AD-A163 900

RADC-TR-85-194
Interim Report
October 1985

(12)

# RADC NONELECTRONIC RELIABILITY NOTEBOOK

DTIC
ELECTE
FEB 1 1 1986
S
D
D

Hughes Aircraft Company

Ray E. Schafer, John E. [illegible], Jack M. Finkelstein, Mal Yerasi/
Hughes Aircraft Company, and Donald W. Fulton/Reliability
Analysis Center (IITRI)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

DISTRIBUTION STATEMENT A
[illegible] public release;
[illegible]

COPY

ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
[illegible] Air Force Base, NY 13441-5700

Best Available Copy

This report has been reviewed by the RADC Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public, including foreign nations.

RADC-TR-85-194 has been reviewed and is approved for publication.

APPROVED: James A. Collins

JAMES A. COLLINS
Project Engineer

APPROVED: W. S. Tuthill

W. S. TUTHILL, Colonel, USAF
Chief, Reliability & Compatibility Division

FOR THE COMMANDER: John A. Ritz

JOHN A. RITZ
Acting Chief, Plans Office

If your address has changed or if you wish to be removed from the RADC mailing list, or if the addressee is no longer employed by your organization, please notify RADC (RBES) Griffiss AFB NY 13441-5700. This will assist us in maintaining a current mailing list.

Do not return copies of this report unless contractual obligations or notices on a specific document requires that it be returned.

Best Available Copy

# REPORT DOCUMENTATION PAGE

| | |
|---|---|
| 1a. REPORT SECURITY CLASSIFICATION<br>UNCLASSIFIED | 1b. RESTRICTIVE MARKINGS<br>N/A |
| 2a. SECURITY CLASSIFICATION AUTHORITY<br>N/A | 3. DISTRIBUTION / AVAILABILITY OF REPORT<br>Approved for public release; distribution unlimited. |
| 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE<br>N/A | |
| 4. PERFORMING ORGANIZATION REPORT NUMBER(S)<br>FR84-16-446 REV B | 5. MONITORING ORGANIZATION REPORT NUMBER(S)<br>RADC-TR-85-194 |
| 6a. NAME OF PERFORMING ORGANIZATION<br>Hughes Aircraft Company<br>Ground Systems Group<br>6b. OFFICE SYMBOL (If applicable) | 7a. NAME OF MONITORING ORGANIZATION<br>Rome Air Development Center (RBES) |
| 6c. ADDRESS (City, State, and ZIP Code)<br>PO Box 3310<br>Fullerton CA 92634 | 7b. ADDRESS (City, State, and ZIP Code)<br>Griffiss AFB NY 13441-5700 |
| 8a. NAME OF FUNDING / SPONSORING ORGANIZATION<br>Rome Air Development Center<br>8b. OFFICE SYMBOL (If applicable)<br>RBES | 9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER<br>F30602-82-C-0127 |
| 8c. ADDRESS (City, State, and ZIP Code)<br>Griffiss AFB NY 13441-5700 | 10. SOURCE OF FUNDING NUMBERS<br>PROGRAM ELEMENT NO. 62702F; PROJECT NO. 2338; TASK NO. 02; WORK UNIT ACCESSION NO. 76 |

11. TITLE (Include Security Classification)
RADC NONELECTRONIC RELIABILITY NOTEBOOK

12. PERSONAL AUTHOR(S) Ray E. Schafer, John E. Angus, Jack M. Finkelstein, Mal Yerasi/Hughes Aircraft Co.; Donald W. Fulton/Reliability Analysis Center (IITRI)

| 13a. TYPE OF REPORT | 13b. TIME COVERED | 14. DATE OF REPORT (Year, Month, Day) | 15. PAGE COUNT |
|---|---|---|---|
| Interim | FROM Jul 82 TO Aug 85 | October 1985 | 588 |

16. SUPPLEMENTARY NOTATION
N/A

| 17. COSATI CODES | | |
|---|---|---|
| FIELD | GROUP | SUB-GROUP |
| 14 | 04 | |
| 09 | 01 | |

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Mechanical Reliability; Statistical Methods; ~~MTBF~~ Failure Rate, Reliability Demonstration, Nonelectronic Reliability, Reliability Prediction, Reliability Specification, Components

19. ABSTRACT (Continue on reverse if necessary and identify by block number)
The objective of this Notebook was the collection, analysis, and presentation of nonelectronic component failure data and the presentation of analytical methods that form the state-of-the-art in nonelectronic reliability analysis. This report replaces the former Nonelectronic Reliability Notebook (RADC-TR-75-22). Topics include:

This notebook is divided into six sections: Introduction, Applicable Statistical Methods for Nonelectronic Reliability; Reliability Specifications; Special Application Methods for Reliability Prediction; Part Failure Characteristics; and Reliability Demonstration Tests. [illegible] between failures;

| | |
|---|---|
| 20. DISTRIBUTION / AVAILABILITY OF ABSTRACT<br>☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS | 21. ABSTRACT SECURITY CLASSIFICATION<br>UNCLASSIFIED |
| 22a. NAME OF RESPONSIBLE INDIVIDUAL<br>JAMES A. COLLINS | 22b. TELEPHONE (Include Area Code)<br>(315) 330-2101<br>22c. OFFICE SYMBOL<br>RADC (RBES) |

DD FORM 1473, 84 MAR 83 APR edition may be used until exhausted. All other editions are obsolete.



Best Available Copy

## PREFACE

This Notebook is the result of research conducted at Hughes Aircraft Company, Ground Systems Group, Fullerton, California, for Rome Air Development Center under contract number F30602-82-C-0127, covering the period July 1982 through August 1985. The RADC project engineer for this effort was Mr. James A. Collins (RADC/RBES). This research was undertaken within the Systems Projects Section of the Systems Effectiveness Department of Hughes under the direction and supervision of Dr. Ray E. Schafer until his untimely death in September 1983. At that time, direction of the research was taken over by Dr. John E. Angus with support and assistance from Mr. Tom F. Pliska, Systems Effectiveness Department Assistant Manager, and Mr. Larry E. James, Systems Projects Section Head.

Several individuals made significant technical contributions to this research. Dr. Mal Yerasi, working closely with Dr. Schafer, collected and compiled the entire database of nonelectronic part failure data. The statistical analyses and report generation for the Part Failure Characteristics Section of the Notebook was undertaken by Dr. Angus with extensive computer programming support from Mr. Shick P. Jue. Under a subcontract, Mr. Donald W. Fulton of RAC/IITRI (and past Rome project engineer on a previous edition of this Notebook) wrote the section on Special Application Methods for Reliability Prediction. Finally, the sections on Reliability Demonstration and Specification were written by Dr. Angus with assistance from Mr. Jack M. Finkelstein who also reviewed the entire Notebook. The Hughes report number for this document is FR84-16-446 Rev B.

This document replaces RADC-TR-75-22, Nonelectronic Reliability Notebook. Although RADC's interest in nonelectronic/mechanical components is limited to those used in electronic systems, this revised Notebook contains failure data and reliability methods pertaining to a variety of applications.


| Accesion For | |
|---|---|
| NTIS CRA&I | ☑ |
| DTIC TAB | ☐ |
| Unannounced | ☐ |
| Justification | |
| By | |
| Distribution / | |
| Availability Codes | |
| Dist | Avail and / or Special |
| A-1 | |

TABLE OF CONTENTS


| | Page |
|---|---|
| SECTION 1.0 - INTRODUCTION | 1-1 |
| SECTION 2.0 - APPLICABLE STATISTICAL METHODS FOR NONELECTRONIC RELIABILITY | 2-1 |
| 2.1 Statistical Failure Models | 2-1 |
| 2.1.1 The Hazard Rate Concept | 2-1 |
| 2.1.2 The Poisson Process and the Exponential Distribution | 2-2 |
| 2.1.2.1 The Poisson Process | 2-3 |
| 2.1.2.2 The Exponential Distribution | 2-3 |
| 2.1.3 The Weibull Distribution | 2-4 |
| 2.1.4 The Normal Distribution | 2-5 |
| 2.1.5 The Log-Normal Distribution | 2-6 |
| 2.1.6 Extreme Value Distribution | 2-6 |
| 2.1.7 Summary | 2-7 |
| 2.2 Design of Statistical Experiments | 2-8 |
| 2.2.1 Introduction | 2-8 |
| 2.2.2 Determination of Stresses and Stress Levels | 2-9 |
| 2.2.3 Statistical and Physical Test Design | 2-10 |
| 2.3 Fitting Failure Distributions | 2-13 |
| 2.3.1 Introduction | 2-13 |
| 2.3.2 Small Sample Sizes (Kolmogorov-Smirnov) | 2-13 |
| 2.3.3 Large Sample Sizes ($\chi^2$ Test) | 2-16 |
| 2.4 Estimation Methods | 2-21 |
| 2.4.1 The Exponential Distribution | 2-21 |
| 2.4.1.1 Analytical Point Estimation | 2-21 |
| 2.4.1.2 Interval Estimation | 2-22 |
| 2.4.1.2.1 Two-Sided Confidence Limits | 2-22 |
| 2.4.1.2.2 One-Sided Confidence Limits | 2-23 |
| 2.4.2 The Weibull Distribution | 2-25 |
| 2.4.2.1 Analytical Point Estimation | 2-25 |
| 2.4.2.1.1 The Method of Least Squares | 2-25 |
| 2.4.2.1.2 Maximum Likelihood Method | 2-27 |
| 2.4.2.2 Graphical Point Estimation | 2-29 |
| 2.4.2.3 Interval Estimation | 2-33 |
| 2.4.2.3.1 Weibull Parameters | 2-33 |
| 2.4.2.3.2 Reliability. | 2-34 |
| 2.4.2.3.2.1 Uncensored Samples | 2-34 |
| 2.4.2.3.2 Reliability | 2-38 |
| 2.4.2.3.2.2 Censored Samples | 2-38 |
| 2.4.3 The Normal Distribution | 2-41 |
| 2.4.3.1 Analytical Point Estimation | 2-41 |
| 2.4.3.2 Graphical Point Estimation | 2-43 |
| 2.4.3.3 Interval Estimation | 2-45 |
| 2.4.3.3.1 Small Sample Sizes ($\sigma$ unknown) | 2-45 |
| 2.4.3.3.2 Large Sample Sizes ($\sigma$ unknown) | 2-46 |
| 2.4.4 The Log-Normal Distribution | 2-48 |

TABLE OF CONTENTS (Continued)


2.4.5 The Extreme Value Distribution . . . . . 2-49
2.4.5.1 Analytical Point Estimation . . . . . 2-49
2.4.5.2 Graphical Point Estimation . . . . . 2-51
2.4.5.3 Interval Estimation . . . . . 2-53
2.4.6 Test for Increasing Failure Rate . . . . . 2-55
2.4.6.1 Distribution Free Test . . . . . 2-55
2.4.6.2 Test Based on Probability Limits and Weibull Assumptions . . 2-58
2.4.7 Outlier Tests . . . . . 2-59
2.4.7.1 Early Failures . . . . . 2-59
2.4.7.2 Late Failures . . . . . 2-61
SECTION 3.0 - RELIABILITY SPECIFICATIONS
3.1 Introduction . . . . . 3-1
3.2 Reliability Specification for the Exponential Distribution. . . 3-2
3.3 Reliability Specification for the Weibull Distribution. . . . . 3-3
3.4 Reliability Specification Without Respect to a Particular Underlying Life Distribution . . . . . 3-4
SECTION 4.0 - SPECIAL APPLICATION METHODS FOR RELIABILITY PREDICTION . . 4-1
4.1 Introduction . . . . . 4-1
4.2 Background for Reliability Prediction Model Development . . . . 4-1
4.3 Graphical Approaches to Reliability Prediction . . . . . 4-3
4.4 General Theory of Interference . . . . . 4-4
4.5 Applications of Interference Theory to Reliability Prediction Methodology . . . . . 4-10
4.5.1 Purpose . . . . . 4-10
4.5.2 Description of Method . . . . . 4-10
4.6 Application of Interference Theory for Normally Distributed Strength and Normally Distributed Stress . . . . . 4-13
4.6.1 Purpose of the Method . . . . . 4-13
4.6.2 Description of the Method . . . . . 4-13
4.6.3 Examples . . . . . 4-15
4.6.3.1 Shaft and Bushing Reliability . . . . . 4-15
4.6.3.2 Lifting Eye Reliability . . . . . 4-16

TABLE OF CONTENTS (Continued)


4.6.3.3 Diaphragm Reliability . . . . . 4-17
4.7 Application of the Average Failure Rate Method for Grease Lubricated Rolling Element Bearings . . . . . 4-18
4.7.1 Purpose of Method . . . . . 4-18
4.7.2 Description of the Method . . . . . 4-18
4.7.3 Examples . . . . . 4-20
4.8 Reliability Prediction Method - Rolling Bearings Oil Lubricated . . . . . 4-21
4.8.1 Purpose of the Method . . . . . 4-21
4.8.2 Description of the Method . . . . . 4-21
4.9 Reliability Prediction Method - Spur Gear Systems. . . . . 4-23
4.9.1 Purpose of the Method . . . . . 4-24
4.9.2 Description of the Method and Example . . . . . 4-24
4.10 Reliability Prediction Method - Minimum Information . . . . . 4-37
4.10.1 Examples . . . . . 4-37
SECTION 5.0 - PART FAILURE CHARACTERISTICS . . . . . 5-1
5.1 Introduction . . . . . 5-1
5.1.1 Use of Constant Failure Rate Analyses . . . . . 5-2
5.1.2 Use of Weibull Analyses . . . . . 5-2
5.2 Constant Failure Rate Analysis . . . . . 5-4
5.2.1 Index to Section 5.2 . . . . . 5-4
5.3 Weibull Analyses - Project 1 . . . . . 5-202
5.3.1 Weibull Analyses Summaries . . . . . 5-203
5.4 Weibull Analyses - Project 2 . . . . . 5-232
5.4.1 Weibull Analyses Summaries . . . . . 5-232
5.5 Weibull Analyses - Project 3 . . . . . 5-270
5.5.1 Weibull Analyses Summaries . . . . . 5-270
5.6 Part Malfunction Data . . . . . 5-284
SECTION 6.0 - RELIABILITY DEMONSTRATION TESTS . . . . . 6-1
6.1 Introduction. . . . . 6-1

6.1.1 Statistical Characteristics of a Reliability Demonstration Test . . . . . 6-1
6.1.2 Cost of Demonstration . . . . . 6-2
6.1.3 Sample Size Limitations . . . . . 6-2
6.1.4 Summary . . . . . 6-3
6.2 Attributes Demonstration Tests . . . . . 6-3
6.2.1 Attributes Plans for Small Lots . . . . . 6-3
6.2.2 Attributes Plans for Large Lots . . . . . 6-6
6.2.3 Attributes Demonstration Test Plans for Large Lots (The Poisson Approximation Method) . . . . . 6-9
6.2.4 Attributes Sampling Using MIL-STD-105D . . . . . 6-11
6.2.5 Sequential Binomial Test Plans . . . . . 6-13
6.3 Variables Demonstration Tests . . . . . 6-15
6.3.1 Introduction . . . . . 6-15
6.3.2 Time Truncated Demonstration Test Plans . . . . . 6-16
6.3.2.1 Nonparametric Reliability Demonstration Test . . . . . 6-16
APPENDIX I - REFERENCES AND BIBLIOGRAPHY . . . . . I-1
APPENDIX II - STATISTICAL TABLES . . . . . II-1

LIST OF ILLUSTRATIONS


| Figure | | Page |
|---|---|---|
| 2.4.2.2 | Graphical Point Estimation for the Weibull Distribution | 2-32 |
| 2.4.2.3.2.1 | Graphical Method for Interval Estimation of Reliability for the Weibull Distribution | 2-35 |
| 2.4.3.2 | Graphical Point Estimation for the Normal Distribution | 2-44 |
| 2.4.5 | Plot of Fitted Straight Line for Use With the Extreme Value Distribution | 2-54 |
| 4.4-1 | Illustration of the Concept of Interference | 4-7 |
| 4.4-2(A) | Time Varying Strength Density | 4-8 |
| 4.4-2(B) | Time Varying Strength Density | 4-9 |
| 4.6.2-1 | Normalized Density Function for Excess Strength Overload | 4-14 |
| 4.9-1 | Planetary Gear Reduction | 4-25 |
| 4.9-2 | Planet Gear Forces | 4-28 |
| 6.3.2.1A | Operating Characteristic Curve for Test Plan 1A | 6-20 |
| 6.3.2.2A | Operating Characteristic Curve for Test Plan 2A | 6-20 |
| 6.3.2.3A | Operating Characteristic Curve for Test Plan 3A | 6-21 |
| 6.3.2.4A | Operating Characteristic Curve for Test Plan 4A | 6-21 |
| 6.3.2.5A | Operating Characteristic Curve for Test Plan 5A | 6-22 |
| 6.3.2.6A | Operating Characteristic Curve for Test Plan 6A | 6-22 |
| 6.3.2.7A | Operating Characteristic Curve for Test Plan 7A | 6-23 |
| 6.3.2.8A | Operating Characteristic Curve for Test Plan 8A | 6-23 |
| 6.3.2.9A | Operating Characteristic Curve for Test Plan 9A | 6-24 |
| 6.3.2.10A | Operating Characteristic Curve for Test Plan 10A | 6-24 |
| 6.3.2.11A | Operating Characteristic Curve for Test Plan 11A | 6-25 |
| 6.3.2.12A | Operating Characteristic Curve for Test Plan 12A | 6-25 |

LIST OF ILLUSTRATIONS (Continued)


| Figure | | Page |
|---|---|---|
| 6.3.2.13A | Operating Characteristic Curve for Test Plan 13A | 6-26 |
| 6.3.2.1B | Operating Characteristic Curve for Test Plan 1B | 6-27 |
| 6.3.2.2B | Operating Characteristic Curve for Test Plan 2B | 6-27 |
| 6.3.2.3B | Operating Characteristic Curve for Test Plan 3B | 6-28 |
| 6.3.2.4B | Operating Characteristic Curve for Test Plan 4B | 6-28 |
| 6.3.2.5B | Operating Characteristic Curve for Test Plan 5B | 6-29 |
| 6.3.2.6B | Operating Characteristic Curve for Test Plan 6B | 6-29 |
| 6.3.2.7B | Operating Characteristic Curve for Test Plan 7B | 6-30 |
| 6.3.2.8B | Operating Characteristic Curve for Test Plan 8B | 6-30 |
| 6.3.2.9B | Operating Characteristic Curve for Test Plan 9B | 6-31 |
| 6.3.2.10B | Operating Characteristic Curve for Test Plan 10B | 6-31 |
| 6.3.2.11B | Operating Characteristic Curve for Test Plan 11B | 6-32 |
| 6.3.2.12B | Operating Characteristic Curve for Test Plan 12B | 6-32 |
| 6.3.2.13B | Operating Characteristic Curve for Test Plan 13B | 6-33 |

## LIST OF TABLES


| Table | | Page |
|---|---|---|
| 1.1 | Beginning Page Index for Part Class Location in Section 5 | 1-3 |
| 4.5.1 | Parameters of Tabulated Probability Distributions as Used in RALC-TR-68-403 (Lipson, et.al, 1968) | 4-11 |
| 4.7.1 | Quality Factors | 4-19 |
| 4.7.2 | $K_g$ Grease Constant | 4-19 |
| 4.8-1 | Life Adjustment Factor of Reliability, $a_1$, (From Source 1) | 4-23 |
| 5.6.1 | Part Malfunction Data | 5-285 |
| 6.3.2.1 | Nonparametric Reliability Demonstration Test Plans | 6-19 |

# 1.0 INTRODUCTION

The purpose of the RADC Nonelectronic Reliability Notebook is twofold. First, it serves as a reference document for the reliability characteristics of the most commonly used, nonelectronic parts based on industry supplied failure data; and secondly, to present the most useful reliability and life data analysis methods applicable to nonelectronic parts. These analysis methods are presented without regard to rigorous mathematical derivation and with an emphasis on making them accessible to reliability practitioners possessing moderate statistical/mathematical training.

The suggested use of this Notebook is described by the table below where each reliability task is associated with a section of this Notebook. The use of section 5.0, Part Failure Characteristics, requires some elaboration. In the majority of cases, the nonelectronic parts covered in this Notebook are adequately described in the reliability sense by a constant failure rate. Thus, mainly, section 5.0 will be used to look up a failure rate for a particular device. Sometimes, however, either the part will exhibit nonconstant failure rate, or the analyst will simply wish to use a Weibull analysis of the part's reliability characteristics. For these purposes, section 5.0 also presents Weibull analyses for selected nonelectronic parts based on the availability of actual failure times in the database. These Weibull analyses are based on data from three different projects, two in the ground mobile application environment, and one in the ground fixed environment. In many cases, the same part type occurs in more than one Weibull analysis. In these cases, if it is desired to use the Weibull analysis for modeling, the analysis in which the most failures were recorded should be used. In some instances, the estimated parameters in the Weibull analyses of the same part type will differ greatly. These differences are explained by differences between project applications (even though the projects have the same use environment) of the parts, and differences between parts of the same name and type due to lack of data which would better characterize the parts (i.e., two parts of the same generic part name and type can be, nevertheless, different). As the results of these analyses indicate the vast majority of the time, the constant failure rate tables will be adequate. In spite of this result, the Weibull analyses have been included for reference.

| Reliability Task | Nonelectronic Reliability Notebook Sections(s) |
|---|---|
| Specification | Section 3.0 |
| Prediction | Section 5.0, if part is represented there;<br>Section 2.0, if failure data is available;<br>Section 4.0, if no failure data is available. |
| Demonstration | Section 6.0 |

Section 2.0 of this Notebook describes the selection and application of several failure distributions which are used for describing the life characteristics of nonelectronic parts, given part failure data. The remainder of this section is devoted to methods of operating on failure data once a failure distribution has been found to, or is assumed to, describe nonelectronic part failure times. The general format used includes methods of point and interval estimation for the reliability parameters of the proven or assumed failure distribution based on empirical data.

Section 3.0 of this notebook presents guidelines and criteria for specifying reliability for nonelectronic parts and equipments. Specifications appropriate for the nonparametric reliability demonstration test plans presented in section 6.0 are included.

The next section of the notebook, section 4.0, addresses reliability prediction, and is intended to supplement section 5.0. It gives rules for using specific prediction models which are known to have application to certain nonelectronic parts. This section is oriented towards strength of alloys, grease and oil lubricated rolling bearings, and spur gear systems. It explains and gives examples on the use of stress-strength interference theory. A new subsection addressing reliability prediction based on minimal vendor information and no life data is also included.

Section 5.0 is Part Failure Characteristics. This section describes the results of the statistical analyses of failure data from more than 250 distinct nonelectronic parts collected from recent commercial and military projects. This data was collected in-house (from operations and maintenance reports) and from industry wide sources, all of whom are aware of the importance of this Notebook. Tables, alphabetized by part class/part type, are presented for easy reference to part failure rates assuming that the part lives are exponentially distributed (as in previous editions of this notebook, the majority of data available included total operating time, and total number of failures only). For parts for which the actual life times for each part under test were included in the database, further tables are presented which describe the results of testing the fit of the exponential and Weibull distributions. A quick reference index for locating the beginning page of the Tables for each part class is presented in Table 1.1 in this introduction. The results show that the exponential distribution is adequate for a large majority of the nonelectronic parts for which its fit was tested. A small number of nonelectronic parts exhibited life times which were better described by the Weibull distribution. Recommendations for approximating these cases by the exponential distribution are presented. Part malfunction data which was available when the part failure data was collected is presented in Table 5.6.1. See the contract Final Technical Report describing the study and investigation for more details on data and data analysis (RADC-TR-85-66 dated April 1985, AD A157242).

Section 6.0 presents reliabilty demonstration test plans applicable to nonelectronic parts. Both attributes and variables types of demonstration plans are described. Attributes plans are used to demonstate whether

or not a finite population of items possesses an acceptable fraction of items which have a particular attribute, while variables plans are used to demonstrate whether or not a particular type of item possesses an acceptable level of some pre-specified reliability quantity. Whenever the exponential distribution is judged appropriate for the life distribution of an item of interest, test plans are documented in Mil-STD-781C and Mil-HDBK-108 and are not reproduced in this section. When the exponential distribution is not appropriate, the variables test plans of this section are nonparametric (i.e., not dependent on the form of the underlying life distribution) and based on one dimensional reliability specifications. Because of this, these test plans are easy to design and use, and operating characteristic curves can be developed and used.

TABLE 1.1

BEGINNING PAGE INDEX FOR PART CLASS LOCATION IN SECTION 5


| PART CLASS | PAGE NO. EXPONENTIAL DIST | *PAGE NO. WEIBULL DIST |
|---|---|---|
| ACCELEROMETER | 5-10 | 5-206, 235 |
| ACCUMULATOR | 5-12 | |
| ACTUATOR | 5-13 | 5-206, 235 |
| AIR CONDITIONER | 5-18 | |
| ANTENNA | 5-19 | 5-236 |
| AXLE | 5-22 | 5-207, 236 |
| AZIMUTH ENCODER | 5-23 | 5-207, 237 |
| BATTERY | 5-24 | 5-208, 237 |
| BEARING | 5-25 | 5-208, 238 |
| BEARING NUT | 5-28 | |
| BELLOWS | 5-29 | 5-210, 239 |
| BELT | 5-30 | 5-210, 240, 272 |
| BINOCULAR | 5-31 | |
| BLADE ASSEMBLY | 5-32 | |
| BLOWERS & FANS | 5-33 | 5-211, 241, 272 |
| BOOT (DUST & MOISTURE) | 5-36 | |
| BRAKE | 5-36 | 5-211, 242 |
| BRUSHES | 5-37 | 5-212, 242 |
| BURNER | 5-38 | |
| BUSHINGS | 5-39 | 5-243 |
| CAM | 5-40 | |
| CAMERA | 5-40 | 5-273 |
| CESIUM BEAM TUBE | 5-41 | |
| CIRCUIT PROTECTION DEVICE | 5-42 | 5-212, 243 |


*NOTE: A listing under this column indicates that a Weibull analysis for one or more part types and environments under this part class is included in Sections 5.3 - 5.5.

| PART CLASS | PAGE NO. EXPONENTIAL DIST | *PAGE NO. WEIBULL DIST |
|---|---|---|
| CLUTCH | 5-44 | 5-213, 244 |
| COMPRESSOR | 5-46 | |
| COMPUTER MASS MEMORY | 5-48 | 5-214, 245, 274 |
| CONTROL TUBE ASSEMBLY | 5-50 | |
| CORD/CABLE | 5-51 | |
| COUNTER | 5-52 | |
| COUPLING | 5-55 | 5-214 |
| CRANKSHAFT | 5-58 | 5-215, 245 |
| CROSS HEAD | 5-59 | |
| DIAPHRAGMS BURST | 5-59 | 5-246 |
| DIFFUSER | 5-60 | |
| DISC ASSEMBLY | 5-60 | |
| DISTILLATION UNIT | 5-61 | |
| DRIVE | 5-62 | 5-216, 247 |
| DRIVE FOR COMPUTER TAPES & DISCS | 5-64 | 5-216, 246, 275 |
| DRIVE ROD | 5-67 | |
| DRUM | 5-67 | 5-217, 248 |
| DUCT | 5-68 | 5-218, 248 |
| ELECTRIC HEATERS | 5-69 | 5-218, 249 |
| ELECTROMECHANICAL TIMERS | 5-70 | 5-249 |
| ENGINES | 5-71 | |
| FEEDHORN | 5-71 | |
| FILTER | 5-72 | 5-219, 250, 276 |
| FITTINGS | 5-74 | 5-219, 251 |
| FLASH LAMP | 5-78 | |
| FUSE HOLDER | 5-79 | 5-252 |
| GAS DRYER DESICATOR | 5-82 | |
| GASKETS & SEALS | 5-83 | 5-220, 253 |
| GEAR | 5-85 | 5-221, 254 |
| GEAR BOX | 5-91 | 5-222, 256 |
| GEAR TRAIN | 5-93 | |
| GENERATOR (ELECTRIC) | 5-93 | |
| GENERATOR (GAS) | 5-94 | |
| GLASS (SIGHT GAUGE) | 5-94 | |
| GROMMET | 5-95 | |
| GIMBALS | 5-96 | |
| GYROSCOPE | 5-97 | |
| HEAT EXCHANGERS | 5-98 | 5-223, 256 |
| HEATER | 5-100 | |
| HEATER BLANKETS | 5-101 | |


*NOTE: A listing under this column indicates that a Weibull analysis for one or more part types and environments under this part class is included in Sections 5.3 - 5.5.

| PART CLASS | PAGE NO. EXPONENTIAL DIST | *PAGE NO. WEIBULL DIST |
|---|---|---|
| HEATER, FLEX ELEMENT | 5-101 | |
| HIGH SPEED PRINTER | 5-102 | 5-223, 257, 277 |
| HOSE | 5-104 | 5-224, 257 |
| HOUSING | 5-107 | |
| INCINERATOR | 5-107 | |
| INSTRUMENTS | 5-108 | 5-225, 258 |
| JOINT, MICROWAVE, ROTARY | 5-116 | 5-225, 259 |
| KEYBOARD | 5-117 | 5-226, 259, 277 |
| KNOB | 5-119 | |
| LAMP | 5-120 | |
| LAMP HOLDER | 5-121 | |
| LENS | 5-122 | |
| LOW SPEED PRINTER | 5-122 | 5-278 |
| MANIFOLD | 5-123 | |
| METAL TUBING | 5-124 | 5-260 |
| MODULES | 5-125 | |
| MOTOR GENERATOR SET | 5-125 | |
| MOTOR, ELECTRIC | 5-127 | 5-226, 260, 278 |
| O-RING | 5-132 | |
| PARTICLE SEPARATOR | 5-132 | |
| PITCH HORN | 5-133 | |
| PLOTTER | 5-133 | |
| POWER CIRCUIT BREAKER | 5-134 | 5-262 |
| POWER SWITCH GEAR | 5-136 | 5-227 |
| PRECIPITATOR | 5-137 | |
| PRISM | 5-137 | |
| PROPELLER | 5-138 | |
| PROPORTIONING UNIT | 5-138 | |
| PULLEY | 5-139 | 5-228, 262, 279 |
| PUMP | 5-140 | 5-263, 279 |
| PURIFIER | 5-145 | |
| QUILL ASSEMBLY | 5-145 | |
| RADOME | 5-146 | |
| REFRIGERATION PLANT | 5-146 | |
| REGULATOR | 5-147 | |
| RESILIENT MOUNT | 5-151 | 5-264 |
| RETAINING RING | 5-153 | 5-228, 265 |
| SEAL | 5-154 | |
| SENSORS | 5-155 | |
| SENSORS/TRANSDUCER/ TRANSMITTER | 5-155 | 5-280 |


*NOTE: A listing under this column indicates that a Weibull analysis for one or more part types and environments under this part class is included in Sections 5.3 - 5.5.

| PART CLASS | PAGE NO. EXPONENTIAL DIST | *PAGE NO. WEIBULL DIST |
|---|---|---|
| SHAFT | 5-162 | 5-229 |
| SHOCK ABSORBERS | 5-163 | 5-265 |
| SLIP RING-BRUSH | 5-165 | |
| SLIP RINGS | 5-166 | |
| SOLENOIDS | 5-167 | 5-229 |
| SPRING | 5-169 | |
| SPROCKET | 5-171 | |
| STEAMBOILER | 5-171 | |
| STOW PIN | 5-172 | |
| SWITCH | 5-172 | 5-230, 266, 281 |
| SWITCHBOARD CONTROL | 5-180 | |
| SYNCRO | 5-181 | |
| SYNCRO ASSEMBLY | 5-181 | |
| SYNCRO/RESOLVER | 5-182 | |
| TACHOMETER | 5-182 | |
| TANK | 5-183 | |
| TELESCOPE | 5-185 | 5-268 |
| TERMINAL BOARDS | 5-186 | |
| THERMOCOUPLE | 5-187 | |
| TRACK BALL | 5-188 | 5-269, 283 |
| TRANSMISSION | 5-189 | |
| TRUNNION ASSEMBLY | 5-189 | |
| VALVE | 5-190 | 5-231, 269 |
| WASHER | 5-196 | |
| WATER DEMINERALIZER | 5-200 | |
| WINDLASS | 5-201 | |


*NOTE: A listing under this column indicates that a Weibull analysis for one or more part types and environments under this part class is included in Sections 5.3 - 5.5.

## 2.0 APPLICABLE STATISTICAL METHODS FOR NONELECTRONIC RELIABILITY*

### 2.1 Statistical Failure Models.

2.1.1 The Hazard Rate Concept. The measure of an equipment's reliability is the infrequency with which failures occur in time. A failure distribution represents an attempt to describe mathematically the length of life of a material, a structure, or a device. There are many physical causes that individually or collectively may be responsible for the failure of a device at any particular instant. The present state-of-the-art does not permit isolation of these physical causes and mathematical account for all of them, and, as a consequence, the choice of a failure distribution is still an art. If one tries to rely on actual observations of time to failure to distinguish among the various nonsymmetrical probability functions, one is still faced with a difficulty because nonsymmetric distributions are significantly different at the tails and actual observations are sparse, particularly at the right-hand tail, because of limited sample size.

In view of these difficulties, it is often necessary to hypothesize the type of failure distribution on the basis of knowledge of the physical failure process. For example, fatigue failure of nonelectronic parts is usually assumed to follow a Weibull probability distribution because the theoretical development of this distribution was based on fatigue type failures.

One useful characteristic of failure distributions is the hazard rate or failure rate.

$$\text{Hazard rate, } h(x) = \frac{f(x)}{1-F(x)}$$

where $f(x)$ = density function

$1-F(x)$ = reliability.

Hazard rate is the probability that a device already in service for time x, will fail in the next instant of time, given no failure up to x.

Each absolutely continuous probability distribution can be characterized by the hazard rate. Physical systems can also be classified in the same manner. Thus the nature of the failure rates in a physical system suggests the type of probability distribution to be assumed.

---

*This entire section has been reprinted (with minor corrections) from RADC-TR-75-22. A revised statistical methods section containing additional advanced methods was done and is included as Appendix III of the Final Report describing the study and investigation (RADC-TR-85-66).

To assist the choice of h(x) three types of failures generally have been recognized as having a time characteristic. The first one, called the initial failure, manifests itself shortly after time x = 0. The frequency of failures of this type decreases during the initial period of operation. A good example of this is the standard human mortality table, in which it is assumed that up to the age of 10 years a child can die of hereditary defects, but having lived past this age, it is almost free of such defects. The second type occurs during the "chance failure period," in which the device exhibits a constant failure rate, generally lower than during the initial period. The cause of this failure is attributed to unusually severe and unpredictable environmental conditions occurring during the operating time of the device. In the example of human mortality tables, it is assumed that deaths between the ages of 10 and 30 years are generally due to accidents. The third type is called the wearout failure period, and is associated with the gradual depletion of a material, or an accumulation of shocks, fatigue, and so on. In the human mortality tables discussed before, after an age of 30 years an increasing proportion of deaths are attributed to "old age." The three types of failures have been classically represented by the "bathtub" curve, wherein each one of the three segments of the curve represents the three time periods of initial, chance, and wearout.

The discussion in the previous paragraphs applies to the theory of life testing in general and may not apply strictly to every case where the life characteristics of nonelectronic parts are involved. For example the wearout process begins immediately in many types of nonelectronic parts.

It was stated before that given the functional form of h(x), the density function f(x) and the cumulative distribution function F(x) could be easily determined. The development of the following two results is straightforward and can be found in Barlow and Proschan (1964).

$$1 - F(x) = \exp\left(-\int_0^x h(x)dx\right) \tag{2.1.1}$$

and

$$f(x) = h(x) \exp\left(-\int_0^x h(x)dx\right). \tag{2.1.2}$$

In the sections to follow a use will be made of this technique to develop the commonly used failure distributions.

2.1.2 The Poisson Process and the Exponential Distribution. In reliability studies, the exponential distribution plays a role analogous to that of the normal distribution in other areas of statistics. An acceptable justification for the assumption of an exponential distribution to life

studies was initially discussed by Epstein in 1953. More recently a mathematical argument has been advanced to support the plausibility of the exponential as the failure law of complex equipment (Barlow & Proschan, 1964, p. 18). Although many life distributions, especially those pertaining to the nonelectronic devices, cannot be adequately described by the exponential distribution, an understanding of the theory in the exponential case facilitates the treatment of the more general cases. The desirability of the exponential distribution is because of its simplicity and its inherent association with the well developed theory of Poisson Processes (Feller, 1968). The applicability of the exponential distribution is limited because of its lack of memory property; this property requires that the previous use does not affect its future life length, and the exponential distribution is the only continuous distribution with this property (Feller, 1968).

2.1.2.1 The Poisson Process. The exponential distribution corresponds to a purely random failure pattern, and mathematically this means that whatever is causing the failure occurs according to a Poisson Process with some parameter $\lambda$. The Poisson probability law can be derived from rigorous mathematical considerations, and the interested reader is referred to Feller (1968). Briefly, the postulates of a Poisson Process are stated below.

Consider a system (or a unit) subjected to instantaneous changes due to the occurrence of random events (shocks). All random events are assumed to be of the same kind, and one is interested in their total number. Let $P_m(t)$ be the probability that exactly m random events occur during a time interval of length t.

The physical process that induces the occurrence of the random events is characterized by the following two postulates:

i) the process is time homogeneous and the future occurrences of the random event are independent of its past occurrences.

ii) the simultaneous occurrences of two or more events is excluded.

The above postulates lead to a system of differential equations for $P_m(t)$, which lead to

$$P_m(t) = \frac{e^{-\lambda t}(\lambda t)^m}{m!}, \quad m = 0, 1, 2, \ldots$$

2.1.2.2 The Exponential Distribution. The probability density function of the exponential distribution can be obtained from either the hazard rate concept, or by considering the waiting time between arrivals in a Poisson Process. Consider the latter situation first.

Suppose that the device under consideration is subjected to an environment in which shocks occur according to the Poisson distribution, with a Poisson rate $\lambda$. The device will fail only if a shock occurs and will not fail otherwise. Let X be the life of the device.

Let $R(x) = Pr(X > x) = Pr$ [no shocks occur during $(0,x)$]

$= e^{-\lambda x}$, by putting $m = 0$.

$Pr(X \leq x) = 1 - e^{-\lambda x}$ or

$$f(x) = \lambda e^{-\lambda x}, \qquad x \geq 0.$$

The same expression for the probability density function of X could be obtained from the hazard rate concept, since the assumption of random shocks with a constant Poisson rate $\lambda$ implies a constant failure rate $h(x) = \lambda$, for $x \geq 0$.

Substituting $h(x) = \lambda$ in equations 2.1.1 and 2.1.2 one has

$$F(x) = 1 - e^{-\lambda x}.$$

This section will be concluded by emphasizing the fact that the exponential distribution can be chosen as a failure distribution if and only if the assumption of a constant hazard rate can be justified. This assumption implies that the failure of a device is not because of its deterioration due to wear, but is due to random shocks which occur according to the postulates of a Poisson Process. This fact is of importance in nonelectronic parts consideration, since invariably the failure of these is due to either a pure wear or due to a combination of wear and shocks.

2.1.3 The Weibull Distribution. Recently, the Weibull distribution has emerged to be a popular parametric family of failure distributions. Its applicability to a wide variety of failure situations was discussed by Weibull (1951); it has been used to describe vacuum tube failure by Kao (1958) and a ball bearing failure by Lieblein et. al. (1956). While the applicability of the exponential distribution in limited because of the assumption of a constant hazard rate, the family of Weibull distributions can be written to include the increasing and the decreasing hazard rates as well. Since many mechanical or electromechanical components have an increasing failure rate (i.e., due to deterioration or wear), the Weibull distribution is more palatable in describing the failure pattern of such devices.

If the hazard rate $h(x)$ is some monotone function of x, say if

$$h(x) = \frac{\beta}{\alpha}(x-\gamma)^{\beta-1}, \quad \beta, \alpha > 0, \ \gamma \geq 0, \ x \geq \gamma$$

then equations 2.1.1, and 2.1.2 give

$$F(x) = 1 - \exp\left[-\frac{(x-\gamma)^{\beta}}{\alpha}\right] \text{ for } x \geq \gamma \text{ and}$$

$$f(x) = \frac{\beta}{\alpha}(x-\gamma)^{\beta-1} \exp\left[-\frac{(x-\gamma)^{\beta}}{\alpha}\right] \quad \ldots\ldots x \geq \gamma$$

$$= 0 \text{ otherwise.}$$

$\beta$, $\alpha$, and $\gamma$ are the shape, the scale, and the location parameters respectively. In Section 5 of this notebook (and other sources) the scale parameter is $\alpha^{1/\beta}$.

The hazard rate for the Weibull distribution is increasing in $(x-\gamma)$ if $\beta > 1$, and is independent of x if $\beta = 1$. When $\beta = 1$, the Weibull distribution becomes the exponential distribution with location parameter $\gamma$, and when $\beta < 1$, the Weibull distribution reduces to what is called the hyper exponential distribution. When $\beta < 1$, the hazard rate decreases in $(x-\gamma)$, and such a hazard rate is useful in characterizing phenomenon such as work hardening or other phenomenon associated with the improvement of reliability such as debugging, etc.

Experience in the use of the Weibull distribution in describing the life characteristics of nonelectronic parts leads to the conclusion that very often the location parameter $\gamma$ can be assumed to be zero. This leads to the failure model referred to in many of the methods presented in this and succeeding sections of this notebook as the two parameter Weibull distribution.

2.1.4 The Normal Distribution. A fundamental derivation of this distribution is not attempted here because of its familiarity.

If X denotes the time to failure random variable of a device which fails according to the normal or Gaussian law, then the probability density function of X is given by

$$f(x) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-1/2\left(\frac{x-\mu}{\sigma}\right)^2} \qquad -\infty < x < \infty.$$

$\mu$ and $\sigma$ are the parameters, commonly referred to as the mean and the standard deviation respectively. The failure rate of the normal distribution is increasing in x, and hence, this distribution can be used to characterize wear. Since it is not possible to observe negative lifetimes, the use of this distribution is limited to positive random variables.

2.1.5 The Log-Normal Distribution. The Log-Normal Distribution can sometimes be used as a failure model when failure is due to fracture. Since failures due to fracture occur quite commonly in practice, especially for nonelectronic devices, a study of the Log-Normal Distribution is warranted.

The Log-Normal Distribution implies that the logarithms of the lifetimes are normally distributed, and hence, it can be easily derived by a simple logarithmic transformation. It can also be derived more fundamentally by considering a physical process wherein failure is due to fatigue cracks, and the interested reader is referred to Kao (1965). The probability density function of the Log-Normal Distribution is given by

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left\{-1/2\left(\frac{\log x-\mu}{\sigma}\right)^2\right\}, \quad x > 0,\ \sigma > 0,\ -\infty < \mu < \infty;$$

$$= 0 \text{ otherwise.}$$

$\mu$ and $\sigma$ are the (usually) unknown parameters.

2.1.6 Extreme Value Distribution. The Largest Extreme Value (L.E.V.) distribution is a two parameter right-skewed probability distribution, similar in appearance to the gamma, log-normal, or Weibull distribution. The L.E.V. distribution has been successfully fitted to failure data, particularly where failures are caused by fluctuation of a random load variable such as stress or voltage. For example, a component with tensile strength Y is subjected to a stress during each mission. Let X be the largest stress observed in n missions. If n is large, the random variable, X, will have a L.E.V. distribution, and reliability for n missions will be given by $P(X < Y)$, assuming that the theory of cumulative damage does not apply.

The L.E.V. distribution reliability function is

$$R(x) = 1 - \exp\left(-e^{-p(x-m)}\right) \qquad p > 0, \qquad -\infty < x < \infty$$

and the density function is

$$f(x) = pe^{-p(x-m)} \exp\left(-e^{-p(x-m)}\right).$$

The Smallest Extreme Value (S.E.V.) distribution is the "mirror image" of the L.E.V. distribution and represents the distribution of the smallest observation in a large number of trials. It is unique among the many life distributions available in that the probability distribution is skewed to the

left. One obvious application for the S.E.V. distribution is the "chain" model, a series system of n components where X is the lowest strength among the components. For large n, X has a S.E.V. distribution.

The reliability function is

$$R(x) = \exp\left(-e^{\beta(x-m)}\right) \qquad \beta > 0, \quad -\infty < x < \infty$$

and the density function

$$f(x) = \beta e^{\beta(x-m)} \exp\left(-e^{\beta(x-m)}\right) .$$

2.1.7 Summary. In the preceding sections several failure models were proposed as possible candidates for describing the life characteristics of nonelectronic parts. In practice, it is very difficult to identify a particular model as the suitable one, because of the considerations given in Section 2.1.1. However, some broad guidelines for the applicability of certain models were given in the other sections and these can be presented in the table below.

| Model | Applicability Conditions | Comments |
|---|---|---|
| Exponential | Failure due to exactly 1 random shock<br><br>Systems comprised of many components | Does not characterize wear |
| Weibull | Applicable under a variety of conditions, especially mechanical parts that fail due to wear | Characterizes wear or work hardening |
| Normal | Failures occur due to wearout | Describes many life processes as well as many manufacturing processes |
| Log-Normal | Failure due to fatigue cracks | Characterizes wear |
| Extreme Value | Failure due to extreme value of some variable | Corrosion is one example |

The remainder of this section of the Notebook is devoted to methods of operating on failure data once one of the previously discussed failure distributions is found to or is assumed to describe nonelectronic part failure times. The section is divided by failure distribution and follows a similar pattern for each. Methods are described for calculating point estimates of the reliability or of other parameters of the proven or assumed failure distribution based on empirical data. Where they are available and have utility for the users of the Notebook, graphical methods for estimating these

same values are presented. The general format used includes methods of point and interval estimation for the reliability parameters of each failure distribution. Numerical examples are presented and the user of the Notebook is furnished with references for theoretical development and additional examples of each of the methods presented.

## 2.2 Design of Statistical Experiments.

2.2.1 Introduction. Since the state of the art of failure data collection for nonelectronic parts does not give sufficient information for proper analysis, it is necessary to generate the needed information in a systematic manner.

In collecting failure data for estimating reliability characteristics for nonelectronic parts, one is frequently faced with insufficient information. This problem arises from the manner in which the data is collected. It is common practice to include only the operating time of the equipments or systems and the number of failures observed during the operational period covered by a failure report. Individual part failure times are generally not recorded.

This section of the Notebook, therefore, is devoted to describing the methodology or the principles to be followed in the event that one has the opportunity to generate failure data for a nonelectronic part. It describes in a logical manner the discrete guidelines for setting up an experiment which will yield an evaluation of the important factors or combinations of factors which affect the life characteristics of the parts of interest.

The general steps for planning and conducting an experiment plus the procedures to be followed to most efficiently analyze the results of a test program for nonelectronic parts are outlined below. The remainder of this subsection describes these steps in detail and references sources which can be used as patterns to be followed in generating and analyzing the types of information which are required to allow a complete and detailed reliability analysis of nonelectronic parts and of the operating and environmental stresses which affect their life characteristics.

When these guidelines are utilized in the generation and analysis of reliability data for nonelectronic parts, a full and complete analysis of all the data should be possible and no assumptions or guesses should be required which might dilute the power of the conclusions that can be reached from a proper treatment of failure data.

The major steps discussed in the succeeding pages are:

1. Determination of Stresses
2. Determination of Stress Levels
3. Statistical Test Designs
4. Physical Test Designs
5. Analysis of Experimental Data

2.2.2 Determination of Stresses and Stress Levels. In setting up an experiment to generate reliability data on nonelectronic parts, those stresses should be evaluated which experience and/or failure mode analysis indicates have the greatest effect on part life for the applications of interest.

Even if a part is operated in a very benign environment, there are still many factors competing in combination to cause deterioration of its life characteristics. The rate of deterioration is a function of the level or concentration of a given stress. It is well-known that certain factors affect a product more than others. For example, a tire's life is reduced by vibration, radiation, corrosive agents, type of road surface, and temperature to name but a few factors. It is well-known, however, that the effects of temperature greatly exceed the effects of other environmental stresses to the point that setting up an experiment to evaluate the life characteristics of this part without including this factor would render useless or distorted results. Some factors work in combination in such a manner that their effect together is greater than the sum of their individual effects acting separately. For example, ozone increases the tendency of rubber to crack, but ozone combined with high temperature creates an even greater amount of damage in most cases. The selection of factors for an experiment then should not only be directed toward including the most important factors affecting life but should seek to apply them in combination since this allows the evaluation of synergistic effects and more closely simulates actual operating conditions.

The goal of an experiment or test program to generate reliability information is therefore to determine the manner in which a part's life characteristics vary over the envelope of environmental and operating stresses to which it will be subjected during normal application. If all the stresses to which it is to be subjected during normal applications are included in the experiment and are evaluated, the size and expense of the experiment required would be prohibitive in nearly every case. The decision as to which stresses to include must therefore be based on experience, knowledge of failure theory, historical data, failure mode analysis, or predicted values in order to yield the most information for a reasonable expenditure of monies and time.

In addition to being certain to include the most important operating or environmental stresses for inclusion in a reliability data generation program, it is important to evaluate the effects of various levels of the stresses. It is expected in most cases that very little degradation occurs in a so-called laboratory environment. However, the rates of deterioration for a given stress usually vary in some systematic manner over the range of stresses to be encountered in a given application. Therefore, it is desirable to investigate what happens at several points in the environmental and operational envelope.

In determining the most significant stress levels to investigate there are several points to consider. The first is to relate failure mode to stress level. This can be done either by prior knowledge or by running some short time screening tests to locate the general stress level at which failure mode changes can be expected. If these stress levels can be located, they may even be used in influencing the operating or environmental limits to be specified in order to effect a meaningful improvement in product life. Another point to

consider in stress level selection is the concept of endurance limit associated with many nonelectronic parts. This assumes that below certain stress levels life can be considered to be infinite or at least extremely long. Therefore, in order to observe failures in a reasonable time these stress levels must be avoided.

This presents the usual dilemma which can best be solved by step-stress testing as described by Dodson and Howard and by Prot. It consists of testing a specimen or group of specimens for a fixed time at a fixed stress level. The survivors are continued on test at the next increment of higher stress for the same fixed time. This procedure continues until it is possible to select several stress levels suitable for evaluation. The stress levels should not be spaced so closely that no differences can be detected but should be selected to sufficiently cover the spectrum of interest.

The objective of the test program is to generate a mathematical model that demonstrates how life characteristics change as operational or operating stresses or combinations of stresses vary. In the case of nonelectronic parts the dimension of time must also be included in the model since the probability of failure increases as the part sees more service.

In summary, this topic discusses the general ground rules for selecting logical stresses and stress levels when setting up an experiment or test program for evaluating the reliability of nonelectronic parts. The objectives of the guidelines are the generation of more useful data for analysis than is now generally available.

2.2.3 Statistical and Physical Test Design. The goal of the designer of an experiment is the generation of accurate and useful conclusions based on economical test program, efficient data collection methods and the proper selection of statistical methods which will lead to the attainment of the goals.

In generating or gathering reliability data on nonelectronic parts, it is possible to simply put a part or group of parts on test at nominal operating and environmental conditions and collect information on operating times and failure times. From this, it will be possible to estimate the parameters of the assumed failure distribution exhibited by the parts with the methods described in Sections 2.3 and 2.4 of this Notebook.

If a greater degree of diversity is desired because the part of interest frequently may encounter stresses other than nominal in different applications then it is probably wise to attempt to evaluate the effect of a given stress on part life when applied at several different levels. Also, it is probably prudent to investigate the effects of several stresses that are thought to be major factors affecting part life again investigating each of these at several levels. More importantly, it is reasonable to evaluate these stresses when they are applied in combination since this comes the closest to simulating the real life situation.

When it is desired to evaluate stresses applied in combination on a part the most efficient type of statistical experiment to use is some form of factorial design. It is true that it would be possible to evaluate the effect of contact current on the life of a switch by holding all environmental and operating conditions constant while varying the stress of interest, in this case contact current over a desired range of values. This same procedure could then be followed for actuation rate, vibration, temperature and the infinite number of other operating and environmental stresses that could and do affect the life of switches. The obvious result would be a series of tests that would take a rather long time to perform. More importantly, however, is the fact that there would be no measure of how two or more of the stresses might act when both were at levels other than nominal. In other words, if a synergistic effect was brought about by a given set of stresses or stress levels, the aforementioned procedure would not be able to evaluate it. The solution to the problem lies in the use of some form of factorial experiment. There are full factorial experiments in which every combination of stresses and stress levels is tested and perhaps replicated. This type of experimental design yields the maximum amount of information regarding main effects and the effects of interactions of stresses. The price paid for the complete information is paid in the cost of parts placed on test and in the test time required to gather the requisite amount of data needed to perform the analysis.

Fractional factorial experiments can be performed in which some of the test cells in the experiment are omitted in order to reduce test time and expenses. The disadvantages associated with the omission of some stress combinations is that the higher order interactions cannot be evaluated. Therefore, the judgment as to which treatments to omit must be based on experience or opinion. Naturally, those that are not felt to be significant will be omitted. There are several other special types of experimental designs which can be used such as central composites, latin squares and many more. For further information regarding the details of how to set up and analyze this type of experiment the reader is referred to "The Design and Analysis of Industrial Experiments," by O.W. Davies, Hafner Publishing Company, 1954. An example of an application of a full factorial experiment is presented in RADC Technical Report 65-46 "Accelerated Reliability Test Methods for Mechanical and Electromechanical Parts," July 1965. Its Defense Documentation Center number is AD 621074. This report details all the steps necessary in selecting the stresses, stress levels, the development of the statistical test design, the physical test design and all the mathematical analyses required to evaluate the effects of environmental and operating stresses and their interactions on part life. Included also is the methodology for fitting the failure distribution and for estimating the values of the parameters of the Weibull distribution. The details presented in the subject report will serve as a complete example for designing and performing a statistical experiment. The methodology used can be followed in almost a step-by-step manner and can therefore be used in a similar manner as this Notebook. An example of a central composite experimental design is Technical Report ECOM-01433-F "Multi-Pole Relay Evaluation Study," December 1968. The central composite analysis yields a response surface in terms of regression equations involving the main stress effects and certain interactions.

With regard to the physical test design there are a few guidelines that should be followed. The test equipment for generating reliability data for nonelectronic parts should simulate actual operating conditions as accurately as possible. In addition to this the test equipment should be economical to build and use and should yield accurate measurements of the parameters which determine whether or not a part has failed. Finally, the physical test design should include a simple and accurate data collection system. When a large number of parts are tested the record-keeping problems can quickly become quite complex. Therefore, automation of data collection is a commendable goal.

In summary, this section has presented the major types of statistical designs that will yield accurate and useful data and refers the reader to typical sources that will aid in the specification of useful, efficient and economical statistical and physical test designs.

## 2.3 Fitting Failure Distributions.

2.3.1 Introduction. The two topics immediately following this one deal with specific methods of fitting failure distributions. The placement of this discussion in the overall table of contents is logical because when empirical data are observed the first logical step in its analysis is to attempt to determine the underlying distribution of failure times. While a method for small sample sizes is presented as well as one for large sample sizes it is a fact of life that must be accepted that tests based on small samples are simply not very powerful. Therefore, the methodology is presented here for completeness but very likely a more logical approach is to first make an assumption regarding the failure distribution based on engineering judgment or on historical data or on knowledge of the failure characteristics of similar parts. Once the failure distribution has been assumed the test can be performed for goodness-of-fit for that particular distribution. If the hypothesized distribution is shown not to fit, it is likely that the assumed distribution was not the one from which the samples were selected. If, however, the goodness-of-fit test shows that the data could have come from the hypothesized distribution, then it is likely that other tests for fit would yield like results.

In summary then, it must be realized that the tests presented in the next two items have limitations. The only cure for these limitations is a larger number of observations. If this proves uneconomical or not feasible from the standpoint of test time required to generate the desired number of failures, then the only alternative is to use the results of small sample size analyses with proper discretion.

### 2.3.2 Small Sample Sizes (Kolmogorov-Smirnov).

1. When to Use

When failure times from a relatively small sample have been observed and it is desired to determine the underlying distribution of failure times.

2. Conditions for Use

a. Usually historical data or engineering judgment suggests that part failure times of interest are from a given statistical failure distribution. This test then follows the step of assuming a given failure distribution and is useful to determine if empirical data disproves this hypothesis.

b. The Kolmogorov-Smirnov test for goodness of fit is distribution free and can therefore be used regardless of the failure distribution that the data is assumed to follow.

c. The discriminating ability of the statistical test is dependent on sample size so naturally the larger the sample size the more reliable the results. Where large sample sizes are available the $\chi^2$ Test for Goodness-of-Fit should be used. Where sample sizes are small the Kolmogorov-Smirnov test provides some assurance.

d. Strictly speaking, this test method requires prior knowledge of the parameters. If the parameters are estimated from the sample the exact error risks are given in Lawless (1982). However, the values from a Kolmogorov-Smirnov table will provide an adequate approximation in most circumstances.

| 3. Method | Example |
|---|---|
| a. Observe and record part failure times. | a. Given the following 20 failure times in hours<br><br>92, 130, 233, 260, 320, 325, 420, 430, 465, 518, 640, 700, 710, 770, 830, 1010, 1020, 1280, 1330, 1690 |
| b. Assume a distribution of failure times based on historical information or on engineering judgment. | b. Assume failure times are distributed according to the two parameter Weibull distribution. |
| c. Estimate the parameters of the assumed distribution from the observed data. | c. By the method of least squares (see Section 2.4.2.1.1) the Weibull shape parameter ($\beta$)=1.50 and the Weibull scale parameter ($\alpha$)=28400. |
| d. Calculate the probability of failure for each observation from the cumulative failure function for the assumed distribution. | d. For the Weibull distribution the cumulative failure function is<br><br>$\hat{F}(x) = 1 - \exp\left(-\frac{x^{\beta}}{\alpha}\right)$<br><br>where x = observed failure time<br>$\beta$=1.5 = Weibull shape parameter<br>$\alpha$=28400 = Weibull scale parameter<br>F(x) = probability of failure at or before time x. |

3. Method

Example

d. (Continued)

For the 20 observations of this example, the probability of failure at the respective x's is:

| x | $\hat{F}(x)$ |
|---|---|
| 92 | 0.03 |
| 130 | 0.05 |
| 233 | 0.12 |
| 260 | 0.14 |
| 320 | 0.18 |
| 325 | 0.19 |
| 420 | 0.26 |
| 430 | 0.27 |
| 465 | 0.30 |
| 518 | 0.24 |
| 640 | 0.43 |
| 700 | 0.48 |
| 710 | 0.49 |
| 770 | 0.53 |
| 830 | 0.57 |
| 1010 | 0.68 |
| 1020 | 0.68 |
| 1280 | 0.80 |
| 1330 | 0.82 |
| 1690 | 0.91 |

e. Calculate the percentile for each of (i) failure times by the relationship $F(i) = \frac{i}{n}$ and subtract these respective values from those of step d. above. Record the absolute value of the difference. Also, shift i to i-1 and compute the differences once again.

e. For n=20, $\frac{i}{n}$ gives the following results:

| $\hat{F}(x)$ | F(i) | F(i-1) | $\lvert\hat{F}(x) - F(i)\rvert$ | $\lvert\hat{F}(x) - F(i-1)\rvert$ |
|---|---|---|---|---|
| 0.03 | 0.05 | 0 | 0.02 | 0.03 |
| 0.05 | 0.10 | 0.05 | 0.05 | 0.00 |
| 0.12 | 0.15 | 0.10 | 0.03 | 0.02 |
| 0.14 | 0.20 | 0.15 | 0.06 | 0.01 |
| 0.18 | 0.25 | 0.20 | 0.07 | 0.02 |
| 0.19 | 0.30 | 0.25 | 0.11 | 0.06 |
| 0.26 | 0.35 | 0.30 | 0.09 | 0.04 |
| 0.27 | 0.40 | 0.35 | 0.13 | 0.08 |
| 0.30 | 0.45 | 0.40 | 0.15 | 0.10 |
| 0.34 | 0.50 | 0.45 | 0.16 | 0.11 |
| 0.43 | 0.55 | 0.50 | 0.12 | 0.07 |
| 0.48 | 0.60 | 0.55 | 0.12 | 0.07 |
| 0.49 | 0.65 | 0.60 | 0.16 | 0.11 |
| 0.53 | 0.70 | 0.65 | 0.17 | 0.12 |

3. Method

Example

e. (Continued)

| $\hat{F}(x)$ | F(i) | F(i-1) | $\lvert\hat{F}(x)-F(i)\rvert$ | $\lvert\hat{F}(x)-F(i-1)\rvert$ |
|---|---|---|---|---|
| 0.57 | 0.75 | 0.70 | 0.18 | 0.13 |
| 0.68 | 0.80 | 0.75 | 0.12 | 0.07 |
| 0.68 | 0.85 | 0.80 | 0.17 | 0.12 |
| 0.80 | 0.90 | 0.85 | 0.10 | 0.05 |
| 0.82 | 0.95 | 0.90 | 0.13 | 0.08 |
| 0.91 | 1.00 | 0.95 | 0.09 | 0.04 |

f. Compare the largest difference from step e. with a value at the desired significance level in the Kolmogorov-Smirnov Tables to test for goodness-of-fit. If the tabled value is not exceeded then it is not possible to reject the hypothesis that the failure times are from the assumed distribution.

f. The largest difference in step e. was .18. From the Kolmogorov-Smirnov Table for a significance of .05 and for a sample of size 20 a difference of greater than .29 must be observed before it can be said that the data could not have come from a Weibull distribution with $\beta$=1.5, $\alpha$=28400.

4. For Further Information

The example presented here illustrates how to test the hypothesis that the failure data came from the Weibull distribution. The Kolmogorov-Smirnov Test can also be used for other failure distributions by properly estimating the parameters in step c. for the appropriate distribution and by using the appropriate cumulative distribution function in step d. Kolmogorov-Smirnov Tables are available on pages 321 and 322 of the Handbook of Tables for Probability and Statistics, Edited by W.H. Beyer, published by the Chemical Rubber Company, Cleveland, Ohio, 1966, and in many texts on statistics.

### 2.3.3 Large Sample Sizes ($\chi^2$ Test)

1. When to Use

When failure times are available from a relatively large sample and it is desired to determine the underlying distribution of failure times.

2. Conditions for Use

a. In the statistical analysis of failure data it is common practice to assume that failure times follow a given failure distribution family. This assumption can be based on historical data or on engineering judgment. This test for goodness of fit is used to determine if the empirical data disproves the hypothesis of fit to the assumed distribution.

b. The $\chi^2$ test for goodness-of-fit is asymptotically distribution free and can therefore be used regardless of the failure distribution that the data is assumed to follow when samples are large.

c. This test is not directly dependent on sample size but on the number of intervals into which the scale of failure times is divided with the restriction that no interval should be so narrow that there are not at least 5 theoretical failures within the interval. Therefore, the test is only useful if a relatively large number of failures has been observed.

d. A table of $\chi^2$ percentage points is required.

| 3. Method | Example |
|---|---|
| a. Observe and record part failure times. | a. The following is the number of cycles to failure for a group of 50 relays on a life test: |

| | | |
|---|---|---|
| 1283 | 6820 | 16306 |
| 1887 | 7733 | 17621 |
| 1888 | 8025 | 17807 |
| 2357 | 8185 | 20747 |
| 3137 | 8559 | 21990 |
| 3606 | 8843 | 23449 |
| 3752 | 9305 | 28946 |
| 3914 | 9460 | 29254 |
| 4394 | 9595 | 30822 |
| 4398 | 10247 | 36319 |
| 4865 | 11492 | 41554 |
| 5147 | 12913 | 42870 |
| 5350 | 12937 | 62690 |
| 5353 | 13210 | 63910 |
| 5410 | 14833 | 68888 |
| 5536 | 14840 | 73473 |
| 6499 | 14988 | |

| | |
|---|---|
| b. Assume a distribution of failure times based on historical information or on engineering judgment. | b. Assume failure times are distributed according to the two parameter Weibull distribution. |
| c. Estimate the parameters of the assumed distribution from the observed data. | c. By the method of least squares (see Section 2.4.2.1.1) the Weibull shape parameter $\beta$=1.21 and the Weibull scale parameter $\alpha$=127978. |

| 3. Method | Example |
|---|---|
| d. Divide the spectrum of failure times into intervals of such a width that the theoretical number of failures in each interval will be at least five. The width of intervals need not be equal. | d. Divide the relay cycles to failure into the following intervals:<br><br>0 - 4000<br>4001 - 7200<br>7201 - 13000<br>13001 - 18000<br>18001 - 25000<br>25001 - ∞ |
| e. Calculate the theoretical number of failures for each interval. | e. The expected number of failures in each interval is obtained as follows:<br><br>For the Weibull distribution the cumulative failure function is<br><br>$F(x) = 1 - \exp\left(-\frac{x}{\alpha}^{\beta}\right)$<br><br>where x = observed failure times<br>$\beta$ = Weibull shape parameter<br>$\alpha$ = Weibull scale parameter<br><br>Then $F(x_n) - F(x_{n-1})$ = probability a failure time falls within the interval.<br><br>Then for each interval the probability of failure in that interval multiplied by the sample size = the theoretical number of failures for each interval. |

3. Method

Example

e. (Continued)

| (1) Upper Boundary of Interval | (2) F(x) | (3) $F(x_n) - F(x_{n-1})$ | (4) Theoretical Failure Frequency (Col. 3x50) |
|---|---|---|---|
| 4000 | 0.16 | 0.16 | 8 |
| 7200 | 0.30 | 0.14 | 7 |
| 13000 | 0.52 | 0.22 | 11 |
| 18000 | 0.66 | 0.14 | 7 |
| 25000 | 0.80 | 0.14 | 7 |
| ∞ | 1.00 | 0.20 | 10 |

NOTE: The theoretical frequency must not be less than 5 for any interval.

f. Calculate the $\chi^2$ statistic by the formula

$$\chi^2 = \sum_{i=1}^{k} \frac{(f_i - F_i)^2}{F_i}$$

where k = number of intervals
f = observed frequency/interval
F = theoretical frequency/interval

f.

| Upper Boundary of Interval | F | f | $\frac{(f_i - F_i)^2}{F_i}$ |
|---|---|---|---|
| 4000 | 8 | 8 | 0 |
| 7200 | 7 | 10 | 1.29 |
| 13000 | 11 | 12 | 0.11 |
| 18000 | 7 | 7 | 0 |
| 25000 | 7 | 3 | 2.29 |
| | 10 | 10 | 0 |
| | 50 | 50 | $\chi^2$=3.69 |

g. Determine if the $\chi^2$ statistic indicates that the data could have come from the hypothesized distribution using $\chi^2$ tables and (k-1) - ρ degrees of freedom.

where
k = number of intervals
ρ = number of parameters estimated from data

g. The degrees of freedom for this example are calculated as:
d.f. = (k-1) - ρ
d.f. = (6-1) - 2 = 3
The value from the $\chi^2$ table for 3 degrees of freedom and 0.05 level of significance is 7.815. Since 3.69 does not exceed the tabled value, then the hypothesis that this data came from a Weibull distribution cannot be rejected at the 5% level of significance.

## 4. For Further Information

The example presented here illustrates how to test the hypothesis that the observed failure data came from the Weibull distribution. The $\chi^2$ test can also be used for other distributions by properly estimating the parameters in step c. for the appropriate distribution and by using the appropriate cumulative distribution function in step c. In step g. the selection of the 5% level of significance was arbitrary and will depend on the researchers willingness to risk a wrong decision in rejecting the hypothesized distribution. There is also a risk of accepting the distribution wrongly which for this test cannot be specified. There are several versions of $\chi^2$ tables but the one used with this example is from "New Tables of the Incomplete Gamma-Function Ratio and of Percentage Points of the Chi-Square and Beta Distributions," by H. Leon Harter, Aerospace Research Laboratories, Office of Aerospace Research, United States Air Force, 1964.

## 2.4 Estimation Methods

### 2.4.1 The Exponential Distribution

#### 2.4.1.1 Analytical Point Estimation

1. When to Use

To estimate the parameter $\theta$, mean-time-between-failures, in the exponential distribution function

$$F(x) = 1 - e^{-x/\theta}$$

this computation may be performed. Also, the estimation of reliability is described.

2. Conditions for Use

a. This estimation method may be used when units are selected at random and placed on test, whether or not all units are allowed to fail, and whether or not failed units are replaced.

b. No burn-in or wear-out type failures occur. Use of the exponential distribution assumes a constant failure rate.

c. Total test time and total number of failures must be collected.

3. Method

a. Sum together the test time accumulated on each unit tested to get the total test time. Whether failed units are replaced or not does not affect the calculation, nor does it matter whether all units are allowed to fail. Only compute the total operating time of parts on test.

Example

a. Suppose 10 units are placed on test for 80 hours and the failed units are not replaced. Failures occur at 20, 30, 35, 45, 70 and 75 hours. So, test time accumulates as follows:

| | |
|---|---|
| Unit 1 | 20 hours |
| Unit 2 | 30 hours |
| Unit 3 | 35 hours |
| Unit 4 | 45 hours |
| Unit 5 | 70 hours |
| Unit 6 | 75 hours |
| Unit 7 | 80 hours |
| Unit 8 | 80 hours |
| Unit 9 | 80 hours |
| Unit 10 | 80 hours |

Total Test Time = 595 hours

3. Method

b. Divide total test time by total number of failures to get an estimate of $\theta$ = mean-time-between-failures.

c. The reliability is given by

$$R(x) = 1 - \left(1 - e^{-x/\theta}\right)$$

Example

b. Since the total number of failures is 6, divide

$$\frac{595}{6} = 99.1 \text{ hours.}$$

c. The reliability for 30 hours is estimated to be:

$$R(30) = e^{-30/99.1}$$

$$R(30) = 0.74$$

4. For Further Information

Additional examples on the use of the exponential distribution are presented in "Reliability Theory and Practice," by Igor Bazovsky, Prentice-Hall, 1961.

2.4.1.2 Interval Estimation

2.4.1.2.1 Two-Sided Confidence Limits

1. When to Use

To compute upper and lower confidence limits on the exponential distribution parameter $\theta$ (mean-time-between-failures), this method is used.

2. Conditions for Use

a. A confidence level, say $1-\alpha$, must be specified.

b. Total test time and total number of failures must be collected, whether or not failed units are replaced.

c. A table of $\chi^2$ percentage points is required.

3. Method

a. If the test is failure truncated, rather than time truncated, then the lower two-sided confidence limit is

$$\frac{2T}{\chi^2_{2r,1-\alpha/2}}$$

Example

a. Suppose 5 units are placed on life test and fail at 20, 30, 35, 45, and 70 hours. If the 90% confidence limits are desired, then

$$1-\alpha = 0.90$$

$$n = 5$$

3. Method

a. (Continued)

where

$T$ = total test time

$1-\alpha$ = confidence level desired

$r$ = total number of failures

$\chi^2_{2r,1-\alpha/2}$ = $1-\alpha/2$ quantile of the chi-square distribution with $2r$ degrees of freedom.

b. The corresponding upper two-sided confidence limit is

$$\frac{2T}{\chi^2_{2r,\alpha/2}}$$

Example

a. (Continued)

$T = 200$ hours

$\hat{\theta} = T/r = 40$ hours

So, the lower two-sided confidence limit is

$$\frac{2 \times 200}{\chi^2_{10,0.95}} = 21.85$$

b. The upper two-sided confidence limit is

$$\frac{2 \times 200}{\chi^2_{10,0.05}} = 101.52$$

4. For Further Information

For a time truncated test, the lower two-sided confidence limit is computed with $2r + 2$ degrees of freedom:

$$\frac{2T}{\chi^2_{2r+2,1-\alpha/2}}$$

The upper two-sided confidence limit is the same as in a failure truncated test, with $2r$ degrees of freedom.

Additional examples demonstrating this method are presented in "Reliability Theory and Practice" by Igor Bazovsky, Prentice-Hall, 1961.

2.4.1.2.2 One-Sided Confidence Limits

1. When to Use

Use this method to compute a lower one-sided confidence limit on the exponential distribution parameter $\theta$ (mean-time-between-failures).

2. Conditions for Use

a. A confidence level, say $1-\alpha$, must be specified.

b. Total test time and total number of failures must be collected, whether or not failed units are replaced.

c. Even if no failures have occurred, this method may be used.

d. A table of $\chi^2$ percentage points is required.

3. Method

a. If the test is failure truncated, rather than time truncated,* then the lower one-sided confidence limit is

$$\frac{2T}{\chi^2_{2r,1-\alpha}}$$

where

$T$ = total test time

$1-\alpha$ = confidence level desired

$r$ = total number of failures

$\chi^2_{2r,1-\alpha}$ = $1-\alpha$ quantile of the chi-square distribution with $2r$ degrees of freedom.

*For a time truncated test, the lower one-sided confidence limit is computed with $2r + 2$ degrees of freedom.

$$\frac{2T}{\chi^2_{2r+2,1-\alpha}}$$

NOTE: If no failures have occurred, the lower one-sided confidence limit is $T/(-\ln\alpha)$.

Example

a. Suppose 5 units are placed on life test and fail at 20, 30, 35, 45, and 70 hours. If the 90% lower confidence limit is desired, then

$1-\alpha = 0.90$

$r = 5$

$T = 200$ hours

$\hat{\theta} = T/r = 40$ hours

So, the lower 90% one-sided confidence limit is

$$\frac{2 \times 200}{\chi^2_{10,0.90}} = 25.02$$

4. For Further Information

Additional examples demonstrating this method are presented in "Reliability Theory and Practice" by Igor Bazovsky, Prentice-Hall, 1961.

2.4.2 The Weibull Distribution

2.4.2.1 Analytical Point Estimation

2.4.2.1.1 The Method of Least Squares

1. When to Use

Estimating Weibull shape and scale parameters may be accomplished by fitting a least squares line to transformed Weibull data, provided that the location parameter $\gamma$ is known or assumed. $\gamma$ is often assumed to be zero. If not the transformation $X' = X - \gamma$ will reduce to the 2 parameter form. This section of the Notebook on the Weibull distribution contains three methods of estimating the shape and scale parameters. The method of least squares is basically a more accurate version of the graphical method. It takes more calculations to estimate $\alpha$ and $\beta$ than the graphical method and hence the added cost of these calculations must be balanced against the costs associated with using a less accurate graphical method and being subject to estimation error. While a computer helps reduce calculation time, the least squares method does not require as complex a computer program as the maximum likelihood method although it may not result in as accurate an estimate.

2. Conditions for Use

a. Failure times must be collected.

b. A computer is helpful.

c. A table of median ranks is required. It is provided in Appendix H, Table I.

3. Method

a. For n ordered Weibull failure times $t_1, t_2, \ldots t_n$, find median rank values $F(t_i)$ from Table I in the Appendix.

Example

a. Table I in the Appendix gives the median ranks for these Weibull failure times.

| Failure Time | Median Rank |
|---|---|
| 92 Hours | 0.0341 |
| 130 Hours | 0.0831 |
| 233 Hours | 0.1322 |
| 260 Hours | 0.1812 |
| 320 Hours | 0.2302 |
| 325 Hours | 0.2793 |
| 420 Hours | 0.3283 |
| 430 Hours | 0.3774 |
| 465 Hours | 0.4264 |
| 518 Hours | 0.4755 |
| 640 Hours | 0.5245 |
| 700 Hours | 0.5736 |

3. Method

b. For $i = 1$ to $n$, let

$$x_i = \ln t_i;$$

$$y_i = \ln\ln \frac{1}{1 - F(t_i)}$$

c. *Compute

$$\beta = \frac{n \sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n \sum_{i=1}^{n} (x_i)^2 - \left( \sum_{i=1}^{n} x_i \right)^2} .$$

d. *Compute

$$\alpha = \exp\left[ - \frac{\sum_{i=1}^{n} (x_i)^2 \sum_{i=1}^{n} y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} x_i y_i}{n \sum_{i=1}^{n} (x_i)^2 - \left( \sum_{i=1}^{n} x_i \right)^2} \right]$$

*NOTE: Steps c. and d. would be lengthy calculations by hand, but a computer program to fit a line $Y = bX + c$ by least squares may be easily adapted to fitting a Weibull line by substituting $\ln t$ for $X$ and $\ln\ln (1/(1-F(t)))$ for $Y$. Then $b$ will be $\beta$ and $c$ will be $-\ln \alpha$.

Example

a. (Continued)

| Failure Time | Median Rank |
|---|---|
| 710 Hours | 0.6226 |
| 770 Hours | 0.6717 |
| 830 Hours | 0.7207 |
| 1010 Hours | 0.7698 |
| 1020 Hours | 0.8188 |
| 1280 Hours | 0.8678 |
| 1330 Hours | 0.9169 |
| 1690 Hours | 0.9659 |

b. An adapted computer program for fitting least squares lines gives

$\beta = 1.52$

$\alpha = 2.36 \times 10^4$ .

4. For Further Information

Additional examples demonstrating the application of this technique to the estimation of Weibull shape and scale parameters are given in RADC TR65-46 "Accelerated Reliability Testing for Nonelectronic Parts", July 1965, AD 621074.

2.4.2.1.2 Maximum Likelihood Method

1. When to Use

Use this method to estimate the shape (c) and scale ($\alpha$) parameters of the Weibull cumulative distribution function given by $F(x)=1-\exp(-x^c/\alpha)$. The maximum likelihood method as its name implies is the most accurate based on the observed data. However, the calculations required are the most complex in that an iterative method must be used. If an iterative computer program is utilized the disadvantages of the maximum likelihood method are not so serious. This estimation method must be used for calculating $\alpha$ and c if the interval estimation method of Section 2.4.2.3.1 is to be used for calculating confidence limits.

2. Conditions for Use

a. Failure times must be collected.

b. An iterative computer program is practically essential for economical use of this method.

| 3. Method | Example |
|---|---|
| a. Make an initial estimate of the shape parameter (possibly by the graphical method of Section 2.4.2.2). Refer to it as C. | a. The 20 failure times given in Section 2.4.2.1.1 have been plotted on Weibull probability paper in Section 2.4.2.2. The graphical estimate of the shape parameter is 1.5. Therefore, a first iteration of C is 1.5. |
| b. Using the first estimate of C, solve the maximum likelihood equation: $$F = \frac{n}{C} - \frac{n \Sigma\left(x_i^C \ln x_i\right)}{\Sigma(x_i)^C} + \Sigma \ln x_i$$ | b. With C = 1.5, the equation yields F = 1.603. Since $F \neq 0$, it is necessary to proceed to Step c. |

| 3. Method | Example |
|---|---|
| b. (Continued)<br><br>where<br><br>$n$ = sample size<br><br>$x_i$ = ith failure time<br><br>If when the equation is solved $F = 0$, then C represents the maximum likelihood estimate of the shape parameter. If $F \neq 0$ go to Step c. | |
| c. Take the derivative (with respect to C) of the equation in Step b:<br><br>$$F' = -\frac{n}{C^2} - \frac{\left\{\Sigma x_i^C \Sigma\left(x_i^C \ln^2 x_i\right) - \left[\Sigma x_i^C \ln x_i\right]^2\right\} \cdot n}{\left(\Sigma x_i^C\right)^2}$$ | c. Using $C = 1.5$, $F' = -13.99$. |
| d. Set $b = C - (F/F')$. | d. $b = 1.5 + 0.115 = 1.615$. |
| e. Set $\epsilon$ = some small number, determined by the accuracy desired in the answer. If accuracy to K places is desired, then set $\epsilon = 10^{-(K+1)}$. | e. Suppose 2 place accuracy is desired, then set $\epsilon = 10^{-3}$. |
| f. If $\lvert F/F' \rvert \geq \epsilon$, set $C = b$ and repeat Steps b. - f. | f. $\lvert F/F' \rvert = 0.115$.<br>$0.115 > 10^{-3}$ so set $C = b$ and return to Step b. The iterative process eventually gives<br>$C = \hat{c} = 1.62$. |
| g. Now it is necessary to apply the unbiasing factor to the maximum likelihood estimate. Appendix Table XI gives factors to be multiplied to the maximum likelihood estimate. | g. From Appendix Table XI the unbiasing factor for a sample size of 20 is 0.931.<br><br>Therefore<br><br>$\hat{c} = 0.931(1.62) = 1.51$. |

3. Method

h. To solve for the Weibull scale parameter $\alpha$

$$\hat{\alpha} = \Sigma \hat{x_i^c}/n$$

Example

h. The estimate of the Weibull scale parameter is

$$\hat{\alpha} = 4.47 \times 10^4$$

4. For Further Information

The statistical theory developing the use of this method is presented in "Inferences on the Parameters of the Weibull Distribution," by Thoman, Bain and Antle, Technometrics, Vol. 11, No. 3, August 1969, pp. 445-460.

2.4.2.2 Graphical Point Estimation

1. When to Use

Estimates of the Weibull shape and scale parameters may be obtained graphically by using specially prepared Weibull probability paper. The decision to use this method over those described in the two previous topics should be based wholly on the accuracy desired. This method is the least accurate but can be done quickly and easily.

2. Conditions for Use

a. Failure times must be collected.

b. Median rank tables are required. They are provided in the Appendix, Table I.

c. Weibull probability paper is required. See Figure 2.4.2.2.

3. Method

a. To plot the $i^{th}$ failure time in a set of n ordered failure times, find the median rank plotting position on the left-hand ordinate by consulting the table of median ranks at n, i. To obtain median ranks for n greater than twenty, the following formula may be used:

$$\text{Median rank } (n, i) = \frac{i - 0.3}{n + 0.4},$$

where

i = order number of failure

n = number of failures.

Example

a. As an example of plotting failure times on Weibull probability paper, consider a case in which 20 items are all tested to failure; the 20 failure times, in ascending order, are given below in the left-hand column. In the right-hand column are the median rank plotting positions for each failure time, obtained from the table of median ranks for n = 20 in the Appendix, Table I.

| Failure Times (Hours) | Median Ranks |
|---|---|
| 92 | 0.0341 |
| 130 | 0.0831 |

3. Method

Example

a. (Continued)

| Failure Times (Hours) | Median Ranks |
|---|---|
| 233 | 0.1322 |
| 260 | 0.1812 |
| 320 | 0.2302 |
| 325 | 0.2793 |
| 420 | 0.3283 |
| 430 | 0.3774 |
| 465 | 0.4264 |
| 518 | 0.4755 |
| 640 | 0.5245 |
| 700 | 0.5736 |
| 710 | 0.6226 |
| 770 | 0.6717 |
| 830 | 0.7207 |
| 1010 | 0.7698 |
| 1020 | 0.8188 |
| 1280 | 0.8678 |
| 1330 | 0.9169 |
| 1690 | 0.9659 |

Before plotting the data, it is necessary to perform a transformation on the bottom scale to accommodate the large failure times. The axis must be multiplied by $10^{-2}$ in order for the failure data to fit on the paper. So, the bottom scale is properly labeled HOURS X $10^{-2}$.

b. The Weibull line is drawn through the plotted data by using the last point plotted as a reference point for a straight-edge and dividing the rest of the points into two equal groups above and below the line.

b. The Weibull line, labeled $k_1$ in Figure 2.4.2.2 is drawn as described.

c. To estimate $\beta$, parallel to the Weibull line draw a line passing through the small circled point on the paper.

c. The shape parameter $\beta$ is estimated by drawing the line, labeled $k_2$, parallel to $k_1$ and passing through point A.

| 3. Method | Example |
|---|---|
| d. Horizontal projection of the point where this line intersects the principal ordinate to the right-hand scale gives $-\beta$. The principal ordinate terminates in 0.0 on the upper scale. | d. The point where $\ell_2$ intersects $\ell_3$, the principal ordinate, is projected horizontally to the right-hand axis and $-\beta$ read off as -1.5. So, $\beta = 1.5$. |
| e. Sometimes in order to plot the failure data it is necessary to convert the bottom scale to handle larger numbers. The scales used on this axis are selected for the purpose of convenience in presenting the data on the graph. If the bottom scale has been multiplied by K, then read $-\ln \alpha_K$ at the horizontal projection to the right-hand axis of the intersection of the Weibull line and the principal ordinate. | e. To find $\alpha$, the intersection of $\ell_1$ and $\ell_3$ is projected horizontally to the right-hand axis. The value read off the axis, -2.9, is $-\ln \alpha_K$, and must be converted. |
| f. Find the value of $\alpha_K$ by using a calculator. The computed $\alpha_K$ is a coded value which is dependent on the time scale used. | f. The value of $\alpha_K$ is found to be 18.2. |
| g. To convert $\alpha_K$ to an uncoded state that is independent of the time scale used on the probability paper, divide $\alpha_K$ by $K^\beta$, where $\beta$ is the previously obtained shape parameter. | g. $\alpha_K$ is converted to an uncoded state by dividing by $K^\beta$. So, divide 18.2 by $10^{-2\beta}$ giving $\alpha = \frac{18.2}{10^{-2\beta}} = 18.2 \times 10^2 \times 1.5$ $= 1.82 \times 10^4$ |

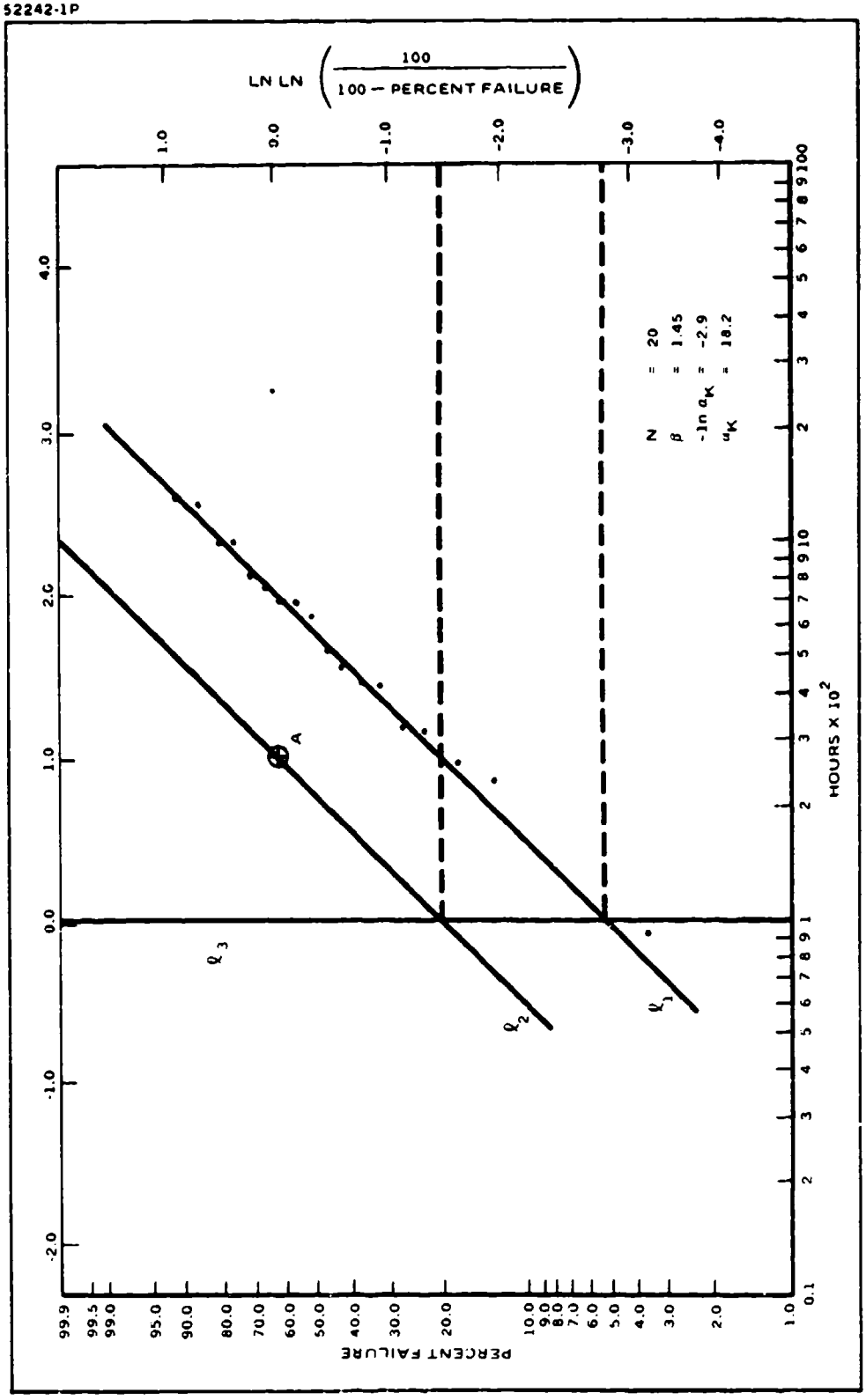



Figure 2.4.2.2. Graphical Point Estimation for the Weibull Distribution

4. For Further Information

If desired, the median ranks may be replaced by the unbiased estimate i/(n+1), where

i = order number of failure

n = number of failures.

2.4.2.3 Interval Estimation

2.4.2.3.1 Weibull Parameters

1. When to Use

Use this method to obtain confidence intervals on the shape (c) and scale ($\alpha$) parameters of the two parameter Weibull cumulative distribution function given by $F(x) = 1 - \exp(-(x^c)/\alpha)$.

2. Conditions for Use

a. Point estimates of c and $\alpha$ must be made using the method of Section 2.4.2.1.2.

b. The tables required in the calculation are provided in Appendix II, Tables V and VI.

3. Method

a. To compute $100(1-\gamma)$ percent confidence limits on c, locate in Table V the column labeled with the value of $\gamma/2$. Read off the table value at N = sample size and call it $L_1$. Locate the column labeled with the value of $1 - \gamma/2$. Read off the table value at N = sample size and call it $L_2$. Then, the confidence interval on c is of the form $(\hat{c}/L_2, \hat{c}/L_1)$, where c was obtained by the method of Section 2.4.2.1.2.

b. To compute $100(1-\gamma)$ percent confidence limits on $\alpha$, locate in Table VI the column labeled with the value of $\gamma/2$. Read off the table value at N = sample size and call it $t_1$. Locate the column labeled with the value

Example

a. Suppose it is desired to compute 90% confidence limits on the Weibull parameters for the example given in Section 2.4.2.1.2. Then N = 20, $\gamma = 0.10$, c = 1.51 and $\hat{\alpha} = 4.47 \times 10^4$. From Table V, at N = 20 in the 0.05 column the value of $L_1$ is read as 0.791 and at N = 20 in the 0.95 column the value at $L_2$ as 1.449. So the interval on $\hat{c}$ is (1.51/1.449, 1.51/0.791) = (1.04, 1.91).

b. The 90% confidence interval on $\alpha$ requires consulting Table VI:

$t_1 = -0.428$

$t_2 = 0.421$

3. Method

b. (Continued)

at $1 - \gamma/2$. Read off the table value at N = sample size and call it $t_2$. Then, the confidence interval on $\alpha$ is of the form

$$\left(\hat{\alpha} \exp(-t_2), \hat{\alpha} \exp(-t_1)\right),$$

where $\hat{\alpha}$ was obtained by the method of Section 2.4.2.1.2.

Example

b. (Continued)

The interval on $\alpha$ is given by

$$\left[4.47 \times 10^4 \exp(-0.421), \; 4.47 \times 10^4 \exp(0.428)\right]$$

$$= (2.93 \times 10^4, \; 6.87 \times 10^4)$$

4. For Further Information

This method is from "Inferences on the Parameters of the Weibull Distribution," Thoman, Bain and Antle, Technometrics, Vol. II, No. 3, August 1969, pp. 445-460.

2.4.2.3.2 Reliability

2.4.2.3.2.1 Uncensored Samples

1. When to Use

Use this method to estimate 90% confidence limits on reliability for the Weibull distribution.

2. Conditions for Use

a. A plot of the failure times must be prepared on Weibull probability paper. See Section 2.4.2.2 for the methodology.

b. A table of 5% ranks and one of 95% ranks are required. These are provided in Appendix II, Tables II and III.

3. Method

a. Draw the Weibull line for the observed data, as described in Section 2.4.2.2.

b. Locate the median ranks on the left-hand axis, project them horizontally and mark their intersection with the Weibull line.

Example

a. Refer to the example of 20 failure times used in Section 2.4.2.2. The Weibull line on Weibull probability paper is presented here again, Figure 2.4.2.3.2.1.

b. The following median ranks, for n = 20, have been marked on the Weibull line:

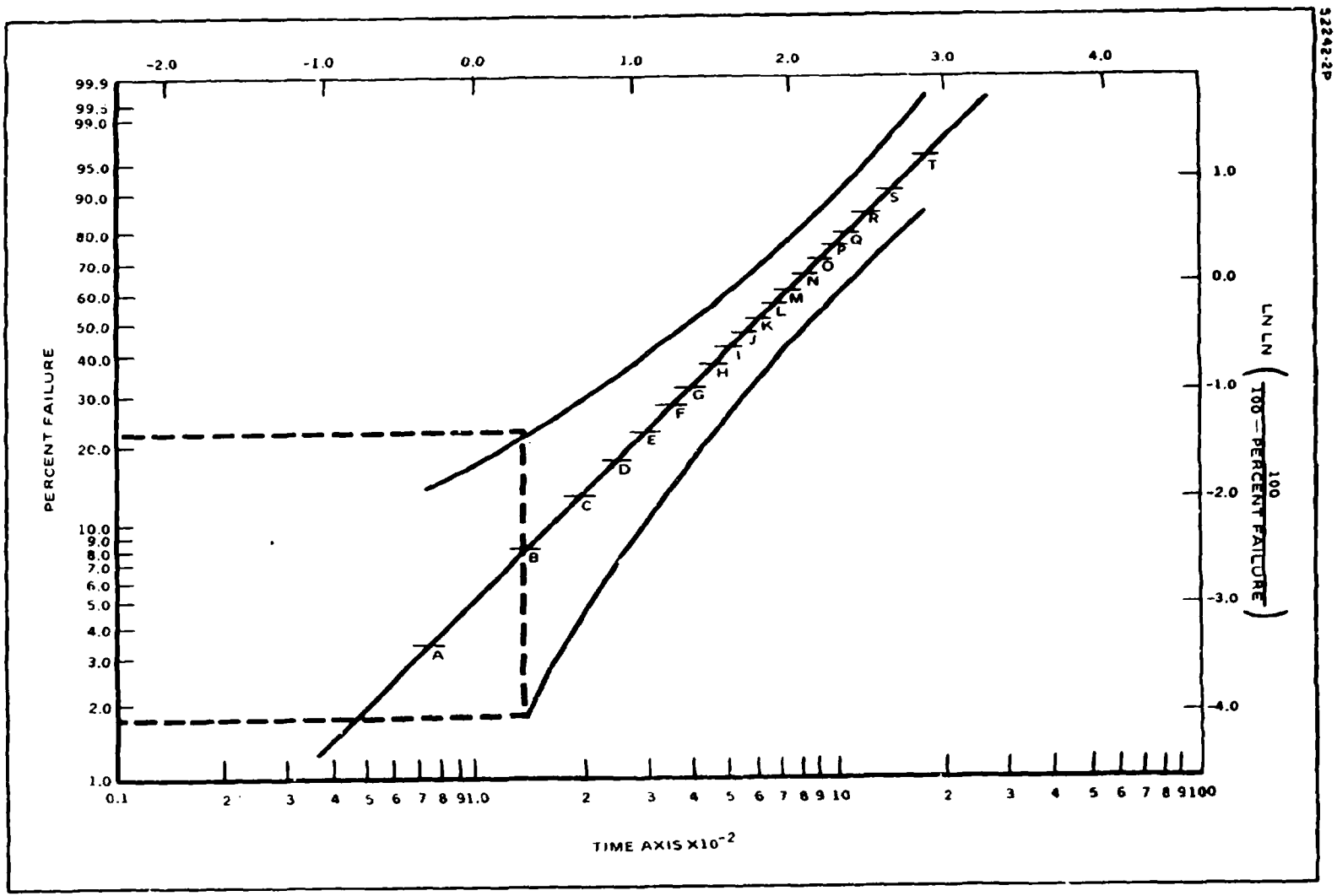



Figure 2.4.2.3.2.1. Graphical Method for Interval Estimation of Reliability for the Weibull Distribution

| 3. Method | Example |
|---|---|

b. (Continued)

| Median Rank | Graph Notation |
|---|---|
| 0.0341 | A |
| 0.0831 | B |
| 0.1322 | C |
| 0.1812 | D |
| 0.2302 | E |
| 0.2793 | F |
| 0.3283 | G |
| 0.3774 | H |
| 0.4264 | I |
| 0.4755 | J |
| 0.5245 | K |
| 0.5736 | L |
| 0.6226 | M |
| 0.6717 | N |
| 0.7207 | O |
| 0.7698 | P |
| 0.8188 | Q |
| 0.8678 | R |
| 0.9169 | S |
| 0.9659 | T |

c. For the $j^{th}$ plotting position of sample size = n, find the 5% and 95% ranks from Tables II and III. Locate them on the left-hand axis of the Weibull paper, then project them horizontally. Their intersection with a vertical line drawn through the previously marked point of intersection of the $j^{th}$ median rank and the Weibull line gives the lower and upper limits on reliability for that point on the time (lower) axis.

c. The tables show a 5% rank value of 0.0183 and a 95% rank value of 0.2182 for n = 20, j = 2. So, these plots have been plotted on the vertical line through point B.

d. Continue plotting each pair of upper and lower limits for all n failures. Then connect the points above the Weibull line with a smooth curve. Likewise connect the points below the Weibull line, thus forming a band around the Weibull line, narrowing at the center and widening at both ends.

d. Curves are drawn through the plotted points.

3. Method

e. To find limits on reliability at a particular time t, locate t on the lower axis and read off upper and lower limits on reliability from the two curves by referring to the left-hand axis.

Example

e. For example, the confidence limits on reliability at 400 hours are 0.19 and 0.49.

4. For Further Information

Tables II and III for 5% and 95% ranks are from Electromechanical Component Reliability, May 1963, Chernowitz, et.al., RADC-TDR-63-295, American Power Jet, Ridgefield, N.J.

If confidence intervals other than the 90% for $n \leq 20$ given here are desired, any percentile ranks may be obtained in the following manner for sample sizes up to 50. Tables of the Incomplete Beta Function are required. The notation used here is found in Tables of the Incomplete Beta Function, K. Pearson, Cambridge University Press, 1956.

Method

a. For the $j^{th}$ failure of n failures, compute

$$k = n - j + 1$$

For $j \geq k$ let $p = j$, $q = k$.

For $j < k$ let $p = k$, $q = j$.

Example

a. Suppose n = 10 and it is required to find the 80% confidence limits on reliability. Then the following table may be constructed:

| j | k | q | p |
|---|---|---|---|
| 1 | 10 | 1 | 10 |
| 2 | 9 | 2 | 9 |
| 3 | 8 | 3 | 8 |
| 4 | 7 | 4 | 7 |
| 5 | 6 | 5 | 6 |
| 6 | 5 | 5 | 6 |
| 7 | 4 | 4 | 7 |
| 8 | 3 | 3 | 8 |
| 9 | 2 | 2 | 9 |
| 10 | 1 | 1 | 10 |

b. To compute 100 $(1-\alpha)$ percent confidence limits, locate values of $I_x(p,q)$ in Table I of the referenced tables, such that $\alpha/2$ and $1-\alpha/2$ are approximated as closely as possible. For $j \geq k$, the $\gamma$ percentile rank, where $\gamma = \alpha/2, 1-\alpha/2$, is given by the x in the left-hand column on the same row as the value of $I_x(p,q) = \gamma$.

b. To compute 80% confidence limits, the 0.10 and 0.90 percentile ranks are needed. So, in Table I find the $\gamma = 0.10$ and $\gamma = 0.90$ percentile ranks for j-1 on pp. 22, 23, for p = 10 and q = 1. The value of x opposite 0.0946828 in the table, the closest value to 0.1 given, is 0.79, and the value of x opposite 0.9043821, closest to 0.9, is 0.99. So, the

Method

b. (Continued)

For $j < k$, the $\gamma$ percentile rank is given by 1-x, where x again is in the left-hand column on the same row as the value of $I_x(p,q) = \gamma$.

Example

b. (Continued)

desired percentile ranks for n = 10, j = 1 are 90%: 1 - 0.79 = 0.21; 10%: 1 - 0.99 = 0.01.

The complete set of percentile ranks follows, as computed from Table I.

| j | 90% | 10% |
|---|---|---|
| 1 | 0.21 | 0.01 |
| 2 | 0.40 | 0.06 |
| 3 | 0.51 | 0.09 |
| 4 | 0.55 | 0.19 |
| 5 | 0.65 | 0.26 |
| 6 | 0.74 | 0.35 |
| 7 | 0.81 | 0.45 |
| 8 | 0.91 | 0.49 |
| 9 | 0.94 | 0.6 |
| 10 | 0.99 | 0.79 |

2.4.2.3.2 Reliability

2.4.2.3.2.2 Censored Samples

1. When to Use

This section describes a procedure for calculating a lower confidence limit on reliability for parts which are known to have Weibull failure distributions. The method is applicable to both censored and uncensored test data.

2. Conditions for Use

a. Failure times must be collected.

b. Certain tables are required in the calculation. They are provided in Appendix II, Tables VII and VIII.

3. Method

a. For a test of n items, r of which are allowed to fail before termination of the test, order the r failure times and for i = 1 to r, set $X_i$ = ith failure time.

