipment. The cumulative failure rate versus time plot shows the failure rate to be increasing. The failure rate for the first three quarters is 6.9/1000 hours and for the last three quarters is 9.7/1000 hours, an increase of 40.5%. This increase is due to the 20 failures reported in the fourth quarter. The value of chi-square is 8.0, which is not significant at the 95% confidence level. It is judged that the failure rate for the electrical components of the equipment is constant with time.

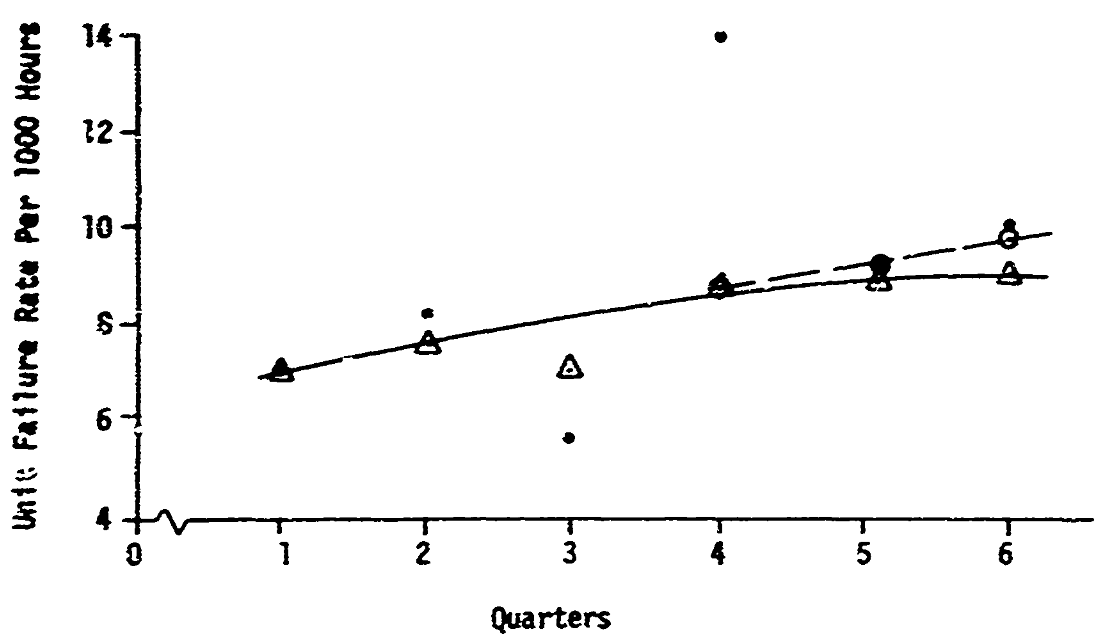

Figure 39. Failure Rate Versus Time - Equipment C-15 (Electrical)

Computer Equipment C-15 (Mechanical)

Figure 40 plots the failure rate versus time for the mechanical components of the magnetic tapes. The point estimates of the failure rates are increasing with time, as is the cumulative failure rate versus time. The point estimate of the failure rate for the first three quarters is 6.4/1000 hours, and the failure rate for the last three quarters is 15.8/1000 hours, an increase of 147%. The value of chi-square is 40.9, highly significant. It is judged that the failure rate of this equipment is increasing with time.

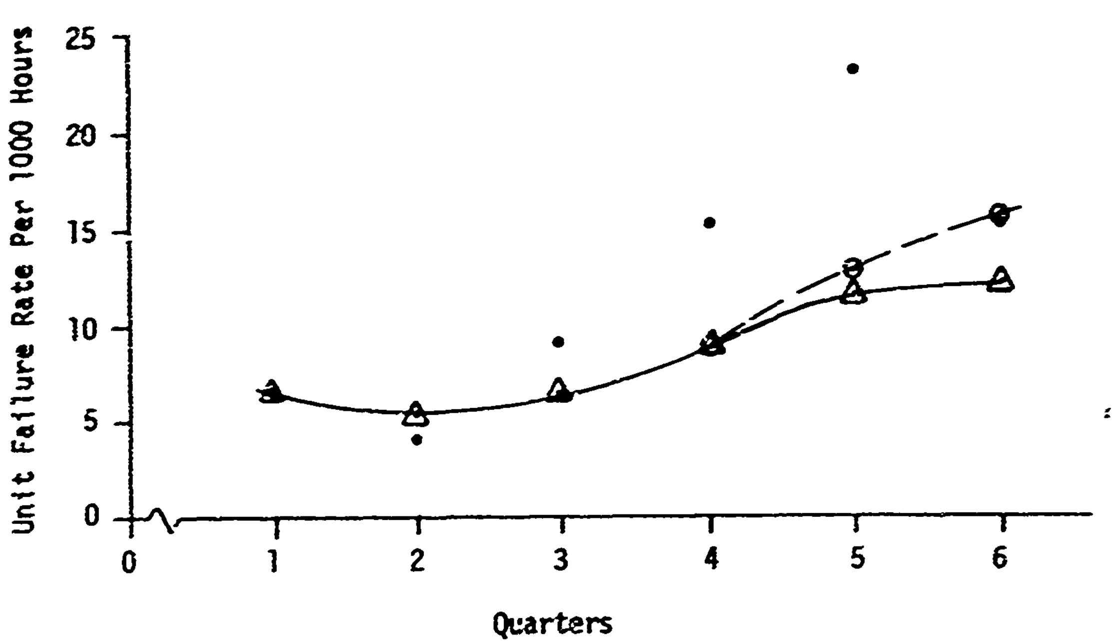

Figure 40. Failure Rate Versus Time - Equipment C-15 (Mechanical)

Display Equipment D-1

The point estimates of the failure rates per quarter are reported as either high (15 failures in the fourth quarter), medium (6-8 failures in the first, second and ninth quarters) and low (0-2 failures in the third, fifth, sixth, seventh and eighth quarters). The result is a decreasing cumulative failure rate vs. time. Chi-square is 15.5, highly significant. The point estimate of the failure rate for the first year is 3.2/1000, for the second year is 0.5/1000, a decrease of 84.4%, with an overall failure rate of 2.0/1000. It is judged the failure rate versus time is decreasing with time. Figure 41 plots the average failure rate for the six consoles.