Example

a. Suppose 20 parts are put on test and the test terminates after the 10th failure. Then n = 20, r = 10, and suppose the following failure times are observed:

3. Method

Example

a. (Continued)

$X_1$ = 92 hours
$X_2$ = 130 hours
$X_3$ = 233 hours
$X_4$ = 260 hours
$X_5$ = 320 hours
$X_6$ = 325 hours
$X_7$ = 420 hours
$X_8$ = 430 hours
$X_9$ = 465 hours
$X_{10}$ = 518 hours

b. To find the lower confidence limit at time $t_o$, compute for i = 1 to r

$$Y_i = \ln X_i - \ln t_o$$

b. Suppose it is desired to find the 95% lower confidence limit on R(50), reliability at 50 hours. Then ln (50) = 3.91202 and

$Y_1$ = 0.60977
$Y_2$ = 0.95551
$Y_3$ = 1.53902
$Y_4$ = 1.64866
$Y_5$ = 1.85630
$Y_6$ = 1.87181
$Y_7$ = 2.12823
$Y_8$ = 2.15177
$Y_9$ = 2.23002
$Y_{10}$ = 2.33796

c. Let p = r/n and find values in Table VII for $a_i$ and $b_i$, for i = 1 to r.

c. Since p = 10/20, Table VII gives the following values for $a_i$'s and $b_i$'s.

| | |
|---|---|
| $a_1$ = -0.04527 | $b_1$ = -0.09198 |
| $a_2$ = -0.04032 | $b_2$ = -0.09230 |
| $a_3$ = -0.03371 | $b_3$ = -0.09010 |
| $a_4$ = -0.02574 | $b_4$ = -0.08597 |
| $a_5$ = -0.01650 | $b_5$ = -0.08013 |

3. Method

Example

a. Compute

$$Z_a = \sum_{i=1}^{r} a_i Y_i$$

$$Z_b = \sum_{i=1}^{r} b_i Y_i$$

c. (Continued)

$a_6 = -0.00596$ $b_6 = -0.07264$
$a_7 = 0.00595$ $b_7 = -0.06345$
$a_8 = 0.01935$ $b_8 = -0.05246$
$a_9 = 0.03444$ $b_9 = -0.03948$
$a_{10} = 1.10777$ $b_{10} = 0.66851$

d. $Z_a = (-0.04527)(0.60977)$
$+ (-0.04032)(0.95551)$
$+ (-0.03371)(1.53902)$
$+ (-0.02574)(1.64866)$
$+ (-0.01650)(1.85630)$
$+ (-0.00596)(1.87181)$
$+ (0.00595)(2.12823)$
$+ (0.01935)(2.15177)$
$+ (0.03444)(2.23002)$
$+ (1.10777)(2.33796)$
$= 2.5188$

$Z_b = (-0.09198)(0.60977)$
$+ (-0.09230)(0.95551)$
$+ (-0.09010)(1.53902)$
$+ (-0.08597)(1.64866)$
$+ (-0.08013)(1.85630)$
$+ (-0.07264)(1.87181)$
$+ (-0.06345)(2.12823)$
$+ (-0.05246)(2.15177)$
$+ (-0.03948)(2.23002)$
$+ (0.66851)(2.33796)$
$= 0.5176$

e. Compute

$Z_a/Z_b$

e. $Z_a/Z_b = 4.87$

f. To find the lower confidence limit on reliability with confidence coefficient $\gamma$, use Table VIII and find the value of $L^*(Z_a/Z_b)$ in the column with the desired $\gamma$ heading. It is the exact lower confidence bound for $R(t_o)$, reliability at time $t_o$.

f. Referring to Table VIII,

$L^*(Z_a/Z_b) = L^*(4.87)$

$= 0.939$

So, the lower 95% confidence limit on reliability at 50 hours is 0.939.

3. Method

g. A point estimate of $R(t_o)$, reliability at time $t_o$, is given by

$$R(t_o) = \exp(-\exp(-Z_a/Z_b)).$$

Example

g. Reliability at 50 hours is given by

$$\exp(-\exp(-4.87)) = 0.991.$$

4. For Further Information

a. The method given in this section is from "An Exact Asymptotically Efficient Confidence Bound for Reliability in the Case of the Weibull Distribution," Johns and Lieberman, Technometrics, Vol. 8, No. 1, February 1966, pp. 135-175. That paper also includes an estimation method for obtaining a lower confidence limit on reliability for large sample sizes.

b. A graphical technique for obtaining two-sided confidence limits on reliability is given in Section 2.4.2.3.2.1.

## 2.4.3 The Normal Distribution

### 2.4.3.1 Analytical Point Estimation

1. When to Use

Use this method to obtain estimates of $\mu$ and $\sigma$, the mean and standard deviation of the Normal distribution. The choice of this method over the graphical method described in the next topic is a matter of the accuracy desired, with this one yielding the most accurate estimate.

2. Conditions for Use

Failure times must be collected and data must be uncensored.

3. Method

a. The sample mean, $\bar{x}$, is an estimate of $\mu$ and is given by

$$\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n},$$

where

$x_i$ = ith failure time

$n$ = sample size.

Example

a. Suppose 20 units are tested to failure and the following failure times observed:

175 hours
695 hours
872 hours
1250 hours
1291 hours
1402 hours
1404 hours
1713 hours
1741 hours
1893 hours
2025 hours
2115 hours

3. Method

Example

a. (Continued)

2172 hours
2418 hours
2583 hours
2725 hours
2844 hours
2980 hours
3268 hours
3538 hours

Then $n = 20$, so

$$\bar{x} = \sum_{i=1}^{20} \frac{x_i}{20} = 1955.2 \text{ hours}$$

b. The sample standard deviation s is an estimate of $\sigma$ and is given by

$$s = \left( \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{(n-1)} \right)^{1/2},$$

where

$x_i$ = ith failure time

$n$ = sample size

$\bar{x}$ = sample mean.

An alternate form, useful in computer programming of this method is

$$s = \left( \frac{\sum_{i=1}^{n} x_i^2}{(n-1)} - \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n(n-1)} \right)^{1/2}$$

b. The sample standard deviation calculation gives

$s = 886.6$ hours

4. For Further Information

Additional information regarding these estimation methods can be obtained from any text on elementary statistics.

### 2.4.3.2 Graphical Point Estimation

1. When to Use

This method estimates $\mu$ and $\sigma$, the mean and standard deviation when failure times are normally distributed. This method yields a less accurate estimate than the method of the previous topic but requires very minimal calculations.

2. Conditions for Use

a. Failure times must be collected, but may be censored.

b. Normal probability paper is required.

3. Method

a. On normal probability paper, plot the ith failure time in a sample of n ordered failure times on the lower axis vs $i/(n+1)$ on right-hand axis.

Example

a. The sample data used on the example for Section 2.4.3.1 is repeated here, with the necessary plotting positions.

| Failure Time | Plotting Position $i/(n+1)$ |
|---|---|
| 175 hours | 0.05 |
| 695 hours | 0.10 |
| 872 hours | 0.14 |
| 1250 hours | 0.19 |
| 1291 hours | 0.24 |
| 1402 hours | 0.29 |
| 1404 hours | 0.33 |
| 1713 hours | 0.38 |
| 1741 hours | 0.43 |
| 1893 hours | 0.48 |
| 2025 hours | 0.52 |
| 2115 hours | 0.57 |
| 2172 hours | 0.62 |
| 2418 hours | 0.67 |
| 2583 hours | 0.71 |
| 2725 hours | 0.76 |
| 2844 hours | 0.81 |
| 2980 hours | 0.86 |
| 3268 hours | 0.90 |
| 3538 hours | 0.95 |

b. Draw the Normal line of best fit through the plotted points by using the last point plotted as a reference point for a straight-edge and dividing the rest of the points into two

b. Figure 2.4.3.2 is the plot of this data on normal paper. The normal line has been labeled $\ell_1$.

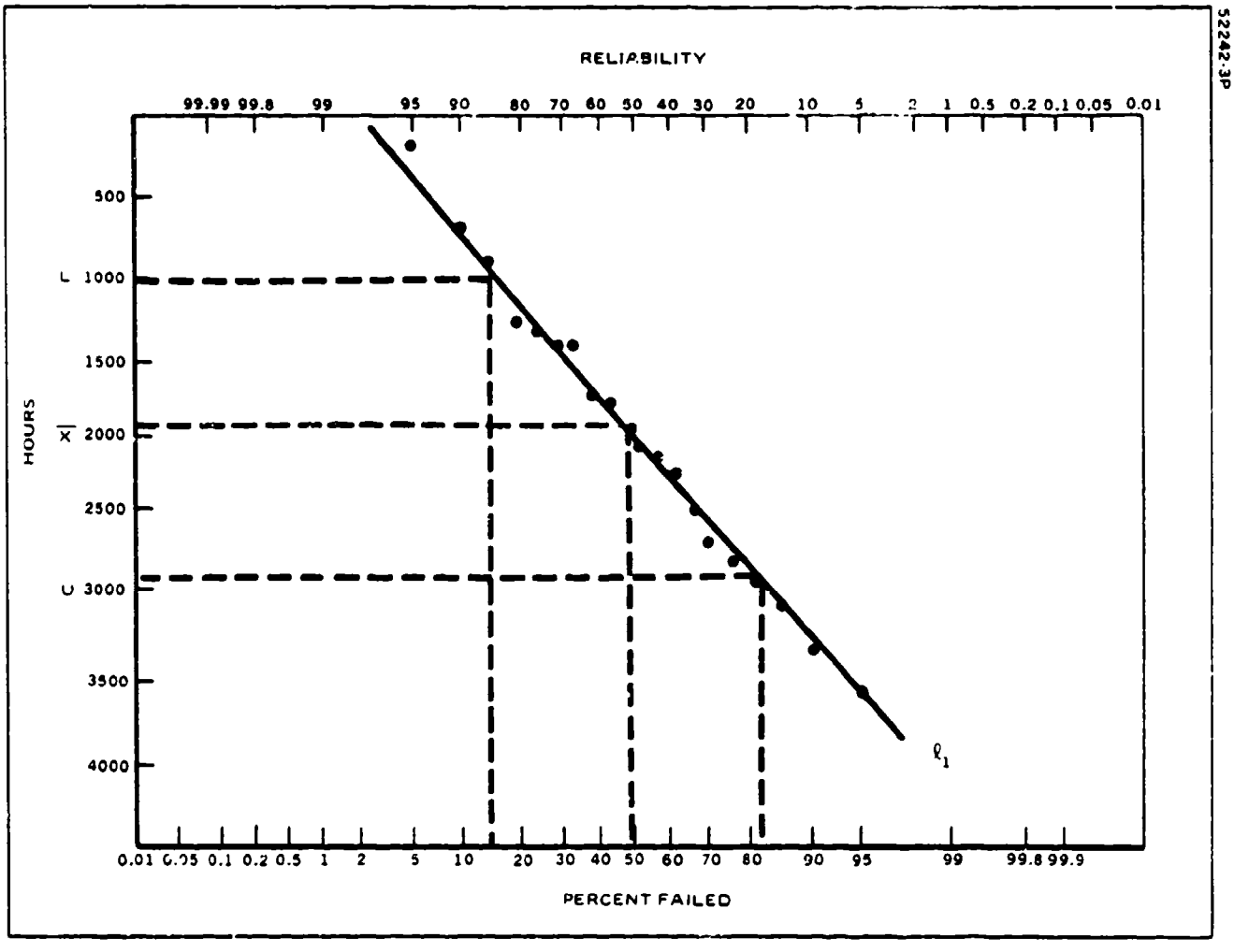



Figure 2.4.3.2. Graphical Point Estimation for the Normal Distribution

| 3. Method | Example |
|---|---|
| b. (Continued)<br><br>equal groups above and below the line. | |
| c. The mean, $\mu$, is estimated by projecting the 50% probability of failure point on the right-hand axis to the normal line and then projecting that intersection point down to the lower axis. The estimate of $\mu$, $\bar{x}$, is read off there. | c. The value of $\bar{x}$ is read off as 1950 hours. |
| d. The estimate of $\sigma$, s, is obtained by projecting the intersection of the 84% probability of failure point on the right-hand axis with the normal line to the lower axis. Call that point on the lower axis U. | d. U = 2900 hours. |
| e. Repeat Step d. with the 16% point. Call the point L. | e. L = 1000 hours. |
| f. The estimate of $\sigma$ is<br><br>$s = \frac{U - L}{2}$ | f. The sample standard deviation, s, is<br><br>$\frac{U - L}{2} = \frac{2900 - 1000}{2} = 950$ hours |

4. For Further Information

Additional examples of the use of this estimation method are presented in most texts on elementary statistics.

2.4.3.3 Interval Estimation

2.4.3.3.1 Small Sample Sizes ($\sigma$ unknown)

1. When to Use

Use this method to obtain confidence limits on the mean of the Normal distribution for sample sizes < 30.

2. Conditions for Use

a. Estimates of the mean and standard deviation must be available. See Section 2.4.3.1 for method of computing.

b. A table of percentiles of Student's t distribution is required.

3. Method

a. To find two-sided* $100(\gamma)$ per cent confidence limits on $\mu$, consult a table of the percentiles of the t distribution, for the value of $t_{(1+\gamma)/2,n-1}$ where t is Student's t with n-1 degrees of freedom.

b. The two-sided confidence limits are given by

$$\bar{x} \pm t_{(1+\gamma)/2,n-1}\, s/\sqrt{n},$$

where $\bar{x}$ = sample mean

$s$ = sample standard deviation

$n$ = sample size

*NOTE: One-sided $100(\gamma)$ per cent confidence limits are given by

$$\text{upper only} \rightarrow \bar{x} + t_{\gamma,n-1}\, s/\sqrt{n}$$

$$\text{lower only} \rightarrow \bar{x} - t_{\gamma,n-1}\, s/\sqrt{n}$$

Example

a. Consider the 20 failure times used as an example in Section 2.4.3.1,

where $\bar{x}$ = 1955.2 hours

$s$ = 886.6 hours

To obtain two-sided 95% confidence limits on $\mu$, the value of t is needed. From a table of percentiles of the t distribution it is seen to be 2.093.

b. The confidence limits are then

$$1955.2 \pm 2.093 \times \frac{886.6}{4.47}$$

$$= (1540.1,\ 2370.3)$$

If it were desired to calculate a lower one-sided 80% confidence limit on $\mu$, it would be given by

$$1955.2 - 0.861 \times \frac{886.6}{4.47}$$

$$= 1784.$$

4. For Further Information

Additional examples demonstrating this method are presented in "Reliability Handbook" edited by W. Grand Ireson, McGraw-Hill, 1966.

2.4.3.3.2 Large Sample Sizes ($\sigma$ unknown)

1. When to Use

Use this method to obtain confidence limits on the mean of the Normal distribution for sample sizes $\geq 30$. If the standards deviation is unknown, Student's t distribution holds. However, for sample sizes of 30 or more the Normal distribution approximates the t distribution.

2. Conditions for Use

a. Estimates of the mean and standard deviation must be available. See Section 2.4.3.1 for method of computing.

b. A table of standardized normal variates is required.

3. Method

a. To find two-sided $100(\gamma)$ confidence limits on $\mu$, consult a table of standardized normal deviates for the value of $z_{(1+\gamma)/2}$, where $z$ is the standardized normal variate and $(1+\gamma)/2$ is the area under the curve to be found in the table.

b. The approximate two-sided confidence limits are given by

$$\bar{x} \pm z_{(1+\gamma)/2}\, s/\sqrt{n}$$

where $\bar{x}$ = sample mean

$s$ = sample standard deviation

$n$ = sample size

c. One-sided $100(\gamma)$ percent confidence limits are given by

upper only $\bar{x} + z_{\gamma}\, s/\sqrt{n}$

lower only $\bar{x} - z_{\gamma}\, s/\sqrt{n}$

Example

a. Suppose, after testing 50 items to failure, the sample mean and standard deviation are found to be

$\bar{x}$ = 3780 hours

$s$ = 1440 hours

by the methods of Section 3.4.3.1. Suppose, it is desired to find two-sided 90% confidence on $\mu$. Then, from a table of standard normal deviates,

$$z_{(1+0.90)/2} = 1.645.$$

b. The confidence limits are then

$$3780 \pm 1.645 \times \frac{1440}{7.07} = (3445, 4115)$$

c. If it were desired to calculate an upper one-sided 99% confidence limit on $\mu$, it would be given by

$$3780 + 2.33 \times \frac{1440}{7.07} = 4255.$$

4. For Further Information

Additional examples describing the use of this method are given in "Reliability Handbook" edited by W. Grant Ireson, McGraw-Hill, 1966.

2.4.4 The Log-Normal Distribution. To treat Log-Normal failure data, one procedure is to first take the natural logarithm of each failure time. Then use the methods of Section 2.4.3, the Normal distribution, on the logarithms. The advantage of this procedure is that tables of the standardized Normal deviates may be used in working with the logarithms of the failure times, since they are Normally distributed.

An alternate procedure for treating Log-Normal data is to use Table IV in Appendix II. Its advantage is that logarithms of the failure times do not have to be computed.

Use of Table IV

| Method | Example |
|---|---|
| a. For n Log-Normally distributed failure times $x_i$, compute<br><br>$\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n}$<br><br>and<br><br>$s = \left( \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n - 1} \right)^{1/2}$ | a. Consider the following set of 6 Log-Normally distributed failure times:<br><br>5.53 hours<br>5.70 hours<br>6.62 hours<br>7.61 hours<br>8.33 hours<br>8.76 hours<br><br>Then<br><br>$\bar{x}$ = 7.09 hours<br><br>s = 1.36 hours |
| b. To find the $\gamma$ percentile value, located in Table IV the column headed "$\gamma$ Percentile." Read off the value in this column opposite the value of s/x in the left-hand column. Call it p. | b. To find the 5th percentile, that column in the table is consulted and the value located opposite s/x = 1.36/7.09 0.19 is read off as p = 0.72. |
| c. The $\gamma$ percentile is estimated by $p\bar{x}$. | c. The 5th percentile then is 0.72 x 7.09 = 5.1. This can be interpreted as an estimate of the reliability ($R_{0.95}$). |

Additional Applications

a. If it is desired to find some percentile other than those presented in the table the following formula will be useful:

Let $p_i$ = the desired percentile

$\mu_x$ = the mean of the observations which are assumed to be Log-Normally distributed

$\sigma_x^2$ = the variance of the observations which are assumed to be Log-Normally distributed

$Z_i$ = the standard Normal deviate associated with $p_i$

Then

$$p_i = \frac{\mu_x^2}{\left[\mu_x^2 + \sigma_x^2\right]^{1/2}} \exp\left[Z_i \left(\log\left[\frac{\sigma_x^2 + \mu_x^2}{\mu_x^2}\right]\right)^{1/2}\right]$$

b. If the observations are in logarithmic form and a given percentile is desired, the following formula is used:

Let $p_i$ = desired percentile

$\mu_y$ = the mean of the $\log_e x_i$'s

$\sigma_y$ = the standard deviation of the $\log_e x_i$'s

$Z_i$ = the standard Normal deviate associated with $p_i$

Then

$$p_i = \exp(\mu_y + Z_i\sigma_y)$$

For Further Information

The mathematical theory of this distribution is presented in "The Log-Normal Distribution" by Aitchison and Brown, Cambridge University Press, 1957. The analysis methods and tables accompanying this method were developed and prepared by J.G. Frost, Hughes Aircraft Company, Fullerton, California.

2.4.5 The Extreme Value Distribution

2.4.5.1 Analytical Point Estimation

1. When to Use

When the distribution of failure times follows the extreme value distribution, this method is applicable. The parameter estimates are calculated by the method of moments. A graphical method for parameter estimation is presented in the next topic. The decision whether to use the analytical or graphical method rests in the accuracy desired when compared to the calculations to be performed in the method described here.

2. Conditions for Use

Failure times must be known or assumed to follow the extreme value distribution. Random failure times must be observed.

3. Method

a. Observe the failure times from a randomly selected sample.

Example

a. Given the following 30 failure times from a process assuming a largest extreme value (L.E.V.) distribution:

| Failure Time (Hours) | |
|---|---|
| 220 | 453 |
| 230 | 455 |
| 262 | 470 |
| 288 | 476 |
| 289 | 517 |
| 297 | 540 |
| 312 | 550 |
| 315 | 552 |
| 360 | 586 |
| 369 | 588 |
| 394 | 633 |
| 399 | 637 |
| 412 | 657 |
| 431 | 690 |
| 438 | 728 |

b. Calculate estimates of the mean and standard deviation from the sample observations.

b. Using the methods of Section 2.4.3.1, calculate estimates of the mean

$$\bar{x} = 451.6$$

and the standard deviation

$$s = 139.0$$

c. Estimate the parameters $\beta$ and m from the following formula:

$$\hat{\beta} = \frac{\sigma_N}{S}$$

$$\hat{m} = \bar{x} - \frac{\bar{Y}_N}{\hat{\beta}}$$

c. For n=30, Gumbel gives the constants

$$\sigma_N = 1.11238$$

$$\bar{Y}_N = .53662$$

3. Method

c. (Continued)

where $\sigma_N$ and $\bar{Y}_N$ are two constants which are functions of sample size only. A table of these constants is available in Gumbel, "Statistics of Extremes," Columbia University Press, 1960.

d. Estimate the reliability for any time t from the formula

$$R(t) = 1-e^{-e^{-\hat{\beta}(t-\hat{m})}}$$

Example

c. (Continued)

Then

$$\hat{\beta} = \frac{1.11238}{139.0} = .008$$

$$\hat{m} = 451.6 - \frac{.53662}{.008} = 384.5$$

d. The estimated reliability for a mission of 500 hours is

$$R(500) = 1-e^{-e^{-.008(500-384.5}}$$

$$R(500) = .335$$

4. For Further Information

The example presented in this section is for the Largest Extreme Value (L.E.V.) Distribution. The methods for the Smallest Extreme Value (S.E.V.) Distribution are essentially equivalent.

2.4.5.2 Graphical Point Estimation

1. When to Use

When the distribution of failure times is known or assumed to follow the extreme value distribution, this method is applicable. This method yields somewhat less accurate estimates than the analytical method of Section 2.4.5.1 but does not require the performance of calculations.

2. Conditions for Use

Either random or ordered censored observations may be used to estimate the parameters.

3. Method

a. Collect failure times from a random process and couple them with median ranks $\hat{F}(x)$ and calculate

$$\ln \ln \frac{1}{F(x)}$$

Example

a. Given 30 random failure times from a process assuming an L.E.V. distribution. Obtain median ranks for n=30 using the method of Section 2.4.2.2 and couple these with the failure times as follows:

3. Method

Example

a. (Continued)

| Median Ranks F(x) | $\ln \ln \frac{1}{1-F(x)}$ | Failure Times (Hours) |
|---|---|---|
| .023 | 1.33 | 220 |
| .056 | 1.06 | 230 |
| .089 | .88 | 262 |
| .122 | .74 | 288 |
| .155 | .62 | 289 |
| .188 | .52 | 297 |
| .220 | .41 | 312 |
| .253 | .32 | 315 |
| .286 | .22 | 360 |
| .319 | .13 | 369 |
| .352 | .04 | 394 |
| .385 | -.05 | 399 |
| .418 | -.14 | 412 |
| .451 | -.23 | 431 |
| .484 | -.32 | 438 |
| .516 | -.41 | 453 |
| .549 | -.51 | 455 |
| .582 | -.61 | 470 |
| .615 | -.72 | 476 |
| .648 | -.84 | 517 |
| .681 | -.96 | 540 |
| .714 | -1.09 | 550 |
| .747 | -1.23 | 552 |
| .780 | -1.39 | 586 |
| .813 | -1.57 | 588 |
| .845 | -1.78 | 633 |
| .878 | -2.04 | 637 |
| .911 | -2.38 | 657 |
| .944 | -2.86 | 690 |
| .977 | -3.76 | 728 |

b. Plot the failure times on the x axis and $\ln \ln \frac{1}{\hat{F}(x)}$ on the y axis and draw a line of best fit through the points.

b. See Figure 2.4.5 for the graph of this data.

c. Estimate parameters b and m from the graph.

c. From the graph the slope is -.0076 and the intercept is 2.85. Then

$\hat{\beta}$ = - the slope = .0076

$\hat{m}\,\hat{\beta}$ = the intercept

3. Method

Example

d. (Continued)

Therefore

$$\hat{m} = \frac{2.85}{.0076} = 380$$

NOTE: These results agree closely with the results of the analytical method Section 2.4.5.1.

4. For Further Information

The example presented in this section is for the Largest Extreme Value (L.E.V.) Distribution. The method for the Smallest Extreme Value (S.E.V.) Distribu[illegible] is essentially the same. Commercial graph paper is available for plo[illegible] the extreme value distribution.

2.4.5.3 Interval Estimation

1. When to Use

When the distribution of failure times follows the extreme value distribution, this method yields an approximate confidence interval or lower confidence bound for reliability.

2. Conditions for Use

This method is applicable if it is assumed that the sample size, n, is large and that the graphical estimates of parameters, $\beta$ and m (see Section 2.4.5.2) are maximum likelihood estimates. The actual maximum likelihood estimate values can be obtained only by iteration.

3. Method

Examples

a. Obtain estimates for the parameters $\beta$ and m using graphical methods of Section 2.4.5.2.

a. From the example in Section 2.4.5.2

$$\hat{\beta} = .0076$$

$$\hat{m} = 380$$

b. Specify the mission time and confidence desired.

b. For a mission time of 300 hours, find a lower 95% confidence bound on reliability.

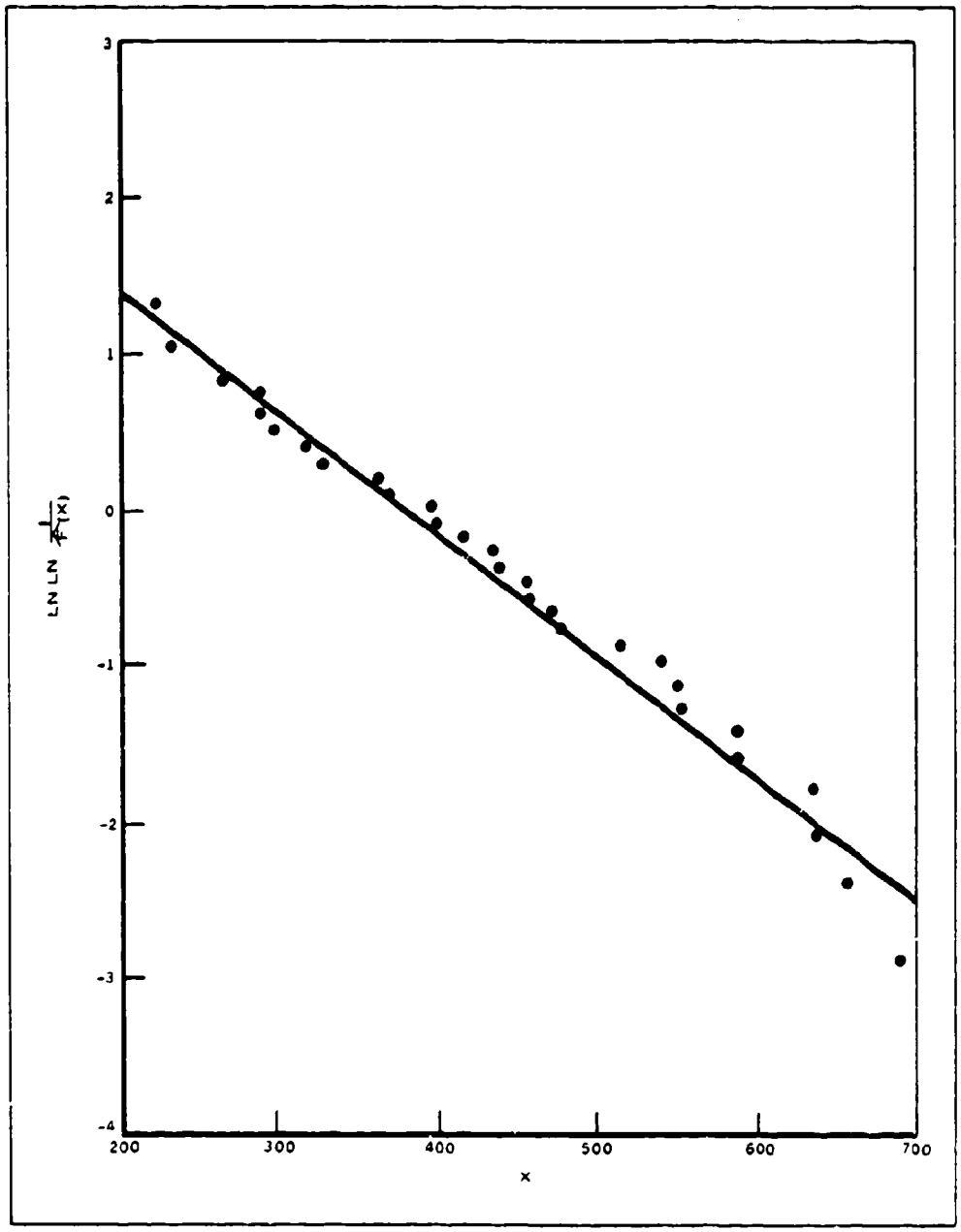



Figure 2.4.5. Plot of Fitted Straight Line for Use With the Extreme Value Distribution

3. Method

c. Perform the following calculations:

$$\hat{\nu} = \hat{\beta}(x - \hat{m})$$

$$c = \sqrt{\frac{6}{N\pi^2}\, Z_{1-\alpha}}$$

$$b = \frac{\pi^2}{6}$$

where

x = mission time
N = sample size
$Z_{1-\alpha}$ = 1-α quantile of the standard normal distribution

Examples

c. The calculations provide the following results:

$$\hat{\nu} = .0076(300-380) = -.6$$

$$Z_{1-.05} = 1.645$$

$$c = \sqrt{\frac{6}{30\pi^2}(1.645)} = .18$$

$$b = \frac{\pi^2}{6} = 1.64$$

d. Calculate a lower bound for $\nu^*$

$$\nu^* = \frac{1}{1-c^2}\left(-.423c^2 + \hat{\nu} + c\sqrt{(\hat{\nu} + .423)^2 + (1-c^2)/b^2}\right)$$

d. $\nu^* = -.52$

e. Calculate a lower bound for reliability as follows:

$$R^* = 1 - \exp\left[-e^{-\nu^*}\right]$$

e. The lower 95% confidence bound for reliability at 300 hours is

$$R^* = 1 - e^{-e^{-.52}}$$

$$R^* = .81$$

4. For Further Information

This example demonstrates the Largest Extreme Value Distribution. The method for the Smallest Extreme Value Distribution is essentially the same.

## 2.4.6 Tests for Increasing Failure Rate

### 2.4.6.1 Distribution Free Test

1. When to Use

When a number of failure times have been observed and the probability distribution is unknown this test may be used to determine if the observations are from a distribution with a decreasing, constant or increasing failure rate. The test is non-parametric and was originally proposed by M.G. Kendall (1938). The detailed method presented here is from the work of Henry Mann (1945), and from Barlow and Proschan (1964).

2. Conditions for Use

The observed failure times must be arranged in ascending order. A simple computer program will facilitate the calculations. Table A in Appendix II is used in conjunction with the calculations to define the values required to hypothesize whether the failure rate is decreasing constant or increasing.

3. Method

a. Arrange the observed failure times ($x_i$'s) in ascending order.

b. Compute $T_i$ for each adjacent pair of failure times as follows:

$$T_1 = x_1$$

$$T_2 = x_2 - x_1$$

$$T_3 = x_3 - x_2$$

$$T_n = x_n - x_{n-1}$$

c. Compute $D_i$ for each $T_i$ as follows:

$$D_1 = nT_1$$

$$D_2 = (n-1)T_2$$

$$D_3 = (n-2)T_3$$

$$D_n = T_n$$

Examples

a. Given the following 8 failure times arranged in ascending order:

2,6,9,12,14,16,17,18

b. In this example, the $T_i$'s are

$$T_1 = 2$$

$$T_2 = 6-2 = 4$$

$$T_3 = 9-6 = 3$$

$$T_4 = 12-9 = 3$$

$$T_5 = 14-12 = 2$$

$$T_6 = 16-14 = 2$$

$$T_7 = 17-16 = 1$$

$$T_8 = 18-17 = 1$$

c. The $D_i$'s are

$$D_1 = 8 \cdot 2 = 16$$

$$D_2 = 7 \cdot 4 = 28$$

$$D_3 = 6 \cdot 3 = 18$$

$$D_4 = 5 \cdot 3 = 15$$

$$D_5 = 4 \cdot 2 = 8$$

$$D_6 = 3 \cdot 2 = 6$$

$$D_7 = 2 \cdot 1 = 2$$

$$D_8 = 1 \cdot 1 = 1$$

3. Method

d. Generate a $V_{ij}$ statistic by comparing each set of two $D_i$'s.

LET $V_{ij} = 1$ if $D_i > D_j$ for all $i,j = 1,2 \ldots n$, with $i<j$

$V_{ij} = 0$ otherwise

e. Generate the test statistic

$$V_n = \sum_{i<j} V_{ij}$$

f. Now enter Table X of the Appendix with $V_n$ and the desired level of significance.

Example

d. Since n=8, there will be $\binom{8}{2} = \frac{8!}{2!6!} = 28$ comparisons of $D_1$ through $D_8$ as follows:

$V_{12} = 0$, since $D_1 \Phi_2 = 16<28$

$V_{13} = 0$, since $D_1 \Phi_3 = 16<18$

$V_{14} = 1$, since $D_1 \Phi_4 = 16>15$

In a similar manner the following $V_{ij}$'s are assigned values of 1 since $D_i > D_j$:

$V_{15}, V_{16}, V_{17}, V_{18}, V_{23}, V_{24}, V_{25},$

$V_{26}, V_{27}, V_{28}, V_{34}, V_{35}, V_{36}, V_{37},$

$V_{38}, V_{45}, V_{46}, V_{47}, V_{48}, V_{56}, V_{57},$

$V_{58}, V_{67}, V_{68}, V_{78}$

e. From step d

$V_n = 26$

f. Enter Table X of the Appendix with n=8 and an $\alpha$=.10 level of significance. Following across the row n=8, the closest value to .10 is .089 which corresponds to an observed $V_n$ of 8. Therefore, if $V_n$ had been from 0 to 8 it could have been concluded at a .089 level of significance that the failure rate was decreasing.

In this example it is desired to test for an increasing failure rate since $V_n = 26$.

Table X in the Appendix is symmetrical; therefore, an .089 level of significance corresponds

3. Method

Example

f. (Continued)

to $V_n = 20$. Since $V_n = 26 > 20$, it can be concluded that the failure rate is increasing.

4. For Further Information

For the full derivation of this method refer to "Nonparametric Tests Against Trend," Henry Mann, Econometrica, Vol. 13, 1945, and "Mathematical Theory of Reliability," by Barlow and Proschan, John Wiley & Sons, 1964, pp. 232-233.

For an example of the use of the method on empirical data, refer to RADC TR-66-425 "Accelerated Reliability Testing for Nonelectronic Parts," September 1966, AD 803 484.

The table from Mann's paper which is reproduced as Table X in Appendix II covers sample sizes up to n=10. Above n=10, tables of the standardized normal distribution can be used because Mann proved that $V_n$ is asymptotically normally distributed with mean $\frac{n(n-1)}{4}$ and a variance of $\frac{2n^3 + 3n^2 - 5n}{72}$.

2.4.6.2 Test Based on Probability Limits and Weibull Assumptions.

1. When to Use

When a set of part failure times has been generated and it is desired to test if the underlying distribution of failure times is exponential ($\beta$ = Weibull shape parameter = 1). In effect, this becomes a form of goodness-of-fit test for deciding between the exponential and Weibull distributions.

2. Conditions for Use

a. The sample size must be greater than 5.

b. The $\beta$ (estimate of Weibull shape parameter) must have been calculated from the empirical data by the maximum likelihood method of Section 2.4.2.1.2.

c. Table IX in Appendix II is required.

3. Method

a. Observe and record part failure times.

b. Calculate the Weibull shape parameter by the maximum likelihood method of Section 2.4.2.1.2.

c. Decide on the desired significance for the test for exponentiality.

d. Enter Table 1X with the sample size (N), the upper percentage points, and the lower percentage points of the probability interval.

e. Compare the probability limits with the calculated value of $(\hat{\beta})$, the Weibull shape parameter. If $\gamma_L \leq \hat{\beta} \leq \gamma_U$, then it can be stated that $\beta = 1$ and hence, the data is from an exponential distribution.

Example

a. Given the following 20 failures times

| | | | |
|---|---|---|---|
| 92 | 325 | 640 | 1010 |
| 130 | 420 | 700 | 1020 |
| 233 | 430 | 710 | 1280 |
| 260 | 465 | 770 | 1330 |
| 320 | 518 | 830 | 1690 |

b. From this same data and from the example in Section 2.4.2.1.2 the Weibull shape parameter is 1.62.

c. For this example, it is desired to have 10% significance level for the hypothesis test (an arbitrary decision).

d. Enter the table at N=20, $\gamma_L$=.95, $\gamma_U$=.05. The tabled values for a 90% probability interval are 0.690 and 1.264.

e. Since $\hat{\beta}$ = 1.62 is not contained in the interval 0.690 - 1.264, then the hypothesis that $\hat{\beta}$ is from a distribution with $\beta$ = 1 (exponential) cannot be supported. The alternate hypothesis is that the failure times were from a distribution with an increasing hazard rate, since $\hat{\beta} > 1.264$.

4. For Further Information

The method presented here is from a paper by D.R. Thoman, L.J. Bain and C.E. Antle. The paper was titled "Inferences on the Parameters of the Weibull Distribution" and was published in Technometrics, Vol. 11, No. 3, August 1969, pp. 445-460.

## 2.4.7 Outlier Tests

### 2.4.7.1 Early Failures

1. When to Use

When an early failure is suspected not to belong to a population of failures which fits a particular failure distribution, this method may be

employed to determine if an early failure occurred too early to be included in the population.

2. Conditions for Use

a. There must be engineering justification for suspecting the early failure to be unrelated to the main group of failures. Such justification might be based upon a difference in failure modes for example.

b. Failure times must be collected.

c. A sample size of at least 20 in the main group is necessary.

3. Method

a. For an early suspect failure time $x_o$, compute $F(x_o)$, the cumulative distribution function, with parameters estimated from the main group of failure times only, evaluated at $x_o$.

b. Compute

$$p = (1 - F(x_o))^n$$

where

n = sample size of main group of failures.

c. If $p > 0.95$, omit the suspect failure time. It probably does not belong to the population determining the distribution of failure times.

Example

a. Consider a Weibull sample of size 20 with parameters, estimated from the 20 failure times by the method of Section 2.4.2.1.1.

$\hat{\beta} = 1.5$

$\hat{\alpha} = 2 \times 10^{10}$ cycles. To examine an early failure at $10^5$ cycles, compute

$$F(10^5) = 1 - \exp\left(\frac{-10^5 \times 1.5}{2 \times 10^{10}}\right) = .00158$$

b. $p = (1 - .00158)^{20} = 0.969$.

c. Since $p = 0.969 > 0.95$, the early failure time does not belong to the population.

4. For Further Information

If $p \leq 0.95$, recalculate estimates for the parameters of F(x) with $x_o$ included in the group.

2.4.7.2 Late Failures

1. When to Use

When a later failure is suspected not to belong to a population of failures which fits a particular failure distribution, this method may be employed to determine if a late failure occurred too late to be included in the population.

2. Conditions for Use

There must be engineering justification for suspecting the late failure to be unrelated to the main group of failures. Such justification might be based upon a difference in failure modes for example. A sample size of at least 20 in the main group is needed.

3. Method

a. For a late suspect failure time $x_o$, compute $F(x_o)$, the cumulative distribution function, with parameters estimated from the main group of failure times only, evaluated at $x_o$.

b. Compute

$$q = (F(x_o))^n$$

c. If $q > 0.95$, omit the suspect failure time. It does not belong to the population determining the distribution of failure times.

d. If $q \leq 0.95$, recalculate estimates for the parameters of $F(x)$ with $x_o$ included in the group.

Example

a. Consider a Weibull sample of size 20 with parameters, estimated from the 20 failure times by the method of Section 2.4.2.1.1,

$$\hat{\beta} = 1.5$$

$$\hat{\alpha} = 2 \times 10^{10} \text{ cycles}$$

To examine a late failure at $2 \times 10^7$ cycles, compute

$$F(2\times10^7) = 1-\exp\left(\frac{-2\times10^{7\times1.5}}{2\times10^{10}}\right) = 0.988$$

b. $q = (0.958)^{20}$

$= 0.794$

c. $q = 0.794 \geq 0.95$

d. Since $q = 0.794 \leq 0.95$, the failure time $2 \times 10^7$ cycles does belong to the population. So, it is necessary to repeat the estimation of the Weibull distribution parameters $\beta$ and $\alpha$ from Section 2.4.2.1.1 with $n = 21$ and the failure time $2 \times 10^7$ cycles included.

## 3.0 RELIABILITY SPECIFICATIONS

3.1 Introduction. The purpose of a reliability specification is to fix the reliability component of mission effectiveness by quantifying required reliability characteristics for the part, equipment, or system. In order to achieve this purpose the reliability specification must be stated in complete and unambiguous terms. A reliability demonstration test will verify whether or not the requirement is satisfied.

Ambiguous requirements may result in an item that passes the demonstration but is not effective with respect to the requirements, and vice versa. For example, to state that a part must have a life of 1000 hours is ambiguous. The intention of such a specification could be: to require all such parts to survive 1000 hours; to require all such parts to have a 1000 hour MTBF; to require 90% (on the average) of all such parts to have 1000 hours; or any number of requirements. Moreover, in an unambiguous statement, the true intention of the specification must be accurately stated. For example, if the reliability requirement is that a part must survive 100 hours with 90% probability it is often tempting to "convert" this requirement to an MTBF specification based on exponentially distributed lifetimes. For an exponential distribution an MTBF of 1000 hours is roughly equivalent to a 100 hour survival probability of .90 (since $\exp(-100/1000)=\exp(-.1)=.9048$). Specifying a 1000 hour MTBF would be approximately equivalent to the requirement in the exponential case. However, if lifetimes are actually Weibull distributed with survival function given by

$$\exp(-(t/308)^2),$$

then the mean of this distribution is only 273 hours, and yet the survival probability for 100 hours is

$$\exp(-(100/308)^2)=\exp(-.105)=.90$$

which satisfies the original requirement. Imposing the 1000 hour mean life would thus cause overdesign. Also, this part actually meets the reliability requirement of survival of 100 hours with .90 probability, but would probably fail the corresponding reliability demonstration test that is designed to a 1000 hour MTBF requirement.

Many of these difficulties are alleviated when the underlying life distribution is exponential. In this case, it is sufficient to specify mean life, and knowing the mean determines all other quantifiable reliability measures associated with the exponential distribution. The exponential distribution has been the life distribution of choice in the electronics industry because of compelling evidence (both empirical and theoretical) which makes it suitable for describing lifetimes for complex electronic units whose failure modes are not wear-out related. Consequently, much effort has been spent in developing and updating MIL-STD-781C, "Reliability Design Qualification and Production Acceptance Tests: Exponential Distribution." And, in view of the success of the exponential distribution in the analyses of section 2 of this notebook concerning its applicability to nonelectronic parts, in many cases specifying mean life will be adequate for nonelectronic parts as well.

In summary, reliability can be quantified in many ways: mean life, median life, probability of mission survival, etc. A reliability specification may be any one or more such quantities depending on the underlying reliability requirements, and/or life distribution. The reliability specification must accurately reflect the underlying reliability requirements, and be both semantically and quantitatively unambiguous.

3.2 Reliability Specification for the Exponential Distribution. The survival function (or reliability function) for the exponential distribution is $R(t)=\exp(-t/\theta)$, $t>0$, where $\theta$ is the mean life. The most direct way to specify any reliability requirement in the context of the exponential distribution is to convert the requirement to a requirement on mean life. The specification of mean life or, equivalently, MTBF, is particularly convenient in subsequent reliability demonstration test design since MIL-STD-781C is based on MTBF specifications. This, along with the fact that the exponential distribution is uniquely determined by the mean life (making MTBF an unambiguous specification) should establish MTBF as the best form of reliability specification. The following table presents formulae for converting various reliability requirements to MTBF in the exponential case.

| RELIABILITY MEASURE | CORRESPONDING MTBF |
|---|---|
| Failure Rate | $\theta$ = 1/(Failure Rate) |
| Probability of survival for t hours = r | $\theta = -t/\ln(r)$ |
| x(p) = the p quantile life (i.e. x(p) = the life beyond which the part will live with probability 1-p) | $\theta = -x(p)/\ln(1-p)$ |

The following examples should clarify these concepts.

Example 1.

The reliability requirement for an equipment is expressed as a failure rate of 250 failures per million hours. The corresponding MTBF requirement is (1/250)(1,000,000) hours = 4000 hours.

Example 2.

The reliability requirement for an equipment is expressed as a probability of mission ( = 1000 hours) survival of .99. The corresponding MTBF requirement is -1000/ln(.99) = 99,499 hours.

Example 3.

The .10 quantile life requirement for an equipment is 1000 hours. The corresponding MTBF requirement is -1000/ln(1-.10) = 9,491 hours.

In order to use MTBF specifications in a reliability demonstration test from MIL-STD-781C, it is necessary to specify the upper (acceptable) test MTBF ($\theta_0$), the lower (unacceptable) test MTBF ($\theta_1$), the producer's risk $\alpha$, and the consumer's risk $\beta$. Further details may be found in MIL-STD-781C.

3.3 Reliability Specification for the Weibull Distribution. The two parameter Weibull survival function is given by

$$R(t) = \exp(-(t/b)^c),\ t > 0,\ b > 0,\ c > 0.$$

The parameter b is called the scale parameter (also, characteristic life), and the parameter c is called the shape parameter. The following table lists common reliability measures in terms of these parameters.

| RELIABILITY MEASURE | FORMULA |
|---|---|
| Mean Life | $b\,\Gamma(1+1/c)$, where $\Gamma$ is the usual Gamma function. |
| p quantile, x(p), i.e. the life beyond which the equipment will survive with probability 1-p. | $b(-\ln(1-p))^{1/c}$ |
| Characteristic Life, i.e. x(.632) | b |

Since the Weibull distribution is a two-parameter distribution, any unambiguous reliability specification must involve two quantities. For example, specifying (b,c) directly would be sufficient, although not much physical significance can be attached to the parameter c. Other specifications which would also be sufficient would be mean life and the .90 quantile life; the .50 and .90 quantiles; or characteristic life (b) and .95 quantile life. These possibilities are summarized in the following table.

| RELIABILITY SPECIFICATION | CORRESPONDING VALUES OF (b,c) |
|---|---|
| Mean Life, $\theta$, and p quantile x(p). | Must be found by iteratively solving:<br>$\theta = b\,\Gamma(1+1/c)$<br>$x(p) = b(\ln(1/(1-p)))^{1/c}$ |

| RELIABILITY SPECIFICATION | CORRESPONDING VALUES OF (b,c) |
|---|---|
| Two quantiles x(p),x(q). | $c = \frac{\ln[\ln(1/\{1-q\})/\ln(1/\{1-p\})]}{\ln[x(q)/x(p)]}$ <br> $b = \frac{x(p)}{[\ln(1/\{1-p\})]^{1/c}}$ |
| Characteristic Life, b, and the quantile x(p). | b is the Characteristic Life <br> $c = \frac{\ln[\ln(1/\{1-p\})]}{\ln[x(p)]-\ln(b)}$ |

It is not often practical to specify reliability in terms of the Weibull or any other two parameter distribution because the corresponding reliability demonstration test procedures are cumbersome. Moveover, since there are two parameters involved, there is no "OC curve" as in the case of MIL-STD-781C for the exponential distribution. Finally, and most importantly, there is no natural ordering of the parameter pairs (b,c). That is, given that "acceptable" values have been established for the parameters (b,c), there is no obvious logical way to assign "unacceptable" values to (b,c). For example, the pairs (b,c)=(308.6,2) and (b,c)=(212,3) both determine Weibull distributions having 100 hours as the .10 quantile. The respective mean lives are 273 hours, and 189 hours, so that the pair (b,c)=(308.6,2) appears more acceptable. However, the .05 quantiles for the pairs (b,c)=(308.6,2) and (b,c)=(212,3) are 69.9 hours and 78.8 hours, respectively. Thus, from this point of view, the pair (b,c)=(212,3) is more acceptable since 78.8 hours are survived with probability .95, whereas for the pair (b,c)=(308.6,2) only 69.9 hours are survived with probability .95.

One way to alleviate this problem is to fix one parameter for all cases. This is the same as assuming that one parameter, either b or c, is known exactly. Since neither b nor c is ever known exactly in practice, this is an unacceptable solution.

3.4 Reliability Specification Without Respect to a Particular Underlying Life Distribution. In many instances, there is no evidence to suggest a feasible parametric (e.g. exponential, Weibull) life distribution for the equipment on which reliability is to be specified. Also, it is often the case that when a two-parameter life distribution is appropriate, the reliability requirement is only sufficient to determine one of the parameters. Moreover, in a two-parameter model, it is not always clear how to specify acceptable values for the parameters versus unacceptable values even when the reliability requirements are sufficient to determine both parameters.

When these situations arise, there is a type of reliability specification which can be used in conjunction with reliability demonstration tests which do not assume any particular underlying parametric life distribution (so-called nonparametric tests). These specifications are life distribution quantiles.

This type of specification has already been discussed in the sections on reliability specification for the exponential distribution. There, however, it was suggested that these quantiles be used to compute corresponding MTBFs to facilitate the use of MIL-STD-781C. The p quantile of the life distribution (denoted by x(p)) is the life beyond which the equipment will live with probability 1-p. The p quantile x(p) can be specified directly, or indirectly, by specifying the probability of survival for a fixed time period. For example, specifying that with .90 probability the equipment shall survive 1000 hours is equivalent to stating that the .10 quantile of the life distribution shall be 1000 hours, i.e. x(.10)=1000 hours. In many cases, it is of interest to place some requirement on some measure of central tendency of the life distribution, e.g. mean life. While mean life does not lend itself to nonparametric demonstration tests, median life does, since median life is x(.50), the .50 quantile of the life distribution. Indeed, when mean life is specified, the reliability engineer is often (mistakenly, in general) thinking of median life, i.e. that life beyond which 50% of the equipments will survive, on the average.

The following table summarizes the strategy for specfying reliability in cases where no particular underlying parametric life distribution is assumed. These types of specifications can be used directly in the nonparametric test plan discussed in section 5.

| RELIABILITY SPECIFICATION | WHEN TO USE |
|---|---|
| x(.50), the median life. | Requirements concern a measure of central tendancy of the life distribution. |
| The probability of surviving a fixed time T. | Requirements concern a particular mission length T which the equipment must survive with high probability. |
| x(p), $0 < p < .5$. | See above. |

## 4.0 SPECIAL APPLICATION METHODS FOR RELIABILITY PREDICTION

4.1 Introduction. This section is concerned with the estimation of reliability of mechanical and electromechanical components in service. We are not concerned herein with the classical estimation problems faced by statisticians which are described in Section 2 but with practical examples where the engineer is required to create an estimate of reliability from whatever data he can find. The methods described in this section involve the use of "engineering experience" or judgment to extend what is usually meager sampling information to obtain meaningful comparisons of materials, designs, and environments.
It is only through the application of engineering judgment to available data that an estimate of reliability in service can be created. The consequence of such methods will of necessity be a point estimate rather than an interval estimate because the probability distribution of the estimator cannot be obtained.

4.2 Background for Reliability Prediction Model Development.
Nonelectronic components have numerous failure modes as compared to electronic components. Some of the more basic failure modes which affect this class of components are fatigue, creep, impact, thermal shock, corrosion, oxidation, fretting-corrosion, elastic deformation, relaxation, lubrication failure, wear, spalling, erosion, leakage, delamination, buckling, and radiation damage. Detailed discussion of these failure modes may be found in ASME (1965). In a proper reliability assessment the dominant mechanisms must be identified and considered since each mechanism represents a competing failure risk with its own failure distribution.

Several possible approaches are available for the model development, each of which has definite merit but is also subject to limiting constraints.

One approach is through the analysis of accelerated life test results. This approach presupposes that a large number of devices has been tested or is currently being tested in combinations representing the various technologies, processes, etc. The results of such controlled tests would provide some indication of the characteristics and peculiarities of the devices as a function of the several configurations, stresses and applications included in the test design. However, the extrapolation of these accelerated test results to more normal operating conditions would be open to questions of validity due to the uncertainties regarding the extrapolation algorithm. Further, while test data under controlled accelerated conditions should aid in understanding the reliability characteristics, it is difficult to obtain data that covers the wide range of technologies and stress conditions that would be necessary in order to place major dependence on this approach alone.

An alternate approach involves the development of a reliability model and its parameters based on a knowledge of fabrication techniques and the anticipated failure modes. Also required by this approach is a thorough understanding of the fundamental physical/metallurgical/chemical/electrical degradation mechanisms involved, as well as the proportionate weighting of these mechanisms in translating to the various configurations the component may assume.

A third approach would be to rely solely on the collection and reduction of empirical operating data where the pertinent information with respect to the model parameters would be extracted using suitable statistical techniques. This approach should provide optimal applicability since the field data reflect the actual reliability experience of the devices operating in their use environment. However, it requires the collection and reduction of a large database on the entire range of device configurations and application environments in order to evaluate each of the critical factors. In some cases, particularly with new devices, the amount of data needed to provide sufficiently accurate results may not be available.

The best approach endeavors to utilize the collective data and knowledge offered by all three approaches and subject it to careful, analytical scrutiny to censor out conflicting and discrepant information. This approach includes the following tasks: a literature review to define the component, equipment and environmental attributes which will be considered during model development, derivation of the preliminary model form, data collection, data reduction and analysis, development of the model parameters, and model refinement and verification.

Regardless of the approach taken, the derived model should have the following attributes:

- verified accuracy over the total range of all factors considered
- an uncomplicated approach using easily accessible information on component characteristics and environmental parameters
- dynamic, flexible expression, easily modified to accommodate new techniques
- appropriate discrimination against design and usage attributes which may degrade reliability

The simultaneous attainment of all of the above objectives is difficult, if not impossible. Often these goals are contradictory or mutually exclusive. As an example, some years ago a prediction model was proposed for microcircuits which possessed commendable accuracy over the range of parameters and was based on sound theoretical considerations. Unfortunately, to use the model, the engineer was required to input such information as metallization area, total diffusion area and other such fabrication/design information. Since this information was not available on vendor specification sheets and indeed was often vendor-proprietary, the model proved to be useless. Modifying the model to use more generic but readily available device parameters degraded the accuracy of the model. The overall utility of the model, however, was enhanced. A discussion of modeling and model limitations can be found in Flint et. al. (1982).

In reviewing the literature it becomes obvious that an abundance of models have been advanced for use in the prediction of nonelectronic component reliability. Unfortunately, most have been found to be deficient in one or

more of the areas below and as a consequence cannot be included in this section:

- Not application-oriented
- Not yet "engineer-ready"
- Not verified
- Single-vendor specific
- Requires information not easily available

4.3 Graphical Approaches to Reliability Prediction. The graphical approach discussed below briefly provides a means of translating meager information into a reliability estimate.

The information is most likely vendor supplied and thus may be optimistic, based on limited test data, or in the worst case represents a design objective. For these reasons, unless prior experience dictates otherwise, assumptions must be conservative in nature. For example, if an $L_{10}$ (life time beyond which 90% survive) supplied by the vendor is based on small sample tests or if the vendor is unwilling to discuss the matter, the $L_{10}$ life should be reduced by one-half as a minimum.

The ambiguity regarding life frequently must be clarified. Life may mean average, median, some period of time/cycles by which some percent will fail on the average, or the time to first failure among a population.

Weibull probability paper is a most useful tool available when the use of a graphical solution is necessary. When the shape or slope parameter, $\beta$, is equal to one, the distribution reduces to the exponential; an approximation of the lognormal distribution results from values of $\beta$ in the range of 1.5 - 3, and the normal distribution approximation results from a $\beta$ value of 3.5. With an estimate of some percentile of life, an assumption of the value of $\beta$, and the use of Weibull paper, the probability of failure before time x, say F(x), and the reliability, 1 - F(x), for any lifetime can be determined.

In those cases when a failure rate must be used in a prediction, it must be remembered that only for the special case of the exponential distribution, i.e., $\beta = 1$, will the failure rate be constant with all other values of $\beta$ greater than one resulting in an increasing failure rate. In the latter case an average failure rate over a stated time period may be calculated employing the average cumulative hazard function, H(t). The expression is (assuming $1-F(x) = \exp\{-(x/\alpha)^{\beta}\}$):

$$\bar{H}(t) = \frac{t^{\beta-1}}{\alpha^{\beta}}. \qquad \text{(Wilson, et. al (1977).}$$

Alternate notation for $\bar{H}(t)$ is $\bar{\lambda}(t)$.

4.4 General Theory of Interference. When the strength of a component is less than the stress imposed on it, a failure can be expected to occur. Strength is the ability of a component to resist failure when subjected to stress. Stress or load may be defined as a mechanical load, dimensional variation, environment, temperature, etc. Since both strength and stress are variables, they may be described by probability distributions.

The strength of nominally identical components can be expected to vary due to variations in materials, dimensions, treatments, surface conditions, and so on. This variability can be described by a distribution function. Various approaches to estimating the strength distribution function are given in Bompass-Smith (1969), Burns (1975), Konno et. al. (1975), ASME (1965), Nilsson (1975), Thomas et. al. (1975), and Welker et. al. (1975). Most typically, however, so little will be known that both the form of the distribution and the variability about the mean will have to be assumed. Unless experience dictates otherwise, the strength variable is often assumed to be normally distributed with standard deviation equal to 5 - 15 percent of the normal value (Fulton, 1983).

The distribution of operational stresses can only be known to a reasonable certainty when the response of a reasonable number of prototypes to the full spectrum of operating conditions has been closely observed. Due to such constraints as time, cost, etc., the distribution of stress cannot be established and assumptions must be made. Further information regarding the estimation of the stress distribution may be found in Kececioglu et. al. (1964, 1967), and Fiderer (1976).

If the expected distributions of stress and strength can be estimated for a component then by employing interference theory the probability of failure of the component can be calculated. The concept is presented in detail in Kececioglu et. al. (1964), Disney et. al. (1968), Lipson et. al. (1973), Kapur et. al. (1977), Kececioglu (1972, 1974, 1977, 1968), Kececioglu et. al. (1974), and Dhillon (1980, 1981).

The mathematical foundations of Interference Theory may be outlined as follows. It is assumed that the stress is a random variable X having probability density function $f_X$ and that the strength is a random variable Y having probability density $f_Y$. It is generally assumed that X and Y are statistically independent (although this assumption is not strictly necessary). The probability of failure, p(f), is then

$$p(f) = P\left|X > Y\right| ,$$

i.e. the probability of failure is the probability that the stress exceeds the strength. An expression may be derived for p(f) as follows.

$$p(f) = P\left|X > Y\right| = \int_{-\infty}^{\infty} \int_{y}^{\infty} f_X(x)\, f_Y(v)\, dxdv$$

$$= \int_{-\infty}^{\infty} f_Y(y) \quad (1 - F_X(y))\, dy$$

where

$$F_X(y) = \int_{-\infty}^{y} f_X(x)\, dx$$

is the cumulative distribution of the random variable X. Thus, the probability of failure is the area beneath the curve $f_Y(y)$ $(1 - F_X(y))$ as y varies over all real numbers. Intuitively, $(1-F_X(y))\, f_Y(y)\, dy$ is the probability that the strength is in the infinitesimal interval (y, y+dy), and that the stress exceeds y. Integrating (or "summing") over all y then gives the total probability that stress exceeds strength.

The area under the curve $f_Y(y)$ $(1 - F_X(y))$ is often referred to as the "interference zone." When the two densities $f_X$ and $f_Y$ coincide (i.e. are exactly equal), the probability of failure is exactly 1/2, although this is by no means the maximum value possible. In fact, when $f_X$ is the normal density with mean $\mu_X$ and variance $\sigma_X^2$, and $f_Y$ is the normal density with mean $\mu_Y$ and variance $\sigma_Y^2$, then it

can be shown that

$$p(f) = \Phi \left( \frac{\mu_X - \mu_Y}{\sqrt{\sigma_X^2 + \sigma_Y^2}} \right)$$

where

$$\Phi(u) = \left(\sqrt{2\pi}\right)^{-1} \int_{-\infty}^{u} e^{-t^2/2}\, dt$$

is the standard normal cumulative distribution function. Hence, for example,

(1) $p(f) = 1/2$, if $\mu_X = \mu_Y$;

(2) $p(f) \to 1$, as $\mu_X \to +\infty$, $\mu_Y$ fixed;

(3) $p(f) \to 0$, as $\mu_Y \to +\infty$, $\mu_X$ fixed;

Thus, p(f) can take any value between zero and one. The explanation of (1) above is that when the mean stress equals the mean strength, it is equally likely for stress to exceed strength and vice-versa. In (2) above, when the mean stress is very large with respect to mean strength, the probability of failure is close to one. In (3) above, when the mean stress is very small with respect to strength, the probability of failure is very small.

The concept of interference is shown in Figure 4.4-1 where the interference zone is given as the shaded area. This illustrates the simple case where the strength distribution remains unchanged across time, i.e., is not affected by exposure to the failure causal stress distribution. Figure 4.4-2(a) and (b) illustrates the case where the strength distribution degrades as a function of time exposure to stress as the result of such failure mechanisms as fatigue, corrosion, and wear. Whether this time shift must be considered or may be dismissed depends of course on the rate of change expected. For example, in a naval environment corrosion is a rapid failure causal mechanism and the effect on the strength distribution must be considered; on the other hand, in most military ground fixed applications corrosion is a weak failure causal mechanism and the effect on the strength distribution may be ignored.

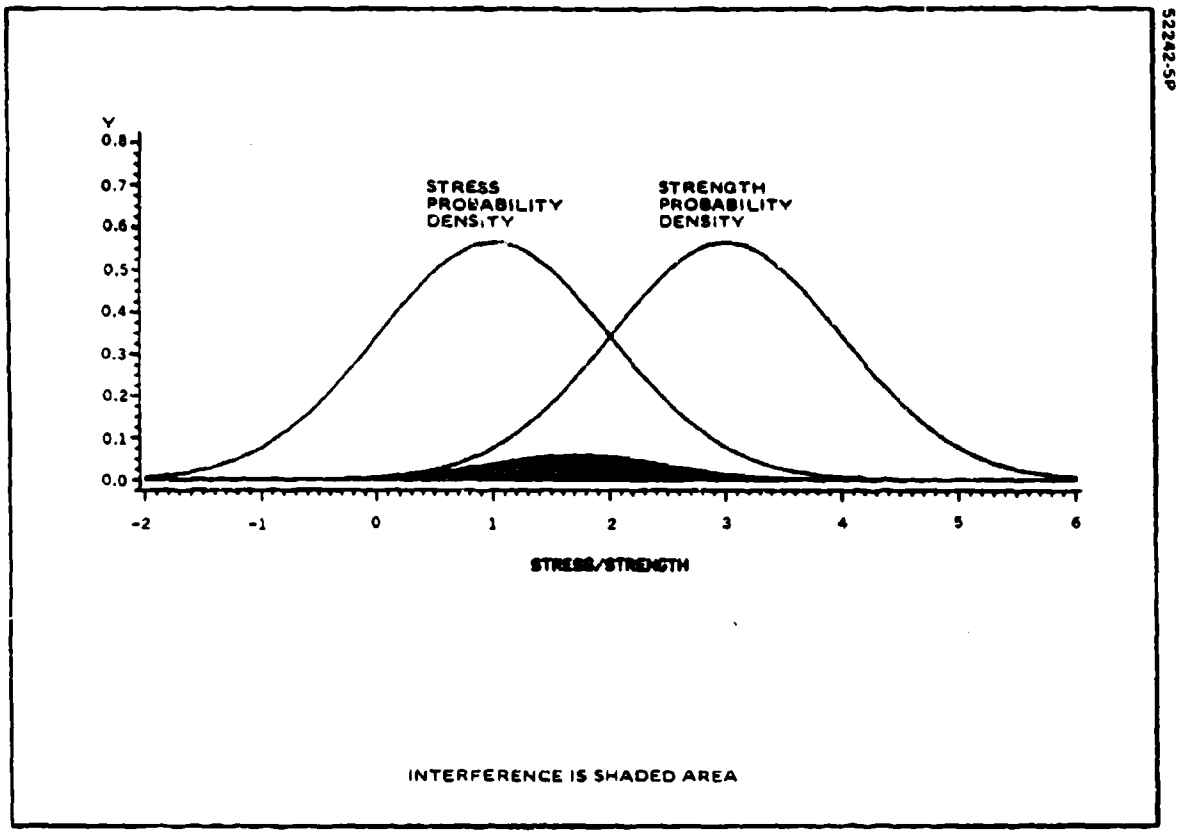



Figure 4.4-1. Illustration of the Concept of Interference

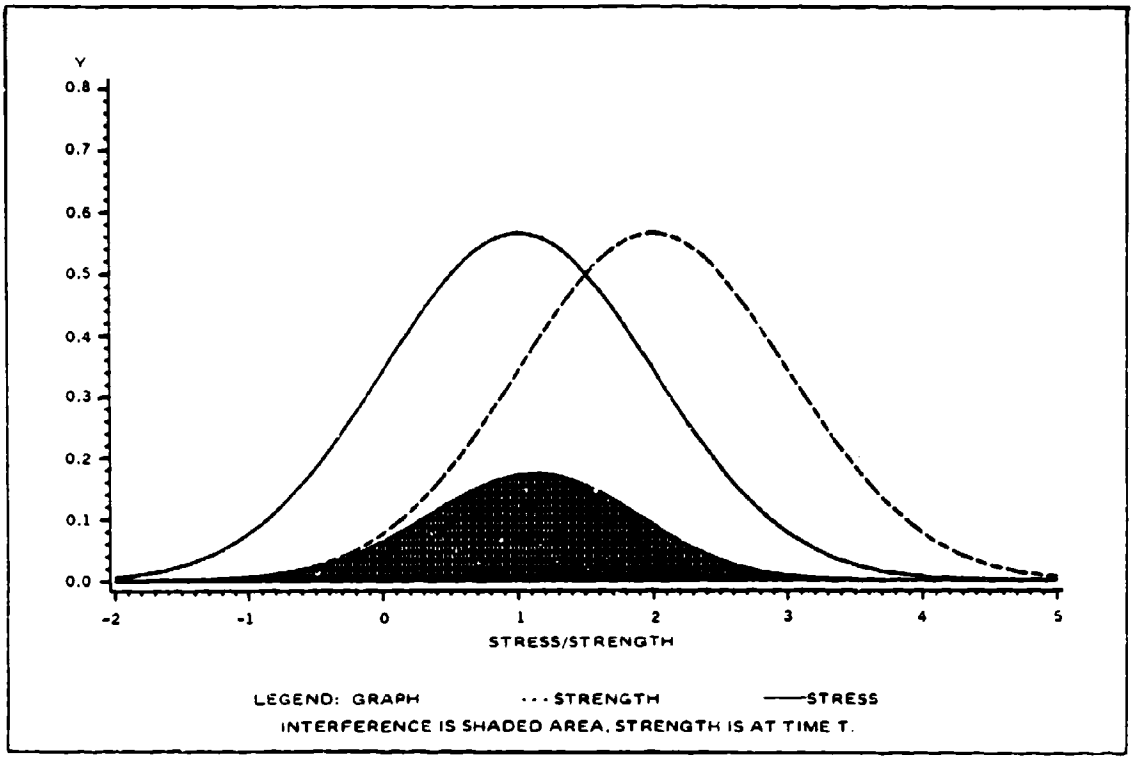



Figure 4.4-2(A) Time Varying Strength Density

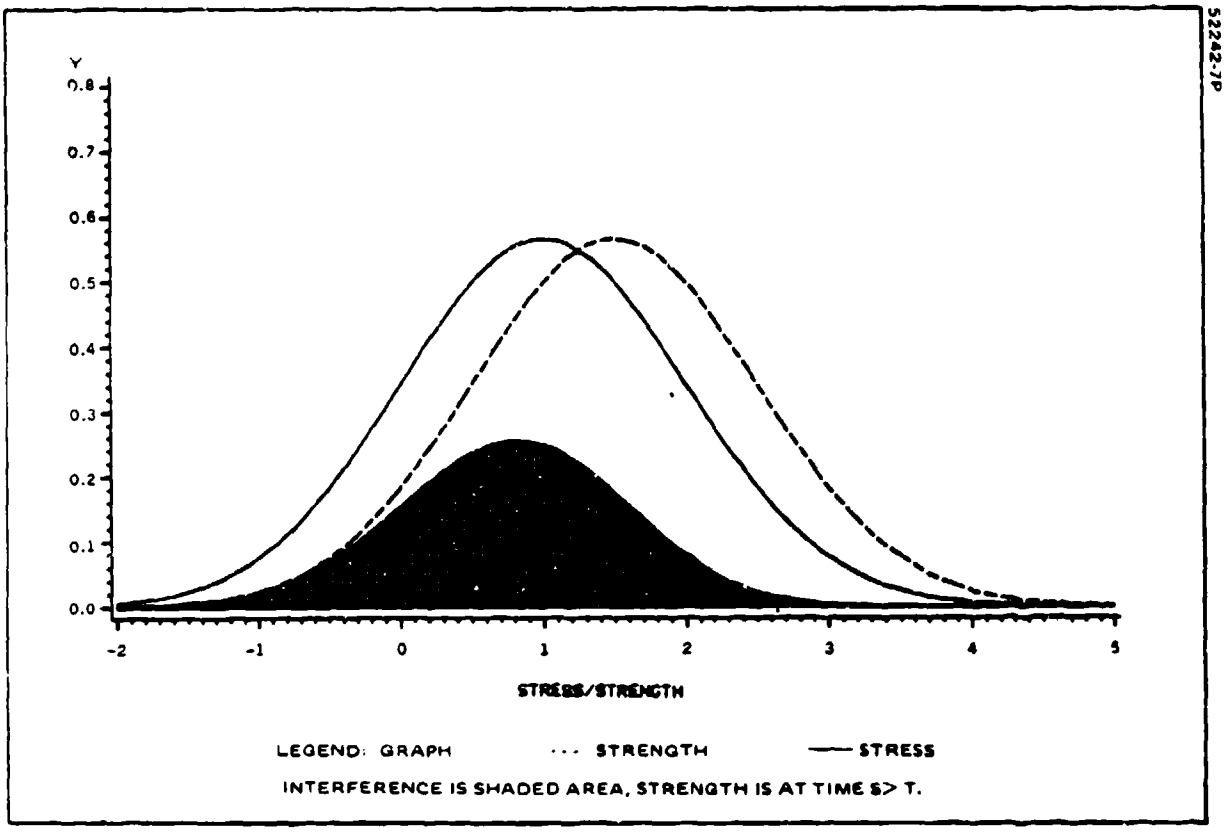



Figure 4.4-2(B) Time Varying Strength Density

## 4.5 Applications of Interference Theory to Reliability Prediction Methodology

Source: RADC-TR-66-710 (March, 1967) by Charles Lipson et. al., entitled "Reliability Prediction-Mechanical Stress/Strength Interference Models."

RADC-TR-68-403 (December, 1968) by Charles Lipson et. al., entitled "Reliability Prediction-Mechanical Stress/Strength Interference (Nonferrous)."

4.5.1 Purpose. The purpose of this method is to obtain a point estimate of reliability in service for mechanical components subject to fatigue failure. The method is applicable to:

a) Components subjected to completely reversed cyclic bending from axial, or torsion loads.

b) Components subjected to a combination of static and cyclic loads.

4.5.2 Description of Method. Given that strength and service stress each have a probability distribution of known type, and that the parameters of the two distributions are known, the probability that a random observation from the strength distribution exceeds a random observation from the stress distribution is equal to the reliability. The term "interference" is used to designate an occurrence where stress exceeds strength, so that reliability is the probability of no interference.

The source documents provide extensive tables giving the probability of failure as a function of the parameters for the following combinations of distributions:

| Strength Distribution | Stress Distribution |
|---|---|
| Weibull | Normal |
| Weibull | Weibull |
| Normal | Normal |
| Largest Extreme Value | Normal |
| Smallest Extreme Value | Normal |

These tables are perfectly general, and may be used for other types of failure than fatigue. However, the two reports tabulate parameters for fatigue failure only. Nonstandard symbols for the parameters are used in these tables. Table 4.5.1 shows their relationship with generally accepted symbols.

Several tables have been compiled in the source documents giving fatigue strength parameters for virtually all of the common ferrous, nonferrous, and light metal alloys, subjected to completely reversed bending or axial stresses. Included are the effect of heat treatment, surface finish, stress concentrators, temperature, and frequency.

TABLE 4.5.1. PARAMETERS OF TABULATED PROBABILITY DISTRIBUTIONS AS USED IN RADC-TR-68-403 (LIPSON, et. al. 1968)

1. Weibull Distribution:

$$R(x) = \exp\left[-\left(\frac{x - x_o}{\theta - x_o}\right)^b\right] \qquad x_o < x < \infty$$

x is the variable

3 parameters:
- $x_o$ is the lower bound of x
- $\theta$ is the characteristic strength
- b is the slope parameter

This compares with the usual 3-parameter Weibull distribution

$$R(x) = \exp\left[-\frac{(x-\gamma)^\beta}{\alpha}\right] \qquad \gamma < x < \infty$$

as follows:

$\gamma = x_o$

$\beta = b$

$\alpha = (\theta - x_o)^b$.

2. Normal Distribution:

The unit normal deviate is characterized as

$$Z = \frac{x - \mu}{\sigma}$$

which agrees with standard notation.

3. Extreme Value Distribution

For the Smallest Extreme Value (S.E.V.) distribution,

$$R(x) = \exp\left[-e^{\beta(x-M)}\right] \quad , \quad -\infty < x < \infty$$

x is the variable

2 parameters:
- $\beta^{-1}$ is the scale parameter
- M is the location parameter .

TABLE 4.5.1. PARAMETERS OF TABULATED PROBABILITY DISTRIBUTIONS AS USED IN RADC-TR-68-403 (LIPSON, et. al. 1968) (Continued)

This compares with the usual 2-parameter S.E.V. distribution,

$$R(x) = \exp\left[-e^{\alpha(x-u)}\right],$$

as follows:

$$\alpha = \beta$$

$$u = M .$$

For the Largest Extreme Value distribution, the same relationship holds, where

$$R(x) = 1 - \exp\left[-e^{-\beta\,(x-M)}\right].$$

Note: in 1), 2) and 3) above, R(x) is the reliability function.

The procedure for estimating reliability using the interference method takes several forms depending upon the assumptions made regarding the strength distribution and the stress distribution. The various methods are illustrated with numerical examples in the source documents.

## 4.6 Application of Interference Theory for Normally Distributed Strength and Normally Distributed Stress

Source: (1) Fiderer, Leo, "Design For Reliability in Hostile Environment," Microelectronics and Reliability, Vol. 15, Supplement, Pergamon Press, 1976, pp. 75-85.

(2) Lipson, Charles, Statistical Design and Analysis of Engineering Experiments, McGraw-Hill, 1973.

4.6.1 Purpose of the Method. To obtain a point estimate of reliability in service for non-electronic components. The method may be applied to a diverse number of failure causal factors.

4.6.2 Description of the Method. The description of interference of stress and strength distributions given in 4.4 applies equally to this method. The difference lies in the assumption that the random variables, which may take various distribution forms, may be approximated by a normal distribution so that in practical calculations normal distributions may be assumed without excessive error.

The steps involved in the procedure are as follows:

(1) Estimate the mean, $\mu_L$, and standard deviation, $\sigma_L$ of the load, L, and $\mu_s$ and $\sigma_s$ of the strength, S.

Where there is no information available to estimate $\sigma_L$ or $\sigma_s$ a value may be assumed from the interval $.05\mu$ - $.15\mu$. Where the part is critical or a high reliability requirements exists, a worse-case approach should be taken, i.e., in the range of $.10\mu$ to $.15\mu$. For most conditions $\sigma$ may be taken as $.09\mu$.

(2) Define the difference between strength and load as a new random variable D:

$$D = S - L,$$

with mean $\mu_D = \mu_s - \mu_L$,

and

standard deviation $\sigma_D = \sqrt{\sigma_s^2 + \sigma_L^2}$.

(3) The probability of failure, P(f), is found by computing:

$$P(f) = P\{D < 0\} = P\{S-L < 0\}$$

$$= P\left\{\frac{D-\mu_D}{\sigma_D} < \frac{-\mu_D}{\sigma_D}\right\}$$

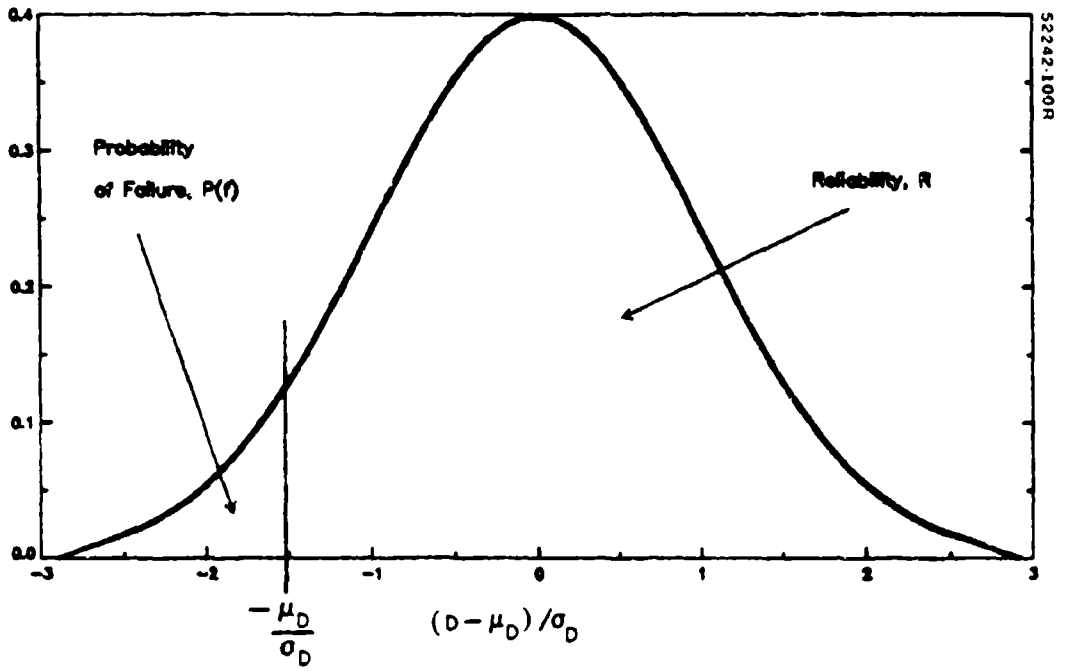



Figure 4.6.2-1.
Normalized Density Function of Excess Strength Over Load.

$$= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{-\mu_D/\sigma_D} \exp\{-t^2/2\}\, dt.$$

Thus, P(f) is found by entering a table of the cumulative distribution function of a standard normal random variable with the value $-\mu_D/\sigma_D$. See figure 4.6.2-1.

(4) The reliability R is then

$$R = 1-P(f).$$

4.6.3 Examples

4.6.3.1 Shaft and Bushing Reliability. The reliability of a shaft and a bushing after ten years exposure (in a nonoperating state) to a heavy industrial environment is to be determined, i.e., the ability of the shaft to rotate without drag.

The dominant failure mechanism is considered to be corrosion. Information on corrosion rates and corrosion product build-up is available from the Battelle operated Metals and Ceramics Information Center.

In the analysis it will be assumed that the part dimensional variability is normally distributed and that the maximum and minimum allowable dimensions may be taken as the upper and lower three sigma points, respectively.

Part Specifications

Shaft - Stainless Steel
Dia. .123 - .124
Corrosion Rate $3.5 \times 10^{-5}$ in/year loss
Corrosion Products $.7 \times 10^{-5}$ in/year buildup
Net Gain $3.5 \times 10^{-5}$ in/year

Bushing - Aluminum Chromated
I.D. .125 - .127 in.
Corrosion Rate $6 \times 10^{-5}$ in/year loss
Corrosion Products $7.8 \times 10^{-5}$ in/year buildup
Net Gain $1.8 \times 10^{-5}$ in/year

The maximum and minimum diameter 3σ points after ten years based on the buildup of corrosion products are:

Shaft
Max $3\sigma_s = .124 + 3.5 \times 10^{-5} \times 10 \times 2 = .1247$
Min $3\sigma_s = .123 + 3.5 \times 10^{-5} \times 10 \times 2 = .1237$
$6\sigma_s = .1247 - .1237 = .001$
$\sigma_s = \frac{.001}{6}$
$\mu_s = .1242$

Bushing

$$\text{Max } 3\sigma_B = .128 + 1.8 \times 10^{-5} \times 10 \times 2 = .12764$$
$$\text{Min } 3\sigma_B = .125 + 1.8 \times 10^{-5} \times 10 \times 2 = .12464$$
$$6\sigma_B = .12764 - .12464 = .003$$
$$\sigma_B = \frac{.003}{6}$$
$$\mu_B = .12614$$

The unreliability or probability of failure, p(f), is evaluated by establishing a new random variable D:

$$D = B - S$$

with mean $\mu_D = \mu_B - \mu_s = .00194$

and standard deviation $\sigma_D = \sqrt{\sigma_B^2 + \sigma_L^2} = 5.27 \times 10^{-4}$

Thus, $$P(f) = P\left\{ D < 0 \right\} = P\left\{ (D-\mu_D)/\sigma_D < -\mu_D/\sigma_D \right\}$$

$$= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{-\mu_D/\sigma_D} \exp\left\{ -t^2/2 \right\} dt.$$

From a table of the standard normal cumulative distribution entered at $-\mu_D/\sigma_D = -.00194/(5.27 \times 10^{-4})$ $-3.68$, it follows that

$$P(f) = 0.0001$$

and the reliability is:

$$R = 1-P(f) = .9999.$$

4.6.3.2 Lifting Eye Reliability. A lifting eye intended to be used in lifting shipboard equipment while the ship is at sea has a nominal strength of 60,000 lbs. The dead weight load is 12,000 lbs. This is all the information available to the reliability analyst.

It will be assumed that both the strength and load can be represented by normal distributions and that the nominal strength and load are the means of the distributions.

$$\mu_s = 60,000 \qquad \mu_L = 12,000$$

The variability of the tensile strength should be controllable such that the standard deviation may be assumed to be eight percent of the mean strength. However, the load due to the dynamics of wave/ship action may be quite variable. Thus, the load standard deviation will be assumed to be twenty percent of the mean load.

$$\sigma_s = .08\mu_s = 4,800 \qquad \sigma_L = .2\mu_L = 2,400$$

The probability of failure is evaluated by forming the new random variable:

$$D = S - L$$

where

$$\mu_D = \mu_s - \mu_L = 48{,}000, \text{ and } \sigma_D = \sqrt{\sigma_s^2 + \sigma_L^2} = 5366.$$

thus,

$$p(f) = P\left|D < 0\right| = P\left\{\frac{D-\mu_D}{\sigma_D} < \frac{-\mu_D}{\sigma_D}\right\} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{-\mu_D/\sigma_D} \exp\left|-t^2/2\right| \quad dt$$

where

$$-\mu_D/\sigma_D = -48000/5366 = -8.9.$$

From a table of the standard normal cumulative distribution function the value of P(f) is approximately 0.

Thus the reliability is

$$R = 1 - P(f) = 1.$$

4.6.3.3 Diaphragm Reliability. Calculate the reliability of a diaphragm intended to be used in a one-shot device. Each diaphragm must pass 5 cycles of a worst-case pressure-time profile proof test as acceptance criteria. The purchaser has specified the lower 3 sigma point to be 5 test cycles.

A small sample size population has been tested to failure which resulted in an estimate of a mean lifetime of 11.44 proof tests. The sample size was not large enough to prove the lifetimes to be normally distributed.

It will be assumed that the proof test lifetimes of the production population will be normally distributed with a mean of 11.44 test times and a $\sigma$ of 2.147.

Denoting by L the lifetime in proof tests of the diaphragm, and noting that this is a one-shot device and therefore the diaphragm needs only to survive one test, it follows that the probability of failure is

$$P(f) = P\left|L < 1\right| = P\left|\frac{L-\mu}{\sigma} < \frac{1-\mu}{\sigma}\right| \text{ where } \frac{1-\mu}{\sigma} = (1 - 11.44)/$$

2.147 = -4.86. Referring to a table of the standard normal cumulative distribution function, it follows that

$$P(f) = .000000605$$

and then

$$R = 1 - P(f) = .999999395$$

4.7 Application of the Average Failure Rate Method for Grease Lubricated Rolling Element Bearings

Source: Wilson, D.S., and Smith, R., "Electric Motor Reliability Model," RADC-TR-77-408, December, 1977 (AD 050179).

4.7.1 Purpose of Method. To obtain an estimate of the average failure rate of grease lubricated rolling element bearings over a related time period.

4.7.2 Description of Method. The method consists of an empirical mathematical model which provides an estimate of the Weibull characteristic life, $\alpha$, and was developed through the use of regression analysis and a large data base. Essential tables are provided.

The average failure rate is obtained by averaging the Weibull cumulative hazard function over the time period of interest.

A modification has been made in the characteristic life model so that it is valid for a single bearing rather than for a population of first failures of pairs of bearings as given in the source. The method employed is given in Ang (1970) under Suspended Item Tests.

The characteristic life model is based primarily on the effect of temperature on the lubrication qualities of grease and such secondary effects as quality, bore size, speed, grease, and load. The consideration of load as a secondary factor is consistent with good design practice which limits the loads on grease-lubricated bearings to 15 percent or less of rated load capacity.

The models are as follows:

$$\bar{\lambda}_t = \frac{t^{1.878}}{\alpha_B^{2.878}} \qquad (1)$$

$$\alpha_B = \frac{1.241}{10^{\left[\frac{2342}{T} + q - 4.32\ DN\times10^{-6} + Kg - .001N\left(\frac{W}{SP}\right)^{1.5}\right]}} + \frac{1}{10^{\left[\frac{-4760}{T} + 19.7\right]}} + 300$$

where

t = time for which failure rate is required (in hours)

$\alpha_B$ = bearing characteristic life (in hours)

q = quality factor

DN = bearing bore (mm) x speed (RPM)

T = bearing operating temperature (degrees Kelvin)

$K_g$ = grease constant

N = RPM

W = load in pounds

SP = Specific dynamic capacity at 33 1/3 RPM in pounds

TABLE 4.7.1. QUALITY FACTORS

| | |
|---|---|
| Military Specification | .12 |
| Commercial | -.27 |

TABLE 4.7.2. $K_g$ GREASE CONSTANT

| Source | Oil | Thickener | MIL-Spec. | Max. T°C | $K_g$ |
|---|---|---|---|---|---|
| 1 | Diester | Sodium and Solid Lubricant | MIL-G-3278A | 170 | 1.35 |
| 2 | Diester | Lithium | MIL-G-3278A | 120 | 1.55 |
| 3 | Silicone | Lithium | - - - - | 150 | 1.74 |
| 4 | Mineral | Sodium | MIL-G-18709A | 150 | 1.41 |
| 5 | Silicon | Lithium | MIL-L-15719A | 177 | 1.81 |
| 6 | Synthetic Hydrocarbon | Non-soap | MIL-G-81322 | 170 | 1.74 |

4.7.3 Examples

Example 1

Determine the average failure rate of a bearing with the following specifications for an operating period of 10,000 hours.

Military quality

Grease 5

Bore Dia. 13 mm

Bearing Operating Temp. 30°C

Speed 3600 RPM

Load 10 lbs

Specific Dynamic Capacity 505 lb (from bearing manufacturer's catalog)

Then:

q (quality factor) = .12 (Table 4.7.1)

$K_g$ (grease constant) = 1.81 (Table 4.7.2)

DN = Bore D x speed = 13 x 3600 = 46800

T = 30 + 273 = 303°K

Using Eq. 2

$$a_B = \frac{1.241}{\frac{1}{10^{\left[\frac{2342}{303} + .12 - 4.32 \times 4680 \times 10^{-6} - 1.81 - .001 \times 3600\left(\frac{10}{505}\right)^{1.5}\right]}} + \frac{1}{10^{\left[\frac{-4760}{303} + 19.7\right]}} + 300}$$

$$= \frac{1.241}{\frac{1}{10^{6.009}} + \frac{1}{10^{3.990}} + 300}$$

$$= \frac{1.241}{9.8 \times 10^{-7} + 9.928 \times 10^{-5}}$$

= 12378 hrs.

Using Eq. 1

$$\bar{\lambda}_{10,000} = \frac{(10,000)^{1.878}}{(12378)^{2.878}} = .000054$$

or 54 failures per million hours.

NOTE: This $\bar{\lambda}$ is valid only if the bearing is replaced at the end of the 10,000 hours of operation.

Example 2

Determine that period of operation, t, for the bearing of Example 1 that will result in the average failure rate equal to 20 failures per million hours.

Solve Eq. 1 for t

$$t = \left(\bar{\lambda} \times a^{2.878}\right)^{\frac{1}{1.878}}$$

$$= \left[20 \times 10^{-6} \times (12378)^{2.878}\right]^{\frac{1}{1.878}}$$

$$= 5886 \text{ hrs.}$$

4.8 Reliability Prediction Method - Rolling Bearings Oil Lubricated

Source:

(1) International Organization for Standardization ISO 281/1-1977(E), "Rolling Bearings - Dynamic Load Ratings and Rated Life - Part 1: Calculation Methods."

(2) Marks' Standard Handbook for Mechanical Engineers, 8th ed., McGraw-Hill, 1977, pp. 8-136 through 8-142.

4.8.1 Purpose of the Method. To obtain a point estimate of the reliability in service of rolling bearings.

4.8.2 Description of the Method. Standard formulas have been developed to predict the $L_{10}$ life of a bearing under any given set of conditions. These formulas are based on an exponential relationship of load to life which has been established from extensive testing.

$$L_{10} = \left(\frac{C}{P}\right)^{K} \times 10^{6} \text{ cyc.}$$

where

$L_{10}$ = the number of revolutions that 90 percent (on the average) of a population of bearings will complete or exceed without failure, i.e., R = .9.

C = basic load rating, lbs.

P = equivalent radial load, lb.

K = 3 for all bearings, 10/3 for roller bearings.

To convert to hours of life ($L_{10}$), this formula becomes

$$L_{10} = \frac{16{,}666.67}{N} \left(\frac{C}{P}\right)^{K} \qquad (2)$$

where N = rotational speed, rpm.

The basic load rating, C, value is readily obtainable from any bearing manufacturer's catalog. All bearing loads are converted to an equivalent radial load, P. Equation 3 is the general expression used for both ball and roller bearings.

$$P = XR + YT \qquad (3)$$

where

R = radial load, lb.

T = thrust (axial) load, lb.

X = radial factor

Y = thrust factor.

The X-Y factors may be calculated using the methods described in Source 1 or, with some loss in precision, average values may be selected from Table 3, pp. 8-140 of Source 2.

One further formula is necessary to adjust the $L_{10}$ life for other levels of reliability and less than optimum operating conditions.

$$L_n = a_1 a_2 a_3 L_{10} \qquad (4)$$

where:

$a_1$ = life reliability factor

$a_2$ = material properties factor

$a_3$ = operating conditions factor.

The reliability factors are given in Table 4.8-1.

TABLE 4.8-1: LIFE ADJUSTMENT FACTOR OF RELIABILITY, $a_1$, (From Source 1)

| Reliability % | $L_n$ | $a_1$ |
|---|---|---|
| 90 | $L_{10}$ | 1 |
| 95 | $L_5$ | 0.62 |
| 96 | $L_4$ | 0.53 |
| 97 | $L_3$ | 0.44 |
| 98 | $L_2$ | 0.33 |
| 99 | $L_1$ | 0.21 |

The life adjustment factor for material, $a_2$, has not been quantified on the basis of material characteristics but rather on test results and bearing applications. In general an $a_2$ value of one applies. However, a value greater than one may apply to bearings made of steel of low impurity content or of special analysis. Values of $a_2$ should be obtained from the bearing manufacturer or from Zaretsky (1971).

Operating conditions which remain to be taken into account are the adequacy of the lubrication (at the operating speed and temperature) and conditions causing changes in material properties (i.e., high temperature causing reduced hardness). The influence on bearing life of such conditions may be considered by the application of a life adjustment factor $a_3$.

The calculation of basic dynamic load rating and basic rating life assumes that bearing life is limited principally by sub-surface fatigue, i.e., that the rolling elements and the ring (washer) raceways are sufficiently separated by a lubricant to make the probability of failures caused by surface distress negligible. Where this requirement if fulfilled, $a_3 = 1$, provided a lower value does not apply, for example, because of a change in material properties caused by the operating conditions.

Reduction of $a_3$ values should be considered whenever the viscosity of the lubricant is less than 13 $mm^2/s$ (1 $mm^2/s$ = 1 cST) for ball bearings or 20 $mm^2/s$ for roller bearings at the operating temperature and/or where the rotational speed is exceptionally low (revolutions per minute times pitch dia. in mm less than 10,000). Values of $a_3$ greater than 1 may be considered only where the lubrication conditions are particularly favorable.

In most cases, discussions with the bearing manufacturer regarding the specifics of the application will help in quantifying a value for $a_3$. Carter (1972) should also be reviewed for guidance.

## 4.9 Reliability Prediction Method - Spur Gear Systems

Source: Savage, M., C.A. Paridon, and J.J. Coy, "Reliability Model for Planetary Gear Trains," U.S. Army Aviation Research and Development Command, AVRADCOM TR 82-C-6.

4.9.1 Purpose of the Method. To estimate the gear system life which will result in a 90 percent probability of survival.

4.9.2 Description of the Method and Example. In the design of a transmission to carry power, high strength alloy steels are normally used in key elements to help minimize the transmission's size for a given power and speed rating. As a result, the endurance limit of soft ductile steels is replaced by a higher capacity which gradually decreases with the load cycle count. Key elements, such as bearings and gears are designed on a life basis in order to keep their size reasonable.

This finite life design for lives greater than $10^7$ load cycles is common practice in the design of bearings. It is the intent of this approach to extend the Weibull reliability, life and load theory to the gears as well as the bearings and to combine the component lives in a consistent fashion in order to predict the transmission reliability and life as a function of the applied load and its critical component capabilities.

Although this theory will apply just as well to a simple gear reduction or any transmission composed of bearings and gears, the presented example will be for the planetary reduction in the main rotor box of a light helicopter. A schematic diagram of a three planet reduction with the ring gear fixed and the sun gear as input is shown in Figure 4.9-1.

In this transmission the overall ratio is 5:1 and the output planetary spider or arm is to be rotated at 300 RPM. The power transmitted by the transmission is to be 200 horsepower (150 kw). The input speed of the sun gear is 1500 RPM. The gears are all 20° full depth AGMA toothed gears with a diametrical pitch of 6 $in^{-1}$ (Ng/Dg) (a module of 4.23 mm). They are all made of case hardened A151 9310 vacuum arc remelt steel with a material constant of 21,000 psi (144 MPa). The sun gear has 24 teeth and a 4 inch pitch diameter (102 mm). The planet gears have 36 teeth each and a 6 inch (153 mm) pitch diameter. And the ring gear which is internal has 96 teeth and a pitch diameter of 16 inches (466 mm). All the gears have a 0.725 inch face width (18.4 mm).

The planet bearings are the other key elements in the transmission. These bearings are 75-02 single row cylindrical roller bearings with a 1 inch width (25 mm) and an outside diameter of 5 1/8 inches (130 mm). These bearings have a nominal basic dynamic capacity of 18,200 pounds (81 kn) each.

Since the transmission is isolated from external side and thrust loads by outside bearings, these three bearings and five gears comprise the critical elements in the transmission. It is assumed that their loading is sufficiently light to prevent early tooth rupture or bearing brinelling. It is assumed that the life of each component is based on Hertzian stress pitting fatigue and that the strength in this mode is continually reduced with load cycles.

In order to combine the reliabilities of the transmission components into a consistent system reliability, all component load cycles will be reflected

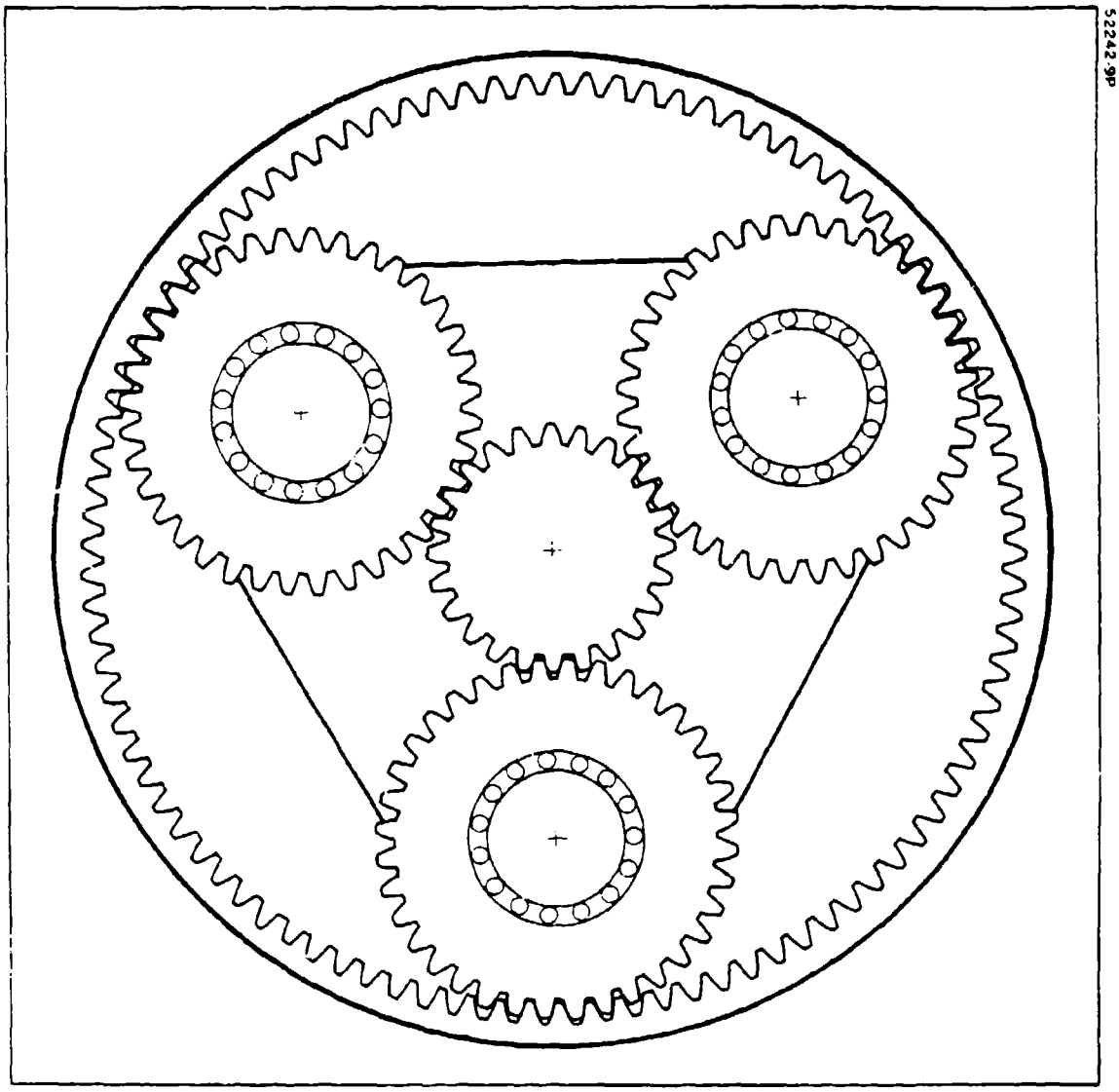



Figure 4.9-1. Planetary Gear Reduction

into a common counting basis of input sun rotations. This requires a little kinematics.

For a planetary gear train, the number of relative rotations of the plant gear with respect to the planet spider or arm in terms of input sun rotations is:

$$\theta_{P/A} = \frac{R_S\ R_R}{R_P(R_S + R_R)}\ \theta_S$$

where the subscripts denote the respective gears: S - sun, R - ring and P - planet. The R's represent the respective gear radii. Thus:

$$\theta_{P/A} = \frac{-2(8)}{3(2+8)}\ \theta_S = -0.533\ \theta_S$$

The negative sign indicates rotation in the opposite direction to $\theta_S$. Since the speeds are proportional to the number of revolutions

$$\omega_{P/A} = -0.533\ (1500) = -800\ \text{RPM}.$$

Since the loads on the gears and bearings are stationary with respect to the planetary spider or arm, we are also interested in the number of relative rotations of the sun gear and the ring gear with respect to the arm in terms of input sun rotations:

$$\theta_{S/A} = \frac{R_R}{R_S + R_R}\ \theta_S = \left(\frac{8}{2+8}\right)\ \theta_S$$

$$\theta_{S/A} = 0.8\ \theta_S$$

$$\omega_{S/A} = 0.8\ (1500) = 1200\ \text{RPM}$$

and

$$\theta_{R/A} = -\frac{R_S}{R_S + R_R}\ \theta_S = \frac{-2}{2+8}\ \theta_S$$

$$\theta_{R/A} = -0.2\ \theta_S$$

$$\omega_{R/A} = -0.2\ (1500) = -300\ \text{RPM}$$

The forces on the components can be found from the power and input speed.

$$T_i = \frac{\text{Power}}{\omega_S}\ \left[63025\ \frac{\text{lb-in RPM}}{\text{HP}}\right]$$

$$T_i = \frac{200}{1500}\ (63025) = 8403\ \text{lb-in}$$

where $T_1$ is the total input torque on the sun gear.

As shown in Figure 4.9-2, this torque produces equal tangential tooth loads $F_T$ and a planet bearing load of twice this value,

$$F_T = \frac{T_1}{nR_S} = \frac{8403}{3(2)}$$

$$F_T = 1400.5 \text{ lbs}$$

$$F_B = 2F_2 = 2801 \text{ lbs}$$

This assumes equal load sharing among the planets and no dynamic loading in the gear meshes.

Given these loads, one can determine the $\ell_{10}$ lines and effective dynamic capacities of the five components in terms of their own load cycle counts. The two basic relationships for each element are:

$$\ln \frac{1}{S} = \left[\ln \frac{1}{.9}\right] \left(\frac{\ell}{\ell_{10}}\right)^E$$

where S is the reliability of the component for $\ell$ load cycles and $\ell_{10}$ is the number of cycles at this load for which the component has a reliability of 90 percent and E is the Weibull shape parameter for this reliability distribution. Normally E is taken as 1.2 for roller bearings (it may be as high as 1.5 for tapered roller bearings) and as 2.5 for gears based on testing at NASA Lewis Research Center. The second relationship is that for basic dynamic capacity, or:

$$\ell_{10} = \left(\frac{C}{F}\right)^p$$

where C is the basic dynamic capacity of the component, or the load at which 90 percent of the units will last for $10^6$ load cycles. Here F is the applied load, $\ell_{10}$ is the corresponding 90% reliability life and p is the load life factor. The exponent p is normally taken as 10/3 for roller bearings and the NASA Lewis Research Center tests for gears indicates that 4.3 is an appropriate value for gears. The dynamic capacity equation is often modified for bearings as

$$\ell_{10} = a \left(\frac{C}{VF}\right)^p$$

where a is a factor used to increase the life estimate for improved material properties due to a reduction in impurities of the roller and race materials. According to the Roller Elements Committee of the lubrication committee of the ASME, life improvements of from 3 to 8 times are not uncommon. This factor

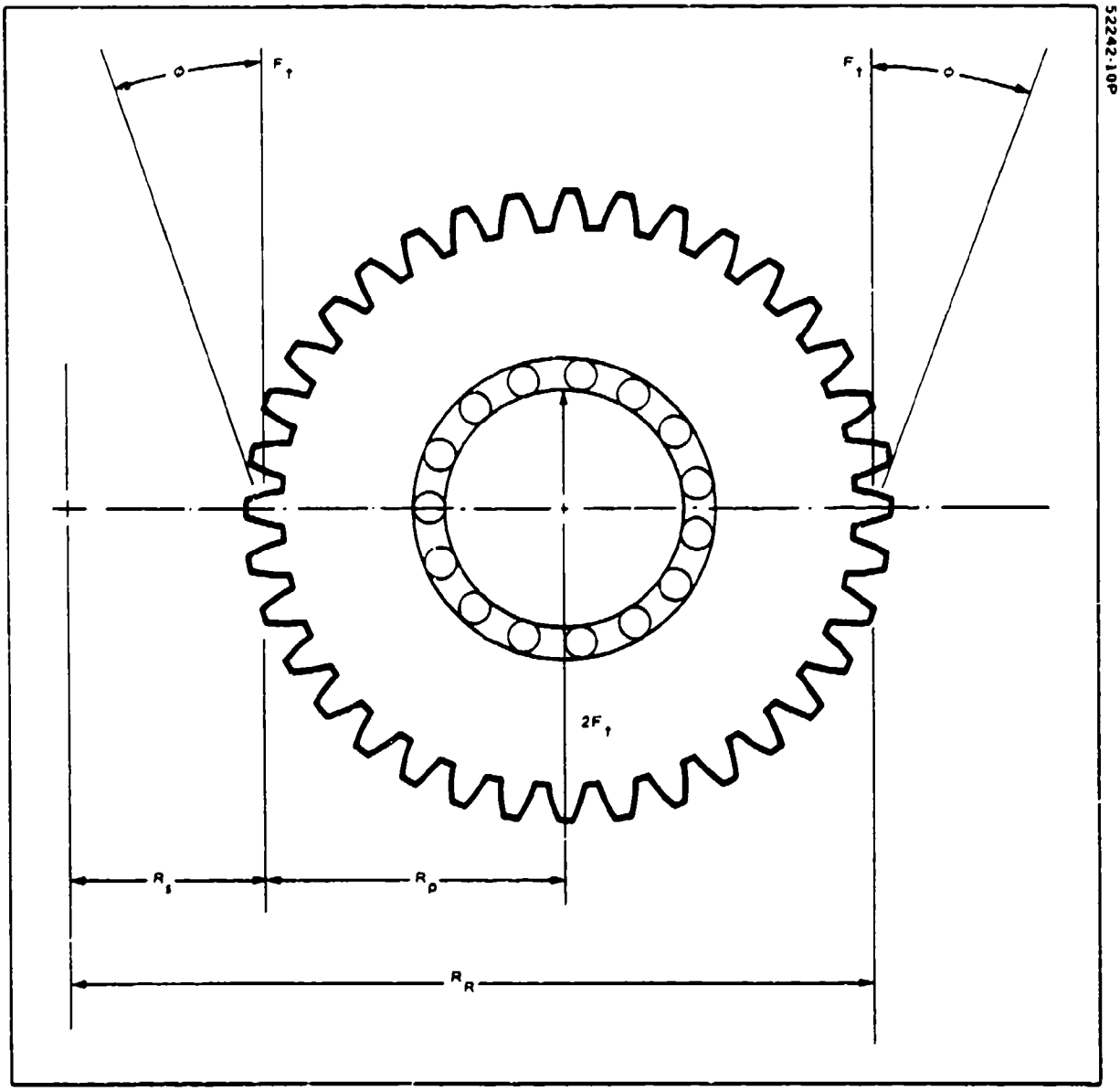



Figure 4.9-2. Planet Gear Forces

'a' may also be used to derate the life of the bearing if its speed of operation is extremely high (DN > 400,000 RPM-mm) or extremely low (DN < 10,000 RPM-mm) or if the lubrication to the bearing is inadequate. For this application the roller speed is

$$DN \approx \left[\frac{75 \text{ mmID} + 130 \text{ mmOD}}{2}\right] 800 \text{ RPM}$$

$$DN \approx 82{,}000 \text{ RPM} \cdot \text{mm}$$

as the operating speed should not be a problem. Although helicopter manufacturers use improved steels and lubrication in their transmissions and often use life improvement factors in the order of 8 in their calculations, we chose, in this example, to use a factor of 1/1.5 or 0.67 to indicate unsureness of the dynamic loading on the bearing (this is equivalent to a load factor of 1.13). At best, one can say that this factor is conservative, the 1972 AFBMA standard recommends a factor of 3 for a reasonable application, but disclaimers are also present. In addition to the life adjustment factor, there is also a load adjustment factor, V. The value of 1.2 is used since the counterformal contact on the inner race produces higher stresses than the conformed contact on the outer race does. The choice of not using this factor may be justified in the wide range of the life improvement factor. However for two identical bearings for which one has the load cycling on the inner race and the second has the same load cycling on the outer race, the first bearing will fail first due to its higher stress state.

With all this under advisement, the component $\ell_{B10}$ life in bearing load cycles of a single planet bearing is:

$$\ell_{B10} = a\left(\frac{C}{VF}\right)^{p}$$

$$\ell_{B10} = \frac{1}{1.5}\left[\frac{18{,}200}{1.2(2801)}\right]^{3.33}$$

$$\ell_{B10} = 184.8 \times 10^{6} \text{ cycles}$$

In a similar fashion, the dynamic capacity of a gear tooth is related to its life as:

$$\ell_{10} = \left(\frac{C_T}{F}\right)^{p}$$

where $C_T$ is the dynamic capacity of a tooth and F is the tangential pitch point load on that tooth. From tests on a particular gear material (AISI 9310

Vacuum Arc Remelt Steel) at over 9,000 ft/min pitch line velocity, the dynamic capacity, $C_T$, is given by:

$$C_T = B_1 \frac{F \sin \phi}{(\frac{1}{R_1} + \frac{1}{R_2})}$$

where $B_1$ is the material constant determined by test to be 21,000 psi, F is the face width of the gear, $\phi$ is the pitch line pressure angle and $R_1$ and $R_2$ are the pitch radii of the two gears.

For the sun-planet mesh,

$$C_S = \frac{(21,000)\ (.725)\ \sin\ (20°)}{\frac{1}{2.0} + \frac{1}{3.0}}$$

$$C_S = 6,250 \text{ lbs}$$

For the ring-planet mesh,

$$C_R = \frac{(21,000)\ (.725)\ \sin\ (20°)}{\frac{1}{3} - \frac{1}{8.0}}$$

$$C_R = 25,000 \text{ lbs.}$$

Unfortunately, the wide range of data available for bearing lives is not matched for gears. Since it is on the basis of this data that the life adjustment factors are established, corresponding factors do not exist in gearing. More statistical gear life data is really needed for gearing. The direct application of the NASA Lewis Research Center gear test data outside the load cycle range of the tests (1.2-3 X $10^7$ cycles) appears to be conservative.

For a sun gear tooth and one side of a planet gear tooth

$$\ell_{S10} = \left(\frac{6250}{1400.5}\right)^{4.3} 10^6 = 620 \text{ X } 10^6 \text{ load cycles.}$$

For a ring gear tooth and the other side of the planet gear tooth

$$\ell_{R10} = \left(\frac{25000}{1400.5}\right)^{4.3} 10^6 = 241 \text{ X } 10^9 \text{ load cycles.}$$

The next step is to reflect these lines and capacities to a common counting basis, input sun torque and rotation.

For a single bearing

$$\frac{L_{B10}}{\theta_S} = \frac{\ell_{B10}}{\theta_{P/A}}$$

$$L_{B10} = \frac{\theta_S}{\theta_{P/A}} \ell_{B10} = \frac{1}{.533} (184.8 \times 10^6)$$

$$L_{B10} = 347 \times 10^6 \text{ Revolutions}$$

$$L_{B10} = 347 \times 10^6 \left[\frac{1}{1500 \times 60}\right] = 3856 \text{ hours}$$

and its dynamic capacity as an input torque is the torque for which this bearing life equals $10^6$ sun rotations

$$D_B = \left[\frac{R_P(R_S + R_R)}{R_S R_R}\right]^{1/p} \left(\frac{nR_S C_B}{2}\right)$$

where

$$C_B = \left(\frac{C}{V}\right) a^{1/p}$$

is the modified bearing dynamic capacity

$$C_B = \left(\frac{18200}{1.2}\right) \left(\frac{1}{1.5}\right)^{1/3.33} = 13,430 \text{ lbs}$$

and

$$D_B = \left[\frac{3(10)}{2(8)}\right]^{1/3.33} \left(\frac{3(2)(13430)}{2}\right)$$

$$D_B = 48,601 \text{ lb-in.}$$

For the sun gear we must combine the lives of the individual teeth. This is done by the product of probabilities of independent events:

$S_S = S_T^{N_S}$, where $S_S$ and $S_T$ are the reliabilities of the sun gear and a single sun gear tooth, respectively.

Thus, $\ln \left(\frac{1}{S_S}\right) = N_S \ln \left(\frac{1}{S_T}\right)$

and

$$\ln \left(\frac{1}{S_S}\right) = N_S \left[\ln \left(\frac{1}{.9}\right)\right] \left(\frac{\ell_S}{\ell_{S10}}\right)^{e_G}$$

where $\ell_S$ is the life of the individual tooth in terms of its own load cycles, and $e_G$ is the Weibull shape parameter. In terms of rotations, counting contacts with each of n planets per revolutions, this becomes:

$$\ell_S = \frac{n\Theta_{S/A}}{\Theta_S} L_S$$

or

$$\ell_S = 3(0.8)\, L_S = 2.4\, L_S$$

so each tooth receives 2.4 load cycles for each sun rotation. In terms of $L_{10}$ lives

$$\ln \frac{1}{S_S} = \left[\ln \frac{1}{.9}\right] \left(\frac{L_S}{L_{S10}}\right)^{e_G} = N_S \left[\ln \frac{1}{.9}\right] \left(\frac{2.4\, L_S}{\ell_{S10}}\right)^{e_G}$$

or

$$L_{S10} = \left(\frac{1}{N_S}\right)^{1/e_G} \frac{\ell_{S10}}{2.4} = \left(\frac{1}{24}\right)^{1/2.5} \frac{620 \times 10^6}{2.4}$$

$$L_{S10} = 72.5 \times 10^6 \text{ Sun Rotations}$$

or

$$L_{S10} = 72.5 \times 10^6 \left[\frac{1}{1500 \times 60}\right] \text{hours}$$

$$L_{S10} = 806 \text{ hours.}$$

Its dynamic capacity can be found from the tooth capacity in a similar fashion:

$$D_S = \left(\frac{1}{N_S}\right)^{1/e_G p_G} \left[\frac{R_R + R_S}{nR_R}\right]^{1/p_G} (nR_S C_S)$$

$$D_S = \left(\frac{1}{24}\right)^{1/2.5(4.3)} \left[\frac{10}{3(8)}\right]^{1/4.3} (3 \cdot 2 \cdot 6250)$$

$$D_S = 22{,}762 \text{ lb-in.}$$

For the ring gear, the calculations are similar to those for the sun gear. The reliability of the gear in terms of its teeth reliabilities are:

$$S_R = S_T^{N_R}$$

so

$$\ln \left(\frac{1}{S_R}\right) = N_R \ln \left(\frac{1}{S_T}\right)$$

and

$$\ln \left(\frac{1}{S_R}\right) = N_S \left[\ln \left(\frac{1}{.9}\right)\right] \left(\frac{\ell}{\ell_{R10}}\right)^{e_G}$$

where $\ell_R$ is the life of the individual tooth in terms of its own load cycles. In terms of sun rotations, counting contacts with each of n planets per revolution, this becomes:

$$\ell_R = n \frac{\theta_{R/A}}{\theta_S} L_R$$

or

$$\ell_R = 3(0.2) L_R = 0.6 L_R$$

so each tooth receives 0.6 load cycles for each sun rotation. In terms of $L_{10}$ lives:

$$\ln \left(\frac{1}{S_R}\right) = \left[\ln \frac{1}{.9}\right] \left(\frac{L_R}{L_{R10}}\right)^{e_G} = N_R \ln \left(\frac{1}{.9}\right) \left(\frac{.6L_R}{L_{R10}}\right)^{e_G}$$

or

$$L_{R10} = \left(\frac{1}{N_R}\right)^{1/e_G} \frac{\ell_{R10}}{0.6} = \left(\frac{1}{96}\right)^{1/2.5} \left(\frac{241 \times 10^9}{.6}\right)$$

$$L_{R10} = 64{,}710 \times 10^6 \text{ Sun Rotations}$$

or

$$L_{R10} = 64{,}710 \times 10^6 \left[\frac{1}{1500 \times 60}\right] \text{ hours} = 719{,}000 \text{ hours.}$$

Its dynamic capacity can be found from the tooth capacity in a similar fashion.

$$D_R = \left(\frac{1}{N_R}\right)^{1/e_G p_G} \left[\frac{R_R + R_S}{nR_S}\right]^{1/p_G} (nR_S C_R)$$

$$D_R = \left(\frac{1}{96}\right)^{1/2.5(4.3)} \left[\frac{10}{3(2)}\right]^{1/4.3} (3(2)(25{,}000))$$

$$D_R = 110{,}500 \text{ lb-in.}$$

For the planet gears, the fact that each tooth is loaded on one side by the sun gear and on the other by the ring gear changes the calculation slightly.

The numbers of load cycles that each tooth sees from either sun gear or planet gear is the number of relative rotations of the planet with respect to the arm. In terms of sun gear rotations, this is

$$\frac{\ell_P}{\theta_{P/A}} = \frac{L_P}{\theta_S}$$

$$\ell_P = \frac{\theta_{P/A}}{\theta_S} L_P = 0.533\, L_P$$

The reliability of a planet gear is the product of the reliabilities of its individual tooth faces:

$$S_P = S_{PS}^{Np} \cdot S_{PR}^{Np}$$

where $S_{PS}$ is the reliability of a planet tooth face meshing with the sun and $S_{PR}$ is the reliability of a planet tooth face meshing with the ring. Thus:

$$\ln\left(\frac{1}{S_p}\right) = N_p \ln\left(\frac{1}{S_{PS}}\right) + N_p \ln\left(\frac{1}{S_{PR}}\right)$$

or

$$\left(\frac{L_p}{L_{P10}}\right)^{e_G} = N_p \left(\frac{.533\, L_p}{\ell_{S10}}\right)^{e_G} + N_p \left(\frac{.533 L_p}{\ell_{R10}}\right)^{e_G} .$$

The single tooth face lives $\ell_{S10}$ and $\ell_{R10}$ are the same as those of the mating teeth on the sun and ring gears. So:

$$L_{P10} = \left(\frac{1}{N_p}\right)^{1/e_G} \left(\frac{\ell_{S10}\ell_{R10}}{.533}\right) \left[\frac{1}{\ell_{R10}^{e_G} + \ell_{S10}^{e_G}}\right]^{1/e_G}$$

$$L_{P10} = \left(\frac{1}{36}\right)^{1/2.5} \left[\frac{(620 \times 10^6)(241 \times 10^9)}{.533}\right] \times$$

$$\left[\frac{1}{(620 \times 10^6)^{2.5} + (241 \times 10^9)^{2.5}}\right]^{1/2.5}$$

$$L_{P10} = 277 \times 10^6 \text{ Sun Revolutions}$$

$$L_{P10} = 277 \times 10^6 \left[\frac{1}{1500(60)}\right] = 3078 \text{ hours}$$

The basic dynamic capacity for a single planet gear is the input torque for which its life equals $10^6$ sun rotations:

$$D_P = \left(\frac{1}{N_P}\right)^{1/e_G p_G} \left[\frac{R_P(R_S+R_R)}{R_S R_R}\right]^{1/p_G} \left(\frac{n\, R_S C_S C_R}{(C_S^{e_G p_G} + C_R^{e_G p_G})^{1/e_G p_G}}\right)$$

$$D_P = \left[\frac{1}{36}\right]^{\frac{1}{2.5(4.3)}} \left[\frac{3(10^4)^{\frac{1}{4.3}}}{2(8)}\right]$$

$$\times \frac{3(2)\ (6250)\ (25{,}000)}{[(6250)^{2.5(4.3)} + (25{,}000)^{2.5(4.3)}]^{1/(2.5)4.3}}$$

$$D_p = 31{,}100 \text{ lb-in.}$$

At this point all the components are rated for 90% reliability life and basic dynamic capacity in terms of sun rotations.

| Component | Life | | Dynamic Capacity |
|---|---|---|---|
| | $10^6$ Sun Rotations | hrs | lb-in |
| Plant Bearing | 347 | 3,856 | 48,661 |
| Sun | 72.5 | 806 | 22,762 |
| Ring | 64,710 | 719,000 | 110,500 |
| Planet Gear | 277 | 3,078 | 31,100 |

The combination of these lives and capacities involves the product of the probabilities of survival of all the components

$$S_T = S_B^{n} S_S S_P^{n} S_R$$

or

$$\ln\left(\frac{1}{S_T}\right) = \ln\left(\frac{1}{.9}\right)\left\{n\left(\frac{L_T}{L_{B10}}\right)^{e_B} + \left(\frac{L_T}{L_{S10}}\right)^{e_G} + n\left(\frac{L_T}{L_{P10}}\right)^{e_G} + \left(\frac{L_T}{L_{R10}}\right)^{e_G}\right\} .$$

Since $e_G$ does not equal $e_B$, this relation cannot be directly set to:

$$\ln\left(\frac{1}{S_T}\right) = \ln\left(\frac{1}{.9}\right)\left(\frac{L_T}{L_{T10}}\right)^{e_T} .$$

However, for values of $S_T$ from 0.5 to 0.95, a least squares fit can be made on Weibull paper to find the values of $e_T$ and $L_{T10}$ which best characterize the system.

For the data of this example:

$$L_{T10} = 58.1 \times 10^6 \text{ Sun Revolutions}$$

$$L_{T10} = 58.1 \times 10^6 \left[\frac{1}{1500(60)}\right] = 646 \text{ hours}$$

and the Weibull slope for the system is

$$e_T = 2.12.$$

At similar situation exists for the system's dynamic capacity. To find:

$$C_{T10} = \left(\frac{D_T}{T_i}\right)^{P_T}$$

one can take the equation for $L_{T10}$ and vary the input torque over a range of 0.1 $D_T$ to $D_T$ and find the corresponding $L_{T10}$ lives. A least square fit of this $L_{T10}$ vs. $T_i$ data on log-log paper will produce a linear curve for which

$$D_T = 22{,}605 \text{ lb-in}$$

and

$$e_T = 4.03.$$

So a system Weibull and load life model for this example is

$$\ln\left(\frac{1}{S_T}\right) = \ln\left(\frac{1}{.9}\right)\left[\frac{L_T}{58.1}\right]^{2.12}$$

and

$$L_{T10} = \left(\frac{22,605}{T_i}\right)^{4.03}$$

## 4.10 Reliability Prediction Method - Minimum Information

The methods of this section are to be employed when there is not sufficient statistical data nor sufficient structural/analytical information concerning the nonelectronic part to allow the use of the other methods of this notebook to obtain reliability predictions.

The circumstances which lead to the necessity of using this section are partly due to rapid advancement of technology. New parts are constantly being introduced with hardly enough lifetime history to allow the vendor to set a warranty or service life (also called useful life). This service life is usually available from the vendor and can be used in conjunction with data from similar devices to provide reliability predictions.

The following examples illustrate the use of this type of information in determining Weibull parameters and failure rates. In the Weibull case, two quantities (usually the shape parameter or "slope" as it is often called, and the vendor supplied service life) are used. In the constant failure rate case (exponential distribution), the service life is sufficient.

### 4.10.1 Examples

Example 1. The expected service life of a hydraulic motor has been calculated by the vendor to be 12,413 hours where the service life is defined as the minimum life expected without failure of the motor section exclusive of the bearing section. The bearing section has been calculated to have an $L_{10}$ life of 50,000 hours in this application, i.e., 90% probability of surviving 50,000 hours. The preceding constitutes the only information available to be reliability analyst.

In the following calculation, the motor section service life estimate will be conservatively assumed to be the tenth pecentile of failure, $L_{10}$, of a Weibull distribution. The slope, $\beta_M$, is assumed to be 2, which is consistent with the scatter in lives to be expected when fatigue is the dominant failure mechanism. The calculated bearing section $L_{10}$ is reduced to 25,000 hours to account for less than ideal lubrication. The distribution is assumed to be Weibull with a slope, $\beta_B$, of 1.5 which is consistent with practice.

The characteristic lives of the motor section, $\alpha_M$ can now be computed. Since the $L_{10}$ life of the motor is 12,413, it must be that

$$.90 = \exp\left\{-(L_{10}/\alpha_M)^{\beta_M}\right\}$$

or

$$.90 = \exp\left\{-(12413/\alpha_M)^{2}\right\}$$

so that $\alpha_M = (12,413)/(-\ln(.90))^{1/2} = 38,241$ hours

Similarly, $\alpha_B = (25,000)/(-\ln(.90)^{1/1.5}) = 112,070$ hours

Finally, an average failure rate for a use life, t, is calculated using an average Weibull competing risk cumulative hazard model:

$$\bar{\lambda}_t = \left(\frac{t^{\beta_m - 1}}{\alpha_m^{\beta_m}} + \frac{t^{\beta_B - 1}}{\alpha_B^{\beta_B}}\right)$$

where:

$t = 10,000$ hours $\quad \beta_m = 2$

$\alpha_M = 38,241 \quad \beta_B = 1.5.$

$\alpha_B = 112,070$

$$\bar{\lambda}_{10,000} = \left[\frac{10,000}{(38241)^2} + \frac{(10,000)^{.5}}{(112070)^{1.5}}\right] = 9.5 \times 10^{-6}$$

or 9.5 failures per million hours.

Should this failure rate be unacceptably high, a lower failure rate can be obtained by reducing the in-use life or by redesign of the motor section to obtain a greater $L_{10}$ life rating.

Example 2. Ball Screw Reliability Estimation

A ball screw is to be applied in an environment which includes vibration and salt-laden air. Vendor catalog information provides an $L_{10}$ life of 20 x $10^6$ inches under the conditions of loading and lubrication of this application. Discussions with the vendor's engineering staff suggest that the given $L_{10}$ is realistic provided a life correction factor of 0.5 is used to account for the special environmental conditions. The vendor also states that test data indicates that the lives will follow the Weibull distribution with a $\beta$ of 3 when grease lubricated as in this application. In operation there will be 60 inches of travel per cycle and 13 cycles per hour.

Estimate the reliability for a service life of 10,000 hours.

Life $L_{10} = 20 \times 10^6 \times 0.5$ inches $= 10^7$ inches.

cyc/hr = 13
in/cyc = 60

$$\text{Weibull Distribution} = 1 - e^{-\left(\frac{t}{\alpha}\right)^{\beta}} \qquad \beta = 3$$

Service Life (t) = 10,000 hours.

Convert $L_{10}$ inches to $L_{10}$ hours.

$$L_{10}\ \text{hrs} = \frac{10^7}{(13)\ (60)} = 12{,}821 \text{ hours.}$$

Since $\beta = 3$, and since the $L_{10}$ life satisfies $.90 = \exp\left\{-(L_{10}/\alpha)^{\beta}\right\}$, it follows that $\alpha = (12821)/(-\ln(.9))^{1/3} = 27{,}145$ hours. Thus, the reliability for t = 10,000 hours is $R(10{,}000) = \exp\left\{-(10000/27145)^3\right\} = 0.951$.

If an average failure rate over the 10,000 hours service life is required, it can be calculated as follows:

$$\bar{\lambda}(t) = \frac{t^{\beta-1}}{\alpha^{\beta}}$$

$$\bar{\lambda}(10{,}000) = \frac{(10{,}000)^2}{(27145)^3} = 5.0 \times 10^{-6}$$

or 5 failures per million hours.

Example 3. Estimation of a Constant Failure Rate Based on Service Life.

As demonstrated in this Notebook, most of the time it can be assumed that the nonelectronic parts represented in this Notebook have constant failure rates. In this case, if the only information available is a vendor supplied "warranty" or "service" life, then a failure rate is easily estimated.

Occasionally, the vendor will indicate at which percentile the warranty is developed. That is, if a warranty or service life of 1000 hours is specified, the vendor may have done life testing which indicates that 1000 hours is the life beyond which 90% of the devices will survive on the

average. This would make 1000 hours the 10th percentile of the life distribution. To compute the constant failure rate, simply set $0.90=\exp(-\lambda 1000)$ and solve for $\lambda$. In this case, $\lambda = -\ln(0.90)/1000 = 0.000105$ or 105 failures per million hours. In general, use the following formula:

$$\text{failure rate} = -\ln(1-p)/(\text{warranty time})$$

where p is the quantile associated with the warranty time. Usually, p=0.10 but occasionally, if the vendor information is suspect, or the vendor will not say what value p should be, use p=0.05.

## 5.0 PART FAILURE CHARACTERISTICS

5.1 Introduction. The following sections of the notebook describe the analyses of the nonelectronic part failure data collected for this study. Section 5.2 presents the results of fitting the exponential distribution to the failure data for each part class, part type, and environment. Sections 5.3 - 5.5 present the results of testing the fit of the exponential distribution against Weibull alternatives for the data corresponding to some items. Section 5.6 gives part malfunction data and frequency of occurrence for some parts. It should be pointed out that the data used for preparation of this notebook was screened to exclude secondary failures and failures caused by maintenance personnel.

The environment abbreviations in the tables of this section follow the conventions of MIL-HDBK-217D. For convenience, these abbreviations are defined in table 5.1.1. More detailed descriptions may be found in MIL-HDBK-217D.

Finally, an explanation of the confidence intervals presented in sections 5.2 through 5.5 is necessary. These confidence intervals (for failure rate in the exponential cases, and for the shape and scale parameters in the Weibull analyses) have been called "60% confidence intervals." In the tables, however, the lower and upper bounds are labeled "80% lower" and "80% upper" bounds. This has been done so that either one-sided bound can be used by itself to form a one-sided 80% confidence interval if desired. When the two 80% bounds are combined to form a two-sided interval, the resultant confidence is 60%.

TABLE 5.1.1 DEFINITIONS OF ENVIRONMENT ABBREVIATIONS

| Abbreviation | Environment |
|---|---|
| AIF | Airborne, Inhabited, Fighter |
| AIT | Airborne, Inhabited, Transport |
| ARW | Airborne, Rotary Winged |
| AUF | Airborne, Uninhabited, Fighter |
| AUT | Airborne, Uninhabited, Transport |
| GB | Ground, Benign |
| GF | Ground, Fixed |
| GM | Ground, Mobile |
| ML | Missile, Launch |
| NS | Naval, Sheltered |
| NSB | Naval, Submarine |
| NU | Naval, Unsheltered |

5.1.1 Use of Constant Failure Rate Analyses. We recommend that the results presented in Section 5.2 be used as follows. First, find the

part class, part type, and environment of interest in the tables listed in section 5.2. The corresponding table will give a point estimate (also referred as a "prediction" in many reliability circles) of failure rate per million hours. A two-sided 60% confidence bound on the failure rate is also given in order to give the user a feel for the precision of the estimate. Also included is the number of independent sources (usually projects) which contributed to the estimates, along with total number of failures, total part operating hours and an estimate of mean life (i.e., mean operating time to failure). In a large number of cases, less than 50,000 hours of operating time were available so that care should be taken to examine the width of these confidence intervals. In cases where the total part operating hours shown are less than 1,000 hours, failure rate information is not tabulated. For these cases, the user should be very cautious in using the information presented for reliability purposes. Wherever there is more than one source contributing to an estimate, the observed significance level of a statistical test of homogeneity (also called a p-value, see Cox & Hinkley (1974), p. 66, for further discussion) is given. This test of homogeneity was performed in order to determine if the sources reporting failures were statistically different. In general, the observed significance level is between 0 and 1 with values close to 0 indicating evidence to reject homogeneity. We recommend a threshold of 0.05 for the homogeneity test, i.e., homogeneity is rejected if the observed significance level is below 0.05.

5.1.2 Use of Weibull Analyses. Most data collected was restricted to total operating time and total number of failures. While this approach is adequate (sufficient, in fact, in the statistical sense) when dealing with the exponential distribution, it does not provide a means of evaluating the "fit" or validity of the exponential model. The validity of the exponential distribution for describing the life distribution for nonelectronic parts was one of the central issues addressed by this study.

In order to address this important issue, data sets that contained actual part lifetimes for each failed part and total operating time were collected. In most cases, part lifetime data simply did not exist. However, for a significant number of part classes, part types, and environments, these data were available and were used to test the fit of the exponential distribution against Weibull alternatives. The Weibull family of distributions is rich enough to approximate virtually any unimodal life distribution and is therefore applicable for most nonelectronic parts. Moreover, the Weibull distribution is the resultant extreme-type distribution for describing lifetimes of nonelectronic parts which fail in accordance with a "weakest link" scenario. This technique for testing the fit of a distribution by embedding it in a parametric family of distributions is called a "smooth goodness-of-fit test," and is described in further detail in Lawless (1982), p. 438. Since the lifetime data was not collected under any of the commonly treated sampling plans, i.e., nonreplacement type I or II censoring, or complete samples, the goodness-of-fit procedure had to be developed ad hoc, and the smooth goodness-of-fit approach allowed the use of standard

likelihood ratio procedures in performing the test. The results of these analyses are presented in sections 5.3 - 5.5.

If the same part class, part type, and environment is reported in sections 5.3 - 5.5 a Weibull analysis was performed (this is indicated in the index to Section 5.2). Use the information in the Weibull table to decide whether to adopt the Weibull distribution, or retain the exponential distribution. For each of the part classes, part types and environments analyzed in sections 5.3 - 5.5, a table summarizing the results is presented. Each table contains a point estimate of mean life (i.e. mean time to failure in hours), and point and 60% confidence interval estimates for the Weibull scale parameter (in hours) and shape parameter (unitless). Also included are total part operating hours, and total failures. In cases where there was a predominant failure mode, this failure mode is given in the comments field, along with the observed significance level for the test of exponentiality. The observed significance level for testing exponentiality is used to decide whether to adopt the Weibull model, or to retain the exponential model. As before, we recommend that the threshold value be 0.05, i.e. reject exponentiality if the observed significance level is less than 0.05, and retain exponentiality otherwise. However, depending on the particular circumstances, the analyst using the observed significance level may wish to base the decision on a different threshold value, e.g. 0.10, 0.005, 0.001, etc. In the majority of cases, the exponential model is shown to be the best fit based on the 0.05 level of significance.

If the Weibull model is shown to be the better fitting model, it may still be desirable to approximate the distribution by the exponential distribution. This approximation is useful if the nonelectronic part(s) under consideration are part of a large system in which the other elements exhibit exponentially distributed lifetimes, and it is necessary to analyze the system as a whole. For exponential approximations it is recommended that the point estimate of the mean for the Weibull be used in the exponential model whenever the Weibull shape parameter is greater than one. When the Weibull shape parameter is less than one, use the mean life estimate from the appropriate table in section 5.2. These guidelines will yield conservative results (i.e. lower bounds) when computing system reliability for the series string in the case where the Weibull shape parameter is greater than one.

A total of 145 part classes/ types were analyzed in sections 5.3 - 5.5. In 6 of those cases exponentiality would be rejected at the 0.05 level of significance. This is not statistically significant. These results suggest that the exponential distribution is an adequate life model for most nonelectronic parts that are operated for time periods smaller than those analyzed in sections 5.3 - 5.5, i.e., there is a time period for most nonelectronic parts during which a constant failure rate model is appropriate. This phenomenon, conjectured in previous editions of this notebook, is supported by the results of sections 5.3 - 5.5.

## 5.2 Constant Failure Rate Analysis

### 5.2.1 Index to Section 5.2

| Part Class | Part Type | Identification Number* |
|---|---|---|
| ACCELEROMETER | FORCED BALANCED | 1* |
| ACCELEROMETER | PENDULUM, LINEAR | 2 |
| ACCELEROMETER | PENDULUM, SINGLE AXIS | 3 |
| ACCUMULATOR | HYDRAULIC | 4 |
| ACCUMULATOR | HYDRAULIC-PNEUMATIC | 5 |
| ACTUATOR | ELECTRICAL | 6 |
| ACTUATOR | ELECTROMECHANICAL (LINEAR) | 7* |
| ACTUATOR | ELECTROMECHANICAL (ROTARY) | 8 |
| ACTUATOR | ELECTROMECHANICAL (LINEAR) | 9* |
| ACTUATOR | HYDRAULIC-PNEUMATIC | 10 |
| ACTUATOR | MECHANICAL | 11 |
| ACTUATOR | ROTARY | 12 |
| AIR CONDITIONER | COMFORT | 13 |
| AIR CONDITIONER | GENERAL | 14 |
| AIR CONDITIONER | PROCESS | 15 |
| ANTENNA | COMMUNICATION | 16* |
| ANTENNA | MICROWAVE (COMMUNICATION) | 17 |
| ANTENNA | RADAR | 18 |
| AXLE | GENERAL | 19* |
| AZIMUTH ENCODER | OPTICAL | 20* |
| BATTERY | RECHARGEABLE | 21* |
| BEARING | BALL | 22* |
| BEARING | ROLLER | 23* |
| BEARING | SLEEVE | 24* |
| BEARING NUT | GENERAL | 25 |
| BELLOWS | GENERAL | 26* |
| BELT | GEARED | 27 |
| BELT | TIMING | 28* |
| BELT | V-BELT | 29* |
| BINOCULAR | NITROGEN PRESSURIZED | 30 |
| BLADE ASSEMBLY | GENERAL | 31 |
| BLOWERS & FANS | AXIAL | 32* |
| BLOWERS & FANS | CENTRIFUGAL | 33* |
| BOOT (DUST & MOISTURE) | GENERAL | 34 |
| BRAKE | ELECTROMECHANICAL | 35* |
| BRUSHES | ELECTRIC MOTOR | 36* |
| BURNER | CATALYTIC | 37 |
| BUSHINGS | GENERAL | 38* |
| CAM | GENERAL | 39 |
| CAMERA | MOTION (TV) | 40* |
| CESIUM BEAM TUBE | GENERAL | 41 |
| CIRCUIT PROTECTION DEVICE | SPARK GAP | 42* |

*Note: An asterisk "*" indicates that a Weibull analysis is included in one or more environments in Sections 5.3 - 5.5.

| Part Class | Part Type | Identification Number* |
|---|---|---|
| DEVICE | SURGE ARRESTER | 43* |
| CLUTCH | FRICTION | 44* |
| CLUTCH | GENERAL | 45 |
| COMPRESSOR | GENERAL | 46 |
| COMPRESSOR | HIGH PRESSURE | 47 |
| COMPRESSOR | LOW PRESSURE | 48 |
| COMPUTER MASS MEMORY | FIXED HEAD DISK | 49* |
| COMPUTER MASS MEMORY | MAGNETIC TAPE | 50* |
| COMPUTER MASS MEMORY | MOVABLE HEAD DISK | 51* |
| CONTROL TUBE ASSEMBLY | GENERAL | 52 |
| CORD/CABLE | GENERAL | 53 |
| COUNTER | ANALOG | 54 |
| COUNTER | DIGITAL | 55 |
| COUNTER | MECHANICAL | 56 |
| COUNTER | WATER CLOCK | 57 |
| COUPLING | FLEXIBLE | 58* |
| COUPLING | FLUID | 59 |
| COUPLING | GENERAL | 60 |
| COUPLING | RIGID | 61* |
| CRANKSHAFT | GENERAL | 62* |
| CROSS HEAD | GENERAL | 63 |
| DIAPHRAGMS BURST | GENERAL | 64* |
| DIFFUSER | GENERAL | 65 |
| DISC ASSEMBLY | GENERAL | 66 |
| DISTILLATION UNIT | FROM DISTILLING PLANT | 67 |
| DRIVE | GEAR | 68* |
| DRIVE | GENERAL | 69 |
| DRIVE | VARIABLE PITCH | 70* |
| DRIVE FOR COMPUTER TAPES & DISCS | CAPSTAN MOTOR | 71 |
| DRIVE FOR COMPUTER TAPES & DISCS | DISCS | 72* |
| DRIVE FOR COMPUTER TAPES & DISCS | MAGNETIC TAPE TRANSPORT | 73* |
| DRIVE FOR COMPUTER TAPES & DISCS | REEL MOTOR | 74 |
| DRIVE ROD | GENERAL | 75 |
| DRUM | GENERAL | 76* |
| DUCT | GENERAL | 77* |
| ELECTRIC HEATERS | RESISTANCE | 78* |
| ELECTROMECHANICAL TIMERS | GENERAL | 79* |
| ENGINES | GENERAL | 80 |
| FEEDHORN | WAVEGUIDE | 81 |
| FILTER | GAS (AIR) | 82* |
| FILTER | LIQUID | 83* |

*Note: An asterisk "*" indicates that a Weibull analysis is included in one or more environments in Sections 5.3 - 5.5.

| Part Class | Part Type | Identification Number* |
|---|---|---|
| FILTER | OPTICAL | 84 |
| FITTINGS | GENERAL | 85 |
| FITTINGS | PERMANENT | 86* |
| FITTINGS | QUICK DISCONNECT | 87* |
| FITTINGS | THREADED | 88* |
| FLASH LAMP | GENERAL | 89 |
| FUSE HOLDER | BLOCK | 90* |
| FUSE HOLDER | EXTRACTOR POST | 91 |
| FUSE HOLDER | PLUG | 92* |
| GAS DRYER DESICATOR | MOLECULAR SIEVE | 93 |
| GASKETS & SEALS | DYNAMIC | 94* |
| GASKETS & SEALS | STATIC | 95* |
| GEAR | ANTIROTATION | 96 |
| GEAR | BEVEL | 97* |
| GEAR | HELICAL | 98* |
| GEAR | HYPOID | 99 |
| GEAR | SPUR | 100 |
| GEAR | WORM | 101 |
| GEAR BOX | MULTIPLIER | 102 |
| GEAR BOX | REDUCTION | 103 |
| GEAR TRAIN | BEVEL | 104 |
| GENERATOR | AC | 105 |
| GENERATOR | GENERAL (OXYGEN GENERATOR) | 106 |
| GLASS (SIGHT GAUGE) | GENERAL | 107 |
| GROMMET | GENERAL | 108 |
| GIMBALS | GENERAL | 109 |
| GIMBALS | TORQUE | 110 |
| GYROSCOPE | SINGLE AXIS | 111 |
| GYROSCOPE | TWO AXIS ROTOR | 112 |
| HEAT EXCHANGERS | COPLATES | 113* |
| HEAT EXCHANGERS | GENERAL | 114 |
| HEAT EXCHANGERS | RADIATOR | 115* |
| HEATER | WATER | 116 |
| HEATER BLANKETS | GENERAL | 117 |
| HEATER, FLEX ELEMENT | HEATER TAPE | 118 |
| HIGH SPEED PRINTER | ELECTROSTATIC | 119* |
| HIGH SPEED PRINTER | IMPACT | 120* |
| HIGH SPEED PRINTER | THERMAL | 121 |
| HOSE | FLEXIBLE | 122 |
| HOSE | FLEXIBLE, PROPELLANT | 123 |
| HOSE | GENERAL | 124* |
| HOUSING | GENERAL | 125 |
| INCINERATOR | FROM SEWAGE TREATMENT | 126 |
| INSTRUMENTS | AMMETER | 127* |
| INSTRUMENTS | FLOW METER | 128 |
| INSTRUMENTS | HUMIDITY INDICATOR | 129 |

*Note: An asterisk "*" indicates that a Weibull analysis is included in one or more environments in Sections 5.3 - 5.5.

| Part Class | Part Type | Identification Number* |
|---|---|---|
| INSTRUMENTS | INDICATOR | 130 |
| INSTRUMENTS | INDICATOR (LIGHT) | 131 |
| INSTRUMENTS | INDICATOR (FLUID LEVEL) | 132 |
| INSTRUMENTS | PRESSURE GAUGE | 133 |
| INSTRUMENTS | TIME METER | 134 |
| INSTRUMENTS | TOTAL TIME METER | 135 |
| INSTRUMENTS | VOLTMETER | 136* |
| JOINT, MICROWAVE ROTARY | GENERAL | 137* |
| KEYBOARD | ELECTROMECHANICAL | 138* |
| KEYBOARD | GENERAL | 139 |
| KEYBOARD | MECHANICAL | 140 |
| KNOB | GENERAL | 141 |
| LAMP | XENON | 142 |
| LAMP HOLDER | GENERAL | 143 |
| LENS | OPTICAL | 144 |
| LOW SPEED PRINTER | DOT MATRIX | 145* |
| MANIFOLD | GENERAL | 146 |
| METAL TUBING | GENERAL | 147* |
| MODULES | GENERAL | 148 |
| MOTOR GENERATOR SET | AC | 149 |
| MOTOR GENERATOR SET | DC | 150 |
| MOTOR GENERATOR SET | GENERAL | 151 |
| MOTOR, ELECTRIC | > 1 HORSE POWER, AC | 152* |
| MOTOR, ELECTRIC | > 10 HORSE POWER, AC | 153 |
| MOTOR, ELECTRIC | DC | 154 |
| MOTOR, ELECTRIC | DC, (4 HORSEPOWER) | 155 |
| MOTOR, ELECTRIC | HYDRAULIC, DC | 156 |
| MOTOR, ELECTRIC | SERVO, DC | 157* |
| MOTOR, ELECTRIC | STEPPER | 158* |
| O-RING | GENERAL | 159 |
| PARTICLE SEPARATOR | GENERAL | 160 |
| PITCH HORN | GENERAL | 161 |
| PLOTTER | ELECTROMECHANICAL | 162 |
| POWER CIRCUIT BREAKER | CURRENT & VOLTAGE TRIP | 163 |
| POWER CIRCUIT BREAKER | CURRENT TRIP | 164* |
| POWER SWITCH GEAR | GENERAL | 165* |
| PRECIPITATOR | ELECTROSTATIC | 166 |
| PRISM | OPTICAL | 167 |
| PROPELLER | GENERAL (FROM SHIP) | 168 |
| PROPORTIONING UNIT | FROM DISTILLING PLANT | 169 |
| PULLEY | GEAR BELT | 170* |
| PULLEY | GROOVED | 171* |
| PULLEY | V-PULLEY | 172* |
| PUMP | CENTRIFUGAL | 173 |
| PUMP | HYDRAULIC | 174* |

*Note: An asterisk "*" indicates that a Weibull analysis is included in one or more environments in Sections 5.3 - 5.5.

| Part Class | Part Type | Identification Number* |
|---|---|---|
| PUMP | HYDRAULIC (ROTARY) | 175 |
| PUMP | PNEUMATIC | 176* |
| PUMP | ROTARY | 177 |
| PUMP | VACUUM | 178* |
| PUMP | VACUUM - LOBE TYPE | 179 |
| PUMP | VACUUM - RING SEAL TYPE | 180 |
| PURIFIER | CENTRIFUGAL | 181 |
| QUILL ASSEMBLY | GENERAL | 182 |
| RADOME | MICROWAVE, ANTENNA | 183 |
| REFRIGERATION PLANT | FROM AIR CONDITIONING PLANT | 184 |
| REGULATOR | ELECTRICAL | 185 |
| REGULATOR | PNEUMATIC (PRESSURE) | 186 |
| REGULATOR | PNEUMATIC (VACUUM BREAKER) | 187 |
| REGULATOR | PRESSURE | 188 |
| REGULATOR | TEMPERATURE | 189 |
| RESILIENT MOUNT | GENERAL | 190* |
| RESILIENT MOUNT | SHOCK MOUNTS | 191 |
| RETAINING RING | GENERAL | 192* |
| SEAL | GENERAL | 193 |
| SEAL | SOLDER | 194 |
| SENSORS | WATER LEVEL | 195 |
| SENSORS/TRANSDUCER/ TRANSMITTER | ACOUSTIC (HYDROPHONES) | 196 |
| SENSORS/TRANSDUCER/ TRANSMITTER | AIRFLOW | 197 |
| SENSORS/TRANSDUCER/ TRANSMITTER | FLOW (LIQUID) | 198 |
| SENSORS/TRANSDUCER/ TRANSMITTER | HUMIDITY | 199 |
| SENSORS/TRANSDUCER/ TRANSMITTER | INFRARED | 200 |
| SENSORS/TRANSDUCER/ TRANSMITTER | MOTION | 201 |
| SENSORS/TRANSDUCER/ TRANSMITTER | PRESSURE | 202* |
| SENSORS/TRANSDUCER/ TRANMSMITTER | TEMPERATURE | 203* |
| SHAFT | GENERAL | 204* |
| SHOCK ABSORBERS | COMBINATION | 205* |
| SHOCK ABSORBERS | RESILIENT | 206* |
| SLIP RING-BRUSH | POWER & SIGNAL | 207 |
| SLIP RINGS | GENERAL | 208 |
| SOLENOIDS | GENERAL | 209 |
| SOLENOIDS | LINEAR | 210* |
| SOLENOIDS | ROTARY | 211 |
| SPRING | COMPRESSION | 212 |

*Note: An asterisk "*" indicates that a Weibull analysis is included in one or more environments in Sections 5.3 - 5.5.

| Part Class | Part Type | Identification Number* |
|---|---|---|
| SPRING | GENERAL | 213 |
| SPRING | TORRISION | 214 |
| SPROCKET | GENERAL | 215 |
| STEAMBOILER | GENERAL (FROM SHIP) | 216 |
| STOW PIN | GENERAL | 217 |
| SWITCH | COAXIAL (ELECTROMECHANICAL) | 218 |
| SWITCH | FLOW (LIQUID) | 219* |
| SWITCH | INTERLOCK | 220 |
| SWITCH | PRESSURE (AIR FLOW) | 221* |
| SWITCH | ROCKER | 222* |
| SWITCH | THERMOSTATIC | 223* |
| SWITCH | THUMBWHEEL | 224* |
| SWITCH | WAVE GUIDE | 225* |
| SWITCHBOARD CONTROL | FROM OXYGEN GENERATOR | 226 |
| SYNCRO | TRANSMITTER | 227 |
| SYNCRO ASSEMBLY | GENERAL | 228 |
| SYNCRO/RESOLVER | LOW SPEED LOW LOAD | 229 |
| TACHOMETER | GENERAL | 230 |
| TANK | NON PRESSURIZED | 231 |
| TANK | PRESSURIZED | 232 |
| TELESCOPE | BORESIGHT | 233* |
| TELESCOPE | GENERAL | 234 |
| TERMINAL BOARDS | GENERAL | 235 |
| THERMOCOUPLE | GENERAL | 236 |
| TRACK BALL | ELECTROMECHANICAL | 237* |
| TRANSMISSION | GENERAL | 238 |
| TRUNNION ASSEMBLY | GENERAL | 239 |
| VALVE | CONTROL-MANUAL | 240 |
| VALVE | GAS (AIR-VENT) | 241 |
| VALVE | HYDRAULIC | 242* |
| VALVE | PNEUMATIC | 243* |
| VALVE | SOLENOID OPERATED | 244 |
| VALVE (ISOLATION) | PYROTECHNICALLY ACTUATED VALVE | 245 |
| VALVE (RELIEF) | PRESSURE ACTUATED | 246 |
| VALVE (FILL & DRAIN) | HAND OPERATED PLUG VALVE | 247 |
| VALVE (BIPROPELLANT-HIGH THURST) | SOLENOID OPERATED | 248 |
| VALVE (BIPROPELLANT-THURST) | TORQUE MOTOR OPERATED | 249 |
| WASHER | FLAT | 250 |
| WASHER | LOCK | 251 |
| WASHER | SHERR | 252 |
| WASHER | SPRING | 253 |
| WASHER | STAR | 254 |
| WATER DEMINERALIZER | MIX-RESIN | 255 |
| WINDLASS | FROM ANCHOR | 256 |

*Note: An asterisk "*" indicates that a Weibull analysis is included in one or more environments in Sections 5.3 - 5.5.

| ACCELEROMETER | / FORCED BALANCED | IDENTIFICATION NUMBER 1 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GM | EXPONENTIAL | 37547. | 18.562 | 26.633 | 37.887 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 2 | 8 | 300376 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.55 |

| ACCELEROMETER | / PENDULUM, LINEAR | IDENTIFICATION NUMBER 2 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUF | EXPONENTIAL | 32886. | 15.559 | 30.408 | 55.908 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUF | 1 | 3 | 98657 | |

| ACCELEROMETER | / PENDULUM, SINGLE AXIS | IDENTIFICATION NUMBER 3 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUF | EXPONENTIAL | 164889. | 3.747 | 6.065 | 9.590 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUF | 1 | 5 | 824445 | |

| ACCUMULATOR | / HYDRAULIC | IDENTIFICATION NUMBER 4 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GM | EXPONENTIAL | 3780. | 59.038 | 264.550 | 792.261 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 3780 | |

| ACCUMULATOR / HYDRAULIC-PNEUMATIC | | | | | IDENTIFICATION NUMBER 5 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| ARW | EXPONENTIAL | 1914. | 481.314 | 522.513 | 567.516 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 116 | 222004 | |

| ACTUATOR / ELECTRICAL | | | | | IDENTIFICATION NUMBER 6 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | ********* | 0.0 | 0.000 | 8.225 |
| GF | EXPONENTIAL | 214907. | 2.875 | 4.653 | 7.358 |
| GM | EXPONENTIAL | 6047. | 128.783 | 165.368 | 212.044 |
| NU | EXPONENTIAL | 43667. | 11.718 | 22.901 | 42.103 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 0 | 195696 | |
| GF | 2 | 5 | 1074536 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.87 |
| GM | 1 | 15 | 90707 | |
| NU | 1 | 3 | 131000 | |

| ACTUATOR | / ELECTROMECHANICAL (LINEAR) | IDENTIFICATION NUMBER 7 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| ARW | EXPONENTIAL | 903. | 1063.898 | 1107.625 | 1153.341 |
| GB | EXPONENTIAL | ********* | 0.0 | 0.000 | 124.985 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 459 | 414400 | |
| GB | 1 | 0 | 12878 | |

| ACTUATOR | / ELECTROMECHANICAL (ROTARY) | IDENTIFICATION NUMBER 8 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GB | EXPONENTIAL | ********* | 0.0 | 0.000 | 249.970 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GB | 1 | 0 | 6439 | |

| ACTUATOR | / ELECTROMECHANICAL (LINEAR) | IDENTIFICATION NUMBER 9 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | 111194. | 2.007 | 8.993 | 26.933 |
| ML | EXPONENTIAL | ********* | SEE NOTE BELOW | | |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 1 | 111194 | |
| ML | 1 | 0 | 91 | |

NOTE: Low total part operating hours, develop failure data with caution

| ACTUATOR / HYDRAULIC--PNEUMATIC | | | | | IDENTIFICATION NUMBER 10 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| ARW | EXPONENTIAL | 1782. | 489.140 | 561.274 | 644.497 |
| AUT | EXPONENTIAL | 27878. | 18.354 | 35.871 | 65.948 |
| GM | EXPONENTIAL | 4610. | 48.409 | 216.920 | 649.619 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 44 | 78393 | |
| AUT | 1 | 3 | 83634 | |
| GM | 1 | 1 | 4610 | |

| ACTUATOR / MECHANICAL | | | | | IDENTIFICATION NUMBER 11 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 195696. | 1.140 | 5.110 | 15.303 |
| GM | EXPONENTIAL | 29741. | 13.859 | 33.624 | 71.943 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 1 | 195696 | |
| GM | 1 | 2 | 59481 | |

| ACTUATOR / ROTARY | | | | | IDENTIFICATION NUMBER 12 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 12538. | 55.588 | 79.758 | 113.460 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 8 | 100304 | |

| AIR CONDITIONER | / COMFORT | IDENTIFICATION NUMBER 13 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | 1406. | 635.451 | 711.111 | 796.307 |
| GM | EXPONENTIAL | ********* | 0.0 | 0.000 | 27.060 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 64 | 90000 | |
| GM | 1 | 0 | 59481 | |

| AIR CONDITIONER | / GENERAL | IDENTIFICATION NUMBER 14 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GM | EXPONENTIAL | ********* | 0.0 | 0.000 | 847.136 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 0 | 1900 | |

| AIR CONDITIONER | / PROCESS | IDENTIFICATION NUMBER 15 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | ********* | 0.0 | 0.000 | 12.876 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 0 | 125000 | |

| ANTENNA | / COMMUNICATION | IDENTIFICATION NUMBER 16 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GM | EXPONENTIAL | 150188. | 2.744 | 6.658 | 14.246 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 2 | 2 | 300376 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.77 |

| ANTENNA | / MICROWAVE (COMMUNICATION) | IDENTIFICATION NUMBER 17 |
|---|---|---|

| ENV | DIST TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| ARW | EXPONENTIAL | 52302. | 16.088 | 19.120 | 22.734 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 29 | 1516770 | |

| ANTENNA / RADAR | | | | | IDENTIFICATION NUMBER 18 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 169. | 5563.172 | 5913.230 | 6287.383 |
| GF | EXPONENTIAL | 500000. | 0.446 | 2.000 | 5.989 |
| GM | EXPONENTIAL | 8710. | 25.625 | 114.812 | 343.830 |
| NU | EXPONENTIAL | 87118. | 2.562 | 11.479 | 34.375 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 205 | 34868 | |
| GF | 1 | 1 | 500000 | |
| GM | 2 | 1 | 8710 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.13 |
| NU | 3 | 1 | 87120 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.56 |

| AXLE / GENERAL | | | | | IDENTIFICATION NUMBER 19 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GM | EXPONENTIAL | 104835. | 3.932 | 9.539 | 20.410 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 2 | 2 | 209669 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.85 |

| AZIMUTH ENCODER / OPTICAL | | | | | IDENTIFICATION NUMBER 20 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GM | EXPONENTIAL | 4845. | 174.759 | 206.408 | 243.927 |
| NSB | EXPONENTIAL | 23250. | 24.695 | 43.011 | 72.276 |
| NU | EXPONENTIAL | 24510. | 9.105 | 40.800 | 122.185 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 2 | 31 | 150188 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.92 |
| NSB | 1 | 4 | 93000 | |
| NU | 1 | 1 | 24510 | |

| BATTERY / RECHARGEABLE | | | | IDENTIFICATION NUMBER 21 | |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| ARW | EXPONENTIAL | 186. | 5131.805 | 5379.859 | 5641.117 |
| GF | EXPONENTIAL | 1433894. | 0.454 | 0.697 | 1.055 |
| GM | EXPONENTIAL | 121420. | 5.088 | 8.236 | 13.023 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 337 | 62641 | |
| GF | 5 | 6 | 8803396 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.90 |
| GM | 4 | 5 | 607102 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.99 |

| BEARING / BALL | | | | | IDENTIFICATION NUMBER 22 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| ARW | EXPONENTIAL | 3688. | 242.952 | 271.142 | 302.800 |
| AUF | EXPONENTIAL | 198680. | 4.545 | 5.033 | 5.577 |
| AUT | EXPONENTIAL | 330237. | 1.739 | 3.028 | 5.089 |
| GF | EXPONENTIAL | 447103. | 1.829 | 2.237 | 2.735 |
| GM | EXPONENTIAL | 165558. | 4.546 | 6.040 | 8.002 |
| NS | EXPONENTIAL | 31552. | 19.580 | 31.694 | 50.116 |
| NU | EXPONENTIAL | 58880. | 9.751 | 16.984 | 28.540 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 67 | 247103 | |
| AUF | 2 | 77 | 15298373 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.71 |
| AUT | 1 | 4 | 1320948 | |
| GF | 3 | 22 | 9836258 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.46 |
| GM | 3 | 12 | 1986699 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.91 |
| NS | 2 | 5 | 157760 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.99 |
| NU | 3 | 4 | 235520 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.20 |

| BEARING / ROLLER | | | | | IDENTIFICATION NUMBER 23 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| ARW | EXPONENTIAL | 9150. | 71.107 | 109.296 | 165.324 |
| AUT | EXPONENTIAL | ********* | 0.0 | 0.000 | 18.450 |
| GM | EXPONENTIAL | 120150. | 5.142 | 8.323 | 13.181 |
| NU | EXPONENTIAL | 147060. | 1.518 | 6.800 | 20.364 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 6 | 54897 | |
| AUT | 1 | 0 | 97848 | |
| GM | 2 | 5 | 600752 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.99 |
| NU | 1 | 1 | 147060 | |

| BEARING / SLEEVE | | | | | IDENTIFICATION NUMBER 24 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| ARW | EXPONENTIAL | 2889. | 278.111 | 346.102 | 430.448 |
| AUT | EXPONENTIAL | 293544. | 0.760 | 3.407 | 10.202 |
| GF | EXPONENTIAL | 202415. | 3.443 | 4.940 | 7.028 |
| GM | EXPONENTIAL | 214554. | 3.152 | 4.661 | 6.814 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 19 | 54897 | |
| AUT | 1 | 1 | 293544 | |
| GF | 5 | 8 | 1619318 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.53 |
| GM | 2 | 7 | 1501880 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.86 |

| BEARING NUT / GENERAL | | | | | IDENTIFICATION NUMBER 25 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| ARW | EXPONENTIAL | 1830. | 425.572 | 546.468 | 700.711 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 15 | 27449 | |

| BELLOWS / GENERAL | | | | | IDENTIFICATION NUMBER 26 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 97848. | 2.281 | 10.220 | 30.606 |
| GM | EXPONENTIAL | 75094. | 5.489 | 13.317 | 28.493 |
| NS | EXPONENTIAL | 26200. | 8.518 | 38.168 | 114.303 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 1 | 97848 | |
| GM | 2 | 2 | 150188 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.77 |
| NS | 1 | 1 | 26200 | |

| BELT | / GEARED | IDENTIFICATION NUMBER 27 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | ********** | 0.0 | 0.000 | 17.927 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 0 | 89785 | |

| BELT | / TIMING | IDENTIFICATION NUMBER 28 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | 27846. | 23.364 | 35.912 | 54.322 |
| GM | EXPONENTIAL | 100125. | 5.110 | 9.987 | 18.362 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 2 | 6 | 167074 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.09 |
| GM | 2 | 3 | 300376 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.82 |

| BELT | / V-BELT | IDENTIFICATION NUMBER 29 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GM | EXPONENTIAL | 59481. | 3.752 | 16.812 | 50.348 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 59481 | |

| BINOCULAR | / NITROGEN PRESSURIZED | IDENTIFICATION NUMBER 30 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GM | EXPONENTIAL | 945. | 607.566 | 1058.201 | 1778.231 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 4 | 3780 | |

| BLADE ASSEMBLY / GENERAL | | | | | IDENTIFICATION NUMBER 31 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| ARW | EXPONENTIAL | 2745. | 294.660 | 364.312 | 450.364 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 20 | 54898 | |

| BLOWERS & FANS | / AXIAL | IDENTIFICATION NUMBER 32 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AIT | EXPONENTIAL | 8340. | 108.908 | 119.900 | 132.078 |
| ARW | EXPONENTIAL | 2246. | 401.425 | 445.148 | 493.943 |
| AUT | EXPONENTIAL | 2059. | 437.736 | 485.774 | 539.422 |
| GB | EXPONENTIAL | ********* | 0.0 | 0.000 | 4.764 |
| GF | EXPONENTIAL | 82575. | 11.080 | 12.110 | 13.268 |
| GM | EXPONENTIAL | 64071. | 12.542 | 15.608 | 19.411 |
| NS | EXPONENTIAL | 631267. | 1.319 | 1.584 | 1.904 |
| NSB | EXPONENTIAL | 28800. | 7.749 | 34.722 | 103.984 |
| NU | EXPONENTIAL | ********* | 0.0 | 0.000 | 68.259 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AIT | 1 | 86 | 717264 | |
| ARW | 1 | 75 | 168483 | |
| AUT | 2 | 74 | 152334 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.23 |
| GB | 1 | 0 | 337888 | |
| GF | 2 | 96 | 7927205 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.61 |
| GM | 4 | 19 | 1217343 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.26 |
| NS | 3 | 26 | 16412950 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.09 |
| NSB | 1 | 1 | 28800 | |
| NU | 1 | 0 | 23580 | |

| BLOWERS & FANS / CENTRIFUGAL | | | | | IDENTIFICATION NUMBER 33 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 3123. | 280.416 | 320.224 | 365.942 |
| GF | EXPONENTIAL | 153191. | 4.662 | 6.528 | 9.081 |
| GM | EXPONENTIAL | 206618. | 2.990 | 4.840 | 7.653 |
| NS | EXPONENTIAL | 120964. | 6.302 | 8.267 | 10.819 |
| NSB | EXPONENTIAL | ********** | 0.0 | 0.000 | 111.775 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 47 | 146772 | |
| GF | 4 | 9 | 1378716 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.18 |
| GM | 3 | 5 | 1033090 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.78 |
| NS | 3 | 13 | 1572530 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.14 |
| NSB | 1 | 0 | 14400 | |

| BOOT ( DUST & MOISTURE ) | / GENERAL | IDENTIFICATION NUMBER 34 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| ARW | EXPONENTIAL | 3050. | 234.177 | 327.881 | 456.106 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 9 | 27449 | |

| BRAKE | / ELECTROMECHANICAL | IDENTIFICATION NUMBER 35 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | 62500. | 6.595 | 16.000 | 34.234 |
| GM | EXPONENTIAL | 4765. | 182.884 | 209.855 | 240.971 |
| NU | EXPONENTIAL | 9403. | 61.064 | 108.355 | 178.722 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 2 | 125000 | |
| GM | 2 | 44 | 209669 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.07 |
| NU | 2 | 4 | 37610 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.07 |

| BRUSHES / ELECTRIC MOTOR | | | | | IDENTIFICATION NUMBER 36 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | ********** | 0.0 | 0.000 | 32.899 |
| GF | EXPONENTIAL | 500000. | 0.446 | 2.000 | 5.989 |
| GM | EXPONENTIAL | 169188. | 3.394 | 5.911 | 9.932 |
| NS | EXPONENTIAL | ********** | 0.0 | 0.000 | 30.717 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 0 | 48924 | |
| GF | 1 | 1 | 500000 | |
| GM | 4 | 4 | 676752 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.80 |
| NS | 1 | 0 | 52400 | |

| BURNER / CATALYTIC | | | | | IDENTIFICATION NUMBER 37 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| NS | EXPONENTIAL | 1886. | 471.959 | 530.241 | 598.124 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 60 | 113156 | |

| BUSHINGS / GENERAL | | | | | IDENTIFICATION NUMBER 38 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 88063. | 8.843 | 11.355 | 14.561 |
| GF | EXPONENTIAL | 163567. | 4.601 | 6.114 | 8.100 |
| GM | EXPONENTIAL | 1287441. | 0.654 | 0.777 | 0.924 |
| NS | EXPONENTIAL | 1250989. | 0.668 | 0.799 | 0.957 |
| NU | EXPONENTIAL | 936632. | 0.440 | 1.068 | 2.284 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 15 | 1320948 | |
| GF | 3 | 12 | 1962806 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.81 |
| GM | 2 | 29 | 37335808 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.27 |
| NS | 3 | 27 | 33776704 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.71 |
| NU | 1 | 2 | 1873264 | |

| CAM / GENERAL | | | | | IDENTIFICATION NUMBER 39 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 244620. | 0.912 | 4.088 | 12.242 |
| GF | EXPONENTIAL | 126102. | 1.770 | 7.930 | 23.748 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 1 | 244620 | |
| GF | 3 | 1 | 126104 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.65 |

| CAMERA / MOTION (TV) | | | | | IDENTIFICATION NUMBER 40 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 7382. | 83.686 | 135.457 | 214.193 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 5 | 36912 | |

| CESIUM BEAM TUBE / GENERAL | | | | | IDENTIFICATION NUMBER 41 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 29174. | 22.300 | 34.277 | 51.848 |
| NS | EXPONENTIAL | 29174. | 22.300 | 34.277 | 51.848 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 6 | 175045 | |
| NS | 1 | 6 | 175045 | |

| CIRCUIT PROTECTION DEVICE / SPARK GAP | | | | IDENTIFICATION NUMBER 42 | |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GM | EXPONENTIAL | 75094. | 5.489 | 13.317 | 28.493 |
| NS | EXPONENTIAL | 49020. | 4.553 | 20.400 | 61.092 |
| NU | EXPONENTIAL | 49020. | 4.553 | 20.400 | 61.092 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 2 | 2 | 150188 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.77 |
| NS | 1 | 1 | 49020 | |
| NU | 1 | 1 | 49020 | |

| CIRCUIT PROTECTION DEVICE / SURGE ARRESTER | | | | | IDENTIFICATION NUMBER 43 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GM | EXPONENTIAL | 61310. | 10.612 | 16.311 | 24.672 |
| NS | EXPONENTIAL | 395320. | 1.452 | 2.530 | 4.251 |
| NSB | EXPONENTIAL | 6100. | 36.589 | 183.936 | 490.944 |
| NU | EXPONENTIAL | 73530. | 3.035 | 13.600 | 40.728 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 3 | 6 | 367857 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.27 |
| NS | 2 | 4 | 1581279 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.10 |
| NSB | 2 | 1 | 6100 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.37 |
| NU | 1 | 1 | 73530 | |

| CLUTCH / FRICTION | | | | | IDENTIFICATION NUMBER 44 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 188052. | 3.053 | 5.318 | 8.936 |
| GM | EXPONENTIAL | 26209. | 26.593 | 38.155 | 54.278 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 4 | 4 | 752208 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.24 |
| GM | 2 | 8 | 209669 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.07 |

| CLUTCH / GENERAL | | | | | IDENTIFICATION NUMBER 45 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUF | EXPONENTIAL | 197314. | 1.131 | 5.068 | 15.178 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUF | 1 | 1 | 197314 | |

| COMPRESSOR / GENERAL | | | | | IDENTIFICATION NUMBER 46 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | ********** | 0.0 | 0.000 | 16.450 |
| GF | EXPONENTIAL | 125000. | 1.785 | 8.000 | 23.958 |
| GM | EXPONENTIAL | 29741. | 13.859 | 33.624 | 71.943 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 0 | 97848 | |
| GF | 1 | 1 | 125000 | |
| GM | 1 | 2 | 59481 | |

| COMPRESSOR / HIGH PRESSURE | | | | | IDENTIFICATION NUMBER 47 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| NS | EXPONENTIAL | 1212. | 774.738 | 824.949 | 878.711 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 194 | 235166 | |

| COMPRESSOR / LOW PRESSURE | | | | | IDENTIFICATION NUMBER 48 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| NS | EXPONENTIAL | 4949. | 149.846 | 202.076 | 271.479 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 11 | 54435 | |

| COMPUTER MASS MEMORY / FIXED HEAD DISK | | | | | IDENTIFICATION NUMBER 49 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 5850. | 128.633 | 170.928 | 228.448 |
| NS | EXPONENTIAL | 12500. | 17.853 | 80.000 | 239.580 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 12 | 70205 | |
| NS | 1 | 1 | 12500 | |

| COMPUTER MASS MEMORY / MAGNETIC TAPE | | | | | IDENTIFICATION NUMBER 50 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 2656. | 350.806 | 376.459 | 404.150 |
| GM | EXPONENTIAL | 2520. | 340.445 | 396.882 | 462.976 |
| NS | EXPONENTIAL | 9825. | 70.938 | 101.781 | 144.790 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 2 | 155 | 411731 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.45 |
| GM | 1 | 36 | 90707 | |
| NS | 1 | 8 | 78600 | |

| COMPUTER MASS MEMORY | / MOVEABLE HEAD DISK | IDENTIFICATION NUMBER 51 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | 9443. | 73.811 | 105.904 | 150.655 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 2 | 8 | 75540 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.12 |

| CONTROL TUBE ASSEMBLY | / GENERAL | IDENTIFICATION NUMBER 52 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| ARW | EXPONENTIAL | 9150. | 55.922 | 109.294 | 200.936 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 3 | 27448 | |

| CORD/CABLE | / GENERAL | IDENTIFICATION NUMBER 53 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | 180149. | 3.754 | 5.551 | 8.115 |
| GM | EXPONENTIAL | 421614. | 1.879 | 2.372 | 2.991 |
| NS | EXPONENTIAL | 773487. | 1.007 | 1.293 | 1.658 |
| NU | EXPONENTIAL | 2270629. | 0.272 | 0.440 | 0.696 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 3 | 7 | 1261040 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.46 |
| GM | 2 | 17 | 7167438 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.18 |
| NS | 3 | 15 | 11602311 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.07 |
| NU | 2 | 5 | 11353145 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.10 |

| COUNTER / ANALOG | | | | IDENTIFICATION NUMBER 54 | |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 166667. | 3.070 | 6.000 | 11.031 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 3 | 500000 | |

| COUNTER | / DIGITAL | IDENTIFICATION NUMBER 55 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUT | EXPONENTIAL | ********* | 0.0 | 0.000 | 32.899 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 0 | 48924 | |

| COUNTER | / MECHANICAL | IDENTIFICATION NUMBER 56 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUF | EXPONENTIAL | ********* | 0.0 | 0.000 | 8.157 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUF | 1 | 0 | 197314 | |

| COUNTER / WATER CLOCK | | | | | IDENTIFICATION NUMBER 57 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 18000. | 34.322 | 55.556 | 87.848 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 5 | 90000 | |

| COUPLING / FLEXIBLE | | | | | IDENTIFICATION NUMBER 58 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 58709. | 11.082 | 17.033 | 25.765 |
| GM | EXPONENTIAL | 100125. | 5.110 | 9.987 | 18.362 |
| NS | EXPONENTIAL | 10480. | 21.294 | 95.420 | 285.758 |
| NU | EXPONENTIAL | ********* | 0.0 | 0.000 | 614.335 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 6 | 352253 | |
| GM | 2 | 3 | 300376 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.34 |
| NS | 1 | 1 | 10480 | |
| NU | 1 | 0 | 2620 | |

| COUPLING / FLUID | | | | | IDENTIFICATION NUMBER 59 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| NSB | EXPONENTIAL | 11700. | 64.321 | 85.470 | 113.232 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NSB | 2 | 12 | 140400 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.61 |

| COUPLING / GENERAL | | | | | IDENTIFICATION NUMBER 60 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| NS | EXPONENTIAL | 766130. | 0.538 | 1.305 | 2.793 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 2 | 1532259 | |

| COUPLING / RIGID | | | | | IDENTIFICATION NUMBER 61 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 52838. | 13.794 | 18.926 | 25.837 |
| GF | EXPONENTIAL | 500000. | 1.023 | 2.000 | 3.677 |
| GM | EXPONENTIAL | 524173. | 1.095 | 1.908 | 3.206 |
| NS | EXPONENTIAL | 78600. | 5.244 | 12.723 | 27.222 |
| NU | EXPONENTIAL | 68670. | 6.002 | 14.562 | 31.158 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 10 | 528379 | |
| GF | 1 | 3 | 1500000 | |
| GM | 2 | 4 | 2096690 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.45 |
| NS | 1 | 2 | 157200 | |
| NU | 2 | 2 | 137340 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.53 |

| CRANKSHAFT / GENERAL | | | | | IDENTIFICATION NUMBER 62 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 97848. | 4.212 | 10.220 | 21.867 |
| GM | EXPONENTIAL | 30038. | 20.568 | 33.292 | 52.643 |
| NU | EXPONENTIAL | ********* | 0.0 | 0.000 | 65.669 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 2 | 195696 | |
| GM | 2 | 5 | 150188 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.30 |
| NU | 1 | 0 | 24510 | |

| CROSS HEAD | / GENERAL | IDENTIFICATION NUMBER 63 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| ARW | EXPONENTIAL | 13725. | 30.031 | 72.862 | 155.899 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 2 | 27449 | |

| DIAPHRAGMS BURST | / GENERAL | IDENTIFICATION NUMBER 64 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GM | EXPONENTIAL | 59481. | 3.752 | 16.812 | 50.348 |
| NS | EXPONENTIAL | 19650. | 20.975 | 50.891 | 108.887 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 59481 | |
| NS | 1 | 2 | 39300 | |

| DIFFUSER | / GENERAL | IDENTIFICATION NUMBER 65 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUT | EXPONENTIAL | ********* | 0.0 | 0.900 | 10.966 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 0 | 146772 | |

| DISC ASSEMBLY | / GENERAL | IDENTIFICATION NUMBER 66 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| ARW | EXPONENTIAL | 2590. | 340.987 | 386.173 | 437.651 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 53 | 137244 | |

| DISTILLATION UNIT / FROM DISTILLING PLANT | | | | | IDENTIFICATION NUMBER 67 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| NS | EXPONENTIAL | 2070. | 345.030 | 483.092 | 672.016 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 9 | 18630 | |

| DRIVE / GEAR | | | | | IDENTIFICATION NUMBER 68 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 195696. | 1.140 | 5.110 | 15.303 |
| GF | EXPONENTIAL | 166667. | 3.070 | 6.000 | 11.031 |
| GM | EXPONENTIAL | 119952. | 5.424 | 8.337 | 12.810 |
| NU | EXPONENTIAL | 10142. | 60.915 | 98.600 | 155.912 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 1 | 195696 | |
| GF | 1 | 3 | 500000 | |
| GM | 2 | 6 | 719714 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.98 |
| NU | 2 | 5 | 50710 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.71 |

| DRIVE | / GENERAL | IDENTIFICATION NUMBER 69 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| ARW | EXPONENTIAL | 3431. | 203.130 | 291.449 | 414.605 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 8 | 27449 | |

| DRIVE | / VARIABLE PITCH | IDENTIFICATION NUMBER 70 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | 139842. | 4.836 | 7.151 | 10.454 |
| GM | EXPONENTIAL | 37547. | 15.291 | 26.633 | 44.755 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 2 | 7 | 978897 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.34 |
| GM | 2 | 4 | 150188 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.67 |

| DRIVE FOR COMPUTER TAPES&DISCS/ CAPSTAN MOTOR | | | | IDENTIFICATION NUMBER 71 | |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 137244. | 3.728 | 7.286 | 13.396 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 2 | 3 | 411731 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.32 |

| DRIVE FOR COMPUTER TAPES&DISCS/ DISCS | | | | IDENTIFICATION NUMBER 72 | |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GB | EXPONENTIAL | 56313. | 7.319 | 17.758 | 37.995 |
| GF | EXPONENTIAL | 43745. | 13.125 | 22.860 | 38.414 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GB | 1 | 2 | 112626 | |
| GF | 3 | 4 | 174980 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.81 |

| DRIVE FOR COMPUTER TAPES&DISCS/ MAGNETIC TAPE TRANSPORT | | | | IDENTIFICATION NUMBER 73 | |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 23402. | 21.865 | 42.732 | 78.563 |
| GM | EXPONENTIAL | 2520. | 340.445 | 396.882 | 462.976 |
| NS | EXPONENTIAL | 26200. | 19.529 | 38.168 | 70.172 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 3 | 70205 | |
| GM | 1 | 36 | 90707 | |
| NS | 1 | 3 | 78600 | |

| DRIVE FOR COMPUTER TAPES&DISCS/ REEL MOTOR | | | | IDENTIFICATION NUMBER 74 | |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 137245. | 4.740 | 7.286 | 11.021 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 2 | 6 | 823472 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.16 |

| DRIVE ROD | / GENERAL | IDENTIFICATION NUMBER 75 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GM | EXPONENTIAL | ********** | 0.0 | 0.000 | 27.060 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 0 | 59481 | |

| DRUM | / GENERAL | IDENTIFICATION NUMBER 76 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | ********** | 0.0 | 0.000 | 12.764 |
| GM | EXPONENTIAL | 4774. | 168.317 | 209.466 | 260.512 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 3 | 0 | 126104 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 1.00 |
| GM | 1 | 19 | 90707 | |

| DUCT | / GENERAL | IDENTIFICATION NUMBER 77 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUT | EXPONENTIAL | 61155. | 9.388 | 16.352 | 27.478 |
| GF | EXPONENTIAL | 344578. | 2.023 | 2.902 | 4.128 |
| GM | EXPONENTIAL | 234353. | 3.110 | 4.267 | 5.825 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 4 | 244620 | |
| GF | 4 | 8 | 2756624 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.38 |
| GM | 2 | 10 | 2343527 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.44 |

| ELECTRIC HEATERS / RESISTANCE | | | | | IDENTIFICATION NUMBER 78 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GM | EXPONENTIAL | 52063. | 12.496 | 19.208 | 29.054 |
| NS | EXPONENTIAL | 6550. | 62.826 | 152.672 | 326.862 |
| NU | EXPONENTIAL | 36765. | 11.211 | 27.200 | 58.188 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 3 | 6 | 312376 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.47 |
| NS | 1 | 2 | 13100 | |
| NU | 1 | 2 | 73530 | |

| ELECTROMECHANICAL TIMERS / GENERAL | | | | | IDENTIFICATION NUMBER 79 |
|---|---|---|---|---|---|
| ENV | DIST TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUF | EXPONENTIAL | 247010. | 2.071 | 4.048 | 7.443 |
| AUT | EXPONENTIAL | 97848. | 4.212 | 10.220 | 21.867 |
| GF | EXPONENTIAL | 211093. | 4.355 | 4.739 | 5.160 |
| GM | EXPONENTIAL | 38186. | 18.703 | 26.188 | 36.429 |
| NS | EXPONENTIAL | 29540. | 27.683 | 33.852 | 41.400 |
| NSB | EXPONENTIAL | 34199. | 6.526 | 29.241 | 87.587 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUF | 1 | 3 | 741030 | |
| AUT | 1 | 2 | 195696 | |
| GF | 5 | 110 | 23210336 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.18 |
| GM | 4 | 9 | 343675 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.44 |
| NS | 2 | 22 | 649889 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.71 |
| NSB | 4 | 1 | 34200 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.66 |

| ENGINES / GENERAL | | | | | IDENTIFICATION NUMBER 80 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| ARW | EXPONENTIAL | 718. | 1328.109 | 1392.106 | 1459.500 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 339 | 243516 | |

| FEEDHORN / WAVEGUIDE | | | | | IDENTIFICATION NUMBER 81 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 19608. | 41.485 | 51.000 | 62.695 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 21 | 411768 | |

| FILTER / GAS (AIR) | | | | | IDENTIFICATION NUMBER 82 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 73386. | 5.616 | 13.627 | 29.156 |
| GF | EXPONENTIAL | 94026. | 7.412 | 10.635 | 15.129 |
| GM | EXPONENTIAL | 308449. | 2.192 | 3.242 | 4.739 |
| NS | EXPONENTIAL | 129100. | 3.193 | 7.746 | 16.573 |
| NU | EXPONENTIAL | 122550. | 3.363 | 8.160 | 17.459 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 2 | 146772 | |
| GF | 4 | 8 | 752208 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.07 |
| GM | 2 | 7 | 2159142 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.72 |
| NS | 2 | 2 | 258200 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.07 |
| NU | 1 | 2 | 245100 | |

| FILTER / LIQUID | | | | | IDENTIFICATION NUMBER 83 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 166667. | 3.070 | 6.000 | 11.031 |
| GM | EXPONENTIAL | 66916. | 10.415 | 14.944 | 21.259 |
| ML | EXPONENTIAL | ********** | SEE NOTE BELOW | | |
| NS | EXPONENTIAL | 21821. | 32.730 | 45.827 | 63.748 |
| NU | EXPONENTIAL | ********** | 0.0 | 0.000 | 32.835 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 3 | 500000 | |
| GM | 1 | 8 | 535329 | |
| ML | 1 | 0 | 18 | |
| NS | 3 | 9 | 196392 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.47 |
| NU | 1 | 0 | 49020 | |

NOTE: Low total part operating hours, develop failure data with caution.

| FILTER | / OPTICAL | IDENTIFICATION NUMBER 84 |
|---|---|---|

| ENV | DIST TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUT | EXPONENTIAL | 244620. | 0.912 | 4.088 | 12.242 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 1 | 244620 | |

| FITTINGS | / GENERAL | IDENTIFICATION NUMBER 85 |
|---|---|---|

| ENV | DIST TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| NS | EXPONENTIAL | 24510. | 9.105 | 40.800 | 122.185 |
| NU | EXPONENTIAL | ********* | 0.0 | 0.000 | 65.689 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 1 | 24510 | |
| NU | 1 | 0 | 24510 | |

| FITTINGS / PERMANENT | | | | | IDENTIFICATION NUMBER 86 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 97848. | 2.281 | 10.220 | 30.606 |
| GF | EXPONENTIAL | 500000. | 1.023 | 2.000 | 3.677 |
| GM | EXPONENTIAL | 306751. | 2.204 | 3.260 | 4.766 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 1 | 97848 | |
| GF | 1 | 3 | 1500000 | |
| GM | 2 | 7 | 2147258 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.85 |

| FITTINGS | / QUICK DISCONNECT | IDENTIFICATION NUMBER 87 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUT | EXPONENTIAL | 146772. | 1.520 | 6.813 | 20.404 |
| GF | EXPONENTIAL | 750000. | 0.550 | 1.333 | 2.853 |
| GM | EXPONENTIAL | 79308. | 6.452 | 12.609 | 23.182 |
| NS | EXPONENTIAL | 52400. | 4.259 | 19.084 | 57.152 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 1 | 146772 | |
| GF | 1 | 2 | 1500000 | |
| GM | 1 | 3 | 237924 | |
| NS | 1 | 1 | 52400 | |

| FITTINGS / THREADED | | | | | IDENTIFICATION NUMBER 88 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 195696. | 1.140 | 5.110 | 15.303 |
| GF | EXPONENTIAL | 416667. | 1.561 | 2.400 | 3.630 |
| GM | EXPONENTIAL | 195213. | 2.941 | 5.123 | 8.608 |
| NSB | EXPONENTIAL | 6571. | 102.901 | 152.174 | 222.459 |
| NU | EXPONENTIAL | 131000. | 3.906 | 7.634 | 14.034 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 1 | 195696 | |
| GF | 1 | 6 | 2500000 | |
| GM | 2 | 4 | 780853 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.78 |
| NSB | 1 | 7 | 46000 | |
| NU | 1 | 3 | 393000 | |

| FLASH LAMP | / GENERAL | IDENTIFICATION NUMBER 89 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUT | EXPONENTIAL | 48924. | 4.561 | 20.440 | 61.212 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 1 | 48924 | |

| FUSE HOLDER / BLOCK | | | | | IDENTIFICATION NUMBER 90 |
|---|---|---|---|---|---|
| ENV | DIST TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 320772. | 2.346 | 3.117 | 4.130 |
| GM | EXPONENTIAL | 250922. | 0.889 | 3.985 | 11.935 |
| NS | EXPONENTIAL | 52400. | 4.259 | 19.084 | 57.152 |
| NSB | EXPONENTIAL | ********* | 0.0 | 0.000 | 402.389 |
| NU | EXPONENTIAL | ********* | 0.0 | 0.000 | 21.890 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 4 | 12 | 3849263 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.49 |
| GM | 2 | 1 | 250924 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.74 |
| NS | 1 | 1 | 52400 | |
| NSB | 1 | 0 | 4000 | |
| NU | 1 | 0 | 73530 | |

| FUSE HOLDER / EXTRACTOR POST | | | | | IDENTIFICATION NUMBER 91 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 250000. | 1.649 | 4.000 | 8.559 |
| GM | EXPONENTIAL | ********** | 0.0 | 0.000 | 6.765 |
| NS | EXPONENTIAL | 98040. | 2.276 | 10.200 | 30.546 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 2 | 500000 | |
| GM | 1 | 0 | 237924 | |
| NS | 1 | 1 | 98040 | |

| FUSE HOLDER / PLUG | | | | | IDENTIFICATION NUMBER 92 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 300000. | 1.374 | 3.333 | 7.132 |
| GM | EXPONENTIAL | 602404. | 0.370 | 1.660 | 4.971 |
| NS | EXPONENTIAL | 1415465. | 0.539 | 0.706 | 0.925 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 2 | 2 | 600000 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.28 |
| GM | 2 | 1 | 02410 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.87 |
| NS | 2 | 13 | 18401056 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.06 |

| GAS DRYER DESICATOR / MOLECULAR SIEVE | | | | | IDENTIFICATION NUMBER 93 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| NS | EXPONENTIAL | 13100. | 17.035 | 76.336 | 228.607 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 1 | 13100 | |

| GASKETS & SEALS | / DYNAMIC | IDENTIFICATION NUMBER 94 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUT | EXPONENTIAL | 110511. | 7.169 | 9.049 | 11.412 |
| GF | EXPONENTIAL | 303450. | 2.444 | 3.295 | 4.427 |
| GM | EXPONENTIAL | 215369. | 3.140 | 4.643 | 6.788 |
| NS | EXPONENTIAL | 520196. | 1.425 | 1.922 | 2.583 |
| NSB | EXPONENTIAL | 46000. | 4.851 | 21.739 | 65.103 |
| NU | EXPONENTIAL | 315118. | 1.308 | 3.173 | 6.790 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 17 | 1878881 | |
| GF | 4 | 11 | 3337948 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.16 |
| GM | 3 | 7 | 1507580 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.06 |
| NS | 4 | 11 | 5722160 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.29 |
| NSB | 1 | 1 | 46000 | |
| NU | 2 | 2 | 630240 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.86 |

| GASKETS & SEALS / STATIC | | | | | IDENTIFICATION NUMBER 95 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AIF | EXPONENTIAL | 137155. | 1.627 | 7.291 | 21.835 |
| AUT | EXPONENTIAL | 108385. | 7.681 | 9.226 | 11.087 |
| GF | EXPONENTIAL | 332896. | 2.031 | 3.004 | 4.391 |
| GM | EXPONENTIAL | 246955. | 2.951 | 4.049 | 5.528 |
| NS | EXPONENTIAL | 546846. | 1.488 | 1.829 | 2.248 |
| NSB | EXPONENTIAL | 46000. | 4.851 | 21.739 | 65.103 |
| NU | EXPONENTIAL | 716918. | 0.801 | 1.395 | 2.344 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AIF | 1 | 1 | 137155 | |
| AUT | 1 | 26 | 2818022 | |
| GF | 4 | 7 | 2330272 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.58 |
| GM | 3 | 10 | 2469547 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.13 |
| NS | 4 | 21 | 11483769 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.27 |
| NSB | 1 | 1 | 46000 | |
| NU | 1 | 4 | 2867670 | |

| GEAR / ANTIROTATION | | | | | IDENTIFICATION NUMBER 96 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GM | EXPONENTIAL | 633. | 807.898 | 1578.948 | 2802.893 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 1900 | |

| GEAR / BEVEL | | | | | IDENTIFICATION NUMBER 97 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AIF | EXPONENTIAL | 68578. | 6.010 | 14.582 | 31.200 |
| AUT | EXPONENTIAL | 146772. | 2.808 | 6.813 | 14.578 |
| GF | EXPONENTIAL | 750000. | 0.550 | 1.333 | 2.853 |
| GM | EXPONENTIAL | 340030. | 1.505 | 2.941 | 5.407 |
| NS | EXPONENTIAL | 104800. | 2.129 | 9.542 | 28.576 |
| NU | EXPONENTIAL | 320317. | 0.697 | 3.122 | 9.349 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AIF | 1 | 2 | 137155 | |
| AUT | 1 | 2 | 293544 | |
| GF | 1 | 2 | 1500000 | |
| GM | 2 | 3 | 1020090 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.64 |
| NS | 1 | 1 | 104800 | |
| NU | 2 | 1 | 320320 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.88 |

| GEAR | / HELICAL | IDENTIFICATION NUMBER 98 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUT | EXPONENTIAL | 146772. | 2.808 | 6.813 | 14.578 |
| GF | EXPONENTIAL | 200000. | 1.116 | 5.000 | 14.974 |
| GM | EXPONENTIAL | 50698. | 10.093 | 19.725 | 36.265 |
| NS | EXPONENTIAL | ********* | 0.0 | 0.000 | 13.134 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 2 | 293544 | |
| GF | 1 | 1 | 200000 | |
| GM | 3 | 3 | 152088 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.08 |
| NS | 1 | 0 | 122550 | |

| GEAR / HYPOID | | | | | IDENTIFICATION NUMBER 99 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 200000. | 1.116 | 5.000 | 14.974 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 1 | 200000 | |

| GEAR / SPUR | | | | | IDENTIFICATION NUMBER 100 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| ARW | EXPONENTIAL | 852054. | 0.725 | 1.174 | 1.856 |
| AUT | EXPONENTIAL | 78278. | 7.892 | 12.775 | 20.200 |
| GF | EXPONENTIAL | 317244. | 2.132 | 3.152 | 4.608 |
| GM | EXPONENTIAL | 168077. | 3.676 | 5.950 | 9.408 |
| NS | EXPONENTIAL | 104800. | 3.933 | 9.542 | 20.416 |
| NU | EXPONENTIAL | 199458. | 1.119 | 5.014 | 15.014 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 5 | 4260268 | |
| AUT | 1 | 5 | 391392 | |
| GF | 4 | 7 | 2220710 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.45 |
| GM | 3 | 5 | 840386 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.75 |
| NS | 1 | 2 | 209600 | |
| NU | 2 | 1 | 199460 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.10 |

| GEAR / WORM | | | | | IDENTIFICATION NUMBER 101 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | ********** | 0.0 | 0.000 | 8.048 |
| GM | EXPONENTIAL | ********** | 0.0 | 0.000 | 26.223 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 0 | 200000 | |
| GM | 2 | 0 | 61381 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.99 |

| GEAR BOX / MULTIPLIER | | | | IDENTIFICATION NUMBER 107 |
|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| ARW | EXPONENTIAL | 463. | 2071.857 | 2159.230 | 2250.676 |
| GF | EXPONENTIAL | ********* | 0.0 | 0.000 | 16.096 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 437 | 202387 | |
| GF | 1 | 0 | 100000 | |

| GEAR BOX / REDUCTION | | | | | IDENTIFICATION NUMBER 103 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 146772. | 2.808 | 6.813 | 14.578 |
| GF | EXPONENTIAL | 200000. | 1.116 | 5.000 | 14.974 |
| GM | EXPONENTIAL | 53320. | 10.768 | 18.755 | 31.516 |
| NS | EXPONENTIAL | 51969. | 13.411 | 19.242 | 27.373 |
| NU | EXPONENTIAL | 62119. | 3.593 | 16.098 | 48.209 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 2 | 293544 | |
| GF | 1 | 1 | 200000 | |
| GM | 4 | 4 | 213279 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.16 |
| NS | 1 | 8 | 415750 | |
| NU | 2 | 1 | 62120 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.49 |

| GEAR TRAIN | / BEVEL | IDENTIFICATION NUMBER 104 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUF | EXPONENTIAL | 172025. | 5.126 | 5.813 | 6.596 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUF | 1 | 52 | 8945282 | |

| GENERATOR | / AC | IDENTIFICATION NUMBER 105 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GM | EXPONENTIAL | 104834. | 3.932 | 9.539 | 20.410 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 2 | 2 | 209669 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.13 |

| GENERATOR | / GENERAL (OXYGEN GENERATOR) | IDENTIFICATION NUMBER 106 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| NS | EXPONENTIAL | 526. | 1759.922 | 1900.320 | 2052.836 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 132 | 69462 | |

| GLASS (SIGHT GAUGE) | / GENERAL | IDENTIFICATION NUMBER 107 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| ARW | EXPONENTIAL | 2287. | 328.998 | 437.174 | 579.174 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 12 | 27449 | |

| GROMMET / GENERAL | | | | | IDENTIFICATION NUMBER 108 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 293544. | 0.760 | 3.407 | 10.202 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 1 | 293544 | |

| GIMBALS / GENERAL | | | | | IDENTIFICATION NUMBER 109 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 48924. | 8.425 | 20.440 | 43.734 |
| ML | EXPONENTIAL | ********** | SEE NOTE BELOW | | |
| NU | EXPONENTIAL | 49020. | 4.553 | 20.400 | 61.092 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 2 | 97848 | |
| ML | 1 | 0 | 10 | |
| NU | 1 | 1 | 49020 | |

NOTE; Low total part operating hours develop failure data with caution

| GIMBALS / TORQUE | | | | | IDENTIFICATION NUMBER 110 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUF | EXPONENTIAL | 193637. | 3.599 | 5.164 | 7.347 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUF | 1 | 8 | 1549092 | |

| GYROSCOPE / SINGLE AXIS | | | | | IDENTIFICATION NUMBER 111 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 2224. | 391.885 | 449.877 | 516.352 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 44 | 97848 | |

| GYROSCOPE | / TWO AXIS ROTOR | IDENTIFICATION NUMBER 112 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUF | EXPONENTIAL | 20234. | 42.919 | 49.422 | 56.949 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUF | 1 | 42 | 849826 | |

| HEAT EXCHANGERS | / COPLATES | IDENTIFICATION NUMBER 113. |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GM | EXPONENTIAL | 90707. | 5.641 | 11.025 | 20.269 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 272121 | |

| HEAT EXCHANGERS / GENERAL | | | | | IDENTIFICATION NUMBER 114 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 36693. | 20.510 | 27.253 | 36.105 |
| GF | EXPONENTIAL | 312500. | 1.319 | 3.200 | 6.847 |
| NS | EXPONENTIAL | 72495. | 11.157 | 13.794 | 17.052 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 12 | 440316 | |
| GF | 1 | 2 | 625000 | |
| NS | 2 | 20 | 1449899 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.18 |

| HEAT EXCHANGERS / RADIATOR | | | | | IDENTIFICATION NUMBER 115 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GM | EXPONENTIAL | 178443. | 2.310 | 5.604 | 11.991 |
| NS | EXPONENTIAL | 4000. | 154.450 | 250.000 | 395.314 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 356886 | |
| NS | 1 | 5 | 20000 | |

| HEATER / WATER | | | | | IDENTIFICATION NUMBER 116 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 2368. | 363.796 | 422.222 | 490.362 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 38 | 90000 | |

| HEATER BLANKETS | / GENERAL | IDENTIFICATION NUMBER 117 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUT | EXPONENTIAL | 97848. | 2.281 | 10.220 | 30.606 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 1 | 97848 | |

| HEATER, FLEX ELEMENT | / HEATER TAPE | IDENTIFICATION NUMBER 118 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUF | EXPONENTIAL | 1358145. | 0.423 | 0.736 | 1.237 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUF | 1 | 4 | 5432580 | |

| HIGH SPEED PRINTER / ELECTROSTATIC | | | | | IDENTIFICATION NUMBER 119 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GM | EXPONENTIAL | 1417. | 630.498 | 705.568 | 780.100 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 64 | 90707 | |

| HIGH SPEED PRINTER / IMPACT | | | | IDENTIFICATION NUMBER 120 |
|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GB | EXPONENTIAL | 112626. | 1.981 | 8.879 | 28.590 |
| GF | EXPONENTIAL | 3269. | 226.851 | 305.921 | 410.990 |
| NS | EXPONENTIAL | 11503. | 44.480 | 86.931 | 159.823 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GB | 1 | 1 | 112626 | |
| GF | 2 | 11 | 35957 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.13 |
| NS | 2 | 3 | 34510 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.18 |

| HIGH SPEED PRINTER | / THERMAL | IDENTIFICATION NUMBER 121 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | 34049. | 22.102 | 29.370 | 38.909 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 2 | 12 | 408583 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.67 |

| HOSE | / FLEXIBLE | IDENTIFICATION NUMBER 122 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| NSB | EXPONENTIAL | 18600. | 39.185 | 53.763 | 73.397 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NSB | 1 | 10 | 186000 | |

| HOSE | / FLEXIBLE, PROPELLANT | | | | IDENTIFICATION NUMBER 123 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| ML | EXPONENTIAL | ********* | SEE NOTE BELOW | | |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ML | 1 | 0 | 27 | |