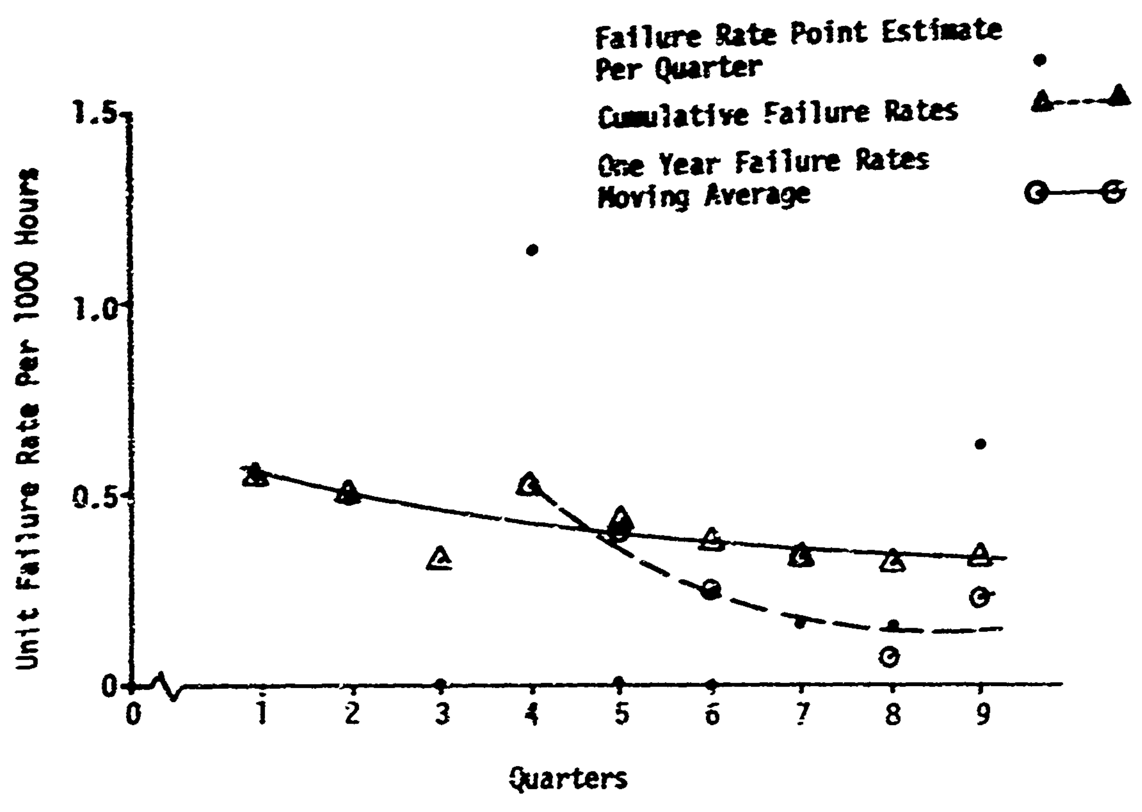

Figure 41. Failure Rate Versus Time - Equipment D-1

Display Equipment D-2

The failure rate per quarter and the cumulative failure rate are decreasing with time. Of the total of 55 failures observed, 46 were recorded in the first year. The failure rate for the first year is 5.3/1000, for the second year is 0.5/1000, a decrease of 91%, with an overall failure rate for 27 months of operation of 2.8/1000. The value of chi-square is 47.0, highly significant. It is judged that the failure rate for this equipment is decreasing with time. Figure 42 plots the average failure rate for the four equipments.

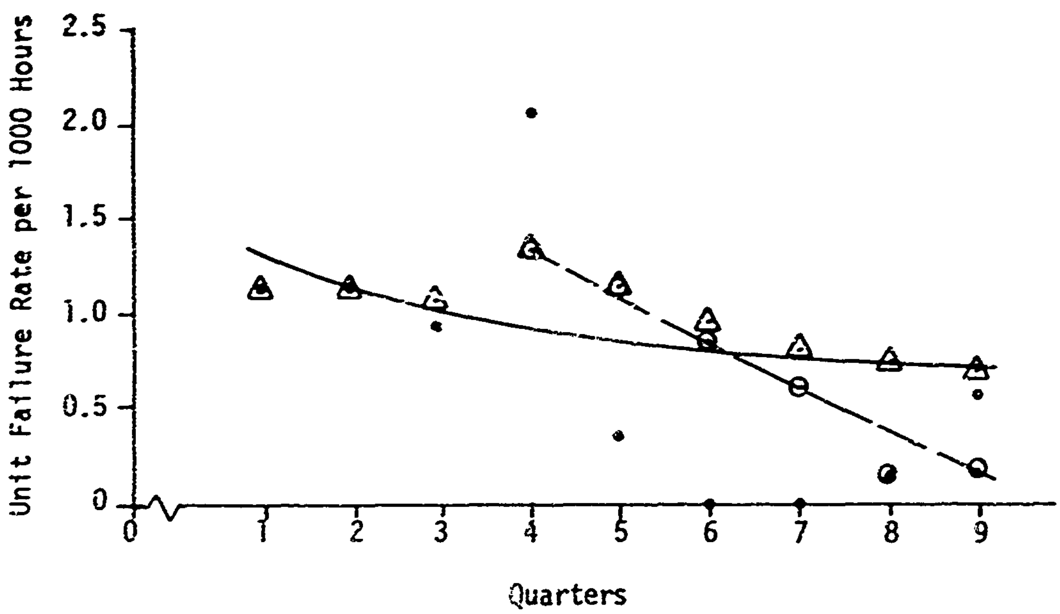

Figure 42. Failure Rate Versus Time - Equipment D-2

Display Equipment D-3

A total of eight quarters of data were accumulated on this equipment. During this time (17,580 calendar hours) a total of 5 failures were recorded, four the first year and one the second year. The failure rate estimate for the first year is 0.46/1000 hours, and 0.12/1000 hours for the second year, a decrease of 73.55%. The chi-square test was not performed since the failure expectancy per cell, when grouped, is less than five. Based on this small number of failures no conclusive judgement can be made, but it appears the failure rate is decreasing with time. However, failures in subsequent quarters would reverse this trend. Figure 43 plots the failure rate versus time for the three equipments.

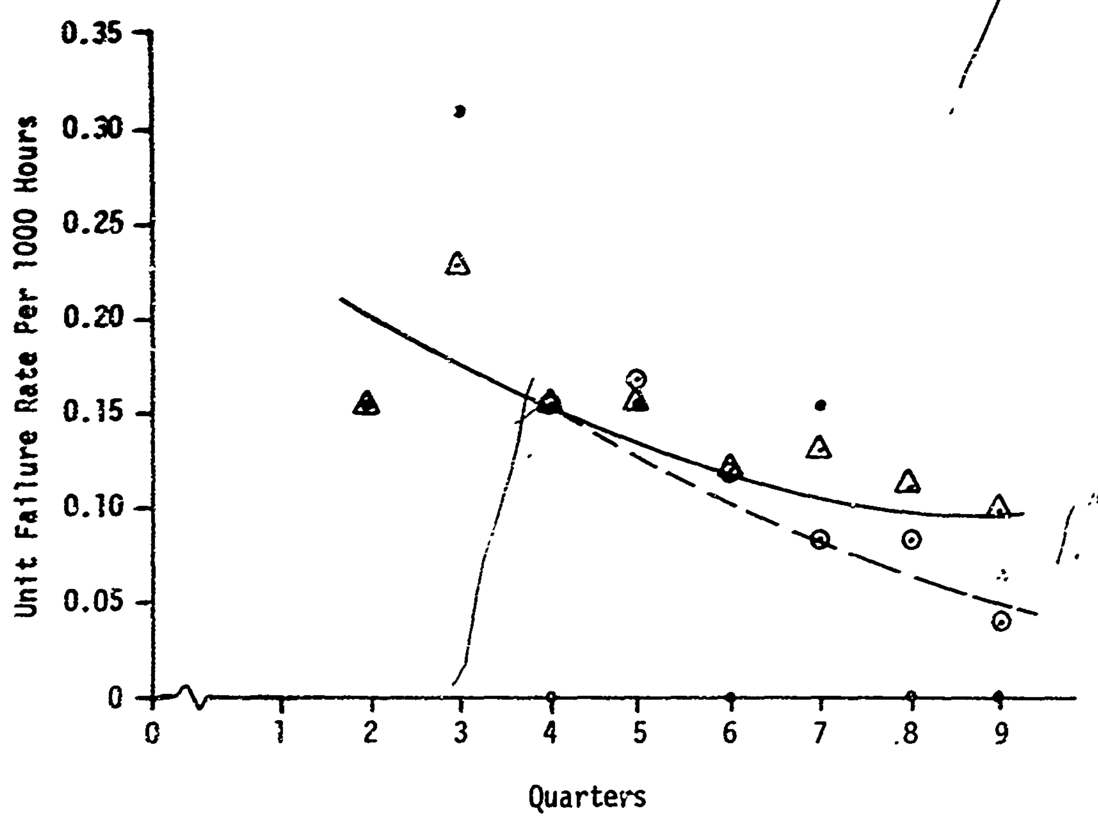

Figure 43. Failure Rate Versus Time - Equipment D-3

Display Equipment D-4

This hardware is similar to equipment D-1. However, the results are not similar. The failure rate estimates per quarter vary from zero failures (second quarter) to six failures (fourth quarter), to one failure (eighth quarter) to 10 failures (ninth quarter). The cumulative failure rate curve rises, then dips and finally rises again. (the curve shown in Figure 44 smooths these variations). The value of chi-square is 6.3, which is significant at the 95% confidence level. Based on the variation of the failure rate estimates per quarter, the only statement that is realistic is that the failure rate is not constant. Figure 44 plots the average failure rate versus time for the four equipments.

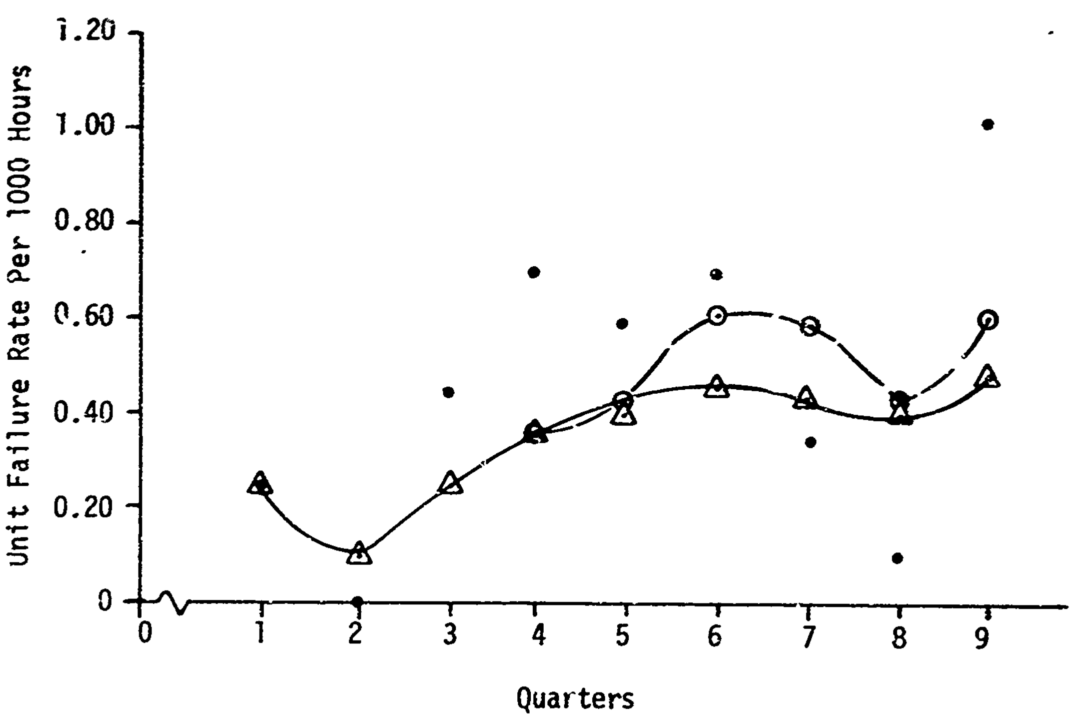

Figure 44. Failure Rate Versus Time - Equipment D-4

Display Equipment D-5

This hardware is similar to equipment D-2. The failure rate point estimates and the cumulative failure rate versus time are decreasing. The point estimate of the failure rate at the end of one year is 6.1/1000 hours, for the second year is 2.3/1000 hours, a decrease of 62.1%, with an overall failure rate for 27 months of operation of 3.8/1000 hours. The value of chi-square is 48.0, highly significant. It is judged that the failure rate for this equipment is decreasing with time. Figure 45 plots the average failure rate versus time for the three equipments.