NOTE: Low total part operating hours, develop failure data with caution

| HOSE | / GENERAL | IDENTIFICATION NUMBER 124 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | 288656. | 2.607 | 3.464 | 4.590 |
| GM | EXPONENTIAL | 225390. | 3.000 | 4.437 | 6.486 |
| NS | EXPONENTIAL | 224538. | 3.181 | 4.454 | 6.195 |
| NU | EXPONENTIAL | 77340. | 5.329 | 12.930 | 27.665 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 4 | 12 | 3463872 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.40 |
| GM | 2 | 7 | 1577732 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.41 |
| NS | 4 | 9 | 2020839 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.17 |
| NU | 3 | 2 | 154680 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.47 |

| HOUSING | / GENERAL | IDENTIFICATION NUMBER 125 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| ARW | EXPONENTIAL | 3580. | 229.535 | 279.309 | 339.940 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 23 | 82346 | |

| INCINERATOR | / FROM SEWAGE TREATMENT | IDENTIFICATION NUMBER 126 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| NS | EXPONENTIAL | 492. | 838.583 | 2034.588 | 4353.273 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 2 | 983 | |

| INSTRUMENTS / AMMETER | | | | | IDENTIFICATION NUMBER 127 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 125000. | 1.785 | 8.000 | 23.958 |
| GM | EXPONENTIAL | 75819. | 5.436 | 13.189 | 28.220 |
| NS | EXPONENTIAL | 132526. | 5.595 | 7.546 | 10.137 |
| NSB | EXPONENTIAL | ********* | 0.0 | 0.000 | 98.145 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 1 | 125000 | |
| GM | 3 | 2 | 151638 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.94 |
| NS | 4 | 11 | 1457787 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.80 |
| NSB | 2 | 0 | 16400 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 1.00 |

| INSTRUMENTS / FLOW METER | | | | | IDENTIFICATION NUMBER 128 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 63333. | 8.079 | 15.789 | 29.029 |
| NS | EXPONENTIAL | 19525. | 29.406 | 51.216 | 88.065 |
| NSB | EXPONENTIAL | 4800. | 148.794 | 208.334 | 289.807 |
| NU | EXPONENTIAL | 15000. | 14.878 | 66.667 | 199.650 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 3 | 190000 | |
| NS | 2 | 4 | 78100 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.68 |
| NSB | 3 | 9 | 43200 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.15 |
| NU | 1 | 1 | 15000 | |

| INSTRUMENTS / HUMIDITY INDICATOR | | | | | IDENTIFICATION NUMBER 129 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 48924. | 4.561 | 20.440 | 61.212 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 1 | 48924 | |

| INSTRUMENTS / INDICATOR | | | | | IDENTIFICATION NUMBER 130 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| ARW | EXPONENTIAL | 925. | 958.565 | 1081.666 | 1221.415 |
| GF | EXPONENTIAL | 242713. | 2.108 | 4.120 | 7.575 |
| NS | EXPONENTIAL | 16340. | 31.314 | 61.199 | 112.515 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 56 | 51772 | |
| GF | 1 | 3 | 728140 | |
| NS | 1 | 3 | 49020 | |

| INSTRUMENTS / INDICATOR (LIGHT) | | | | | IDENTIFICATION NUMBER 131 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| NS | EXPONENTIAL | 766130. | 0.538 | 1.305 | 2.793 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 2 | 1532259 | |

| INSTRUMENTS / INDICATOR(FLUID LEVEL) | | | | | IDENTIFICATION NUMBER 132 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GM | EXPONENTIAL | 1260. | 406.086 | 793.651 | 1459.126 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 3780 | |

| INSTRUMENTS / PRESSURE GAUGE | | | | | IDENTIFICATION NUMBER 133 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 24462. | 26.596 | 40.880 | 61.836 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 6 | 146772 | |

| INSTRUMENTS / TIME METER | | | | | IDENTIFICATION NUMBER 134 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| NS | EXPONENTIAL | 383065. | 1.499 | 2.611 | 4.387 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 4 | 1532259 | |

| INSTRUMENTS / TOTAL TIME METER | | | | | IDENTIFICATION NUMBER 135 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 58369. | 14.955 | 17.132 | 19.640 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 45 | 2626598 | |

| INSTRUMENTS / VOLTMETER | | | | | IDENTIFICATION NUMBER 136 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 266458. | 1.547 | 3.753 | 8.030 |
| GM | EXPONENTIAL | 104458. | 4.898 | 9.573 | 17.600 |
| NS | EXPONENTIAL | 586924. | 1.053 | 1.704 | 2.694 |
| NSB | EXPONENTIAL | ********* | 0.0 | 0.000 | 30.142 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 2 | 2 | 532916 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.68 |
| GM | 3 | 3 | 313376 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.86 |
| NS | 5 | 5 | 2934631 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.74 |
| NSB | 3 | 0 | 53400 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 1.00 |

| JOINT, MICROWAVE ROTARY / GENERAL | | | | | IDENTIFICATION NUMBER 137 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 3550. | 259.500 | 281.712 | 305.975 |
| GF | EXPONENTIAL | 41667. | 12.280 | 24.000 | 44.124 |
| GM | EXPONENTIAL | 126941. | 4.867 | 7.878 | 12.457 |
| NU | EXPONENTIAL | 20707. | 24.710 | 48.294 | 88.788 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 116 | 411768 | |
| GF | 1 | 3 | 125000 | |
| GM | 3 | 5 | 634707 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.72 |
| NU | 2 | 3 | 62120 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.62 |

| KEYBOARD / ELECTROMECHANICAL | | | | | IDENTIFICATION NUMBER 138 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AIT | EXPONENTIAL | 75000. | 2.976 | 13.333 | 39.930 |
| GB | EXPONENTIAL | 112626. | 1.981 | 8.879 | 26.590 |
| NS | EXPONENTIAL | 47609. | 4.688 | 21.004 | 62.902 |
| NSB | EXPONENTIAL | ********* | 0.0 | 0.000 | 804.779 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AIT | 1 | 1 | 75000 | |
| GB | 1 | 1 | 112626 | |
| NS | 3 | 1 | 47610 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.28 |
| NSB | 1 | 0 | 2000 | |

| KEYBOARD / GENERAL | | | | | IDENTIFICATION NUMBER 139 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 144741. | 4.495 | 6.909 | 10.451 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 2 | 6 | 868447 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.19 |

| KEYBOARD / MECHANICAL | | | | | IDENTIFICATION NUMBER 140 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 214323. | 2.879 | 4.666 | 7.841 |
| GM | EXPONENTIAL | 7509. | 107.707 | 133.188 | 164.821 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 4 | 857290 | |
| GM | 2 | 20 | 150188 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.17 |

| KNOB / GENERAL | | | | | IDENTIFICATION NUMBER 141 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 16308. | 48.942 | 61.320 | 76.782 |
| GF | EXPONENTIAL | 480622. | 0.858 | 2.081 | 4.452 |
| NS | EXPONENTIAL | 1384822. | 0.298 | 0.722 | 1.545 |
| NSB | EXPONENTIAL | 10200. | 40.409 | 98.040 | 209.769 |
| NU | EXPONENTIAL | ********** | 0.0 | 0.000 | 21.890 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 18 | 293544 | |
| GF | 2 | 2 | 961243 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.14 |
| NS | 2 | 2 | 2769659 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.54 |
| NSB | 2 | 2 | 20400 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.35 |
| NU | 1 | 0 | 73530 | |

| LAMP / XENON | | | | | IDENTIFICATION NUMBER 142 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| NS | EXPONENTIAL | 130. | 6503.187 | 7704.156 | 9131.840 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 30 | 3894 | |

| LAMP HOLDER / GENERAL | | | | | IDENTIFICATION NUMBER 143 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 24462. | 16.849 | 40.880 | 87.468 |
| GF | EXPONENTIAL | 220268. | 3.242 | 4.540 | 6.315 |
| NS | EXPONENTIAL | 631139. | 0.910 | 1.584 | 2.663 |
| NSB | EXPONENTIAL | 20667. | 31.480 | 48.387 | 73.192 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 2 | 48924 | |
| GF | 2 | 9 | 1982414 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.71 |
| NS | 1 | 4 | 2524554 | |
| NSB | 1 | 6 | 124000 | |

| LENS | / OPTICAL | IDENTIFICATION NUMBER 144 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUT | EXPONENTIAL | ********* | 0.0 | 0.000 | 2.742 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 0 | 587088 | |

| LOW SPEED PRINTER | / DOT MATRIX | IDENTIFICATION NUMBER 145 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | 3076. | 244.854 | 325.097 | 430.693 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 12 | 36912 | |

| MANIFOLD / GENERAL | | | | | IDENTIFICATION NUMBER 146 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 97848. | 4.212 | 10.220 | 21.867 |
| GF | EXPONENTIAL | 750000. | 0.550 | 1.333 | 2.853 |
| ML | EXPONENTIAL | ********* | SEE NOTE BELOW | | |
| NS | EXPONENTIAL | 766130. | 0.538 | 1.305 | 2.793 |
| NSB | EXPONENTIAL | 155000. | 3.704 | 6.452 | 10.841 |
| NU | EXPONENTIAL | ********* | 0.0 | 0.000 | 65.669 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 2 | 195696 | |
| GF | 1 | 2 | 1500000 | |
| ML | 1 | 0 | 76 | |
| NS | 1 | 2 | 1532259 | |
| NSB | 1 | 4 | 620000 | |
| NU | 1 | 0 | 24510 | |

NOTE: Low total part operating hours, develop failure data with caution

| METAL TUBING | / GENERAL | IDENTIFICATION NUMBER 147 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | 6666666. | 0.077 | 0.150 | 0.278 |
| GM | EXPONENTIAL | 1371027. | 0.301 | 0.729 | 1.581 |
| NS | EXPONENTIAL | 829984. | 0.744 | 1.205 | 1.905 |
| NU | EXPONENTIAL | 1643844. | 0.136 | 0.608 | 1.822 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 3 | 20000000 | |
| GM | 2 | 2 | 2742068 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.45 |
| NS | 2 | 5 | 4149919 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.96 |
| NU | 2 | 1 | 1643860 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.86 |

| MODULES | / GENERAL | IDENTIFICATION NUMBER 148 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| ARW | EXPONENTIAL | 1794. | 521.754 | 557.491 | 595.895 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 175 | 313906 | |

| MOTOR GENERATOR SET | / AC | IDENTIFICATION NUMBER 149 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GM | EXPONENTIAL | ********* | 0.0 | 0.000 | 425.809 |
| NS | EXPONENTIAL | 13100. | 17.035 | 76.336 | 228.607 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 0 | 3780 | |
| NS | 1 | 1 | 13100 | |

| MOTOR GENERATOR SET / DC | | | | | IDENTIFICATION NUMBER 150 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| NS | EXPONENTIAL | 26200. | 8.518 | 38.168 | 114.303 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 1 | 26200 | |

| MOTOR GENERATOR SET / GENERAL | | | | | IDENTIFICATION NUMBER 151 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUF | EXPONENTIAL | 39395. | 22.261 | 25.384 | 28.964 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUF | 1 | 48 | 1890976 | |

| MOTOR, ELECTRIC | / > 1 HORSE POWER, AC | IDENTIFICATION NUMBER 152 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | 750000. | 0.550 | 1.333 | 2.853 |
| GM | EXPONENTIAL | 36240. | 11.373 | 27.594 | 59.040 |
| NS | EXPONENTIAL | 24274 | 35.778 | 41.196 | 47.470 |
| NU | EXPONENTIAL | 8170. | 62.628 | 122.399 | 225.030 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 2 | 1500000 | |
| GM | 2 | 2 | 72481 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.37 |
| NS | 1 | 42 | 1019520 | |
| NU | 1 | 3 | 24510 | |

| MOTOR, ELECTRIC / > 10 HORSE POWER, AC | | | | | IDENTIFICATION NUMBER 153 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 90000. | 2.480 | 11.111 | 33.275 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 1 | 90000 | |

| MOTOR, ELECTRIC / DC | | | | | IDENTIFICATION NUMBER 154 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| NS | EXPONENTIAL | 54024. | 14.110 | 18.510 | 24.225 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 2 | 13 | 702310 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.67 |

| MOTOR, ELECTRIC | / DC, (4 HORSEPOWER) | IDENTIFICATION NUMBER 155 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GB | EXPONENTIAL | ********** | 0.0 | 0.000 | 83.323 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GB | 1 | 0 | 19317 | |

| MOTOR, ELECTRIC | / HYDRAULIC, DC | IDENTIFICATION NUMBER 156 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUT | EXPONENTIAL | 16308. | 39.894 | 61.320 | 92.754 |
| GF | EXPONENTIAL | 90000. | 2.480 | 11.111 | 33.275 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 6 | 97848 | |
| GF | 1 | 1 | 90000 | |

| MOTOR, ELECTRIC / SERVO, DC | | | | | IDENTIFICATION NUMBER 157 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AIF | EXPONENTIAL | 34289. | 16.745 | 29.164 | 49.008 |
| ARW | EXPONENTIAL | 81928. | 10.161 | 12.206 | 14.668 |
| AUT | EXPONENTIAL | 65232. | 7.844 | 15.330 | 28.184 |
| GF | EXPONENTIAL | 99425. | 7.183 | 10.058 | 13.991 |
| GM | EXPONENTIAL | 31520. | 19.601 | 31.726 | 50.168 |
| NU | EXPONENTIAL | ********* | 0.0 | 0.000 | 65.669 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AIF | 1 | 4 | 137155 | |
| ARW | 1 | 26 | 2130134 | |
| AUT | 1 | 3 | 195696 | |
| GF | 1 | 9 | 894826 | |
| GM | 4 | 5 | 157598 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.53 |
| NU | 1 | 0 | 24510 | |

| MOTOR, ELECTRIC / STEPPER | | | | | IDENTIFICATION NUMBER 158 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUF | EXPONENTIAL | 125215. | 6.219 | 7.986 | 10.240 |
| GM | EXPONENTIAL | 75094. | 5.489 | 13.317 | 28.493 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUF | 1 | 15 | 1878222 | |
| GM | 2 | 2 | 150188 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.77 |

| O-RING | / GENERAL | IDENTIFICATION NUMBER 159 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUT | EXPONENTIAL | 56723. | 15.823 | 17.629 | 19.654 |
| GM | EXPONENTIAL | 3780. | 59.038 | 264.550 | 792.261 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 69 | 3913920 | |
| GM | 1 | 1 | 3780 | |

| PARTICLE SEPARATOR | / GENERAL | IDENTIFICATION NUMBER 160 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| ARW | EXPONENTIAL | 1085. | 858.023 | 921.659 | 990.418 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 151 | 163835 | |

| PITCH HORN | / GENERAL | IDENTIFICATION NUMBER 161 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| ARW | EXPONENTIAL | 2287. | 383.404 | 437.178 | 498.845 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 48 | 109795 | |

| PLOTTER | / ELECTROMECHANICAL | IDENTIFICATION NUMBER 162 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| NS | EXPONENTIAL | 144730. | 4.816 | 6.909 | 9.828 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 8 | 1157842 | |

| POWER CIRCUIT BREAKER / CURRENT & VOLTAGE TRIP | | | | | IDENTIFICATION NUMBER 163 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 100707. | 7.363 | 9.930 | 13.340 |
| NS | EXPONENTIAL | 16667. | 46.726 | 60.000 | 76.935 |
| NSB | EXPONENTIAL | 37999. | 5.874 | 26.317 | 78.810 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 2 | 11 | 1107781 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.62 |
| NS | 1 | 15 | 250000 | |
| NSB | 4 | 1 | 38000 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.62 |

| POWER CIRCUIT BREAKER / CURRENT TRIP | | | | | IDENTIFICATION NUMBER 164 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 243017. | 2.542 | 4.115 | 6.507 |
| GM | EXPONENTIAL | 154105. | 5.214 | 6.489 | 8.070 |
| NS | EXPONENTIAL | 357597. | 1.819 | 2.796 | 4.230 |
| NU | EXPONENTIAL | 355395. | 1.16[illegible] | 2.814 | 6.020 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 3 | 5 | 1215091 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.38 |
| GM | 3 | 19 | 2927995 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.07 |
| NS | 2 | 6 | 2145579 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.06 |
| NU | 1 | 2 | 710790 | |

| POWER SWITCH GEAR | / GENERAL | IDENTIFICATION NUMBER 165 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | 250000. | 0.893 | 4.000 | 11.979 |
| GM | EXPONENTIAL | 304150. | 0.734 | 3.288 | 9.846 |
| NU | EXPONENTIAL | ********* | 0.0 | 0.000 | 65.869 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 1 | 250000 | |
| GM | 3 | 1 | 304158 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.60 |
| NU | 1 | 0 | 24510 | |

| PRECIPITATOR | / ELECTROSTATIC | IDENTIFICATION NUMBER 166 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| NS | EXPONENTIAL | 2777. | 184.230 | 360.057 | 661.985 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 3 | 8332 | |

| PRISM | / OPTICAL | IDENTIFICATION NUMBER 167 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUT | EXPONENTIAL | ********* | 0.0 | 0.000 | 10.966 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 0 | 146772 | |

| PROPELLER | | / GENERAL (FROM SHIP) | | | IDENTIFICATION NUMBER 168 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| NS | EXPONENTIAL | 1120. | 368.167 | 893.256 | 1911.242 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 2 | 2239 | |

| PROPORTIONING UNIT | | / FROM DISTILLING PLANT | | | IDENTIFICATION NUMBER 169 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| NS | EXPONENTIAL | ********* | 0.0 | 0.000 | 102.357 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 0 | 15725 | |

| PULLEY / GEAR BELT | | | | | IDENTIFICATION NUMBER 170 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 189156. | 3.439 | 5.287 | 7.997 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 3 | 6 | 1134936 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.23 |

| PULLEY / GROOVED | | | | | IDENTIFICATION NUMBER 171 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GM | EXPONENTIAL | 80298. | 6.372 | 12.454 | 22.896 |
| NS | EXPONENTIAL | 766130. | 0.538 | 1.305 | 2.793 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 2 | 3 | 240895 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.74 |
| NS | 1 | 2 | 1532259 | |

| PULLEY | / V-PULLEY | IDENTIFICATION NUMBER 172 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GM | EXPONENTIAL | 79308. | 6.452 | 12.609 | 23.182 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 237924 | |

| PUMP | / CENTRIFUGAL | IDENTIFICATION NUMBER 173 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| NS | EXPONENTIAL | 26825. | 32.693 | 37.279 | 42.537 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 48 | 1287605 | |

| PUMP / HYDRAULIC | | | | | IDENTIFICATION NUMBER 174 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 48924. | 4.561 | 20.440 | 61.212 |
| GF | EXPONENTIAL | 68000. | 9.085 | 14.706 | 23.254 |
| GM | EXPONENTIAL | 473. | 1475.055 | 2116.402 | 3010.715 |
| NS | EXPONENTIAL | 17700. | 28.908 | 56.497 | 103.870 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 1 | 48924 | |
| GF | 2 | 5 | 340000 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.12 |
| GM | 1 | 8 | 3780 | |
| NS | 2 | 3 | 53100 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.74 |

| PUMP | / HYDRAULIC(ROTARY) | IDENTIFICATION NUMBER 175 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| NU | EXPONENTIAL | 24510. | 9.105 | 40.800 | 122.185 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NU | 1 | 1 | 24510 | |

| PUMP | / PNEUMATIC | IDENTIFICATION NUMBER 176 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | 106153. | 4.820 | 9.420 | 17.319 |
| GM | EXPONENTIAL | 19827. | 25.807 | 50.436 | 92.727 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 2 | 3 | 318459 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.96 |
| GM | 1 | 3 | 59481 | |

| PUMP / ROTARY | | | | | IDENTIFICATION NUMBER 177 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| NS | EXPONENTIAL | 3667. | 60.857 | 272.702 | 816.875 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 1 | 3667 | |

| PUMP / VACUUM | | | | | IDENTIFICATION NUMBER 178 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 94250. | 5.429 | 10.610 | 19.507 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 3 | 3 | 282750 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.45 |

| PUMP | / VACUUM - LOBE TYPE | IDENTIFICATION NUMBER 179 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | 4091. | 199.898 | 244.444 | 298.946 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 22 | 90000 | |

| PUMP | / VACUUM - RING SEAL TYPE | IDENTIFICATION NUMBER 180 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | 90000. | 2.480 | 11.111 | 33.275 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 1 | 90000 | |

| PURIFIER | / CENTRIFUGAL | IDENTIFICATION NUMBER 181 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| NS | EXPONENTIAL | 655. | 1033.057 | 1527.717 | 2233.328 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 7 | 4582 | |

| QUILL ASSEMBLY | / GENERAL | IDENTIFICATION NUMBER 182 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| ARW | EXPONENTIAL | 771. | 1186.734 | 1296.933 | 1418.125 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 100 | 77105 | |

| RADOME | / MICROWAVE. ANTENNA | IDENTIFICATION NUMBER 183 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AIF | EXPONENTIAL | 137155. | 3.005 | 7.291 | 15.600 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AIF | 1 | 2 | 274310 | |

| REFRIGERATION PLANT | / FROM AIR CONDITIONG PLANT | IDENTIFICATION NUMBER 184 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| NS | EXPONENTIAL | 9337. | 95.233 | 107.106 | 120.541 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 59 | 550856 | |

| REGULATOR / ELECTRICAL | | | | | IDENTIFICATION NUMBER 185 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 377134. | 1.093 | 2.652 | 5.873 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 2 | 2 | 754268 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.46 |

| REGULATOR / PNEUMATIC (PRESSURE) | | | | | IDENTIFICATION NUMBER 186 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 6429. | 119.929 | 155.556 | 201.397 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 14 | 90000 | |

| REGULATOR / PNEUMATIC (VACUUM BREAKER) | | | | | IDENTIFICATION NUMBER 187 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 9000. | 80.982 | 111.111 | 151.687 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 10 | 90000 | |

| REGULATOR / PRESSURE | | | | | IDENTIFICATION NUMBER 188 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 97848. | 2.281 | 10.220 | 30.806 |
| GF | EXPONENTIAL | 500000. | 1.023 | 2.000 | 3.677 |
| GM | EXPONENTIAL | 97771. | 5.872 | 10.228 | 17.187 |
| ML | EXPONENTIAL | ********* | SEE NOTE BELOW | | |
| NS | EXPONENTIAL | 34040. | 15.031 | 29.377 | 54.010 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 1 | 97848 | |
| GF | 1 | 3 | 1500000 | |
| GM | 2 | 4 | 391083 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.81 |
| ML | 1 | 0 | 216 | |
| NS | 3 | 3 | 102120 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.13 |

NOTE: Low total part operating hours, develop failure data with caution

| REGULATOR / TEMPERATURE | | | | | IDENTIFICATION NUMBER 189 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GM | EXPONENTIAL | 4535 | 90.885 | 220.507 | 471.805 |
| NS | EXPONENTIAL | 13100. | 17.035 | 76.336 | 228.607 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 9070 | |
| NS | 1 | 1 | 13100 | |

| RESILIENT MOUNT / GENERAL | | | | | IDENTIFICATION NUMBER 190 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 330237. | 1.739 | 3.028 | 5.089 |
| GF | EXPONENTIAL | 250000. | 2.297 | 4.000 | 6.722 |
| GM | EXPONENTIAL | 34166. | 21.704 | 29.268 | 39.321 |
| NS | EXPONENTIAL | 772117. | 0.744 | 1.295 | 2.176 |
| NSB | EXPONENTIAL | 12300. | 33.509 | 81.301 | 173.954 |
| NU | EXPONENTIAL | 424840. | 1.204 | 2.354 | 4.328 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 4 | 1320948 | |
| GF | 1 | 4 | 1000000 | |
| GM | 2 | 11 | 375828 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.39 |
| NS | 2 | 4 | 3088468 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.83 |
| NSB | 1 | 2 | 24600 | |
| NU | 1 | 3 | 1274520 | |

| RESILIENT MOUNT / SHOCK MOUNTS | | | | | IDENTIFICATION NUMBER 101 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GM | EXPONENTIAL | 5600. | 91.369 | 178.571 | 328.303 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 16800 | |

| RETAINING RING / GENERAL | | | | | IDENTIFICATION NUMBER 192 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 15759. | 59.726 | 83.455 | 87.439 |
| GF | EXPONENTIAL | 812693. | 1.104 | 1.632 | 2.386 |
| GM | EXPONENTIAL | 391925. | 1.822 | 2.552 | 3.549 |
| NS | EXPONENTIAL | 1474697. | 0.347 | 0.678 | 1.247 |
| NU | EXPONENTIAL | 339590. | 1.214 | 2.945 | 6.301 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 208 | 3277908 | |
| GF | 4 | 7 | 4288853 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.37 |
| GM | 3 | 9 | 3527328 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.58 |
| NS | 2 | 3 | 4424091 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.41 |
| NU | 2 | 2 | 879180 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.09 |

| SEAL | / GENERAL | IDENTIFICATION NUMBER 193 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| ARW | EXPONENTIAL | 1961. | 393.223 | 510.037 | 660.340 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 14 | 27449 | |

| SEAL | / SOLDER | IDENTIFICATION NUMBER 194 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUF | EXPONENTIAL | 460402. | 1.583 | 2.172 | 2.985 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUF | 1 | 10 | 4604017 | |

| SENSORS / WATER LEVEL | | | | | IDENTIFICATION NUMBER 195 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 12857. | 52.594 | 77.778 | 113.701 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 7 | 90000 | |

| SENSORS/TRANSDUCER/TRANSMITTER/ ACOUSTIC (HYDROPHONES) | | | | | IDENTIFICATION NUMBER 196 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| NSB | EXPONENTIAL | ********* | 0.0 | 0.000 | 184.244 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NSB | 1 | 0 | 8736 | |

| SENSORS/TRANSDUCER/TRANSMITTER/ AIRFLOW | | | | | IDENTIFICATION NUMBER 197 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GM | EXPONENTIAL | 1900. | 216.928 | 526.316 | 1126.124 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 3800 | |

| SENSORS/TRANSDUCER/TRANSMITTER/ FLOW (LIQUID) | | | | IDENTIFICATION NUMBER 198 | |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUF | EXPONENTIAL | 98657. | 4.178 | 10.136 | 21.688 |
| GM | EXPONENTIAL | 95764. | 7.611 | 10.442 | 14.256 |
| NS | EXPONENTIAL | 36765. | 11.211 | 27.200 | 58.198 |
| NU | EXPONENTIAL | 39300. | 5.678 | 25.445 | 76.202 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUF | 1 | 2 | 197314 | |
| GM | 2 | 10 | 957638 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.16 |
| NS | 1 | 2 | 73530 | |
| NU | 1 | 1 | 39300 | |

| SENSORS/TRANSDUCER/TRANSMITTER/ HUMIDITY | | | | | IDENTIFICATION NUMBER 199 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 48924. | 4.561 | 20.440 | 61.212 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 1 | 48924 | |

| SENSORS/TRANSDUCER/TRANSMITTER/ INFRARED | | | | | IDENTIFICATION NUMBER 200 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 1553. | 574.805 | 643.855 | 721.681 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 63 | 97848 | |

| SENSORS/TRANSDUCER/TRANSMITTER/ MOTION | | | | | IDENTIFICATION NUMBER 201 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GM | EXPONENTIAL | 10728. | 71.867 | 93.217 | 120.687 |
| NS | EXPONENTIAL | ********* | 0.0 | 0.000 | 65.669 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 2 | 14 | 150188 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.80 |
| NS | 1 | 0 | 24510 | |

| SENSORS/TRANSDUCER/TRANSMITTER/ PRESSURE | | | | IDENTIFICATION NUMBER 202 | |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 24462. | 26.596 | 40.880 | 61.836 |
| GF | EXPONENTIAL | 5201. | 172.717 | 192.271 | 214.175 |
| GM | EXPONENTIAL | 1890. | 218.076 | 529.100 | 1132.082 |
| NS | EXPONENTIAL | 43315. | 9.515 | 23.087 | 49.397 |
| NSB | EXPONENTIAL | 364. | 613.087 | 2747.252 | 8227.320 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 6 | 146772 | |
| GF | 1 | 70 | 364070 | |
| GM | 1 | 2 | 3780 | |
| NS | 2 | 2 | 86630 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.25 |
| NSB | 1 | 1 | 364 | |

| SENSORS/TRANSDUCER/TRANSMITTER/ TEMPERATURE | | | IDENTIFICATION NUMBER 203 | | |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 97848. | 4.212 | 10.220 | 21.867 |
| GF | EXPONENTIAL | 15763. | 44.215 | 63.440 | 90.247 |
| GM | EXPONENTIAL | 75342. | 9.989 | 13.273 | 17.584 |
| NS | EXPONENTIAL | 63809. | 3.498 | 15.672 | 46.932 |
| NSB | EXPONENTIAL | 34073. | 18.132 | 29.349 | 46.408 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 2 | 195696 | |
| GF | 3 | 8 | 126104 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.21 |
| GM | 2 | 12 | 904099 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.78 |
| NS | 2 | 1 | 63810 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.32 |
| NSB | 3 | 5 | 170364 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.30 |

| SHAFT / GENERAL | | | | | IDENTIFICATION NUMBER 204 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| ARW | EXPONENTIAL | 3431. | 240.616 | 291.453 | 353.124 |
| AUT | EXPONENTIAL | 207927. | 2.761 | 4.809 | 8.082 |
| GF | EXPONENTIAL | 186771. | 3.824 | 5.354 | 7.448 |
| GM | EXPONENTIAL | 80642. | 9.453 | 12.401 | 16.229 |
| NU | EXPONENTIAL | 99729. | 2.238 | 10.027 | 30.029 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 24 | 82346 | |
| AUT | 1 | 4 | 831708 | |
| GF | 4 | 9 | 1630937 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.97 |
| GM | 2 | 13 | 1048345 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.06 |
| NU | 2 | 1 | 99730 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.44 |

| SHOCK ABSORBERS / COMBINATION | | | | | IDENTIFICATICN NUMBER 205 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 73386. | 5.616 | 13.627 | 29.156 |
| GM | EXPONENTIAL | 52417. | 13.296 | 19.078 | 27.139 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 2 | 146772 | |
| GM | 2 | 8 | 419338 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.07 |

| SHOCK ABSORBERS / RISILIENT | | | | | IDENTIFICATION NUMBER 206 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GM | EXPONENTIAL | 52417. | 10.953 | 19.078 | 32.059 |
| NU | EXPONENTIAL | 122550. | 4.175 | 8.160 | 15.002 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 2 | 4 | 209669 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.79 |
| NU | 1 | 3 | 367650 | |

| SLIP RING-BRUSH / POWER & SIGNAL | | | | | IDENTIFICATION NUMBER 207 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUF | EXPONENTIAL | 1760462. | 0.421 | 0.568 | 0.763 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUF | 1 | 11 | 19365088 | |

| SLIP RINGS / GENERAL | | | | | IDENTIFICATION NUMBER 208 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 1500000. | 0.149 | 0.667 | 1.996 |
| GM | EXPONENTIAL | 3800. | 171.209 | 263.158 | 398.061 |
| NS | EXPONENTIAL | 73530. | 3.035 | 13.600 | 40.728 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 1 | 1500000 | |
| GM | 1 | 6 | 22800 | |
| NS | 1 | 1 | 73530 | |

| SOLENOIDS / GENERAL | | | | | IDENTIFICATION NUMBER 209 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| NS | EXPONENTIAL | 24510. | 9.105 | 40.800 | 122.185 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 1 | 24510 | |

| SOLENOIDS / LINEAR | | | | | IDENTIFICATION NUMBER 210 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 90000. | 2.480 | 11.111 | 33.275 |
| GM | EXPONENTIAL | 50379. | 12.914 | 19.849 | 30.025 |
| NS | EXPONENTIAL | 32750. | 12.585 | 30.534 | 85.332 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 1 | 90000 | |
| GM | 3 | 6 | 302276 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.06 |
| NS | 1 | 2 | 65500 | |

| SOLENOIDS / ROTARY | | | | | IDENTIFICATION NUMBER 211 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 29493. | 20.947 | 33.906 | 53.614 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 3 | 5 | 147466 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.88 |

| SPRING / COMPRESSION | | | | | IDENTIFICATION NUMBER 212 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 91812. | 6.254 | 10.892 | 18.303 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 4 | 367248 | |

| SPRING | / GENERAL | IDENTIFICATION NUMBER 213 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AIF | EXPONENTIAL | 45718. | 11.192 | 21.873 | 40.214 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AIF | 1 | 3 | 137155 | |

| SPRING | / TORRISION | IDENTIFICATION NUMBER 214 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | 69952. | 7.315 | 14.296 | 26.282 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 3 | 209856 | |

| SPROCKET | / GENERAL | IDENTIFICATION NUMBER 215 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUT | EXPONENTIAL | 244620. | 0.912 | 4.088 | 12.242 |
| GF | EXPONENTIAL | 175662. | 3.517 | 5.693 | 9.002 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 1 | 244620 | |
| GF | 4 | 5 | 878312 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.50 |

| STEAMBOILER | / GENERAL (FROM SHIP) | IDENTIFICATION NUMBER 216 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| NS | EXPONENTIAL | 1958. | 378.790 | 510.820 | 686.262 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 11 | 21534 | |

| STOW PIN | / GENERAL | IDENTIFICATION NUMBER 217 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| NU | EXPONENTIAL | 163400. | 3.131 | 6.120 | 11.252 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NU | 1 | 3 | 490200 | |

| SWITCH | / COAXIAL (ELECTROMECHANICAL) | IDENTIFICATION NUMBER 218 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| NS | EXPONENTIAL | 27780. | 26.236 | 35.997 | 49.143 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 10 | 277800 | |

| SWITCH / FLOW (LIQUID) | | | | | IDENTIFICATION NUMBER 219 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GM | EXPONENTIAL | 133992. | 4.285 | 7.463 | 12.541 |
| NS | EXPONENTIAL | 198017. | 3.415 | 5.050 | 7.383 |
| NU | EXPONENTIAL | 10480. | 39.329 | 95.420 | 204.164 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 2 | 4 | 535968 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.21 |
| NS | 3 | 7 | 1386117 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.06 |
| NU | 1 | 2 | 20960 | |

| SWITCH / INTERLOCK | | | | | IDENTIFICATION NUMBER 220 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GM | EXPONENTIAL | 1583. | 410.902 | 631.579 | 955.348 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 6 | 9500 | |

| SWITCH / PRESSURE (AIR FLOW) | | | IDENTIFICATION NUMBER 221 | | |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 239465. | 2.983 | 4.176 | 5.809 |
| GM | EXPONENTIAL | 90047. | 7.932 | 11.105 | 15.448 |
| ML | EXPONENTIAL | ********* | SEE NOTE BELOW | | |
| NS | EXPONENTIAL | 110582. | 7.792 | 9.043 | 10.502 |
| NU | EXPONENTIAL | 40000. | 5.579 | 25.000 | 74.869 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 5 | 9 | 2155190 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.83 |
| GM | 2 | 9 | 810421 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.51 |
| ML | 1 | 0 | 164 | |
| NS | 4 | 38 | 4202120 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.33 |
| NU | 1 | 1 | 40000 | |

NOTE: Low total part operating hours, develop failure data with caution

| SWITCH / ROCKER | | | | | IDENTIFICATION NUMBER 222 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 95067. | 8.452 | 10.519 | 13.082 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 2 | 19 | 1806280 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.46 |

| SWITCH / THERMOSTATIC | | | | IDENTIFICATION NUMBER 223 | |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 61155. | 9.388 | 16.352 | 27.478 |
| GF | EXPONENTIAL | 205556. | 3.475 | 4.865 | 6.767 |
| GM | EXPONENTIAL | 63101. | 13.024 | 15.848 | 19.288 |
| NS | EXPONENTIAL | 334866. | 2.383 | 2.986 | 3.739 |
| NSB | EXPONENTIAL | 18232. | 44.075 | 54.850 | 68.217 |
| NU | EXPONENTIAL | 66730. | 7.668 | 14.986 | 27.551 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 4 | 244620 | |
| GF | 2 | 9 | 1850000 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.08 |
| GM | 1 | 23 | 1451312 | |
| NS | 3 | 18 | 6027596 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.73 |
| NSB | 4 | 19 | 346400 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.75 |
| NU | 3 | 3 | 200190 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.48 |

| SWITCH / THUMBWHEEL | | | | | IDENTIFICATION NUMBER 224 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 249616. | 2.792 | 4.006 | 5.699 |
| GM | EXPONENTIAL | 3780. | 59.038 | 264.550 | 792.261 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 3 | 8 | 1996924 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.32 |
| GM | 1 | 1 | 3780 | |

| SWITCH / WAVE GUIDE | | | | | IDENTIFICATION NUMBER 225 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 250000. | 1.649 | 4.000 | 8.559 |
| GM | EXPONENTIAL | 19827. | 25.807 | 50.436 | 92.727 |
| NS | EXPONENTIAL | 15400. | 33.225 | 64.935 | 119.383 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 2 | 500000 | |
| GM | 1 | 3 | 59481 | |
| NS | 2 | 3 | 46200 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.42 |

| SWITCHBOARD CONTROL / FROM OXYGEN GENERATOR | | | | | IDENTIFICATION NUMBER 226 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| NS | EXPONENTIAL | 1670. | 542.640 | 598.877 | 661.336 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 82 | 136923 | |

| SYNCRO | / TRANSMITTER | IDENTIFICATION NUMBER 227 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| NS | EXPONENTIAL | 193115. | 3.502 | 5.178 | 7.570 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 7 | 1351805 | |

| SYNCRO ASSEMBLY | / GENERAL | IDENTIFICATION NUMBER 228 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| NS | EXPONENTIAL | 21882. | 36.723 | 45.701 | 56.838 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 19 | 415750 | |

| SYNCRO/RESOLVER | / LOW SPEED LOW LOAD | IDENTIFICATION NUMBER 229 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUF | EXPONENTIAL | 774548. | 0.532 | 1.291 | 2.782 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUF | 1 | 2 | 1549092 | |

| TACHOMETER | / GENERAL | IDENTIFICATION NUMBER 230 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| AUT | EXPONENTIAL | 16308. | 43.795 | 61.320 | 85.300 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 9 | 146772 | |

| TANK / NON PRESSURIZED | | | | | IDENTIFICATION NUMBER 231 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GM | EXPONENTIAL | 1890. | 218.076 | 529.100 | 1132.082 |
| NU | EXPONENTIAL | 17467. | 29.294 | 57.252 | 105.258 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 3780 | |
| NU | 1 | 3 | 52400 | |

| TANK / PRESSURIZED | | | | | IDENTIFICATION NUMBER 232 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 125000. | 1.785 | 8.000 | 23.952 |
| ML | EXPONENTIAL | ********* | 0.0 | 0.000 | 18084.918 |
| NU | EXPONENTIAL | 14837. | 34.487 | 67.401 | 123.918 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 1 | 125000 | |
| ML | 1 | 0 | 89 | |
| NU | 2 | 3 | 44510 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.68 |

| TELESCOPE / BORESIGHT | | | | | IDENTIFICATION NUMBER 233 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GM | EXPONENTIAL | 30038. | 20.568 | 33.292 | 52.643 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 2 | 5 | 150188 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.99 |

| TELESCOPE / GENERAL | | | | | IDENTIFICATION NUMBER 234 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | ********** | 0.0 | 0.000 | 32.899 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 0 | 48924 | |

| TERMINAL BOARDS / GENERAL | | | | | IDENTIFICATION NUMBER 235 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 195696. | 2.934 | 5.110 | 8.587 |
| GF | EXPONENTIAL | 260072. | 2.746 | 3.845 | 5.349 |
| GM | EXPONENTIAL | 492827. | 1.595 | 2.029 | 2.579 |
| NS | EXPONENTIAL | 1011841. | 0.812 | 0.988 | 1.203 |
| NSB | EXPONENTIAL | 131760. | 4.689 | 7.590 | 12.001 |
| NU | EXPONENTIAL | 99560. | 2.241 | 10.044 | 30.080 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 4 | 782784 | |
| GF | 5 | 9 | 2340648 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.35 |
| GM | 3 | 16 | 7885228 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.13 |
| NS | 3 | 23 | 23272336 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.17 |
| NSB | 3 | 5 | 658800 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.48 |
| NU | 1 | 1 | 99560 | |

| THERMOCOUPLE / GENERAL | | | | | IDENTIFICATION NUMBER 236 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 750000. | 0.550 | 1.333 | 2.853 |
| GM | EXPONENTIAL | 75342. | 9.989 | 13.273 | 17.584 |
| NS | EXPONENTIAL | 16903. | 30.270 | 59.160 | 108.765 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 2 | 1500000 | |
| GM | 2 | 12 | 904099 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.78 |
| NS | 2 | 3 | 50710 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.52 |

| TRACK BALL | / ELECTROMECHANICAL | IDENTIFICATION NUMBER 237 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | 24383. | 34.823 | 41.012 | 48.329 |
| GM | EXPONENTIAL | 30794. | 20.063 | 32.474 | 51.350 |
| NS | EXPONENTIAL | 128100. | 6.350 | 7.806 | 9.597 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 2 | 32 | 780257 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.70 |
| GM | 3 | 5 | 153968 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.88 |
| NS | 2 | 21 | 2690101 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.17 |

| TRANSMISSION | / GENERAL | IDENTIFICATION NUMBER 238 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| ARW | EXPONENTIAL | 907. | 1044.302 | 1101.965 | 1163.125 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 262 | 237757 | |

| TRUNNION ASSEMBLY | / GENERAL | IDENTIFICATION NUMBER 239 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| ARW | EXPONENTIAL | 518. | 1704.926 | 1930.854 | 2188.241 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ARW | 1 | 53 | 27449 | |

| VALVE | / CONTROL-MANUAL | IDENTIFICATION NUMBER 240 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| NS | EXPONENTIAL | 91970. | 8.183 | 10.873 | 14.405 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 12 | 1103639 | |

| VALVE | / GAS (AIR-VENT) | IDENTIFICATION NUMBER 241 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| NS | EXPONENTIAL | 894630. | 0.461 | 1.118 | 2.392 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 2 | 1789259 | |

| VALVE / HYDRAULIC | | | | | IDENTIFICATION NUMBER 242 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | ********* | 0.0 | 0.000 | 32.899 |
| GF | EXPONENTIAL | 166667. | 3.904 | 6.000 | 9.076 |
| GM | EXPONENTIAL | 51001. | 12.757 | 19.608 | 29.659 |
| NS | EXPONENTIAL | 31690. | 18.118 | 31.556 | 53.027 |
| NSB | EXPONENTIAL | 4356. | 163.977 | 229.592 | 319.379 |
| NU | EXPONENTIAL | 23100. | 17.843 | 43.290 | 92.625 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 0 | 48924 | |
| GF | 1 | 6 | 1000000 | |
| GM | 2 | 6 | 306003 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.15 |
| NS | 2 | 4 | 126760 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.44 |
| NSB | 2 | 9 | 39200 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.92 |
| NU | 2 | 2 | 46200 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.85 |

| VALVE / PNEUMATIC | | | | | IDENTIFICATION NUMBER 243 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 48924. | 13.298 | 20.440 | 30.918 |
| GF | EXPONENTIAL | 250000. | 1.649 | 4.000 | 8.559 |
| GM | EXPONENTIAL | 60471. | 8.461 | 16.537 | 30.403 |
| NS | EXPONENTIAL | ********** | 0.0 | 0.000 | 1.118 |
| NU | EXPONENTIAL | 21690. | 10.289 | 46.104 | 138.070 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 6 | 293544 | |
| GF | 1 | 2 | 500000 | |
| GM | 1 | 3 | 181414 | |
| NS | 1 | 0 | 1440000 | |
| NU | 1 | 1 | 21690 | |

| VALVE | / SOLENOID OPERATED | IDENTIFICATION NUMBER 244 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | 90000. | 2.480 | 11.111 | 33.275 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 1 | 90000 | |

| VALVE ( ISOLATION ) | / PYROTECHNICALLY ACTUATED VALVE | IDENTIFICATION NUMBER 245 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| ML | EXPONENTIAL | ********** | SEE NOTE BELOW | | |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ML | 1 | 0 | 124 | |

NOTE: Low total part operating hours, develop failure data with caution

| VALVE ( RELIEF ) / PRESSURE ACTUATED | | | | | IDENTIFICATION NUMBER 246 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| ML | EXPONENTIAL | ********* | SEE NOTE BELOW | | |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ML | 1 | 0 | 42 | |

| VALVE (FILL & DRAIN) / HAND OPERATED PLUG VALVE | | | | | IDENTIFICATION NUMBER 247 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| ML | EXPONENTIAL | ********* | 0.0 | 0.000 | 922.383 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ML | 1 | 0 | 1745 | |

NOTE: Low total part operating hours, develop failure data with caution

| VALVE(BIPROPELLANT-HIGH THURST/ SOLENOID OPERATED | | | | | IDENTIFICATION NUMBER 248 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| ML | EXPONENTIAL | ********** | SEE NOTE BELOW | | |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ML | 1 | 0 | 45 | |

| VALVE(BIPROPELLANT-LOW THURST)/ TORQUE MOTOR OPERATED | | | | | IDENTIFICATION NUMBER 249 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| ML | EXPONENTIAL | ********** | 0.0 | 0.000 | 5152.230 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| ML | 1 | 0 | 312 | |

NOTE: Low total part operating hours, develop failure data with caution

| WASHER / FLAT | | | IDENTIFICATION NUMBER 250 | | |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 14567. | 65.568 | 68.647 | 71.886 |
| GF | EXPONENTIAL | 1629170. | 0.493 | 0.614 | 0.763 |
| GM | EXPONENTIAL | 6051034. | 0.152 | 0.165 | 0.180 |
| NS | EXPONENTIAL | 2345333. | 0.343 | 0.426 | 0.530 |
| NSB | EXPONENTIAL | ********* | 0.0 | 0.000 | 2.454 |
| NU | EXPONENTIAL | 2742413. | 0.225 | 0.365 | 0.577 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 356 | 5185944 | |
| GF | 3 | 19 | 30954240 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.27 |
| GM | 2 | 110 | 665613824 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.96 |
| NS | 1 | 19 | 44561328 | |
| NSB | 2 | 0 | 656000 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 1.00 |
| NU | 2 | 5 | 13712066 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.25 |

| WASHER / LOCK | | | | IDENTIFICATION NUMBER 251 | |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| AUT | EXPONENTIAL | 11605. | 81.168 | 86.168 | 91.483 |
| GF | EXPONENTIAL | 1706841. | 0.447 | 0.586 | 0.767 |
| GM | EXPONENTIAL | 8636816. | 0.097 | 0.116 | 0.138 |
| NS | EXPONENTIAL | 1161859. | 0.711 | 0.861 | 1.043 |
| NSB | EXPONENTIAL | ********* | 0.0 | 0.000 | 7.186 |
| NU | EXPONENTIAL | 834536. | 0.688 | 1.198 | 2.014 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| AUT | 1 | 215 | 2495124 | |
| GF | 3 | 13 | 22188944 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.77 |
| GM | 2 | 28 | 241830848 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.97 |
| NS | 2 | 24 | 27884624 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.84 |
| NSB | 1 | 0 | 224000 | |
| NU | 1 | 4 | 3338142 | |

| WASHER / SHERR | | | | | IDENTIFICATION NUMBER 252 |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| NS | EXPONENTIAL | 637260. | 0.350 | 1.569 | 4.699 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 1 | 637260 | |

| WASHER / SPRING | | | | IDENTIFICATION NUMBER 253 | |
|---|---|---|---|---|---|
| | | | FAILURE RATE (FAILURES PER MILLION HOURS) | | |
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| GF | EXPONENTIAL | 615994. | 0.669 | 1.623 | 3.473 |
| GM | EXPONENTIAL | 232437. | 3.381 | 4.302 | 5.469 |
| NS | EXPONENTIAL | 41920. | 15.520 | 23.855 | 36.084 |
| NU | EXPONENTIAL | ********** | 0.0 | 0.000 | 25.597 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 3 | 2 | 1231994 | SIGNIFICANCE LEVEL FOR COMBINING SOURCES= 0.16 |
| GM | 1 | 16 | 3718986 | |
| NS | 1 | 6 | 251520 | |
| NU | 1 | 0 | 62880 | |

| WASHER | / STAR | IDENTIFICATION NUMBER 254 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| GF | EXPONENTIAL | 56624992. | 0.010 | 0.018 | 0.030 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 4 | 226500000 | |

| WATER DEMINERALIZER | / MIX-RESIN | IDENTIFICATION NUMBER 255 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|
| NS | EXPONENTIAL | 13100. | 17.035 | 76.336 | 228.607 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 1 | 13100 | |

| WINDLASS / FROM ANCHOR | | | | | IDENTIFICATION NUMBER 256 |
|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE (HOURS) | FAILURE RATE (FAILURES PER MILLION HOURS) 80% LOWER BOUND | FAILURE RATE ESTIMATE | 80% UPPER BOUND |
| NS | EXPONENTIAL | SEE NOTE BELOW | | | |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| NS | 1 | 1 | 83 | |

NOTE: Low total part operating hours, develop failure data with caution

5.3 Weibull Analyses -- Project 1. This section contains the results of fitting the Weibull distribution to nonelectronic part lifetime data collected on a ground mobile mortar locating radar. For each part type and class represented, a table is presented which gives the part identification number, a point estimate of mean life in hours, a point and 60% confidence interval estimate of the Weibull scale parameter in hours, and a point and 60% confidence interval estimate of the Weibull shape parameter. The form of the Weibull survival function considered here is given by:

$$\Pr(\text{survive } t) = \exp[-(t/b)^c],$$

where $b>0$ is the scale parameter, $c>0$ is the shape parameter, and $t>0$ is measured in hours. This convention is followed throughout sections 5.3 - 5.5.

In addition to these quantities, the total part operating hours are given, along with the total number of failures. The "comments" field contains the predominant failure mode observed (i.e. the failure mode which occurred most often in the sample) and the observed significance level for testing exponentiality. We recommend that exponentiality be rejected if the observed significance level is below 0.05, although other thresholds may be used according to the particular application.

In some cases, less than two failures are reported. However, because there are multiple systems reporting (53 in this case) and one or more parts per system, the systems which have no failures were also used as "data" so that the two parameters of interest could actually be estimated. This applies to section 5.4 also.

In only one instance in project 1 is exponentiality rejected at the 0.05 significance level, namely for electrostatic high speed printers (identification number 1-2-36). The Weibull shape parameter estimate in this case was 0.748. The corresponding Weibull distribution would, in this case, have a decreasing failure rate and its probability density function would be shaped somewhat like that of the exponential distribution. One interpretation for the shape parameter being less than one is that infant failures were still taking place in the printers after they were installed. If this is true, it would be indicative of poor vendor quality control.

5.3.1 Weibull Analyses Summaries. Following is an index of the nonelectronic parts analyzed in this section. Each part is identified by a number of the form "x-y-z". The prefix "x" identifies the project from which the data was collected ("x" is 1 in this section). The number "y", being either 1,2, or 3 indicates the sampling and censoring scheme (in the statistical sense) used in collection the data for that part. These schemes are described in the Final Technical Report of this study. The number "z" is the sequence number as listed in the index that follows.

The column under "Best Fit" indicates which distribution is the better fitting distribution (assuming 0.05 significance level) with E=exponential, and W=Weibull. The format for this index is used in sections 5.4 and 5.5. also.

## Index to Project 1 Weibull Analyses

| Part Name | Part Type | Environment | Sequence Number | Best Fit |
|---|---|---|---|---|
| ACCELEROMETER | FORCED BALANCE | GM | 1 | E |
| ACTUATOR | LINEAR | GM | 2 | E |
| AXLE | GENERAL | GM | 3 | E |
| AZIMUTH ENCODER | OPTICAL | GM | 4 | E |
| BATTERY | RECHARGEABLE | GM | 5 | E |
| BEARING | BALL | GM | 6 | E |
| BEARING | ROLLER | GM | 7 | E |
| BEARING | SLEEVE | | 8 | E |
| BELLOWS | GENERAL | GM | 9 | E |
| BELT | TIMING | GM | 10 | E |
| BLOWERS & FANS | AXIAL | GM | 11 | E |
| BRAKES | ELECTROMECHANICAL | GM | 12 | E |
| BRUSHES | ELECTRICAL MOTOR | GM | 13 | E |
| CIRCUIT PROTECTION DEVICE | SPARK GAP | GM | 14 | E |
| CIRCUIT PROTECTION DEVICE | SURGE ARRESTER | GM | 15 | E |
| CLUTCH | FRICTION | GM | 16 | E |
| COMPUTER MASS MEMORY | MAGNETIC TAPE | GM | 17 | E |
| COUPLING | FLEXIBLE | GM | 18 | E |
| COUPLING | RIGID | GM | 19 | E |
| CRANK SHAFT | GENERAL | GM | 20 | E |
| DRIVE FOR COMPUTER TAPES/DISCS | MAGNETIC TAPE DRIVE | GM | 21 | E |
| DRIVES | GEAR | GM | 22 | E |
| DRIVES | VARIABLE PITCH | GM | 23 | E |
| DRUM | WEAPON LOCATION UNIT | GM | 24 | E |
| DUCT | GENERAL | GM | 25 | E |
| ELECTRIC HEATERS | RESISTANCE | GM | 26 | E |
| FILTERS | AIR (GAS) | GM | 27 | E |
| FITTINGS | PERMANENT | GM | 28 | E |
| GASKETS & SEALS | DYNAMIC | GM | 29 | E |
| GEAR | STATIC | GM | 30 | E |
| GEAR | BEVEL | GM | 31 | E |
| GEAR | HELICAL | GM | 32 | E |
| GEAR | SPUR | GM | 33 | E |
| GEAR BOX | REDUCTION | GM | 34 | E |
| HEAT EXCHANGERS | COPLATES | GM | 35 | E |
| HIGH SPEED PRINTERS | ELECTROSTATIC | GM | 36 | W |
| HOSES | GENERAL | GM | 37 | E |
| INSTRUMENTS | AMMETER | GM | 38 | E |
| INSTRUMENTS | VOLTMETER | GM | 39 | E |
| JOINT, MICROWAVE ROTARY | GENERAL | GM | 40 | E |
| KEYBOARD | ELECTROMECHANICAL | GM | 41 | E |
| MOTOR, ELECTRIC | SERVO, DC | GM | 42 | E |
| MOTOR, ELECTRIC | STEPPER | GM | 43 | E |
| POWER SWITCH GEAR | | GM | 44 | E |
| PULLEY | GROOVED | GM | 45 | E |

## Index to Project 1 Weibull Analyses

| Part Name | Part Type | Environment | Sequence Number | Best Fit |
|---|---|---|---|---|
| RETAINING RING | GENERAL | GM | 46 | E |
| SHAFT | GENERAL | GM | 47 | E |
| SOLENOIDS | LINEAR | GM | 48 | E |
| SWITCH | PRESSURE (AIR FLOW) | GM | 49 | E |
| SWITCH | THERMOSTATIC | GM | 50 | E |
| VALVES | PENUMATIC | GM | 51 | E |

| ACCELEROMETER | / FORCED BALANCED | | | | | IDENTIFICATION NUMBER 1-1- 1 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 65890.17 | 0.0 | 62580.41 | 131290.35 | 0.623 | 0.899 | 1.175 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 4 | 181414. | DEFECTIVE PARTS INSIDE<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.762 |

| ACTUATOR | / LINEAR | | | | | IDENTIFICATION NUMBER 1-2- 2 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 7518.42 | 5018.08 | 7361.84 | 9705.60 | 0.790 | 0.954 | 1.118 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 13 | 90707. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.616 |

| AXLE / GENERAL | | | | | | IDENTIFICATION NUMBER 1-1- 3 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 26360.24 | 795.80 | 29306.49 | 57817.18 | 0.842 | 1.549 | 2.256 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 90707. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.487 |

| AZIMUTH ENCODER / OPTICAL | | | | | | IDENTIFICATION NUMBER 1-2- 4 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 3898.20 | 3430.82 | 4158.22 | 4885.62 | 1.054 | 1.216 | 1.378 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 19 | 90707. | ANTENNA WON'T MOVE<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.244 |

| BATTERY / RECHARGEABLE | | | | | | IDENTIFICATION NUMBER 1-1- 5 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 130716.62 | 0.0 | 129683.31 | 310343.12 | 0.650 | 0.982 | 1.314 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 362828. | CONNECTOR PINS SHORTED<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.963 |

| BEARING / BALL | | | | | | IDENTIFICATION NUMBER 1-1- 6 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 113304.26 | 15188.33 | 117998.94 | 220799.55 | 0.865 | 1.117 | 1.368 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 6 | 1088484. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.692 |

| BEARING / ROLLER | | | | | | IDENTIFICATION NUMBER 1-1- 7 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 279610.93 | 0.0 | 254716.67 | 716746.73 | 0.531 | 0.838 | 1.145 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 362828. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.668 |

| BEARING / SLEEVE | | | | | | IDENTIFICATION NUMBER 1-1- 8 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 124555.02 | 0.0 | 130751.50 | 269865.58 | 0.836 | 1.146 | 1.457 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 4 | 907070. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.687 |

| BELLOWS | / GENERAL | | | | | IDENTIFICATION NUMBER 1-1- 9 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 10734.21 | 7589.02 | 11989.22 | 16389.42 | 1.668 | 3.176 | 4.683 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 90707. | CRACKED<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.103 |

| BELT | / TIMING | | | | | IDENTIFICATION NUMBER 1-1-10 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 20305.47 | 9855.58 | 22817.05 | 35778.51 | 1.210 | 1.773 | 2.336 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 181414. | WORN OUT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.206 |

| BLOWERS & FANS / AXIAL | | | | | | IDENTIFICATION NUMBER 1-3-11 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 221726.04 | 0.0 | 187582.37 | 398396.87 | 0.580 | 0.757 | 0.933 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 8 | 516594. | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.271 |

| BRAKES / ELECTROMECHANICAL | | | | | | IDENTIFICATION NUMBER 1-2-12 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 3367.52 | 2911.59 | 3507.71 | 4103.83 | 0.979 | 1.117 | 1.255 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 24 | 90707. | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.465 |

| BRUSHES / ELECTRICAL MOTOR | | | | | | IDENTIFICATION NUMBER 1-1-13 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 68275.17 | 0.0 | 73790.65 | 158845.39 | 0.829 | 1.289 | 1.748 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 362828. | SHORTED<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.585 |

| CIRCUIT PROTECTION DEVICE / SPARK GAP | | | | | | IDENTIFICATION NUMBER 1-1-14 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 64458.65 | 0.0 | 66765.81 | 190449.44 | 0.494 | 1.098 | 1.702 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 90707. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.890 |

| CIRCUIT PROTECTION DEVICE / SURGE ARRESTER | | | | | | IDENTIFICATION NUMBER 1-1-15 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 31693.39 | 7753.35 | 33976.80 | 60200.25 | 0.875 | 1.242 | 1.609 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 181414. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.569 |

| CLUTCH / FRICTION | | | | | | IDENTIFICATION NUMBER 1-2-16 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 10397.23 | 6485.69 | 11087.16 | 15688.62 | 0.941 | 1.215 | 1.489 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 6 | 90707. | ANTENNA FAILS TO ROTATE<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.497 |

| COMPUTER MASS MEMORY / MAGNETIC TAPE | | | | | | IDENTIFICATION NUMBER 1-2-17 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 3254.01 | 2330.26 | 2876.68 | 3423.10 | 0.716 | 0.802 | 0.888 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 35 | 90707. | WON'T LOAD<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.064 |

| COUPLING / FLEXIBLE | | | | | | IDENTIFICATION NUMBER 1-1-18 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 51383.91 | 0.0 | 56492.70 | 133424.34 | 0.740 | 1.419 | 2.097 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 181414. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.587 |

| COUPLING | / RIGID | | | | | IDENTIFICATION NUMBER 1-1-19 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 1079237.26 | 0.0 | 1066291.17 | 4931904.61 | 0.398 | 0.973 | 1.547 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 907070. | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.968 |

| CRANK SHAFT | / GENERAL | | | | | IDENTIFICATION NUMBER 1-1-20 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 31668.10 | 0.0 | 33113.46 | 67287.92 | 0.698 | 1.131 | 1.564 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 90707. | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.795 |

| DRIVE FOR COMPUTER TAPES/DISCS/ MAGNETIC TAPE DRIVE | | | | | | IDENTIFICATION NUMBER 1-2-21 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 2691.13 | 2187.81 | 2598.07 | 3008.34 | 0.834 | 0.927 | 1.020 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 36 | 90707. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.515 |

| DRIVES / GEAR | | | | | | IDENTIFICATION NUMBER 1-1-22 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 54124.41 | 5467.83 | 58133.14 | 110798.45 | 0.882 | 1.252 | 1.622 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 362828. | IMPROPER ADJUSTMENT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.556 |

| DRIVES | / VARIABLE PITCH | | | | | IDENTIFICATION NUMBER 1-1-23 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 19581.54 | 6588.69 | 21489.09 | 36389.48 | 0.932 | 1.402 | 1.872 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 90707. | IMPROPER ADJUSTMENT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.454 |

| DRUM | / WEAPON LOCATION UNIT | | | | | IDENTIFICATION NUMBER 1-2-24 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 4664.01 | 3683.43 | 4707.49 | 5731.54 | 0.882 | 1.023 | 1.164 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 19 | 91088. | DRUM STICKS<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.891 |

| DUCT | / GENERAL | | | | | IDENTIFICATION NUMBER 1-1-25 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 454731.46 | 0.0 | 437147.91 | 1072003.25 | 0.670 | 0.920 | 1.169 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 5 | 1451312. | USED UP.NEEDS REPLACEMENT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.789 |

| ELECTRIC HEATERS | / RESISTANCE | | | | | IDENTIFICATION NUMBER 1-1-26 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 33384.04 | 6986.72 | 35612.00 | 64237.29 | 0.852 | 1.216 | 1.581 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 181414. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.609 |

| FILTERS / AIR (GAS) | | | | | | IDENTIFICATION NUMBER 1-3-27 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 238600.87 | 0.0 | 240544.09 | 693739.61 | 0.609 | 1.020 | 1.430 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 525672. | NEEDS REPLACEMENT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.987 |

| FITTINGS / PERMANENT | | | | | | IDENTIFICATION NUMBER 1-1-28 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 89359.57 | 0.0 | 97964.93 | 257768.71 | 0.717 | 1.393 | 2.069 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 362828. | IMPROPER ADJUSTMENT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.609 |

| GASKETS & SEALS / DYNAMIC | | | | | | IDENTIFICATION NUMBER 1-1-29 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 175631.12 | 0.0 | 183181.28 | 429526.25 | 0.768 | 1.122 | 1.476 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 907070. | NEEDS REPLACEMENT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.768 |

| GASKETS & SEALS / STATIC | | | | | | IDENTIFICATION NUMBER 1-1-30 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 83986.29 | 2554.53 | 87783.95 | 173013.17 | 0.823 | 1.130 | 1.437 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 4 | 544242. | NEEDS REPLACEMENT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.717 |

| GEAR / BEVEL | | | | | | IDENTIFICATION NUMBER 1-1-31 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 118856.11 | 0.0 | 126548.84 | 305564.45 | 0.760 | 1.207 | 1.654 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 544242. | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.689 |

| GEAR / HELICAL | | | | | | IDENTIFICATION NUMBER 1-1-32 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 35476.88 | 0.0 | 38672.51 | 87971.17 | 0.687 | 1.347 | 2.007 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 90707. | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.646 |

| GEAR / SPUR | | | | | | IDENTIFICATION NUMBER 1-1-33 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 55819.02 | 4712.54 | 59815.99 | 114919.43 | 0.871 | 1.240 | 1.608 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 362828. | WORN OUT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.574 |

| GEAR BOX / REDUCTION | | | | | | IDENTIFICATION NUMBER 1-1-34 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 34678.72 | 0.0 | 37860.85 | 85458.13 | 0.696 | 1.359 | 2.022 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 90707. | NEEDS OVERHAUL<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.636 |

| HEAT EXCHANGERS / COPLATES | | | | | | IDENTIFICATION NUMBER 1-1-35 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 40579.80 | 8321.07 | 43790.21 | 79259.35 | 0.906 | 1.279 | 1.652 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 272121. | NEEDS ADJUSTMENT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.518 |

| HIGH SPEED PRINTERS / ELECTROSTATIC | | | | | | IDENTIFICATION NUMBER 1-2-36 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 1732.16 | 1279.95 | 1486.24 | 1692.53 | 0.706 | 0.770 | 0.835 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 64 | 90707. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.005 |

| HOSES | / GENERAL | | | | | IDENTIFICATION NUMBER 1-1-37 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 34968.20 | 0.0 | 38164.63 | 86043.48 | 0.695 | 1.356 | 2.018 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 90707. | WORN OUT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.637 |

| INSTRUMENTS | / AMMETER | | | | | IDENTIFICATION NUMBER 1-1-38 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 55723.50 | 0.0 | 58510.81 | 159288.74 | 0.530 | 1.147 | 1.765 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 90707. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.838 |

| INSTRUMENTS / VOLTMETER | | | | | | IDENTIFICATION NUMBER 1-1-39 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 49694.65 | 0.0 | 52728.06 | 112377.31 | 0.749 | 1.191 | 1.634 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 181414. | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.710 |

| JOINT,MICROWAVE ROTARY / GENERAL | | | | | | IDENTIFICATION NUMBER 1-1-40 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 53027.44 | 2131.45 | 55938.90 | 109746.35 | 0.808 | 1.166 | 1.524 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 272121. | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.691 |

| KEYBOARD | / ELECTROMECHANICAL | IDENTIFICATION NUMBER 1-2-41 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|---|---|---|
| GM | WEIBULL | 10215.75 | 5395.26 | 8841.30 | 12287.33 | 0.647 | 0.779 | 0.911 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 14 | 90707. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.180 |

| MOTOR,ELECTRIC | / SERVO,DC | IDENTIFICATION NUMBER 1-1-42 |
|---|---|---|

| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|---|---|---|
| GM | WEIBULL | 97451.22 | 0.0 | 87189.28 | 244094.99 | 0.448 | 0.816 | 1.184 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 90707. | WLU MAP DRUM OSCILLATES,DEMAGNETIZED<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.885 |

| MOTOR,ELECTRIC / STEPPER | | | | | | IDENTIFICATION NUMBER 1-1-43 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 36136.15 | 0.0 | 33353.01 | 89861.35 | 0.680 | 1.340 | 2.000 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 90707. | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.852 |

| POWER SWITCH GEAR / | | | | | | IDENTIFICATION NUMBER 1-1-44 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 47998.39 | 0.0 | 52967.52 | 121520.84 | 0.769 | 1.456 | 2.143 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 181414. | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.557 |

| PULLEY / GROOVED | | | | | | IDENTIFICATION NUMBER 1-1-45 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 50940.81 | 0.0 | 53924.21 | 116745.09 | 0.735 | 1.181 | 1.627 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 181414. | PRINTER INOPERATIVE<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.727 |

| RETAINING RING / GENERAL | | | | | | IDENTIFICATION NUMBER 1-3-46 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 229156.66 | 14887.05 | 237905.12 | 460923.18 | 0.878 | 1.106 | 1.334 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 7 | 2652030. | NEEDS REPLACEMENT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.692 |

| SHAFT | / GENERAL | | | | | IDENTIFICATION NUMBER 1-3-47 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 92956.61 | 11801.65 | 86557.76 | 161313.87 | 0.678 | 0.868 | 1.058 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 8 | 434030. | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.570 |

| SOLENOIDS | / LINEAR | | | | | IDENTIFICATION NUMBER 1-1-48 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 83937.45 | 0.0 | 84638.07 | 210877.66 | 0.607 | 1.020 | 1.434 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 181414. | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.987 |

| SWITCH | / PRESSURE (AIR FLOW) | | | | | IDENTIFICATION NUMBER 1-1-49 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 47632.70 | 16600.12 | 50014.64 | 83429.15 | 0.896 | 1.147 | 1.399 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 6 | 453535. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.616 |

| SWITCH | / THERMOSTATIC | | | | | IDENTIFICATION NUMBER 1-3-50 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 65219.07 | 23705.78 | 67732.24 | 111758.70 | 0.910 | 1.107 | 1.304 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 12 | 1179360. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.841 |

| VALVES / PNEUMATIC | | | | | | IDENTIFICATION NUMBER 1-1-51 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 27337.24 | 9207.89 | 29694.76 | 50181.04 | 0.943 | 1.321 | 1.700 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 181414. | SEAL WORN OUT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.459 |

5.4 Weibull Analyses -- Project 2. This section contains the results of fitting the Weibull distribution to nonelectronic part lifetime data collected from a ground mobile artillery locating radar. For a description of the tables in this section, refer to section 5.3.

In only three cases is exponentiality rejected at the 0.05 level of significance. These cases are listed below.

| Part Class | Type | Shape Parameter Estimate |
|---|---|---|
| Accelerometer | Forced Balanced | 0.297 |
| Azimuth Encoder | Optical | 0.641 |
| Crank Shaft | General | 0.413 |

Note that in each of these cases, the corresponding Weibull distribution has a decreasing failure rate. This is perhaps indicative of the occurrence of infant failures which were not properly screened by the vendor, or, as with the Accelerometer nd Crank Shaft, a very small sample of failures.

5.4.1 Weibull Analyses Summaries. Following is an index of the nonelectronic parts analyzed in this section. See section 5.3.1 for a description of the entries of this index.

## Index to Project 2 Weibull Analyses

| Part Name | Part Type | Environment | Sequence Number | Best Fit |
|---|---|---|---|---|
| ACCELEROMETER | FORCED BALANCED | GM | 1 | W |
| ACTUATOR | MECHANICAL | GM | 2 | E |
| ANTENNA | COMMUNICATION | GM | 3 | E |
| AXLE | GENERAL | GM | 4 | E |
| AZIMUTH ENCODER | OPTICAL | GM | 5 | W |
| BATTERY | RECHARGEABLE | GM | 6 | E |
| BEARING | BALL | GM | 7 | E |
| BEARING | ROLLER | GM | 8 | E |
| BEARING | SLEEVE | GM | 9 | E |
| BELLOWS | GENERAL | GM | 10 | E |
| BELT | TIMING | GM | 11 | E |
| BELT | V-BELT | GM | 12 | E |
| BLOWERS & FANS | AXIAL | GM | 13 | E |
| BLOWERS & FANS | CENTRIFUGAL | GM | 14 | E |
| BRAKES | ELECTROMECHANICAL | GM | 15 | E |
| BRUSHES | ELECTRIC MOTOR | GM | 16 | E |
| BUSHINGS | GENERAL | GM | 17 | E |
| CIRCUIT PROTECTION DEVICE | SPARK GAP | GM | 18 | E |
| CIRCUIT PROTECTION DEVICE | SURGE ARRESTER | GM | 19 | E |
| CLUTCH | FRICTION | GM | 20 | E |
| COMPUTER MASS MEMORY | MAGNETIC TAPE | GM | 21 | E |
| CRANK SHAFT | GENERAL | GM | 22 | W |
| DIAPHRAGMS BURST | GENERAL | GM | 23 | E |
| DRIVE FOR COMPUTER TAPES/DISCS | MAGNETIC TAPE TRANS. | GM | 24 | E |
| DRIVES | GEAR | GM | 25 | E |
| DRIVES | VARIABLE PITCH | GM | 26 | E |
| DRUM | WEAPON LOCATING UNIT | GM | 27 | E |
| DUCT | GENERAL | GM | 28 | E |
| ELECTRIC HEATERS | RESISTANCE | GM | 29 | E |
| ELECTROMECHANICAL TIMERS | GENERAL | GM | 30 | E |
| FILTERS | AIR | GM | 31 | E |
| FILTERS | LIQUID | GM | 32 | E |
| FITTINGS | PERMANENT | GM | 33 | E |
| FITTINGS | QUICK DISCONNECT | GM | 34 | E |
| FITTINGS | THREADED | GM | 35 | E |
| FUSE HOLDER | BLOCK | GM | 36 | E |
| FUSE HOLDER | PLUG | GM | 37 | E |
| GASKETS & SEALS | DYNAMIC | GM | 38 | E |
| GASKETS & SEALS | STATIC | GM | 39 | E |
| GEAR | BEVEL | GM | 40 | E |
| GEAR | HELICAL | GM | 41 | E |
| GEAR | SPUR | GM | 42 | E |
| GEAR BOX | REDUCTION | GM | 43 | E |
| HEAT EXCHANGERS | RADIATOR | GM | 44 | E |
| HIGH SPEED PRINTERS | ELECTROSTATIC | GM | 45 | E |
| HOSES | GENERAL | GM | 46 | E |

## Index to Project 2 Weibull Analyses

| Part Name | Part Type | Environment | Sequence Number | Best Fit |
|---|---|---|---|---|
| INSTRUMENTS | AMMETER | GM | 47 | E |
| INSTRUMENTS | VOLTMETER | GM | 48 | E |
| JOINT, MICROWAVE ROTARY | GENERAL | GM | 49 | E |
| KEYBOARD | ELECTROMECHANICAL | GM | 50 | E |
| METAL TUBING | GENERAL | GM | 51 | E |
| MOTOR, ELECTRIC | > 1 HORSE POWER, AC | GM | 52 | E |
| MOTOR, ELECTRIC | SERVO, DC | GM | 53 | E |
| MOTOR, ELECTRIC | STEPPER | GM | 54 | E |
| POWER CIRCUIT BREAKER | CURRENT TRIP | GM | 55 | E |
| PULLEY | GROOVED | GM | 56 | E |
| PULLEY | V-PULLEY | GM | 57 | E |
| PUMP | HYDRAULIC | GM | 58 | E |
| PUMP | PNEUMATIC | GM | 59 | E |
| RESILIENT MOUNT | GENERAL | GM | 60 | E |
| RETAINING RING | GENERAL | GM | 61 | E |
| SHOCK ABSORBERS | COMBINATION | GM | 62 | E |
| SHOCK ABSORBERS | RESILIENT | GM | 63 | E |
| SWITCH | LIQUID FLOW | GM | 64 | E |
| SWITCH | PRESSURE (AIR FLOW) | GM | 65 | E |
| SWITCH | THERMOSTATIC | GM | 66 | E |
| SWITCH | WAVE GUIDE | GM | 67 | E |
| TELESCOPE | BORE SIGHT | GM | 68 | E |
| TRACK BALL | ELECTROMECHANICAL | GM | 69 | E |
| VALVES | HYDRAULIC | GM | 70 | E |

| ACCELEROMETER | / FORCED BALANCED | IDENTIFICATION NUMBER 2-3- 1 |
|---|---|---|

| ENV | DIST TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|---|---|---|
| GM | WEIBULL | ********** | 0.0 | 21611482.92 | ********** | 0.160 | 0.297 | 0.433 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 112682. | DEFECTIVE PARTS INSIDE<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.003 |

| ACTUATOR | / MECHANICAL | IDENTIFICATION NUMBER 2-1- 2 |
|---|---|---|

| ENV | DIST TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|---|---|---|
| GM | WEIBULL | 17576.23 | 4960.86 | 18972.54 | 32984.22 | 0.784 | 1.281 | 1.778 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 59481. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.620 |

| ANTENNA | / COMMUNICATION | | | | | IDENTIFICATION NUMBER 2-1- 3 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 1400759.62 | 0.0 | 993079.80 | 5427732.47 | 0.178 | 0.632 | 1.086 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 118962. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.543 |

| AXLE | / GENERAL | | | | | IDENTIFICATION NUMBER 2-1- 4 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 58898.86 | 0.0 | 62992.93 | 168271.36 | 0.530 | 1.229 | 1.929 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 118962. | DAMAGED<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.775 |

| AZIMUTH ENCODER / OPTICAL | | | | | | IDENTIFICATION NUMBER 2-2- 5 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 10502.73 | 4023.89 | 7571.59 | 11119.30 | 0.513 | 0.641 | 0.770 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 12 | 59481. | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.034 |

| BATTERY / RECHARGEABLE | | | | | | IDENTIFICATION NUMBER 2-1- 6 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 1433685.15 | 0.0 | 1012499.18 | 4224447.36 | 0.310 | 0.630 | 0.951 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 237924. | SHORTED VR1-3 TO CHASSIS SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.387 |

| BEARING / BALL | | | | | | IDENTIFICATION NUMBER 2-1- 7 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 98318.52 | 8451.73 | 97196.10 | 185940.48 | 0.726 | 0.974 | 1.222 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 6 | 535329. | EXCESSIVE PLAY<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.930 |

| BEARING / ROLLER | | | | | | IDENTIFICATION NUMBER 2-1- 8 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 133721.94 | 0.0 | 132010.90 | 357064.22 | 0.543 | 0.971 | 1.399 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 237924. | LUBRICATION DRIED OUT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.955 |

| BEARING / SLEEVE | | | | | | IDENTIFICATION NUMBER 2-1- 9 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 437249.87 | 0.0 | 402329.97 | 1172904.55 | 0.529 | 0.851 | 1.174 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 594810. | REQUIRES OVERHAUL<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.709 |

| BELLOWS / GENERAL | | | | | | IDENTIFICATION NUMBER 2-1-10 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 262866.38 | 0.0 | 207917.25 | 879943.96 | 0.214 | 0.701 | 1.188 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 59481. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.635 |

| BELT / TIMING | | | | | | IDENTIFICATION NUMBER 2-1-11 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 56859.35 | 0.0 | 60995.18 | 160377.56 | 0.542 | 1.245 | 1.949 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 118962. | WORN OUT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.760 |

| BELT / V-BELT | | | | | | IDENTIFICATION NUMBER 2-1-12 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 29334.21 | 0.0 | 31777.46 | 71473.99 | 0.586 | 1.303 | 2.021 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 59481. | BROKEN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.709 |

| BLOWERS & FANS / AXIAL | | | | | | IDENTIFICATION NUMBER 2-3-13 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 289726.63 | 0.0 | 247070.90 | 597030.43 | 0.541 | 0.764 | 0.987 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 6 | 509460. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.409 |

| BLOWERS & FANS / CENTRIFUGAL | | | | | | IDENTIFICATION NUMBER 2-1-14 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 570851.43 | 0.0 | 491516.46 | 1519208.55 | 0.471 | 0.774 | 1.076 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 475848. | BEARINGS WORN OUT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.554 |

| BRAKES | / ELECTROMECHANICAL | | | | | IDENTIFICATION NUMBER 2-3-15 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 21667.34 | 7828.78 | 17422.70 | 27016.62 | 0.563 | 0.713 | 0.864 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 10 | 105056. | EXCESSIVE GAP<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.137 |

| BRUSHES | / ELECTRIC MOTOR | | | | | IDENTIFICATION NUMBER 2-1-16 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 795505.51 | 0.0 | 700628.80 | 3354568.10 | 0.263 | 0.798 | 1.333 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 237924. | NEEDS ADJUSTMENT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.763 |

| BUSHINGS | / GENERAL | | | | | IDENTIFICATION NUMBER 2-1-17 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 207816.85 | 40062.94 | 231388.30 | 422713.67 | 1.234 | 1.571 | 1.908 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 6 | 13026339. | WORN OUT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.118 |

| CIRCUIT PROTECTION DEVICE | / SPARK GAP | | | | | IDENTIFICATION NUMBER 2-1-18 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 124668.75 | 0.0 | 111922.87 | 400619.42 | 0.279 | 0.820 | 1.360 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 59481. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.789 |

| CIRCUIT PROTECTION DEVICE / SURGE ARRESTER | | | | | | IDENTIFICATION NUMBER 2-1-19 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 1347662.81 | 0.0 | 886354.76 | 3701416.46 | 0.289 | 0.595 | 0.902 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 178443. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.330 |

| CLUTCH / FRICTION | | | | | | IDENTIFICATION NUMBER 2-1-20 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 119774.67 | 0.0 | 108271.87 | 304747.72 | 0.441 | 0.828 | 1.216 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 118962. | ANTENNA FAILS TO ROTATE<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.721 |

| COMPUTER MASS MEMORY / MAGNETIC TAPE | | | | | | IDENTIFICATION NUMBER 2-1-21 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 29420.65 | 1812.84 | 24868.76 | 47924.68 | 0.505 | 0.756 | 1.007 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 4 | 59481. | WON'T LOAD<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.443 |

| CRANK SHAFT / GENERAL | | | | | | IDENTIFICATION NUMBER 2-2-22 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 1013766.24 | 0.0 | 331808.41 | 1175986.58 | 0.231 | 0.413 | 0.595 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 59481. | BRACKET BROKEN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.037 |

| DIAPHRAGMS BURST | / GENERAL | | | | | IDENTIFICATION NUMBER 2-1-23 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| | WEIBULL | 409183.72 | 0.0 | 298265.16 | 1376933.67 | 0.186 | 0.648 | 1.109 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 59481 | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.564 |

| IVE FOR COMPUTER TAPES/DISCS/ MAGNETIC TAPE TRANSPORT | | | | | | IDENTIFICATION NUMBER 2-1-24 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 1262797.98 | 0.0 | 517993.27 | 2197885.61 | 0.209 | 0.453 | 0.698 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 59481 | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.133 |

| DRIVES / GEAR | | | | | | IDENTIFICATION NUMBER 2-1-25 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 112079.01 | 0.0 | 112796.38 | 260004.45 | 0.655 | 1.016 | 1.376 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 356886. | NEEDS REPLACEMENT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.971 |

| DRIVES / VARIABLE PITCH | | | | | | IDENTIFICATION NUMBER 2-1-26 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 16828.00 | 5613.63 | 18281.23 | 30948.82 | 0.815 | 1.322 | 1.830 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 59481. | WORN OUT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.573 |

| DRUM | / WEAPON LOCATING UNIT | | | | | IDENTIFICATION NUMBER 2-1-27 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 15290.09 | 4908.24 | 15199.73 | 25491.22 | 0.663 | 0.986 | 1.310 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 4 | 59481. | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.972 |

| DUCT | / GENERAL | | | | | IDENTIFICATION NUMBER 2-1-28 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 320770.11 | 0.0 | 301519.04 | 715859.70 | 0.627 | 0.882 | 1.138 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 5 | 892215. | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.707 |

| ELECTRIC HEATERS / RESISTANCE | | | | | | IDENTIFICATION NUMBER 2-1-29 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 21004.97 | 8111.19 | 23371.17 | 38631.14 | 0.992 | 1.561 | 2.129 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 118962. | SHORTED<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.367 |

| ELECTROMECHANICAL TIMERS / GENERAL | | | | | | IDENTIFICATION NUMBER 2-1-30 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 19663.70 | 7630.35 | 21453.53 | 35276.70 | 0.906 | 1.153 | 1.801 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 118962. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.480 |

| FILTERS / AIR | | | | | | IDENTIFICATION NUMBER 2-1-31 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 20949.63 | 3472.11 | 20728.06 | 37984.01 | 0.625 | 0.976 | 1.327 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 59481. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.954 |

| FILTERS / LIQUID | | | | | | IDENTIFICATION NUMBER 2-1-32 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 37650.97 | 19720.18 | 40196.86 | 60673.54 | 0.975 | 1.220 | 1.466 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 8 | 535329. | LEAKING<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.433 |

| FITTINGS / PERMANENT | | | | | | IDENTIFICATION NUMBER 2-3-33 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 10254430.80 | 0.0 | 7302483.72 | 28354012.69 | 0.410 | 0.635 | 0.859 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 4 | 1723290. | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.222 |

| FITTINGS / QUICK DISCONNECT | | | | | | IDENTIFICATION NUMBER 2-1-34 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 139991.19 | 0.0 | 129990.22 | 324602.92 | 0.540 | 0.864 | 1.188 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 237924. | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.733 |

| FITTINGS / THREADED | | | | | | IDENTIFICATION NUMBER 2-1-35 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 339122.53 | 0.0 | 319992.17 | 815290.52 | 0.602 | 0.888 | 1.175 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 4 | 773253. | LEAKING<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.750 |

| FUSE HOLDER / BLOCK | | | | | | IDENTIFICATION NUMBER 2-1-36 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 707994.58 | 0.0 | 632133.96 | 2966092.95 | 0.271 | 0.813 | 1.356 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 237924. | DAMAGED<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.782 |

| FUSE HOLDER / PLUG | | | | | | IDENTIFICATION NUMBER 2-1-37 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 5863776.40 | 0.0 | 11400990.36 | 81379544.47 | 0.181 | 0.640 | 1.099 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 594810. | DAMAGED SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.555 |

| GASKETS & SEALS / DYNAMIC | | | | | | IDENTIFICATION NUMBER 2-3-38 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 2393608.94 | 0.0 | 1912170.23 | 8253465.48 | 0.359 | 0.708 | 1.057 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 594810. | LEAKING SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.518 |

| GASKETS & SEALS | / STATIC | | | | IDENTIFICATION NUMBER 2-1-39 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND | |
| GM | WEIBULL | 443979.34 | 0.0 | 424115.17 | 1038827.92 | 0.647 | 0.909 | 1.170 | |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 5 | 1368063. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.773 |

| GEAR | / BEVEL | | | | IDENTIFICATION NUMBER 2-1-40 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND | |
| GM | WEIBULL | 933130.85 | 0.0 | 852593.58 | 4100974.33 | 0.287 | 0.742 | 1.397 | |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 356886. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.818 |

| GEAR / HELICAL | | | | | | IDENTIFICATION NUMBER 2-1-41 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 28725.94 | 0.0 | 31179.10 | 69486.06 | 0.594 | 1.316 | 2.038 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 59481. | WORN OUT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.698 |

| GEAR / SPUR | | | | | | IDENTIFICATION NUMBER 2-1-42 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 305094.17 | 0.0 | 297975.62 | 916483.59 | 0.526 | 0.949 | 1.372 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 475848. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.920 |

| GEAR BOX / REDUCTION | | | | | | IDENTIFICATION NUMBER 2-1-43 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 73061.95 | 0.0 | 71067.04 | 177693.41 | 0.521 | 0.941 | 1.361 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 118962. | NO OIL IN GEAR BOX<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.907 |

| HEAT EXCHANGERS / RADIATOR | | | | | | IDENTIFICATION NUMBER 2-1-44 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 968374.54 | 0.0 | 793508.09 | 3064689.05 | 0.373 | 0.720 | 1.084 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 356888. | NOT PROPERLY FABRICATED BY VENDOR<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.552 |

| HIGH SPEED PRINTERS / ELECTROSTATIC | | | | | | IDENTIFICATION NUMBER 2-2-45 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 5317.82 | 3667.88 | 5171.37 | 6674.85 | 0.770 | 0.941 | 1.111 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 12 | 59481. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.773 |

| HOSES / GENERAL | | | | | | IDENTIFICATION NUMBER 2-3-46 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 1697362.80 | 0.0 | 1610694.75 | 4540045.06 | 0.640 | 0.897 | 1.155 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 5 | 4299481. | HOSE HAS CRACKS DUE TO ANTENNA MOVEMENT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.744 |

| INSTRUMENTS / AMMETER | | | | | | IDENTIFICATION NUMBER 2-1-47 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 122545.11 | 0.0 | 110322.28 | 393320.44 | 0.281 | 0.823 | 1.365 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 59481 | SEALING DAMAGED<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.793 |

| INSTRUMENTS / VOLTMETER | | | | | | IDENTIFICATION NUMBER 2-1-48 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 2827205.96 | 0.0 | 1671884.11 | 9987333.85 | 0.156 | 0.581 | 1.006 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 118962 | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.472 |

| JOINT.MICROWAVE ROTARY / GENERAL | | | | | | IDENTIFICATION NUMBER 2-1-49 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 270665.42 | 0.0 | 259247.87 | 794649.12 | 0.500 | 0.913 | 1.326 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 356886. | DEFECTIVE<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.862 |

| KEYBOARD / ELECTROMECHANICAL | | | | | | IDENTIFICATION NUMBER 2-2-50 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 23734.58 | 3456.68 | 19793.06 | 36129.44 | 0.510 | 0.744 | 0.977 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 5 | 59481. | LOCKED UP<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.393 |

| METAL TUBING | / GENERAL | IDENTIFICATION NUMBER 2-1-51 |
|---|---|---|

| ENV | DIST TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|---|---|---|
| GM | WEIBULL | 306441.73 | 0.0 | 321143.95 | 926619.51 | 0.665 | 1.140 | 1.614 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 1189620. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.799 |

| MOTOR,ELECTRIC | / > 1 HORSE POWER, AC | IDENTIFICATION NUMBER 2-1-52 |
|---|---|---|

| ENV | DIST TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
|---|---|---|---|---|---|---|---|---|
| GM | WEIBULL | 371635.49 | 0.0 | 212811.17 | 764417.81 | 0.260 | 0.541 | 0.822 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 59481. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.244 |

| MOTOR.ELECTRIC / SERVO.DC | | | | | | IDENTIFICATION NUMBER 2-1-53 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 30337.19 | 0.0 | 30237.56 | 63713.84 | 0.565 | 0.992 | 1.420 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 59481. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.988 |

| MOTOR.ELECTRIC / STEPPER | | | | | | IDENTIFICATION NUMBER 2-1-54 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 72837.22 | 0.0 | 70850.67 | 219393.30 | 0.348 | 0.941 | 1.535 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 59481. | PAPER TAKE UP UNEVEN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.935 |

| POWER CIRCUIT BREAKER / CURRENT TRIP | | | | | | IDENTIFICATION NUMBER 2-3-55 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 132440.51 | 12053.05 | 130601.23 | 249149.41 | 0.742 | 0.969 | 1.196 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 7 | 816970. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.909 |

| PULLEY / GROOVED | | | | | | IDENTIFICATION NUMBER 2-1-56 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 34714.05 | 0.0 | 36986.36 | 89230.82 | 0.524 | 1.211 | 1.897 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 59481. | WORN OUT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.790 |

| PULLEY | / V-PULLEY | | | | | IDENTIFICATION NUMBER 2-1-57 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 89085.97 | 0.0 | 87826.09 | 198794.33 | 0.619 | 0.968 | 1.317 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 237924. | WORN OUT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.939 |

| PUMP | / HYDRAULIC | | | | | IDENTIFICATION NUMBER 2-1-58 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 7784.48 | 6591.90 | 8756.86 | 10921.83 | 1.376 | 1.814 | 2.252 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 4 | 59481. | CIRCUIT BREAKER TRIPS<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.080 |

| PUMP | / PNEUMATIC | | | | | IDENTIFICATION NUMBER 2-1-59 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 17897.50 | 5075.40 | 18249.51 | 31423.62 | 0.692 | 1.050 | 1.408 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 59481. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.905 |

| RESILIENT MOUNT | / GENERAL | | | | | IDENTIFICATION NUMBER 2-1-60 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 332403.25 | 0.0 | 325104.59 | 759332.85 | 0.683 | 0.952 | 1.220 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 5 | 1308582. | IMPROPER MOUNT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.881 |

| RETAINING RING / GENERAL | | | | | | IDENTIFICATION NUMBER 2-1-61 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 517555.16 | 0.0 | 536833.42 | 2156620.53 | 0.445 | 1.103 | 1.760 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 1 | 892215. | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.893 |

| SHOCK ABSORBERS / COMBINATION | | | | | | IDENTIFICATION NUMBER 2-1-62 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 32380.29 | 6750.00 | 36039.38 | 65328.76 | 0.979 | 1.565 | 2.152 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 237924. | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.376 |

| SHOCK ABSORBERS | / RESILIENT | | | | | IDENTIFICATION NUMBER 2-1-63 | | | |
|---|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND | |
| GM | WEIBULL | 22550.79 | 7271.53 | 24970.42 | 42669.31 | 0.936 | 1.495 | 2.054 | |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 118962. | IMPROPER MOUNT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.421 |

| SWITCH | / LIQUID FLOW | | | | | IDENTIFICATION NUMBER 2-3-64 | | | |
|---|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND | |
| GM | WEIBULL | 71833.38 | 0.0 | 75533.35 | 174174.56 | 0.677 | 1.153 | 1.628 | |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 237924. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.781 |

| SWITCH / PRESSURE(AIR FLOW) | | | | | | IDENTIFICATION NUMBER 2-1-65 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 699927.62 | 0.0 | 554124.50 | 1796714.96 | 0.419 | 0.702 | 0.985 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 356886 | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.415 |

| SWITCH / THERMOSTATIC | | | | | | IDENTIFICATION NUMBER 2-3-66 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 468654.17 | 0.0 | 439528.39 | 1006599.28 | 0.664 | 0.879 | 1.094 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 8 | 1906536 | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.647 |

| SWITCH | / WAVE GUIDE | | | | | IDENTIFICATION NUMBER 2-1-67 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 145020.37 | 0.0 | 87969.92 | 241296.36 | 0.327 | 0.562 | 0.796 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 3 | 59481. | IMPROPER WIRING<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.178 |

| TELESCOPE | / BORE SIGHT | | | | | IDENTIFICATION NUMBER 2-1-68 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 163948.91 | 0.0 | 115523.25 | 364350.35 | 0.311 | 0.629 | 0.946 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 59481. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.381 |

| TRACK BALL | / ELECTROMECHANICAL | | | | | IDENTIFICATION NUMBER 2-1-69 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 22514.64 | 2009.95 | 23506.14 | 45002.33 | 0.663 | 1.126 | 1.589 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 2 | 59481. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.816 |

| VALVES | / HYDRAULIC | | | | | IDENTIFICATION NUMBER 2-1-70 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GM | WEIBULL | 235410.87 | 0.0 | 189933.98 | 456807.08 | 0.495 | 0.716 | 0.937 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GM | 1 | 5 | 297405. | IMPROPER SEALING<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.318 |

5.5 Weibull Analyses -- Project 3. This section presents the results of fitting the Weibull distribution to nonelectronic part lifetimes collected from an air defense, ground fixed system. For a description of the tables presented in this section, refer to section 5.3.

The part classes/types for which the observed significance level was below 0.05 (supporting the Weibull over the exponential at the 0.05 level of significance) are listed below.

| Part Class | Type | Significance Level | Shape Parameter Estimate |
|---|---|---|---|
| Drive for Computer Tapes | Magnetic Tape Drive | 0.028 | 4.649 |
| Track Ball | Electromechanical | < 0.0005 | 2.319 |

5.5.1 Weibull Analyses Summaries. Following is an index of the nonelectronic parts analyzed in this section. See Section 5.3.1 for a description of the entries of this index.

## Index to Project 3 Weibull Analyses

| Part Name | Part Type | Environment | Sequence Number | Best Fit |
|---|---|---|---|---|
| BELT | TIMING | GF | 1 | E |
| BLOWERS & FANS | AXIAL | GF | 2 | E |
| BLOWERS & FANS | CENTRIFUGAL | GF | 3 | E |
| CAMERA | TV | GF | 4 | E |
| COMPUTER MASS MEMORY | FIXED HEAD DISK MEMORY | GF | 5 | E |
| COMPUTER MASS MEMORY | MAGNETIC TAPE | GF | 6 | E |
| COMPUTER MASS MEMORY | MOVABLE HEAD DISK | GF | 7 | E |
| DRIVE FOR COMPUTER TAPES/DISCS | DISCS | GF | 8 | E |
| DRIVE FOR COMPUTER TAPES/DISCS | MAGNETIC TAPE DRIVE | GF | 9 | W |
| FILTERS | AIR | GF | 10 | E |
| HIGH SPEED PRINTERS | IMPACT | GF | 11 | E |
| KEYBOARD | ELECTROMECHANICAL | GF | 12 | E |
| LOW SPEED PRINTERS | DOT MATRIX | GF | 13 | E |
| MOTOR, ELECTRIC | SERVO, DC | GF | 14 | E |
| PULLEY | GEAR, BELT | GF | 15 | E |
| PUMP | PNEUMATIC | GF | 16 | E |
| PUMP | VACUUM | GF | 17 | E |
| SENSOR/TRANSDUCER/TRANSMITTER | PRESURE | GF | 18 | E |
| SENSOR/TRANSDUCER/TRANSMITTER | TEMPERATURE | GF | 19 | E |
| SWITCH | PRESSURE | GF | 20 | E |
| SWITCH | ROCKER | GF | 21 | E |
| SWITCH | THERMOSTATIC | GF | 22 | E |
| SWITCH | THUMBWHEEL | GF | 23 | E |
| TRACK BALL | ELECTROMECHANICAL | GF | 24 | W |

| BELT / TIMING | | | | | | IDENTIFICATION NUMBER 3-1- 1 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 43941.38 | 20040.97 | 49527.46 | 79013.96 | 1.267 | 1.910 | 2.554 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 6 | 1386500. | DUE TO EXCESSIVE USE<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.146 |

| BLOWERS & FANS / AXIAL | | | | | | IDENTIFICATION NUMBER 3-1- 2 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 127945.26 | 14379.14 | 129342.22 | 244305.29 | 0.707 | 1.027 | 1.347 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 7 | 972930. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.943 |

| BLOWERS & FANS | / CENTRIFUGAL | | | | | IDENTIFICATION NUMBER 3-3- 3 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 193218.87 | 43916.16 | 204932.58 | 365948.99 | 0.878 | 1.189 | 1.501 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 8 | 2822220. | DEFECTIVE SENSOR<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.591 |

| CAMERA | / T V | | | | | IDENTIFICATION NUMBER 3-1- 4 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 264889.87 | 0.0 | 262206.68 | 603822.75 | 0.613 | 0.977 | 1.340 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 5 | 1213498. | DEFECTIVE POWER SUPPLY<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.958 |

| COMPUTER MASS MEMORY / FIXED HEAD DISK MEMORY | | | | | | IDENTIFICATION NUMBER 3-3- 5 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 91718.40 | 51064.13 | 99837.22 | 148610.31 | 1.028 | 1.336 | 1.645 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 9 | 1735360. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.324 |

| COMPUTER MASS MEMORY / MAGNETIC TAPE | | | | | | IDENTIFICATION NUMBER 3-3- 6 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 274772.53 | 155580.66 | 285606.52 | 415632.39 | 0.954 | 1.110 | 1.266 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 28 | 11224044. | DEFECTIVE SENSOR<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.542 |

| COMPUTER MASS MEMORY / MOVABLE HEAD DISK | | | | | | IDENTIFICATION NUMBER 3-1- 7 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 27646.90 | 17636.62 | 31196.55 | 44756.48 | 1.569 | 2.358 | 3.148 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 6 | 998280. | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.060 |

| DRIVE FOR COMPUTER TAPES/DISCS/ DISCS | | | | | | IDENTIFICATION NUMBER 3-1- 8 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 20502.52 | 14032.96 | 22584.47 | 31135.98 | 1.915 | 4.111 | 6.308 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 2 | 377910. | UNKNOWN SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.085 |

| DRIVE FOR COMPUTER TAPES/DISCS/ MAGNETIC TAPE DRIVE | | | | | | IDENTIFICATION NUMBER 3-1- 9 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 38707.09 | 27147.14 | 42334.91 | 57522.69 | 2.534 | 4.649 | 6.765 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 3 | 2095632. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.028 |

| FILTERS / AIR | | | | | | IDENTIFICATION NUMBER 3-1-10 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 58780.63 | 646.53 | 62802.44 | 124958.35 | 0.647 | 1.224 | 1.801 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 3 | 290320. | DAMAGED<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.728 |

| HIGH SPEED PRINTERS / IMPACT | | | | | | IDENTIFICATION NUMBER 3-3-11 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 7644.37 | 5787.38 | 8531.28 | 11275.19 | 1.163 | 1.611 | 2.058 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 7 | 106750. | DEFECTIVE IC<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.196 |

| KEYBOARD / ELECTROMECHANICAL | | | | | | IDENTIFICATION NUMBER 3-3-12 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 211230.96 | 0.0 | 228449.22 | 588391.99 | 0.669 | 1.293 | 1.916 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 3 | 1735620. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.668 |

| LOW SPEED PRINTERS | / DOT MATRIX | | | | | IDENTIFICATION NUMBER 3-3-13 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 70051.86 | 43692.92 | 77545.46 | 111398.00 | 1.153 | 1.492 | 1.830 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 8 | 1496250. | FUSE BLOWN OUT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.185 |

| MOTOR,ELECTRIC | / SERVO,DC | | | | | IDENTIFICATION NUMBER 3-1-14 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 741309.54 | 0.0 | 599300.01 | 1591129.00 | 0.451 | 0.718 | 0.984 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 5 | 910840. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.427 |

| PULLEY / GEAR BELT | | | | | | IDENTIFICATION NUMBER 3-1-15 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 46517.77 | 7266.77 | 52526.13 | 97785.49 | 1.140 | 2.188 | 3.235 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 3 | 1249110. | DUE TO EXCESSIVE USE<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.225 |

| PUMP / PNEUMATIC | | | | | | IDENTIFICATION NUMBER 3-1-16 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 86950.69 | 40540.86 | 95710.03 | 150879.19 | 1.027 | 1.430 | 1.834 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 6 | 1304767. | DEFECTIVE COMPONENTS<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.332 |

| PUMP / VACUUM | | | | | | IDENTIFICATION NUMBER 3-1-17 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 9236.81 | 7571.16 | 10258.59 | 12946.01 | 1.091 | 3.548 | 6.005 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 1 | 19132. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.218 |

| SENSOR/TRANSDUCER/TRANSMITTER / PRESSURE | | | | | | IDENTIFICATION NUMBER 3-1-18 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 226790.74 | 51892.87 | 248791.11 | 445689.36 | 1.008 | 1.399 | 1.789 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 7 | 5196390. | NO TAPE LOADING<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.350 |

| SENSOR/TRANSDUCER/TRANSMITTER / TEMPERATIVE | | | | | | IDENTIFICATION NUMBER 3-1-19 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 345074.16 | 0.0 | 186319.12 | 524388.85 | 0.278 | 0.522 | 0.767 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 3 | 116035. | PRINTER INOPERATIVE<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.188 |

| SWITCH / PRESSURE | | | | | | IDENTIFICATION NUMBER 3-1-20 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 63917.24 | 0.0 | 72067.57 | 160814.47 | 0.795 | 1.933 | 3.072 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 2 | 957050. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.397 |

| SWITCH / ROCKER | | | | | | IDENTIFICATION NUMBER 3-1-21 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 996681.35 | 0.0 | 1104908.26 | 3096761.48 | 0.943 | 1.510 | 2.076 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 5 | 62505757. | DEFECTIVE WIRING<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.388 |

| SWITCH / THERMOSTATIC | | | | | | IDENTIFICATION NUMBER 3-1-22 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 1298702.01 | 0.0 | 1397896.50 | 4338015.14 | 0.734 | 1.264 | 1.794 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 4 | 20703888. | UNKNOWN<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.651 |

| SWITCH | / THUMBWHEEL | | | | | IDENTIFICATION NUMBER 3-1-23 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 40932.97 | 1660.29 | 46198.29 | 90736.30 | 0.842 | 2.027 | 3.213 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 2 | 466416. | DAMAGED<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.364 |

| TRACK BALL | / ELECTROMECHANICAL | | | | | IDENTIFICATION NUMBER 3-3-24 | | |
|---|---|---|---|---|---|---|---|---|
| ENV | DIST. TYPE | MEAN ESTIMATE | 80% LOWER BOUND | SCALE POINT ESTIMATE | 80% UPPER BOUND | 80% LOWER BOUND | SHAPE POINT ESTIMATE | 80% UPPER BOUND |
| GF | WEIBULL | 86684.26 | 57744.82 | 97837.46 | 137930.10 | 1.928 | 2.319 | 2.710 |

| ENV | NUMBER OF SOURCES | NUMBER OF PARTS FAILED | TOTAL PART OPERATING HOURS | COMMENTS |
|---|---|---|---|---|
| GF | 1 | 22 | 51605371. | DEFECTIVE COMPONENT<br>SIGNIFICANCE LEVEL FOR TESTING EXPONENTIALITY =0.000 |

5.6 Part Malfunction Data. Table 5.6.1 gives the malfunction data and frequency of occurrence for each part name based only on the information which was available when the part failure data was collected. The malfunction data for each part name are accumulated over all use environments and part types for the particular part name.

Not all malfunctions reported are mutually exclusive. For example, "improper adjustment" and "improperly installed" may overlap. We leave it to the reader to combine the malfunction data into categories, as needed, using the information presented.

Table 5.6.1. PART MALFUNCTION DATA

| PART NAME | MALFUNCTION | FREQUENCY OF OCCURRENCE % |
|---|---|---|
| ACCELEROMETER | | |
| | DEFECTIVE PARTS INSIDE | 100.0 |
| ACTUATOR | | |
| | BEARING & BRAKE RUSTED | 6.7 |
| | CABLE INSULATION FRAYED | 6.7 |
| | CABLE SLEEVE NEEDS FIXING | 6.7 |
| | IMPROPER CONFIGURATION SHOULD BE -2 | 6.7 |
| | IMPROPER CONNECTOR INSTALLED | 6.7 |
| | REQUIRES ADJUSTMENT OF TM | 6.7 |
| | REQUIRES OVERHAUL | 6.7 |
| | SAFETY WIRE BRACKET BROKEN | 6.7 |
| | THERMAL SWITCH FOUND TO BE DEFECTIVE | 6.7 |
| | UNKNOWN | 40.0 |
| ANTENNA | | |
| | UNKNOWN | 100.0 |
| AXLE | | |
| | DAMAGED | 50.0 |
| | UNKNOWN | 50.0 |
| AZIMUTH ENCODER | | |
| | ANTENNA WON'T MOVE | 32.3 |
| | CASING ROTATES | 3.2 |
| | CRACKED GLASS DISC | 3.2 |
| | ENCODER MARKING SHOULD BE REMOVED | 3.2 |
| | INCORRECT ANTENNA ROTATION | 3.2 |
| | LAMP DESIGN DEFECTIVE | 3.2 |
| | NO MOVEMENT BETWEEN DWELLS | 3.2 |
| | OPTICAL ASSEMBLY DEFECTIVE | 3.2 |
| | RESISTER IS DEFECTIVE | 3.2 |
| | UNKNOWN | 41.9 |
| BATTERY | | |
| | CONNECTOR PANEL DEFECTIVE | 20.0 |
| | CONNECTOR PINS SHORTED | 20.0 |
| | CONNECTOR SHORTED | 20.0 |
| | K-1 MISWIRED | 20.0 |
| | SHORTED VR1-3 TO CHASSIS | 20.0 |

**Table 5.6.1, continued.** PART MALFUNCTION DATA

| PART NAME | MALFUNCTION | FREQUENCY OF OCCURRENCE % |
|---|---|---|
| BEARING | | |
| | AZIMUTH DRIVE INOPERATIVE | 4.2 |
| | BLOWER BEARINGS WORN OUT | 4.2 |
| | BLOWER INOPERATIVE | 4.2 |
| | DEFECTIVE | 4.2 |
| | EXCESSIVE PLAY | 12.5 |
| | LUBRICATION DRIED OUT | 4.2 |
| | PRINTER INOPERATIVE | 4.2 |
| | REQUIRES OVERHAUL | 12.5 |
| | UNKNOWN. | 45.8 |
| | WLW HAS EXCESSIVE WEIGHT | 4.2 |
| BELLOWS | | |
| | CRACKED | 50.0 |
| | UNKNOWN | 50.0 |
| BELT | | |
| | BROKEN | 10.0 |
| | DUE TO EXCESSIVE USE | 60.0 |
| | WORN OUT | 30.0 |
| BLOWERS & FANS | | |
| | BEARINGS WORN OUT | 15.8 |
| | DEFECTIVE SENSOR | 18.4 |
| | DEFECTIVE SWITCH | 2.6 |
| | EXCESSIVE CURRENT HAS SHORTED | 2.6 |
| | EXCESSIVE VIBRATIONS & BEARINGS LOOSE | 5.3 |
| | HAS EXCESSIVE VIBRATIONS & MOUNT IS LOOSE | 5.3 |
| | IMPROPER INSTALLATION | 2.6 |
| | MOTOR DAMAGED | 2.6 |
| | NOISY DUE TO DEFECTIVE BEARINGS | 5.3 |
| | REVERSE WIRING | 2.6 |
| | SHORTED | 5.3 |
| | SWITCH IS LOOSE | 2.6 |
| | SWITCH NOT PROPERLY INSTALLED | 2.6 |
| | SWITCH NOT WORKING | 2.6 |
| | UNKNOWN | 23.7 |

Table 5.6.1, continued. PART MALFUNCTION DATA

| PART NAME | MALFUNCTION | FREQUENCY OF OCCURRENCE % |
|---|---|---|
| BRAKES | | |
| | ASSY SCREW TOO TIGHT | 2.3 |
| | BRAKE CABLE TOO SHORT | 2.3 |
| | BRAKE DISCS WORN OUT | 2.3 |
| | BRAKE PAD BUSHINGS SCREW LOOSE | 2.3 |
| | BRAKES CORRODED | 4.7 |
| | EXCESSIVE GAP | 18.6 |
| | IMPROPER ADJUSTMENT | 7.0 |
| | IMPROPER POSITIONING | 4.7 |
| | IMPPOPERLY INSTALLED | 2.3 |
| | LOCK SCREW NEEDS REPLACEMENT | 2.3 |
| | NEEDS ADJUSTMENT | 18.6 |
| | PARTS ARE WORN OUT | 2.3 |
| | PARTS BROKEN | 2.3 |
| | RECRIMP TERMINAL D&C REQUIRED | 2.3 |
| | SCREW LOOSE | 2.3 |
| | UNKNOWN | 20.9 |
| | WORN OUT | 2.3 |
| BRUSHES | | |
| | NEEDS ADJUSTMENT | 66.7 |
| | SHORTED | 33.3 |
| BUSHINGS | | |
| | UNKNOWN | 16.7 |
| | WORN OUT | 83.3 |
| CAMERA | | |
| | DEFECTIVE POWER SUPPLY | 40.0 |
| | PICTURE BECOMES WEAK & BREAKS UP | 20.0 |
| | UNKNOWN | 40.0 |
| CIRCUIT PROTECTION DEVICE | | |
| | PAINT STENCILED ON ARRESTER SHORTED | 14.3 |
| | UNKNOWN | 85.7 |
| CLUTCH | | |
| | ANTENNA FAILS TO ROTATE | 62.5 |
| | ANTENNA MOVES SLOWLY | 12.5 |
| | NEEDS ADJUSTMENT | 25.0 |
| COMPUTER MASS MEMORY | | |

Table 5.6.1, continued. PART MALFUNCTION DATA

| PART NAME | MALFUNCTION | FREQUENCY OF OCCURRENCE % |
|---|---|---|
| | BAD REEL HUB ASSEMBLY | 1.0 |
| | BAD SOLDER JOINTS ON CONNECTOR PINS | 1.0 |
| | CABLE WIRES SWITCHED | 1.0 |
| | CAPSTAN MOTOR DEFECTIVE | 1.0 |
| | CAPSTAN MOTOR JAMMED | 1.0 |
| | CONNECTOR PINS HAVE BROKEN | 1.0 |
| | DEFECTIVE CAPACITOR | 2.0 |
| | DEFECTIVE CCA | 1.0 |
| | DEFECTIVE CHECK VALVE | 1.0 |
| | DEFECTIVE CONTROL SYSTEM | 1.0 |
| | DEFECTIVE DISC | 1.0 |
| | DEFECTIVE IC | 6.9 |
| | DEFECTIVE MOTOR ASSEMBLY | 1.0 |
| | DEFECTIVE POWER SUPPLY | 1.0 |
| | DEFECTIVE SENSOR | 14.9 |
| | DEFECTIVE SOLDERING ON IC. | 2.0 |
| | DEFECTIVE TRANSISTOR | 3.0 |
| | DEFECTIVE TRANSISTOR IN SERVO ASSEMBLY | 1.0 |
| | DEFECTIVE VACUUM CHAMBER SENSOR | 1.0 |
| | FLOPPY DRIVE ONE IS DEFECTIVE | 1.0 |
| | FUSE BLOWN | 1.0 |
| | HAS LOW PRESSURE | 2.0 |
| | MTC DEFECTIVE | 1.0 |
| | PINS 1 & 3 ARE DAMAGED | 1.0 |
| | POWER SUPPL DEFECTIVE | 1.0 |
| | Q1 & Q2 IMPROPERLY ORIENTED | 1.0 |
| | READ/WRITE HEAD IS DEFECTIVE | 1.0 |
| | RIBBON CABLE BROKEN | 1.0 |
| | SERVO AMP. DEFECTIVE | 1.0 |
| | TWO PINS SHORTED ON CONNECTOR | 1.0 |
| | UNKNOWN | 8.9 |
| | WON'T ACCEPT CERTAIN PROGRAMS | 1.0 |
| | WON'T ACCEPT VRS-131 | 1.0 |
| | WON'T LOAD | 19.8 |
| | WON'T RECORD | 4.0 |
| | WON'T REWIND | 9.9 |
| | WRONG FUSE WAS INSTALLED | 1.0 |
| COUPLING | | |
| | UNKNOWN | 100.0 |
| CRANK SHAFT | | |
| | BRACKET BROKEN | 40.0 |

Table 5.6.1, continued. PART MALFUNCTION DATA

| PART NAME | MALFUNCTION | FREQUENCY OF OCCURRENCE % |
|---|---|---|
| | UNKNOWN | 60.0 |
| DIAPHRAGMS BURST | | |
| | UNKNOWN | 100.0 |
| DRIVE FOR COMPUTER TAPES/DISCS | | |
| | DATA LOST FROM TAPES | 2.3 |
| | DEFECTIVE | 25.6 |
| | DEFECTIVE IC | 2.3 |
| | LOOSE CONNECTION | 4.7 |
| | UNKNOWN | 65.1 |
| DRIVES (GEAR) | | |
| | IMPROPER ADJUSTMENT | 30.0 |
| | IMPROPER INSTALLATIONS | 10.0 |
| | NEEDS REPLACEMENT | 10.0 |
| | UNKNOWN | 30.0 |
| | WORN OUT | 20.0 |
| DRUM | | |
| | BAD ROTATION AFTER DROP TEST | 4.3 |
| | BRACKET BROKEN | 4.3 |
| | CONNECTOR P-4 DEFECTIVE | 4.3 |
| | DAMAGED DUE TO OVERSPEED & MANY IMPACTS | 4.3 |
| | DRUM HAS EXCESSIVE WEIGHT BEARING DAMAGE | 4.3 |
| | DRUM OUT OF ALIGNMENT | 8.7 |
| | DRUM STICKS | 30.4 |
| | HAS OPEN TACH WINDING | 4.3 |
| | NOT PROPERLY ALIGNED | 4.3 |
| | SERVO AMP FOUND TO BE DEFECTIVE | 4.3 |
| | UNKNOWN | 26.1 |
| DUCT | | |
| | CRACKED | 30.0 |
| | IMPROPERLY INSTALLED | 10.0 |
| | UNKNOWN | 20.0 |
| | USED UP. NEEDS REPLACEMENT | 40.0 |
| ELECTRIC HEATERS | | |

**Table 5.6.1, continued.** PART MALFUNCTION DATA

| PART NAME | MALFUNCTION | FREQUENCY OF OCCURRENCE % |
|---|---|---|
| | SHORTED | 40.0 |
| | UNKNOWN | 60.0 |
| ELECTROMECHANICAL TIMERS | | |
| | NEEDS ADJUSTMENT | 33.3 |
| | UNKNOWN | 66.7 |
| FILTER | | |
| | DAMAGED | 16.7 |
| | LEAKING | 38.9 |
| | LINE FILTER PIN-D OPEN | 5.6 |
| | NEEDS REPLACEMENT | 11.1 |
| | UNKNOWN | 27.8 |
| FITTINGS | | |
| | IMPROPER ADJUSTMENT | 7.1 |
| | LEAKING | 28.6 |
| | NEEDS CLEANING | 7.1 |
| | UNKNOWN | 57.1 |
| FUSE HOLDER | | |
| | DAMAGED | 100.0 |
| GASKETS & SEALS | | |
| | BAD INTERNAL SEAL IN GEAR DRIVE | 6.7 |
| | IMPROPER INSTALLATION | 6.7 |
| | LEAKING | 6.7 |
| | NEEDS REPLACEMENT | 46.7 |
| | POPS UP DURING ANTENNA MOVEMENT | 6.7 |
| | UNKNOWN | 26.7 |
| GEAR | | |
| | UNKNOWN | 60.0 |
| | WORN OUT | 40.0 |
| GEAR BOX | | |
| | NEEDS OVERHAUL | 33.3 |
| | NO OIL IN GEAR BOX | 66.7 |

Table 5.6.1, continued. PART MALFUNCTION DATA

| PART NAME | MALFUNCTION | FREQUENCY OF OCCURRENCE % |
|---|---|---|
| HEAT EXCHANGERS | | |
| | NEEDS ADJUSTMENT | 20.0 |
| | NEEDS REPLACEMENT | 20.0 |
| | NOT PROPERLY FABRICATED BY VENDOR | 20.0 |
| | UNKNOWN | 40.0 |
| HIGH SPEED PRINTERS | | |
| | AC INPUT SHORTED | 0.9 |
| | AC INPUT SHORTED UNDER LOAD | 0.9 |
| | BEARINGS WORN OUT. REQUIRES REPLACEMENT | 0.9 |
| | BELT IS SLIPPING | 0.9 |
| | DEFECTIVE IC | 10.5 |
| | DEFECTIVE POTENTIOMETER | 0.9 |
| | DEFECTIVE SENSOR | 1.8 |
| | DEFECTIVE TRANSISTOR | 3.5 |
| | FEEDING MECHANISM NEEDS REPAIR | 0.9 |
| | HAMMER BLOWER NOISY | 0.9 |
| | HAMMER DRIVER DAMAGED | 0.9 |
| | HAMMER HEAD BROKEN | 0.9 |
| | HAS RIBBON SKEWING PROBLEM | 0.9 |
| | LOOSE PULLEY | 2.6 |
| | MOTOR & ROLLER ARE DEFECTIVE | 0.9 |
| | MOTOR DEFECTIVE | 1.8 |
| | MOTOR JAMMED | 0.9 |
| | MOTOR NOT WORKING PROPERLY | 1.8 |
| | MOTOR SHORTED | 0.9 |
| | NEEDS OVERHAUL | 0.9 |
| | NEEDS WIRE REPLACEMENT | 0.9 |
| | NO POWER AT - 32C | 0.9 |
| | OVER CURRENT, SHORTED | 1.8 |
| | PAPER FEED NOT WORKING | 1.8 |
| | PAPER FEEDING MECHANISM JAMMED | 0.9 |
| | PAPER SPINDLE ROTATION SLOW | 0.9 |
| | PAPER SPINDLE TENSION LOW | 1.8 |
| | PARTS MISSING | 3.5 |
| | PRINT FINGERS BENT | 1.8 |
| | PROBLEM WITH TAKE UP | 0.9 |
| | PULLEY BROKEN | 0.9 |
| | RESISTOR R-35, IS OPEN | 0.9 |
| | RIBBON MOTOR INOPERATIVE | 0.9 |
| | RIBBON WORN OUT | 1.8 |
| | RIBBON WORN OUT & BAD SWITCH | 0.9 |
| | ROLLER PRESSURE IS LOW-NEEDS ADJUSTMENT | 0.9 |
| | ROLLER PRESSURE NEEDS ADJUSTMENT | 0.9 |

**Table 5.6.1, continued.** PART MALFUNCTION DATA

| PART NAME | MALFUNCTION | FREQUENCY OF OCCURRENCE % |
|---|---|---|
| | STEPPER MOTOR DEFECTIVE | 1.8 |
| | STEPPER MOTOR IS INOPERATIVE | 0.9 |
| | TAKE UP REEL LATCH IS INOPERATIVE | 1.8 |
| | TIMING BELT & PULLEY WORN OUT | 0.9 |
| | TIMING BELT BROKEN | 1.8 |
| | TIMING BELT DAMAGED & WORN OUT | 0.9 |
| | TIMING BELT WORN OUT | 1.8 |
| | TOP ROLLER PRESSURE NEEDS ADJUSTMENT | 0.9 |
| | TRANSFORMER HAS OPEN LEAD | 0.9 |
| | UNKNOWN | 32.5 |
| HOSES | | |
| | DEFECTIVE | 28.6 |
| | HOSE HAS CRACKS DUE TO ANTENNA MOVEMENT | 42.9 |
| | UNKNOWN | 14.3 |
| | WORN OUT | 14.3 |
| INSTRUMENTS | | |
| | SEALING DAMAGED | 20.0 |
| | UNKNOWN | 80.0 |
| JOINT, MICROWAVE ROTARY | | |
| | DEFECTIVE | 40.0 |
| | UNKNOWN | 60.0 |
| KEYBOARD | | |
| | CABLE(GP554)DEFECTIVE | 4.3 |
| | IMPROPER CONNECTIONS | 4.3 |
| | LED DISPLAY DEFECTIVE | 4.3 |
| | LOCKED UP | 13.0 |
| | U-32 DEFECTIVE | 4.3 |
| | UNKNOWN | 69.6 |
| LOW SPEED PRINTERS | | |
| | DEFECTIVE CAPACITOR | 8.3 |
| | DEFECTIVE IC | 16.7 |
| | DEFECTIVE RELAY | 8.3 |
| | DEFECTIVE SWITCH | 8.3 |
| | FUSE BLOWN OUT | 33.3 |
| | TEAR BAR BROKEN | 8.3 |

Table 5.6.1, continued. PART MALFUNCTION DATA

| PART NAME | MALFUNCTION | FREQUENCY OF OCCURRENCE % |
|---|---|---|
| | TERMINAL WILL NOT LINE FEED | 8.3 |
| | TRANSFORMER SHORTED | 8.3 |
| METAL TUBING | | |
| | UNKNOWN | 100.0 |
| MOTOR, ELECTRIC | | |
| | HAS OPEN TACH-WINDING | 7.7 |
| | PAPER TAKE UP UNEVEN | 7.7 |
| | SWITCH DEFECTIVE | 15.4 |
| | UNKNOWN | 61.5 |
| | WLU MAP DRUM OSCILLATES. DEMAGNETIZED | 7.7 |
| POWER CIRCUIT BREAKER | | |
| | CONNECTOR DEFECTIVE | 12.5 |
| | IMPROPER CONNECTIONS | 25.0 |
| | UNKNOWN | 62.5 |
| POWER SWITCH GEAR | | |
| | UNKNOWN | 100.0 |
| PULLEY | | |
| | DUE TO EXCESSIVE USE | 33.3 |
| | PRINTER INOPERATIVE | 22.2 |
| | WORN OUT | 44.4 |
| PUMP | | |
| | CIRCUIT BREAKER TRIPS | 7.1 |
| | DEFECTIVE CHECK VALVE | 7.1 |
| | DEFECTIVE COMPONENTS | 21.4 |
| | HAS HIGH 10N CURRENT | 7.1 |
| | LOW PRESSURE | 14.3 |
| | NEEDS ADJUSTMENT | 7.1 |
| | OUTPUT PRESSURE VERY LOW | 7.1 |
| | UNKNOWN | 28.6 |
| RESILIENT MOUNT | | |
| | IMPROPER MOUNT | 40.0 |

Table 5.6.1, continued. PART MALFUNCTION DATA

| PART NAME | MALFUNCTION | FREQUENCY OF OCCURRENCE % |
|---|---|---|
| | SCREWS MISSING | 20.0 |
| | UNKNOWN | 40.0 |
| RETAINING RING | | |
| | NEEDS ADJUSTMENT | 33.3 |
| | NEEDS REPLACEMENT | 33.3 |
| | UNKNOWN | 33.3 |
| SENSOR/TRANSDUCER/TRANSMITTER | | |
| | NO TAPE LOADING | 30.0 |
| | PRINTER INOPERATIVE | 30.0 |
| | RELAY DEFECTIVE | 20.0 |
| | VACUUM COLUMN NOISY | 20.0 |
| SHAFT | | |
| | HINGE REDESIGN REQUIRED | 11.1 |
| | RUST UNDER GUSSET | 11.1 |
| | UNIT HAD GREASE WHICH HAS FROZEN | 11.1 |
| | UNKNOWN | 66.7 |
| SHOCK ABSORBERS | | |
| | IMPROPER MOUNT | 50.0 |
| | REQUIRES REFURBISHING | 25.0 |
| | UNKNOWN | 25.0 |
| SOLENOIDS | | |
| | UNKNOWN | 100.0 |
| SWITCH | | |
| | BRAKE INTERLOCK SYSTEM STUCK | 1.6 |
| | CONNECTION LOOSE | 1.6 |
| | CONNECTOR BASE PULLED OUT | 1.6 |
| | DAMAGED | 4.8 |
| | DEFECTIVE WIRING | 4.8 |
| | IMPROPER CONNECTION | 3.2 |
| | IMPROPER INSTALLATION | 6.5 |
| | IMPROPER WIRING | 9.7 |
| | IMPROPERLY BONDED | 1.6 |
| | LOOSE DUE TO EXCESSIVE VIBRATIONS | 1.6 |

Table 5.6.1, continued. PART MALFUNCTION DATA

| PART NAME | MALFUNCTION | FREQUENCY OF OCCURRENCE % |
|---|---|---|
| | LOOSE INSTALLATION | 1.6 |
| | LOW PRESSURE | 1.6 |
| | NEEDS REPOSITIONING | 4.8 |
| | NEEDS REWIRING | 1.6 |
| | OPEN | 1.6 |
| | Q-3 LEADS SHORTED | 1.6 |
| | REVERSED LEADS | 1.6 |
| | SHORTED | 3.2 |
| | SWITCH IS BENT | 1.6 |
| | UNKNOWN | 43.5 |
| TELESCOPE | | |
| | DAMAGED | 50.0 |
| | UNKNOWN | 50.0 |
| TRACK BALL | | |
| | CONSOLE CANNOT ENTER MODE BITE | 3.2 |
| | DEFECTIVE COMPONENT | 67.7 |
| | DEFECTIVE DIODE | 3.2 |
| | DEFECTIVE IC | 3.2 |
| | DEFECTIVE LAMP | 9.7 |
| | IMPROPER SOLDERING INSIDE | 3.2 |
| | LOOSE CONNECTOR | 3.2 |
| | UNKNOWN | 6.5 |
| VALVES | | |
| | CRACKS ON BODY | 12.5 |
| | DUE TO LOW PRESSURE | 12.5 |
| | IMPROPER SEALING | 12.5 |
| | SEAL WORN OUT | 37.5 |
| | UNKNOWN | 25.0 |

## 6.0 RELIABILITY DEMONSTRATION TESTS

6.1 Introduction. The purpose of a reliability demonstration test is to decide if additional reliability design effort is necessary to achieve the specified reliability for the nonelectronic item when it is operated in the field environment. The reliability specification (see section 3.0) identifies the parameter(s) and the values to be nominally and minimally acceptable. Reliability demonstrations are statistical hypothesis tests which lead to one of two mutually exclusive decisions:

(a) The reliability parameter(s) of the component is (are) acceptable and no additional design effort is required under the contract;

(b) The realiability parameter(s) of the component is (are) unacceptable and additional design effort is required.

The demonstration is designed to have a high probability that the decision reached is correct. When the decision is (a), the consumer runs the risk that the decision is incorrect, i.e. that (b) is true but there were an unusually low number of failures during the test. The probability of this type of incorrect decision is called the consumer's risk ($\beta$).

Similarly, the probability that the decision is (b) when (a) is true (i.e. the component has an unusually large number of failures during the test) is called the producer's risk ($\alpha$).

It is important that the demonstration simulate the field environment or that there be a known relationship between the field environment and the test environment. For example, if the component actuation rate in the field is low and the effect of actuation rate is known, it would save test time to raise the actuation rate and lower the acceptable reliability values accordingly.

6.1.1 Statistical Characteristics of a Reliability Demonstration Test. There are six essential characteristics of a reliability demonstration test.

(1) The reliability parameter(s) in the specification. If the distribution of the number of failures in the period of time [0,T] is available in a mathematical expression then the reliability parameters will be related to the distribution parameters.

(2) The acceptable values for the reliability parameter(s). For example, the upper test MTBF ($\theta_0$) in MIL-STD-781C is the smallest desired value of MTBF.

(3) The unacceptable values for the reliability parameter(s). For example, the lower test MTBF ($\theta_1$) in MIL-STD-781C is the largest unacceptable value for MTBF.

(4) The producer's risk, $\alpha$.

(5) The consumer's risk, $\beta$.

# 6.0 RELIABILITY DEMONSTRATION TESTS

6.1 Introduction. The purpose of a reliability demonstration test is to decide if additional reliability design effort is necessary to achieve the specified reliability for the nonelectronic item when it is operated in the field environment. The reliability specification (see section 3.0) identifies the parameter(s) and the values to be nominally and minimally acceptable. Reliability demonstrations are statistical hypothesis tests which lead to one of two mutually exclusive decisions:

(a) The reliability parameter(s) of the component is (are) acceptable and no additional design effort is required under the contract;

(b) The realiability parameter(s) of the component is (are) unacceptable and additional design effort is required.

The demonstration is designed to have a high probability that the decision reached is correct. When the decision is (a), the consumer runs the risk that the decision is incorrect, i.e. that (b) is true but there were an unusually low number of failures during the test. The probability of this type of incorrect decision is called the consumer's risk ($\beta$).

Similarly, the probability that the decision is (b) when (a) is true (i.e. the component has an unusually large number of failures during the test) is called the producer's risk ($\alpha$).

It is important that the demonstration simulate the field environment or that there be a known relationship between the field environment and the test environment. For example, if the component actuation rate in the field is low and the effect of actuation rate is known, it would save test time to raise the actuation rate and lower the acceptable reliability values accordingly.

6.1.1 Statistical Characteristics of a Reliability Demonstration Test. There are six essential characteristics of a reliability demonstration test.

(1) The reliability parameter(s) in the specification. If the distribution of the number of failures in the period of time [0,T] is available in a mathematical expression then the reliability parameters will be related to the distribution parameters.

(2) The acceptable values for the reliability parameter(s). For example, the upper test MTBF ($\theta_0$) in MIL-STD-781C is the smallest desired value of MTBF.

(3) The unacceptable values for the reliability parameter(s). For example, the lower test MTBF ($\theta_1$) in MIL-STD-781C is the largest unacceptable value for MTBF.

(4) The producer's risk, $\alpha$.

(5) The consumer's risk, $\beta$.

(6) The sampling plan which defines how and what parameters will be observed, and the criterion for ending the demonstration test and reaching a decision.

In what follows, R will denote a generic reliability parameter (e.g. MTBF, probability of survival of a prespecified time period, etc.) larger values of which are preferred. The smallest acceptable value of R in (2) above is denoted by $R_0$, and the largest unacceptable value of R is denoted by $R_1$. $R_0$ must be strictly greater than $R_1$. The values of R which lie between $R_1$ and $R_0$ are called indifference values. The ratio $R_0/R_1$ is called the discrimination ratio.

The statistical characteristics of a demonstration are summarized in the operating characteristic (OC) relationship between R and the probability of passing the test when R is the "true" reliability, P(R). Characteristics (4) and (5) give two points in the OC relationship, namely $P(R_0)=(1-\alpha)$, and $P(R_1)=\beta$.

6.1.2 Cost of Demonstration. The cost of demonstration is determined by the number of samples collected and the calendar time the test facility is occupied. Cost efficient demonstrations require the smallest number of samples and the least calendar time to meet the risk objectives of the demonstration.

If the reliability parameters are related to the parameters of a life distribution, then the most cost efficient demonstration is to measure the time of failure (a variable) for each sample. The demonstration is then called a variables test and the sample of failure times provides the maximum information on the reliability of the design of the component. If the reliability parameter is the fraction of components in a lot which will live beyond some time T, the demonstration will attribute success or failure to each sample according to whether or not the component is operational at time T (attributes testing).

The rule for terminating the demonstration also affects the cost. Given the values for the characteristics in 6.1.1 (1)-(5), it is possible to design a fixed sample size (or fixed time) or sequential demonstration test. In a fixed sample demonstration test termination occurs when (i) all the sample values are observed or (ii) when enough failures have been observed to decide the reliability is unacceptable. Similarly, a fixed time demonstration terminates when (i) the fixed time limit is reached or (ii) when enough failures are observed to decide the reliability is unacceptable. During a sequential demonstration, a sequence of decision points for both acceptable and unacceptable reliability are formulated and a decision is reached the first time one of these decision points is reached. On the average a sequential demonstration will require a smaller sample than a fixed sample test for the same $R_0$, $R_1$, $\alpha$, $\beta$. Sequential demonstrations are possible for both variables and attributes testing.

6.1.3 Sample Size limitations. In general sample size (N) (or average sample size, for sequential demonstration tests) is the dependent variable of

a reliability demonstration (i.e. the demonstration characteristics in 6.1.1 (1)-(5) are allowed to determine N). N increases as either the discrimination ratio, $\alpha$, or $\beta$ decrease. There is a maximum value for N (NMAX) in all practical situations. If the N required by the characteristics of 6.1.1 (1)-(5) exceeds NMAX, one of the parameters (usually $\alpha$) must be changed ($R_0$, $\alpha$, or $\beta$ can be increased, or $R_1$ can be decreased).

6.1.4 Summary. The remainder of this section presents step-by-step instructions on the use of various types of reliability demonstration test plans. The section is arranged to present first test plans based on attributes, followed by variables test plans.

## 6.2 Attributes Demonstration Tests

### 6.2.1 Attributes Plans for Small Lots

#### 1. When to use

When testing parts from a small lot where the accept/reject decision for the lot is based on attributes, the hypergeometric distribution is applicable. Attributes tests should be used when the parameter of interest is the fraction of components in a lot which possess a certain reliability attribute.

The example demonstrating the method is based on a small lot and small sample size. This situation frequently characterizes the demonstration test problem associated with nonelectronic parts. The sample size limits the discriminatory power of the demonstration test plan but frequently cost and time constraints force us into larger than desired risks.

#### 2. Conditions for Use

The attribute of interest may be that a part survives at least t hours. A "success" for a component tested would be that it survives t hours. The parameter to be evaluated then is the fraction of the parts in the lot whose lives would exceed t hours.The estimation of the parameter would be based on a fixed sample size and testing without replacement. The selection of the criteria for success (t hours) can be derived from a requirement (such as mission length, for example). If the lot size is 30 or more, then the Poisson approximation may be used to make the calculation simpler. (See Section 6.2.3).

| 3. Method | Example |
|---|---|
| a. Define criterion for success/failure, i.e. define the attribute. | a. A part that lasts 100 or more hours on a given life test is considered a success. Parts failing before 100 hours are considered failures. |

| 3. Method | Example |
|---|---|
| b. Define acceptable lot quality level ($1-p_o$). | b. Lots in which ($1-p_o$) = 90% of of the parts will survive 100 hours are to be accepted by this demonstration test plan with high probability. |
| c. Specify producer's risk ($\alpha$) (i.e, the probability that acceptable lots be rejected). | c. Let $\alpha = .2$. This decision is an engineering one based on the consequences of allowing defective lots to be accepted and based on the time and dollar constraints associated with inspecting the lot. |
| d. Define unacceptable quality level ($1-p_1$). | d. Lots in which only $1-p_1$ = 20% of the parts will survive 100 hours will be accepted by the demonstrations test plan with low probability. |
| e. Specify the consumer's risk ($\beta$) (i.e., the probability that unacceptable quality lots will pass the demonstration test). | e. Let $\beta = .022$ (Taken for convenience in calculations). |
| f. Now that $\alpha$, $\beta$, $1-p_o$, and $1-p_1$ have been specified the following steps describe the calculations required to determine the sample size and accept/ reject criteria which will satisfy the stated risks. | f. Given: lot size N=10<br>$1-p_o = .9$<br>$1-p_1 = .2$<br>$\alpha = .2$<br>$\beta = .022$ |
| g. The process consists of a trial and error solution of the hypergeometric equation using N, $1-p_o$, $1-p_1$ and various sample sizes until the conditions of $\alpha$ and $\beta$ are | g. The calculations are as follows: If N = 10 and it is assumed that samples are taken from a lot with $1-p_o = .9$ then that lot contains 9 good parts and 1 defective part. As the |

3. Method

g. met. The equation used is

$$Pr(x) = \frac{\binom{r}{x}\binom{N-r}{n-x}}{\binom{N}{n}}$$

$x = \max(0, n-N+r), 1, 2 \ldots \min(n, r)$

where x = number of successes in sample
r = number of successes in lot
N = lot size
n = sample size

$$\binom{r}{x} = \frac{r!}{x!(r-x)!}$$

Example

first step in the trial and error procedure assume a sample size of 2. The possible outcomes are either 0, 1 or 2 good parts. The probability of each outcome using the hypergeometric formula is

$$Pr(2) = \frac{\binom{9}{2}\binom{1}{0}}{\binom{10}{2}} = .8$$

$Pr(1) = .2$
$Pr(0) = 0$

The same calculations for $1-p_1 = .2$ results in

$Pr(2) = .022$
$Pr(1) = .356$
$Pr(0) = .622$

h. Find the number of successes which satisfies $\alpha$ and $\beta$ in the calculations involving $1-p_o$ and $1-p_1$.

h. From these 2 sets of results it can be seen that if a sample size of 2 is specified, then $\alpha$ and $\beta$ will be satisfied if the decision rule is made that if 2 successes are observed in the sample the lot is accepted and for all other outcomes the lot is rejected.

If $1-p_o = .9$, then $Pr(2) = .8$, therefore $1-.8 = .2 = \alpha$ If $1-p_1 = .2$, then $Pr(2) = .022 = \beta$.

NOTE: A different sample size can be traded off against different $\alpha$, $\beta$, $1-p_o$, $1-p_1$.

| 3. Method | Example |
|---|---|
| i. The demonstration test is then specified. | i. The test procedure is as follows:<br>1. Test a random sample of 2 parts from a lot of 10 parts for 100 hours.<br>2. If both parts survive 100 hours, accept the lot.<br>3. If only 0 or 1 parts survive 100 hours reject the lot. |

4. For Further Information.

There are "Tables of the Hypergeometric Distribution" by G. J. Lieberman and D. B. Owen, Stanford University Press, Stanford, California, 1961 to perform the mathematical calculations of Step g. Also if N becomes large (say 30 or more) then the binomial or the Poisson distribution can be used as an approximation for the hypergeometric distribution.

### 6.2.2 Attributes Plans for Large Lots (Binomial)

1. When to Use

When testing parts from a large lot where the accept/reject decision for the lot is based on attributes, the binomial distribution is applicable. Strictly speaking, all reliability attributes testing should follow the hypergeometric distribution as long as individual parts are placed on test and tested to failure without replacement. However, when the lot size is large, the binomial distribution is a good approximation for the hypergeometric and therefore the example presented in this section covers the use of the binomial. Attributes test should be used when the parameter of interest is the fraction of components in a lot which possess a certain reliability attribute.

2. Conditions for Use

The attribute of interest may be that a part survives for at least t hours. A "success" for a component tested would be that it survives t hours. The parameter to be evaluated then is the fraction of the parts in the lot that would survive t hours. The estimation of the parameter would be based on a fixed sample size and testing without replacement. The selection of the criteria for success (t hours) can be derived from a requirement (such as a mission length, for example).

| 3. Method | Example |
|---|---|
| a. Define criterion for success/failure, i.e. define the attribute. | a. A part that lasts 100 or more hours on a given life test is considered a success. Parts failing before 100 hours are considered failures. |
| b. Define acceptable lot quality level ($1-p_o$). | b. Lots in which $1-p_o = .9$ (i.e., the life of 90% of the parts will exceed 100 hours) are to be accepted by this demonstration test plan with high probability. |
| c. Specify producer's risk ($\alpha$) (i.e., the probability that acceptable lots will be rejected). | c. let $\alpha = .01$. |
| d. Define unacceptable lot quality level ($1-p_1$). | d. Lots with only a true fraction of acceptable parts $1-p_1 = .5$ are to be accepted by this demonstration test plan with low probability. |
| e. Specify consumer's risk ($\beta$). (i.e., the probability that lots of unacceptable quality level will be accepted). | e. let $\beta = .17$ (selected for ease of calculation). |
| f. Now that $\alpha$, $\beta$, $1-p_o$, and $1-p_1$ have been specified, the following steps describe the calculations required to determine the sample size and accept/reject criteria which will satisfy the stated risks. | f. Given: lot size N = large say > 30<br><br>$1-p_o = .9$<br>$1-p_1 = .5$<br>$\alpha = .01$<br>$\beta = .17$ |
| g. The process now consists of a trial and error solution of the binomial equation using $1-p_o$, $1-p_1$ and various sample sizes until at a given decision point, the conditions of $\alpha$ and $\beta$ are | g. Assume a random sample of size $n = 10$ is taken from a lot whose true fraction of good parts is .9. Solve the binomial equation for the total number of consecutive outcomes whose summed probabilities equal |

| 3. Method | Example |
|---|---|
| g. satisfied. The binomial equation is:<br><br>$Pr(x) = \binom{n}{x} (1-p)^x (p)^{n-x}$<br><br>where n = sample size<br>x = observed successes in sample<br>p = lot fraction defective | α starting at 0 successes. The calculations for this decision point are:<br><br>$Pr(10) = \binom{10}{10}(.9)^{10}(.1)^0 = .3486$<br>Pr(9) = .387<br>Pr(8) = .1935<br>Pr(7) = .0574<br>Pr(7 or more) = .9865<br><br>Then<br><br>Pr(6 or less) = 1-Pr (7 or more)<br>= 1.0 - .9865<br>≈ .01 (which satisfies the α risk).<br>Perform the same type of calculations assuming the true fraction defective is .5. In this instance sum the probabilities starting at 10 successes until succeeding consecutive probabilities sum to the value of β. This yields the following results:<br><br>$Pr(10) = \binom{10}{10}(.5)^{10}(.5)^0 = .001$<br>Pr(9) = .010<br>Pr(8) = .044<br>Pr(7) = .117<br>Pr(7 or more) ≈.17 (which satisfies the β risk) |
| h. The demonstration test is then specified. | h. The test procedure is as follows:<br><br>1. Test a random sample of 10 parts for 100 hours. |

| 3. Method | Example |
|---|---|
| h. | 2. If 7 or more parts survive 100 hours, accept the lot.<br>3. If 6 or less successes are observed, reject the lot. |

4. For Further Information

There are several published tables for use in determining binomial probabilities in the event that the sample size makes calculations too lengthy. One of these is Tables of the Binomial Probability Distribution, National Bureau of Standards, Applied Mathematics Series 6, Washington, D.C., 1950. It gives individual terms and the distribution function for p = .01 to p = .50 in graduations of .01 and n = 2 to n = 49 in graduations of 1.

6.2.3 Attributes Demonstration Test Plans for Large Lots (The Poisson Approximation Method)

1. When to Use

In attributes demonstration test plans if the lot size gets much above 100 the calculations required to generate a demonstration test plan become very time consuming. The Poisson distribution can be used as an approximation of both the hypergeometric and the binomial distributions if the lot size is large and if the fraction defective in the lot is small. This method can therefore be used in lieu of the previous two methods in many cases.

2. Conditions for Use

If the lot size is large and the fraction defective is small, this method is applicable. Its use is initiated by specifying a desired producer's risk, consumer's risk, acceptable lot fraction defective and unacceptable lot fraction defective. As before, it is also necessary to specify the characteristics that constitute a defective part since this is an attributes type test.

| 3. Method | Example |
|---|---|
| a. Define criterion for success/failure. | a. A part that lasts 100 or more hours on a given life test is considered a success. Parts failing before 100 hours are considered failures. |

| 3. Method | Example |
|---|---|
| b. Define acceptable lot quality level ($1-p_o$). | b. Lots in which $1-p_o = .9$ (the life of 90% of the parts in the lot will exceed 100 hours) are to be accepted by this demonstration test plan with high probability. |
| c. Specify the producer's risk ($\alpha$) (i.e., the probability that acceptable lots will be rejected). | c. Select $\alpha = .05$. |
| d. Define unacceptable lot quality level ($1-p_1$). | d. Lots with only a true fraction of acceptable parts $1-p_1 = .75$ are to be accepted by this demonstration test plan with low probability. |
| e. Specify the Consumer's risk $\beta$ (i.e. the probability that lots of unacceptable quality level will be accepted by this plan). | e. Select $\beta = .02$. |
| f. Now that $\alpha$, $\beta$, $1-p_o$, and $1-p_1$ have been specified, the accept/reject criteria are determined by the following formulas: | f. Given: lot size N=1000<br>$1-p_0 = .90$<br>$1-p_1 = .75$<br>$\alpha = .05$<br>$\beta = .02$ |
| $1 - \alpha = \sum_{x=0}^{c} \frac{(np_0)^x \exp(-np_0)}{x!}$ | |
| $\beta = \sum_{x=0}^{c} \frac{(np_1)^x \exp(-np_1)}{x!}$ | |
| g. The solution now consists of trying various values of n in the above formulas until they are approximately satisfied. | g. Assume n = (sample size) = 100.<br>Then,<br>$np_0 = 100\ (.10) = 10$<br>$np_1 = 100\ (.25) = 25.$<br>Using a digital computer to |

| 3. Method | Example |
|---|---|
| | compute the formulas in (f) above leads to c=15, and<br>$\alpha$ = .049<br>$\beta$ = .022.<br>The decision criterion is now specified as c=15 or less failures. |
| h. The demonstration is then fully specified. | The demonstration test procedure is as follows:<br>1) Take a random sample of 100 parts from the lot of size 1000 and test each part for 100 hours.<br>2) If 15 or less fail to survive 100 hours, accept the lot. If more than 15 parts fail to survive 100 hours, reject the lot. |

4. For additional examples using this method, refer to E.B. Grant, Statistical Quality Control, McGraw Hill, 1964.

### 6.2.4 Attributes Sampling Using MIL-STD-105D

#### 1. When to Use

When the accept/reject criteria for a part is based on attributes decisions MIL-STD-105D is a useful tool. These sampling plans are keyed to fixed AQL's (Acceptable Quality Level) and are expressed in lot size, sample size, AQL and acceptance number. Plans are available for single sampling, double sampling and multiple sampling. The decision as to which type to use is based on a trade-off between the average amount of inspection, the administrative cost and the information yielded regarding lot quality. For example, single sampling usually results in the greatest amount of inspection, but this can be offset by the fact that it requires less training of personnel, and record keeping is simpler, and it gives a greater amount of information regarding the lot being sampled. The main difference between MIL-STD-105D plans and the previous plans is that the unacceptable quality level need not be specified.

#### 2. Conditions for Use:

The user of a MIL-STD-105D sampling plan must have items a and b below. MIL-STD-105D will determine items c, d, and e below, for a given type of sampling type (i.e. single, double, multiple, etc.):

a. Lot Size
b. Acceptable Quality Level
c. Sample Size

d. Acceptance Number
e. Criteria for Acceptance or Rejection.

The specification of the AQL is an engineering decision based on the fraction defective that a user of parts considers acceptable. Lots with this percent defective will be accepted a high fraction of the time. Operating characteristic curves are supplied with each sampling plan and these can be used to evaluate the protection afforded by the plan for various quality levels.

MIL-STD-105D also contains plans for normal, tightened and reduced inspection plans which can be invoked if the fraction defective of lots seems to be varying or trending.

| 3. Method | Example |
|---|---|
| a. Determine lot size and specify AQL and type of sampling. | a. Given a lot containing 100 parts and an AQL is specified at 6.5% with single sampling specified. |
| b. Enter the table with lot size and select the sample size code letter. | b. From Table I (Sample Size Code Letters) on page 9, MIL-STD-105D, find the sample size code letter for a lot of size 100. For this example and for normal sampling, the specified code number is F (General inspection level II is the default). |
| c. Enter the single sampling plan table for normal inspection with the code number from Step b. | c. Enter Table II-A (Single Sampling Plans for Normal Inspection) page 10 with code letter F. Under the column titled Sample Size, find the number 20 in the same row as the letter F. This is the number of parts to be randomly selected and inspected. |
| d. Enter the same table in the proper column for the specified AQL. | d. Find the column in Table II-A page 10 corresponding to an AQL of 6.5%. |

| 3. Method | Example |
|---|---|
| e. Proceed horizontally along the Sample Size Code Number row until it intersects with the AQL column to obtain the acceptance number. | e. At the intersection of row F and column 6.5%, the acceptance number is 3 and the rejection number is 4. |
| f. The Single Sampling Plan from MIL-STD-105D is to select a random sample of size n from a lot of size N, inspect it and accept the lot if the number of defectives in the lot is equal to or less than the Acceptance Number. If the observed number of defects is equal to or greater than the rejection number, the lot is rejected. | f. For the single sampling plan N = 100, AQL = 6.5%, select a random sample of size n = 20 and inspect it for attributes criteria. If 3 or less f. defectives are found in the sample accept the lot. If 4 or more defectives are found in the sample reject the lot. |

4. For Further Information

In addition to the example discussed above, MIL-STD-105D contains other plans for any lot size and for selected AQL's from .01 to 1000% (AQL's over 10% are defects per hundred units, rather than percent of defective units). MIL-STD-105D also presents operating characteristic curves for each sampling plan.

### 6.2.5 Sequential Binomial Test Plans

1. When to Use

When the accept/reject criterion for the parts on test is based on attributes, and when the exact test time available and sample size to be used are not known or specified then this type of test plan is useful. The test procedure consists of testing parts one at a time and classifying the tested parts as good or defective. After each part is tested, calculations are made based on the test data generated to that point and the decision is made either that the test has been passed, failed, or that another observation should be made. A sequential test will result in a shorter average number of parts tested than either failure truncated or time truncated tests when the lot tested has a fraction defective at or close to $p_0$ or $p_1$.

2. Conditions for Use

a. The parts subjected to test will be classified as either good or defective. In other words, testing will be by attributes.

b. The acceptable fraction defective in the lot $p_0$, the unacceptable fraction defective $p_1$, the producer's risk $\alpha$, and consumer's risk $\beta$ must be specified.

c. The test procedure will be to test one part at a time. After the part fails or its test time is sufficient to classify it as a success, the decision to accept, reject or continue testing the lot will be made.

d. The part lot size must be large (greater than 100).

3. Method

a. Specify $p_0$, $p_1$, $\alpha$, $\beta$

b. Calculate decision points with the following formula

$$\frac{1-\beta}{\alpha} \text{ and } \frac{\beta}{1-\alpha}$$

c. As each part is tested, classify it as a failure or a success and evaluate the expression:

$$(p_1/p_0)^f((1-p_1)/(1-p_0))^s$$

where f = total number of failures

s = total number of successes.

If at some point, this expression exceeds $(1-\beta)/\alpha$ reject the lot. If at some point, this expression is less than $\beta/(1-\alpha)$ accept the lot. Continue

Example

a. Given a lot of parts to be tested by attributes. Lots having only $p_0 = .04$ fraction defective parts are to be accepted by the demonstration test plan 95% of the time (i.e., $\alpha = .05$). Lots having $p_1 = .10$ fraction defective are to be accepted 10% of the time (i.e., $\beta = .10$).

b. The decision points are:

$$\frac{1-\beta}{\alpha} = \frac{1-.10}{.05} = 18$$

$$\frac{\beta}{1-\alpha} = \frac{.10}{1-.05} = .105$$

c. In this example, if $(.10/.04)^f (.90/.96)^s$ is:
1) > 18, reject the lot.
2) < .105, accept the lot;
3) between .105 and 18, the test is continued.

| 3. Method | Example |
|---|---|
| c. sampling as long as neither of these conditions arises. | |
| d. The operating characteristic curve (i.e. the probability of acceptance as a function true fraction defective) can be roughly sketched from the following points: | d. The five points on the OC curve are as follows: |

| P | Probability of Acceptance |
|---|---|
| 0 | 1 |
| $p_0$ | $1-\alpha$ |
| $p_1$ | $\beta$ |
| 1 | 0 |
| p' | Pa |

where:

$$p' = \frac{\ln((1-p_1)/(1-p_0))}{\ln((1-p_1)/(1-p_0))-\ln(p_1/p_0)}$$

$$Pa = \frac{\ln((1-\beta)/\alpha}{\ln((1-\beta)/\alpha)-\ln(\beta/(1-\alpha))}$$

| p | Prob. of Accept |
|---|---|
| 0.00 | 1.00 |
| .04 | .95 |
| .10 | .10 |
| 1.00 | 0.00 |
| .063 | .56 |

The last point above is calculated as follows:

ln(.94)/(ln(.94)-ln(2.5))
= .063;

ln(18)/(ln(18)-ln(.105))
= .56

## 6.3 Variables Demonstration Tests

6.3.1 Introduction. Reliability demonstration tests conducted in industrial applications are virtually always constrained by time. It is almost never the case that a demonstration test is carried out by placing n items on test, and waiting until all (in the complete sample case) or r < n (in the failure censored case) items have failed and recording their respective lifetimes. In practice, such sampling schemes are not used because the time necessary to complete the test is random, making it impossible for management to allocate the correct amount of time and resources to conduct the test. Instead, a time truncated test is appropriate (and often easier to administer) because an upper bound on the time to complete the test is known in advance of testing. Such tests were developed in MIL-STD-781C for the exponential distribution, and have been used almost exclusively in industry for electronic equipment.

Another aspect of sampling for reliability demonstration tests is replacement versus nonreplacement tests. That is, if n items are placed on life test initially, should failed items be replaced (or repaired to new working order) or not. Just as in the failure truncated case discussed above, the replacement life test presents a problem with respect to planning, since the ultimate number of items needed to complete the test is random and thus impossible to plan exactly in advance. Moreover, except in the exponential case, replacement tests are mathematically extremely difficult to develop in the time truncated case. Replacement tests are appropriate, however, when the item under test is a complete system, and "replacement" signifies "repair/restore to new working condition." Indeed, the MIL-STD-781C time truncated tests are replacement tests. Whenever the item to be tested is a complete, complex system in which the predominant failure modes are due to electronic (or other constant failure rate) equipments, then the MIL-STD-781C time truncated tests can be used. However, if the system is primarily composed of nonelectronic parts having increasing failure rates and the predominant failure modes are associated with these parts, then a replacement (by repair to new working order) test is out of the question, since in order to restore the system to new working order at each failure, each wear-out related part would have to be replaced with a new part whether failed or not.

In summary, when the exponential distribution is assumed, the time truncated tests presented in MIL-STD-781C are recommended in the replacement case. In the nonreplacement case, MIL-HDBK-108 (H 108) contains time truncated test plans for the exponential case. In view of the applicability of the exponential distribution to most nonelectronic parts in section 2 of this notebook, these documents should be adequate most of the time. When the exponential distribution is not justified, then a time truncated, nonreplacement demonstration test is recommended. Although they possess interesting statistical properties and are mathematically tractable, failure truncated demonstration tests (which include the complete sample case) are not desirable when time must be limited, and are not recommended here. For information concerning statistical inference for various life distributions under failure truncated sampling, refer to section 3 of this notebook, MIL-HDBK-108, or to Mann, et.al. (1974) or to Lawless (1982).

### 6.3.2 Time Truncated Demonstration Test Plans

#### 6.3.2.1 Nonparametric Reliability Demonstration Test

1. When to use

This type of test is applicable to any situation in which reliability (i.e. probability of survival for a preselected time period), median life, or any quantile of the underlying life distribution is specified. This test procedure is valid no matter what form the underlying life distribution assumes (i.e. exponential, Weibull, Gamma, Lognormal, etc.) as long as it is of the continuous type.

2. Conditions for use

The user of this type of test plan must specify (or select from the table of test plans) the producer's risk ($\alpha$), the consumer's risk

($\beta$), the acceptable reliability ($R_0$), the unacceptable reliability ($R_1$), and the time (T) corresponding to the reliability values (i.e. $R_0$ is the acceptable probability of surviving the time T, while $R_1$ is the unacceptable probability of surviving the time T).

The test entails placing a predetermined fixed number of parts or equipments on test for T units of time, and recording the number items that fail before time T. Failed items are not replaced. The demonstration test is passed (i.e. items are judged to have the acceptable reliability $R_0$) if c or less items fail before time T, and the demonstration test is failed if c+1 or more items fail before time T. The value of c is predetermined by the user's specifications.

| 3. Method | Example |
|---|---|
| a. Specify $R_0$, $R_1$, T, $\alpha$, $\beta$ or select them from the table of test plans, table 6.3.2.1. | a. An axial blower must survive T=100 hours of continuous use with high probability. The acceptable reliability is $R_0 = .95$ and unacceptable reliability is $R_1 = .85$. A producer's risk of no more than .10 and a consumer's risk of no more than .10 are acceptable. |
| b. Determine sample size n, and pass/fail number c as follows: Choose the smallest c and the smallest n which satisfy the inequalities: $1 - \alpha \leq \sum_{k=0}^{c} \binom{n}{k} (1-R_0)^k R_0^{n-k}$ $\beta \geq \sum_{k=0}^{c} \binom{n}{k} (1-R_1)^k R_1^{n-k}$ This value of n is the sample size, and c is the decision criterion; that | b. From table 6.3.2.1, test plan 9A is appropriate. The sample size is n=60, and the test is passed if 5 or less failures occur before time T, and the test is failed if 6 or more failures occur before time T. |

| 3. Method | Example |
|---|---|
| b. is, the test is passed for c or less failures before time T, and the test is failed if c+1 or more failures occur before time T.<br><br>Alternatively, table 6.3.2.1 can be used to identify n and c. | |
| c. Because the binomial distribution is discrete, the planned risks cannot be achieved exactly. The exact producer's and consumer's risks are given by one minus the first summation in b above, and the second summation in b above, respectively. Alternatively, if table 6.3.2.1 is used, the exact producer's and consumer's risks are given there. The test plans 1A-13A are based on planned values of .10 for both risks, and the test plans 1B-13B are based on planned values of .20 for both risks. | c. From table 6.3.2.1, test plan 9A, the exact risks are:<br><br>$\alpha$ = .079<br>$\beta$ = .097 |
| d. Once a test plan is defined, it is often necessary to know what the probability of passing the test is as a function of true reliability, that is, the operating characteristic curve is needed. This curve gives the probability of passing the test (i.e. the probability of accepting the parts or equipments) for the entire range of possible values of the reliability, | d. Figure 6.3.2.9A is the operating characteristic curve for test plan 9A. As expected, when true reliability is $R_0$ = .95, the probability of acceptance is 1- .079= .921, and when true reliability is $R_1$= .85, the probability of acceptance is .097. If, for example, true reliability is .90, then the probability of acceptance is about .45. |

3. Method

d. not just at $R_0$ and $R_1$. The operating characteristic curve is defined by:

$$P\{\text{acceptance} \mid \text{reliability}=R\} = \sum_{k=0}^{c} \binom{n}{k} (1-R)^k R^{n-k}$$

Figures 6.3.2.1A-6.3.2.13A and 6.3.2.1B-6.3.2.13B are the operating characteristic curves for test plans 1A-13A and 1B-13B, respectively.

TABLE 6.3.2.1. NONPARAMETRIC RELIABILITY DEMONSTRATION TEST PLANS

The planned producer's and consumer's risks are .10 for test plans 1A-13A, and .20 for test plans 1B-13B.

| Plan | alpha | beta | R0 | R1 | n | ACCEPT equal or less | REJECT equal or more |
|---|---|---|---|---|---|---|---|
| 1A | .095 | .096 | .50 | .40 | 168 | 92 | 93 |
| 2A | .091 | .099 | .80 | .70 | 127 | 31 | 32 |
| 3A | .087 | .099 | .85 | .75 | 109 | 21 | 22 |
| 4A | .086 | .099 | .90 | .80 | 86 | 12 | 13 |
| 5A | .096 | .094 | .91 | .81 | 79 | 10 | 11 |
| 6A | .087 | .093 | .92 | .82 | 77 | 9 | 10 |
| 7A | .095 | .098 | .93 | .83 | 67 | 7 | 8 |
| 8A | .088 | .096 | .94 | .84 | 64 | 6 | 7 |
| 9A | .079 | .097 | .95 | .85 | 60 | 5 | 6 |
| 10A | .073 | .092 | .96 | .86 | 56 | 4 | 5 |
| 11A | .063 | .096 | .97 | .87 | 50 | 3 | 4 |
| 12A | .055 | .097 | .98 | .88 | 43 | 2 | 3 |
| 13A | .045 | .099 | .99 | .89 | 34 | 1 | 2 |
| 1B | .181 | .194 | .50 | .40 | 77 | 42 | 43 |
| 2B | .197 | .190 | .80 | .70 | 55 | 13 | 14 |
| 3B | .191 | .183 | .85 | .75 | 49 | 9 | 10 |
| 4B | .190 | .180 | .90 | .80 | 39 | 5 | 6 |
| 5B | .187 | .199 | .91 | .81 | 34 | 4 | 5 |
| 6B | .157 | .199 | .92 | .82 | 36 | 4 | 5 |
| 7B | .183 | .183 | .93 | .83 | 32 | 3 | 4 |
| 8B | .145 | .184 | .94 | .84 | 34 | 3 | 4 |
| 9B | .163 | .187 | .95 | .85 | 28 | 2 | 3 |
| 10B | .117 | .189 | .96 | .86 | 30 | 2 | 3 |
| 11B | .151 | .180 | .97 | .87 | 23 | 1 | 2 |
| 12B | .083 | .199 | .98 | .88 | 24 | 1 | 2 |
| 13B | .131 | .196 | .99 | .89 | 14 | 0 | 1 |