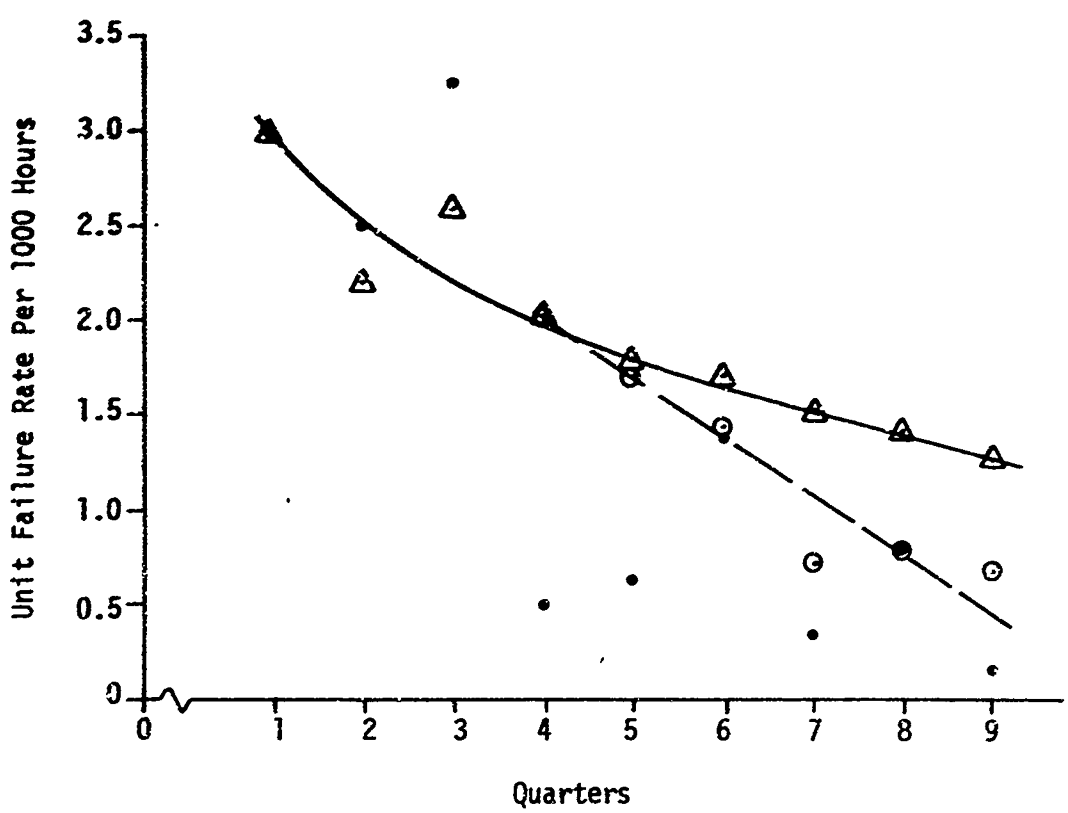

Figure 45. Failure Rate Versus Time - Equipment D-5

Display Equipment D-6

A total of '0,850 calendar hours of operation were recorded and one failure was observed. This failure occurred during the first quarter of reporting on the equipment. Hence, the cumulative failure rate versus time is decreasing. The chi-square test was not performed as insufficient data is available. Based on this small quantity of data, it is not reasonable to judge whether the failure rate is constant or decreasing. Figure 46 plots the average failure rate versus time for the three equipments.

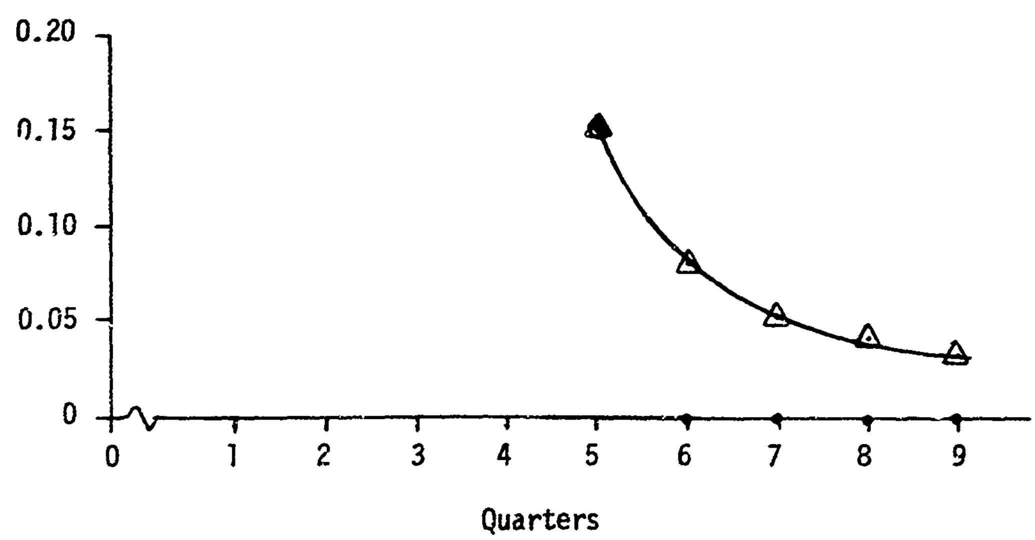

Figure 46. Failure Rate Versus Time - Equipment D-6

Display Equipment D-7

The point estimates of the failure rate per quarter and the cumulative failure rate versus time are both constant. The value of chi-square is 3.1, which is not significant at the 95% significance level. The failure rate estimate for the first three quarters is 3.0/1000 hours, and for the last three quarters is 3.1/1000 hours, an increase of 3.3%. It is concluded that the failure rate of this equipment is constant with time. Figure 47 plots the failure rate versus time for the eleven display consoles.