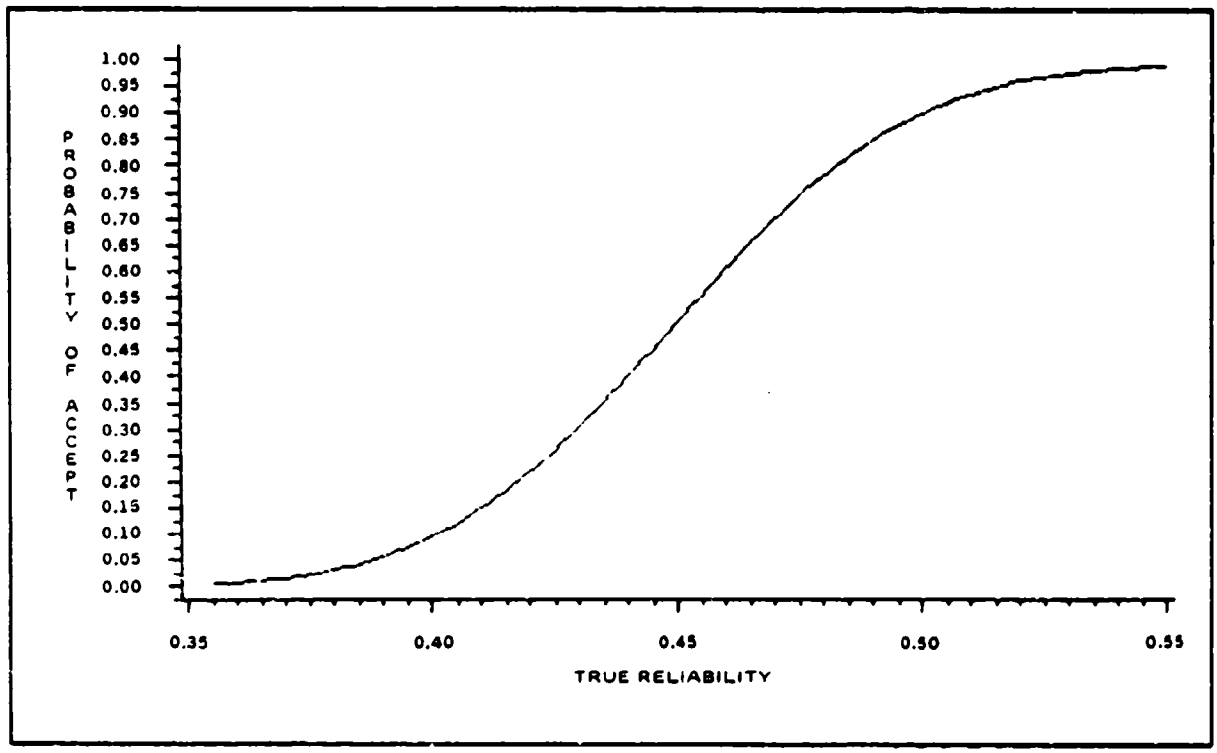



Figure 6.3.2.1A. Operating Characteristic Curve for Test Plan 1A

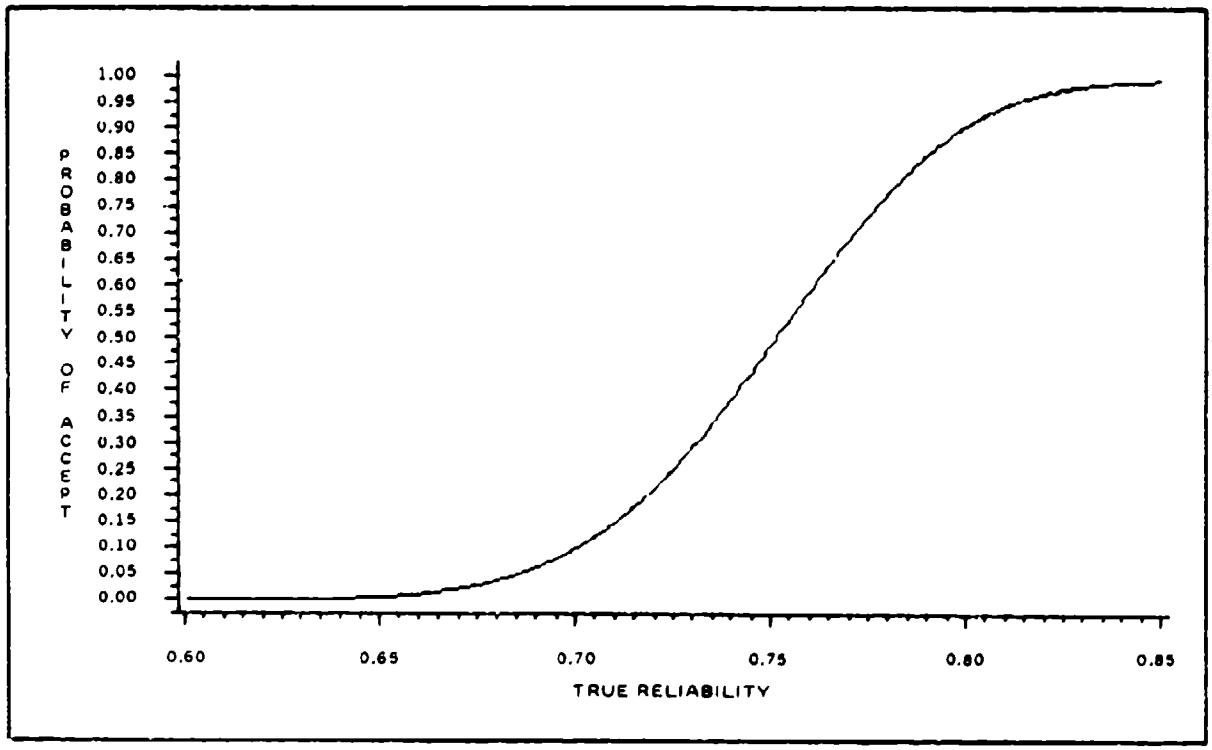



Figure 6.3.2.2A. Operating Characteristic Curve for Test Plan 2A

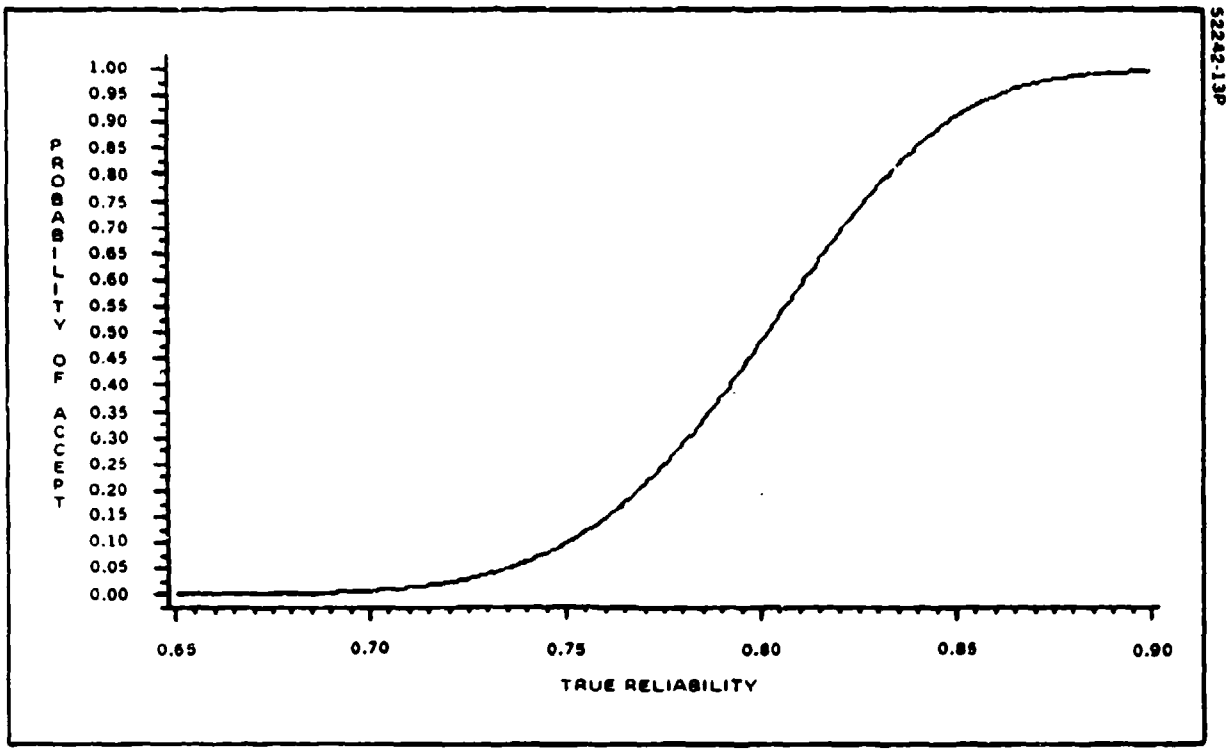



Figure 6.3.2.3A. Operating Characteristic Curve for Test Plan 3A

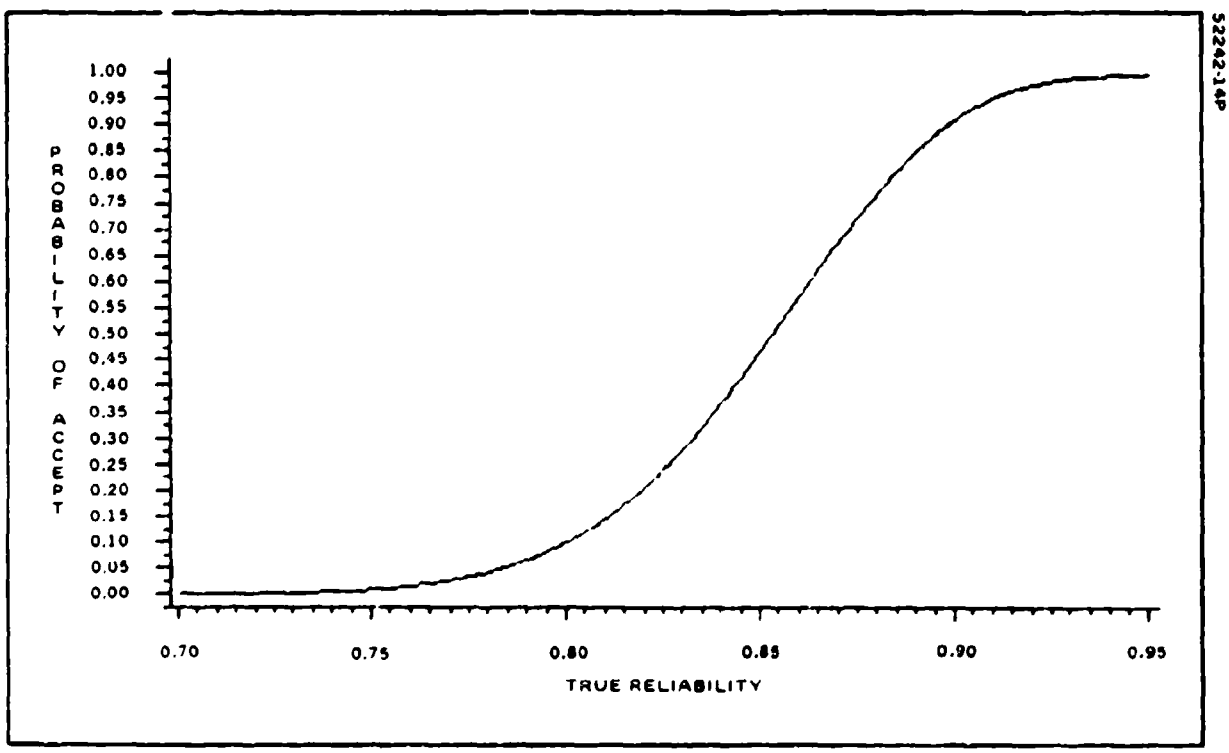



Figure 6.3.2.4A. Operating Characteristic Curve for Test Plan 4A

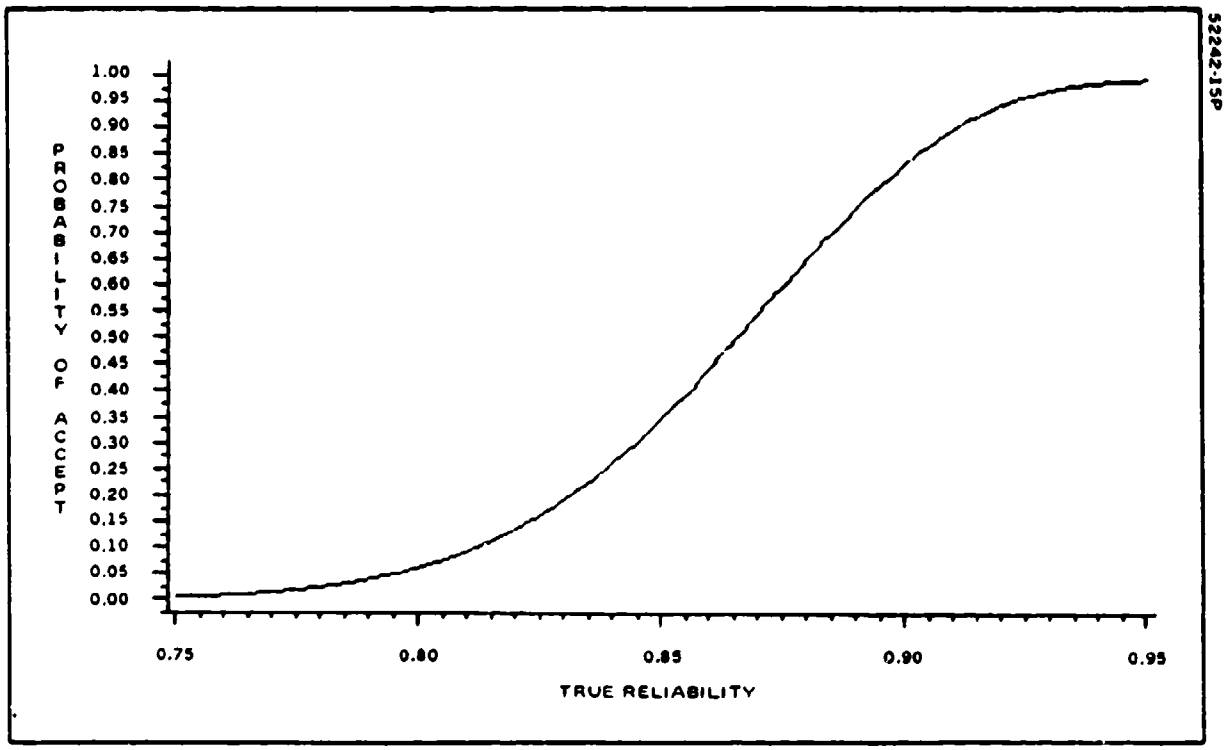



Figure 6.3.2.5A. Operating Characteristic Curve for Test Plan 5A

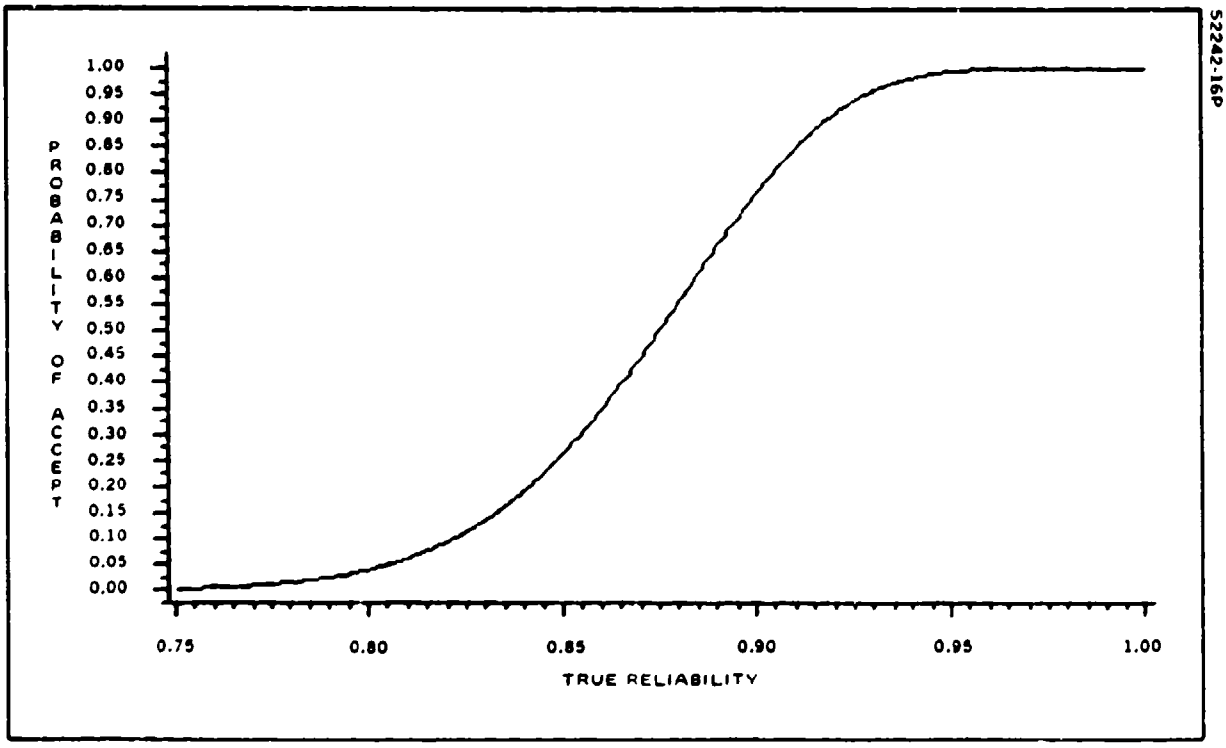



Figure 6.3.2.6A. Operating Characteristic Curve for Test Plan 6A

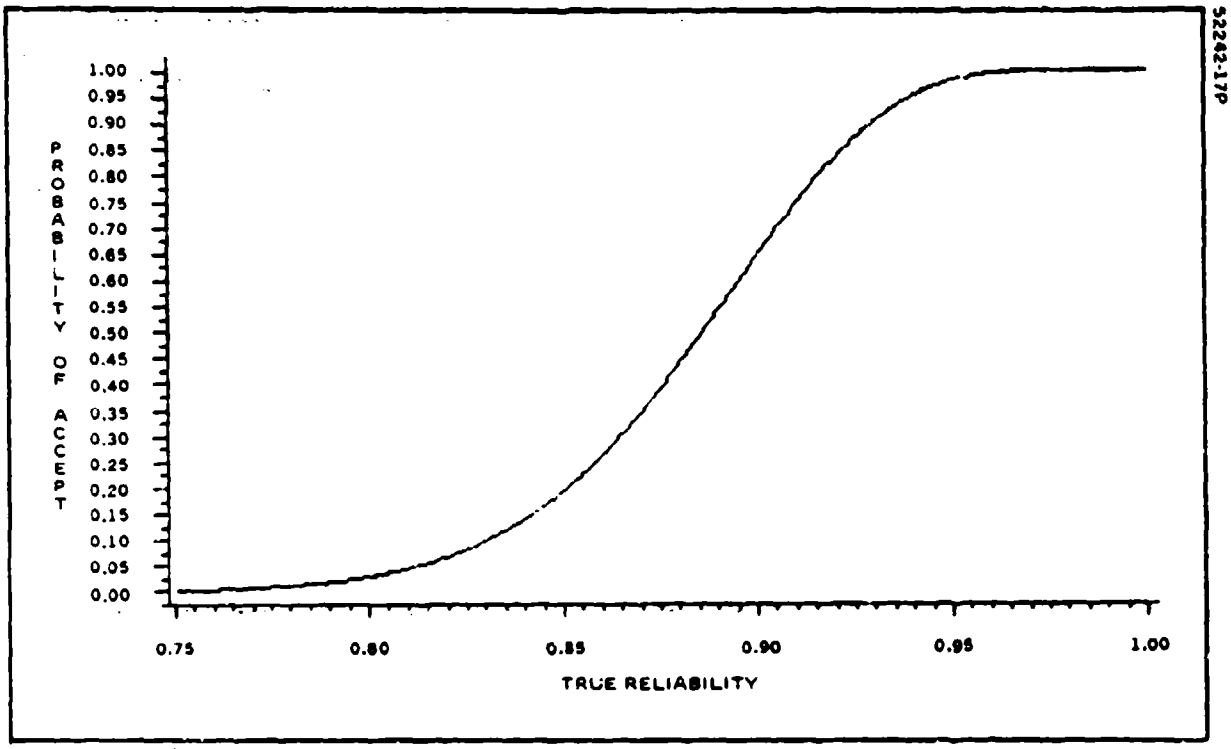



Figure 6.3.2.7A. Operating Characteristic Curve for Test Plan 7A

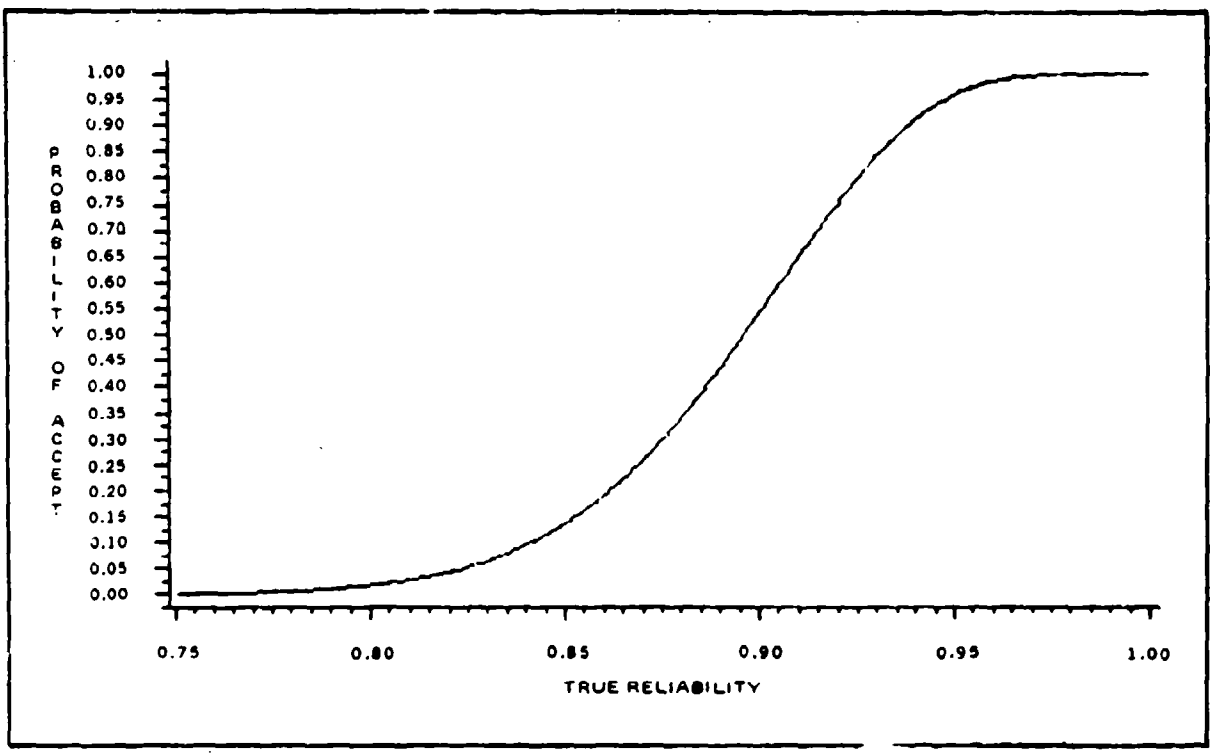



Figure 6.3.2.8A. Operating Characteristic Curve for Test Plan 8A

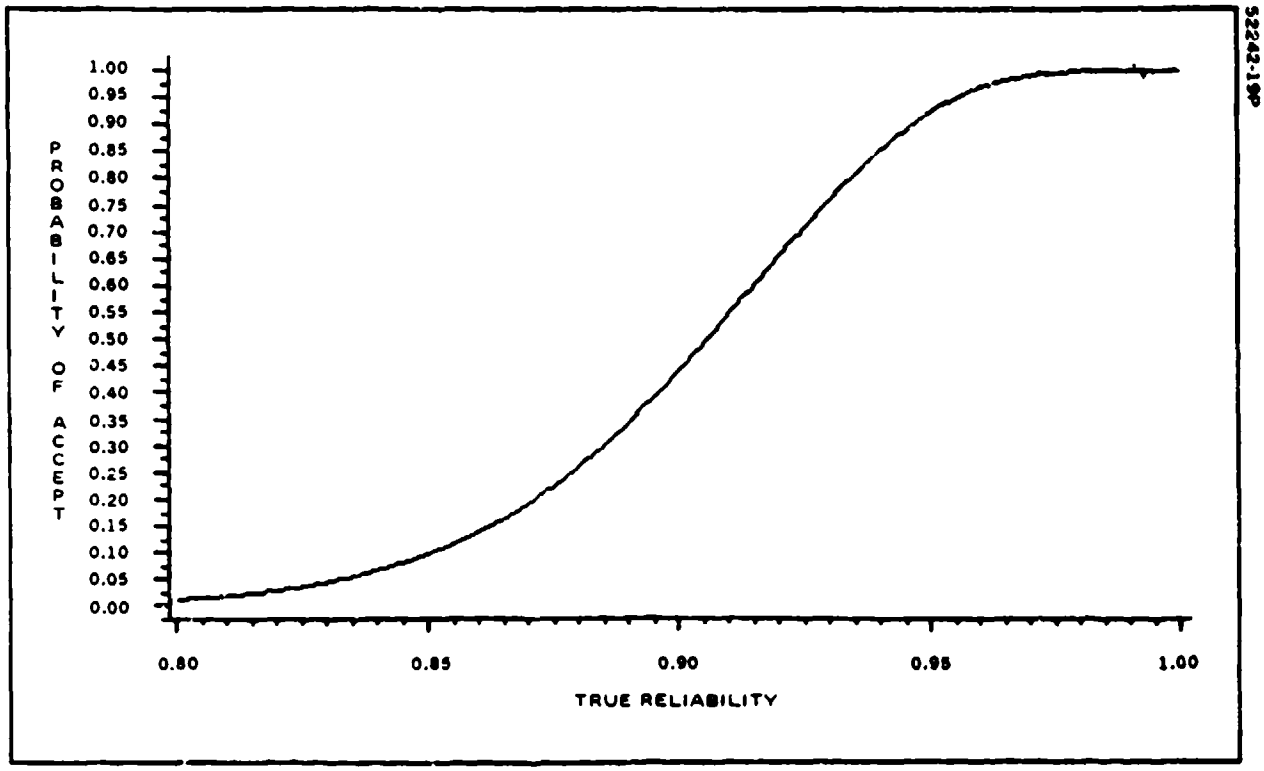



Figure 6.3.2.9A. Operating Characteristic Curve for Test Plan 9A

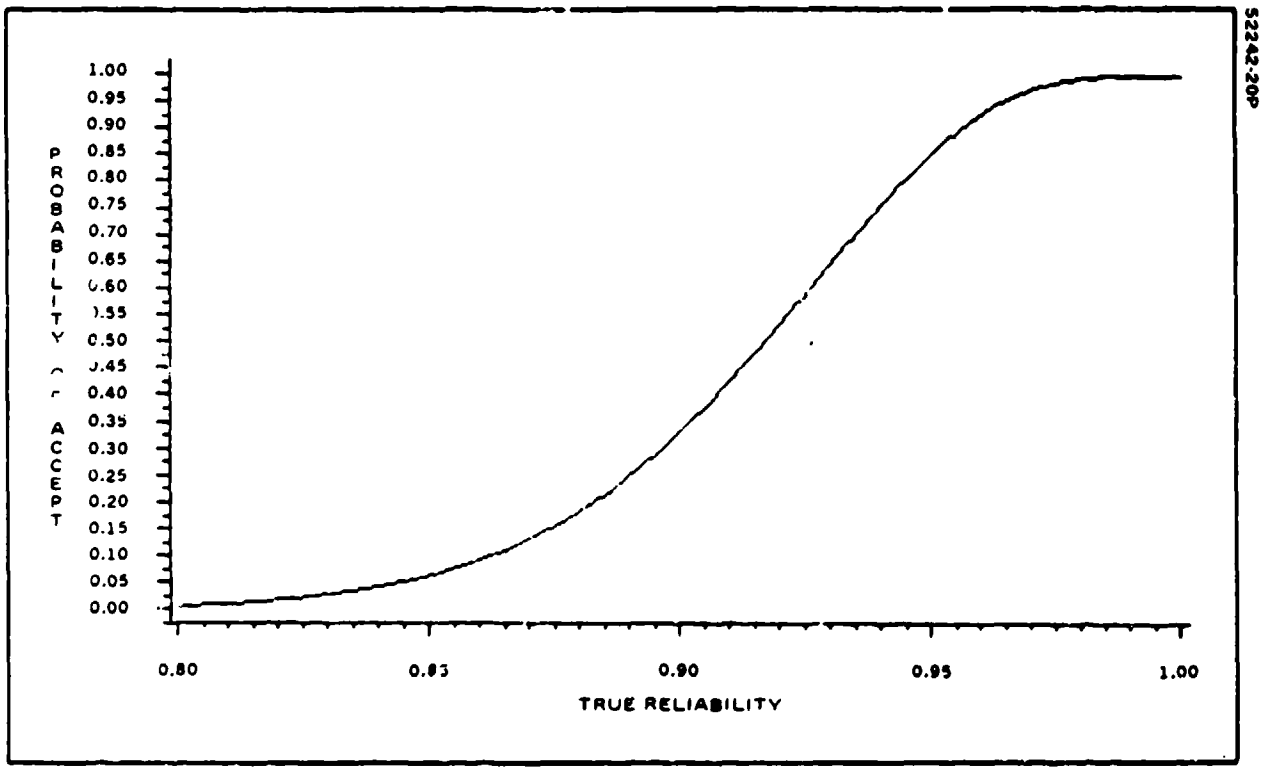



Figure 6.3.2.10A. Operating Characteristic Curve for Test Plan 10A

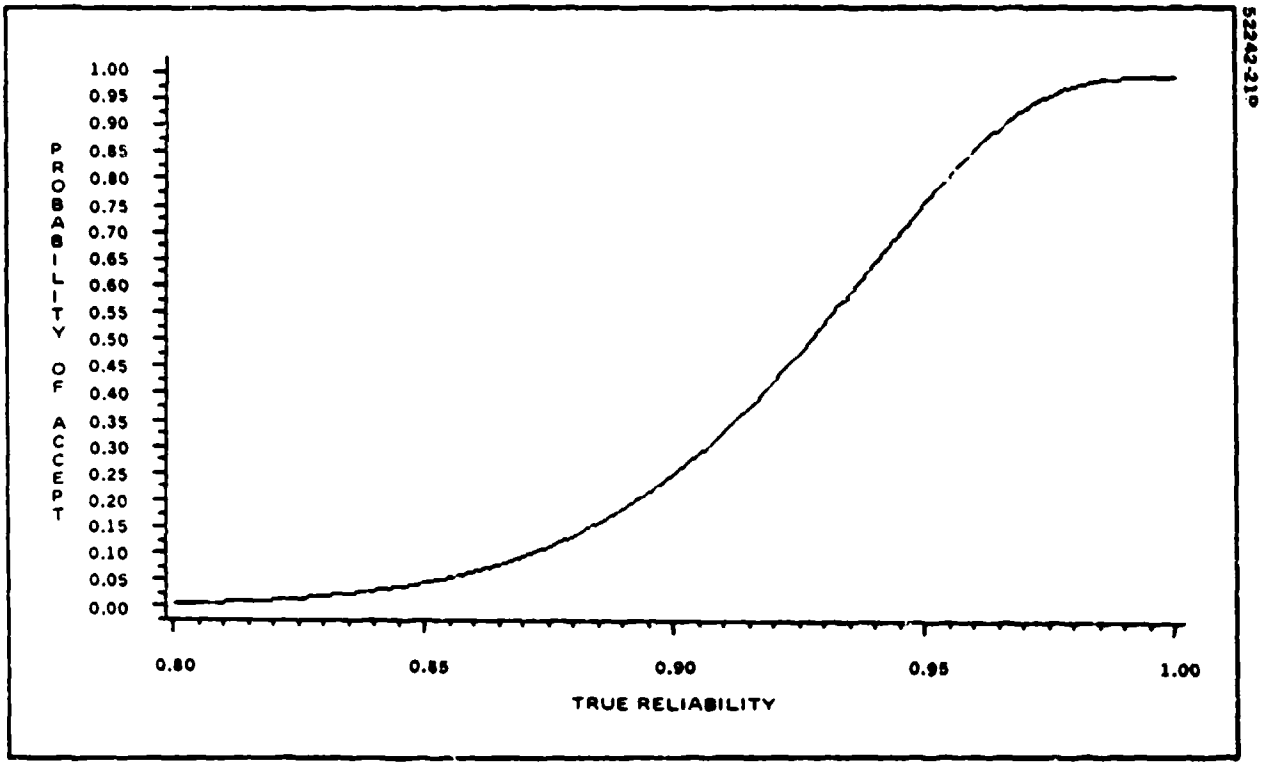



Figure 6.3.2.11A. Operating Characteristics Curve for Test Plan 11A

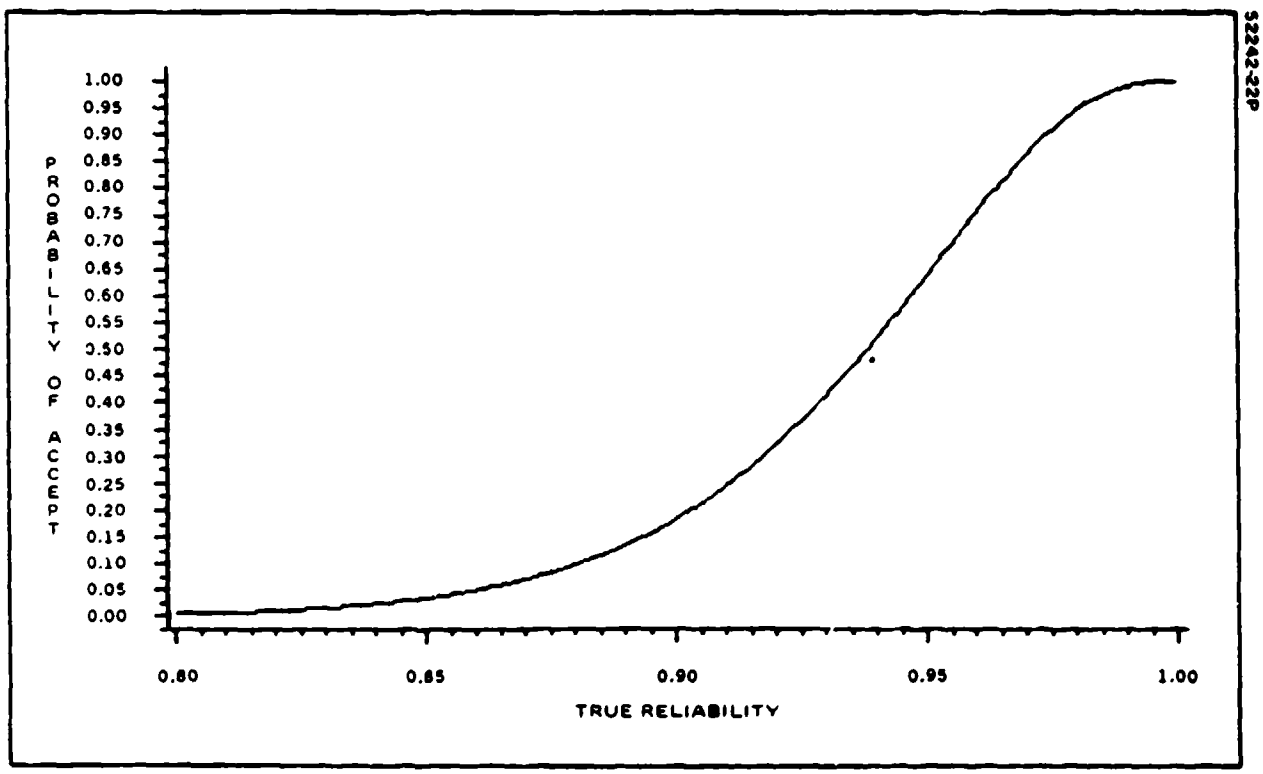



Figure 6.3.2.12A. Operating Characteristic Curve for Test Plan 12A

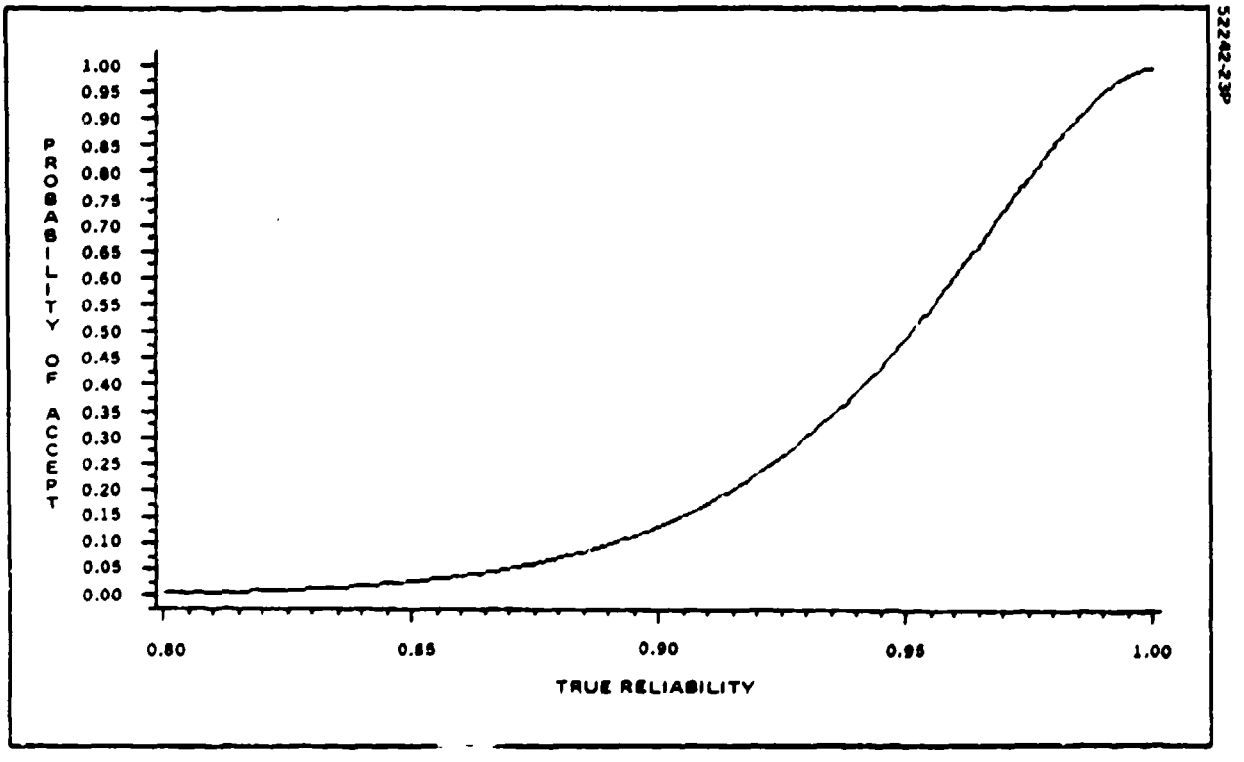



Figure 6.3.2.13A. Operating Characteristic Curve for Test Plan 13A

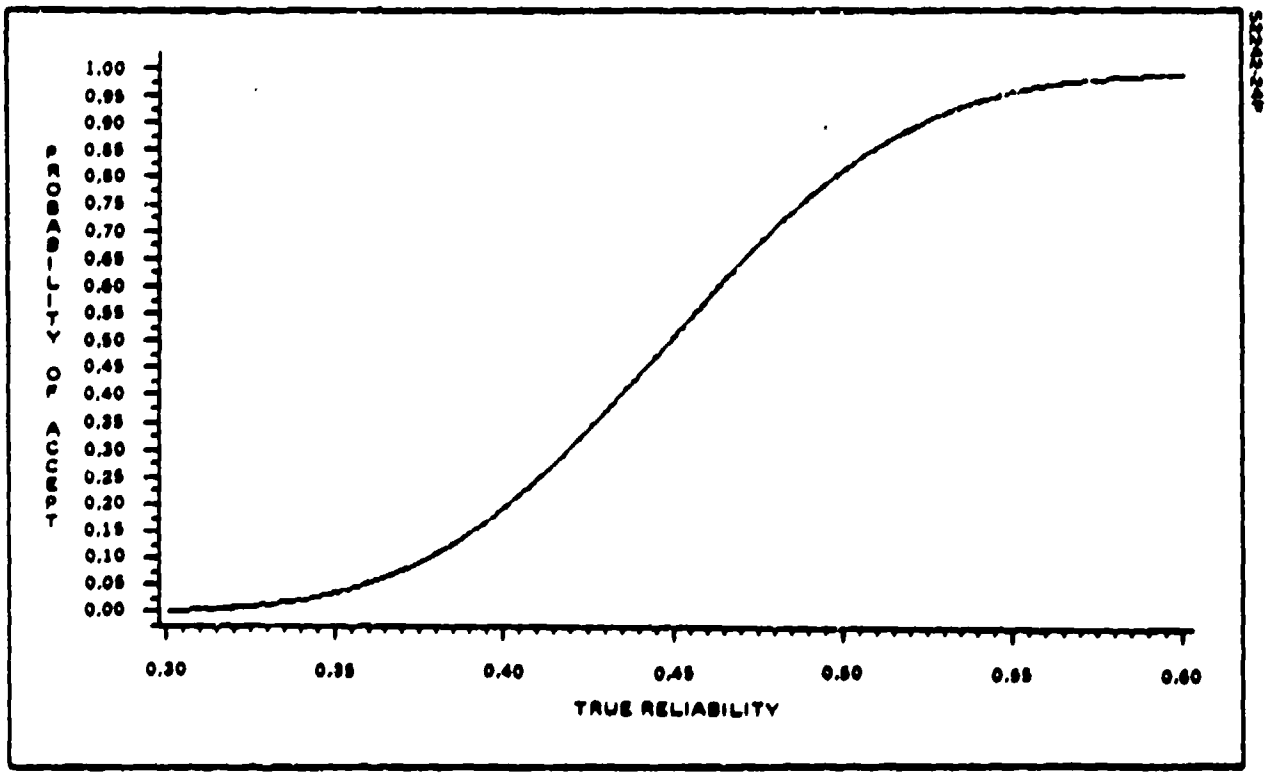



Figure 6.3.2.1B. Operating Characteristic Curve for Test Plan 1B

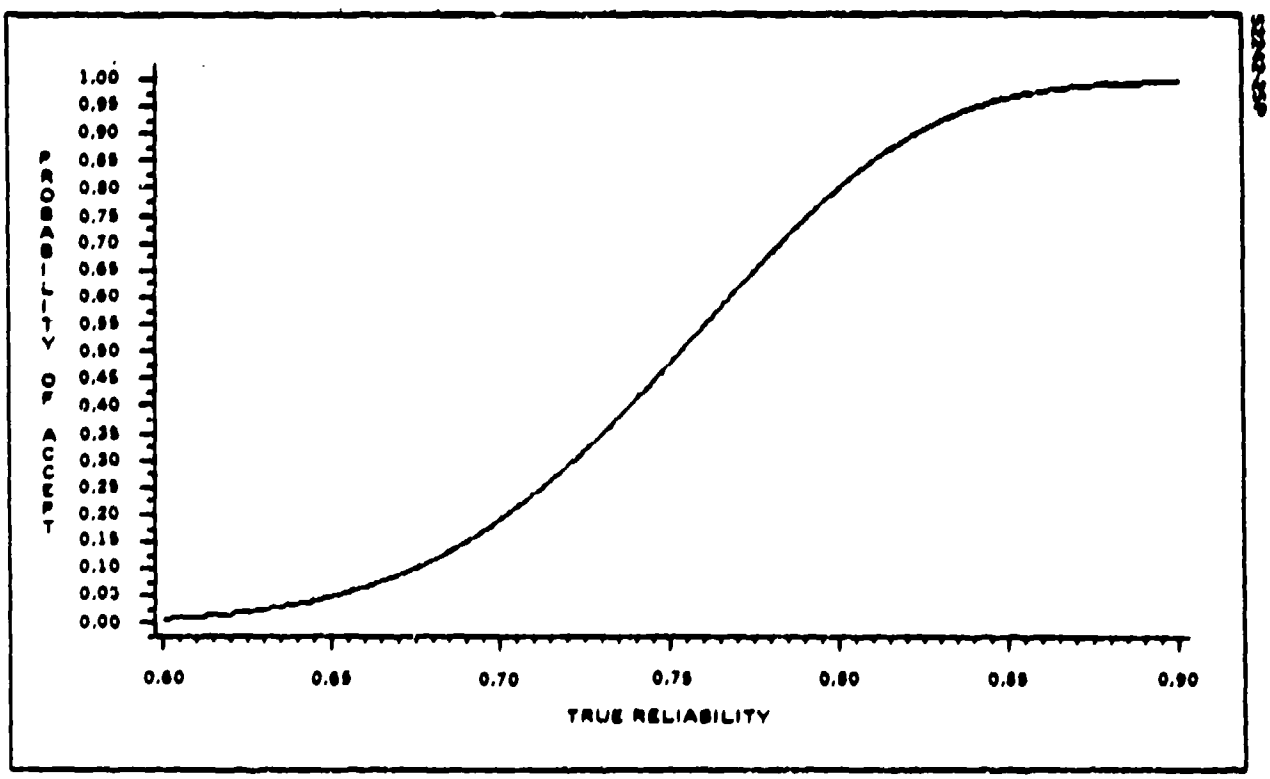



Figure 6.3.2.2B. Operating Characteristic Curve for Test Plan 2B

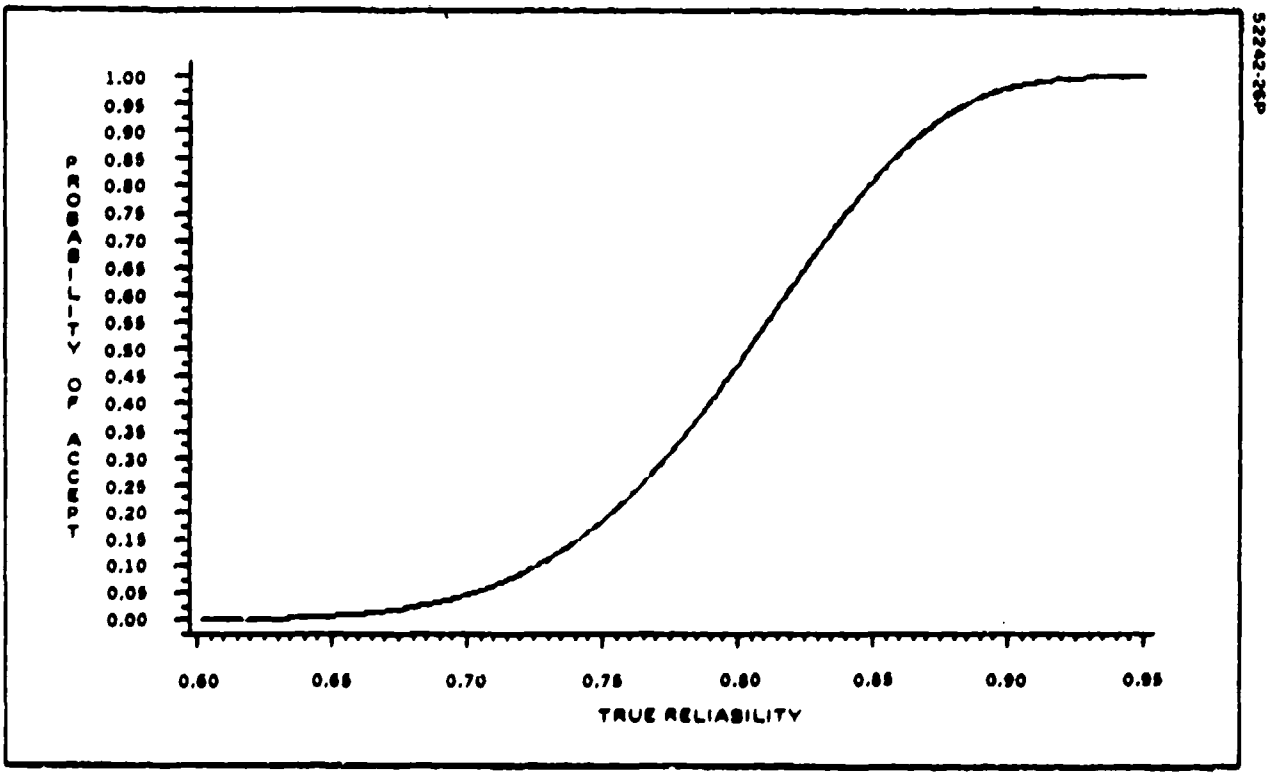



Figure 6.3.2.3B. Operating Characteristic Curve for Test Plan 3B

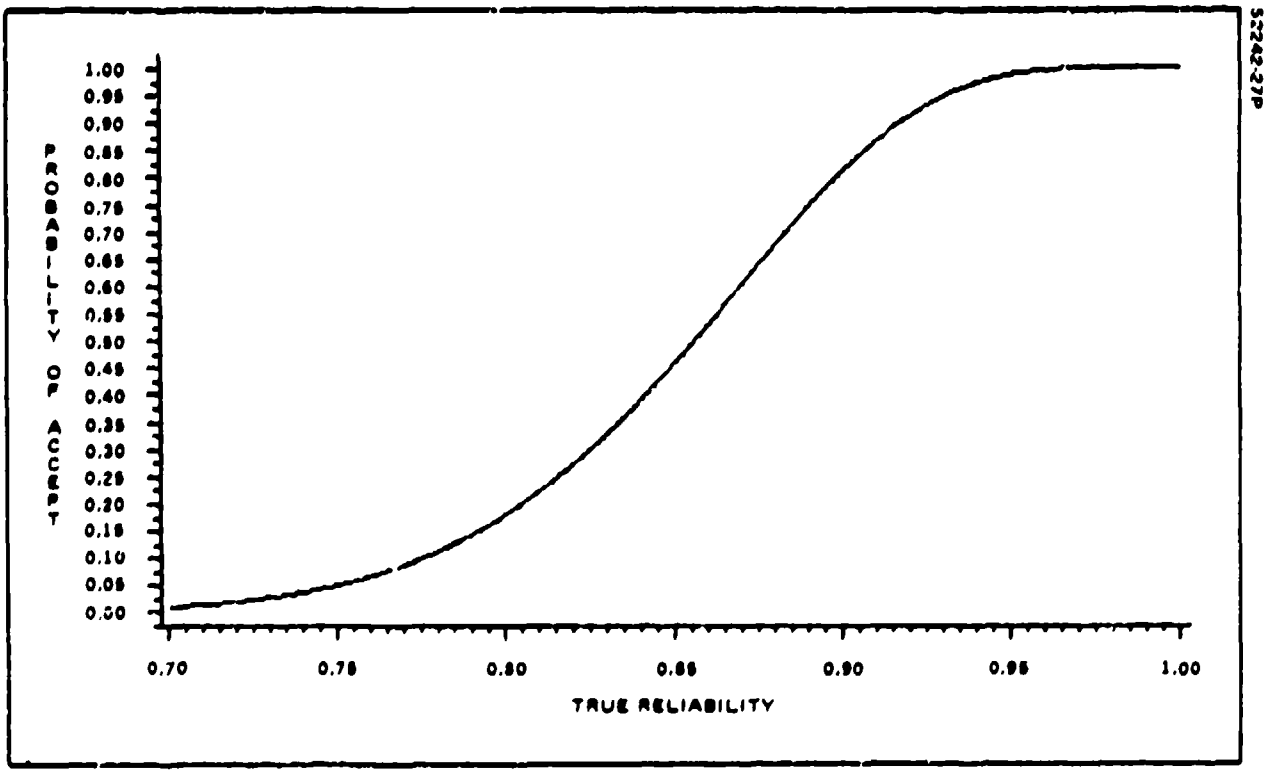



Figure 6.3.2.4B. Operating Characteristic Curve for Test Plan 4B

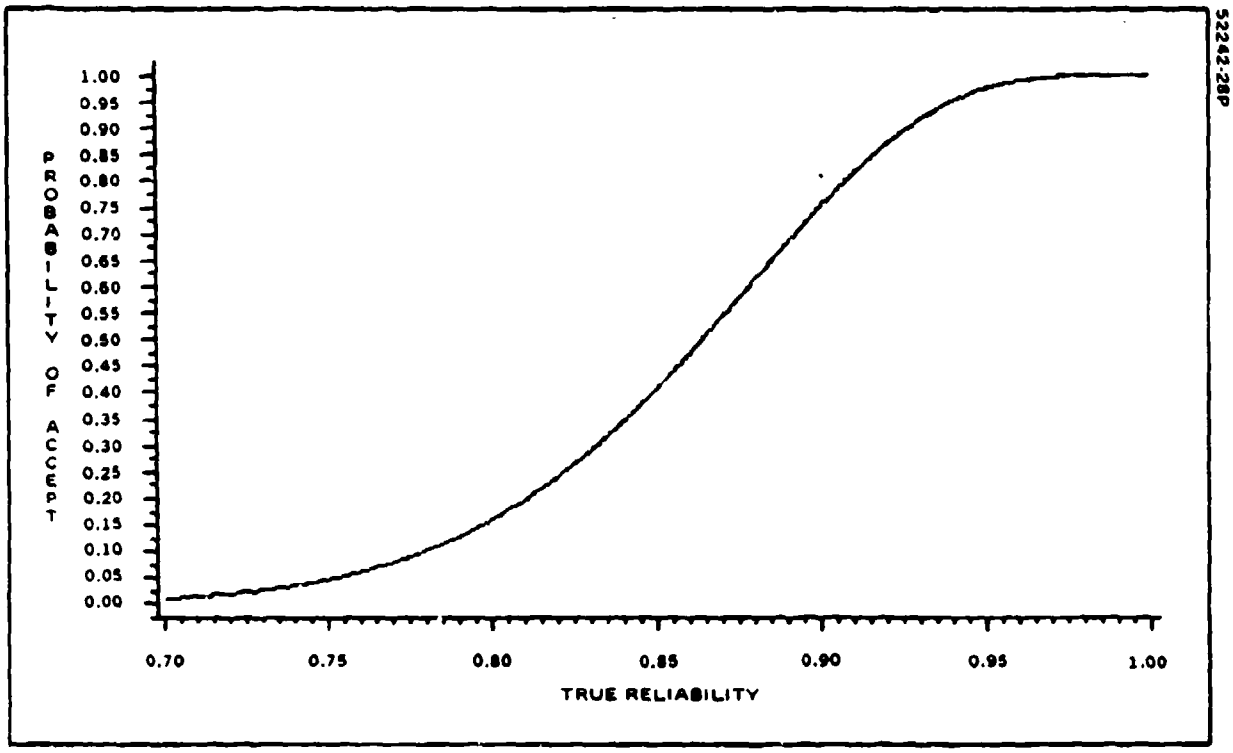



Figure 6.3.2.5B. Operating Characteristic Curve for Test Plan 5B

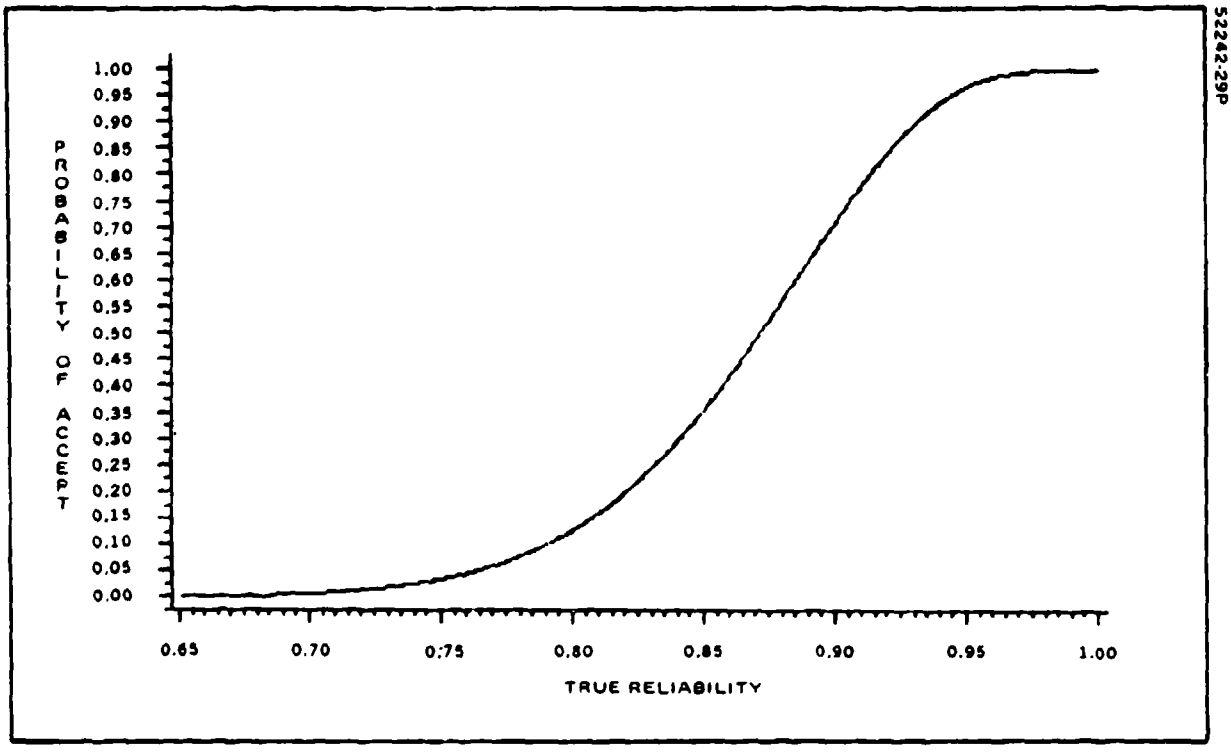



Figure 6.3.2.6B. Operating Characteristic Curve for Test Plan 6B

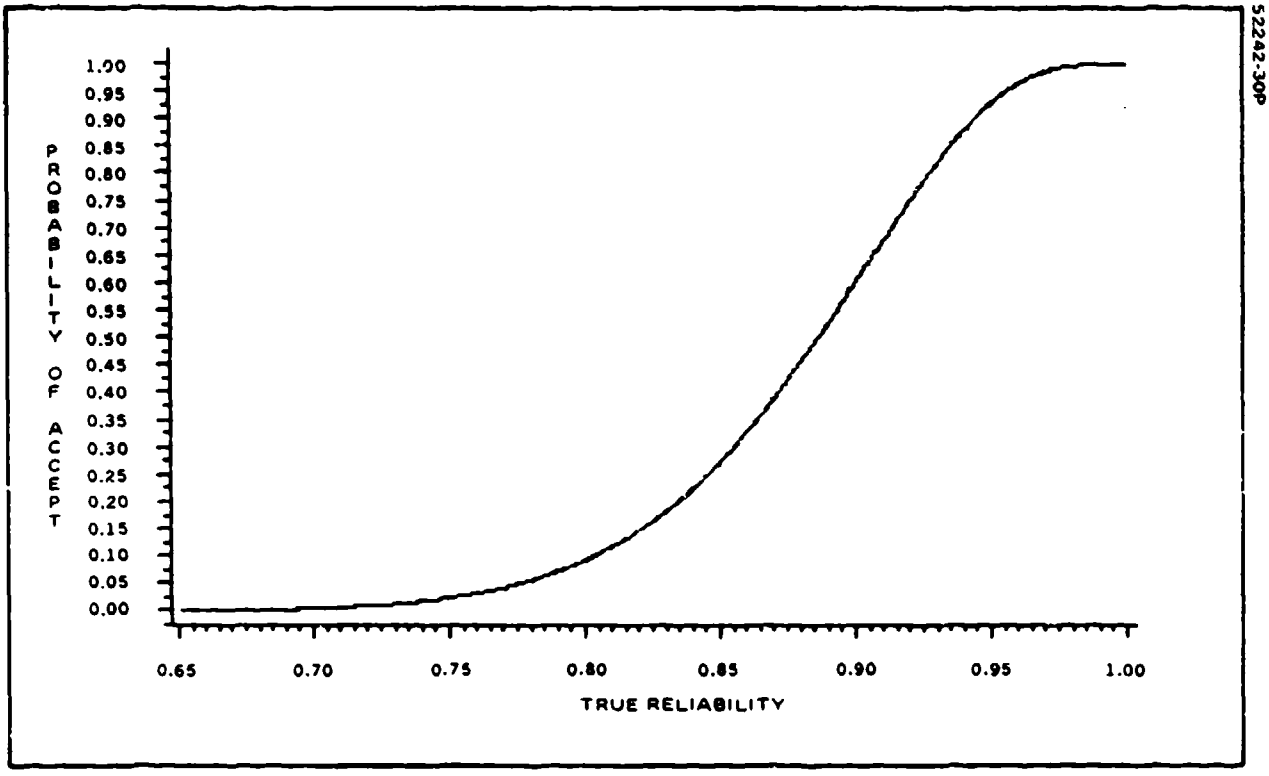



Figure 6.3.2.7B. Operating Characteristic Curve for Test Plan 7B

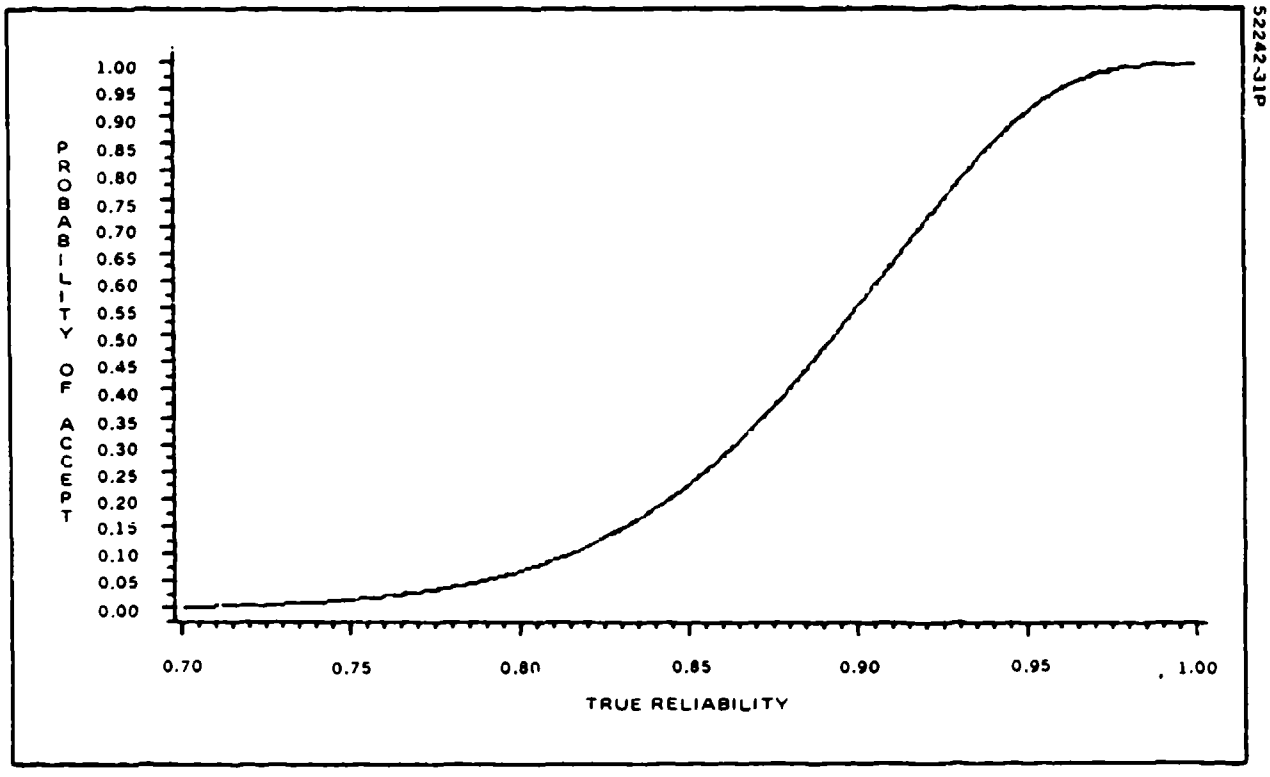



Figure 6.3.2.8B. Operating Characteristic Curve for Test Plan 8B

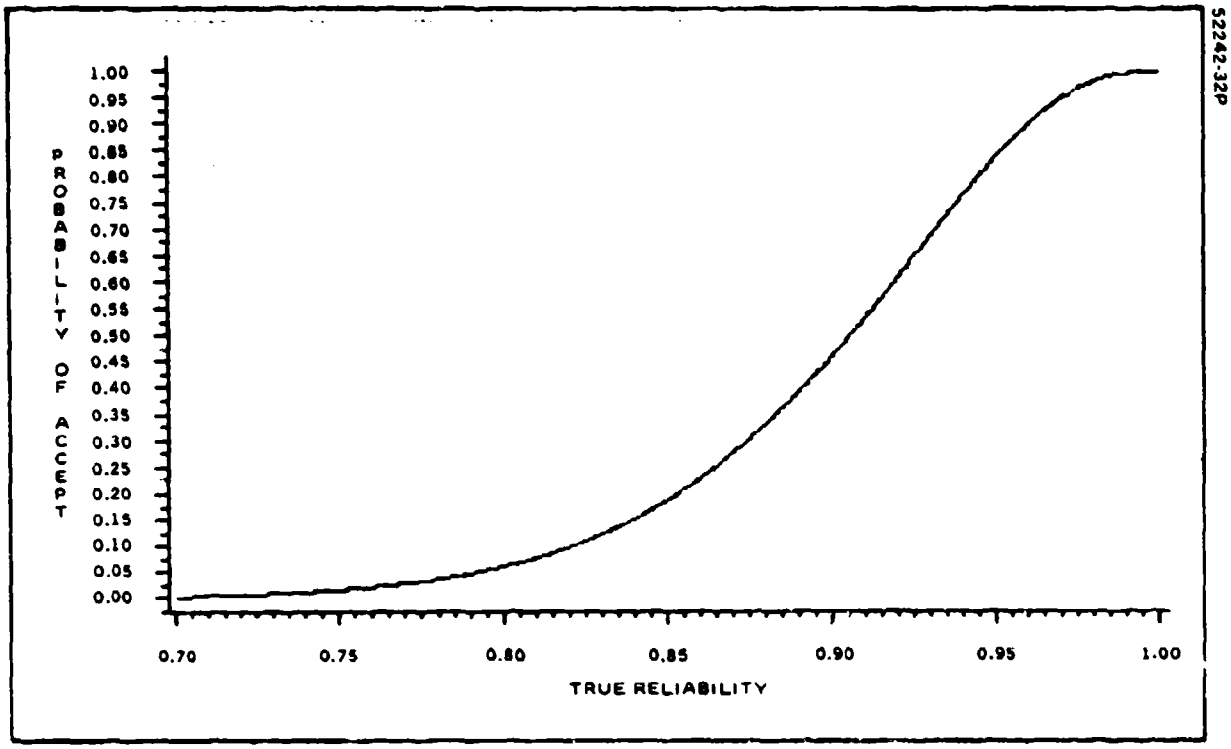



Figure 6.3.2.9B. Operating Characteristic Curve for Test Plan 9B

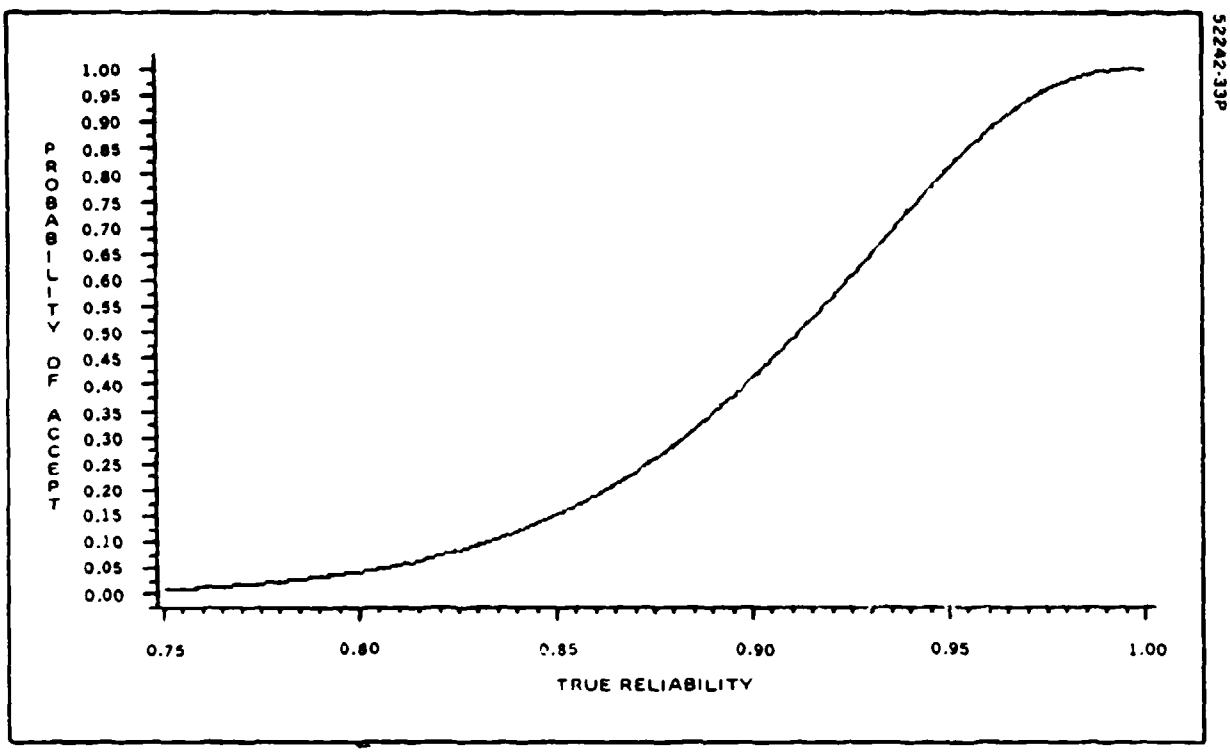



Figure 6.3.2.10B. Operating Characteristic Curve for Test Plan 10B

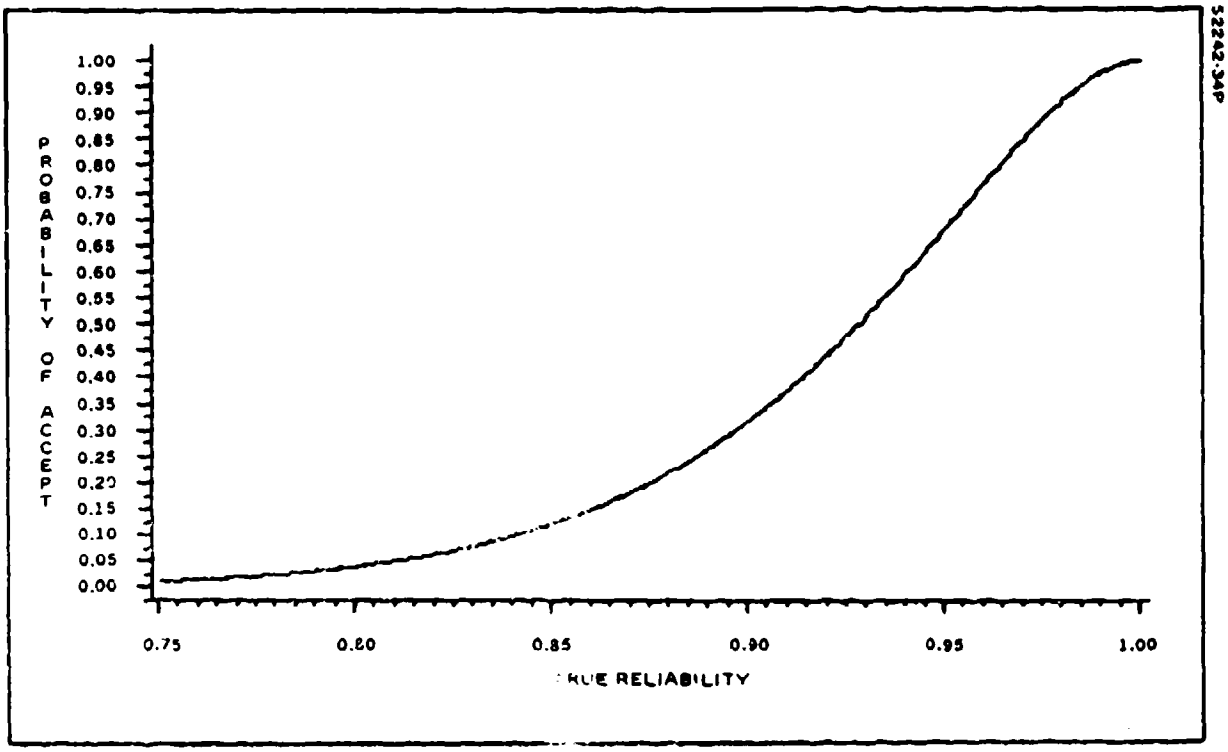



Figure 6.3.2.11B. Operating Characteristic Curve for Test Plan 11B

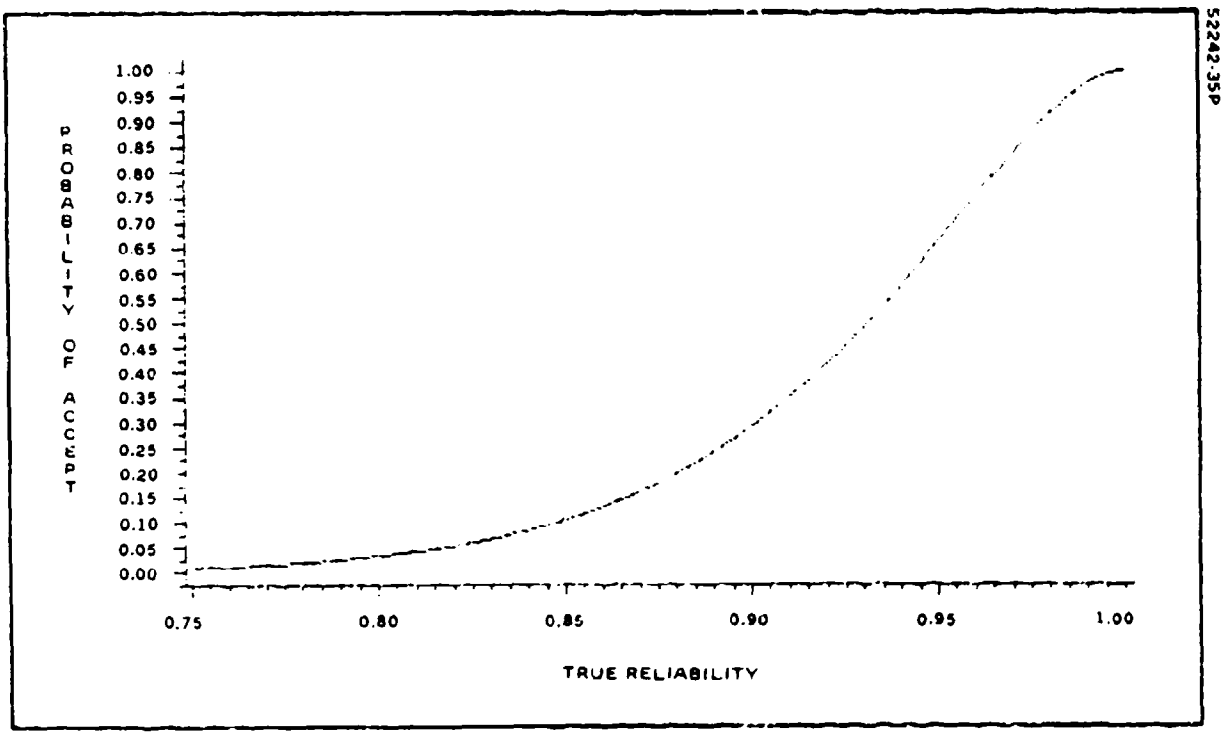



Figure 6.3.2.12B. Operating Characteristic Curve for Test Plan 12B

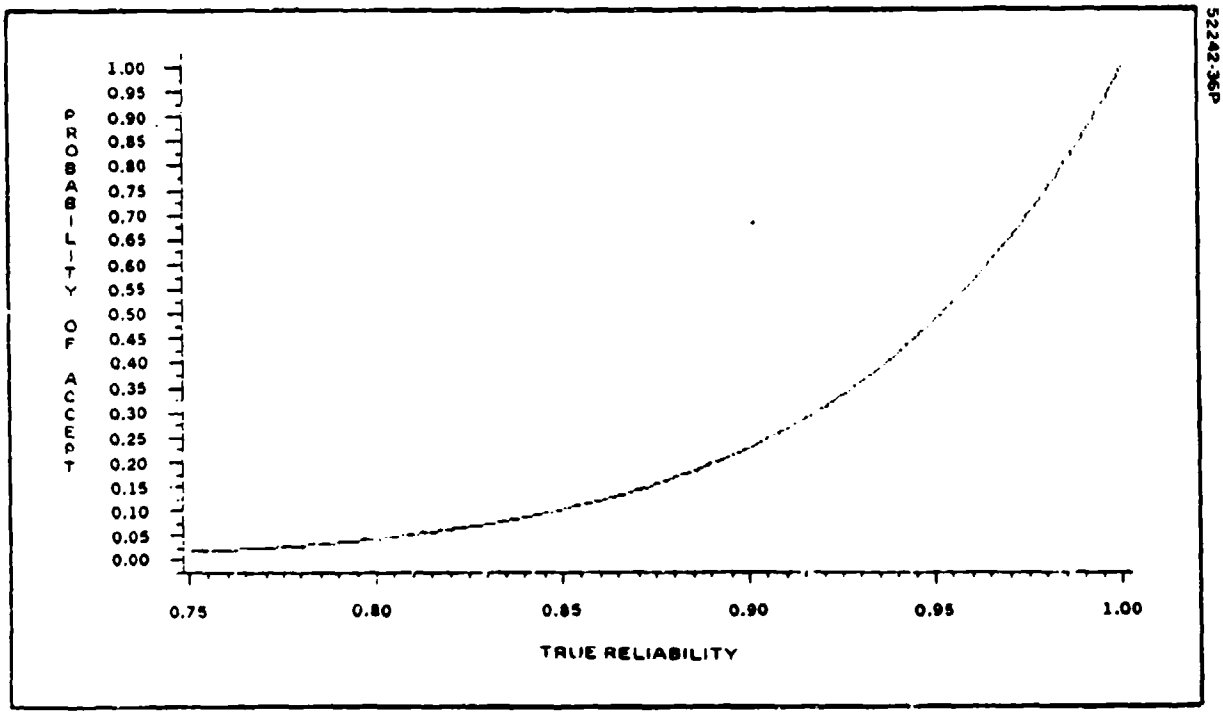



Figure 6.3.2.13B. Operating Characteristic Curve for Test Plan 13B

# APPENDIX I
# REFERENCES AND BIBLIOGRAPHY

# APPENDIX I REFERENCES AND BIBLIOGRAPHY


ASCE (1982). Fatigue reliability: Introduction. ASCE, Vol. 108, No. ST1, June 1982, pp. 3-23.

ASME (1965). Mechanical reliability concepts. ASME design engineering conference, New York.

Abramowitz, M. and Stegun, I. A. Eds. (1965). Handbook of Mathematical Functions. New York: Dover.

Ang, A.H.S. (1970). Extended reliability basis of structural design under uncertainties. 1970 Annals of reliability and maintainability conference. New York: IEEE., pp. 642-649.

Atchison, J., and Brown, J.A.C. (1963). The lognormal distribution. Cambridge University Press, New York.

Austin, W. H. (1967). Development of improved gust load criteria for USAF aircraft. 1967 Annals of Reliability and Maintainability Conference, New York: IEEE, pp. 68-74.

Bain, L. J. (1972). Inference based on censored sampling from the Weibull or extreme value distribution. Technometrics, 14, 693-702.

Bain, L. J. (1978). Statistical Analysis of Reliability and Life-Testing Models. New York: Dekker.

Barlow, R. E. and Proschan, F. (1964). Mathematical Theory of Reliability. New York: Wiley.

Bartholomew, D. J. (1963). The sampling distribution of an estimate arising in life testing. Technometrics, 5, 361-374.

Bazovsky, I. (1971). Reliability of rifles, machine guns and other small arms. Proceedings Annual Symposium on Reliability, IEEE, New York, pp. 71-73.

Bell, R., and Mioduski, R. (1976). Extension of life of U.S. Army trucks. 1976 Annual Reliability and Maintainability Symposium, IEEE, New York, pp. 200-205.

Bennet, S. B., Ross, A. L., and Zemanick, P. Z., editors (1977). Failure prevention and reliability. Society of Mechanical Engineers, New York.

Bhattacharyya, G. K., and Johnson, R. A. (1975). Stress-strength models for system reliability, reliability and fault tree analysis. Philadelphia: SIAM, pp. 509-532.

Billet, R. B. (1964). Reliability of hydraulic controls in space vehicles. National Symposium on Reliability, IEEE, New York, pp. 69-84.

Billman, B. Antle, C. and Bain, L. J. (1972). Statistical Inferences from censored Weibull sample. Technometrics, 14, 831-840.

Birnbaum, Z. W., and Saunders, S. C. (May 1968). A probabilistic interpretation of Miner's rule. SIAM Journal on Applied Mathematics, Vol. 16, No.3, pp. 637-652.

Birnbaum, Z. W., and Saunders, S. C. (October 1969). A new family of life distributions. J. Appl. Probl., pp. 319-327.

Bompass-Smith, J. H. (1969). The determination of distributions that describe the failures of mechanical components. Annals of Reliability and Maintainability Conference, IEEE, New York, pp. 343-356.

Bompass-Smith, J. H. (1973). Mechanical Survival: The Use of Reliability Data. London: McGraw-Hill.

Bratt, M. J., Truscott, H. A. and Weber, G. W. (1968). Probabilistic strength mapping reliability vs life prediction tool. 1968 Annals of Reliability and Maintainability Conference, IEEE, New York, pp. 501-510.

Bratt, M. J., Reethoff, G., and Weber, G. W. (1969). A model for time varying and interfering stress/strength probability density distributions with consideration for failure incidence and property degradation. Proceedings 3rd Annual Aerospace Reliability and Maintainability Conference, IEEE, New York, 566-575.

Brewer, J. W. (1971). Interim scale reliability statements consistent with conventional materials strength criteria. 1971 Annals of Reliability and Maintainability Conference, IEEE, New York, pp. 63-71.

Buckland, W. R. (1964). Statistical Assessment of the Life Characteristics. London: Griffin.

Burns, J. J. (1975). Reliability of nuclear mechanical systems. Annual Reliability and Maintainability Symposium, IEEE, New York, pp. 163-169.

Carter, A.D.S. (1972). Mechanical Reliability. London: Wiley.

Chester, L. B., Nolf, C. F., and Kececioglu, D. (1975). Combined bending-torsion fatigue reliability - III. 1975 Annual Reliability and Maintainability Symposium, IEEE, New York, pp. 511-518.

Cohen, A. C. (1965). Maximum likelihood estimation in the Weibull distribution. Technometrics, 17, 347-351.

Collins, J. A., Hagan, G. T., and Bratt, H. M. (1975). Helicopter failure modes and corrective actions. 1975 Annual Reliability and Maintainability Symposium, IEEE, New York, pp. 504-510.

Crow, L. H. (1974). Reliability Analysis for complex, repairable systems. In Reliability and Biometry, F. Proschan and R. J. Serfling, Eds. Philadelphia: SIAM.

D'Agostino, R. B. and Stephens, M., Eds. (1984). Goodness-of-Fit Techniques. New York: Dekker.

Davidson, J. R. (1973). Reliability after inspection. Proceedings of the ASTM Symposium on the Fatigue of Composite Materials, Bal Harbor, Florida.

Davis, D. J. (1952). An analysis of some failure data. J. Amer. Stat. Assoc., pp. 113-150.

Dehardt, J. H., and McLaughlin, H. D. (1966). Using Bayesian Methods to Select a Design with Known Reliability Without a Confidence Coefficient. 1966 Annals of Reliability and Maintainability Conference. New York: IEEE, pp. 611-617.

Dennis, N. G. (1977). PMR, NDE, design practices; present and future. 1977 Annual Reliability and Maintainability Symposium. New York: IEEE, pp. 164-170.

Dhillon, B. S., and Singh, C. (1981). Engineering Reliability - New Techniques and Applications. John Wiley.

Dhillon, B. S. (1980). Mechanical reliability: Interference theory models. Proceedings Annual Reliability and Maintainability Symposium, pp. 462-467.

Dhillon, B. S. (1981). Interference theory application to mechanical systems. Proceedings Annual Reliability and Maintainability Symposium, pp. 24-27.

Dillin, A. L. (1971). Reliability assessment of army weapons and weapon systems. Proceedings of the Annual Symposium on Reliability, IEEE, New York, pp. 74-76.

Disney, R. L., and Sheth, N. J. (1968). The determination of the probability of failure by stress/strength interference theory. 1968 Annual Symposium on Reliability, IEEE, New York, pp. 417-422.

Disney, R. L., Lipson, C., and Sheth, N. J. (January 1968). The determination of the probability of failure by stress/strength interference theory. Proceedings of the Symposium on Reliability, pp. 417-422.

Dixon, W. J. and Brown, M. B. (1977). BMDP-77: Biomedical Computer Programs P Series. Berkeley: University of California Press.

Dumonceau, R., and Antle, C. E. (November 1973). "Discrimination between the log normal and Weibull distributions." Technometrics, Vol. 15, No. 4, pp. 923-926.

Engelhardt, M. (1975). On simple estimation of parameters of the Weibull or extreme value distribution. Technometrics, 17, 369-374.

Engelhardt, M. and Bain, L. J. (1973). Some complete and censored sampling results for the Weibull or extreme value distribution. Technometrics, 15, 542-549.

Engelhardt, M. and Bain, L. J. (1974). Some results on point estimation for the two-parameter Weibull or extreme value distribution. Technometrics, 17, 353-356.

Engelhardt, M. and Bain, L. J. (1977). Simplified statistical procedures for the Weibull or extreme value distribution. Technometrics, 19, 323-331.

Epstein, B. and Sobel, M. (1953). Life Testing. Journal of the American Statistical Association, Vol. 48.

Feller, W. (1968). An Introduction to Probability Theory and Its Applications, Vol. 1, 3rd ed. New York: Wiley.

Fiderer, L. (1976). Design for reliability in hostile environment. Microelectronics and Reliability, Vol. 15 Supplement, pp. 75-85.

Fisher, G. K. (June 1981). Advanced power transmission technology. NASA Conf. Pub. 2210, AVRADCOM TR-82-C-16.

Fisher, R. A. and Tippett, L. M. C. (1928). Limiting forms of the frequency distribution of the largest or smallest member of a sample. Cambridge Phil. Soc., 24, 180-190.

Flint, S. J., and Steinkirchner, J. J. (1982). Reliability models - practical constraints. NATO ASI Electronic Systems Effectiveness and Life Cycle Costing Conference. New York: Springer Verlag.

Forrestor, E. R., and Thevenow, V. H. (1968). Designing for expected fatigue life. 1968 Annals of Reliability and Maintainability, IEEE, New York, pp. 511-519.

Furth, J. A., Upton, C. and Kimball, A. W. (1959). Late pathologic effects of atomic detonation and their pathogenesis. Radia. Res. Suppl. 1, 243-264.

Ghane, P. M. (1970). Quality and safety factors in reliability. 1970 Annals of Reliability and Maintainability, IEEE, New York, pp. 637-641.

Gnedenko, B. V. (1943). Sur la distribution limite du terme maximum d'une series aleatoire. Ann. Math., 44, 423-453.

Grow, A. J., and Clark, V. A., Survival Distribution: Reliability Applications in the Biomedical Sciences. Wiley, New York, 1975.

Grubbs, F. E. (1971). Fiducial bounds on reliability for the two-parameter negative exponential distribution. Technometrics, 13, 873-876.

Gumbel, E. J. (1958). Statistics of Extremes. Columbia University Press, New York.

Gupta, S., and Groll, P. (December 1961). Gamma distribution in acceptance sampling based on life tests. J. Amer. Stat. Assoc., IEEE, New York, pp. 942-970.

Hahn, G. J., Nelson, W. B. and Cillay, C. (1975). STATSYSTEM - A user-oriented interactive system for statistical data analysis in 1975 Statistical Computing Section Proceedings of the American Statistical Association, Washington, D. C.: American Statistical Association.

Hald, A. (1952). Statistical Theory with Engineering Applications. New York: Wiley.

Hassanein, K. M. (1972). Simultaneous estimation of the parameters of the extreme value distribution by sample quantiles. Technometrics, 17, 63-70.

Haugen, E. G. (1964). Statistical methods for structural reliability analysis. National Symposium on Reliability, IEEE, New York, pp. 97-121.

Havilan, R. P. (1964). Engineering reliability and longlife design. Princeton: Van Nostrand.

Heller, R. A., and Heller, H. S. (1973). Analysis of early failures in unequal. 1973 Annual Reliability and Maintainability Symposium, IEEE, New York, pp. 198-200.

Heller, R. A., and Shinozuka, M. (1970). State-of-the-Art: Reliability techniques in materials and structures. 1970 Annals of Reliability and Maintainability Conference, IEEE, New York, pp. 635-636.

Ingram, G. E., Herrmann, C. R., and Welker, E. L. (1968). Designing for reliability based on probabilistic modeling using remote access computer system. 1968 Annals of Reliability and Maintainability Conference, IEEE, New York, pp. 492-500.

Ingram, G. E., Haugen, E. B., Dicks, C., and Wilson, S. (1965). Panel discussion - structural reliability. National Symposium on Reliability, IEEE, New York, pp. 154-169.

Inoue, K., Daito, H. (1977). Safety analysis of automobile brake systems by fault tree methods. Proceedings HOPE International JSME Symposium, Japan Society of Mechanical Engineers, Tokyo, pp. 213-220.

Japan Society of Mechanical Engineers (1979). Proceedings of the HOPE international symposium.

Johnson, C. W., and Maxwell, R. E. (1976). "Reliability analysis of structures - a new approach. 1976 Annual Reliability and Maintainability Symposium, IEEE, New York, pp. 213-217.

Johnson, W. S., Heller, R. A., and Yang, J. N. (1977). Flight inspection data and crack initiation times. 1977 Annual Reliability and Maintainability Symposium, IEEE, New York, pp. 148-154.

Johnson, N. L. and Kotz, S. (1970). Continuous Univariate Distributions. Vols. 1 and 2. Boston, Massachusetts: Houghton Mifflin.

Jones, L. G., and Thompson, D. (1971). Essential elements of analysis from army test and field data. Proceedings Annual Symposium on Reliability, IEEE, New York, pp. 85-90.

Kalivoda, F. E., and Yun, K. W. (1976). Modeling mechanical system accelerated life tests. 1976 Annual Reliability and Maintainability Symposium, IEEE, New York, 206-212.

Kao, J.H.K. (1958). Computer methods for estimating Weibull parameters in reliability studies. IRE Transactions on Reliability and Quality Control.

Kao, J.H.K. (1960). A summary of some new techniques for failure analysis. Proceedings Sixth National Symposium on Reliability, IEEE, New York, p. 191.

Kao, J.H.K. (1959). A graphical estimation of mixed Weibull parameters in life-testing of electron tubes. Technometrics 1, pp. 389-407.

Kao, J.H.K. (1965). Statistical models in mechanical reliability. National Symposium on Reliability, IEEE, New York, pp. 240-247.

Kapur, K. C., and Lamberson, L. R. (1977). Reliability in Engineering Design. New York: John Wiley.

Karnopp, D. (1971). Structural reliability predictions using finite element programs. 1971 Annals of Reliability and Maintainability Conference, IEEE, New York, pp. 72-80.

Kececioglu, D., McKinley, J. W., and Saroni, M. (Jan. 1967). A probabilistic method of designing a specified reliability into mechanical components with time dependent stress and strength distributions. The University of Arizona, Tucson, Arizona, (NASA report under contract NGR 03-002-044).

Kececioglu, D., and Cormier, D. (1964). Designing a specified reliability directly into a component. Proceedings 3rd Annual Conference on Aerospace Reliability and Maintainability. Washington DC, IEEE, New York, pp. 546-565.

Kececioglu, D. (1968). Why design by reliability? 1968 Annals of Reliability and Maintainability Conference, IEEE, New York, p. 491.

Kececioglu, D. (1972). Reliability analysis of mechanical components and systems. Nucl. Eng. Design, pp. 259-290.

Kececioglu, D. (1974). Fundamentals of mechanical reliability theory and applications to vibroacoustic failures. Proceedings of Reliability Design for Vibroacoustic Environments. ASME, New York, pp. 1-38.

Kececioglu, D. (1977). Probabilistic design methods for reliability and their data and research requirements. Failure Prevention and Reliability Conference Proceedings, ASME, New York.

Kececioglu, D., Chester, L. B. and Dodge, T. M. (1974). Alternating bending - steady torque fatigue reliability. Annual Reliability and Maintainability Symposium, IEEE, New York, pp. 153-173.

Kececioglu, D., and Koharcheck, A. (1977). Wear reliability of aircraft splines. 1977 Annual Reliability and Maintainability Symposium, IEEE, New York, pp. 155-163.

Kececioglu, D., and Haugen, E. B. (1968). A unified look at design safety factors, safety margins and measures of reliability. 1968 Annals of Reliability and Maintainability Conference, IEEE, New York, pp. 520-530.

Kececioglu, D. B., Smith, R. E. and Felsted, E. A. (1970). Distribution of strength in simple fatigue and the associated reliabilities. Annals of reliability and maintainability conference, IEEE, New York, pp. 659-672.

Kendall, M.G. (1938). A new measure of rank correlation. Biometrika, Vol. 30.

King, J. R. (1971). Probability Charts for Decision Making. New York: Industrial Press.

Kirkpatrick, I. (1960). Predicting reliability of electromechanical devices. Sixth National Symposium on Reliability and Quality Control, IEEE, New York, pp. 272-281.

Konno, K., K. Nakano, and Yoshimura, Y. (1975). A new accelerated fatigue test. The effective random peak method. Annual Reliability and Maintainability Symnposium, IEEE, New York, pp. 263-268.

Kullman, L. W., and Phillips, G. W. (1964). Reliability engineering disciplines applied to commercial weapon systems - guns and ammunition. National Symposium on Reliability, IEEE, New York, pp. 122-137.

Kurtz, P. H. (1975). A strength-stress interference model for time-varying probability of failure and its application to an electromechanical system. Naval Sea Systems Command, TM-75-122, AD A016299, NTIS.

Kurtz, P. H. (1971). Reliability study of a hydraulic control system using the hybrid computer. Annals of Reliability and Maintainability Conference, IEEE, New York, pp. 81-85.

Lambert, R. G. (1978). Mechanical reliability for low cycle fatigue. 1978 Annual Reliability and Maintainability Symposium, IEEE, New York, pp. 179-183.

Lawless, J. F. (1982). Statistical Models and Methods for Lifetime Data. New York: Wiley.

Lemaitre, J., and Plumtree, A. (July 1979). Application of damage concepts to predict creep-fatigue failures. Journal of Engineering Materials and Technology, Vol. 101, ASME, pp. 284-292.

Lemon, G. H., and Manning, S. D. (October 1974). Literature survey on structural reliability. IEEE Trans. Reliab. R-23.

Lieblein, J., and Zelen, M. (1956). Statistical investigation of the fatigue life of deep-groove ball bearings. J. Res. Nat. Bur. Stand., 5 (Res. Paper 2719), pp. 273-316.

Lieblein, L. and Zelen, M. (1956). Statistical investigation of the fatigue life of deep groove ball bearings. J. Res. Nat. Bur. Stand., 57, 273-316.

Liebowitz, H. (1967). Navy reliability research. 1967 Annals of Reliability and Maintainability Conference, IEEE, New York, pp. 33-53.

Linhart, H. (1965). Approximate confidence limits for the coefficient of variation of gamma distributions. Biometrics, 21, 733-738.

Lipson, C., and Sheth, N. J. (1973). Statistical Design and Analysis of Engineering Experiment. McGraw-Hill, pp. 311-343.

Lipson, C., Sheth, N. J., and Disney R. L.(March 1977). Reliability prediction - mechanical stress/strength interference. RADC-TR-66-710.

Lipson, C., Sheth, N. J., Disney, R. L., and Altun, M. (December 1968). Reliability prediction - mechanical stress/strength interference (nonferrous). RADC-TR-68-403.

Lloyd, G. J., and Wareing, J. (August 1981). Life-prediction methods for combined creep-fatigue endurance. Metals Technology, pp. 297-305.

Lloyds, D., and Lipow, M. (1961). Reliability: Management, Methods and Mathematics. Englewood Cliffs, NJ: Prentice-Hall.

Mann, H. (1945). Nonparametric tests against trend. Econometrica, Vol. 13.

Mann, N. R., Shafer, R. E. and Singpurwalla, N. D. (1974). Methods for Statistical Analysis of Reliability and Life Data, Wiley, New York.

Mann, N. R. (1967a). Results on location and scale parameter estimation with application to the extreme value distribution. Wright-Patterson Air Force Base, Ohio, ARL Technical Report ARL 67-0023.

Mann, N. R. (1967b). Tables for obtaining the best linear invariant estimates of parameters of the Weibull distribution. Technometrics, 9, 629-645.

Mann, N. R. (1968) Point and interval estimation procedures for the two-parameter Weibull and extreme value distributions. Technometrics, 10, 231-256.

Mann, N. R. (1977). An F approximation for two parameter Weibull and log-normal tolerance bounds based on possibly censored data. Nav. Res. Log. Q. 24, 187-196.

Mann, N. R. and Fertig, K. W. (1973). Tables for obtaining confidence bounds and tolerance bounds based on best linear invariant estimates of parameters of the extreme value distribution. Technometrics, 15, 87-101.

Mann, N. R. and Fertig, K. W. (1975a). Simplified efficient point and interval estimators for Weibull parameters. Technometrics, 17, 237-245.

Mann, N. R. and Fertig, K. W. (1975b). A goodness-of-fit test for the two parameter vs. three-parameter Weibull: confidence bounds for the threshold. Technometrics, 17, 237-245.

Mann, N. R. and Fertig, K. W. (1977). Efficient unbiased quantile estimators for moderate-size complete samples from extreme value and Weibull distributions: confidence bounds and tolerance and prediction intervals. Technometrics, 19, 87-93.

Manning, S. D., and Lemon, G. H. (1974). Plan for developing structural criteria for composite airframes. 1974 Annual Reliability and Maintainability Symposium. IEEE, New York, pp. 155-162.

Marble, Q. G. (1965). Improving mechanical reliability of digital computers. National Symposium on Reliability and Quality Control, IEEE, New York, pp. 136-143.

Martin, P. (1976). Reliability in mechanical design and production. Proceedings Generic Techniques in Systems Reliability Assessment. Noordhoff-Leyden, Amsterdam, pp. 267-271.

Matney, V. D. (1974). Reliability, pollutants and aluminum raw. Annual Reliability and Maintainability Symposium, IEEE, New York, pp. 174-178.

Mesloh, R. (1966). Reliability design criteria for mechanical creep. 1966 Annals of Reliability and Maintainability Conference, IEEE, New York, pp. 590-597.

Moreno, F. J. (1973). Reliability estimate of a space deployable antenna. 1973 Annual Reliability and Maintainability Symposium, IEEE, New York, pp. 182-185.

Mukkayee, B. (January 1979). Residual fatigue life determination of anchor bolts. Journal of Engineering Materials and Technology, Vol. 101, ASME, pp. 47-52.

Naresky, J. J. (1966). Reliability and maintainability research in the USAF. Reliability and Maintainability Conference, IEEE, New York, pp. 769-787.

Nelson W. and Hahn, G. J. (1972). Linear estimation of a regression relationship from censored data. Part I - Simple methods and their applications. Technometrics, 14, pp. 247-269.

Nelson, W. (1982). Applied Life Data Analysis. New York: Wiley.

Nilsson, S. O. (1975). Reliability data on automotive components. Annual Reliability and Maintainability Symposium, IEEE, New York, pp. 276-279.

Niyogi, P. K. (1968). Application of statistical methods and information theory to structural reliability estimates. PhD Dissertation, Department of Civil Engineering, University of Pennsylvania, Philadelphia, PA.

Niyogi, P. K., Shah, H. C., Doshi, K. D., and Tang, W. (April 1969). Statistical evaluation of load factors for concrete bridge design. Chicago.

Odeh, R. E. and Owen, D. B. (1980). Tables for Normal Tolerance Limits, Sampling Plans, and Screening. New York: Dekker.

Persson, T. and Rootzen, T. (1977). Simple and highly efficient estimators for a Type-I censored normal sample. Biometrika, 64, 123-128.

Pettitt, A. N. (1976). Cramer-von Mises statistics for testing normality with censored samples. Biometrika, 63, 475-481.

Pettitt, A. N. (1977). Tests for the exponential distribution with censored data using Cramer-von Mises statistics. Biometrika, 64, 629-632.

Proschan, F (1963). Theoretical explanation of observed decreasing failure rate. Technometrics, 5, 541-554.

Quality assurance: Reliability handbook. (October 1968). Headquarters, U.S. Army Material Command, (AMCP 702-C, AD 702 936), NTIS, Springfield, VA.

Redler, W. M. (1966). Mechanical reliability research in the NASA, 1966 Annals of Reliability and Maintainability Conference, IEEE, New York, pp. 763-768.

Reethof, G. (1973). Session organizer's report. Annual Reliability and Maintainability Symposium, IEEE, New York, p. 181.

Reethof, G. (1971). State-of-the-art: Mechanical and structural reliability. 1971 Annals of Reliability and Maintainability Conference, IEEE, New York, p. 62.

Roberts, N. (1964). Mathematical Methods in Reliability Engineering. New York: McGraw-Hill.

Sarhan, A. E. and Greenberg, B. G. (1962). Contributions to Order Statistics. New York: Wiley.

Schatz, R., Shooman M. L., and Shaw, L. (January 1974). Application of time dependent stress-strength models of non-electrical and electrical systems. Proceedings of the Reliability and Maintainability Symposium, IEEE, New York, pp. 540-547.

Schupbach, M. and Husler, J. (1983). Simple estimators for the parameters of the extreme-value distribution based on censored data. Technometrics, 25, 189-192.

Shah, H. C. (1966). Use of maximum entropy in estimating the damage distribution of a single degree of freedom system subjected to random loading. 1966 Annals of Reliability and Maintainability Conference, IEEE, New York, pp. 598-604.

Shah, H. C., and Tang, W. H. (1970). Statistical evaluation of load factors in structural design. 1970 Annals of Reliability and Maintainability Conference, IEEE, New York, pp. 650-658.

Shaw, L., Shooman, M. and Schatz, R. (1973). Time-dependent stress-strength models for non-electrical and electronic systems. 1973 Annual Reliability and Maintainability Symposium, IEEE, New York, pp. 186-197.

Shinozuka, M., and Hanai, M. (1967). Structural reliability of a simple rigid frame. 1967 Annals of Reliability and Maintainability Conference, IEEE, New York, pp. 63-67.

Shinozuka, M., and Itagaki, H. (1966). On the reliability of redundant structures. 1966 Annals of Reliability and Maintainability Conference, IEEE, New York, pp. 605-610.

Shooman, M. L. (1968). Probabilistic Reliability: An Engineering Approach. New York: McGraw-Hill.

Singpurwalla, N. D. Statistical fatigue models: A survey, IEEE Trans. Reliab., R-20, 1971, pp. 185-189.

Spoormaker, J. L. (1977). Reliability prediction of hairpin type springs. 1977 Annual Reliability and Maintainability Symposium. IEEE, New York, pp. 142-147.

Spoormaker, J. L. (1975). Design of reliable plastic assemblies. 1975 Annual Reliability and Maintainability Symposium, IEEE, New York, pp. 498-503.

Stephens, M. A. (1974). EDF statistics for goodness of fit and some comparisons. J. Amer. Statist. Assoc., 69, 730-737.

Stephens, M. A. (1977). Goodness of fit for the extreme value distribution. Biometrika, 64, 583-588.

Stiles, E. M. (1964). Reliability in mass-produced consumer products. National Symposium on Reliability, IEEE, New York, pp. 85-96.

Tallian, T.E. (July 1982). A unified model for rolling contact life prediction. Journal of lubrication technology, Vol. 104, pp. 336-346.

Taraman, S. I., and Kapur, K. C. (1975). Optimization considerations in design reliability by stress-strength interference theory. IEEE Trans. Reliability, 24, pp. 136-138.

Thomas, J. M., Hanagnd, S. and Hawk, J. D. (1975). Decision theory in structural reliability. 1975 Annual Reliability and Maintainability Symposium, IEEE, New York, pp. 255-262.

Thoman, D. R., Bain, L. J. and Antle, C. E. (1969). Inferences on the parameters of the Weibull distribution. Technometrics, 11, 445-460.

Thoman, D. R., Bain, L. J. and Antle, C. E. (1970). Reliability and tolerance limits in the Weibull distribution. Technometrics, 12, 363-371.

Tumolillo, T. A. (1974). Methods for calculating the reliability function for systems subjected to random stresses. IEEE Trans. Reliability, 23, pp. 256-262.

Weaver, L., and Scarlett, T. (1965). Reliability and failure distributions of inertial sensors. National Symposium on Reliability and Quality Control, IEEE, New York, p. 144-153.

Weibull, W. (1951). A statistical distribution function of wide applicability. J. Appl. Mech., 18, pp. 293-297.

Welker, D. R., and Buchanan, H. N. (1975). Safety-availability study methods applied to BART. 1975 Annual Reliability and Maintainability Symposium, IEEE, New York, pp. 269-275.

Whittemore, A., Altschuler, B. (1976). Lung cancer incidence in cigarette smokers: further analysis of Doll and Hill's data for British physicians. Biometrics, 32, 805-816.

Wilson, D. S., and Smith, R. (1977). Electric motor reliability model. Rome Air Development Center, RADC-TR-77-408 dated Dec 77, AD 050179, NTIS.

Yadav, R. P. S. (1973). A reliability model for stress vs strength problem. Microelectron. Reliability, 12, pp. 119-123.

Yadav, R. P. S. (1974). Component reliability under environmental stress. Microelectron. Reliability, 13, pp. 473-475.

Yao, J. T. P., and Yeh, H. Y. (1967). Safety analysis of statically indeterminate trusses. 1967 Annals of Reliability and Maintainability Conference, IEEE, New York, pp. 54-62.

Zaretsky, E. V. (1971). Life adjustment factors for ball and roller bearings. American Society of Mechanical Engineers.

# APPENDIX II

# STATISTICAL TABLES

TABLE I. MEDIAN RANKS

sample size = n

failure rank = j

| j | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .5000 | .2929 | .2063 | .1591 | .1294 | .1091 | .0943 | .0830 | .0741 | .0670 |
| 2 | | .7071 | .5000 | .3864 | .3147 | .2655 | .2295 | .2021 | .1806 | .1632 |
| 3 | | | .7937 | .6136 | .5000 | .4218 | .3648 | .3213 | .2871 | .2594 |
| 4 | | | | .8409 | .6853 | .5782 | .5000 | .4404 | .3935 | .3557 |
| 5 | | | | | .8706 | .7345 | .6352 | .5596 | .5000 | .4519 |
| 6 | | | | | | .8909 | .7705 | .6787 | .6065 | .5481 |
| 7 | | | | | | | .9057 | .7979 | .7129 | .6443 |
| 8 | | | | | | | | .9170 | .8194 | .7406 |
| 9 | | | | | | | | | .9259 | .8368 |
| 10 | | | | | | | | | | .9330 |

sample size = n
failure size = j

| j | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .0611 | .0561 | .0519 | .0483 | .0452 | .0424 | .0400 | .0378 | .0358 | .0341 |
| 2 | .1489 | .1368 | .1266 | .1788 | .1101 | .1034 | .0975 | .0922 | .0874 | .0831 |
| 3 | .2366 | .2175 | .2013 | .1873 | .1751 | .1644 | .1550 | .1465 | .1390 | .1322 |
| 4 | .3244 | .2982 | .2760 | .2568 | .2401 | .2254 | .2125 | .2009 | .1905 | .1812 |
| 5 | .4122 | .3789 | .3506 | .3263 | .3051 | .2865 | .2700 | .2553 | .2421 | .2302 |
| 6 | .5000 | .4596 | .4253 | .3958 | .3700 | .3475 | .3275 | .3097 | .2937 | .2793 |
| 7 | .5878 | .5404 | .5000 | .4653 | .4350 | .4085 | .3850 | .3641 | .3453 | .3283 |
| 8 | .6756 | .6211 | .5747 | .5347 | .5000 | .4695 | .4425 | .4184 | .3968 | .3774 |
| 9 | .7634 | .7018 | .6494 | .6042 | .5650 | .5305 | .5000 | .4728 | .4484 | .4264 |
| 10 | .8511 | .7825 | .7240 | .6737 | .6300 | .5915 | .5575 | .5272 | .5000 | .4755 |
| 11 | .9389 | .8632 | .7987 | .7432 | .6949 | .6525 | .6150 | .5816 | .5516 | .5245 |
| 12 | | .9439 | .8734 | .8127 | .7599 | .7135 | .6725 | .6359 | .6032 | .5736 |
| 13 | | | .9481 | .8822 | .8249 | .7746 | .7300 | .6903 | .6547 | .6226 |
| 14 | | | | .9517 | .8899 | .8356 | .7875 | .7447 | .7063 | .6717 |
| 15 | | | | | .9548 | .8966 | .8450 | .7991 | .7579 | .7207 |
| 16 | | | | | | .9576 | .9025 | .8535 | .8095 | .7698 |
| 17 | | | | | | | .9600 | .9078 | .8610 | .8188 |
| 18 | | | | | | | | .9622 | .9126 | .8678 |
| 19 | | | | | | | | | .9642 | .9169 |
| 20 | | | | | | | | | | .9659 |

## TABLE II. TABLE of 5% RANKS

sample size = n

| j | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .0500 | .0253 | .0170 | .0127 | .0102 | .0085 | .0074 | .0065 | .0057 | .0051 |
| 2 | | .2236 | .1354 | .0976 | .0764 | .0629 | .0534 | .0468 | .0410 | .0368 |
| 3 | | | .3684 | .2486 | .1893 | .1532 | .1287 | .1111 | .0978 | .0873 |
| 4 | | | | .4729 | .3426 | .2713 | .2253 | .1929 | .1688 | .1500 |
| 5 | | | | | .5493 | .4182 | .3413 | .2892 | .2514 | .2224 |
| 6 | | | | | | .6070 | .4793 | .4003 | .3449 | .3035 |
| 7 | | | | | | | .6518 | .5293 | .4504 | .3934 |
| 8 | | | | | | | | .6877 | .5709 | .4931 |
| 9 | | | | | | | | | .7169 | .6058 |
| 10 | | | | | | | | | | .7411 |

sample size = n

| j | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .0047 | .0043 | .0040 | .0037 | .0034 | .0032 | .0030 | .0029 | .0028 | .0026 |
| 2 | .0333 | .0307 | .0281 | .0263 | .0245 | .0227 | .0216 | .0205 | .0194 | .0183 |
| 3 | .0800 | .0719 | .0665 | .0611 | .0574 | .0536 | .0499 | .0476 | .0452 | .0429 |
| 4 | .1363 | .1245 | .1127 | .1047 | .0967 | .0910 | .0854 | .0797 | .0761 | .0725 |
| 5 | .2007 | .1824 | .1671 | .1527 | .1424 | .1321 | .1247 | .1173 | .1099 | .1051 |
| 6 | .2713 | .2465 | .2255 | .2082 | .1909 | .1786 | .1664 | .1575 | .1485 | .1396 |
| 7 | .3498 | .3152 | .2883 | .2652 | .2459 | .2267 | .2128 | .1990 | .1887 | .1785 |
| 8 | .4356 | .3909 | .3548 | .3263 | .3016 | .2805 | .2601 | .2449 | .2298 | .2183 |
| 9 | .5299 | .4727 | .4274 | .3904 | .3608 | .3350 | .3131 | .2912 | .2749 | .2586 |
| 10 | .6356 | .5619 | .5054 | .4600 | .4226 | .3922 | .3542 | .3429 | .3201 | .3029 |
| 11 | .7616 | .6613 | .5899 | .5343 | .4893 | .4517 | .4208 | .3927 | .3703 | .3469 |
| 12 | | .7791 | .6837 | .6416 | .5602 | .5156 | .4781 | .4460 | .4196 | .3957 |
| 13 | | | .7942 | .7033 | .6366 | .5834 | .5395 | .5022 | .4711 | .4434 |
| 14 | | | | .8074 | .7206 | .6562 | .6044 | .5611 | .5242 | .4932 |
| 15 | | | | | .8190 | .7360 | .6738 | .6233 | .5809 | .5444 |
| 16 | | | | | | .8274 | .7475 | .6871 | .6379 | .5964 |
| 17 | | | | | | | .8358 | .7589 | .7005 | .6525 |
| 18 | | | | | | | | .8441 | .7704 | .7138 |
| 19 | | | | | | | | | .8525 | .7818 |
| 20 | | | | | | | | | | .8609 |

## TABLE III. TABLE OF 95% RANKS

sample size = n

| j | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .9500 | .7764 | .6316 | .5271 | .4507 | .3930 | .3482 | .3123 | .2831 | .2589 |
| 2 | | .9747 | .8646 | .7514 | .6574 | .5818 | .5207 | .4707 | .4291 | .3942 |
| 3 | | | .9830 | .9024 | .8107 | .7287 | .6587 | .5997 | .5496 | .5069 |
| 4 | | | | .9873 | .9236 | .8468 | .7747 | .7108 | .6551 | .6056 |
| 5 | | | | | .9898 | .9371 | .8713 | .8071 | .7486 | .6965 |
| 6 | | | | | | .9915 | .9466 | .8889 | .8312 | .7776 |
| 7 | | | | | | | .9926 | .9532 | .9032 | .8500 |
| 8 | | | | | | | | .9935 | .9590 | .9127 |
| 9 | | | | | | | | | .9943 | .9632 |
| 10 | | | | | | | | | | .9949 |

sample size = n

| j | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .2384 | .2209 | .2058 | .1926 | .1810 | .1726 | .1642 | .1559 | .1475 | .1391 |
| 2 | .3644 | .3387 | .3163 | .2967 | .2794 | .2640 | .2525 | .2411 | .2296 | .2182 |
| 3 | .4701 | .4381 | .4101 | .3854 | .3634 | .3438 | .3262 | .3129 | .2995 | .2862 |
| 4 | .5644 | .5273 | .4946 | .4657 | .4398 | .4166 | .3956 | .3767 | .3621 | .3475 |
| 5 | .6502 | .6091 | .5726 | .5400 | .5107 | .4844 | .4605 | .4389 | .4191 | .4036 |
| 6 | .7287 | .6848 | .6452 | .6096 | .5774 | .5483 | .5219 | .4978 | .4758 | .4556 |
| 7 | .7993 | .7535 | .7117 | .6737 | .6392 | .6078 | .5792 | .5540 | .5289 | .5068 |
| 8 | .8637 | .8176 | .7745 | .7348 | .6984 | .6650 | .6458 | .6063 | .5804 | .5566 |
| 9 | .9200 | .8755 | .8329 | .7918 | .7541 | .7195 | .6869 | .6571 | .6297 | .6043 |
| 10 | .9667 | .9281 | .8873 | .8473 | .8091 | .7733 | .7399 | .7088 | .6799 | .6531 |
| 11 | .9953 | .9693 | .9335 | .8953 | .8576 | .8214 | .7872 | .7551 | .7251 | .6971 |
| 12 | | .9957 | .9719 | .9389 | .9033 | .8679 | .8336 | .8010 | .7702 | .7413 |
| 13 | | | .9960 | .9737 | .9426 | .9090 | .8753 | .8425 | .8113 | .7818 |
| 14 | | | | .9963 | .9755 | .9464 | .9146 | .8827 | .8525 | .8215 |
| 15 | | | | | .9966 | .9773 | .9501 | .9203 | .8901 | .8604 |
| 16 | | | | | | .9968 | .9784 | .9534 | .9239 | .8949 |
| 17 | | | | | | | .9970 | .9795 | .9548 | .9275 |
| 18 | | | | | | | | .9971 | .9806 | .9571 |
| 19 | | | | | | | | | .9972 | .9817 |
| 20 | | | | | | | | | | .9974 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION

| S/X | .5th | 1st | 2.5th | 5th |
|---|---|---|---|---|
| .01 | .974522 | .976956 | .980542 | .983637 |
| .02 | .949602 | .954342 | .96137 | .967447 |
| .03 | .925235 | .932184 | .942484 | .951434 |
| .04 | .901413 | .91045 | .923886 | .9356 |
| .05 | .87813 | .889146 | .905574 | .919946 |
| .06 | .855381 | .86827 | .887551 | .904476 |
| .07 | .833158 | .847817 | .869815 | .889191 |
| .08 | .811453 | .827785 | .852368 | .874093 |
| .09 | .790261 | .808169 | .835208 | .859184 |
| .1 | .769574 | .788966 | .818334 | .844465 |
| .11 | .749384 | .77017 | .801747 | .829938 |
| .12 | .729683 | .751778 | .785445 | .815604 |
| .13 | .710465 | .733785 | .769428 | .801464 |
| .14 | .69172 | .716186 | .753693 | .787519 |
| .15 | .673442 | .698976 | .73824 | .773769 |
| .16 | .655622 | .68215 | .723067 | .760215 |
| .17 | .638252 | .665703 | .708172 | .746857 |
| .18 | .621324 | .649629 | .693553 | .733697 |
| .19 | .60483 | .6333924 | .679208 | .720732 |
| .2 | .588761 | .618581 | .665135 | .707965 |
| .21 | .57311 | .603596 | .651331 | .695394 |
| .22 | .557868 | .588961 | .637794 | .683019 |
| .23 | .543026 | .574672 | .624522 | .670839 |
| .24 | .528577 | .560723 | .611511 | .658855 |
| .25 | .514512 | .547108 | .598759 | .647065 |
| .26 | .500823 | .533821 | .586263 | .635468 |
| .27 | .487502 | .520856 | .57402 | .624063 |
| .28 | .474541 | .508207 | .562026 | .61285 |
| .29 | .461931 | .495868 | .550279 | .601827 |
| .3 | .449665 | .483834 | .538775 | .590992 |
| .31 | .437735 | .472097 | .527512 | .580345 |
| .32 | .426132 | .460653 | .516484 | .569884 |
| .33 | .414849 | .449495 | .50569 | .559607 |
| .34 | .403879 | .438618 | .495125 | .549513 |
| .35 | .393213 | .428015 | .484787 | .539599 |
| .36 | .382844 | .417681 | .47467 | .529865 |
| .37 | .372764 | .407609 | .464773 | .520308 |
| .38 | .362967 | .397795 | .455091 | .510926 |
| .39 | .353445 | .388232 | .445621 | .501718 |
| .4 | .344191 | .378914 | .436358 | .49268 |
| .41 | .335198 | .369837 | .4273 | .483812 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | .5th | 1st | 2.5th | 5th |
|---|---|---|---|---|
| .42 | .326459 | .360994 | .418442 | .475111 |
| .43 | .317968 | .35238 | .409782 | .466575 |
| .44 | .309717 | .34399 | .401315 | .458201 |
| .45 | .301701 | .335818 | .393037 | .449987 |
| .46 | .293912 | .327858 | .384946 | .441932 |
| .47 | .286346 | .320107 | .377036 | .434032 |
| .48 | .278994 | .312558 | .369306 | .426286 |
| .49 | .271853 | .305208 | .361751 | .418691 |
| .5 | .264915 | .298049 | .354368 | .411244 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| S/$\bar{X}$ | 10th | 20th | 30th | 40th |
|---|---|---|---|---|
| .01 | .987217 | .991569 | .99472 | .997419 |
| .02 | .974502 | .983113 | .989369 | .994747 |
| .03 | .961858 | .9764634 | .983951 | .991983 |
| .04 | .94929 | .966135 | .978468 | .98913 |
| .05 | .936799 | .957621 | .972921 | .986188 |
| .06 | .92439 | .949092 | .967313 | .983159 |
| .07 | .912066 | .940554 | .961647 | .980044 |
| .08 | .899829 | .932009 | .955925 | .976846 |
| .09 | .887682 | .92346 | .95015 | .973566 |
| .1 | .87563 | .914911 | .944325 | .970205 |
| .11 | .863673 | .906364 | .938451 | .966766 |
| .12 | .851815 | .897823 | .932531 | .96325 |
| .13 | .840058 | .889289 | .926569 | .959659 |
| .14 | .828405 | .880768 | .920567 | .955995 |
| .15 | .816858 | .87226 | .914527 | .95226 |
| .16 | .805419 | .86377 | .908451 | .948456 |
| .17 | .794089 | .8553 | .902344 | .944586 |
| .18 | .782872 | .846852 | .896207 | .940651 |
| .19 | .771768 | .83843 | .890042 | .936653 |
| .2 | .760779 | .830035 | .883853 | .932594 |
| .21 | .749907 | .821671 | .877642 | .928478 |
| .22 | .739154 | .81334 | .871412 | .924305 |
| .23 | .728519 | .805044 | .865164 | .920079 |
| .24 | .718006 | .796786 | .858903 | .915801 |
| .25 | .707614 | .788568 | .852629 | .911473 |
| .26 | .697344 | .780391 | .846345 | .907099 |
| .27 | .687198 | .772259 | .840055 | .902679 |
| .28 | .677176 | .764173 | .83376 | .898217 |
| .29 | .667278 | .756135 | .827462 | .893714 |
| .3 | .657506 | .748147 | .821164 | .889173 |
| .31 | .647859 | .740211 | .814868 | .884596 |
| .32 | .638337 | .732328 | .808576 | .879986 |
| .33 | .628942 | .7245 | .80229 | .875343 |
| .34 | .619673 | .716728 | .796013 | .870671 |
| .35 | .61053 | .709015 | .789746 | .865972 |
| .36 | .601512 | .70136 | .783492 | .861247 |
| .37 | .59262 | .693767 | .777251 | .856499 |
| .38 | .583854 | .686235 | .771027 | .851729 |
| .39 | .575213 | .678766 | .76482 | .846941 |
| .4 | .566696 | .671362 | .758633 | .842135 |
| .41 | .558304 | .664022 | .752467 | .837314 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\overline{X}$ | .5th | 1st | 2.5th | 5th |
|---|---|---|---|---|
| .42 | .550034 | .656748 | .746324 | .83248 |
| .43 | .541888 | .649541 | .740205 | .827634 |
| .44 | .533864 | .642401 | .734112 | .822779 |
| .45 | .525961 | .635329 | .728046 | .817916 |
| .46 | .518179 | .628327 | .722009 | .813046 |
| .47 | .510517 | .621393 | .716002 | .808173 |
| .48 | .502973 | .61453 | .710026 | .803296 |
| .49 | .495547 | .607736 | .704083 | .798418 |
| .5 | .488238 | .601014 | .698173 | .793541 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | 60th | 70th | 80th | 90th |
|---|---|---|---|---|
| .01 | 1.00249 | 1.00521 | 1.0084 | 1.01285 |
| .02 | 1.00488 | 1.01034 | 1.01677 | 1.02575 |
| .03 | 1.00717 | 1.0154 | 1.0251 | 1.03872 |
| .04 | 1.00937 | 1.02037 | 1.0334 | 1.05174 |
| .05 | 1.01148 | 1.02527 | 1.4165 | 1.0648 |
| .06 | 1.01348 | 1.03008 | 1.04986 | 1.07791 |
| .07 | 1.01539 | 1.03481 | 1.05802 | 1.09107 |
| .08 | 1.01719 | 1.03945 | 1.06613 | 1.10425 |
| .09 | 1.0189 | 1.04401 | 1.07418 | 1.11748 |
| .1 | 1.0205 | 1.04847 | 1.08218 | 1.13073 |
| .11 | 1.02201 | 1.05285 | 1.09012 | 1.144 |
| .12 | 1.02341 | 1.05713 | 1.09799 | 1.1573 |
| .13 | 1.02472 | 1.06131 | 1.1058 | 1.17061 |
| .14 | 1.02592 | 1.0654 | 1.11355 | 1.18393 |
| .15 | 1.02702 | 1.0694 | 1.12122 | 1.19726 |
| .16 | 1.02803 | 1.0733 | 1.12882 | 1.2106 |
| .17 | 1.02893 | 1.0771 | 1.13634 | 1.22393 |
| .18 | 1.02973 | 1.0808 | 1.14378 | 1.23726 |
| .19 | 1.03043 | 1.08439 | 1.15115 | 1.25058 |
| .2 | 1.03104 | 1.08789 | 1.15843 | 1.26389 |
| .21 | 1.03154 | 1.09129 | 1.16563 | 1.27717 |
| .22 | 1.03195 | 1.09458 | 1.17274 | 1.29044 |
| .23 | 1.03226 | 1.09778 | 1.17976 | 1.30368 |
| .24 | 1.03247 | 1.10087 | 1.18669 | 1.31689 |
| .25 | 1.03259 | 1.10385 | 1.19353 | 1.33007 |
| .26 | 1.03261 | 1.10673 | 1.20027 | 1.34321 |
| .27 | 1.03254 | 1.10951 | 1.20692 | 1.35631 |
| .28 | 1.03238 | 1.11219 | 1.21347 | 1.36936 |
| .29 | 1.03212 | 1.11476 | 1.21992 | 1.38237 |
| .3 | 1.03178 | 1.11723 | 1.22627 | 1.39532 |
| .31 | 1.03135 | 1.1196 | 1.23252 | 1.40822 |
| .32 | 1.03083 | 1.12186 | 1.23867 | 1.42105 |
| .33 | 1.03022 | 1.12402 | 1.24471 | 1.43383 |
| .34 | 1.02953 | 1.12608 | 1.25065 | 1.44653 |
| .35 | 1.02875 | 1.12804 | 1.25649 | 1.45917 |
| .36 | 1.02789 | 1.1299 | 1.26222 | 1.47174 |
| .37 | 1.02695 | 1.13166 | 1.26784 | 1.48423 |
| .38 | 1.02594 | 1.13332 | 1.27335 | 1.49664 |
| .39 | 1.02484 | 1.13488 | 1.27876 | 1.50897 |
| .4 | 1.02367 | 1.13634 | 1.28406 | 1.52122 |
| .41 | 1.02242 | 1.13771 | 1.28925 | 1.53338 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| S/X | 60th | 70th | 80th | 90th |
|---|---|---|---|---|
| .42 | 1.02111 | 1.13898 | 1.29433 | 1.54545 |
| .43 | 1.01972 | 1.14016 | 1.29931 | 1.55743 |
| .44 | 1.01826 | 1.14124 | 1.30417 | 1.56931 |
| .45 | 1.1673 | 1.14224 | 1.30893 | 1.5811 |
| .46 | 1.01514 | 1.14314 | 1.31358 | 1.5928 |
| .47 | 1.01348 | 1.14395 | 1.31811 | 1.60439 |
| .48 | 1.01176 | 1.14467 | 1.32255 | 1.61588 |
| .49 | 1.00998 | 1.1453 | 1.32687 | 1.62726 |
| .5 | 1.00814 | 1.14585 | 1.33108 | 1.63854 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | 95th | 97.5th | 99th | 99.5th |
|---|---|---|---|---|
| .01 | 1.01653 | 1.10974 | 1.02348 | 1.02604 |
| .02 | 1.03323 | 1.03977 | 1.04741 | 1.05265 |
| .03 | 1.0501 | 1.06007 | 1.07178 | 1.07983 |
| .04 | 1.06713 | 1.08066 | 1.0966 | 1.1076 |
| .05 | 1.08431 | 1.10152 | 1.12187 | 1.13594 |
| .06 | 1.10165 | 1.12265 | 1.14758 | 1.16488 |
| .07 | 1.11913 | 1.14406 | 1.17375 | 1.1944 |
| .08 | 1.13677 | 1.16574 | 1.20036 | 1.22452 |
| .09 | 1.15454 | 1.18769 | 1.22742 | 1.25524 |
| .1 | 1.17246 | 1.20989 | 1.25493 | 1.28655 |
| .11 | 1.1905 | 1.23236 | 1.28289 | 1.31848 |
| .12 | 1.20868 | 1.25509 | 1.3113 | 1.351 |
| .13 | 1.22698 | 1.27807 | 1.34015 | 1.38414 |
| .14 | 1.2454 | 1.30129 | 1.36944 | 1.41788 |
| .15 | 1.26394 | 1.32476 | 1.39918 | 1.45223 |
| .16 | 1.28258 | 1.34848 | 1.42936 | 1.4872 |
| .17 | 1.30133 | 1.37242 | 1.45998 | 1.52277 |
| .18 | 1.32019 | 1.3966 | 1.49103 | 1.55895 |
| .19 | 1.33913 | 1.421 | 1.52251 | 1.59575 |
| .2 | 1.35817 | 1.44563 | 1.55442 | 1.63315 |
| .21 | 1.37729 | 1.47047 | 1.58676 | 1.67117 |
| .22 | 1.3965 | 1.49552 | 1.61952 | 1.70978 |
| .23 | 1.41577 | 1.52077 | 1.65269 | 1.74901 |
| .24 | 1.43512 | 1.54623 | 1.68628 | 1.78883 |
| .25 | 1.45453 | 1.57188 | 1.72027 | 1.82926 |
| .26 | 1.474 | 1.59771 | 1.75467 | 1.87028 |
| .27 | 1.49352 | 1.62373 | 1.78946 | 1.91189 |
| .28 | 1.51309 | 1.64992 | 1.82465 | 1.9541 |
| .29 | 1.53271 | 1.67628 | 1.86022 | 1.99688 |
| .3 | 1.55236 | 1.70281 | 1.89617 | 2.04025 |
| .31 | 1.57204 | 1.72949 | 1.93249 | 2.08419 |
| .32 | 1.59175 | 1.75632 | 1.96918 | 2.12871 |
| .33 | 1.61148 | 1.78329 | 2.00624 | 2.17379 |
| .34 | 1.63122 | 1.81041 | 2.04364 | 2.21942 |
| .35 | 1.65098 | 1.83765 | 2.08139 | 2.26561 |
| .36 | 1.67074 | 1.86502 | 2.11946 | 2.31235 |
| .37 | 1.69051 | 1.8925 | 2.15791 | 2.35962 |
| .38 | 1.71027 | 1.9201 | 2.19666 | 2.40743 |
| .39 | 1.73002 | 1.9478 | 2.23572 | 2.45577 |
| .4 | 1.74975 | 1.9756 | 2.2751 | 2.50462 |
| .41 | 1.76947 | 2.00349 | 2.31478 | 2.55398 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| S/$\bar{X}$ | 95th | 97.5th | 99th | 99.5th |
|---|---|---|---|---|
| .42 | 1.78916 | 2.03146 | 2.35475 | 2.60385 |
| .43 | 1.80883 | 2.05952 | 2.395 | 2.6542 |
| .44 | 1.82846 | 2.08764 | 2.43554 | 2.70505 |
| .45 | 1.84805 | 2.11583 | 2.47634 | 2.75637 |
| .46 | 1.86761 | 2.14408 | 2.51741 | 2.80816 |
| .47 | 1.88711 | 2.17238 | 2.55873 | 2.86041 |
| .48 | 1.90657 | 2.20073 | 2.60029 | 2.91311 |
| .49 | 1.92597 | 2.22912 | 2.64209 | 2.96626 |
| .5 | 1.94531 | 2.25754 | 2.68412 | 3.01983 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | .5th | 1st | 2.5th | 5th |
|---|---|---|---|---|
| .5 | .264915 | .298049 | .354368 | .411244 |
| .51 | .258175 | .291079 | .347152 | .403944 |
| .52 | .251628 | .284292 | .340102 | .396788 |
| .53 | .245268 | .277683 | .333213 | .389774 |
| .54 | .239089 | .271248 | .326481 | .382898 |
| .55 | .233086 | .264983 | .319904 | .37616 |
| .56 | .227256 | .258882 | .313478 | .369557 |
| .57 | .221591 | .252942 | .3072 | .363085 |
| .58 | .216088 | .247159 | .301066 | .356743 |
| .59 | .210742 | .241527 | .295074 | .350529 |
| .6 | .205548 | .236044 | .28922 | .34444 |
| .61 | .200502 | .230706 | .283501 | .338474 |
| .62 | .195599 | .225507 | .277914 | .332629 |
| .63 | .190836 | .220445 | .272456 | .326901 |
| .64 | .186207 | .215517 | .267124 | .32129 |
| .65 | .18171 | .210717 | .261916 | .315793 |
| .66 | .17734 | .206043 | .256827 | .310407 |
| .67 | .173093 | .201492 | .251856 | .305131 |
| .68 | .168966 | .19706 | .247 | .299962 |
| .69 | .164956 | .192743 | .242256 | .294898 |
| .7 | .161057 | .188539 | .237621 | .289937 |
| .71 | .157268 | .184444 | .233092 | .285077 |
| .72 | .153585 | .180456 | .228668 | .280316 |
| .73 | .150005 | .176571 | .224346 | .275652 |
| .74 | .146525 | .172787 | .220123 | .271083 |
| .75 | .143141 | .169101 | .215997 | .266606 |
| .76 | .139851 | .16551 | .211963 | .262221 |
| .77 | .136653 | .162011 | .208026 | .257924 |
| .78 | .133542 | .158603 | .204176 | .253715 |
| .79 | .130517 | .155281 | .200414 | .249591 |
| .8 | .127575 | .152045 | .196738 | .245551 |
| .81 | .124713 | .148891 | .193146 | .241593 |
| .82 | .12193 | .145817 | .189634 | .237714 |
| .83 | .119222 | .142821 | .186203 | .233914 |
| .84 | .116588 | .139901 | .182849 | .230191 |
| .85 | .114025 | .137055 | .17957 | .226542 |
| .86 | .111531 | .134281 | .176365 | .222967 |
| .87 | .109104 | .131576 | .173232 | .219464 |
| .88 | .106742 | .128939 | .17017 | .216031 |
| .89 | .104443 | .126368 | .167175 | .212666 |
| .9 | .102205 | .12386 | .164248 | .209369 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| S/$\bar{X}$ | .5th | 1st | 2.5th | 5th |
|---|---|---|---|---|
| .91 | .100027 | .121415 | .161385 | .206138 |
| .92 | .097906 | .11903 | .158586 | .20297 |
| .93 | .095842 | .116705 | .155849 | .199866 |
| .94 | .093831 | .114436 | .153172 | .196823 |
| .95 | .091873 | .112223 | .150554 | .19384 |
| .96 | .089966 | .110063 | .147994 | .190916 |
| .97 | .088108 | .107957 | .145489 | .18805 |
| .98 | .086299 | .105901 | .143039 | .18524 |
| .99 | .08453[illegible] | .103895 | .140642 | .182485 |
| 1. | .082819 | .101938 | .138297 | .179783 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | 10th | 20th | 30th | 40th |
|---|---|---|---|---|
| .5 | .488238 | .601014 | .698173 | .793541 |
| .51 | .481044 | .594362 | .692297 | .788666 |
| .52 | .473965 | .587781 | .686457 | .783794 |
| .53 | .467 | .581272 | .680654 | .778927 |
| .54 | .460146 | .574834 | .674888 | .774066 |
| .55 | .453404 | .568468 | .669161 | .769213 |
| .56 | .446771 | .562174 | .663473 | .764369 |
| .57 | .440247 | .555951 | .657824 | .759535 |
| .58 | .43383 | .5498 | .652217 | .754712 |
| .59 | .427519 | .54372 | .64665 | .749902 |
| .6 | .421313 | .537712 | .641126 | .745106 |
| .61 | .41521 | .531775 | .635644 | .740324 |
| .62 | .409209 | .525908 | .630205 | .735559 |
| .63 | .403308 | .520113 | .624809 | .73081 |
| .64 | .397506 | .514387 | .619457 | .726078 |
| .65 | .391803 | .508732 | .61415 | .721366 |
| .66 | .386196 | .503147 | .608887 | .716673 |
| .67 | .380683 | .497631 | .603669 | .712 |
| .68 | .375265 | .492183 | .598496 | .707348 |
| .69 | .369939 | .486805 | .593368 | .702719 |
| .7 | .364703 | .481494 | .588287 | .698112 |
| .71 | .359557 | .476251 | .583251 | .693528 |
| .72 | .354499 | .471075 | .578261 | .688968 |
| .73 | .349528 | .465965 | .573317 | .684433 |
| .74 | .344642 | .460922 | .568419 | .679923 |
| .75 | .33984 | .455943 | .563567 | .675438 |
| .76 | .33512 | .45103 | .558762 | .670979 |
| .77 | .330482 | .446181 | .554003 | .666548 |
| .78 | .325924 | .441395 | .549289 | .662143 |
| .79 | .321444 | .436673 | .544622 | .657765 |
| .8 | .317041 | .432013 | .540001 | .653416 |
| .81 | .312715 | .427415 | .535426 | .649094 |
| .82 | .308462 | .422877 | .530897 | .644802 |
| .83 | .304284 | .418401 | .526413 | .640537 |
| .84 | .300177 | .413984 | .521975 | .636303 |
| .85 | .296141 | .409626 | .517582 | .632097 |
| .86 | .292174 | .405327 | .513234 | .627921 |
| .87 | .288276 | .401085 | .508931 | .623775 |
| .88 | .284445 | .396901 | .504672 | .619658 |
| .89 | .28068 | .392773 | .500458 | .615572 |
| .9 | .276979 | .388701 | .496289 | .611516 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | 10th | 20th | 30th | 40th |
|---|---|---|---|---|
| .91 | .273342 | .384684 | .492163 | .607491 |
| .92 | .269767 | .380721 | .48808 | .603495 |
| .93 | .266254 | .376812 | .484042 | .599531 |
| .94 | .2628 | .372956 | .480046 | .595597 |
| .95 | .259406 | .369152 | .476093 | .591694 |
| .96 | .256069 | .3654 | .472182 | .587821 |
| .97 | .25279 | .361699 | .468313 | .583979 |
| .98 | .249566 | .358048 | .464487 | .580168 |
| .99 | .246397 | .354447 | .460701 | .576387 |
| 1. | .243282 | .350895 | .456957 | .572638 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | 60th | 70th | 80th | 90th |
|---|---|---|---|---|
| .5 | 1.09814 | 1.14585 | 1.33108 | 1.63854 |
| .51 | 1.00624 | 1.14631 | 1.33519 | 1.64972 |
| .52 | 1.00429 | 1.14669 | 1.33919 | 1.66078 |
| .53 | 1.00228 | 1.14699 | 1.34309 | 1.67174 |
| .54 | 1.00022 | 1.1472 | 1.34688 | 1.68258 |
| .55 | .998103 | 1.14734 | 1.35057 | 1.69331 |
| .56 | .99594 | 1.1474 | 1.35415 | 1.70393 |
| .57 | .993731 | 1.14738 | 1.35763 | 1.71443 |
| .58 | .991475 | 1.14729 | 1.361 | 1.72482 |
| .59 | .989174 | 1.14712 | 1.36428 | 1.73509 |
| .6 | .986831 | 1.14688 | 1.36745 | 1.74524 |
| .61 | .984446 | 1.14657 | 1.37052 | 1.75528 |
| .62 | .982021 | 1.14619 | 1.3735 | 1.7652 |
| .63 | .979557 | 1.14574 | 1.37638 | 1.775 |
| .64 | .977057 | 1.14523 | 1.37916 | 1.78466 |
| .65 | .974522 | 1.14465 | 1.38184 | 1.79424 |
| .66 | .971953 | 1.14401 | 1.38443 | 1.80368 |
| .67 | .969351 | 1.14331 | 1.38693 | 1.813 |
| .68 | .966718 | 1.14254 | 1.38933 | 1.8222 |
| .69 | .964056 | 1.14172 | 1.39165 | 1.83128 |
| .7 | .961365 | 1.14084 | 1.39387 | 1.84024 |
| .71 | .958647 | 1.1399 | 1.39601 | 1.84908 |
| .72 | .955904 | 1.13891 | 1.39805 | 1.8578 |
| .73 | .953136 | 1.13787 | 1.40001 | 1.8664 |
| .74 | .950345 | 1.13677 | 1.40189 | 1.87488 |
| .75 | .947532 | 1.13562 | 1.40368 | 1.88324 |
| .76 | .944699 | 1.13443 | 1.40539 | 1.89148 |
| .77 | .941846 | 1.13318 | 1.40702 | 1.8996 |
| .78 | .938974 | 1.13189 | 1.40857 | 1.90761 |
| .79 | .936086 | 1.13055 | 1.41004 | 1.9155 |
| .8 | .933181 | 1.12917 | 1.41143 | 1.92327 |
| .81 | .930261 | 1.12775 | 1.41274 | 1.93092 |
| .82 | .927328 | 1.12629 | 1.41398 | 1.93846 |
| .83 | .924381 | 1.12478 | 1.41515 | 1.94588 |
| .84 | .921422 | 1.12324 | 1.41625 | 1.95319 |
| .85 | .918452 | 1.12166 | 1.41727 | 1.96039 |
| .86 | .915472 | 1.12004 | 1.41822 | 1.96747 |
| .87 | .912483 | 1.11839 | 1.41911 | 1.97444 |
| .88 | .909485 | 1.11671 | 1.41993 | 1.9813 |
| .89 | .90648 | 1.11499 | 1.42068 | 1.98805 |
| .9 | .903468 | 1.11323 | 1.42136 | 1.99468 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | 60th | 70th | 80th | 90th |
|---|---|---|---|---|
| .91 | .900451 | 1.11145 | 1.42199 | 2.00121 |
| .92 | .897428 | 1.10964 | 1.42255 | 2.00763 |
| .93 | .894401 | 1.1078 | 1.42305 | 2.01395 |
| .94 | .891371 | 1.10593 | 1.42349 | 2.02015 |
| .95 | .888337 | 1.10404 | 1.42387 | 2.02626 |
| .96 | .885302 | 1.10212 | 1.42419 | 2.03226 |
| .97 | .882265 | 1.10017 | 1.42446 | 2.03815 |
| .98 | .879227 | 1.0982 | 1.42467 | 2.04394 |
| .99 | .876189 | 1.09621 | 1.42482 | 2.04964 |
| 1. | .873151 | 1.09419 | 1.42493 | 2.05523 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| S/X̄ | 95th | 97.5th | 99th | 99.5th |
|---|---|---|---|---|
| .5 | 1.94531 | 2.25754 | 2.68412 | 3.01983 |
| .51 | 1.9646 | 2.28599 | 2.72636 | 3.07383 |
| .52 | 1.98381 | 2.31446 | 2.76882 | 3.12824 |
| .53 | 2.00296 | 2.34295 | 2.81148 | 3.18305 |
| .54 | 2.02203 | 2.37145 | 2.85433 | 3.23826 |
| .55 | 2.04103 | 2.39995 | 2.89737 | 3.29385 |
| .56 | 2.05994 | 2.42845 | 2.94059 | 3.34982 |
| .57 | 2.07878 | 2.45694 | 2.98397 | 3.40615 |
| .58 | 2.09752 | 2.48542 | 3.02752 | 3.46284 |
| .59 | 2.11618 | 2.51389 | 3.07122 | 3.51987 |
| .6 | 2.13475 | 2.54233 | 3.11506 | 3.57723 |
| .61 | 2.15322 | 2.57074 | 3.15904 | 3.63492 |
| .62 | 2.17159 | 2.59912 | 3.20315 | 3.69292 |
| .63 | 2.18986 | 2.62747 | 3.24738 | 3.75123 |
| .64 | 2.20803 | 2.65577 | 3.29172 | 3.80983 |
| .65 | 2.2261 | 2.68402 | 3.33616 | 3.86872 |
| .66 | 2.24406 | 2.71222 | 3.3807 | 3.92788 |
| .67 | 2.26191 | 2.74036 | 3.42533 | 3.98731 |
| .68 | 2.27964 | 2.76845 | 3.47005 | 4.04699 |
| .69 | 2.29727 | 2.79647 | 3.51483 | 4.10692 |
| .7 | 2.31478 | 2.82442 | 3.55969 | 4.16708 |
| .71 | 2.33217 | 2.85229 | 3.6046 | 4.22747 |
| .72 | 2.34944 | 2.88009 | 3.64956 | 4.28807 |
| .73 | 2.3666 | 2.90781 | 3.69457 | 4.34889 |
| .74 | 2.38363 | 2.93545 | 3.73962 | 4.40989 |
| .75 | 2.40054 | 2.963 | 3.78471 | 4.47109 |
| .76 | 2.41733 | 2.99046 | 3.82981 | 4.53247 |
| .77 | 2.43399 | 3.01782 | 3.87494 | 4.59401 |
| .78 | 2.45052 | 3.04509 | 3.92008 | 4.65572 |
| .79 | 2.46693 | 3.07226 | 3.96522 | 4.71758 |
| .8 | 2.48321 | 3.09932 | 4.01036 | 4.77958 |
| .81 | 2.49936 | 3.12628 | 4.0555 | 4.84172 |
| .82 | 2.51538 | 3.15313 | 4.10063 | 4.90398 |
| .83 | 2.53127 | 3.17987 | 4.14574 | 4.96636 |
| .84 | 2.54703 | 3.20649 | 4.19082 | 5.02885 |
| .85 | 2.56266 | 3.233 | 4.23588 | 5.09144 |
| .86 | 2.57815 | 3.25939 | 4.2809 | 5.15412 |
| .87 | 2.59351 | 3.28566 | 4.32588 | 5.21689 |
| .88 | 2.60874 | 3.31181 | 4.37082 | 5.27973 |
| .89 | 2.62384 | 3.33783 | 4.41571 | 5.34265 |
| .9 | 2.63881 | 3.36372 | 4.46054 | 5.40562 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | 95th | 97.5th | 99th | 99.5th |
|---|---|---|---|---|
| .91 | 2.65364 | 3.38949 | 4.50532 | 5.46865 |
| .92 | 2.66834 | 3.41513 | 4.55003 | 5.53173 |
| .93 | 2.6829 | 3.44064 | 4.59468 | 5.59485 |
| .94 | 2.69733 | 3.46601 | 4.63925 | 5.658 |
| .95 | 2.71163 | 3.49125 | 4.68374 | 5.72118 |
| .96 | 2.72579 | 3.51636 | 4.72816 | 5.78438 |
| .97 | 2.73982 | 3.54132 | 4.77248 | 5.84759 |
| .98 | 2.75372 | 3.56615 | 4.81672 | 5.9108 |
| .99 | 2.76749 | 3.59084 | 4.86087 | 5.97402 |
| 1. | 2.78112 | 3.61539 | 4.90493 | 6.03723 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\overline{X}$ | .5th | 1st | 2.5th | 5th |
|---|---|---|---|---|
| 1. | .082819 | .101938 | .138297 | .179783 |
| 1.01 | .081145 | .100027 | .136003 | .177134 |
| 1.02 | .079515 | .098162 | .133758 | .174537 |
| 1.03 | .077925 | .096342 | .131561 | .17199 |
| 1.04 | .076376 | .094564 | .129412 | .169492 |
| 1.05 | .074866 | .092829 | .127308 | .167043 |
| 1.06 | .073393 | .091135 | .125249 | .16464 |
| 1.07 | .071958 | .08948 | .123233 | .162283 |
| 1.08 | .070558 | .087864 | .12126 | .159972 |
| 1.09 | .069193 | .086286 | .119329 | .157704 |
| 1.1 | .067862 | .084744 | .117438 | .15548 |
| 1.11 | .066563 | .083238 | .115586 | .153297 |
| 1.12 | .065296 | .081767 | .113773 | .151156 |
| 1.13 | .06406 | .080329 | .111998 | .149055 |
| 1.14 | .062855 | .078924 | .110259 | .146993 |
| 1.15 | .061678 | .077551 | .108556 | .14497 |
| 1.16 | .06053 | .076209 | .106889 | .142985 |
| 1.17 | .059409 | .074898 | .105255 | .141036 |
| 1.18 | .058315 | .073616 | .103654 | .139124 |
| 1.19 | .057247 | .072363 | .102086 | .137247 |
| 1.2 | .056204 | .071137 | .10055 | .135404 |
| 1.21 | .055186 | .069939 | .099045 | .133595 |
| 1.22 | .054192 | .068768 | .097569 | .131819 |
| 1.23 | .053221 | .067622 | .096124 | .130076 |
| 1.24 | .052272 | .066501 | .094707 | .128364 |
| 1.25 | .051346 | .065405 | .093318 | .126683 |
| 1.26 | .050441 | .064332 | .091957 | .125032 |
| 1.27 | .049557 | .063283 | .090622 | .123411 |
| 1.28 | .048693 | .062257 | .089314 | .121818 |
| 1.29 | .047849 | .061252 | .088031 | .120255 |
| 1.3 | .047024 | .060269 | .086773 | .118718 |
| 1.31 | .046217 | .059307 | .085539 | .11721 |
| 1.32 | .045429 | .058366 | .08433 | .115727 |
| 1.33 | .044658 | .057444 | .083143 | .114271 |
| 1.34 | .043905 | .056542 | .08198 | .11284 |
| 1.35 | .043168 | .055658 | .080838 | .111434 |
| 1.36 | .042447 | .054793 | .079718 | .110053 |
| 1.37 | .041743 | .053946 | .07862 | .108695 |
| 1.38 | .041053 | .053116 | .077542 | .107361 |
| 1.39 | .040379 | .052304 | .076484 | .106049 |
| 1.4 | .03972 | .051508 | .075446 | .10476 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | .5th | 1st | 2.5th | 5th |
|---|---|---|---|---|
| 1.41 | .039074 | .050728 | .074427 | .103493 |
| 1.42 | .038443 | .049965 | .073428 | .102248 |
| 1.43 | .037825 | .049216 | .072446 | .101024 |
| 1.44 | .03722 | .048483 | .071483 | .09982 |
| 1.45 | .036628 | .047764 | .070537 | .098636 |
| 1.46 | .036049 | .04706 | .069609 | .097472 |
| 1.47 | .035482 | .04637 | .068698 | .096328 |
| 1.48 | .034926 | .045694 | .067803 | .095203 |
| 1.49 | .034383 | .04503 | .066924 | .094096 |
| 1.5 | .03385 | .04438 | .066061 | .093007 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | 10th | 20th | 30th | 40th |
|---|---|---|---|---|
| 1. | .243282 | .350895 | .456957 | .572638 |
| 1.01 | .240219 | .34739 | .453253 | .568918 |
| 1.02 | .237208 | .343934 | .44959 | .56523 |
| 1.03 | .234248 | .340525 | .445967 | .561572 |
| 1.04 | .231338 | .337161 | .442383 | .557944 |
| 1.05 | .228476 | .333844 | .438839 | .554347 |
| 1.06 | .225663 | .330571 | .435334 | .55078 |
| 1.07 | .222896 | .327343 | .431867 | .547243 |
| 1.08 | .220176 | .324158 | .428438 | .543737 |
| 1.09 | .217501 | .321017 | .425047 | .54026 |
| 1.1 | .21487 | .317918 | .421694 | .536813 |
| 1.11 | .212283 | .314861 | .418377 | .533396 |
| 1.12 | .209739 | .311845 | .415097 | .530008 |
| 1.13 | .207237 | .30887 | .411854 | .52665 |
| 1.14 | .204776 | .305935 | .408646 | .52332 |
| 1.15 | .202355 | .303039 | .405474 | .52002 |
| 1.16 | .199974 | .300182 | .402336 | .516749 |
| 1.17 | .197632 | .297363 | .399234 | .513507 |
| 1.18 | .195327 | .294582 | .396166 | .510293 |
| 1.19 | .193061 | .291839 | .393131 | .507107 |
| 1.2 | .19083 | .289131 | .390131 | .50395 |
| 1.21 | 1.88636 | .28646 | .387163 | .500821 |
| 1.22 | .186478 | .283825 | .384229 | .497719 |
| 1.23 | .184353 | .281224 | .381326 | .494645 |
| 1.24 | .1842263 | .278658 | .378456 | .491599 |
| 1.25 | .180206 | .276125 | .375618 | .48858 |
| 1.26 | .178182 | .273626 | .37281 | .485587 |
| 1.27 | .17619 | .27116 | .370034 | .482622 |
| 1.28 | .174229 | .268726 | .367288 | .479683 |
| 1.29 | .1723 | .266325 | .364573 | .47677 |
| 1.3 | .1704 | .263954 | .361887 | .473884 |
| 1.31 | .168531 | .261615 | .359231 | .471023 |
| 1.32 | .16669 | .259306 | .356604 | .468188 |
| 1.33 | .164879 | .257027 | .354006 | .465379 |
| 1.34 | .163095 | .254777 | .351436 | .462595 |
| 1.35 | .161339 | .252557 | .348894 | .459836 |
| 1.36 | .15961 | .250365 | .34638 | .457102 |
| 1.37 | .157907 | .248201 | .343893 | .454393 |
| 1.38 | .15623 | .246065 | .341434 | .451708 |
| 1.39 | .15458 | .243957 | .339001 | .449047 |
| 1.4 | .152954 | .241875 | .336595 | .44641 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | 10th | 20th | 30th | 40th |
|---|---|---|---|---|
| 1.41 | .151353 | .23982 | .334214 | .443797 |
| 1.42 | .149776 | .237791 | .331859 | .441208 |
| 1.43 | .148222 | .235788 | .32953 | .438642 |
| 1.44 | .146692 | .23381 | .327226 | .436098 |
| 1.45 | .145185 | .231857 | .324946 | .433578 |
| 1.46 | .143701 | .229929 | .322691 | .431081 |
| 1.47 | .142238 | .228024 | .320461 | .428606 |
| 1.48 | .140797 | .226144 | .318254 | .426153 |
| 1.49 | .139377 | .224286 | .31607 | .423722 |
| 1.5 | .137979 | .222452 | .31391 | .421313 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | 60th | 70th | 80th | 90th |
|---|---|---|---|---|
| 1. | .873151 | 1.09419 | 1.42493 | 2.05523 |
| 1.01 | .870115 | 1.09216 | 1.42498 | 2.06072 |
| 1.02 | .86708 | 1.0901 | 1.42498 | 2.06611 |
| 1.03 | .864046 | 1.08803 | 1.42493 | 2.07141 |
| 1.04 | .861016 | 1.08593 | 1.42483 | 2.07661 |
| 1.05 | .857989 | 1.08382 | 1.42469 | 2.08172 |
| 1.06 | .854965 | 1.08169 | 1.4245 | 2.08673 |
| 1.07 | .851946 | 1.07955 | 1.42426 | 2.09165 |
| 1.08 | .84893 | 1.07739 | 1.42398 | 2.09648 |
| 1.09 | .84592 | 1.07521 | 1.42365 | 2.10122 |
| 1.1 | .842916 | 1.07303 | 1.42328 | 2.10586 |
| 1.11 | .839917 | 1.07082 | 1.42288 | 2.11042 |
| 1.12 | .836924 | 1.06861 | 1.42243 | 2.11489 |
| 1.13 | .833938 | 1.06638 | 1.42194 | 2.11928 |
| 1.14 | .830959 | 1.06414 | 1.42141 | 2.12358 |
| 1.15 | .827987 | 1.06189 | 1.42084 | 2.12779 |
| 1.16 | .825022 | 1.05963 | 1.42024 | 2.13192 |
| 1.17 | .822065 | 1.05737 | 1.4196 | 2.13597 |
| 1.18 | .819117 | 1.05509 | 1.41892 | 2.13994 |
| 1.19 | .816177 | 1.0528 | 1.41821 | 2.14383 |
| 1.2 | .813246 | 1.05051 | 1.41747 | 2.14764 |
| 1.21 | .810324 | 1.04821 | 1.4167 | 2.15137 |
| 1.22 | .807411 | 1.0459 | 1.41589 | 2.15502 |
| 1.23 | .804508 | 1.04358 | 1.41505 | 2.1586 |
| 1.24 | .801614 | 1.04126 | 1.41418 | 2.1621 |
| 1.25 | .79873 | 1.03894 | 1.41328 | 2.16553 |
| 1.26 | .795857 | 1.03661 | 1.41236 | 2.16889 |
| 1.27 | .792994 | 1.03427 | 1.4114 | 2.17217 |
| 1.28 | .790141 | 1.03193 | 1.41042 | 2.17539 |
| 1.29 | .787299 | 1.02959 | 1.40941 | 2.17853 |
| 1.3 | .784468 | 1.02724 | 1.40838 | 2.1816 |
| 1.31 | .781648 | 1.0249 | 1.40731 | 2.18461 |
| 1.32 | .778839 | 1.02254 | 1.40623 | 2.18755 |
| 1.33 | .776042 | 1.02019 | 1.40512 | 2.19042 |
| 1.34 | .773255 | 1.01784 | 1.40399 | 2.19323 |
| 1.35 | .770481 | 1.01548 | 1.40283 | 2.19597 |
| 1.36 | .767718 | 1.01312 | 1.40166 | 2.19865 |
| 1.37 | .764967 | 1.01077 | 1.40046 | 2.20127 |
| 1.38 | .762228 | 1.00841 | 1.39924 | 2.20382 |
| 1.39 | .759501 | 1.00605 | 1.398 | 2.20632 |
| 1.4 | .756786 | 1.00369 | 1.39674 | 2.20875 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\overline{X}$ | 60th | 70th | 80th | 90th |
|---|---|---|---|---|
| 1.41 | .754083 | 1.00134 | 1.39546 | 2.21113 |
| 1.42 | .751393 | .998978 | 1.39416 | 2.21344 |
| 1.43 | .748715 | .996623 | 1.39285 | 2.2157 |
| 1.44 | .746049 | .99427 | 1.39152 | 2.21791 |
| 1.45 | .743396 | .991917 | 1.39017 | 2.22006 |
| 1.46 | .740755 | .989567 | 1.3888 | 2.22215 |
| 1.47 | .738126 | .987219 | 1.38742 | 2.22419 |
| 1.48 | .735511 | .984874 | 1.38602 | 2.22618 |
| 1.49 | .732907 | .982531 | 1.38461 | 2.22811 |
| 1.5 | .730317 | .98019 | 1.38318 | 2.22999 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | 95th | 97.5th | 99th | 99.5th |
|---|---|---|---|---|
| 1. | 2.78112 | 3.61539 | 4.90493 | 6.03723 |
| 1.01 | 2.79462 | 3.6398 | 4.94888 | 6.10043 |
| 1.02 | 2.80799 | 3.66407 | 4.99273 | 6.16361 |
| 1.03 | 2.82123 | 3.68819 | 5.03647 | 6.22677 |
| 1.04 | 2.83434 | 3.71217 | 5.0801 | 6.2899 |
| 1.05 | 2.84731 | 3.736 | 5.12363 | 6.35299 |
| 1.06 | 2.86016 | 3.75969 | 5.16703 | 6.41605 |
| 1.07 | 2.87288 | 3.78324 | 5.21032 | 6.47906 |
| 1.08 | 2.88547 | 3.80664 | 5.25348 | 6.54201 |
| 1.09 | 2.89793 | 3.82989 | 5.29653 | 6.60492 |
| 1.1 | 2.91027 | 3.85299 | 5.33944 | 6.66776 |
| 1.11 | 2.92247 | 3.87595 | 5.38223 | 6.73053 |
| 1.12 | 2.93456 | 3.89876 | 5.42489 | 6.79324 |
| 1.13 | 2.94651 | 3.92143 | 5.46741 | 6.85587 |
| 1.14 | 2.95834 | 3.94394 | 5.50979 | 6.91843 |
| 1.15 | 2.97005 | 3.96631 | 5.55204 | 6.9809 |
| 1.16 | 2.98163 | 3.98853 | 5.59415 | 7.03428 |
| 1.17 | 2.9931 | 4.0106 | 5.63612 | 7.10558 |
| 1.18 | 3.00443 | 4.03252 | 5.67794 | 7.16778 |
| 1.19 | 3.01565 | 4.0543 | 5.71962 | 7.22988 |
| 1.2 | 3.02675 | 4.07593 | 5.76115 | 7.29187 |
| 1.21 | 3.03773 | 4.09741 | 5.80253 | 7.35376 |
| 1.22 | 3.04859 | 4.11874 | 5.84376 | 7.41554 |
| 1.23 | 3.05934 | 4.13992 | 5.88484 | 7.47721 |
| 1.24 | 3.06996 | 4.16096 | 5.92577 | 7.53876 |
| 1.25 | 3.08047 | 4.18185 | 5.96654 | 7.6002 |
| 1.26 | 3.09087 | 4.20259 | 6.00716 | 7.66151 |
| 1.27 | 3.10115 | 4.22319 | 6.04762 | 7.72269 |
| 1.28 | 3.11132 | 4.24364 | 6.08792 | 7.78375 |
| 1.29 | 3.12138 | 4.26395 | 6.12806 | 7.84467 |
| 1.3 | 3.13132 | 4.28411 | 6.16805 | 7.90546 |
| 1.31 | 3.14116 | 4.30413 | 6.20787 | 7.96612 |
| 1.32 | 3.15088 | 4.324 | 6.24753 | 8.02663 |
| 1.33 | 3.1605 | 4.34373 | 6.28702 | 8.08701 |
| 1.34 | 3.17001 | 4.36331 | 6.32636 | 8.14724 |
| 1.35 | 3.17941 | 4.38276 | 6.36552 | 8.20732 |
| 1.36 | 3.1887 | 4.40206 | 6.40453 | 8.26725 |
| 1.37 | 3.19789 | 4.42122 | 6.44337 | 8.32704 |
| 1.38 | 3.20698 | 4.44023 | 6.48204 | 8.38667 |
| 1.39 | 3.21596 | 4.45911 | 6.52054 | 8.44615 |
| 1.4 | 3.22485 | 4.47785 | 6.55888 | 8.50547 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | 95th | 97.5th | 99th | 99.5th |
|---|---|---|---|---|
| 1.41 | 3.23363 | 4.49645 | 6.59705 | 8.56464 |
| 1.42 | 3.24231 | 4.51491 | 6.63506 | 8.62364 |
| 1.43 | 3.25089 | 4.53323 | 6.67289 | 8.68248 |
| 1.44 | 3.25937 | 4.55142 | 6.71056 | 8.74116 |
| 1.45 | 3.26775 | 4.56947 | 6.74806 | 8.79968 |
| 1.46 | 3.27604 | 4.58738 | 6.78539 | 8.85802 |
| 1.47 | 3.28423 | 4.60516 | 6.82255 | 8.9162 |
| 1.48 | 3.29233 | 4.6228 | 6.85954 | 8.97422 |
| 1.49 | 3.30034 | 4.64032 | 6.89636 | 9.03206 |
| 1.5 | 3.30825 | 4.65769 | 6.93302 | 9.08973 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\overline{X}$ | .5th | 1st | 2.5th | 5th |
|---|---|---|---|---|
| 1.5 | .03385 | .04438 | .066061 | .093007 |
| 1.51 | .033329 | .043743 | .065213 | .091936 |
| 1.52 | .032818 | .043118 | .06438 | .090883 |
| 1.53 | .032318 | .042505 | .063562 | .089847 |
| 1.54 | .031828 | .041904 | .062759 | .088828 |
| 1.55 | .031347 | .041314 | .06197 | .087825 |
| 1.56 | .030877 | .040736 | .061194 | .086838 |
| 1.57 | .030416 | .040169 | .060432 | .085867 |
| 1.58 | .029964 | .039612 | .059684 | .084911 |
| 1.59 | .029522 | .039066 | .058948 | .083971 |
| 1.6 | .029088 | .03853 | .058225 | .083046 |
| 1.61 | .028662 | .038005 | .057514 | .082135 |
| 1.62 | .028246 | .037489 | .056816 | .081238 |
| 1.63 | .027837 | .036982 | .056129 | .080356 |
| 1.64 | .027436 | .036485 | .055454 | .079487 |
| 1.65 | .027043 | .035998 | .05479 | .078632 |
| 1.66 | .026657 | .035519 | .054138 | .07779 |
| 1.67 | .026279 | .035048 | .053496 | .076961 |
| 1.68 | .025909 | .034587 | .052865 | .076145 |
| 1.69 | .025545 | .034134 | .052245 | .075341 |
| 1.7 | .025188 | .033688 | .051635 | .074549 |
| 1.71 | .024838 | .033251 | .051034 | .073769 |
| 1.72 | .024495 | .032822 | .050444 | .073002 |
| 1.73 | .024158 | .0324 | .049863 | .072245 |
| 1.74 | .023827 | .031986 | .049292 | .0715 |
| 1.75 | .023503 | .031579 | .04873 | .070767 |
| 1.76 | .023184 | .031179 | .048177 | .070044 |
| 1.77 | .022871 | .030787 | .047633 | .069331 |
| 1.78 | .022565 | .030401 | .047098 | .06863 |
| 1.79 | .022263 | .030021 | .046571 | .067938 |
| 1.8 | .021967 | .029649 | .046053 | .067257 |
| 1.81 | .021677 | .029282 | .045542 | .066586 |
| 1.82 | .021392 | .028922 | .04504 | .065924 |
| 1.83 | .021112 | .028568 | .044546 | .065272 |
| 1.84 | .020837 | .02822 | .044059 | .064629 |
| 1.85 | .020566 | .027878 | .04358 | .063996 |
| 1.86 | .020301 | .027542 | .043108 | .063372 |
| 1.87 | .02004 | .027212 | .042644 | .062756 |
| 1.88 | .019784 | .026886 | .042187 | .062149 |
| 1.89 | .019532 | .026567 | .041737 | .061551 |
| 1.9 | .019285 | .026252 | .041293 | .060962 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | .5th | 1st | 2.5th | 5th |
|---|---|---|---|---|
| 1.91 | .019042 | .025943 | .040856 | .06038 |
| 1.92 | .018803 | .025639 | .040426 | .059807 |
| 1.93 | .018569 | .02534 | .040003 | .059242 |
| 1.94 | .018338 | .025045 | .039586 | .058684 |
| 1.95 | .018111 | .024756 | .039175 | .058134 |
| 1.96 | .017889 | .024471 | .03877 | .057592 |
| 1.97 | .017669 | .024191 | .038371 | .057057 |
| 1.98 | .017454 | .023915 | .037978 | .05653 |
| 1.99 | .017242 | .023643 | .03759 | .056009 |
| 2. | .017034 | .023376 | .037209 | .055496 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\overline{X}$ | 10th | 20th | 30th | 40th |
|---|---|---|---|---|
| 1.5 | .137979 | .222452 | .31391 | .421313 |
| 1.51 | .1366 | .220641 | .311773 | .418925 |
| 1.52 | .135242 | .218852 | .309658 | .416559 |
| 1.53 | .133903 | .217085 | .307566 | .414214 |
| 1.54 | .132584 | .21534 | .305496 | .41189 |
| 1.55 | .131284 | .213616 | .303448 | .409586 |
| 1.56 | .130003 | .211913 | .301421 | .407304 |
| 1.57 | .12874 | .210231 | .299416 | .405041 |
| 1.58 | .127495 | .20857 | .297431 | .402799 |
| 1.59 | .126267 | .206928 | .295468 | .400576 |
| 1.6 | .125058 | .205307 | .293524 | .398373 |
| 1.61 | .123865 | .203704 | .291601 | .39619 |
| 1.62 | .122689 | .202121 | .289698 | .394026 |
| 1.63 | .121529 | .200557 | .287815 | .391881 |
| 1.64 | .120396 | .199012 | .285951 | .389755 |
| 1.65 | .119259 | .197485 | .284106 | .387648 |
| 1.66 | .118147 | .195976 | .28228 | .385559 |
| 1.67 | .11705 | .194485 | .280473 | .383489 |
| 1.68 | .115969 | .193011 | .278684 | .381437 |
| 1.69 | .114903 | .191555 | .276913 | .379402 |
| 1.7 | .113851 | .190116 | .275161 | .377386 |
| 1.71 | .112813 | .188693 | .273426 | .375387 |
| 1.72 | .11179 | .187287 | .271709 | .373405 |
| 1.73 | .11078 | .185898 | .270009 | .371441 |
| 1.74 | .109784 | .184524 | .268327 | .369493 |
| 1.75 | .108802 | .183167 | .266661 | .367563 |
| 1.76 | .107832 | .181824 | .265012 | .365649 |
| 1.77 | .106876 | .180498 | .263379 | .363752 |
| 1.78 | .105932 | .179186 | .261762 | .361871 |
| 1.79 | .105001 | .177889 | .260162 | .360006 |
| 1.8 | .104081 | .176607 | .258577 | .358157 |
| 1.81 | .103174 | .17534 | .257009 | .356324 |
| 1.82 | .102279 | .174086 | .255455 | .354506 |
| 1.83 | .101396 | .172847 | .253917 | .352704 |
| 1.84 | .100524 | .171622 | .252394 | .350918 |
| 1.85 | .099663 | .17041 | .250886 | .349146 |
| 1.86 | .098814 | .169212 | .249392 | .34739 |
| 1.87 | .097975 | .168027 | .247913 | .345648 |
| 1.88 | .097147 | .166855 | .246448 | .343921 |
| 1.89 | .09633 | .165696 | .244998 | .342208 |
| 1.9 | .095523 | .16455 | .243561 | .34051 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | 10th | 20th | 30th | 40th |
|---|---|---|---|---|
| 1.91 | .094726 | .163416 | .242138 | .338826 |
| 1.92 | .093939 | .162295 | .240729 | .337156 |
| 1.93 | .093163 | .161186 | .239334 | .3355 |
| 1.94 | .092395 | .160089 | .237951 | .333858 |
| 1.95 | .091638 | .159004 | .236582 | .33223 |
| 1.96 | .09089 | .15793 | .235226 | .330614 |
| 1.97 | .090151 | .156868 | .233882 | .329013 |
| 1.98 | .089421 | .155817 | .232551 | .327424 |
| 1.99 | .088701 | .154778 | .231233 | .325849 |
| 2. | .087989 | .153749 | .229927 | .324286 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | 60th | 70th | 80th | 90th |
|---|---|---|---|---|
| 1.5 | .730317 | .98019 | 1.38318 | 2.22999 |
| 1.51 | .727739 | .977853 | 1.38274 | 2.23182 |
| 1.52 | .725174 | .975519 | 1.38028 | 2.23361 |
| 1.53 | .722622 | .973188 | 1.37881 | 2.23534 |
| 1.54 | .720082 | .970861 | 1.37733 | 2.23702 |
| 1.55 | .717556 | .968538 | 1.37584 | 2.23866 |
| 1.56 | .715042 | .966219 | 1.37433 | 2.24025 |
| 1.57 | .71254 | .963904 | 1.37281 | 2.24179 |
| 1.58 | .710052 | .961593 | 1.37128 | 2.24329 |
| 1.59 | .707576 | .959287 | 1.36974 | 2.24474 |
| 1.6 | .705113 | .956985 | 1.36819 | 2.24615 |
| 1.61 | .702663 | .954688 | 1.36663 | 2.24751 |
| 1.62 | .700226 | .952396 | 1.36506 | 2.24883 |
| 1.63 | .697801 | .950108 | 1.36348 | 2.25011 |
| 1.64 | .695389 | .947826 | 1.36189 | 2.25135 |
| 1.65 | .69299 | .94555 | 1.36029 | 2.25255 |
| 1.66 | .690603 | .943278 | 1.35868 | 2.2537 |
| 1.67 | .688229 | .941012 | 1.35706 | 2.25482 |
| 1.68 | .685868 | .938752 | 1.35544 | 2.2559 |
| 1.69 | .683519 | .936497 | 1.35381 | 2.25694 |
| 1.7 | .681183 | .934249 | 1.35217 | 2.25794 |
| 1.71 | .67886 | .932006 | 1.35052 | 2.2589 |
| 1.72 | .676549 | .929769 | 1.34887 | 2.25983 |
| 1.73 | .67425 | .927538 | 1.34721 | 2.26072 |
| 1.74 | .671964 | .925314 | 1.34555 | 2.26158 |
| 1.75 | .66969 | .923095 | 1.34388 | 2.2624 |
| 1.76 | .667429 | .920883 | 1.3422 | 2.26318 |
| 1.77 | .66518 | .918678 | 1.34052 | 2.26394 |
| 1.78 | .662943 | .916478 | 1.33883 | 2.26465 |
| 1.79 | .660719 | .914286 | 1.33714 | 2.26534 |
| 1.8 | .658506 | .9121 | 1.33544 | 2.26599 |
| 1.81 | .656306 | .90992 | 1.33374 | 2.26661 |
| 1.82 | .654118 | .907748 | 1.33203 | 2.26721 |
| 1.83 | .651942 | .905582 | 1.33032 | 2.26776 |
| 1.84 | .649778 | .903423 | 1.32861 | 2.26829 |
| 1.85 | .647626 | .901271 | 1.32689 | 2.26879 |
| 1.86 | .645485 | .899126 | 1.32517 | 2.26926 |
| 1.87 | .643357 | .896987 | 1.32345 | 2.2697 |
| 1.88 | .64124 | .894856 | 1.32172 | 2.27012 |
| 1.89 | .639135 | .892732 | 1.31999 | 2.8705 |
| 1.9 | .637042 | .890615 | 1.31826 | 2.27086 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | 60th | 70th | 80th | 90th |
|---|---|---|---|---|
| 1.91 | .63496 | .888505 | 1.31652 | 2.27119 |
| 1.92 | .63289 | .886402 | 1.31478 | 2.27149 |
| 1.93 | .630832 | .884306 | 1.31304 | 2.27177 |
| 1.94 | .628784 | .882218 | 1.3113 | 2.27202 |
| 1.95 | .626749 | .880137 | 1.30956 | 2.27224 |
| 1.96 | .624724 | .878063 | 1.30781 | 2.27244 |
| 1.97 | .622711 | .875996 | 1.30606 | 2.27262 |
| 1.98 | .620709 | .873936 | 1.30432 | 2.27277 |
| 1.99 | .618718 | .871884 | 1.30257 | 2.2729 |
| 2. | .616738 | .869889 | 1.30081 | 2.273 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| S/$\bar{X}$ | 95th | 97.5th | 99th | 99.5th |
|---|---|---|---|---|
| 1.5 | 3.30825 | 4.65769 | 6.93302 | 9.08973 |
| 1.51 | 3.31607 | 4.67494 | 6.9695 | 9.14723 |
| 1.52 | 3.32379 | 4.69205 | 7.00581 | 9.20455 |
| 1.53 | 3.33143 | 4.70904 | 7.04196 | 9.2617 |
| 1.54 | 3.33898 | 4.72589 | 7.07793 | 9.31867 |
| 1.55 | 3.34644 | 4.74262 | 7.11374 | 9.37547 |
| 1.56 | 3.35381 | 4.75922 | 7.14938 | 9.43209 |
| 1.57 | 3.36109 | 4.77569 | 7.18484 | 9.48853 |
| 1.58 | 3.36829 | 4.79203 | 7.22014 | 9.54479 |
| 1.59 | 3.37541 | 4.80825 | 7.25527 | 9.60087 |
| 1.6 | 3.38244 | 4.82434 | 7.29024 | 9.65677 |
| 1.61 | 3.38939 | 4.84031 | 7.32503 | 9.71249 |
| 1.62 | 3.39625 | 4.85616 | 7.35966 | 9.76802 |
| 1.63 | 3.40303 | 4.87188 | 7.39412 | 9.82338 |
| 1.64 | 3.40973 | 4.88748 | 7.42841 | 9.87855 |
| 1.65 | 3.41636 | 4.90296 | 7.46253 | 9.93353 |
| 1.66 | 3.4229 | 4.91832 | 7.49649 | 9.98834 |
| 1.67 | 3.42937 | 4.93356 | 7.53028 | 10.043 |
| 1.68 | 3.43575 | 4.94869 | 7.56391 | 10.0974 |
| 1.69 | 3.44206 | 4.96369 | 7.59737 | 10.1516 |
| 1.7 | 3.4483 | 4.97858 | 7.63067 | 10.2057 |
| 1.71 | 3.45446 | 4.99335 | 7.6638 | 10.2596 |
| 1.72 | 3.46055 | 5.00801 | 7.69677 | 10.3133 |
| 1.73 | 3.46656 | 5.02255 | 7.72957 | 10.3668 |
| 1.74 | 3.4725 | 5.03698 | 7.76221 | 10.4201 |
| 1.75 | 3.47837 | 5.0513 | 7.79469 | 10.4732 |
| 1.76 | 3.48417 | 5.06551 | 7.82701 | 10.5262 |
| 1.77 | 3.48989 | 5.0796 | 7.85916 | 10.5789 |
| 1.78 | 3.49555 | 5.09359 | 7.89115 | 10.6315 |
| 1.79 | 3.50114 | 5.10746 | 7.92299 | 10.6839 |
| 1.8 | 3.50666 | 5.12123 | 7.95466 | 10.7361 |
| 1.81 | 3.51211 | 5.13489 | 7.98618 | 10.7881 |
| 1.82 | 3.5175 | 5.14844 | 8.01753 | 10.8399 |
| 1.83 | 3.52282 | 5.16188 | 8.04873 | 10.8915 |
| 1.84 | 3.52807 | 5.17522 | 8.07977 | 10.943 |
| 1.85 | 3.53326 | 5.18846 | 8.11065 | 10.9942 |
| 1.86 | 3.53839 | 5.20159 | 8.14138 | 11.0453 |
| 1.87 | 3.54345 | 5.21462 | 8.17195 | 11.0962 |
| 1.88 | 3.54845 | 5.22755 | 8.20236 | 11.1469 |
| 1.89 | 3.55339 | 5.24037 | 8.23262 | 11.1974 |
| 1.9 | 3.55827 | 5.2531 | 8.26273 | 11.2477 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | 95th | 97.5th | 99th | 99.5th |
|---|---|---|---|---|
| 1.91 | 3.56309 | 5.26573 | 8.29268 | 11.2979 |
| 1.92 | 3.56785 | 5.27825 | 8.32249 | 11.3478 |
| 1.93 | 3.57254 | 5.29068 | 8.35214 | 11.3976 |
| 1.94 | 3.57718 | 5.30301 | 8.38163 | 11.4472 |
| 1.95 | 3.58177 | 5.31525 | 8.41098 | 11.4966 |
| 1.96 | 3.58629 | 5.32738 | 8.44018 | 11.5458 |
| 1.97 | 3.59076 | 5.33943 | 8.46923 | 11.5948 |
| 1.98 | 3.59517 | 5.35138 | 8.49813 | 11.6437 |
| 1.99 | 3.59953 | 5.36323 | 8.52688 | 11.6923 |
| 2. | 3.60383 | 5.37499 | 8.55549 | 11.7408 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | .5th | 1st | 2.5th | 5th |
|---|---|---|---|---|
| 2. | .017034 | .023376 | .037209 | .055496 |
| 2.01 | .016829 | .023113 | .036833 | .05499 |
| 2.02 | .016628 | .022855 | .036462 | .05449 |
| 2.03 | .01643 | .0226 | .036097 | .053997 |
| 2.04 | .016235 | .022349 | .035737 | .053511 |
| 2.05 | .016044 | .022103 | .035382 | .053031 |
| 2.06 | .015855 | .02186 | .035033 | .052558 |
| 2.07 | .01567 | .02162 | .034688 | .05209 |
| 2.08 | .015487 | .021385 | .034348 | .051629 |
| 2.09 | .015308 | .021153 | .034013 | .051174 |
| 2.1 | .015131 | .020924 | .033683 | .050725 |
| 2.11 | .014957 | .0207 | .033357 | .050282 |
| 2.12 | .014786 | .020478 | .033036 | .049844 |
| 2.13 | .014618 | .02026 | .032719 | .049413 |
| 2.14 | .014452 | .020045 | .032407 | .048986 |
| 2.15 | .014289 | .019833 | .032099 | .048565 |
| 2.16 | .014129 | .019625 | .031795 | .04815 |
| 2.17 | .013971 | .019419 | .031496 | .04774 |
| 2.18 | .013815 | .019217 | .0312 | .047335 |
| 2.19 | .013662 | .019017 | .030909 | .046935 |
| 2.2 | .013511 | .018821 | .030621 | .04654 |
| 2.21 | .013363 | .018627 | .030338 | .04615 |
| 2.22 | .013217 | .018436 | .030058 | .045765 |
| 2.23 | .013073 | .018248 | .029782 | .045384 |
| 2.24 | .012931 | .018063 | .02951 | .045009 |
| 2.25 | .012791 | .01788 | .029241 | .044638 |
| 2.26 | .012654 | .0177 | .028976 | .044272 |
| 2.27 | .012518 | .017523 | .028714 | .04391 |
| 2.28 | .012385 | .017348 | .028456 | .043552 |
| 2.29 | .012254 | .017175 | .028201 | .043199 |
| 2.3 | .012124 | .017005 | .027949 | .04285 |
| 2.31 | .011996 | .016838 | .027701 | .042506 |
| 2.32 | .011871 | .016672 | .027456 | .042165 |
| 2.33 | .011747 | .016509 | .027214 | .041829 |
| 2.34 | .011625 | .016348 | .026975 | .041496 |
| 2.35 | .011505 | .01619 | .026739 | .041168 |
| 2.36 | .011386 | .016034 | .026507 | .040843 |
| 2.37 | .011269 | .015879 | .026277 | .040523 |
| 2.38 | .011154 | .015727 | .02605 | .040206 |
| 2.39 | .01104 | .015577 | .025826 | .039892 |
| 2.4 | .010929 | .015429 | .025605 | .039583 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| S/X̄ | .5th | 1st | 2.5th | 5th |
|---|---|---|---|---|
| 2.41 | .010818 | .015283 | .025386 | .039277 |
| 2.42 | .010709 | .015139 | .025171 | .038974 |
| 2.43 | .010602 | .014997 | .024958 | .038676 |
| 2.44 | .010497 | .014857 | .024747 | .03838 |
| 2.45 | .010392 | .014719 | .02454 | .038088 |
| 2.46 | .01029 | .014582 | .024334 | .037799 |
| 2.47 | .010188 | .014448 | .024132 | .037514 |
| 2.48 | .010088 | .014315 | .023931 | .037232 |
| 2.49 | .00999 | .014184 | .023734 | .036953 |
| 2.5 | .009892 | .014054 | .023538 | .036677 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | 10th | 20th | 30th | 40th |
|---|---|---|---|---|
| 2. | .087989 | .153749 | .229927 | .324286 |
| 2.01 | .087286 | .152732 | .228633 | .322736 |
| 2.02 | .086591 | .151725 | .227351 | .321199 |
| 2.03 | .085905 | .150729 | .226081 | .319674 |
| 2.04 | .085227 | .149743 | .224823 | .318162 |
| 2.05 | .084557 | .148767 | .223577 | .316662 |
| 2.06 | .083896 | .147802 | .222342 | .315174 |
| 2.07 | .083242 | .146847 | .221118 | .313698 |
| 2.08 | .082596 | .145901 | .219906 | .312234 |
| 2.09 | .081957 | .144966 | .218704 | .310782 |
| 2.1 | .081327 | .14404 | .217514 | .309341 |
| 2.11 | .080703 | .143123 | .216334 | .307912 |
| 2.12 | .080087 | .142216 | .215165 | .306494 |
| 2.13 | .079478 | .141318 | .214006 | .305088 |
| 2.14 | .078877 | .140429 | .212858 | .303692 |
| 2.15 | .078282 | .139549 | .211721 | .302308 |
| 2.16 | .077694 | .138678 | .210593 | .300934 |
| 2.17 | .077113 | .137816 | .209475 | .299572 |
| 2.18 | .076539 | .136962 | .208368 | .29822 |
| 2.19 | .075971 | .136117 | .20727 | .296879 |
| 2.2 | .075409 | .135281 | .206182 | .295548 |
| 2.21 | .074854 | .134452 | .205103 | .294227 |
| 2.22 | .074306 | .133632 | .204034 | .292917 |
| 2.23 | .073763 | .13282 | .202974 | .291617 |
| 2.24 | .073227 | .132016 | .201924 | .290327 |
| 2.25 | .072697 | .13122 | .200883 | .289046 |
| 2.26 | .072172 | .130431 | .19985 | .287776 |
| 2.27 | .071654 | .12965 | .198827 | .286516 |
| 2.28 | .071141 | .128877 | .197812 | .285265 |
| 2.29 | .070634 | .128112 | .196807 | .284023 |
| 2.3 | .070132 | .127353 | .19581 | .282791 |
| 2.31 | .069636 | .126602 | .194821 | .281569 |
| 2.32 | .069145 | .125858 | .193841 | .280355 |
| 2.33 | .06866 | .125121 | .192869 | .279151 |
| 2.34 | .06818 | .124392 | .191905 | .277956 |
| 2.35 | .067705 | .123669 | .19095 | .27677 |
| 2.36 | .067236 | .122953 | .190002 | .275593 |
| 2.37 | .066771 | .122244 | .189063 | .274424 |
| 2.38 | .066311 | .121541 | .188131 | .273265 |
| 2.39 | .065857 | .120845 | .187207 | .272114 |
| 2.4 | .065407 | .120155 | .186291 | .270971 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\overline{X}$ | 10th | 20th | 30th | 40th |
|---|---|---|---|---|
| 2.41 | .064962 | .119472 | .185383 | .269837 |
| 2.42 | .064521 | .118796 | .184482 | .268711 |
| 2.43 | .064085 | .118125 | .183588 | .267594 |
| 2.44 | .063654 | .117461 | .182702 | .266484 |
| 2.45 | .063228 | .116802 | .181823 | .265383 |
| 2.46 | .062985 | .11615 | .180952 | .26429 |
| 2.47 | .062388 | .115504 | .180087 | .263205 |
| 2.48 | .061974 | .114864 | .179229 | .262128 |
| 2.49 | .061565 | .114229 | .178379 | .261058 |
| 2.5 | .06116 | .1136 | .177535 | .259996 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\overline{X}$ | 60th | 70th | 80th | 90th |
|---|---|---|---|---|
| 2. | .616738 | .869839 | 1.30081 | 2.273 |
| 2.01 | .614769 | .867802 | 1.29906 | 2.27308 |
| 2.02 | .612811 | .865772 | 1.29731 | 2.27314 |
| 2.03 | .610865 | .863749 | 1.29556 | 2.27318 |
| 2.04 | .608928 | .861734 | 1.2938 | 2.27319 |
| 2.05 | .607003 | .859726 | 1.29205 | 2.27318 |
| 2.06 | .605088 | .857725 | 1.29029 | 2.27316 |
| 2.07 | .603184 | .855732 | 1.28854 | 2.27311 |
| 2.08 | .601291 | .853746 | 1.28678 | 2.27303 |
| 2.09 | .599408 | .851768 | 1.28503 | 2.27294 |
| 2.1 | .597536 | .849796 | 1.28327 | 2.27283 |
| 2.11 | .595674 | .847833 | 1.28152 | 2.2727 |
| 2.12 | .593822 | .845877 | 1.27977 | 2.27255 |
| 2.13 | .591981 | .843928 | 1.27801 | 2.27238 |
| 2.14 | .59015 | .841986 | 1.27626 | 2.2722 |
| 2.15 | .588329 | .840052 | 1.27451 | 2.27199 |
| 2.16 | .586518 | .838126 | 1.27275 | 2.27177 |
| 2.17 | .584717 | .836206 | 1.271 | 2.27153 |
| 2.18 | .582926 | .834294 | 1.26925 | 2.27127 |
| 2.19 | .581145 | .83239 | 1.2675 | 2.27099 |
| 2.2 | .579373 | .830492 | 1.26576 | 2.2707 |
| 2.21 | .577612 | .828603 | 1.26401 | 2.27039 |
| 2.22 | .57596 | .82672 | 1.26226 | 2.27006 |
| 2.23 | .574118 | .824845 | 1.26052 | 2.26972 |
| 2.24 | .572386 | .822977 | 1.25878 | 2.26936 |
| 2.25 | .570663 | .821116 | 1.25704 | 2.26898 |
| 2.26 | .568949 | .819263 | 1.2553 | 2.26859 |
| 2.27 | .567245 | .817417 | 1.25356 | 2.26819 |
| 2.28 | .56555 | .815578 | 1.25182 | 2.26777 |
| 2.29 | .563865 | .813746 | 1.25009 | 2.26734 |
| 2.3 | .562189 | .811922 | 1.24835 | 2.26689 |
| 2.31 | .560522 | .810105 | 1.24662 | 2.26642 |
| 2.32 | .558864 | .808295 | 1.24489 | 2.26595 |
| 2.33 | .557215 | .8064.2 | 1.24317 | 2.26546 |
| 2.34 | .555575 | .804696 | 1.24144 | 2.26495 |
| 2.35 | .553944 | .802907 | 1.23972 | 2.26444 |
| 2.36 | .552322 | .801126 | 1.238 | 2.26391 |
| 2.37 | .550708 | .799352 | 1.23628 | 2.26336 |
| 2.38 | .549104 | .797584 | 1.23457 | 2.26281 |
| 2.39 | .547508 | .795824 | 1.23285 | 2.26224 |
| 2.4 | .54592 | .794071 | 1.23114 | 2.26166 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| S/$\bar{X}$ | 60th | 70th | 80th | 90th |
|---|---|---|---|---|
| 2.41 | .544342 | .792324 | 1.22943 | 2.26107 |
| 2.42 | .542772 | .790585 | 1.22773 | 2.26047 |
| 2.43 | .54121 | .788853 | 1.22602 | 2.26985 |
| 2.44 | .539657 | .787127 | 1.22432 | 2.25923 |
| 2.45 | .538112 | .785409 | 1.22262 | 2.25859 |
| 2.46 | .536575 | .783697 | 1.22093 | 2.25794 |
| 2.47 | .535046 | .781993 | 1.21924 | 2.25728 |
| 2.48 | .533526 | .780295 | 1.21754 | 2.25661 |
| 2.49 | .532014 | .778604 | 1.21586 | 2.25593 |
| 2.5 | .53051 | .776919 | 1.21417 | 2.25524 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\bar{X}$ | 95th | 97.5th | 99th | 99.5th |
|---|---|---|---|---|
| 2. | 3.60383 | 5.37499 | 8.55549 | 11.7408 |
| 2.01 | 3.60808 | 5.38666 | 8.58395 | 11.7891 |
| 2.02 | 3.61227 | 5.39824 | 8.61226 | 11.8372 |
| 2.03 | 3.61641 | 5.40973 | 8.64043 | 11.8852 |
| 2.04 | 3.6203 | 5.42113 | 8.66845 | 11.9329 |
| 2.05 | 3.62454 | 5.43244 | 8.69633 | 11.9805 |
| 2.06 | 3.62853 | 5.44366 | 8.72407 | 12.0279 |
| 2.07 | 3.63246 | 5.45479 | 8.75167 | 12.0751 |
| 2.08 | 3.63634 | 5.46583 | 8.77912 | 12.1221 |
| 2.09 | 3.64018 | 5.47679 | 8.80643 | 12.169 |
| 2.1 | 3.64397 | 5.48767 | 8.83361 | 12.2157 |
| 2.11 | 3.6477 | 5.49846 | 8.86064 | 12.2622 |
| 2.12 | 3.65139 | 5.50916 | 8.88754 | 12.3085 |
| 2.13 | 3.65503 | 5.51978 | 8.91429 | 12.3546 |
| 2.14 | 3.65863 | 5.53032 | 8.94091 | 12.4006 |
| 2.15 | 3.66218 | 5.54077 | 8.9674 | 12.4464 |
| 2.16 | 3.66568 | 5.55114 | 8.99374 | 12.492 |
| 2.17 | 3.66914 | 5.56144 | 9.01996 | 12.5374 |
| 2.18 | 3.67255 | 5.57165 | 9.04604 | 12.5827 |
| 2.19 | 3.67591 | 5.58178 | 9.07198 | 12.6278 |
| 2.2 | 3.67924 | 5.59184 | 9.09779 | 12.6727 |
| 2.21 | 3.68252 | 5.60181 | 9.12347 | 12.7174 |
| 2.22 | 3.68575 | 5.61171 | 9.14902 | 12.762 |
| 2.23 | 3.68895 | 5.62153 | 9.17444 | 12.8064 |
| 2.24 | 3.6921 | 5.63127 | 9.19972 | 12.8506 |
| 2.25 | 3.69521 | 5 64094 | 9.22488 | 12.8947 |
| 2.26 | 3.69828 | 5.65053 | 9.24991 | 12.9386 |
| 2.27 | 3.70131 | 5.66005 | 9.27481 | 12.9823 |
| 2.28 | 3.70429 | 5.6695 | 9.29959 | 13.0258 |
| 2.29 | 3.70724 | 5.67887 | 9.32423 | 13.0692 |
| 2.3 | 3.71015 | 5.68817 | 9.34875 | 13.1124 |
| 2.31 | 3.71302 | 5.69739 | 9.37315 | 13.1554 |
| 2.32 | 3.71585 | 5.70655 | 9.39742 | 13.1983 |
| 2.33 | 3.71864 | 5.71563 | 9.42157 | 13.241 |
| 2.34 | 3.7214 | 5.72464 | 9.4456 | 13.2836 |
| 2.35 | 3.72412 | 5.73359 | 9.4695 | 13.326 |
| 2.36 | 3.7268 | 5.74246 | 9.49328 | 13.3682 |
| 2.37 | 3.72944 | 5.75127 | 9.51694 | 13.4102 |
| 2.38 | 3.73205 | 5.76 | 9.54048 | 13.4521 |
| 2.39 | 3.73462 | 5.76867 | 9.5639 | 13.4938 |
| 2.4 | 3.73716 | 5.77728 | 9.5872 | 13.5354 |

TABLE IV. PERCENTILES OF THE LOG-NORMAL DISTRIBUTION (Continued)

| $S/\overline{X}$ | 95th | 97.5th | 99th | 99.5th |
|---|---|---|---|---|
| 2.41 | 3.73966 | 5.78581 | 9.61038 | 13.5768 |
| 2.42 | 3.74213 | 5.79428 | 9.63345 | 13.6181 |
| 2.43 | 3.74456 | 5.80269 | 9.6564 | 13.6592 |
| 2.44 | 3.74696 | 5.81103 | 9.67923 | 13.7001 |
| 2.45 | 3.74932 | 5.8193 | 9.70195 | 13.7408 |
| 2.46 | 3.75165 | 5.82752 | 9.72455 | 13.7815 |
| 2.47 | 3.75395 | 5.83567 | 9.74704 | 13.8219 |
| 2.48 | 3.75622 | 5.84375 | 9.76941 | 13.8622 |
| 2.49 | 3.75845 | 5.85178 | 9.79167 | 13.9023 |
| 2.5 | 3.76066 | 5.85974 | 9.81382 | 13.9423 |

*TABLE V. PERCENTAGE POINTS, $b_\gamma$, SUCH THAT $P[\hat{c}/c < b_\gamma] = \gamma$

| N \ γ | 0.02 | 0.05 | 0.10 | 0.25 | 0.40 | 0.50 | 0.60 |
|---|---|---|---|---|---|---|---|
| 5 | 0.604 | 0.683 | 0.766 | 0.951 | 1.116 | 1.238 | 1.378 |
| 6 | 0.623 | 0.697 | 0.778 | 0.937 | 1.080 | 1.188 | 1.304 |
| 7 | 0.639 | 0.709 | 0.785 | 0.930 | 1.059 | 1.155 | 1.256 |
| 8 | 0.653 | 0.720 | 0.792 | 0.926 | 1.045 | 1.131 | 1.223 |
| 9 | 0.665 | 0.729 | 0.797 | 0.925 | 1.035 | 1.114 | 1.198 |
| 10 | 0.676 | 0.738 | 0.802 | 0.924 | 1.028 | 1.101 | 1.179 |
| 11 | 0.686 | 0.745 | 0.807 | 0.924 | 1.022 | 1.090 | 1.163 |
| 12 | 0.695 | 0.752 | 0.811 | 0.924 | 1.017 | 1.082 | 1.151 |
| 13 | 0.703 | 0.759 | 0.815 | 0.924 | 1.014 | 1.075 | 1.140 |
| 14 | 0.710 | 0.764 | 0.819 | 0.925 | 1.011 | 1.069 | 1.132 |
| 15 | 0.716 | 0.770 | 0.823 | 0.925 | 1.008 | 1.064 | 1.124 |
| 16 | 0.723 | 0.775 | 0.826 | 0.926 | 1.006 | 1.059 | 1.117 |
| 17 | 0.728 | 0.779 | 0.829 | 0.927 | 1.004 | 1.056 | 1.111 |
| 18 | 0.734 | 0.784 | 0.832 | 0.927 | 1.003 | 1.052 | 1.106 |
| 19 | 0.739 | 0.788 | 0.835 | 0.928 | 1.001 | 1.049 | 1.101 |
| 20 | 0.743 | 0.791 | 0.838 | 0.929 | 1.000 | 1.047 | 1.097 |
| 22 | 0.752 | 0.798 | 0.843 | 0.930 | 0.998 | 1.042 | 1.090 |
| 24 | 0.759 | 0.805 | 0.848 | 0.932 | 0.997 | 1.038 | 1.084 |
| 26 | 0.766 | 0.810 | 0.852 | 0.933 | 0.995 | 1.035 | 1.079 |
| 28 | 0.772 | 0.815 | 0.856 | 0.934 | 0.994 | 1.033 | 1.074 |
| 30 | 0.778 | 0.820 | 0.860 | 0.935 | 0.993 | 1.030 | 1.070 |
| 32 | 0.783 | 0.824 | 0.863 | 0.937 | 0.993 | 1.028 | 1.067 |
| 34 | 0.788 | 0.828 | 0.866 | 0.938 | 0.992 | 1.027 | 1.064 |
| 36 | 0.793 | 0.832 | 0.869 | 0.939 | 0.992 | 1.025 | 1.061 |
| 38 | 0.797 | 0.835 | 0.872 | 0.940 | 0.991 | 1.024 | 1.059 |
| 40 | 0.801 | 0.839 | 0.875 | 0.940 | 0.991 | 1.023 | 1.056 |
| 42 | 0.804 | 0.842 | 0.877 | 0.941 | 0.990 | 1.022 | 1.054 |
| 44 | 0.808 | 0.845 | 0.880 | 0.942 | 0.990 | 1.021 | 1.052 |
| 46 | 0.811 | 0.847 | 0.882 | 0.943 | 0.990 | 1.020 | 1.051 |
| 48 | 0.814 | 0.850 | 0.884 | 0.944 | 0.990 | 1.019 | 1.049 |
| 50 | 0.817 | 0.852 | 0.886 | 0.944 | 0.989 | 1.018 | 1.048 |
| 52 | 0.820 | 0.854 | 0.888 | 0.945 | 0.989 | 1.017 | 1.046 |
| 54 | 0.822 | 0.857 | 0.890 | 0.946 | 0.989 | 1.017 | 1.045 |
| 56 | 0.825 | 0.859 | 0.891 | 0.946 | 0.989 | 1.016 | 1.044 |
| 58 | 0.827 | 0.861 | 0.893 | 0.947 | 0.989 | 1.015 | 1.043 |
| 60 | 0.830 | 0.863 | 0.894 | 0.948 | 0.989 | 1.015 | 1.041 |
| 62 | 0.832 | 0.864 | 0.896 | 0.948 | 0.989 | 1.014 | 1.040 |
| 64 | 0.834 | 0.866 | 0.897 | 0.949 | 0.989 | 1.014 | 1.040 |

*Reproduced from "Inferences on the Parameters of the Weibull Distribution," by Darrel R. Thoman, Lee J. Bain, and Charles E. Antle, Technometrics, Vol. 11 No. 3, (1969), pp. 445-460.

TABLE V. PERCENTAGE POINTS, $b_\gamma$, SUCH THAT $P[\hat{c}/c < b_\gamma] = \gamma$ (Continued)

| N | γ 0.70 | 0.75 | 0.80 | 0.85 | 0.90 | 0.95 | 0.98 |
|---|---|---|---|---|---|---|---|
| 66 | 0.836 | 0.868 | 0.899 | 0.949 | 0.988 | 1.014 | 1.039 |
| 68 | 0.838 | 0.869 | 0.900 | 0.950 | 0.988 | 1.013 | 1.038 |
| 70 | 0.840 | 0.871 | 0.901 | 0.950 | 0.988 | 1.013 | 1.037 |
| 72 | 0.841 | 0.872 | 0.903 | 0.951 | 0.988 | 1.012 | 1.036 |
| 74 | 0.843 | 0.874 | 0.904 | 0.951 | 0.988 | 1.012 | 1.036 |
| 76 | 0.845 | 0.875 | 0.905 | 0.952 | 0.988 | 1.012 | 1.035 |
| 78 | 0.846 | 0.876 | 0.906 | 0.952 | 0.988 | 1.011 | 1.034 |
| 80 | 0.848 | 0.878 | 0.907 | 0.952 | 0.988 | 1.011 | 1.034 |
| 85 | 0.852 | 0.881 | 0.910 | 0.953 | 0.988 | 1.011 | 1.032 |
| 90 | 0.855 | 0.883 | 0.912 | 0.954 | 0.988 | 1.010 | 1.031 |
| 95 | 0.858 | 0.886 | 0.914 | 0.955 | 0.988 | 1.009 | 1.030 |
| 100 | 0.861 | 0.888 | 0.916 | 0.956 | 0.988 | 1.009 | 1.029 |
| 110 | 0.866 | 0.893 | 0.920 | 0.958 | 0.988 | 1.008 | 1.027 |
| 120 | 0.871 | 0.897 | 0.923 | 0.959 | 0.988 | 1.007 | 1.025 |

TABLE V. PERCENTAGE POINTS, $b_\gamma$, SUCH THAT $P\{\hat{c}/c < b_\gamma\} = \gamma$ (Continued)

| N \ γ | 0.70 | 0.75 | 0.80 | 0.85 | 0.90 | 0.95 | 0.98 |
|---|---|---|---|---|---|---|---|
| 5 | 1.557 | 1.671 | 1.812 | 2.001 | 2.277 | 2.779 | 3.518 |
| 6 | 1.453 | 1.543 | 1.662 | 1.812 | 2.030 | 2.436 | 3.067 |
| 7 | 1.386 | 1.461 | 1.561 | 1.688 | 1.861 | 2.183 | 2.640 |
| 8 | 1.338 | 1.404 | 1.491 | 1.602 | 1.747 | 2.015 | 2.377 |
| 9 | 1.303 | 1.361 | 1.439 | 1.538 | 1.665 | 1.896 | 2.199 |
| 10 | 1.275 | 1.328 | 1.399 | 1.489 | 1.602 | 1.807 | 2.070 |
| 11 | 1.253 | 1.302 | 1.367 | 1.450 | 1.553 | 1.738 | 1.972 |
| 12 | 1.234 | 1.281 | 1.341 | 1.418 | 1.513 | 1.682 | 1.894 |
| 13 | 1.219 | 1.263 | 1.319 | 1.391 | 1.480 | 1.636 | 1.830 |
| 14 | 1.206 | 1.248 | 1.300 | 1.369 | 1.452 | 1.597 | 1.777 |
| 15 | 1.195 | 1.234 | 1.284 | 1.349 | 1.427 | 1.564 | 1.732 |
| 16 | 1.185 | 1.223 | 1.270 | 1.332 | 1.406 | 1.535 | 1.693 |
| 17 | 1.176 | 1.213 | 1.258 | 1.317 | 1.388 | 1.510 | 1.660 |
| 18 | 1.168 | 1.204 | 1.247 | 1.303 | 1.371 | 1.487 | 1.630 |
| 19 | 1.162 | 1.196 | 1.237 | 1.291 | 1.356 | 1.467 | 1.603 |
| 20 | 1.155 | 1.188 | 1.228 | 1.281 | 1.343 | 1.449 | 1.579 |
| 22 | 1.144 | 1.176 | 1.213 | 1.262 | 1.320 | 1.418 | 1.538 |
| 24 | 1.135 | 1.165 | 1.200 | 1.246 | 1.301 | 1.392 | 1.504 |
| 26 | 1.128 | 1.156 | 1.189 | 1.232 | 1.284 | 1.370 | 1.475 |
| 28 | 1.121 | 1.148 | 1.180 | 1.220 | 1.269 | 1.351 | 1.450 |
| 30 | 1.115 | 1.141 | 1.171 | 1.210 | 1.257 | 1.334 | 1.429 |
| 32 | 1.110 | 1.135 | 1.164 | 1.201 | 1.246 | 1.319 | 1.409 |
| 34 | 1.105 | 1.129 | 1.157 | 1.193 | 1.236 | 1.306 | 1.392 |
| 36 | 1.101 | 1.125 | 1.151 | 1.186 | 1.227 | 1.294 | 1.377 |
| 38 | 1.097 | 1.120 | 1.146 | 1.179 | 1.219 | 1.283 | 1.363 |
| 40 | 1.094 | 1.116 | 1.141 | 1.173 | 1.211 | 1.273 | 1.351 |
| 42 | 1.091 | 1.112 | 1.137 | 1.167 | 1.204 | 1.265 | 1.339 |
| 44 | 1.088 | 1.109 | 1.132 | 1.162 | 1.198 | 1.256 | 1.329 |
| 46 | 1.085 | 1.106 | 1.129 | 1.158 | 1.192 | 1.249 | 1.319 |
| 48 | 1.083 | 1.103 | 1.125 | 1.153 | 1.187 | 1.242 | 1.310 |
| 50 | 1.081 | 1.100 | 1.122 | 1.149 | 1.182 | 1.235 | 1.301 |
| 52 | 1.078 | 1.098 | 1.119 | 1.145 | 1.177 | 1.229 | 1.294 |
| 54 | 1.076 | 1.095 | 1.116 | 1.142 | 1.173 | 1.224 | 1.286 |
| 56 | 1.075 | 1.093 | 1.113 | 1.139 | 1.169 | 1.218 | 1.280 |
| 58 | 1.073 | 1.091 | 1.111 | 1.135 | 1.165 | 1.213 | 1.273 |
| 60 | 1.071 | 1.089 | 1.108 | 1.133 | 1.162 | 1.208 | 1.267 |
| 62 | 1.070 | 1.087 | 1.106 | 1.130 | 1.158 | 1.204 | 1.262 |
| 64 | 1.068 | 1.086 | 1.104 | 1.127 | 1.155 | 1.200 | 1.256 |
| 66 | 1.067 | 1.084 | 1.102 | 1.125 | 1.152 | 1.196 | 1.251 |
| 68 | 1.066 | 1.083 | 1.100 | 1.122 | 1.149 | 1.192 | 1.246 |
| 70 | 1.064 | 1.081 | 1.098 | 1.120 | 1.146 | 1.188 | 1.242 |
| 72 | 1.063 | 1.080 | 1.097 | 1.118 | 1.144 | 1.185 | 1.237 |

TABLE V. PERCENTAGE POINTS, $b_\gamma$, SUCH THAT

$P[\hat{c}/c < b_\gamma] = \gamma$ (Continued)

| N \ $\gamma$ | 0.70 | 0.75 | 0.80 | 0.85 | 0.90 | 0.95 | 0.98 |
|---|---|---|---|---|---|---|---|
| 74 | 1.062 | 1.078 | 1.095 | 1.116 | 1.141 | 1.182 | 1.233 |
| 76 | 1.061 | 1.077 | 1.093 | 1.114 | 1.139 | 1.179 | 1.229 |
| 78 | 1.060 | 1.076 | 1.092 | 1.112 | 1.136 | 1.176 | 1.225 |
| 80 | 1.059 | 1.075 | 1.090 | 1.110 | 1.134 | 1.173 | 1.222 |
| 85 | 1.057 | 1.072 | 1.087 | 1.106 | 1.129 | 1.166 | 1.213 |
| 90 | 1.055 | 1.069 | 1.084 | 1.102 | 1.124 | 1.160 | 1.206 |
| 95 | 1.053 | 1.067 | 1.081 | 1.099 | 1.120 | 1.155 | 1.199 |
| 100 | 1.051 | 1.065 | 1.079 | 1.096 | 1.116 | 1.150 | 1.192 |
| 110 | 1.048 | 1.061 | 1.074 | 1.090 | 1.110 | 1.141 | 1.181 |
| 120 | 1.046 | 1.058 | 1.070 | 1.086 | 1.104 | 1.133 | 1.171 |

*TABLE VI. PERCENTAGE POINTS, $\ell_\gamma$, SUCH THAT

$P\left[\hat{c}\ \ell n\ (\hat{b}/b) < \ell_\gamma\right] = \gamma$

| N \ γ | 0.02 | 0.05 | 0.10 | 0.25 | 0.40 | 0.50 | 0.60 |
|---|---|---|---|---|---|---|---|
| 5 | -1.631 | -1.247 | -0.888 | -0.444 | -0.241 | -0.056 | 0.085 |
| 6 | -1.396 | -1.007 | -0.740 | -0.385 | -0.194 | -0.045 | 0.079 |
| 7 | -1.196 | -0.874 | -0.652 | -0.344 | -0.168 | -0.038 | 0.074 |
| 8 | -1.056 | -0.784 | -0.591 | -0.313 | -0.150 | -0.032 | 0.070 |
| 9 | -0.954 | -0.717 | -0.544 | -0.289 | -0.137 | -0.029 | 0.067 |
| 10 | -0.876 | -0.665 | -0.507 | -0.269 | -0.126 | -0.026 | 0.065 |
| 11 | -0.813 | -0.622 | -0.477 | -0.253 | -0.118 | -0.023 | 0.062 |
| 12 | -0.762 | -0.587 | -0.451 | -0.239 | -0.111 | -0.021 | 0.061 |
| 13 | -0.719 | -0.557 | -0.429 | -0.228 | -0.106 | -0.019 | 0.059 |
| 14 | -0.683 | -0.532 | -0.410 | -0.217 | -0.100 | -0.018 | 0.057 |
| 15 | -0.651 | -0.509 | -0.393 | -0.208 | -0.096 | -0.016 | 0.056 |
| 16 | -0.624 | -0.489 | -0.379 | -0.200 | -0.092 | -0.015 | 0.054 |
| 17 | -0.599 | -0.471 | -0.365 | -0.193 | -0.089 | -0.014 | 0.053 |
| 18 | -0.578 | -0.455 | -0.353 | -0.187 | -0.085 | -0.013 | 0.052 |
| 19 | -0.558 | -0.441 | -0.342 | -0.181 | -0.083 | -0.013 | 0.051 |
| 20 | -0.540 | -0.428 | -0.332 | -0.175 | -0.080 | -0.012 | 0.050 |
| 22 | -0.509 | -0.404 | -0.314 | -0.166 | -0.075 | -0.011 | 0.048 |
| 24 | -0.483 | -0.384 | -0.299 | -0.158 | -0.071 | -0.009 | 0.047 |
| 26 | -0.460 | -0.367 | -0.286 | -0.150 | -0.068 | -0.009 | 0.046 |
| 28 | -0.441 | -0.352 | -0.274 | -0.144 | -0.065 | -0.008 | 0.044 |
| 30 | -0.423 | -0.338 | -0.264 | -0.139 | -0.062 | -0.007 | 0.043 |
| 32 | -0.408 | -0.326 | -0.254 | -0.134 | -0.059 | -0.006 | 0.042 |
| 34 | -0.394 | -0.315 | -0.246 | -0.129 | -0.057 | -0.006 | 0.041 |
| 36 | -0.382 | -0.305 | -0.238 | -0.125 | -0.055 | -0.005 | 0.040 |
| 38 | -0.370 | -0.296 | -0.231 | -0.121 | -0.053 | -0.005 | 0.040 |
| 40 | -0.360 | -0.288 | -0.224 | -0.118 | -0.052 | -0.004 | 0.039 |
| 42 | -0.350 | -0.280 | -0.218 | -0.115 | -0.050 | -0.004 | 0.038 |
| 44 | -0.341 | -0.273 | -0.213 | -0.112 | -0.048 | -0.004 | 0.037 |
| 46 | -0.333 | -0.266 | -0.208 | -0.109 | -0.047 | -0.003 | 0.037 |
| 48 | -0.325 | -0.260 | -0.203 | -0.106 | -0.046 | -0.003 | 0.036 |
| 50 | -0.318 | -0.254 | -0.198 | -0.104 | -0.045 | -0.003 | 0.036 |
| 52 | -0.312 | -0.249 | -0.194 | -0.102 | -0.043 | -0.003 | 0.035 |
| 54 | -0.305 | -0.244 | -0.190 | -0.100 | -0.042 | -0.002 | 0.035 |
| 56 | -0.299 | -0.239 | -0.186 | -0.098 | -0.041 | -0.002 | 0.034 |
| 58 | -0.294 | -0.234 | -0.183 | -0.096 | -0.040 | -0.002 | 0.034 |
| 60 | -0.289 | -0.230 | -0.179 | -0.094 | -0.039 | -0.002 | 0.033 |
| 62 | -0.284 | -0.226 | -0.176 | -0.092 | -0.039 | -0.002 | 0.033 |
| 64 | -0.279 | -0.222 | -0.173 | -0.091 | -0.038 | -0.001 | 0.032 |

*Reproduced from "Inferences on the Parameters of the Weibull Distribution," by Darrel R. Thoman, Lee J. Bain, and Charles E. Antle, Technometrics, Vol. 11, No. 3, (1969), pp. 445-460.

TABLE VI. PERCENTAGE POINTS, $\ell_\gamma$, SUCH THAT
$P\,[\hat{c}\,\ln(\hat{b}/b) < \ell_\gamma] = \gamma$ (Continued)

| N \ γ | 0.02 | 0.05 | 0.10 | 0.25 | 0.40 | 0.50 | 0.60 |
|---|---|---|---|---|---|---|---|
| 66 | -0.274 | -0.218 | -0.170 | -0.089 | -0.037 | -0.001 | 0.032 |
| 68 | -0.270 | -0.215 | -0.167 | -0.088 | -0.036 | -0.001 | 0.032 |
| 70 | -0.266 | -0.211 | -0.165 | -0.086 | -0.035 | -0.001 | 0.031 |
| 72 | -0.262 | -0.208 | -0.162 | -0.085 | -0.035 | -0.001 | 0.031 |
| 74 | -0.259 | -0.205 | -0.160 | -0.084 | -0.034 | -0.001 | 0.031 |
| 76 | -0.255 | -0.202 | -0.158 | -0.083 | -0.033 | -0.001 | 0.030 |
| 78 | -0.252 | -0.199 | -0.155 | -0.081 | -0.033 | -0.001 | 0.030 |
| 80 | -0.248 | -0.197 | -0.153 | -0.080 | -0.032 | -0.000 | 0.030 |
| 85 | -0.241 | -0.190 | -0.148 | -0.078 | -0.031 | -0.000 | 0.029 |
| 90 | -0.234 | -0.184 | -0.144 | -0.075 | -0.030 | 0.000 | 0.028 |
| 95 | -0.227 | -0.179 | -0.139 | -0.073 | -0.028 | 0.000 | 0.028 |
| 100 | -0.221 | -0.174 | -0.136 | -0.071 | -0.027 | 0.000 | 0.027 |
| 110 | -0.211 | -0.165 | -0.129 | -0.067 | -0.025 | 0.001 | 0.026 |
| 120 | -0.202 | -0.158 | -0.123 | -0.064 | -0.024 | 0.001 | 0.025 |

TABLE VI. PERCENTAGE POINTS, $\ell_\gamma$, SUCH THAT

$P\left[\hat{c}\ \ell n\ (\hat{b}/b) < \ell_\gamma\right] = \gamma$ (Continued)

| N \ γ | 0.70 | 0.75 | 0.80 | 0.85 | 0.90 | 0.95 | 0.98 |
|---|---|---|---|---|---|---|---|
| 5 | 0.254 | 0.349 | 0.452 | 0.587 | 0.772 | 0.107 | 1.582 |
| 6 | 0.221 | 0.302 | 0.404 | 0.516 | 0.666 | 0.939 | 1.291 |
| 7 | 0.200 | 0.272 | 0.362 | 0.465 | 0.598 | 0.829 | 1.120 |
| 8 | 0.185 | 0.251 | 0.331 | 0.427 | 0.547 | 0.751 | 1.003 |
| 9 | 0.174 | 0.235 | 0.307 | 0.397 | 0.507 | 0.691 | 0.917 |
| 10 | 0.165 | 0.222 | 0.288 | 0.372 | 0.475 | 0.644 | 0.851 |
| 11 | 0.157 | 0.211 | 0.273 | 0.351 | 0.448 | 0.605 | 0.797 |
| 12 | 0.150 | 0.202 | 0.260 | 0.334 | 0.425 | 0.572 | 0.752 |
| 13 | 0.145 | 0.194 | 0.249 | 0.319 | 0.406 | 0.544 | 0.714 |
| 14 | 0.140 | 0.187 | 0.239 | 0.306 | 0.389 | 0.520 | 0.681 |
| 15 | 0.135 | 0.180 | 0.230 | 0.294 | 0.374 | 0.499 | 0.653 |
| 16 | 0.131 | 0.175 | 0.223 | 0.284 | 0.360 | 0.480 | 0.627 |
| 17 | 0.128 | 0.170 | 0.216 | 0.274 | 0.348 | 0.463 | 0.605 |
| 18 | 0.124 | 0.165 | 0.209 | 0.266 | 0.338 | 0.447 | 0.584 |
| 19 | 0.121 | 0.161 | 0.204 | 0.258 | 0.328 | 0.433 | 0.566 |
| 20 | 0.118 | 0.157 | 0.199 | 0.251 | 0.318 | 0.421 | 0.549 |
| 22 | 0.113 | 0.150 | 0.189 | 0.239 | 0.302 | 0.398 | 0.519 |
| 24 | 0.109 | 0.144 | 0.181 | 0.228 | 0.288 | 0.379 | 0.494 |
| 26 | 0.105 | 0.138 | 0.174 | 0.219 | 0.276 | 0.362 | 0.472 |
| 28 | 0.102 | 0.134 | 0.168 | 0.210 | 0.265 | 0.347 | 0.453 |
| 30 | 0.098 | 0.129 | 0.163 | 0.203 | 0.256 | 0.334 | 0.435 |
| 32 | 0.095 | 0.125 | 0.158 | 0.197 | 0.247 | 0.323 | 0.420 |
| 34 | 0.093 | 0.122 | 0.153 | 0.191 | 0.239 | 0.312 | 0.406 |
| 36 | 0.090 | 0.118 | 0.149 | 0.185 | 0.232 | 0.302 | 0.393 |
| 38 | 0.088 | 0.115 | 0.145 | 0.180 | 0.226 | 0.293 | 0.382 |
| 40 | 0.086 | 0.113 | 0.142 | 0.175 | 0.220 | 0.285 | 0.371 |
| 42 | 0.084 | 0.110 | 0.139 | 0.171 | 0.214 | 0.278 | 0.361 |
| 44 | 0.082 | 0.108 | 0.136 | 0.167 | 0.209 | 0.271 | 0.352 |
| 46 | 0.080 | 0.105 | 0.133 | 0.164 | 0.204 | 0.264 | 0.344 |
| 48 | 0.079 | 0.103 | 0.130 | 0.160 | 0.199 | 0.258 | 0.336 |
| 50 | 0.077 | 0.101 | 0.128 | 0.157 | 0.195 | 0.253 | 0.328 |
| 52 | 0.076 | 0.099 | 0.126 | 0.154 | 0.191 | 0.247 | 0.321 |
| 54 | 0.074 | 0.097 | 0.123 | 0.151 | 0.187 | 0.243 | 0.315 |
| 56 | 0.073 | 0.096 | 0.121 | 0.148 | 0.184 | 0.238 | 0.309 |
| 58 | 0.072 | 0.094 | 0.119 | 0.146 | 0.181 | 0.233 | 0.303 |
| 60 | 0.071 | 0.092 | 0.117 | 0.143 | 0.177 | 0.229 | 0.297 |
| 62 | 0.070 | 0.091 | 0.116 | 0.141 | 0.174 | 0.225 | 0.292 |
| 64 | 0.068 | 0.089 | 0.114 | 0.139 | 0.171 | 0.221 | 0.287 |
| 66 | 0.067 | 0.088 | 0.112 | 0.137 | 0.169 | 0.218 | 0.282 |
| 68 | 0.066 | 0.087 | 0.111 | 0.135 | 0.166 | 0.214 | 0.278 |

TABLE VI. PERCENTAGE POINTS, $\ell_\gamma$, SUCH THAT

$P\,[\hat{c}\ \ln(\hat{b}/b) < \ell_\gamma] = \gamma$ (Continued)

| N \ γ | 0.70 | 0.75 | 0.80 | 0.85 | 0.90 | 0.95 | 0.98 |
|---|---|---|---|---|---|---|---|
| 70 | 0.065 | 0.085 | 0.109 | 0.133 | 0.164 | 0.211 | 0.274 |
| 72 | 0.064 | 0.084 | 0.108 | 0.131 | 0.161 | 0.208 | 0.269 |
| 74 | 0.064 | 0.083 | 0.107 | 0.129 | 0.159 | 0.205 | 0.266 |
| 76 | 0.063 | 0.082 | 0.105 | 0.128 | 0.157 | 0.202 | 0.262 |
| 78 | 0.062 | 0.081 | 0.104 | 0.126 | 0.155 | 0.199 | 0.258 |
| 80 | 0.061 | 0.080 | 0.103 | 0.125 | 0.153 | 0.197 | 0.255 |
| 85 | 0.059 | 0.077 | 0.100 | 0.121 | 0.148 | 0.190 | 0.246 |
| 90 | 0.057 | 0.075 | 0.097 | 0.118 | 0.143 | 0.185 | 0.239 |
| 95 | 0.056 | 0.073 | 0.095 | 0.115 | 0.139 | 0.179 | 0.232 |
| 100 | 0.054 | 0.071 | 0.093 | 0.112 | 0.136 | 0.175 | 0.226 |
| 110 | 0.051 | 0.067 | 0.089 | 0.107 | 0.129 | 0.166 | 0.215 |
| 120 | 0.049 | 0.064 | 0.085 | 0.103 | 0.123 | 0.159 | 0.205 |

TABLE VII. TABLE OF COEFFICIENTS FOR COMPUTING $Z_a$ AND $Z_b$*

n = 10

| p=r/n | 1 | | 7/10 | | 5/10 | | 2/10 | |
|---|---|---|---|---|---|---|---|---|
| i | $a_i$ | $b_i$ | $a_i$ | $b_i$ | $a_i$ | $b_i$ | $a_i$ | $b_i$ |
| 1 | .03958 | - .07107 | - .00255 | - .12531 | - .08169 | - .18478 | - .67530 | - .46452 |
| 2 | .05108 | - .07334 | .01280 | - .12299 | - .05458 | - .17371 | 1.67530 | .46452 |
| 3 | .06219 | - .07177 | .03094 | - .11279 | - .01793 | - .14970 | | |
| 4 | .07342 | - .06675 | .05228 | - .09525 | .02859 | - .11335 | | |
| 5 | .08512 | - .05797 | .07763 | - .06949 | 1.12561 | .62153 | | |
| 6 | .09767 | - .04452 | .10833 | - .03336 | | | | |
| 7 | .11155 | - .02459 | .72057 | .55919 | | | | |
| 8 | .12761 | .00548 | | | | | | |
| 9 | .14751 | .05431 | | | | | | |
| 10 | .20427 | .35022 | | | | | | |

*Reproduced from "An Exact Asymptotically Efficient Confidence Bound for Reliability in the Case of the Weibull Distribution," by M. V. Johns, Jr. and G. J. Lieberman, Technometrics, Vol. 8, No. 1, (1966), pp. 135-175.

TABLE VII. TABLE OF COEFFICIENTS FOR COMPUTING $Z_a$ AND $Z_b$ (Continued)

n = 15

| p=r/n | 1 | | 11/15 | | 7/15 | | 3/15 | |
|---|---|---|---|---|---|---|---|---|
| i | $a_i$ | $b_i$ | $a_i$ | $b_i$ | $a_i$ | $b_i$ | $a_i$ | $b_i$ |
| 1 | .02383 | -.04619 | .00065 | -.07776 | -.07407 | -.13306 | -.47594 | -.31963 |
| 2 | .02932 | -.04830 | .00683 | -.07905 | -.06265 | -.13055 | -.41146 | -.29297 |
| 3 | .03452 | -.04890 | .01367 | -.07754 | -.04717 | -.12274 | 1.88740 | .61260 |
| 4 | .03961 | -.04832 | .02120 | -.07379 | -.02811 | -.11056 | | |
| 5 | .04471 | -.04667 | .02950 | -.06793 | -.00541 | -.09416 | | |
| 6 | .04990 | -.04392 | .03871 | -.05989 | .02125 | -.07332 | | |
| 7 | .05525 | -.03996 | .04899 | -.04941 | 1.19616 | .66438 | | |
| 8 | .06084 | -.03461 | .06059 | -.03610 | | | | |
| 9 | .06677 | -.02757 | .07386 | -.01931 | | | | |
| 10 | .07315 | -.01835 | .08930 | .00194 | | | | |
| 11 | .08016 | -.00619 | .61672 | .53884 | | | | |
| 12 | .08808 | .01025 | | | | | | |
| 13 | .09740 | .03359 | | | | | | |
| 14 | .10911 | .06982 | | | | | | |
| 15 | .14734 | .29532 | | | | | | |

n = 20

| p=r/n | 1 | | 15/20 | | 10/20 | | 5/20 | |
|---|---|---|---|---|---|---|---|---|
| i | $a_i$ | $b_i$ | $a_i$ | $b_i$ | $a_i$ | $b_i$ | $a_i$ | $b_i$ |
| 1 | .01682 | -.03402 | .00120 | -.05593 | -.04527 | -.09198 | -.24498 | -.19315 |
| 2 | .02007 | -.03564 | .00456 | -.05745 | -.04032 | -.09230 | -.22587 | -.18644 |
| 3 | .02312 | -.03645 | .00816 | -.05754 | -.03371 | -.09010 | -.19843 | -.17383 |
| 4 | .02607 | -.03667 | .01201 | -.05657 | -.02574 | -.08597 | -.16426 | -.15659 |
| 5 | .02898 | -.03639 | .01612 | -.05468 | -.01650 | -.08013 | 1.83354 | -.71001 |
| 6 | .03189 | -.03563 | .02053 | -.05190 | -.00596 | -.07264 | | |
| 7 | .03482 | -.03441 | .02526 | -.04822 | .00595 | -.06345 | | |
| 8 | .03780 | -.03269 | .03037 | -.04361 | .01935 | -.05246 | | |
| 9 | .04086 | -.03045 | .03591 | -.03798 | .03444 | -.03948 | | |
| 10 | .04401 | -.02762 | .04196 | -.03119 | 1.10777 | -.66851 | | |
| 11 | .04729 | -.02411 | .04862 | -.02306 | | | | |
| 12 | .05074 | -.01980 | .05600 | -.01336 | | | | |
| 13 | .05439 | -.01451 | .06428 | -.00172 | | | | |
| 14 | .05830 | -.00798 | .07369 | .01235 | | | | |
| 15 | .06257 | .00016 | .56132 | .52087 | | | | |
| 16 | .06730 | .01054 | | | | | | |
| 17 | .07268 | .02419 | | | | | | |
| 18 | .07906 | .04312 | | | | | | |
| 19 | .08714 | .07197 | | | | | | |
| 20 | .11608 | .25640 | | | | | | |

TABLE VII. TABLE OF COEFFICIENTS FOR COMPUTING $Z_a$ AND $Z_b$ (Continued)

| | n = 30 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| p=r/n | 1 | | 22/30 | | 15/30 | | 7/30 | |
| i | $a_i$ | $b_i$ | $a_i$ | $b_i$ | $a_i$ | $b_i$ | $a_i$ | $b_i$ |
| 1 | .01046 | - .02215 | - .00105 | - .03780 | - .03092 | - .06072 | - .18830 | - .13857 |
| 2 | .01201 | - .02314 | .00042 | - .03893 | - .02916 | - .06164 | - .18110 | - .13688 |
| 3 | .01345 | - .02379 | .00198 | - .03944 | - .02675 | - .06151 | - .17012 | - .13259 |
| 4 | .01483 | - .02419 | .00363 | - .03951 | - .02385 | - .06063 | - .15631 | - .12611 |
| 5 | .01618 | - .02440 | .00536 | - .03923 | - .02052 | - .05914 | - .14008 | - .11862 |
| 6 | .01751 | - .02445 | .00718 | - .03863 | - .01679 | - .05710 | - .12169 | - .10937 |
| 7 | .01882 | - .02434 | .00910 | - .03775 | - .01267 | - .05453 | 1.95751 | .76245 |
| 8 | .02013 | - .02409 | .01111 | - .03658 | - .00816 | - .05146 | | |
| 9 | .02145 | - .02369 | .01323 | - .03513 | - .00325 | - .04788 | | |
| 10 | .02277 | - .02315 | .01546 | - .03339 | .00209 | - .04379 | | |
| 11 | .02411 | - .02246 | .01781 | - .03137 | .00787 | - .03915 | | |
| 12 | .02546 | - .02162 | .02030 | - .02903 | .01413 | - .03393 | | |
| 13 | .02684 | - .02062 | .02294 | - .02636 | .02092 | - .02811 | | |
| 14 | .02824 | - .01944 | .02574 | - .02334 | .02827 | - .02161 | | |
| 15 | .02969 | - .01807 | .02873 | - .01992 | 1.09870 | - .68119 | | |
| 16 | .03117 | - .01648 | .03192 | - .01607 | | | | |
| 17 | .03270 | - .01466 | .03535 | - .01173 | | | | |
| 18 | .03428 | - .01257 | .03904 | - .00683 | | | | |
| 19 | .03593 | - .01017 | .04305 | .00129 | | | | |
| 20 | .03767 | - .00740 | .04743 | .00500 | | | | |
| 21 | .03949 | - .00420 | .05225 | .01218 | | | | |
| 22 | .04143 | - .00047 | .56902 | .52514 | | | | |
| 23 | .04350 | .00391 | | | | | | |
| 24 | .04574 | .00913 | | | | | | |
| 25 | .04821 | .01545 | | | | | | |
| 26 | .05096 | .02331 | | | | | | |
| 27 | .05412 | .03343 | | | | | | |
| 28 | .05789 | .04719 | | | | | | |
| 29 | .06270 | .06779 | | | | | | |
| 30 | .08227 | .20535 | | | | | | |

| | n = 50 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| p=r/n | 1 | | 37/50 | | 25/50 | | 12/50 | |
| i | $a_i$ | $b_i$ | $a_i$ | $b_i$ | $a_i$ | $b_i$ | $a_i$ | $b_i$ |
| 1 | .00588 | - .01296 | - .00067 | - .02197 | - .01880 | - .03594 | - .10798 | - .08046 |
| 2 | .00648 | - .01344 | - .00016 | - .02259 | - .01837 | - .03662 | - .10666 | - .08072 |
| 3 | .00705 | - .01380 | .00038 | - .02299 | - .01772 | - .03694 | - .10414 | - .08013 |
| 4 | .00758 | - .01407 | .00093 | - .02325 | - .01691 | - .03701 | - .10078 | - .07896 |
| 5 | .00810 | - .01428 | .00150 | - .02340 | - .01599 | - .03689 | - .09675 | - .07731 |
| 6 | .00861 | - .01444 | .00209 | - .02345 | - .01496 | - .03661 | - .09213 | - .07527 |
| 7 | .00911 | - .01456 | .00270 | - .02342 | - .01382 | - .03619 | - .08699 | - .07287 |
| 8 | .00960 | - .01463 | .00333 | - .02332 | - .01260 | - .03563 | - .08135 | - .07013 |

TABLE VII. TABLE OF COEFFICIENTS FOR COMPUTING $Z_a$ AND $Z_b$ (Continued)

n = 50

| p=r/n | 1 | | 37/50 | | 25/50 | | 12/50 | |
|---|---|---|---|---|---|---|---|---|
| i | $a_i$ | $b_i$ | $a_i$ | $b_i$ | $a_i$ | $b_i$ | $a_i$ | $b_i$ |
| 9 | .01008 | - .01467 | .00398 | - .02315 | - .01129 | - .03495 | - .07523 | - .06709 |
| 10 | .01057 | - .01467 | .00464 | - .02291 | - .00989 | - .03415 | - .06865 | - .06373 |
| 11 | .01105 | - .01463 | .00532 | - .02261 | - .00840 | - .03324 | - .06162 | - .06008 |
| 12 | .01152 | - .01457 | .00603 | - .02224 | - .00683 | - .03221 | 1.98227 | .80675 |
| 13 | .01200 | - .01447 | .00675 | - .02182 | - .00517 | - .03107 | | |
| 14 | .01248 | - .01434 | .00750 | - .02133 | - .00342 | - .02982 | | |
| 15 | .01296 | - .01418 | .00827 | - .02079 | .00158 | - .02846 | | |
| 16 | .01344 | - .01399 | .00907 | - .02018 | .00035 | - .02698 | | |
| 17 | .01393 | - .01376 | .00989 | - .01951 | .00238 | - .02538 | | |
| 18 | .01442 | - .01351 | .01073 | - .01877 | .00451 | - .02366 | | |
| 19 | .01491 | - .01321 | .01161 | - .01796 | .00675 | - .02181 | | |
| 20 | .01540 | - .01289 | .01252 | - .01709 | .00910 | - .01984 | | |
| 21 | .01591 | - .01252 | .01345 | - .01614 | .01156 | - .01772 | | |
| 22 | .01642 | - .01212 | .01443 | - .01512 | .01415 | - .01546 | | |
| 23 | .01693 | - .01168 | .01544 | - .01401 | .01687 | - .01305 | | |
| 24 | .01745 | - .01119 | .01648 | - .01282 | .01973 | - .01047 | | |
| 25 | .01798 | - .01067 | .01757 | - .01154 | 1.09036 | .69008 | | |
| 26 | .01852 | - .01009 | .01871 | - .01017 | | | | |
| 27 | .01907 | - .00946 | .01989 | - .00869 | | | | |
| 28 | .01964 | - .00877 | .02113 | - .00709 | | | | |
| 29 | .02021 | - .00803 | .02243 | - .00538 | | | | |
| 30 | .02080 | - .00722 | .02379 | - .00354 | | | | |
| 31 | .02140 | - .00634 | .02521 | - .00154 | | | | |
| 32 | .02202 | - .00538 | .02672 | - .00060 | | | | |
| 33 | .02266 | - .00434 | .02831 | - .00203 | | | | |
| 34 | .02332 | - .00319 | .02999 | - .00545 | | | | |
| 35 | .02401 | - .00194 | .03178 | .00820 | | | | |
| 36 | .02471 | - .00057 | .03369 | .01119 | | | | |
| 37 | .02545 | .00095 | .53455 | .51043 | | | | |
| 38 | .02623 | .00263 | | | | | | |
| 39 | .02704 | .00450 | | | | | | |
| 40 | .02789 | .00659 | | | | | | |
| 41 | .02880 | .00894 | | | | | | |
| 42 | .02977 | .01163 | | | | | | |
| 43 | .03082 | .01473 | | | | | | |
| 44 | .03196 | .01834 | | | | | | |
| 45 | .03322 | .02266 | | | | | | |
| 46 | .03464 | .02793 | | | | | | |
| 47 | .03627 | .03462 | | | | | | |
| 48 | .03823 | .04360 | | | | | | |
| 49 | .04074 | .05685 | | | | | | |
| 50 | .05269 | .15062 | | | | | | |

TABLE VII. TABLE OF COEFFICIENTS FOR COMPUTING $Z_a$ AND $Z_b$ (Continued)

n = 100

| p=r/n | 1 | | 75/100 | | 50/100 | | 25/100 | |
|---|---|---|---|---|---|---|---|---|
| i | $a_i$ | $b_i$ | $a_i$ | $b_i$ | $a_i$ | $b_i$ | $a_i$ | $b_i$ |
| 1 | .00277 | - .00632 | - .00020 | - .01056 | - .00944 | - .01768 | - .04999 | - .03820 |
| 2 | .00294 | - .00648 | - .00013 | - .01079 | - .00940 | - .01797 | - .05003 | - .03854 |
| 3 | .00310 | - .00662 | - .00000 | - .01096 | - .00931 | - .01817 | - .04981 | - .03868 |
| 4 | .00325 | - .00673 | .00013 | - .01109 | - .00918 | - .01831 | - .04249 | - .03869 |
| 5 | .00339 | - .00682 | .00027 | - .01121 | - .00902 | - .01841 | - .04889 | - .03861 |
| 6 | .00353 | - .00690 | .00040 | - .01130 | - .00885 | - .01847 | - .04824 | - .03844 |
| 7 | .00367 | - .00698 | .00054 | - .01137 | - .00865 | - .01850 | - .04750 | - .03820 |
| 8 | .00380 | - .00704 | .00068 | - .01143 | - .00844 | - .01851 | - .04668 | - .03789 |
| 9 | .00393 | - .00710 | .00082 | - .11477 | - .00821 | - .01848 | - .04577 | - .03754 |
| 10 | .00406 | - .00715 | .00097 | - .01150 | - .00797 | - .01844 | - .04479 | - .03713 |
| 11 | .00419 | - .00719 | .00111 | - .01152 | - .00771 | - .01838 | - .04375 | - .03667 |
| 12 | .00432 | - .00723 | .00126 | - .01153 | - .00745 | - .01829 | - .04264 | - .03616 |
| 13 | .00445 | - .00726 | .00141 | - .01153 | - .00716 | - .01819 | - .04146 | - .03562 |
| 14 | .00457 | - .00728 | .00157 | - .01152 | - .00687 | - .01808 | - .04023 | - .03503 |
| 15 | .00469 | - .00730 | .00172 | - .01150 | - .00657 | - .01794 | - .03894 | - .03440 |
| 16 | .00482 | - .00732 | .00188 | - .01147 | - .00625 | - .01779 | - .03759 | - .03374 |
| 17 | .00494 | - .00733 | .00204 | - .01143 | - .00592 | - .01762 | - .03619 | - .03303 |
| 18 | .00506 | - .00733 | .00220 | - .01138 | - .00558 | - .01744 | - .03473 | - .03229 |
| 19 | .00519 | - .00733 | .00236 | - .01133 | - .00523 | - .01724 | - .03322 | - .03151 |
| 20 | .00531 | - .00733 | .00253 | - .01127 | - .00487 | - .01703 | - .03165 | - .03069 |
| 21 | .00543 | - .00732 | .00270 | - .01120 | - .00450 | - .01681 | - .03003 | - .02984 |
| 22 | .00555 | - .00731 | .00287 | - .01112 | - .00412 | - .01656 | - .02836 | - .02895 |
| 23 | .00567 | - .00730 | .00304 | - .01103 | - .00372 | - .01631 | - .02663 | - .02803 |
| 24 | .00579 | - .00728 | .00322 | - .01094 | - .00332 | - .01604 | - .02485 | - .02707 |
| 25 | .00591 | - .00726 | .00389 | - .01084 | - .00290 | - .01576 | 1.97141 | .83495 |
| 26 | .00603 | - .00723 | .00357 | - .01073 | - .00248 | - .01546 | | |
| 27 | .00615 | - .00720 | .00376 | - .01061 | - .00204 | - .01515 | | |
| 28 | .00627 | - .00716 | .00394 | - .01049 | - .00159 | - .01482 | | |
| 29 | .00640 | - .00712 | .00413 | - .01036 | - .00113 | - .01448 | | |
| 30 | .00652 | - .00708 | .00432 | - .01022 | - .00065 | - .01412 | | |
| 31 | .00664 | - .00703 | .00452 | - .01007 | - .00017 | - .01375 | | |
| 32 | .00676 | - .00698 | .00472 | - .00992 | .00033 | - .01337 | | |
| 33 | .00688 | - .00692 | .00492 | - .00976 | .00084 | - .01297 | | |
| 34 | .00701 | - .00686 | .00512 | - .00959 | .00137 | - .01255 | | |
| 35 | .00713 | - .00680 | .00533 | - .00941 | .00190 | - .01212 | | |
| 36 | .00725 | - .00673 | .00544 | - .00922 | .00245 | - .01167 | | |
| 37 | .00738 | - .00665 | .00575 | - .00903 | .00301 | - .01121 | | |
| 38 | .00750 | - .00658 | .00597 | - .00882 | .00359 | - .01073 | | |
| 39 | .00763 | - .00650 | .00619 | - .00861 | .00418 | - .01023 | | |
| 40 | .00775 | - .00611 | .00642 | - .00839 | .00479 | - .00971 | | |

TABLE VII. TABLE OF COEFFICIENTS FOR COMPUTING $Z_a$ AND $Z_b$ (Continued)

| | n = 100 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| p=r/n | 1 | | 75/100 | | 50/100 | | 25/100 | |
| i | $a_i$ | $b_i$ | $a_i$ | $b_i$ | $a_i$ | $b_i$ | $a_i$ | $b_i$ |
| 41 | .00788 | - .00632 | .00664 | - .00816 | .00541 | - .00918 | | |
| 42 | .00801 | - .00622 | .00688 | - .00792 | .00695 | - .00863 | | |
| 43 | .00813 | - .00612 | .00711 | - .00767 | .00670 | - .00806 | | |
| 44 | .00826 | - .00601 | .00736 | - .00741 | .00737 | - .00747 | | |
| 45 | .00839 | - .00590 | .00760 | - .00714 | .00805 | - .00687 | | |
| 46 | .00852 | - .00579 | .00785 | - .00686 | .00875 | - .00624 | | |
| 47 | .00866 | - .00566 | .00811 | - .00657 | .00948 | - .00559 | | |
| 48 | .00879 | - .00554 | .00837 | - .00627 | .01022 | - .00492 | | |
| 49 | .00892 | - .00540 | .00863 | - .00595 | .01097 | - .00422 | | |
| 50 | .00906 | - .00526 | .00890 | - .00563 | 1.08321 | .69595 | | |
| 51 | .00919 | - .00512 | .00918 | - 00529 | | | | |
| 52 | .00933 | - .00497 | .00946 | - .00494 | | | | |
| 53 | .00947 | - .00481 | .00975 | - .00458 | | | | |
| 54 | .00961 | - .00464 | .01005 | - .00420 | | | | |
| 55 | .00975 | - .00447 | .01035 | - .00381 | | | | |
| 56 | .00990 | - .00429 | .01065 | - .00340 | | | | |
| 57 | .01004 | - .00410 | .01097 | - .00298 | | | | |
| 58 | .01019 | - .00390 | .01129 | - .00255 | | | | |
| 59 | .01034 | - .00370 | .01162 | - .00209 | | | | |
| 60 | .01049 | - .00348 | .01196 | - .00162 | | | | |
| 61 | .01064 | - .00326 | .01231 | - .00113 | | | | |
| 62 | .01080 | - .00303 | .01266 | - .00062 | | | | |
| 63 | .01095 | - .00278 | .01303 | - .00009 | | | | |
| 64 | .01111 | - .00253 | .01341 | .00046 | | | | |
| 65 | .01127 | - .00226 | .01379 | .00104 | | | | |
| 66 | .01144 | - .00199 | .01419 | .00163 | | | | |
| 67 | .01160 | - .00170 | .01460 | .00226 | | | | |
| 68 | .01177 | - .00139 | .01502 | .00291 | | | | |
| 69 | .01195 | - .00107 | .01546 | .00359 | | | | |
| 70 | .01212 | - .00074 | .01591 | .00429 | | | | |
| 71 | .01230 | - .00039 | .01637 | .00504 | | | | |
| 72 | .01240 | - .00002 | .01685 | .00581 | | | | |
| 73 | .01267 | .00037 | .01735 | .00663 | | | | |
| 74 | .01287 | .00077 | .01786 | .00748 | | | | |
| 75 | .01306 | .00120 | .49752 | .49223 | | | | |
| 76 | .01326 | .00165 | | | | | | |
| 77 | .01347 | .00213 | | | | | | |

TABLE VII. TABLE OF COEFFICIENTS FOR COMPUTING $Z_a$ AND $Z_b$ (Continued)

| | | | | | n = 100 | | | |
|---|---|---|---|---|---|---|---|---|
| p=r/n | 1 | | 75/100 | | 80/100 | | 25/100 | |
| i | $a_i$ | $b_i$ | $a_i$ | $b_i$ | $a_i$ | $b_i$ | $a_i$ | $b_i$ |
| 78 | .01368 | .00264 | | | | | | |
| 79 | .01390 | .00317 | | | | | | |
| 80 | .01412 | .00374 | | | | | | |
| 81 | .01436 | .00435 | | | | | | |
| 82 | .01459 | .00500 | | | | | | |
| 83 | .01484 | .00569 | | | | | | |
| 84 | .01510 | .00643 | | | | | | |
| 85 | .01537 | .00723 | | | | | | |
| 86 | .01565 | .00810 | | | | | | |
| 87 | .01594 | .00904 | | | | | | |
| 88 | .01625 | .01006 | | | | | | |
| 89 | .01657 | .01119 | | | | | | |
| 90 | .01692 | .01243 | | | | | | |
| 91 | .01728 | .01382 | | | | | | |
| 92 | .01768 | .01538 | | | | | | |
| 93 | .01810 | .01716 | | | | | | |
| 94 | .01857 | .01922 | | | | | | |
| 95 | .01908 | .02164 | | | | | | |
| 96 | .01967 | .02458 | | | | | | |
| 97 | .02034 | .02826 | | | | | | |
| 98 | .02115 | .03314 | | | | | | |
| 99 | .02220 | .01027 | | | | | | |
| 100 | .02829 | .09493 | | | | | | |

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$*

$n = 10$
$p = r/n = 2/10$

| $z_a/z_b$ | $\gamma = 0.50$ $L^*(z_a/z_b)$ | $\gamma = 0.75$ $L^*(z_a/z_b)$ | $\gamma = 0.90$ $L^*(z_a/z_b)$ | $\gamma = 0.95$ $L^*(z_a/z_b)$ | $\gamma = 0.99$ $L^*(z_a/z_b)$ |
|---|---|---|---|---|---|
| .0 | .726 | .543 | .319 | .154 | .010 |
| .1 | .734 | .564 | .357 | .193 | .022 |
| .2 | .742 | .585 | .381 | .224 | .045 |
| .3 | .749 | .599 | .409 | .274 | .072 |
| .4 | .755 | .614 | .439 | .314 | .104 |
| .5 | .763 | .626 | .469 | .345 | .135 |
| .6 | .773 | .647 | .493 | .385 | .169 |
| .7 | .780 | .660 | .520 | .423 | .224 |
| .8 | .789 | .677 | .539 | .450 | .256 |
| .9 | .797 | .690 | .560 | .477 | .304 |
| 1.0 | .806 | .702 | .585 | .508 | .338 |
| 1.1 | .814 | .717 | .601 | .538 | .412 |
| 1.2 | .822 | .725 | .614 | .556 | .428 |
| 1.3 | .828 | .738 | .634 | .578 | .467 |
| 1.4 | .835 | .751 | .648 | .594 | .484 |
| 1.5 | .842 | .759 | .661 | .609 | .501 |
| 1.6 | .848 | .769 | .672 | .618 | .514 |
| 1.7 | .855 | .778 | .685 | .626 | .526 |
| 1.8 | .860 | .785 | .694 | .639 | .541 |
| 1.9 | .865 | .793 | .708 | .645 | .545 |
| 2.0 | .873 | .800 | .717 | .652 | .554 |
| 2.1 | .878 | .806 | .722 | .659 | .562 |
| 2.2 | .883 | .811 | .731 | .670 | .569 |
| 2.3 | .888 | .815 | .738 | .675 | .572 |
| 2.4 | .892 | .821 | .743 | .686 | .578 |
| 2.5 | .897 | .829 | .746 | .688 | .578 |
| 2.6 | .900 | .833 | .751 | .691 | .586 |
| 2.7 | .903 | .838 | .757 | .694 | .589 |
| 2.8 | .907 | .842 | .760 | .700 | .595 |
| 2.9 | .912 | .849 | .767 | .707 | .596 |
| 3.0 | .915 | .853 | .773 | .711 | .597 |
| 3.1 | .918 | .855 | .779 | .714 | .600 |
| 3.2 | .921 | .859 | .784 | .717 | .605 |
| 3.3 | .924 | .863 | .786 | .721 | .609 |
| 3.4 | .926 | .865 | .791 | .724 | .609 |
| 3.5 | .928 | .869 | .796 | .728 | .609 |
| 3.6 | .930 | .870 | .798 | .732 | .609 |
| 3.7 | .932 | .873 | .800 | .736 | .609 |

$L^*(z_a/z_b)$ is the exact lower confidence bound for $R(t_0)$

*Reproduced from "An Exact Asymptotically Efficient Confidence Bound for Reliability in the Case of the Weibull Distribution," by M. V. Johns, Jr. and G. J. Lieberman, Technometrics, Vol. 8, No. 1, (1966), pp. 135-175.