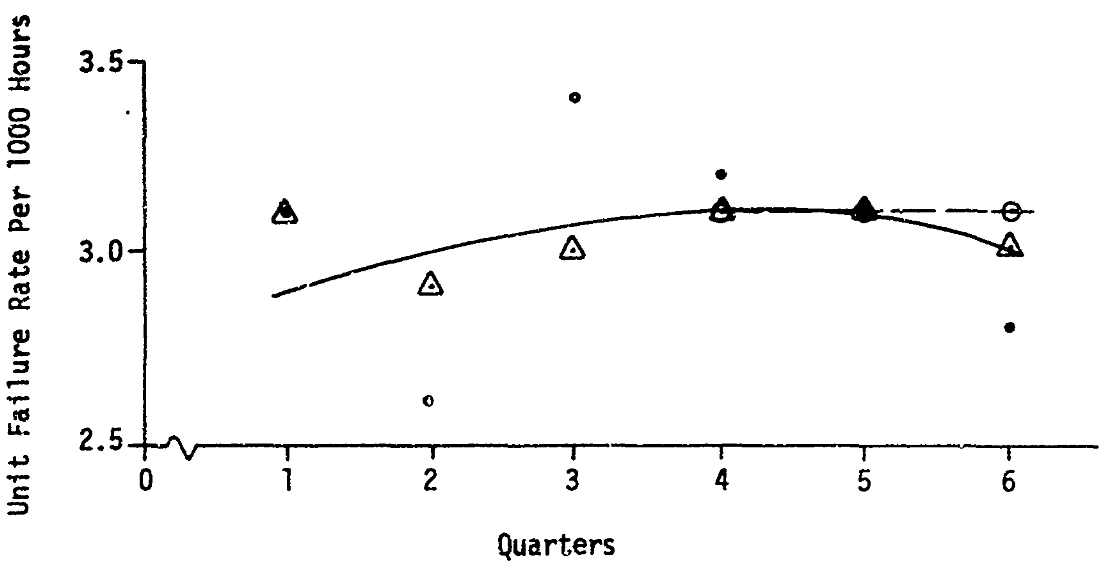

Figure 47. Failure Rate Versus Time - Equipment D-7

Display Equipment D-8

This equipment is a camera display unit for a large dynamic display. A total of 28 failures being recorded. The failure rate per quarter is 26/1000 hours, 21.3/1000 hours, 10.2/1000 hours and 4.7/1000 hours. The value of chi-square is 9.7, which is significant. Although less than 2000 hours of actual operation were accumulated, it is judged that the failure rate for this equipment is decreasing with time. Figure 48 plots the failure rate versus time for this display equipment.

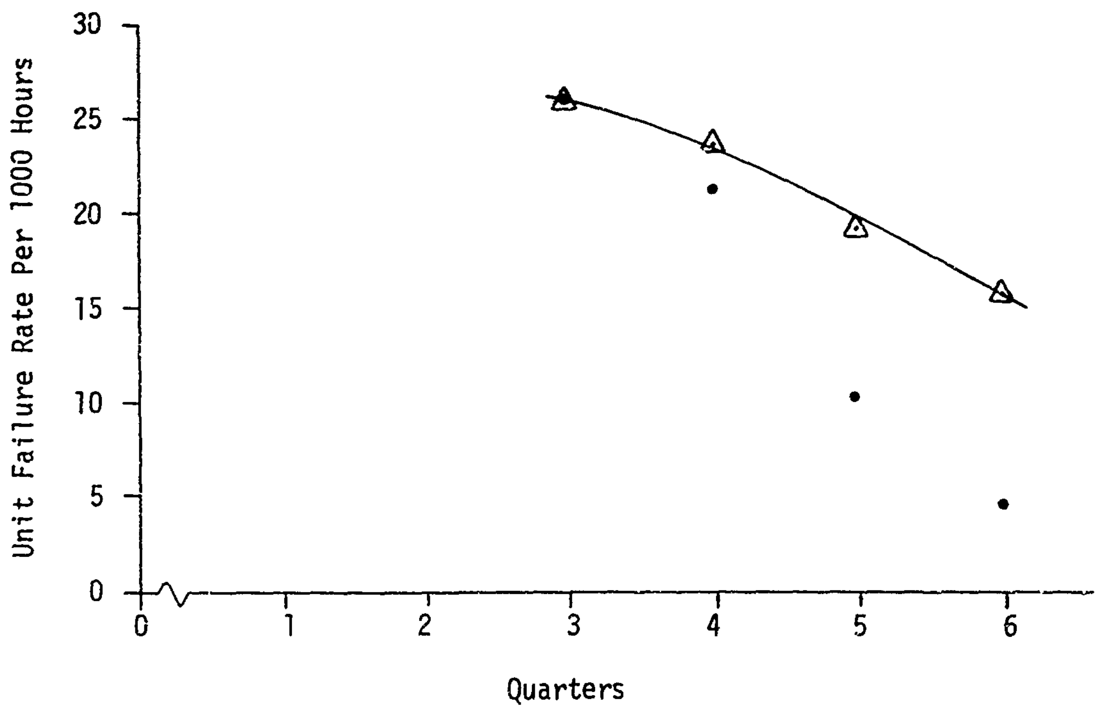

Figure 48. Failure Rate Versus Time - Equipment D-8

Display Equipment D-9

This equipment accumulated a total of nine failures in 3164 hours of operation. The failure rate per quarter is 8.1/1000 hours, 4.4/1000 hours, 3.6/1000 hours, and 0.6/1000 hours. The failure rate trend, both for the point estimates per quarter and the cumulative failure rate versus time are decreasing. Chi-square was not computed since the failure expectancy per cell did not exceed five. Although only 3164 hours of operation were accumulated, it is judged that the failure rate for this equipment is decreasing with time. Figure 49 plots the failure rate versus time for this equipment.

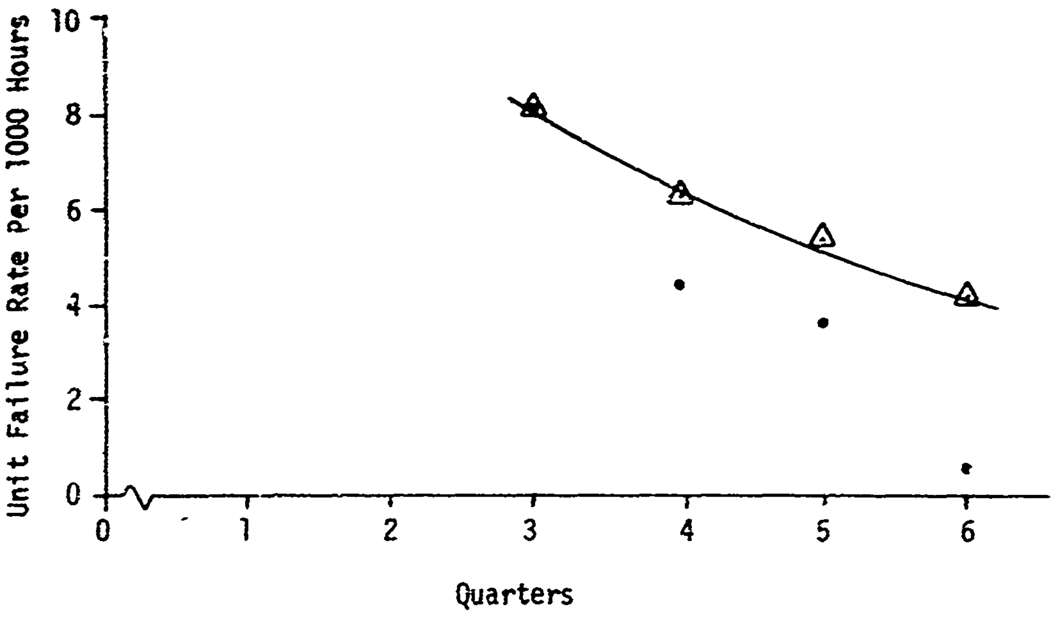

Figure 49. Failure Rate Versus Time - Equipment D-9

(3) Failure Rate vs Time Characteristic of the Equipment

This section presents the results of the examination of the failure rate vs time characteristics of the equipments analyzed in the study. Table LXXV presents a summary of the data presented in 5.C.(2) above. This table shows that 27.1 percent of the equipments have failure rate vs time characteristics which could be considered constant with time, and 72.9 percent of the equipment have failure rate vs time characteristics which are judged not constant with time. Based on the total equipment count, 45.9 percent have failure rate vs time characteristics which are decreasing with time, 10.8 percent have failure rate vs time characteristics that are increasing with time, and 16.2 percent have failure rate vs time characteristics which are oscillating with time or for which sufficient data does not exist to estimate the change in failure rate vs time. These determinations (increasing, decreasing, constant or not determinable from the data) are based upon the chi-square test for goodness of fit for statistical verification, and on engineering judgment.

Table LXXVI shows the change in failure rate, comparing the point estimate of the failure rate for the first year with the point estimate of the failure rate for the second year.[1] If the failure rate for the first year exceeded the failure rate for the second year, the following ratio was established:

$$\frac{\lambda \text{ Second Year} - \lambda \text{ First Year}}{\lambda \text{ Second Year}} \times 100 = -K\%$$

This value (-K%) is the percentage failure rate decrease from the first year to the second year. For example, if λ first year = 10/1000 hours and λ second year = 5/1000 hours,

$$-K = \frac{5-10}{5} \times 100 = -100\%$$

This means a two to one decrease in the failure rate was observed from the first year to the second year.

1. In the situation where only six quarters of data were available, comparisons were made between the first three quarters and the last three quarters.

If the failure rate for the second year exceeded the failure rate for the first year, this second ratio was established.

$$\frac{\lambda \text{ Second Year} - \lambda \text{ First Year}}{\lambda \text{ First Year}} \times 100 = +K\%$$

For example, if λ first year = 5/1000 hours and λ second year = 10/1000 hours,

$$K = \frac{10-5}{5} \times 100 = +100\%$$

This means a two to one increase in the failure rate was observed from the first year to the second year.

Table LXXV presents these percentages for those equipments which have been judged to have constant, decreasing and increasing failure rate vs time characteristics. All equipment included in Table LXXV is included in Table LXXVI except two display equipments (D-8 and D-9) where year to year comparisons were not possible as only one year of data was collected on those two equipments.

Table LXXVI shows that 48.4% of the equipments (14 equipments) experienced failure rate decreases greater than 50%, and 20.7% of the equipments (6) experienced failure rate decreases between zero and 50%. A total of 30.9% of the equipments experienced failure rate increases and of those, 20.7% experienced failure rate increases of up to 50%. In three cases the failure rate increase was greater than 50%. For those equipments where the failure rate is judged to be constant with time, 90% of the equipments experienced failure changes of plus or minus 50%. The one equipment which did not fall into this range (C-10), experienced a large number of failures during the second reporting period which led to a decreasing failure rate vs time characteristic. However, this point was judged to be an anomaly in the data and the failure rate, based on the remaining data, was judged to be constant with time. Further, of the 9 equipments whose failure rates are judged constant (chi-square test and engineering judgment), six equipments experienced increases in failure rates from the first to second year of operation. Hence, it appears that an increase in failure rate can be observed (67% of the cases) and the constant failure rate assumption is not invalidated.

TABLE LXXV EQUIPMENT FAILURE RATE CHARACTERISTICS VS TIME

Equipment Type	Constant Failure Rate	Decreasing Failure Rate	Increasing Failure Rate	Undetermined From Data
Transmitter	0	3	1	0
Receiver	3	3	1	1
Computer	6	5	2	3
Display	1	6	0	2
Totals	10	17	4	6
Percentage of Totals (37 Equipments)	27.1	45.9	10.8	16.2

TABLE LXXVI PERCENTAGE FAILURE RATE CHANGE

	Change In Failure Rate - Second Year to First Year, *K%						
Failure Rate Characteristics	+200% To +51%	+50% To +1%	0% To -50%	-51% To -100%	-101% To -200%	-200% To -500%	>500%(-)
Constant	0	6	3	0	1	0	0
Decreasing	0	0	2	5	5	0	3
Increasing	3	0	1	0	0	0	0
Totals	3	6	6	5	6	0	3
Percentage of Totals (29 Equipments)	10.2	20.7	20.7	17.3	20.7	0.0	10.4

SECTION IX

RECOMMENDATIONS

1. Investigation should be continued of the relationships established in this study between prediction accuracy and the following equipment characteristics:

   o Design approach category

   o Functional category

   o Non-Part related failure

   o Decreasing equipment failure rates

   o Part Technologies

2. Investigation should be continued of the relationship established between program reliability ratings and prediction accuracy.

3. A formal prediction by similarity technique should be developed to include a detailed data baseline representing a complete range of electronic circuits, sub-assemblies and equipment for a full range of ground environments.

4. Specific elements of the RADC Notebook, Volume II stress analysis prediction technique which the study indicates to require revision and further development include:

   o Part quality grade modifiers

   o Semi-conductor failure rate modifiers for digital and analog equipment.

REFERENCES

1. Feduccia, A. J., Klion, J., "How Accurate are Reliability Predictions?" Proceedings of the IEEE Symposium on Reliability, Boston, Massachusetts, 17 January 1968., Unclassified.

2. Feduccia, A. J., "Reliability Prediction - Today and Tomorrow," RADC-SP-66-3, AD 645743, Rome Air Development Center, AFSC, Griffiss Air Force Base, New York, January 1967, Unclassified.

3. MacFarland, W. J., Olson, J. E., Weir, W. T., "Application of Bayes Theorem to RSD Reliability," General Electric Company, 64SD261, 15 July 1964, Unclassified.

4. Babillis, R. A., Crellin, G. L., "Application and Use of Bayesian Statistics on ASPD Reliability Measurement," General Electric Company, 64SD4943, 14 September 1964, Unclassified.

5. Weir, W. T., "On Bayes Theorem and its Application to Reliability Evaluation," General Electric Company, 67SD213, 27 April 1967, Unclassified.

BIBLIOGRAPHY

GROUND ELECTRONICS

Aerojet-General Corporation, Sacramento, California, "A Mathematical Model to Predict Performance Reliability of a Manufactured Component with Multiple Critical Characteristics by Nondestructive Testing," Eberhard H. Baur, U. S. Department of Commerce, Document No. AD 609 964, 4 November 1964.

U. S. Army Electronics Command, Fort Monmouth, New Jersey, "Program to Establish Review Point Criteria for Reliability Monitoring," J. M. Finkelstein and F. A. Famolaro, 31 December 1964.

U. S. Army Missile Command, Redstone Arsenal, Alabama, "Reliability of Integrated Circuits Used in Missile Systems," J. L. Easterday, R. G. Bowman, W. L. Gahm and B. C. Spradlin; Redstone Scientific Information Center, Report No. RSIC-330, October 1964.

Arinc Research Corporation, "System Reliability Prediction by Function, Volume I - Development of Prediction Techniques," AD 416 494, August 1963.

Autonetics, "Predicting System Reliability with Associated Confidence Level from Component Test Data," P. E. Pendleton, July 1962.

Department of Defense, "Reliability Tests, Exponential Distribution, MIL-STD-781A," 10 December 1965.

Department of Defense, "Quality Control and Reliability Handbook H108," 20 April 1960.

Electronic Industries Association, "Relationship Between Estimated, Demonstrated and Actual Field Reliability," October 1966.

Electronic Systems Division, AFSC L. G. Hanscom Field, "Reliability Demonstration: Some Management and Technical Considerations," (ESD-TR-65-304), August 1965.

Electronic Systems Division AFSC, "Reliability Demonstration: Theory: Application and Problems," (ESD-TR-65-198), April 1965.

General Electric Re-Entry Systems Department, "Proceedings of the Second Missile and Space Division Seminar on Bayes' Theorem and its Application to Reliability Measurement," W. T. Weir, 65SD995, December 1965.

General Electric, "On Bayes' Theorem and its Application to Reliability Evaluation," W. T. Weir, 67SD213, April 1967.

Hughes Aircraft Company, Fullerton, California, "Accelerated Reliability Test Methods for Mechanical and Electromechanical Parts," William Yurkowsky, et al, Report No. AD 621 074, U. S. Department of Commerce.

Martin Marietta Corporation, "Reliability Measurement and Demonstration Plan," R. D. Rinehart, January 1963.

RADC, "Reliability Prediction - Today and Tomorrow," Anthony J. Feduccia, (RADC-SP-66-8), January 1967.

RADC, "Study of Comprehensive Failure Theory," (RADC-TDR-64-309), September 1964.

RADC, "Parts Reliability Application Notebook," (RADC-TR-65-528), June 1966.

RADC, "Final Report, System Reliability Prediction by Function," (RADC-TDR-63-146), May 1967.

RADC, "Investigation of Reliability Testing and Prediction Techniques for Integrated Circuits," H. G. Carlson, W. L. Gill, J. E. Hall, et al; RADC-TR-65-463.

RADC, "System Reliability Prediction by Function," (RADC-TDR-63-300 Supplement) Harold Balaban, AD 614227, March 1965.

RADC, "System Reliability Prediction by Function," (RADC-TR-65-27) Robert Tommaney, May 1965.

RADC, "RADC Case Histories in Reliability and Maintainability Demonstration," Anthony Coppola and Anthony D. Pettinato, 1966 R/M Symposium.

RADC, "Reliability Physics Notebook," (RADC-TR-65-330), J. Vaccaro, October 1965.

RADC, "Non-Parametric (Distribution Free) Methods Applied to Reliability Testing of Complex Electronic Equipment," (RADC-TN-20-282), T. J. Burke, D. Goss, L. A. Trivieri, August 1960.

RADC, "Accelerated Testing of High Reliability Parts," (RADC-TR-65-288, Volume I), T. M. Walsh, H. S. Endicott, G. Best, H. McLean, November 1965.

RADC, "Development of Non-Parametric Techniques to the Reliability Testing of Air Force Ground Electronic Equipment," (RADC-TDR-62-499), T. J. Burke, D. Goss, September 1962.

RADC, "Accelerated Testing Technology," (RADC-TR-67-420), W. Yurkowsky, R. E. Schafer, J. M. Finkelstein, November 1967.

RADC, "Mathematical Simulation for Reliability Prediction, (RADC-TR-61-299) I. Bosinoff, et al; October 1961.

RADC, "RADC Reliability Notebook, Volume II," (RADC-TR-67-108), C. Ryerson, S. Webster, F. Albright, September 1967.

The Rand Corporation, "Selected Rand Publications on Reliability," Ernest M. Scheuer and David S. Stoller; Memorandum No. RM-2613-2, May 1966.

BLANK PAGE

APPENDIX I

MULTIPLE LINEAR REGRESSION PROGRAM

PROGRAM: MLR-1

LANGUAGE: FORTRAN IV

MACHINE: IBM 7094

PURPOSE: This program uses the least square technique to estimate the constant (a) and the coefficients (b_I) in the equation;

$$\frac{\lambda_p}{\lambda_o} = a + b_1 K_1 + b_2 K_2 + ---- + b_N K_n$$

In addition, the program generates statistical quantities such as

- Multiple R
- Standard error of estimate
- Analysis of variance table
- Covariance and correlation matrices

ASSUMPTIONS: The least squares method is a valid technique to obtain the best linear fit to a set of data regardless of the nature of data. However, in order to use the statistical quantities mentioned above the following assumptions must be made.

1. The dependent variable λ_p/λ_o can be expressed as follows:

   $\lambda_p/\lambda_o = a + b_1 K_1 + b_2 K_2 + ---- + b_N K_n + \varepsilon$

   where

   ε is a normally distributed random variable with mean = 0.
2. For any set $\{K_1\}$ the variance of λ_p/λ_o is the same.
3. The error of the estimate in any observation is uncorrelated with the error in any other observation.

INPUT: Inputs required to run a problem include:

1. Sample size
2. Number of variables
3. Transgeneration cards (used to transform input variables and create new variables)
4. Sample values
5. F level for inclusion
6. F level for exclusion
7. Tolerance level

OUTPUT: Outputs from the program include:

1. Multiple R
2. Standard error of estimate
3. Analysis of variance table
4. For each independent variable
   a. Regression coefficient
   b. Standard error
5. Means and standard deviation
6. Covariance and correlation matrices
7. List of residuals

APPENDIX II

STRESS ANALYSIS PREDICTION PROGRAMS

PROGRAM PRG I

LANGUAGE FORTRAN IV

MACHINE GE 235

DESCRIPTION

This program is used to generate the prediction variability curves described in the text of the final report. The equation used to compute system failure rate at a fixed environment, part grade, stress and temperature level is:

$$\lambda_S = \sum_{k=1}^{N} Q_k \left\{ \lambda_{j,k} \times \pi_{P_k} \times \pi_{E_{i,l,k}} + \Sigma_{E_{i,l,k}} \right\}$$

Where N = The number of different types of parts in the system.

Q_k = The number of parts of type k.

$\lambda_{j,k}$ = Failure rate of part k at stress, temperature level j (as determined by Volume II).

π_{P_k} = The product of the non-environmental π factors for part k.

i = Part Quality grade indicator, i.e., 1 = upper, 2 = lower

l = Environment indicator, i.e., 1 = spacecraft, 2 = ground, 3 = missile

$\pi_{E_{i,l,k}}$ = The Volume II environmental factor for part k of reliability grade i used in environment l.

$\Sigma_{E_{i,l,k}}$ = The Volume II Σ_E factor of part k of reliability grade i when used in environment l.

INPUT

The permanent data to the program consists of:

1. For each type of component

(a) A table of component failure rates for pre-determined levels of stress and temperature.

(b) The product of the non-environmental π_P factors.

(c) The environmental π_E factor and the Σ_E factor for each of three environments and each of two part grades.

To compute the failure rate of a given system operating in a given environment, the following data is required:

(a) An environment indicator

(b) The quantity of each type of part

OUTPUT

Given this information the program computes a family of system failure rates varying:

(a) Stress

(b) Temperature

(c) Part grade

In addition, the program prints the quantity of each part type along with its percent contribution to the overall system failure rate.

LOAD SHEETS

The input to the program is "free format." That is, the user merely enters a series of numbers separated by commas, where the first number indicates the environment and the remaining number indicates the quantity of each part type.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) TRW, Inc., TRW Systems Group One Space Park Redondo Beach, California 90278	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE

RELIABILITY PREDICTION AND DEMONSTRATION FOR GROUND ELECTRONIC EQUIPMENT

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report - 24 Apr 67 to 24 May 68

5. AUTHOR(S) (First name, middle initial, last name)

Dwight Q. Bellinger
Gerald M. Pittler
Robert E. Shelton, et al

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 1968	218	5

8a. CONTRACT OR GRANT NO. F30602-67-C-0247 b. PROJECT NO. 5519 c. 551902 d.	9a. ORIGINATOR'S REPORT NUMBER(S) 68.6373.3-146 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) RADC-TR-68-280

10. DISTRIBUTION STATEMENT

This document is subject to special export controls and each transmittal to foreign governments, foreign nationals, or representatives thereto may be made only with prior approval of RADC (EMERR), GAFB, NY 13440

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
RADC PROJECT ENGINEER: Anthony J. Feduccia (EMERR) AC 315 330-4064	Rome Air Development Center (EMERR) Griffiss Air Force Base, New York 13440

13. ABSTRACT

This study evaluates the accuracy of pre-design and stress analysis reliability prediction techniques, including the RADC Reliability Notebook, Volume II, stress analysis method, when applied to a variety of ground electronic equipment. Sources of prediction inaccuracy are investigated and identified. Program-related factors significant to the achievement of reliability and prediction accuracy are identified and a quantitive rating system is established and related to system prediction accuracy.

New and improved pre-design and stress analysis reliability prediction methods are developed and tested. Equipment design approach categories having different prediction accuracy characteristics are identified with statistical distributions of prediction accuracy ratios. Degradation analysis processes and techniques are identified, evaluated, and presented with a recommended approach for their application. Reliability demonstration methods, including the Bayesian approach, are evaluated. A recommended reliability demonstration approach for ground electronic equipment is developed. A new base for integrated circuit failure rates is also provided.

DD FORM 1 NOV 65 1473

UNCLASSIFIED

Security Classification

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Reliability Prediction Ground Electronics						

UNCLASSIFIED

Security Classification