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 10
p = r/n = 2/10

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| 3.8 | .934 | .875 | .804 | .740 | .609 |
| 3.9 | .937 | .879 | .807 | .745 | .611 |
| 4.0 | .939 | .880 | .809 | .748 | .613 |
| 4.1 | .941 | .883 | .810 | .752 | .616 |
| 4.2 | .944 | .887 | .813 | .753 | .617 |
| 4.3 | .946 | .890 | .816 | .754 | .617 |
| 4.4 | .948 | .892 | .818 | .755 | .618 |
| 4.5 | .950 | .894 | .820 | .756 | .622 |
| 4.6 | .951 | .896 | .823 | .759 | .623 |
| 4.7 | .953 | .899 | .825 | .762 | .623 |
| 4.8 | .955 | .900 | .826 | .764 | .623 |
| 4.9 | .957 | .901 | .830 | .766 | .626 |
| 5.0 | .959 | .902 | .833 | .769 | .628 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 10$
$p = r/n = 5/10$

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| .0 | .464 | .341 | .244 | .193 | .095 |
| .1 | .490 | .374 | .281 | .234 | .126 |
| .2 | .516 | .403 | .315 | .270 | .153 |
| .3 | .543 | .434 | .350 | .304 | .180 |
| .4 | .568 | .466 | .381 | .334 | .217 |
| .5 | .593 | .493 | .410 | .357 | .236 |
| .6 | .617 | .518 | .436 | .386 | .269 |
| .7 | .640 | .542 | .462 | .413 | .300 |
| .8 | .663 | .568 | .484 | .430 | .327 |
| .9 | .684 | .589 | .508 | .455 | .352 |
| 1.0 | .703 | .611 | .531 | .475 | .378 |
| 1.1 | .720 | .633 | .543 | .495 | .404 |
| 1.2 | .738 | .653 | .564 | .513 | .426 |
| 1.3 | .766 | .674 | .581 | .526 | .440 |
| 1.4 | .771 | .692 | .599 | .540 | .453 |
| 1.5 | .789 | .707 | .616 | .557 | .467 |
| 1.6 | .805 | .719 | .631 | .573 | .486 |
| 1.7 | .817 | .731 | .643 | .589 | .495 |
| 1.8 | .829 | .745 | .657 | .603 | .505 |
| 1.9 | .840 | .759 | .670 | .618 | .518 |
| 2.0 | .850 | .773 | .683 | .630 | .530 |
| 2.1 | .859 | .784 | .696 | .642 | .538 |
| 2.2 | .868 | .794 | .707 | .651 | .551 |
| 2.3 | .877 | .804 | .720 | .662 | .561 |
| 2.4 | .885 | .815 | .733 | .671 | .568 |
| 2.5 | .892 | .824 | .742 | .678 | .576 |
| 2.6 | .899 | .832 | .750 | .687 | .592 |
| 2.7 | .906 | .843 | .760 | .696 | .606 |
| 2.8 | .912 | .850 | .771 | .707 | .616 |
| 2.9 | .919 | .858 | .780 | .718 | .627 |
| 3.0 | .924 | .864 | .789 | .724 | .634 |
| 3.1 | .929 | .870 | .797 | .730 | .640 |
| 3.2 | .934 | .878 | .806 | .736 | .646 |
| 3.3 | .939 | .885 | .813 | .743 | .652 |
| 3.4 | .942 | .891 | .820 | .751 | .657 |
| 3.5 | .946 | .896 | .826 | .756 | .663 |
| 3.6 | .950 | .901 | .834 | .762 | .669 |
| 3.7 | .953 | .906 | .841 | .767 | .675 |
| 3.8 | .956 | .911 | .846 | .775 | .681 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 10$
$p = r/n = 5/10$

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| 3.9 | .960 | .916 | .850 | .783 | .687 |
| 4.0 | .963 | .921 | .855 | .789 | .693 |
| 4.1 | .965 | .925 | .862 | .795 | .699 |
| 4.2 | .968 | .929 | .867 | .801 | .704 |
| 4.3 | .970 | .932 | .872 | .806 | .710 |
| 4.4 | .972 | .935 | .877 | .812 | .716 |
| 4.5 | .974 | .939 | .883 | .818 | .721 |
| 4.6 | .975 | .942 | .887 | .823 | .727 |
| 4.7 | .977 | .944 | .891 | .828 | .732 |
| 4.8 | .978 | .947 | .896 | .834 | .738 |
| 4.9 | .980 | .950 | .899 | .839 | .744 |
| 5.0 | .981 | .953 | .903 | .843 | .750 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 10$
$p = r/n = 7/10$

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| .0 | .415 | .332 | .260 | .215 | .141 |
| .1 | .448 | .362 | .290 | .245 | .163 |
| .2 | .480 | .396 | .323 | .275 | .191 |
| .3 | .509 | .423 | .351 | .302 | .214 |
| .4 | .537 | .453 | .380 | .328 | .243 |
| .5 | .567 | .482 | .402 | .357 | .271 |
| .6 | .595 | .509 | .426 | .387 | .304 |
| .7 | .620 | .535 | .452 | .408 | .322 |
| .8 | .645 | .560 | .475 | .425 | .340 |
| .9 | .668 | .582 | .493 | .447 | .359 |
| 1.0 | .691 | .607 | .514 | .469 | .377 |
| 1.1 | .712 | .629 | .537 | .491 | .402 |
| 1.2 | .730 | .650 | .555 | .508 | .420 |
| 1.3 | .747 | .669 | .578 | .522 | .435 |
| 1.4 | .767 | .687 | .595 | .537 | .453 |
| 1.5 | .784 | .704 | .612 | .554 | .467 |
| 1.6 | .800 | .722 | .630 | .570 | .485 |
| 1.7 | .814 | .736 | .645 | .583 | .500 |
| 1.8 | .827 | .752 | .659 | .599 | .514 |
| 1.9 | .840 | .765 | .672 | .615 | .529 |
| 2.0 | .852 | .779 | .687 | .628 | .543 |
| 2.1 | .862 | .791 | .702 | .645 | .556 |
| 2.2 | .873 | .804 | .714 | .660 | .567 |
| 2.3 | .883 | .813 | .727 | .674 | .576 |
| 2.4 | .892 | .824 | .741 | .684 | .583 |
| 2.5 | .900 | .835 | .752 | .697 | .590 |
| 2.6 | .908 | .845 | .763 | .710 | .597 |
| 2.7 | .915 | .855 | .773 | .717 | .604 |
| 2.8 | .921 | .863 | .782 | .727 | .615 |
| 2.9 | .927 | .871 | .792 | .738 | .626 |
| 3.0 | .932 | .879 | .802 | .748 | .634 |
| 3.1 | .937 | .886 | .811 | .758 | .640 |
| 3.2 | .942 | .892 | .819 | .768 | .651 |
| 3.3 | .947 | .899 | .830 | .778 | .662 |
| 3.4 | .951 | .905 | .837 | .787 | .674 |
| 3.5 | .955 | .910 | .845 | .795 | .684 |
| 3.6 | .958 | .916 | .853 | .804 | .698 |
| 3.7 | .962 | .921 | .860 | .813 | .702 |
| 3.8 | .965 | .926 | .866 | .821 | .709 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 10
p = r/n = 7/10

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| 3.9 | .968 | .930 | .873 | .827 | .715 |
| 4.0 | .970 | .934 | .878 | .836 | .722 |
| 4.1 | .973 | .939 | .883 | .845 | .730 |
| 4.2 | .975 | .943 | .888 | .851 | .737 |
| 4.3 | .977 | .946 | .893 | .856 | .744 |
| 4.4 | .979 | .949 | .898 | .861 | .750 |
| 4.5 | .980 | .952 | .904 | .866 | .755 |
| 4.6 | .982 | .955 | .908 | .870 | .759 |
| 4.7 | .983 | .958 | .911 | .875 | .764 |
| 4.8 | .985 | .960 | .915 | .880 | .770 |
| 4.9 | .986 | .963 | .919 | .884 | .778 |
| 5.0 | .987 | .965 | .924 | .889 | .785 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 10$
$p = r/n = 1$

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| .0 | .393 | .315 | .255 | .212 | .153 |
| .1 | .428 | .345 | .283 | .238 | .176 |
| .2 | .458 | .376 | .311 | .264 | .202 |
| .3 | .492 | .409 | .336 | .291 | .226 |
| .4 | .522 | .442 | .363 | .319 | .247 |
| .5 | .552 | .474 | .389 | .345 | .273 |
| .6 | .581 | .502 | .416 | .371 | .298 |
| .7 | .607 | .527 | .439 | .396 | .317 |
| .8 | .634 | .553 | .464 | .421 | .334 |
| .9 | .658 | .579 | .490 | .442 | .352 |
| 1.0 | .682 | .605 | .512 | .463 | .369 |
| 1.1 | .705 | .627 | .535 | .485 | .395 |
| 1.2 | .726 | .649 | .559 | .505 | .421 |
| 1.3 | .747 | .670 | .582 | .525 | .445 |
| 1.4 | .768 | .690 | .605 | .546 | .462 |
| 1.5 | .786 | .707 | .621 | .567 | .478 |
| 1.6 | .800 | .725 | .644 | .587 | .494 |
| 1.7 | .816 | .742 | .662 | .603 | .506 |
| 1.8 | .830 | .758 | .680 | .622 | .522 |
| 1.9 | .843 | .772 | .697 | .636 | .540 |
| 2.0 | .855 | .787 | .710 | .654 | .559 |
| 2.1 | .868 | .801 | .727 | .668 | .573 |
| 2.2 | .879 | .814 | .743 | .684 | .587 |
| 2.3 | .889 | .826 | .758 | .700 | .600 |
| 2.4 | .898 | .837 | .772 | .713 | .613 |
| 2.5 | .907 | .847 | .783 | .725 | .626 |
| 2.6 | .915 | .856 | .795 | .738 | .639 |
| 2.7 | .921 | .865 | .806 | .751 | .651 |
| 2.8 | .928 | .874 | .816 | .762 | .665 |
| 2.9 | .934 | .883 | .826 | .775 | .677 |
| 3.0 | .939 | .890 | .835 | .787 | .689 |
| 3.1 | .944 | .898 | .846 | .800 | .698 |
| 3.2 | .949 | .904 | .853 | .811 | .708 |
| 3.3 | .954 | .911 | .861 | .820 | .719 |
| 3.4 | .957 | .917 | .868 | .827 | .729 |
| 3.5 | .961 | .922 | .875 | .837 | .739 |
| 3.6 | .964 | .927 | .883 | .846 | .748 |
| 3.7 | .968 | .933 | .889 | .854 | .757 |
| 3.8 | .970 | .937 | .895 | .862 | .766 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 10$
$p = r/n = 1$

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| 3.9 | .973 | .941 | .901 | .869 | .775 |
| 4.0 | .975 | .945 | .906 | .875 | .784 |
| 4.1 | .977 | .949 | .912 | .880 | .792 |
| 4.2 | .979 | .952 | .917 | .885 | .800 |
| 4.3 | .981 | .956 | .922 | .892 | .808 |
| 4.4 | .982 | .959 | .926 | .896 | .815 |
| 4.5 | .984 | .962 | .931 | .903 | .822 |
| 4.6 | .985 | .964 | .935 | .907 | .827 |
| 4.7 | .987 | .967 | .939 | .912 | .833 |
| 4.8 | .988 | .969 | .943 | .916 | .838 |
| 4.9 | .989 | .972 | .946 | .921 | .843 |
| 5.0 | .990 | .974 | .950 | .925 | .848 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 15
p = r/n = 3/15

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| .0 | .646 | .443 | .210 | .090 | .001 |
| .1 | .660 | .475 | .242 | .118 | .006 |
| .2 | .673 | .508 | .276 | .160 | .017 |
| .3 | .688 | .534 | .318 | .194 | .037 |
| .4 | .702 | .561 | .357 | .240 | .064 |
| .5 | .716 | .583 | .392 | .285 | .101 |
| .6 | .732 | .607 | .433 | .331 | .147 |
| .7 | .742 | .627 | .478 | .382 | .202 |
| .8 | .755 | .647 | .520 | .428 | .257 |
| .9 | .766 | .665 | .553 | .465 | .300 |
| 1.0 | .776 | .681 | .584 | .495 | .348 |
| 1.1 | .787 | .698 | .610 | .533 | .395 |
| 1.2 | .799 | .715 | .631 | .559 | .451 |
| 1.3 | .812 | .733 | .651 | .591 | .491 |
| 1.4 | .821 | .749 | .671 | .619 | .522 |
| 1.5 | .832 | .762 | .691 | .642 | .547 |
| 1.6 | .840 | .773 | .707 | .658 | .566 |
| 1.7 | .849 | .785 | .725 | .673 | .587 |
| 1.8 | .857 | .797 | .736 | .684 | .604 |
| 1.9 | .866 | .806 | .744 | .697 | .609 |
| 2.0 | .873 | .814 | .751 | .707 | .620 |
| 2.1 | .879 | .823 | .761 | .718 | .642 |
| 2.2 | .886 | .829 | .768 | .729 | .654 |
| 2.3 | .893 | .839 | .774 | .739 | .661 |
| 2.4 | .900 | .846 | .782 | .749 | .676 |
| 2.5 | .905 | .853 | .791 | .757 | .688 |
| 2.6 | .911 | .859 | .798 | .763 | .699 |
| 2.7 | .914 | .864 | .805 | .772 | .704 |
| 2.8 | .919 | .869 | .814 | .776 | .707 |
| 2.9 | .923 | .874 | .819 | .784 | .709 |
| 3.0 | .927 | .879 | .824 | .790 | .711 |
| 3.1 | .932 | .883 | .829 | .794 | .717 |
| 3.2 | .936 | .887 | .832 | .799 | .720 |
| 3.3 | .939 | .891 | .836 | .802 | .723 |
| 3.4 | .942 | .896 | .842 | .803 | .726 |
| 3.5 | .945 | .899 | .849 | .810 | .733 |
| 3.6 | .948 | .902 | .852 | .819 | .735 |
| 3.7 | .951 | .906 | .857 | .822 | .736 |
| 3.6 | .953 | .910 | .860 | .825 | .738 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 15$
$p = r/n = 3/15$

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| 3.9 | .955 | .914 | .863 | .828 | .741 |
| 4.0 | .957 | .917 | .865 | .832 | .743 |
| 4.1 | .960 | .919 | .868 | .835 | .745 |
| 4.2 | .962 | .921 | .871 | .837 | .745 |
| 4.3 | .964 | .924 | .875 | .841 | .746 |
| 4.4 | .966 | .927 | .878 | .843 | .748 |
| 4.5 | .968 | .929 | .880 | .846 | .749 |
| 4.6 | .969 | .932 | .884 | .849 | .752 |
| 4.7 | .971 | .934 | .888 | .853 | .757 |
| 4.8 | .972 | .936 | .890 | .857 | .763 |
| 4.9 | .974 | .938 | .892 | .860 | .768 |
| 5.0 | .975 | .939 | 895 | .862 | .769 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 15
p = r/n = 7/15

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| .0 | .443 | .343 | .247 | .205 | .111 |
| .1 | .471 | .373 | .284 | .245 | .149 |
| .2 | .502 | .404 | .320 | .280 | .197 |
| .3 | .530 | .438 | .356 | .317 | .243 |
| .4 | .560 | .472 | .391 | .351 | .285 |
| .5 | .586 | .500 | .427 | .385 | .318 |
| .6 | .615 | .528 | .457 | .417 | .344 |
| .7 | .639 | .556 | .486 | .446 | .381 |
| .8 | .661 | .582 | .514 | .470 | .403 |
| .9 | .684 | .608 | .542 | .496 | .421 |
| 1.0 | .705 | .630 | .562 | .521 | .444 |
| 1.1 | .725 | .653 | .587 | .548 | .466 |
| 1.2 | .743 | .672 | .606 | .567 | .487 |
| 1.3 | .760 | .690 | .626 | .585 | .502 |
| 1.4 | .776 | .710 | .646 | .604 | .516 |
| 1.5 | .794 | .729 | .664 | .624 | .530 |
| 1.6 | .809 | .743 | .677 | .642 | .543 |
| 1.7 | .823 | .759 | .690 | .658 | .564 |
| 1.8 | .835 | .773 | .706 | .673 | .579 |
| 1.9 | .846 | .786 | .719 | .689 | .592 |
| 2.0 | .857 | .799 | .732 | .702 | .610 |
| 2.1 | .868 | .810 | .744 | .715 | .627 |
| 2.2 | .877 | .822 | .757 | .725 | .642 |
| 2.3 | .886 | .832 | .768 | .735 | .658 |
| 2.4 | .895 | .841 | .779 | .744 | .670 |
| 2.5 | .902 | .851 | .788 | .755 | .680 |
| 2.6 | .910 | .859 | .799 | .764 | .689 |
| 2.7 | .916 | .866 | .810 | .774 | .697 |
| 2.8 | .922 | .873 | .819 | .783 | .707 |
| 2.9 | .928 | .881 | .827 | .791 | .719 |
| 3.0 | .933 | .889 | .836 | .798 | .731 |
| 3.1 | .938 | .895 | .844 | .806 | .743 |
| 3.2 | .943 | .901 | .851 | .815 | .754 |
| 3.3 | .948 | .906 | .857 | .822 | .760 |
| 3.4 | .952 | .911 | .864 | .828 | .765 |
| 3.5 | .955 | .916 | .870 | .836 | .770 |
| 3.6 | .958 | .920 | .876 | .843 | .775 |
| 3.7 | .962 | .925 | .882 | .851 | .780 |
| 3.8 | .965 | .929 | .888 | .857 | .784 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 15$
$p = r/n = 7/15$

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| 3.9 | .967 | .933 | .894 | .862 | .789 |
| 4.0 | .969 | .937 | .898 | .867 | .795 |
| 4.1 | .972 | .940 | .902 | .872 | .801 |
| 4.2 | .974 | .944 | .907 | .876 | .808 |
| 4.3 | .976 | .947 | .911 | .882 | .814 |
| 4.4 | .978 | .949 | .915 | .886 | .821 |
| 4.5 | .979 | .952 | .919 | .891 | .827 |
| 4.6 | .981 | .955 | .922 | .896 | .834 |
| 4.7 | .982 | .958 | .926 | .900 | .840 |
| 4.8 | .984 | .960 | .929 | .905 | .845 |
| 4.9 | .985 | .963 | .932 | .908 | .850 |
| 5.0 | .986 | .965 | .935 | .912 | .852 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 15$
$p = r/n = 11/15$

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| .0 | .401 | .328 | .269 | .233 | .179 |
| .1 | .433 | .362 | .304 | .262 | .207 |
| .2 | .467 | .395 | .335 | .297 | .233 |
| .3 | .499 | .427 | .369 | .325 | .264 |
| .4 | .530 | .458 | .400 | .355 | .295 |
| .5 | .559 | .488 | .430 | .383 | .318 |
| .6 | .587 | .516 | .457 | .412 | .340 |
| .7 | .614 | .544 | .485 | .440 | .363 |
| .8 | .641 | .573 | .512 | .468 | .388 |
| .9 | .664 | .598 | .535 | .492 | .413 |
| 1.0 | .688 | .624 | .557 | .518 | .434 |
| 1.1 | .712 | .646 | .578 | .539 | .450 |
| 1.2 | .732 | .667 | .599 | .559 | .469 |
| 1.3 | .752 | .685 | .622 | .580 | .490 |
| 1.4 | .772 | .705 | .642 | .601 | .510 |
| 1.5 | .790 | .724 | .659 | .620 | .527 |
| 1.6 | .807 | .742 | .676 | .639 | .539 |
| 1.7 | .823 | .759 | .691 | .657 | .560 |
| 1.8 | .837 | .775 | .707 | .672 | .580 |
| 1.9 | .851 | .790 | .721 | .687 | .599 |
| 2.0 | .862 | .805 | .736 | .700 | .618 |
| 2.1 | .873 | .818 | .752 | .716 | .634 |
| 2.2 | .883 | .830 | .765 | .729 | .645 |
| 2.3 | .892 | .842 | .779 | .742 | .663 |
| 2.4 | .901 | .852 | .792 | .755 | .675 |
| 2.5 | .909 | .861 | .803 | .768 | .687 |
| 2.6 | .917 | .870 | .813 | .779 | .702 |
| 2.7 | .924 | .879 | .823 | .790 | .712 |
| 2.8 | .930 | .887 | .832 | .801 | .722 |
| 2.9 | .936 | .896 | .842 | .812 | .734 |
| 3.0 | .941 | .903 | .852 | .822 | .746 |
| 3.1 | .946 | .910 | .861 | .829 | .758 |
| 3.2 | .951 | .916 | .869 | .837 | .769 |
| 3.3 | .955 | .922 | .877 | .845 | .779 |
| 3.4 | .958 | .927 | .883 | .853 | .789 |
| 3.5 | .962 | .932 | .890 | .861 | .798 |
| 3.6 | .965 | .936 | .896 | .869 | .806 |
| 3.7 | .968 | .941 | .901 | .875 | .813 |
| 3.8 | .971 | .945 | .907 | .882 | .819 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 15
p = r/n = 11/15

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| 3.9 | .973 | .949 | .912 | .888 | .825 |
| 4.0 | .976 | .953 | .917 | .893 | .831 |
| 4.1 | .978 | .956 | .922 | .898 | .837 |
| 4.2 | .980 | .959 | .927 | .903 | .846 |
| 4.3 | .981 | .962 | .932 | .907 | .854 |
| 4.4 | .983 | .965 | .936 | .911 | .862 |
| 4.5 | .984 | .967 | .939 | .916 | .870 |
| 4.6 | .985 | .969 | .942 | .920 | .877 |
| 4.7 | .987 | .971 | .946 | .923 | .882 |
| 4.8 | .988 | .973 | .949 | .928 | .887 |
| 4.9 | .989 | .975 | .952 | .932 | .892 |
| 5.0 | .990 | .977 | .955 | .936 | .896 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 15$
$p = r/n = 1$

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| .0 | .388 | .321 | .271 | .234 | .180 |
| .1 | .422 | .355 | .302 | .261 | .207 |
| .2 | .455 | .388 | .334 | .286 | .235 |
| .3 | .488 | .419 | .365 | .317 | .267 |
| .4 | .521 | .452 | .393 | .345 | .291 |
| .5 | .552 | .482 | .422 | .376 | .314 |
| .6 | .580 | .513 | .450 | .403 | .336 |
| .7 | .610 | .540 | .478 | .430 | .362 |
| .8 | .638 | .568 | .505 | .461 | .390 |
| .9 | .664 | .595 | .531 | .489 | .411 |
| 1.0 | .688 | .620 | .556 | .515 | .428 |
| 1.1 | .712 | .645 | .581 | .539 | .454 |
| 1.2 | .734 | .668 | .602 | .565 | .471 |
| 1.3 | .754 | .690 | .623 | .588 | .495 |
| 1.4 | .773 | .711 | .643 | .612 | .518 |
| 1.5 | .791 | .731 | .663 | .631 | .539 |
| 1.6 | .808 | .748 | .683 | .653 | .555 |
| 1.7 | .823 | .765 | .701 | .670 | .571 |
| 1.8 | .836 | .781 | .720 | .687 | .587 |
| 1.9 | .851 | .797 | .738 | .704 | .605 |
| 2.0 | .864 | .813 | .755 | .719 | .623 |
| 2.1 | .875 | .826 | .770 | .732 | .640 |
| 2.2 | .885 | .839 | .784 | .747 | .658 |
| 2.3 | .895 | .850 | .798 | .762 | .673 |
| 2.4 | .904 | .861 | .809 | .776 | .688 |
| 2.5 | .912 | .871 | .823 | .787 | .703 |
| 2.6 | .920 | .880 | .835 | .799 | .718 |
| 2.7 | .927 | .889 | .845 | .810 | .732 |
| 2.8 | .933 | .897 | .855 | .821 | .745 |
| 2.9 | .939 | .906 | .865 | .831 | .758 |
| 3.0 | .945 | .912 | .873 | .840 | .770 |
| 3.1 | .950 | .919 | .882 | .849 | .782 |
| 3.2 | .954 | .925 | .890 | .857 | .793 |
| 3.3 | .958 | .931 | .897 | .865 | .802 |
| 3.4 | .962 | .936 | .904 | .874 | .812 |
| 3.5 | .966 | .940 | .910 | .881 | .822 |
| 3.6 | .968 | .945 | .916 | .888 | .830 |
| 3.7 | .971 | .949 | .922 | .895 | .836 |
| 3.8 | .974 | .953 | .927 | .900 | .844 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 15
p = r/n = 1

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| 3.9 | .976 | .957 | .932 | .906 | .854 |
| 4.0 | .978 | .960 | .936 | .911 | .863 |
| 4.1 | .980 | .963 | .941 | .916 | .871 |
| 4.2 | .982 | .966 | .945 | .921 | .878 |
| 4.3 | .984 | .969 | .949 | .926 | .884 |
| 4.4 | .985 | .971 | .952 | .931 | .887 |
| 4.5 | .986 | .973 | .956 | .935 | .890 |
| 4.6 | .988 | .975 | .959 | .939 | .893 |
| 4.7 | .989 | .977 | .962 | .942 | .896 |
| 4.8 | .990 | .979 | .964 | .945 | .899 |
| 4.9 | .991 | .980 | .966 | .949 | .902 |
| 5.0 | .992 | .982 | .968 | .952 | .907 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 20
p = r/n = 5/20

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| .0 | .523 | .350 | .188 | .105 | .008 |
| .1 | .544 | .387 | .228 | .140 | .020 |
| .2 | .569 | .423 | .271 | .186 | .037 |
| .3 | .596 | .459 | .305 | .231 | .068 |
| .4 | .620 | .491 | .343 | .274 | .118 |
| .5 | .642 | .524 | .385 | .317 | .164 |
| .6 | .663 | .552 | .427 | .360 | .229 |
| .7 | .683 | .582 | .465 | .401 | .287 |
| .8 | .704 | .610 | .501 | .439 | .331 |
| .9 | .720 | .640 | .539 | .477 | .380 |
| 1.0 | .735 | .665 | .570 | .519 | .430 |
| 1.1 | .754 | .687 | .601 | .552 | .464 |
| 1.2 | .768 | .706 | .631 | .583 | .484 |
| 1.3 | .783 | .724 | .656 | .614 | .519 |
| 1.4 | .796 | .742 | .679 | .637 | .538 |
| 1.5 | .809 | .758 | .698 | .659 | .559 |
| 1.6 | .824 | .775 | .718 | .674 | .587 |
| 1.7 | .835 | .790 | .735 | .697 | .609 |
| 1.8 | .846 | .802 | .746 | .713 | .628 |
| 1.9 | .858 | .813 | .761 | .728 | .644 |
| 2.0 | .868 | .823 | .773 | .741 | .665 |
| 2.1 | .878 | .834 | .785 | .753 | .677 |
| 2.2 | .887 | .842 | .797 | .762 | .687 |
| 2.3 | .895 | .850 | .807 | .773 | .695 |
| 2.4 | .903 | .857 | .817 | .781 | .702 |
| 2.5 | .909 | .865 | .824 | .791 | .713 |
| 2.6 | .916 | .873 | .831 | .798 | .720 |
| 2.7 | .922 | .879 | .837 | .803 | .726 |
| 2.8 | .928 | .885 | .843 | .809 | .733 |
| 2.9 | .933 | .891 | .851 | .815 | .745 |
| 3.0 | .938 | .896 | .857 | .823 | .752 |
| 3.1 | .942 | .902 | .865 | .826 | .755 |
| 3.2 | .946 | .907 | .870 | .833 | .763 |
| 3.3 | .950 | .912 | .875 | .830 | .768 |
| 3.4 | .953 | .917 | .880 | .844 | .773 |
| 3.5 | .956 | .921 | .885 | .850 | .779 |
| 3.6 | .959 | .925 | .889 | .854 | .784 |
| 3.7 | .962 | .929 | .893 | .858 | .788 |
| 3.8 | .965 | .933 | .898 | .862 | .793 |

$L^*(Z_a/Z_b)$ is the exact ower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 20
p = r/n = 5/20

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| 3.9 | .967 | .936 | .902 | .866 | .797 |
| 4.0 | .969 | .939 | .905 | .870 | .802 |
| 4.1 | .971 | .942 | .909 | .873 | .806 |
| 4.2 | .973 | .945 | .912 | .878 | .810 |
| 4.3 | .975 | .948 | .915 | .880 | .815 |
| 4.4 | .977 | .951 | .919 | .883 | .819 |
| 4.5 | .978 | .954 | .922 | .886 | .824 |
| 4.6 | .980 | .957 | .924 | .889 | .828 |
| 4.7 | .981 | .959 | .927 | .893 | .832 |
| 4.8 | .983 | .962 | .931 | .898 | .836 |
| 4.9 | .984 | .963 | .933 | .902 | .839 |
| 5.0 | .985 | .965 | .936 | .904 | .843 |

$L^*(Z_a/Z_b)$ is the exact ower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 20
p = r/n = 10/20

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| .0 | .415 | .333 | .257 | .224 | .141 |
| .1 | .446 | .369 | .294 | .263 | .180 |
| .2 | .479 | .405 | .332 | .297 | .222 |
| .3 | .509 | .441 | .365 | .332 | .264 |
| .4 | .542 | .472 | .402 | .367 | .290 |
| .5 | .573 | .502 | .436 | .401 | .336 |
| .6 | .604 | .530 | .468 | .432 | .370 |
| .7 | .632 | .559 | .497 | .461 | .404 |
| .8 | .657 | .588 | .530 | .492 | .432 |
| .9 | .681 | .614 | .559 | .520 | .453 |
| 1.0 | .704 | .637 | .584 | .546 | .474 |
| 1.1 | .725 | .659 | .608 | .571 | .495 |
| 1.2 | .746 | .680 | .633 | .591 | .516 |
| 1.3 | .764 | .701 | .652 | .614 | .534 |
| 1.4 | .780 | .721 | .672 | .637 | .546 |
| 1.5 | .796 | .740 | .691 | .657 | .564 |
| 1.6 | .811 | .758 | .707 | .673 | .588 |
| 1.7 | .824 | .773 | .721 | .692 | .607 |
| 1.8 | .837 | .790 | .737 | .710 | .628 |
| 1.9 | .850 | .804 | .751 | .723 | .646 |
| 2.0 | .862 | .817 | .764 | .737 | .660 |
| 2.1 | .872 | .829 | .777 | .750 | .671 |
| 2.2 | .882 | .840 | .789 | .761 | .681 |
| 2.3 | .892 | .850 | .801 | .772 | .692 |
| 2.4 | .900 | .860 | .812 | .782 | .702 |
| 2.5 | .909 | .869 | .823 | .793 | .712 |
| 2.6 | .916 | .878 | .832 | .804 | .722 |
| 2.7 | .922 | .887 | .842 | .815 | .731 |
| 2.8 | .929 | .894 | .851 | .821 | .740 |
| 2.9 | .935 | .901 | .859 | .830 | .749 |
| 3.0 | .940 | .907 | .868 | .839 | .758 |
| 3.1 | .945 | .913 | .875 | .848 | .766 |
| 3.2 | .950 | .918 | .883 | .855 | .774 |
| 3.3 | .954 | .924 | .890 | .862 | .782 |
| 3.4 | .958 | .929 | .896 | .869 | .792 |
| 3.5 | .962 | .933 | .902 | .875 | .801 |
| 3.6 | .965 | .938 | .908 | .881 | .809 |
| 3.7 | .968 | .942 | .913 | .887 | .817 |
| 3.8 | .970 | .946 | .918 | .892 | .825 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 20$
$p = r/n = 10/20$

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| 3.9 | .973 | .949 | .923 | .898 | .833 |
| 4.0 | .975 | .953 | .928 | .903 | .840 |
| 4.1 | .977 | .956 | .932 | .908 | .848 |
| 4.2 | .979 | .959 | .936 | .912 | .854 |
| 4.3 | .981 | .961 | .939 | .916 | .860 |
| 4.4 | .982 | .964 | .943 | .920 | .864 |
| 4.5 | .984 | .967 | .946 | .925 | .868 |
| 4.6 | .985 | .969 | .949 | .929 | .871 |
| 4.7 | .987 | .971 | .952 | .933 | .875 |
| 4.8 | .988 | .973 | .955 | .936 | .879 |
| 4.9 | .989 | .975 | .957 | .940 | .882 |
| 5.0 | .990 | .976 | .960 | .943 | .886 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 20
p = r/n = 15/20

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| .0 | .390 | .332 | .278 | .240 | .192 |
| .1 | .424 | .367 | .310 | .272 | .221 |
| .2 | .457 | .400 | .342 | .306 | .253 |
| .3 | .492 | .433 | .374 | .338 | .279 |
| .4 | .524 | .466 | .408 | .373 | .307 |
| .5 | .558 | .496 | .438 | .408 | .332 |
| .6 | .589 | .523 | .466 | .439 | .361 |
| .7 | .617 | .550 | .497 | .466 | .387 |
| .8 | .645 | .575 | .528 | .489 | .412 |
| .9 | .671 | .603 | .554 | .516 | .436 |
| 1.0 | .697 | .629 | .580 | .540 | .459 |
| 1.1 | .720 | .655 | .605 | .565 | .482 |
| 1.2 | .741 | .676 | .629 | .589 | .503 |
| 1.3 | .761 | .698 | .649 | .612 | .524 |
| 1.4 | .780 | .719 | .668 | .634 | .544 |
| 1.5 | .797 | .737 | .687 | .654 | .564 |
| 1.6 | .812 | .756 | .705 | .672 | .584 |
| 1.7 | .827 | .772 | .723 | .690 | .603 |
| 1.8 | .840 | .788 | .739 | .707 | .621 |
| 1.9 | .853 | .803 | .755 | .723 | .639 |
| 2.0 | .866 | .816 | .770 | .738 | .656 |
| 2.1 | .877 | .830 | .784 | .753 | .670 |
| 2.2 | .887 | .842 | .797 | .765 | .688 |
| 2.3 | .896 | .854 | .810 | .778 | .704 |
| 2.4 | .905 | .864 | .821 | .792 | .719 |
| 2.5 | .913 | .875 | .832 | .805 | .733 |
| 2.6 | .920 | .883 | .842 | .817 | .746 |
| 2.7 | .927 | .892 | .851 | .826 | .757 |
| 2.8 | .933 | .899 | .860 | .835 | .769 |
| 2.9 | .939 | .907 | .869 | .845 | .780 |
| 3.0 | .944 | .914 | .877 | .856 | .790 |
| 3.1 | .949 | .920 | .884 | .863 | .800 |
| 3.2 | .953 | .925 | .891 | .870 | .809 |
| 3.3 | .958 | .930 | .898 | .877 | .818 |
| 3.4 | .961 | .936 | .905 | .884 | .827 |
| 3.5 | .964 | .940 | .911 | .890 | .835 |
| 3.6 | .967 | .945 | .916 | .895 | .843 |
| 3.7 | .970 | .949 | .921 | .902 | .851 |
| 3.8 | .973 | .953 | .927 | .908 | .858 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 20
p = r/n = 15/20

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| 3.9 | .975 | .956 | .932 | .914 | .865 |
| 4.0 | .977 | .960 | .936 | .919 | .872 |
| 4.1 | .979 | .963 | .939 | .923 | .878 |
| 4.2 | .981 | .966 | .943 | .928 | .884 |
| 4.3 | .983 | .968 | .947 | .931 | .890 |
| 4.4 | .985 | .971 | .950 | .935 | .895 |
| 4.5 | .986 | .973 | .954 | .939 | .900 |
| 4.6 | .987 | .975 | .957 | .942 | .904 |
| 4.7 | .988 | .977 | .959 | .945 | .907 |
| 4.8 | .989 | .979 | .962 | .948 | .910 |
| 4.9 | .990 | .980 | .964 | .951 | .915 |
| 5.0 | .991 | .982 | .967 | .954 | .919 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 20$
$p = r/n = 1$

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| .0 | .380 | .328 | .278 | .249 | .202 |
| .1 | .416 | .363 | .309 | .283 | .228 |
| .2 | .451 | .395 | .338 | .313 | .256 |
| .3 | .487 | .429 | .370 | .348 | .281 |
| .4 | .519 | .462 | .403 | .379 | .312 |
| .5 | .553 | .491 | .433 | .406 | .338 |
| .6 | .586 | .521 | .464 | .434 | .364 |
| .7 | .615 | .548 | .494 | .461 | .388 |
| .8 | .642 | .575 | .525 | .490 | .413 |
| .9 | .668 | .603 | .552 | .514 | .436 |
| 1.0 | .693 | .629 | .579 | .541 | .462 |
| 1.1 | .717 | .654 | .605 | .568 | .486 |
| 1.2 | .740 | .679 | .628 | .593 | .510 |
| 1.3 | .761 | .700 | .649 | .615 | .533 |
| 1.4 | .781 | .722 | .670 | .636 | .557 |
| 1.5 | .799 | .742 | .692 | .657 | .579 |
| 1.6 | .816 | .761 | .713 | .680 | .600 |
| 1.7 | .831 | .779 | .732 | .700 | .621 |
| 1.8 | .846 | .795 | .748 | .721 | .640 |
| 1.9 | .859 | .810 | .763 | .737 | .661 |
| 2.0 | .871 | .824 | .778 | .755 | .681 |
| 2.1 | .883 | .837 | .792 | .768 | .700 |
| 2.2 | .893 | .849 | .806 | .785 | .719 |
| 2.3 | .902 | .861 | .819 | .798 | .732 |
| 2.4 | .911 | .872 | .830 | .811 | .745 |
| 2.5 | .919 | .881 | .842 | .823 | .758 |
| 2.6 | .926 | .890 | .852 | .834 | .772 |
| 2.7 | .933 | .898 | .863 | .844 | .785 |
| 2.8 | .939 | .906 | .873 | .854 | .796 |
| 2.9 | .944 | .914 | .881 | .862 | .807 |
| 3.0 | .949 | .920 | .889 | .872 | .817 |
| 3.1 | .954 | .926 | .896 | .881 | .827 |
| 3.2 | .958 | .932 | .904 | .888 | .836 |
| 3.3 | .962 | .938 | .911 | .895 | .844 |
| 3.4 | .965 | .943 | .917 | .901 | .853 |
| 3.5 | .969 | .947 | .923 | .907 | .861 |
| 3.6 | .971 | .951 | .928 | .914 | .869 |
| 3.7 | .974 | .955 | .933 | .920 | .877 |
| 3.8 | .976 | .959 | .938 | .925 | .885 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 20$
$p = 1/n = 1$

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| 3.9 | .979 | .962 | .942 | .930 | .893 |
| 4.0 | .981 | .965 | .947 | .935 | .898 |
| 4.1 | .982 | .968 | .951 | .939 | .903 |
| 4.2 | .984 | .971 | .954 | .943 | .908 |
| 4.3 | .985 | .973 | .957 | .947 | .913 |
| 4.4 | .987 | .975 | .960 | .950 | .918 |
| 4.5 | .988 | .977 | .963 | .953 | .923 |
| 4.6 | .989 | .979 | .966 | .956 | .927 |
| 4.7 | .990 | .981 | .968 | .959 | .931 |
| 4.8 | .991 | .982 | .970 | .962 | .935 |
| 4.9 | .992 | .984 | .972 | .964 | .938 |
| 5.0 | .993 | .985 | .974 | .967 | .942 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 30
p = r/n = 7/30

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| .0 | .485 | .335 | .198 | .104 | .015 |
| .1 | .512 | .372 | .238 | .136 | .033 |
| .2 | .542 | .408 | .282 | .179 | .060 |
| .3 | .567 | .442 | .323 | .220 | .098 |
| .4 | .592 | .477 | .367 | .268 | .143 |
| .5 | .615 | .513 | .408 | .322 | .188 |
| .6 | .637 | .543 | .449 | .361 | .237 |
| .7 | .661 | .576 | .486 | .409 | .289 |
| .8 | .683 | .604 | .520 | .456 | .346 |
| .9 | .705 | .630 | .555 | .501 | .397 |
| 1.0 | .723 | .656 | .590 | .544 | .442 |
| 1.1 | .742 | .681 | .619 | .577 | .482 |
| 1.2 | .759 | .704 | .643 | .604 | .515 |
| 1.3 | .776 | .726 | .669 | .631 | .552 |
| 1.4 | .793 | .745 | .688 | .655 | .589 |
| 1.5 | .809 | .761 | .711 | .676 | .608 |
| 1.6 | .823 | .777 | .729 | .694 | .633 |
| 1.7 | .836 | .794 | .746 | .716 | .659 |
| 1.8 | .847 | .807 | .761 | .735 | .669 |
| 1.9 | .858 | .819 | .774 | .752 | .691 |
| 2.0 | .869 | .831 | .787 | .765 | .712 |
| 2.1 | .878 | .841 | .799 | .777 | .732 |
| 2.2 | .887 | .851 | .810 | .787 | .741 |
| 2.3 | .895 | .860 | .820 | .798 | .750 |
| 2.4 | .903 | .869 | .829 | .809 | .762 |
| 2.5 | .911 | .877 | .839 | .820 | .773 |
| 2.6 | .918 | .885 | .846 | .829 | .783 |
| 2.7 | .925 | .892 | .855 | .835 | .791 |
| 2.8 | .930 | .898 | .862 | .843 | .800 |
| 2.9 | .935 | .903 | .868 | .851 | .809 |
| 3.0 | .940 | .909 | .874 | .857 | .816 |
| 3.1 | .945 | .914 | .881 | .864 | .824 |
| 3.2 | .948 | .920 | .886 | .869 | .831 |
| 3.3 | .952 | .925 | .892 | .874 | .838 |
| 3.4 | .956 | .929 | .896 | .878 | .842 |
| 3.5 | .959 | .933 | .901 | .882 | .846 |
| 3.6 | .962 | .938 | .907 | .886 | .849 |
| 3.7 | .965 | .941 | .911 | .891 | .855 |
| 3.8 | .968 | .945 | .916 | .895 | .860 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 30
p = r/n = 7/30

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| 3.9 | .970 | .948 | .920 | .898 | .865 |
| 4.0 | .972 | .951 | .923 | .902 | .870 |
| 4.1 | .974 | .954 | .926 | .906 | .875 |
| 4.2 | .977 | .957 | .929 | .910 | .879 |
| 4.3 | .978 | .960 | .932 | .914 | .882 |
| 4.4 | .980 | .962 | .935 | .918 | .885 |
| 4.5 | .981 | .964 | .939 | .920 | .886 |
| 4.6 | .983 | .966 | .942 | .923 | .888 |
| 4.7 | .984 | .968 | .944 | .925 | .890 |
| 4.8 | .985 | .970 | .946 | .928 | .892 |
| 4.9 | .986 | .972 | .949 | .931 | .894 |
| 5.0 | .988 | .974 | .951 | .933 | .895 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 30$
$p = r/n = 15/30$

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| .0 | .399 | .329 | .269 | .230 | .169 |
| .1 | .432 | .369 | .303 | .270 | .212 |
| .2 | .464 | .402 | .341 | .309 | .252 |
| .3 | .496 | .437 | .375 | .348 | .292 |
| .4 | .527 | .470 | .412 | .384 | .330 |
| .5 | .560 | .501 | .445 | .421 | .368 |
| .6 | .591 | .534 | .481 | .456 | .403 |
| .7 | .619 | .563 | .513 | .487 | .434 |
| .8 | .646 | .593 | .541 | .514 | .463 |
| .9 | .673 | .618 | .571 | .542 | .490 |
| 1.0 | .696 | .643 | .597 | .567 | .518 |
| 1.1 | .719 | .667 | .620 | .595 | .540 |
| 1.2 | .740 | .689 | .645 | .619 | .562 |
| 1.3 | .760 | .712 | .664 | .640 | .582 |
| 1.4 | .778 | .730 | .685 | .660 | .603 |
| 1.5 | .796 | .748 | .706 | .677 | .624 |
| 1.6 | .812 | .766 | .723 | .693 | .643 |
| 1.7 | .826 | .782 | .740 | .711 | .660 |
| 1.8 | .840 | .798 | .756 | .729 | .676 |
| 1.9 | .853 | .811 | .771 | .746 | .688 |
| 2.0 | .865 | .825 | .784 | .759 | .701 |
| 2.1 | .877 | .837 | .797 | .773 | .721 |
| 2.2 | .886 | .849 | .810 | .787 | .735 |
| 2.3 | .895 | .859 | .820 | .800 | .749 |
| 2.4 | .903 | .871 | .832 | .811 | .760 |
| 2.5 | .910 | .879 | .841 | .824 | .769 |
| 2.6 | .918 | .887 | .852 | .834 | .779 |
| 2.7 | .925 | .895 | .861 | .845 | .789 |
| 2.8 | .931 | .903 | .870 | .853 | .798 |
| 2.9 | .936 | .910 | .878 | .861 | .805 |
| 3.0 | .941 | .917 | .885 | .869 | .813 |
| 3.1 | .946 | .922 | .891 | .875 | .821 |
| 3.2 | .950 | .928 | .898 | .883 | .827 |
| 3.3 | .955 | .933 | .904 | .889 | .834 |
| 3.4 | .959 | .938 | .910 | .895 | .840 |
| 3.5 | .962 | .942 | .916 | .900 | .847 |
| 3.6 | .965 | .947 | .922 | .906 | .854 |
| 3.7 | .968 | .951 | .927 | .911 | .861 |
| 3.8 | .971 | .954 | .932 | .917 | .868 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 30$
$p = r/n = 15/30$

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| 3.9 | .974 | .958 | .936 | .921 | .873 |
| 4.0 | .976 | .961 | .940 | .926 | .877 |
| 4.1 | .978 | .964 | .943 | .930 | .883 |
| 4.2 | .980 | .966 | .947 | .934 | .889 |
| 4.3 | .981 | .969 | .950 | .938 | .895 |
| 4.4 | .983 | .971 | .953 | .942 | .899 |
| 4.5 | .984 | .973 | .956 | .945 | .904 |
| 4.6 | .986 | .975 | .959 | .949 | .908 |
| 4.7 | .987 | .977 | .961 | .952 | .912 |
| 4.8 | .988 | .979 | .964 | .954 | .916 |
| 4.9 | .989 | .980 | .966 | .957 | .920 |
| 5.0 | .990 | .982 | .968 | .959 | .924 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 30
p = r/n = 22/30

| $Z_a/Z_b$ | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| .0 | .382 | .333 | .281 | .257 | .206 |
| .1 | .416 | .366 | .318 | .290 | .243 |
| .2 | .453 | .400 | .353 | .325 | .277 |
| .3 | .489 | .433 | .385 | .359 | .307 |
| .4 | .521 | .465 | .419 | .392 | .341 |
| .5 | .553 | .497 | .449 | .424 | .373 |
| .6 | .583 | .528 | .479 | .455 | .406 |
| .7 | .612 | .560 | .512 | .486 | .438 |
| .8 | .640 | .589 | .540 | .517 | .465 |
| .9 | .666 | .615 | .566 | .544 | .486 |
| 1.0 | .691 | .641 | .593 | .569 | .511 |
| 1.1 | .716 | .665 | .618 | .592 | .534 |
| 1.2 | .737 | .687 | .642 | .615 | .556 |
| 1.3 | .758 | .709 | .664 | .637 | .577 |
| 1.4 | .777 | .729 | .685 | .659 | .602 |
| 1.5 | .795 | .748 | .705 | .677 | .623 |
| 1.6 | .812 | .766 | .722 | .697 | .641 |
| 1.7 | .827 | .782 | .741 | .717 | .656 |
| 1.8 | .842 | .798 | .758 | .734 | .675 |
| 1.9 | .855 | .813 | .774 | .749 | .692 |
| 2.0 | .867 | .826 | .788 | .765 | .706 |
| 2.1 | .878 | .840 | .803 | .778 | .718 |
| 2.2 | .888 | .852 | .816 | .793 | .732 |
| 2.3 | .897 | .864 | .828 | .807 | .746 |
| 2.4 | .906 | .875 | .839 | .818 | .759 |
| 2.5 | .914 | .884 | .851 | .829 | .771 |
| 2.6 | .921 | .894 | .862 | .839 | .783 |
| 2.7 | .928 | .901 | .871 | .850 | .795 |
| 2.8 | .935 | .909 | .880 | .859 | .806 |
| 2.9 | .940 | .916 | .888 | .867 | .816 |
| 3.0 | .945 | .923 | .896 | .876 | .826 |
| 3.1 | .950 | .929 | .902 | .884 | .836 |
| 3.2 | .955 | .934 | .909 | .891 | .845 |
| 3.3 | .958 | .940 | .915 | .898 | .853 |
| 3.4 | .962 | .944 | .921 | .905 | .861 |
| 3.5 | .966 | .949 | .927 | .911 | .868 |
| 3.6 | .969 | .953 | .932 | .917 | .874 |
| 3.7 | .971 | .956 | .937 | .922 | .881 |
| 3.8 | .974 | .960 | .941 | .927 | .888 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 30
p = r/n = 22/30

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| 3.9 | .976 | .963 | .945 | .931 | .892 |
| 4.0 | .979 | .966 | .948 | .935 | .897 |
| 4.1 | .981 | .969 | .952 | .939 | .902 |
| 4.2 | .982 | .971 | .956 | .943 | .907 |
| 4.3 | .984 | .973 | .959 | .947 | .912 |
| 4.4 | .985 | .975 | .961 | .950 | .916 |
| 4.5 | .987 | .977 | .964 | .953 | .921 |
| 4.6 | .988 | .979 | .967 | .956 | .926 |
| 4.7 | .989 | .981 | .969 | .959 | .930 |
| 4.8 | .990 | .982 | .971 | .962 | .934 |
| 4.9 | .991 | .984 | .973 | .964 | .938 |
| 5.0 | .992 | .985 | .975 | .966 | .942 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 30$
$p = r/n = 1$

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| .0 | .376 | .326 | .283 | .265 | .222 |
| .1 | .413 | .361 | .317 | .297 | .255 |
| .2 | .450 | .394 | .349 | .328 | .286 |
| .3 | .483 | .429 | .381 | .362 | .317 |
| .4 | .516 | .462 | .413 | .394 | .350 |
| .5 | .550 | .494 | .446 | .426 | .380 |
| .6 | .580 | .526 | .478 | .455 | .409 |
| .7 | .610 | .556 | .507 | .485 | .436 |
| .8 | .638 | .585 | .536 | .515 | .463 |
| .9 | .665 | .613 | .565 | .544 | .490 |
| 1.0 | .691 | .639 | .593 | .570 | .515 |
| 1.1 | .715 | .664 | .618 | .593 | .543 |
| 1.2 | .738 | .688 | .641 | .618 | .566 |
| 1.3 | .759 | .710 | .665 | .639 | .587 |
| 1.4 | .780 | .730 | .687 | .662 | .608 |
| 1.5 | .798 | .751 | .708 | .683 | .629 |
| 1.6 | .815 | .770 | .728 | .703 | .648 |
| 1.7 | .830 | .787 | .746 | .721 | .667 |
| 1.8 | .845 | .803 | .764 | .739 | .685 |
| 1.9 | .858 | .818 | .781 | .755 | .706 |
| 2.0 | .871 | .832 | .797 | .772 | .724 |
| 2.1 | .882 | .844 | .811 | .788 | .741 |
| 2.2 | .892 | .857 | .824 | .802 | .758 |
| 2.3 | .902 | .868 | .836 | .815 | .773 |
| 2.4 | .910 | .879 | .849 | .827 | .786 |
| 2.5 | .919 | .888 | .860 | .839 | .797 |
| 2.6 | .926 | .897 | .870 | .851 | .808 |
| 2.7 | .933 | .906 | .879 | .861 | .819 |
| 2.8 | .939 | .913 | .888 | .870 | .829 |
| 2.9 | .944 | .920 | .897 | .879 | .838 |
| 3.0 | .949 | .926 | .904 | .887 | .847 |
| 3.1 | .954 | .932 | .911 | .895 | .858 |
| 3.2 | .958 | .938 | .917 | .903 | .864 |
| 3.3 | .962 | .943 | .923 | .910 | .873 |
| 3.4 | .965 | .948 | .929 | .916 | .880 |
| 3.5 | .968 | .952 | .934 | .922 | .888 |
| 3.6 | .971 | .956 | .939 | .927 | .895 |
| 3.7 | .974 | .960 | .943 | .933 | .902 |
| 3.8 | .976 | .963 | .948 | .938 | .908 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 30
p = r/n = 1

| | $\gamma = 0.50$ | $\gamma = 0.75$ | $\gamma = 0.90$ | $\gamma = 0.95$ | $\gamma = 0.99$ |
|---|---|---|---|---|---|
| $Z_a/Z_b$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ | $L^*(Z_a/Z_b)$ |
| 3.9 | .978 | .966 | .952 | .942 | .914 |
| 4.0 | .980 | .969 | .955 | .946 | .920 |
| 4.1 | .982 | .971 | .958 | .950 | .925 |
| 4.2 | .984 | .974 | .961 | .954 | .929 |
| 4.3 | .985 | .976 | .964 | .957 | .934 |
| 4.4 | .987 | .978 | .967 | .960 | .938 |
| 4.5 | .988 | .980 | .969 | .963 | .942 |
| 4.6 | .989 | .981 | .972 | .966 | .945 |
| 4.7 | .990 | .983 | .974 | .968 | .949 |
| 4.8 | .991 | .984 | .976 | .971 | .952 |
| 4.9 | .992 | .986 | .978 | .973 | .955 |
| 5.0 | .992 | .987 | .979 | .975 | .958 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 50
p = r/n = 12/50

| | $\gamma = 0.50$ | | $\gamma = 0.75$ | | $\gamma = 0.90$ | | $\gamma = 0.95$ | | $\gamma = 0.99$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{Z_a}{Z_b}$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ |
| .0 | .441 | .368 | .320 | .252 | .207 | .158 | .163 | .111 | .080 | .048 |
| .1 | .471 | .405 | .359 | .292 | .249 | .197 | .203 | .147 | .119 | .073 |
| .2 | .504 | .441 | .397 | .334 | .292 | .240 | .246 | .188 | .155 | .105 |
| .3 | .532 | .477 | .433 | .375 | .337 | .284 | .291 | .231 | .196 | .144 |
| .4 | .560 | .512 | .467 | .417 | .380 | .329 | .335 | .277 | .240 | .187 |
| .5 | .588 | .545 | .503 | .458 | .427 | .375 | .379 | .324 | .291 | .233 |
| .6 | .614 | .578 | .537 | .497 | .469 | .419 | .419 | .372 | .350 | .282 |
| .7 | .638 | .609 | .567 | .535 | .508 | .463 | .463 | .418 | .397 | .332 |
| .8 | .664 | .638 | .600 | .571 | .545 | .504 | .505 | .462 | .454 | .381 |
| .9 | .689 | .666 | .632 | .605 | .580 | .543 | .543 | .505 | .494 | .428 |
| 1.0 | .711 | .692 | .661 | .636 | .614 | .580 | .577 | .544 | .536 | .478 |
| 1.1 | .734 | .717 | .687 | .666 | .642 | .614 | .609 | .581 | .571 | .514 |
| 1.2 | .754 | .740 | .710 | .693 | .669 | .645 | .637 | .614 | .600 | .552 |
| 1.3 | .774 | .761 | .733 | .718 | .693 | .674 | .665 | .645 | .626 | .586 |
| 1.4 | .792 | .781 | .753 | .741 | .715 | .700 | .689 | .673 | .650 | .617 |
| 1.5 | .808 | .800 | .772 | .762 | .736 | .723 | .710 | .698 | .674 | .644 |
| 1.6 | .823 | .817 | .790 | .781 | .754 | .744 | .727 | .720 | .696 | .669 |
| 1.7 | .837 | .833 | .805 | .799 | .770 | .764 | .746 | .740 | .711 | .691 |
| 1.8 | .849 | .848 | .819 | .815 | .787 | .781 | .762 | .758 | .724 | .710 |
| 1.9 | .861 | .861 | .832 | .830 | .803 | .797 | .777 | .775 | .738 | .727 |
| 2.0 | .873 | .873 | .844 | .844 | .816 | .811 | .791 | .789 | .750 | .742 |
| 2.1 | .883 | .885 | .855 | .856 | .828 | .825 | .805 | .803 | .762 | .756 |
| 2.2 | .892 | .895 | .865 | .867 | .839 | .837 | .817 | .815 | .777 | .769 |
| 2.3 | .900 | .905 | .875 | .878 | .850 | .848 | .828 | .827 | .787 | .780 |
| 2.4 | .908 | .913 | .883 | .887 | .860 | .858 | .840 | .837 | .796 | .791 |
| 2.5 | .915 | .921 | .891 | .896 | .868 | .867 | .851 | .847 | .805 | .800 |
| 2.6 | .922 | .928 | .898 | .904 | .876 | .876 | .860 | .856 | .813 | .809 |
| 2.7 | .929 | .935 | .905 | .912 | .883 | .884 | .866 | .864 | .823 | .817 |
| 2.8 | .935 | .941 | .912 | .919 | .891 | .892 | .874 | .872 | .831 | .825 |
| 2.9 | .940 | .946 | .918 | .925 | .897 | .899 | .881 | .879 | .840 | .832 |
| 3.0 | .945 | .951 | .924 | .931 | .903 | .905 | .888 | .886 | .848 | .839 |
| 3.1 | .949 | .956 | .929 | .936 | .908 | .911 | .894 | .892 | .856 | .846 |
| 3.2 | .954 | .960 | .934 | .941 | .914 | .917 | .900 | .898 | .863 | .852 |
| 3.3 | .957 | .964 | .938 | .946 | .919 | .922 | .905 | .904 | .868 | .868 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 50$
$p = r/n = 12/50$

| | $\gamma = 0.50$ | | $\gamma = 0.75$ | | $\gamma = 0.90$ | | $\gamma = 0.95$ | | $\gamma = 0.99$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{Z_a}{Z_b}$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ |
| 3.4 | .961 | .967 | .942 | .950 | .923 | .927 | .909 | .909 | .873 | .863 |
| 3.5 | .964 | .970 | .946 | .954 | .928 | .932 | .914 | .914 | .878 | .868 |
| 3.6 | .967 | .973 | .950 | .957 | .932 | .936 | .919 | .919 | .883 | .873 |
| 3.7 | .970 | .976 | .953 | .961 | .936 | .940 | .922 | .923 | .888 | .878 |
| 3.8 | .972 | .978 | .957 | .964 | .940 | .944 | .925 | .927 | .892 | .882 |
| 3.9 | .975 | .980 | .960 | .967 | .943 | .947 | .930 | .931 | .898 | .887 |
| 4.0 | .977 | .982 | .962 | .969 | .946 | .951 | .934 | .935 | .903 | .891 |
| 4.1 | .979 | .984 | .965 | .972 | .949 | .954 | .937 | .938 | .908 | .895 |
| 4.2 | .981 | .985 | .967 | .974 | .952 | .957 | .940 | .942 | .912 | .899 |
| 4.3 | .982 | .987 | .969 | .976 | .955 | .959 | .944 | .945 | .917 | .902 |
| 4.4 | .984 | .988 | .971 | .978 | .957 | .962 | .947 | .948 | .921 | .906 |
| 4.5 | .985 | .989 | .973 | .980 | .960 | .964 | .949 | .951 | .924 | .909 |
| 4.6 | .986 | .990 | .975 | .981 | .962 | .967 | .951 | .953 | .926 | .913 |
| 4.7 | .987 | .991 | .977 | .983 | .965 | .969 | .954 | .956 | .928 | .916 |
| 4.8 | .988 | .992 | .979 | .984 | .967 | .971 | .957 | .958 | .931 | .919 |
| 4.9 | .989 | .993 | .980 | .985 | .969 | .973 | .959 | .960 | .934 | .922 |
| 5.0 | .990 | .993 | .982 | .988 | .971 | .974 | .961 | .962 | .937 | .924 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$
$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 50
p = r/n = 25/50

| | $\gamma = 0.50$ | | $\gamma = 0.75$ | | $\gamma = 0.90$ | | $\gamma = 0.95$ | | $\gamma = 0.99$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{Z_a}{Z_b}$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ |
| .0 | .383 | .368 | .333 | .313 | .286 | .264 | .258 | .236 | .209 | .186 |
| .1 | .419 | .405 | .368 | .351 | .325 | .303 | .297 | .275 | .249 | .224 |
| .2 | .456 | .441 | .406 | .389 | .363 | .342 | .336 | .315 | .288 | .263 |
| .3 | .488 | .477 | .444 | .427 | .399 | .382 | .377 | .354 | .328 | .303 |
| .4 | .522 | .512 | .477 | .464 | .436 | .420 | .414 | .393 | .368 | .342 |
| .5 | .555 | .545 | .509 | .499 | .471 | .457 | .451 | .430 | .408 | .381 |
| .6 | .586 | .578 | .543 | .534 | .507 | .492 | .483 | .466 | .441 | .417 |
| .7 | .615 | .600 | .573 | .566 | .540 | .526 | .515 | .500 | .475 | .452 |
| .8 | .643 | .638 | .603 | .597 | .569 | .557 | .546 | .533 | .502 | .484 |
| .9 | .670 | .666 | .630 | .626 | .596 | .587 | .575 | .563 | .534 | .515 |
| 1.0 | .695 | .692 | .658 | .653 | .622 | .615 | .601 | .591 | .560 | .544 |
| 1.1 | .718 | .717 | .682 | .679 | .647 | .641 | .626 | .618 | .584 | .570 |
| 1.2 | .741 | .740 | .705 | .703 | .672 | .666 | .651 | .642 | .605 | .595 |
| 1.3 | .761 | .761 | .727 | .725 | .693 | .689 | .673 | .666 | .627 | .618 |
| 1.4 | .780 | .781 | .746 | .746 | .714 | .710 | .692 | .687 | .649 | .640 |
| 1.5 | .798 | .800 | .766 | .766 | .732 | .730 | .711 | .707 | .669 | .660 |
| 1.6 | .816 | .817 | .783 | .784 | .750 | .749 | .728 | .726 | .688 | .679 |
| 1.7 | .830 | .833 | .799 | .800 | .767 | .767 | .745 | .744 | .706 | .697 |
| 1.8 | .845 | .848 | .815 | .816 | .784 | .783 | .761 | .761 | .724 | .714 |
| 1.9 | .857 | .801 | .829 | .831 | .800 | .798 | .776 | .776 | .741 | .729 |
| 2.0 | .869 | .873 | .842 | .844 | .813 | .812 | .789 | .791 | .757 | .744 |
| 2.1 | .880 | .885 | .854 | .856 | .827 | .825 | .804 | .804 | .770 | .758 |
| 2.2 | .890 | .895 | .865 | .868 | .839 | .838 | .816 | .817 | .781 | .771 |
| 2.3 | .900 | .905 | .875 | .878 | .850 | .849 | .828 | .829 | .793 | .784 |
| 2.4 | .908 | .913 | .885 | .888 | .861 | .860 | .839 | .840 | .803 | .796 |
| 2.5 | .916 | .921 | .893 | .897 | .871 | .870 | .849 | .850 | .814 | .807 |
| 2.6 | .923 | .928 | .901 | .906 | .879 | .879 | .859 | .860 | .823 | .817 |
| 2.7 | .930 | .935 | .909 | .913 | .888 | .888 | .867 | .869 | .834 | .827 |
| 2.8 | .936 | .941 | .916 | .920 | .896 | .896 | .875 | .878 | .843 | .836 |
| 2.9 | .942 | .946 | .922 | .927 | .903 | .903 | .884 | .886 | .851 | .845 |
| 3.0 | .947 | .951 | .928 | .933 | .910 | .910 | .891 | .893 | .859 | .854 |
| 3.1 | .951 | .956 | .934 | .938 | .916 | .917 | .898 | .900 | .867 | .862 |
| 3.2 | .956 | .960 | .939 | .943 | .922 | .923 | .905 | .907 | .874 | .869 |
| 3.3 | .960 | .964 | .944 | .948 | .927 | .928 | .911 | .913 | .880 | .876 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 50
p = r/n = 25/50

| | $\gamma = 0.50$ | | $\gamma = 0.75$ | | $\gamma = 0.90$ | | $\gamma = 0.95$ | | $\gamma = 0.99$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{Z_a}{Z_b}$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ |
| 3.4 | .963 | .967 | .948 | .952 | .932 | .933 | .917 | .919 | .887 | .883 |
| 3.5 | .966 | .970 | .952 | .956 | .937 | .938 | .923 | .924 | .894 | .889 |
| 3.6 | .969 | .973 | .956 | .960 | .941 | .943 | .928 | .929 | .901 | .895 |
| 3.7 | .972 | .976 | .959 | .963 | .946 | .947 | .933 | .934 | .907 | .901 |
| 3.8 | .975 | .978 | .963 | .966 | .949 | .951 | .937 | .938 | .913 | .907 |
| 3.9 | .977 | .980 | .966 | .969 | .953 | .954 | .941 | .942 | .918 | .912 |
| 4.0 | .979 | .982 | .969 | .972 | .956 | .958 | .945 | .946 | .922 | .917 |
| 4.1 | .981 | .984 | .971 | .974 | .959 | .961 | .949 | .950 | .927 | .921 |
| 4.2 | .983 | .985 | .973 | .976 | .962 | .964 | .953 | .953 | .931 | .925 |
| 4.3 | .984 | .987 | .975 | .978 | .965 | .966 | .956 | .956 | .935 | .930 |
| 4.4 | .986 | .988 | .977 | .980 | .967 | .969 | .959 | .959 | .940 | .933 |
| 4.5 | .987 | .989 | .979 | .982 | .969 | .971 | .962 | .962 | .943 | .937 |
| 4.6 | .988 | .990 | .981 | .983 | .972 | .973 | .964 | .965 | .947 | .941 |
| 4.7 | .989 | .991 | .982 | .985 | .973 | .975 | .967 | .967 | .950 | .944 |
| 4.8 | .990 | .992 | .984 | .986 | .975 | .977 | .969 | .969 | .953 | .947 |
| 4.9 | .991 | .993 | .985 | .987 | .977 | .979 | .971 | .971 | .955 | .950 |
| 5.0 | .992 | .993 | .986 | .988 | .979 | .980 | .973 | .973 | .958 | .953 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 50
p = r/n = 37/50

| | $\gamma = 0.50$ | | $\gamma = 0.75$ | | $\gamma = 0.90$ | | $\gamma = 0.95$ | | $\gamma = 0.99$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{Z_a}{Z_b}$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ |
| .0 | .377 | .368 | .335 | .327 | .304 | .291 | .283 | .270 | .252 | .231 |
| .1 | .413 | .405 | .371 | .364 | .339 | .327 | .317 | .305 | .291 | .265 |
| .2 | .448 | .441 | .406 | .400 | .373 | .363 | .352 | .341 | .328 | .300 |
| .3 | .483 | .477 | .442 | .436 | .409 | .399 | .387 | .376 | .358 | .334 |
| .4 | .517 | .512 | .477 | .471 | .441 | .434 | .422 | .411 | .389 | .368 |
| .5 | .549 | .545 | .510 | .505 | .475 | .467 | .457 | .444 | .422 | .401 |
| .6 | .580 | .578 | .542 | .538 | .506 | .500 | .489 | .477 | .452 | .432 |
| .7 | .610 | .609 | .572 | .569 | .537 | .531 | .521 | .508 | .478 | .463 |
| .8 | .639 | .638 | .601 | .599 | .567 | .561 | .548 | .538 | .506 | .492 |
| .9 | .666 | .666 | .630 | .627 | .596 | .590 | .574 | .566 | .533 | .520 |
| 1.0 | .692 | .692 | .657 | .654 | .621 | .617 | .601 | .593 | .555 | .546 |
| 1.1 | .717 | .717 | .681 | .679 | .645 | .642 | .626 | .619 | .575 | .572 |
| 1.2 | .789 | .740 | .704 | .703 | .669 | .666 | .649 | .643 | .599 | .596 |
| 1.3 | .760 | .761 | .726 | .725 | .692 | .689 | .671 | .666 | .625 | .619 |
| 1.4 | .780 | .781 | .746 | .746 | .713 | .711 | .691 | .688 | .645 | .641 |
| 1.5 | .798 | .800 | .765 | .766 | .733 | .731 | .712 | .708 | .665 | .661 |
| 1.6 | .815 | .817 | .783 | .784 | .751 | .750 | .731 | .727 | .687 | .681 |
| 1.7 | .831 | .833 | .799 | .801 | .768 | .768 | .748 | .746 | .708 | .699 |
| 1.8 | .845 | .848 | .816 | .817 | .785 | .784 | .765 | .763 | .728 | .717 |
| 1.9 | .858 | .861 | .830 | .831 | .800 | .800 | .780 | .779 | .743 | .734 |
| 2.0 | .870 | .873 | .844 | .845 | .815 | .814 | .795 | .794 | .755 | .750 |
| 2.1 | .882 | .885 | .857 | .857 | .828 | .828 | .809 | .808 | .768 | .764 |
| 2.2 | .892 | .895 | .868 | .869 | .840 | .841 | .822 | .821 | .779 | .779 |
| 2.3 | .901 | .905 | .879 | .880 | .852 | .852 | .834 | .833 | .792 | .792 |
| 2.4 | .910 | .913 | .889 | .890 | .863 | .863 | .846 | .845 | .805 | .804 |
| 2.5 | .918 | .921 | .898 | .899 | .873 | .874 | .857 | .856 | .817 | .816 |
| 2.6 | .926 | .928 | .906 | .907 | .883 | .883 | .867 | .866 | .829 | .828 |
| 2.7 | .932 | .935 | .913 | .915 | .892 | .892 | .877 | .875 | .840 | .838 |
| 2.8 | .938 | .941 | .921 | .922 | .899 | .900 | .885 | .884 | .850 | .848 |
| 2.9 | .944 | .946 | .927 | .929 | .907 | .908 | .893 | .892 | .860 | .857 |
| 3.0 | .949 | .951 | .933 | .935 | .914 | .915 | .901 | .900 | .869 | .866 |
| 3.1 | .954 | .956 | .939 | .940 | .920 | .921 | .908 | .907 | .877 | .875 |
| 3.2 | .958 | .960 | .944 | .945 | .927 | .927 | .915 | .914 | .885 | .882 |
| 3.3 | .961 | .964 | .948 | .950 | .932 | .933 | .921 | .920 | .893 | .890 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 50$

$p = r/n = 37/50$

| | $\gamma = 0.50$ | | $\gamma = 0.75$ | | $\gamma = 0.90$ | | $\gamma = 0.95$ | | $\gamma = 0.99$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{Z_a}{Z_b}$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ |
| 3.4 | .965 | .967 | .952 | .954 | .937 | .938 | .927 | .926 | .900 | .897 |
| 3.5 | .968 | .970 | .956 | .958 | .942 | .943 | .932 | .931 | .905 | .903 |
| 3.6 | .971 | .973 | .960 | .962 | .946 | .947 | .937 | .936 | .911 | .909 |
| 3.7 | .974 | .976 | .963 | .965 | .950 | .951 | .942 | .941 | .916 | .915 |
| 3.8 | .976 | .978 | .966 | .968 | .954 | .955 | .946 | .945 | .921 | .920 |
| 3.9 | .978 | .980 | .969 | .971 | .957 | .958 | .950 | .949 | .926 | .925 |
| 4.0 | .980 | .982 | .972 | .973 | .961 | .962 | .954 | .953 | .930 | .930 |
| 4.1 | .982 | .984 | .974 | .975 | .963 | .965 | .957 | .956 | .934 | .934 |
| 4.2 | .984 | .985 | .976 | .977 | .966 | .967 | .960 | .959 | .938 | .939 |
| 4.3 | .985 | .987 | .978 | .979 | .969 | .970 | .963 | .962 | .942 | .942 |
| 4.4 | .987 | .988 | .980 | .981 | .971 | .972 | .966 | .965 | .945 | .946 |
| 4.5 | .988 | .989 | .982 | .983 | .973 | .974 | .968 | .968 | .949 | .950 |
| 4.6 | .989 | .990 | .983 | .984 | .975 | .976 | .971 | .970 | .952 | .953 |
| 4.7 | .990 | .991 | .985 | .986 | .977 | .978 | .973 | .972 | .955 | .956 |
| 4.8 | .991 | .992 | .986 | .987 | .979 | .980 | .975 | .974 | .957 | .959 |
| 4.9 | .992 | .993 | .987 | .988 | .981 | .981 | .977 | .976 | .960 | .961 |
| 5.0 | .992 | .993 | .988 | .989 | .982 | .983 | .979 | .978 | .953 | .964 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 50
p = r/n = 1

| | $\gamma = 0.50$ | | $\gamma = 0.75$ | | $\gamma = 0.90$ | | $\gamma = 0.95$ | | $\gamma = 0.99$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{Z_a}{Z_b}$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ |
| .0 | .372 | .368 | .336 | .331 | .304 | .298 | .284 | .279 | .263 | .243 |
| .1 | .408 | .405 | .372 | .367 | .339 | .333 | .320 | .312 | .294 | .275 |
| .2 | .444 | .441 | .408 | .402 | .374 | .367 | .356 | .346 | .325 | .307 |
| .3 | .480 | .477 | .443 | .438 | .407 | .402 | .390 | .380 | .356 | .339 |
| .4 | .514 | .512 | .477 | .472 | .442 | .435 | .422 | .413 | .388 | .371 |
| .5 | .547 | .545 | .510 | .506 | .474 | .468 | .456 | .446 | .417 | .403 |
| .6 | .579 | .578 | .542 | .538 | .506 | .501 | .487 | .478 | .448 | .433 |
| .7 | .610 | .609 | .572 | .569 | .537 | .532 | .517 | .508 | .476 | .464 |
| .8 | .639 | .638 | .603 | .599 | .586 | .561 | .548 | .538 | .507 | .493 |
| .9 | .667 | .666 | .630 | .627 | .595 | .590 | .577 | .567 | .535 | .521 |
| 1.0 | .693 | .692 | .657 | .654 | .621 | .617 | .603 | .594 | .562 | .548 |
| 1.1 | .718 | .717 | .683 | .680 | .647 | .643 | .628 | .620 | .590 | .574 |
| 1.2 | .741 | .740 | .707 | .704 | .671 | .668 | .652 | .645 | .617 | .599 |
| 1.3 | .762 | .761 | .728 | .726 | .695 | .691 | .675 | .669 | .641 | .623 |
| 1.4 | .782 | .781 | .749 | .747 | .718 | .713 | .698 | .691 | .663 | .646 |
| 1.5 | .800 | .800 | .769 | .767 | .738 | .734 | .719 | .712 | .682 | .668 |
| 1.6 | .818 | .817 | .787 | .786 | .757 | .753 | .738 | .732 | .701 | .689 |
| 1.7 | .834 | .833 | .804 | .803 | .775 | .772 | .757 | .751 | .720 | .708 |
| 1.8 | .848 | .848 | .819 | .819 | .791 | .789 | .774 | .769 | .739 | .727 |
| 1.9 | .861 | .861 | .834 | .833 | .806 | .804 | .791 | .785 | .756 | .744 |
| 2.0 | .874 | .873 | .848 | .847 | .821 | .819 | .807 | .801 | .773 | .761 |
| 2.1 | .885 | .885 | .860 | .860 | .834 | .833 | .822 | .815 | .789 | .776 |
| 2.2 | .895 | .895 | .872 | .871 | .847 | .846 | .835 | .828 | .803 | .791 |
| 2.3 | .905 | .905 | .882 | .882 | .859 | .858 | .847 | .841 | .817 | .805 |
| 2.4 | .914 | .913 | .892 | .892 | .870 | .869 | .858 | .853 | .829 | .818 |
| 2.5 | .922 | .921 | .901 | .901 | .880 | .879 | .869 | .864 | .840 | .830 |
| 2.6 | .929 | .928 | .910 | .910 | .890 | .889 | .878 | .874 | .851 | .842 |
| 2.7 | .935 | .935 | .917 | .917 | .899 | .897 | .887 | .883 | .860 | .852 |
| 2.8 | .941 | .941 | .924 | .924 | .907 | .905 | .896 | .892 | .870 | .862 |
| 2.9 | .946 | .946 | .931 | .931 | .914 | .913 | .904 | .900 | .878 | .872 |
| 3.0 | .951 | .951 | .937 | .937 | .921 | .920 | .911 | .908 | .886 | .881 |
| 3.1 | .956 | .956 | .942 | .942 | .927 | .926 | .918 | .915 | .894 | .889 |
| 3.2 | .960 | .960 | .947 | .947 | .933 | .932 | .924 | .921 | .901 | .897 |
| 3.3 | .964 | .964 | .952 | .952 | .939 | .938 | .930 | .927 | .908 | .904 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 50$
$p = r/n = 1$

| | $\gamma = 0.50$ | | $\gamma = 0.75$ | | $\gamma = 0.90$ | | $\gamma = 0.95$ | | $\gamma = 0.99$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{z_a}{z_b}$ | $L^*\left(\frac{z_a}{z_b}\right)$ | $L_A^*\left(\frac{z_a}{z_b}\right)$ | $L^*\left(\frac{z_a}{z_b}\right)$ | $L_A^*\left(\frac{z_a}{z_b}\right)$ | $L^*\left(\frac{z_a}{z_b}\right)$ | $L_A^*\left(\frac{z_a}{z_b}\right)$ | $L^*\left(\frac{z_a}{z_b}\right)$ | $L_A^*\left(\frac{z_a}{z_b}\right)$ | $L^*\left(\frac{z_a}{z_b}\right)$ | $L_A^*\left(\frac{z_a}{z_b}\right)$ |
| 3.4 | .967 | .967 | .956 | .956 | .944 | .943 | .935 | .933 | .914 | .910 |
| 3.5 | .970 | .970 | .960 | .960 | .948 | .947 | .940 | .938 | .920 | .917 |
| 3.6 | .973 | .973 | .963 | .963 | .952 | .952 | .945 | .943 | .925 | .922 |
| 3.7 | .976 | .976 | .966 | .966 | .956 | .956 | .949 | .947 | .930 | .928 |
| 3.8 | .978 | .978 | .969 | .969 | .960 | .959 | .953 | .951 | .935 | .933 |
| 3.9 | .980 | .980 | .972 | .972 | .963 | .962 | .956 | .955 | .940 | .938 |
| 4.0 | .982 | .982 | .974 | .975 | .966 | .965 | .960 | .959 | .944 | .942 |
| 4.1 | .983 | .984 | .977 | .977 | .969 | .968 | .963 | .962 | .948 | .946 |
| 4.2 | .985 | .985 | .979 | .979 | .971 | .971 | .966 | .965 | .951 | .950 |
| 4.3 | .986 | .987 | .981 | .981 | .974 | .973 | .969 | .968 | .955 | .954 |
| 4.4 | .988 | .988 | .982 | .982 | .976 | .975 | .971 | .970 | .958 | .957 |
| 4.5 | .989 | .989 | .984 | .984 | .978 | .977 | .973 | .972 | .960 | .960 |
| 4.6 | .990 | .990 | .985 | .985 | .980 | .979 | .976 | .975 | .963 | .963 |
| 4.7 | .991 | .991 | .980 | .987 | .981 | .981 | .978 | .977 | .965 | .965 |
| 4.8 | .992 | .992 | .988 | .988 | .983 | .983 | .979 | .978 | .968 | .968 |
| 4.9 | .993 | .993 | .989 | .989 | .984 | .984 | .981 | .980 | .970 | .970 |
| 5.0 | .993 | .993 | .990 | .990 | .986 | .985 | .982 | .982 | .972 | .972 |

$L^*(z_a/z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(z_a/z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 100$
$p = r/n = 25/100$

| $\frac{z_a}{z_b}$ | $\gamma = 0.50$ | | $\gamma = 0.75$ | | $\gamma = 0.90$ | | $\gamma = 0.95$ | | $\gamma = 0.99$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $L^*\left(\frac{z_a}{z_b}\right)$ | $L_A^*\left(\frac{z_a}{z_b}\right)$ | $L^*\left(\frac{z_a}{z_b}\right)$ | $L_A^*\left(\frac{z_a}{z_b}\right)$ | $L^*\left(\frac{z_a}{z_b}\right)$ | $L_A^*\left(\frac{z_a}{z_b}\right)$ | $L^*\left(\frac{z_a}{z_b}\right)$ | $L_A^*\left(\frac{z_a}{z_b}\right)$ | $L^*\left(\frac{z_a}{z_b}\right)$ | $L_A^*\left(\frac{z_a}{z_b}\right)$ |
| .0 | .402 | .308 | .315 | .288 | .243 | .220 | .193 | .182 | .119 | .119 |
| .1 | .437 | .405 | .353 | .328 | .282 | .261 | .234 | .222 | .157 | .156 |
| .2 | .469 | .441 | .390 | .368 | .325 | .303 | .280 | .205 | .198 | .197 |
| .3 | .501 | .477 | .428 | .409 | .368 | .346 | .321 | .309 | .240 | .241 |
| .4 | .534 | .512 | .466 | .448 | .408 | .389 | .863 | .353 | .284 | .287 |
| .5 | .564 | .545 | .503 | .487 | .449 | .431 | .408 | .397 | .333 | .384 |
| .6 | .593 | .578 | .538 | .524 | .487 | .472 | .451 | .441 | .384 | .380 |
| .7 | .622 | .609 | .573 | .559 | .526 | .512 | .492 | .483 | .432 | .426 |
| .8 | .648 | .638 | .605 | .593 | .562 | .550 | .533 | .522 | .484 | .469 |
| .9 | .675 | .636 | .635 | .625 | .595 | .585 | .569 | .560 | .525 | .511 |
| 1.0 | .699 | .692 | .663 | .655 | .626 | .618 | .605 | .595 | .566 | .550 |
| 1.1 | .723 | .717 | .690 | .682 | .655 | .649 | .637 | .628 | .603 | .585 |
| 1.2 | .745 | .740 | .713 | .708 | .683 | .677 | .668 | .657 | .635 | .618 |
| 1.3 | .765 | .761 | .737 | .732 | .708 | .703 | .695 | .685 | .662 | .648 |
| 1.4 | .784 | .781 | .758 | .754 | .730 | .727 | .717 | .710 | .683 | .675 |
| 1.5 | .801 | .800 | .777 | .774 | .752 | .749 | .740 | .732 | .704 | .699 |
| 1.6 | .818 | .817 | .796 | .793 | .771 | .768 | .758 | .753 | .724 | .721 |
| 1.7 | .833 | .833 | .812 | .810 | .790 | .787 | .776 | .772 | .746 | .741 |
| 1.8 | .848 | .848 | .827 | .825 | .806 | .803 | .791 | .789 | .764 | .759 |
| 1.9 | .861 | .861 | .840 | .840 | .821 | .818 | .806 | .804 | .777 | .775 |
| 2.0 | .873 | .873 | .853 | .853 | .834 | .832 | .820 | .818 | .791 | .790 |
| 2.1 | .884 | .885 | .865 | .865 | .846 | .845 | .832 | .831 | .805 | .803 |
| 2.2 | .894 | .893 | .875 | .876 | .857 | .856 | .843 | .843 | .819 | .815 |
| 2.3 | .902 | .905 | .885 | .886 | .867 | .867 | .854 | .854 | .832 | .827 |
| 2.4 | .911 | .913 | .894 | .896 | .876 | .877 | .863 | .864 | .843 | .837 |
| 2.5 | .919 | .921 | .903 | .904 | .885 | .886 | .872 | .874 | .853 | .847 |
| 2.6 | .926 | .928 | .910 | .912 | .894 | .894 | .880 | .882 | .862 | .856 |
| 2.7 | .932 | .935 | .917 | .919 | .901 | .902 | .888 | .890 | .872 | .864 |
| 2.8 | .938 | .941 | .923 | .926 | .908 | .909 | .895 | .898 | .881 | .872 |
| 2.9 | .944 | .946 | .929 | .932 | .914 | .916 | .902 | .905 | .888 | .879 |
| 3.0 | .949 | .951 | .934 | .938 | .920 | .922 | .909 | .911 | .895 | .886 |
| 3.1 | .953 | .956 | .940 | .943 | .926 | .928 | .915 | .917 | .901 | .892 |
| 3.2 | .957 | .960 | .944 | .948 | .931 | .933 | .921 | .923 | .907 | .899 |
| 3.3 | .961 | .964 | .949 | .952 | .935 | .938 | .926 | .928 | .913 | .904 |

$L^*(z_a/z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(z_a/z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 100$
$p = r/n = 25/100$

| | $\gamma = 0.50$ | | $\gamma = 0.75$ | | $\gamma = 0.90$ | | $\gamma = 0.95$ | | $\gamma = 0.99$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{Z_a}{Z_b}$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ |
| 3.4 | .965 | .967 | .953 | .956 | .940 | .942 | .931 | .933 | .918 | .909 |
| 3.5 | .968 | .970 | .956 | .959 | .944 | .947 | .935 | .937 | .923 | .914 |
| 3.6 | .971 | .973 | .960 | .963 | .948 | .950 | .939 | .941 | .928 | .919 |
| 3.7 | .973 | .976 | .963 | .966 | .951 | .954 | .944 | .945 | .932 | .924 |
| 3.8 | .976 | .978 | .965 | .969 | .955 | .957 | .947 | .949 | .936 | .928 |
| 3.9 | .978 | .980 | .908 | .971 | .958 | .960 | .951 | .952 | .940 | .932 |
| 4.0 | .980 | .982 | .971 | .974 | .961 | .963 | .954 | .955 | .943 | .935 |
| 4.1 | .982 | .984 | .973 | .976 | .964 | .966 | .957 | .958 | .947 | .939 |
| 4.2 | .983 | .985 | .976 | .978 | .966 | .968 | .960 | .961 | .950 | .942 |
| 4.3 | .985 | .987 | .977 | .980 | .968 | .971 | .963 | .964 | .953 | .945 |
| 4.4 | .986 | .988 | .979 | .981 | .971 | .973 | .965 | .966 | .956 | .948 |
| 4.5 | .987 | .989 | .981 | .983 | .973 | .975 | .967 | .968 | .958 | .951 |
| 4.6 | .989 | .990 | .982 | .984 | .975 | .977 | .969 | .970 | .961 | .954 |
| 4.7 | .990 | .991 | .984 | .986 | .976 | .978 | .971 | .972 | .963 | .956 |
| 4.8 | .991 | .992 | .985 | .987 | .978 | .980 | .973 | .974 | .985 | .959 |
| 4.9 | .991 | .993 | .986 | .988 | .979 | .981 | .975 | .976 | .967 | .961 |
| 5.0 | .992 | .993 | .987 | .989 | .981 | .983 | .977 | .978 | .969 | .963 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 100
p = r/n = 50/100

| | $\gamma = 0.50$ | | $\gamma = 0.75$ | | $\gamma = 0.90$ | | $\gamma = 0.95$ | | $\gamma = 0.99$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{Z_a}{Z_b}$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ |
| .0 | .377 | .368 | .339 | .329 | .309 | .294 | .287 | .273 | .244 | .236 |
| .1 | .413 | .405 | .377 | .367 | .348 | .333 | .323 | .312 | .284 | .275 |
| .2 | .448 | .441 | .413 | .405 | .386 | .371 | .361 | .352 | .318 | .315 |
| .3 | .483 | .477 | .450 | .442 | .422 | .410 | .400 | .390 | .359 | .354 |
| .4 | .516 | .512 | .486 | .478 | .458 | .447 | .439 | .428 | .399 | .393 |
| .5 | .549 | .545 | .522 | .513 | .493 | .483 | .476 | .465 | .441 | .430 |
| .6 | .581 | .578 | .555 | .547 | .525 | .518 | .510 | .500 | .477 | .466 |
| .7 | .612 | .609 | .586 | .579 | .557 | .551 | .542 | .534 | .511 | .500 |
| .8 | .640 | .638 | .615 | .609 | .587 | .582 | .571 | .565 | .540 | .533 |
| .9 | .668 | .666 | .643 | .638 | .617 | .611 | .598 | .595 | .567 | .563 |
| 1.0 | .694 | .692 | .669 | .665 | .644 | .639 | .626 | .623 | .595 | .591 |
| 1.1 | .718 | .717 | .695 | .690 | .669 | .665 | .652 | .649 | .621 | .618 |
| 1.2 | .741 | .740 | .717 | .714 | .691 | .689 | .676 | .673 | .644 | .642 |
| 1.3 | .761 | .761 | .738 | .736 | .713 | .712 | .698 | .696 | .667 | .666 |
| 1.4 | .781 | .781 | .759 | .757 | .734 | .733 | .720 | .718 | .687 | .687 |
| 1.5 | .798 | .800 | .777 | .776 | .753 | .753 | .739 | .738 | .707 | .707 |
| 1.6 | .816 | .817 | .794 | .794 | .771 | .771 | .756 | .756 | .726 | .726 |
| 1.7 | .831 | .833 | .810 | .811 | .788 | .788 | .773 | .774 | .745 | .744 |
| 1.8 | .846 | .848 | .825 | .826 | .804 | .804 | .790 | .790 | .762 | .761 |
| 1.9 | .859 | .861 | .840 | .840 | .818 | .819 | .804 | .805 | .776 | .776 |
| 2.0 | .872 | .873 | .852 | .853 | .832 | .832 | .818 | .819 | .792 | .791 |
| 2.1 | .883 | .885 | .864 | .865 | .845 | .845 | .832 | .832 | .805 | .804 |
| 2.2 | .893 | .895 | .875 | .876 | .857 | .857 | .844 | .844 | .818 | .817 |
| 2.3 | .903 | .905 | .885 | .887 | .867 | .868 | .855 | .855 | .830 | .829 |
| 2.4 | .912 | .913 | .894 | .896 | .877 | .878 | .866 | .866 | .842 | .840 |
| 2.5 | .919 | .921 | .903 | .905 | .887 | .887 | .875 | .876 | .851 | .850 |
| 2.6 | .927 | .928 | .911 | .913 | .895 | .896 | .884 | .885 | .861 | .860 |
| 2.7 | .933 | .935 | .918 | .920 | .903 | .904 | .892 | .893 | .870 | .869 |
| 2.8 | .939 | .941 | .925 | .927 | .910 | .912 | .900 | .901 | .879 | .878 |
| 2.9 | .944 | .946 | .931 | .933 | .917 | .919 | .907 | .908 | .887 | .886 |
| 3.0 | .949 | .951 | .937 | .939 | .923 | .925 | .914 | .915 | .894 | .893 |
| 3.1 | .954 | .956 | .942 | .944 | .929 | .931 | .919 | .921 | .902 | .900 |
| 3.2 | .958 | .960 | .947 | .949 | .934 | .936 | .925 | .927 | .908 | .907 |
| 3.3 | .962 | .964 | .952 | .953 | .940 | .941 | .931 | .933 | .915 | .913 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 100$
$p = r/n = 50/100$

| | $\gamma = 0.50$ | | $\gamma = 0.75$ | | $\gamma = 0.90$ | | $\gamma = 0.95$ | | $\gamma = 0.99$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{Z_a}{Z_b}$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ |
| 3.4 | .966 | .967 | .956 | .957 | .944 | .946 | .936 | .938 | .921 | .919 |
| 3.5 | .969 | .970 | .959 | .961 | .949 | .950 | .941 | .942 | .926 | .924 |
| 3.6 | .972 | .973 | .963 | .964 | .953 | .954 | .945 | .947 | .932 | .929 |
| 3.7 | .974 | .976 | .966 | .967 | .956 | .958 | .949 | .951 | .937 | .934 |
| 3.8 | .977 | .978 | .968 | .970 | .960 | .961 | .953 | .954 | .941 | .938 |
| 3.9 | .979 | .980 | .971 | .973 | .963 | .964 | .957 | .958 | .945 | .942 |
| 4.0 | .981 | .982 | .974 | .975 | .966 | .967 | .960 | .961 | .948 | .946 |
| 4.1 | .982 | .984 | .976 | .977 | .968 | .970 | .963 | .964 | .952 | .950 |
| 4.2 | .984 | .985 | .978 | .979 | .971 | .972 | .966 | .966 | .955 | .953 |
| 4.3 | .986 | .987 | .980 | .981 | .973 | .974 | .968 | .969 | .958 | .956 |
| 4.4 | .987 | .988 | .981 | .983 | .975 | .976 | .971 | .971 | .961 | .959 |
| 4.5 | .988 | .989 | .983 | .984 | .977 | .978 | .973 | .973 | .964 | .962 |
| 4.6 | .989 | .990 | .984 | .986 | .979 | .980 | .975 | .975 | .966 | .965 |
| 4.7 | .990 | .991 | .986 | .987 | .981 | .981 | .977 | .977 | .968 | .967 |
| 4.8 | .991 | .992 | .987 | .988 | .982 | .983 | .979 | .979 | .971 | .969 |
| 4.9 | .992 | .993 | .988 | .989 | .983 | .984 | .980 | .981 | .973 | .971 |
| 5.0 | .993 | .993 | .989 | .990 | .985 | .986 | .982 | .982 | .975 | .973 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 100
p = r/n = 75/100

| | $\gamma$ = 0.50 | | $\gamma$ = 0.75 | | $\gamma$ = 0.90 | | $\gamma$ = 0.95 | | $\gamma$ = 0.99 | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{Z_a}{Z_b}$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ |
| .0 | .374 | .368 | .347 | .339 | .320 | .314 | .305 | .298 | .273 | .270 |
| .1 | .410 | .405 | .383 | .376 | .357 | .350 | .341 | .335 | .307 | .306 |
| .2 | .445 | .441 | .419 | .412 | .393 | .386 | .377 | .371 | .343 | .342 |
| .3 | .480 | .477 | .455 | .448 | .427 | .422 | .414 | .406 | .383 | .377 |
| .4 | .515 | .512 | .489 | .483 | .461 | .457 | .448 | .441 | .421 | .411 |
| .5 | .548 | .545 | .523 | .517 | .494 | .491 | .481 | .475 | .452 | .445 |
| .6 | .579 | .578 | .555 | .550 | .526 | .523 | .513 | .508 | .482 | .477 |
| .7 | .609 | .609 | .585 | .581 | .557 | .555 | .543 | .539 | .513 | .508 |
| .8 | .639 | .638 | .613 | .611 | .587 | .585 | .572 | .569 | .541 | .538 |
| .9 | .666 | .666 | .641 | .639 | .615 | .613 | .599 | .597 | .568 | .566 |
| 1.0 | .692 | .692 | .668 | .665 | .642 | .640 | .625 | .624 | .594 | .593 |
| 1.1 | .716 | .717 | .692 | .691 | .666 | .665 | .650 | .650 | .619 | .619 |
| 1.2 | .739 | .740 | .715 | .714 | .690 | .689 | .675 | .674 | .642 | .643 |
| 1.3 | .761 | .761 | .737 | .736 | .712 | .712 | .695 | .696 | .666 | .666 |
| 1.4 | .780 | .781 | .758 | .757 | .732 | .733 | .718 | .718 | .688 | .688 |
| 1.5 | .798 | .800 | .777 | .776 | .753 | .753 | .738 | .738 | .709 | .708 |
| 1.6 | .816 | .817 | .794 | .794 | .771 | .772 | .757 | .757 | .728 | .727 |
| 1.7 | .831 | .833 | .811 | .811 | .788 | .789 | .775 | .775 | .747 | .746 |
| 1.8 | .846 | .848 | .826 | .826 | .804 | .805 | .790 | .791 | .764 | .763 |
| 1.9 | .859 | .861 | .840 | .841 | .819 | .820 | .807 | .806 | .779 | .779 |
| 2.0 | .872 | .873 | .853 | .854 | .833 | .834 | .821 | .821 | .793 | .794 |
| 2.1 | .883 | .885 | .865 | .866 | .846 | .847 | .834 | .834 | .808 | .808 |
| 2.2 | .893 | .895 | .876 | .877 | .858 | .859 | .847 | .847 | .821 | .821 |
| 2.3 | .903 | .905 | .887 | .888 | .809 | .870 | .858 | .858 | .835 | .834 |
| 2.4 | .911 | .913 | .896 | .897 | .880 | .880 | .868 | .869 | .846 | .845 |
| 2.5 | .919 | .921 | .905 | .906 | .889 | .890 | .878 | .879 | .856 | .856 |
| 2.6 | .927 | .928 | .913 | .914 | .898 | .899 | .887 | .888 | .885 | .866 |
| 2.7 | .933 | .935 | .920 | .921 | .906 | .907 | .896 | .897 | .875 | .876 |
| 2.8 | .939 | .941 | .927 | .928 | .913 | .914 | .904 | .905 | .885 | .884 |
| 2.9 | .945 | .946 | .933 | .934 | .920 | .921 | .911 | .912 | .894 | .893 |
| 3.0 | .950 | .951 | .939 | .940 | .927 | .928 | .918 | .919 | .902 | .900 |
| 3.1 | .956 | .956 | .944 | .945 | .932 | .934 | .924 | .925 | .910 | .907 |
| 3.2 | .959 | .960 | .949 | .950 | .938 | .939 | .929 | .931 | .916 | .914 |
| 3.3 | .962 | .964 | .953 | .954 | .943 | .944 | .935 | .937 | .922 | .920 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 100
p = r/n = 75/100

| | γ = 0.50 | | γ = 0.75 | | γ = 0.90 | | γ = 0.95 | | γ = 0.99 | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{Z_a}{Z_b}$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ |
| 3.4 | .966 | .967 | .957 | .958 | .947 | .949 | .940 | .942 | .928 | .926 |
| 3.5 | .969 | 970 | .961 | .962 | .952 | .953 | .944 | .946 | .933 | .931 |
| 3.6 | .972 | .973 | .964 | .965 | .955 | .957 | .949 | .950 | .938 | .936 |
| 3.7 | .975 | .976 | .967 | .968 | .959 | .960 | .953 | .954 | .942 | .941 |
| 3.8 | .977 | .978 | .970 | .971 | .962 | .963 | .957 | .958 | .946 | .945 |
| 3.9 | .979 | .980 | .973 | .974 | .965 | .966 | .960 | .961 | .950 | .949 |
| 4.0 | .981 | .982 | .975 | .976 | .968 | .969 | .963 | .964 | .954 | .953 |
| 4.1 | .983 | .984 | .977 | .978 | .971 | .972 | .966 | .967 | .957 | .956 |
| 4.2 | .984 | .985 | .979 | .980 | .973 | .974 | .969 | .970 | .960 | .959 |
| 4.3 | .986 | .987 | .981 | .982 | .975 | .976 | .971 | .972 | .963 | .962 |
| 4.4 | .987 | .988 | .983 | .983 | .977 | .978 | .978 | .974 | .966 | .965 |
| 4.5 | .988 | .989 | .984 | .985 | .979 | .980 | .975 | .976 | .968 | .968 |
| 4.6 | .989 | .990 | .986 | .986 | .981 | .982 | .977 | .978 | .971 | .970 |
| 4.7 | .990 | .991 | .987 | .987 | .983 | .983 | .979 | .980 | .973 | .972 |
| 4.8 | .991 | .992 | .988 | .989 | .984 | .985 | .981 | .982 | .975 | .974 |
| 4.9 | .992 | .993 | .989 | .990 | .985 | .986 | .982 | .983 | .976 | .976 |
| 5.0 | .993 | .993 | .990 | .991 | .987 | .987 | .984 | .984 | .978 | .978 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

n = 100
p = r/n = 1

| | $\gamma = 0.50$ | | $\gamma = 0.75$ | | $\gamma = 0.90$ | | $\gamma = 0.95$ | | $\gamma = 0.99$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{Z_a}{Z_b}$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ |
| .0 | .371 | .368 | .347 | .342 | .325 | .318 | .304 | .304 | .282 | .279 |
| .1 | .408 | .405 | .382 | .378 | .361 | .354 | .340 | .339 | .314 | .312 |
| .2 | .445 | .441 | .419 | .414 | .394 | .389 | .377 | .374 | .348 | .346 |
| .3 | .480 | .477 | .455 | .449 | .428 | .424 | .412 | .409 | .381 | .380 |
| .4 | .514 | .512 | .489 | .481 | .461 | .458 | .447 | .443 | .415 | .413 |
| .5 | .547 | .545 | .522 | .517 | .494 | .492 | .479 | .476 | .448 | .446 |
| .6 | .579 | .578 | .554 | .550 | .526 | .524 | .512 | .508 | .481 | .478 |
| .7 | .610 | .609 | .585 | .581 | .558 | .555 | .544 | .539 | .510 | .508 |
| .8 | .639 | .638 | .614 | .611 | .587 | .585 | .572 | .569 | .543 | .538 |
| .9 | .666 | .666 | .642 | .639 | .615 | .613 | .601 | .598 | .573 | .567 |
| 1.0 | .693 | .692 | .669 | .666 | .642 | .641 | .629 | .625 | .602 | .594 |
| 1.1 | .717 | .717 | .694 | .691 | .667 | .666 | .653 | .651 | .626 | .620 |
| 1.2 | .741 | .740 | .718 | .715 | .692 | .690 | .677 | .675 | .650 | .645 |
| 1.3 | .762 | .761 | .740 | .737 | .715 | .713 | .700 | .698 | .672 | .669 |
| 1.4 | .782 | .781 | .760 | .758 | .736 | .735 | .721 | .720 | .693 | .691 |
| 1.5 | .800 | .800 | .779 | .777 | .756 | .755 | .742 | .741 | .713 | .712 |
| 1.6 | .817 | .817 | .797 | .795 | .774 | .774 | .761 | .760 | .732 | .732 |
| 1.7 | .833 | .833 | .814 | .812 | .792 | .791 | .779 | .778 | .750 | .751 |
| 1.8 | .848 | .848 | .829 | .828 | .808 | .808 | .795 | .795 | .767 | .769 |
| 1.9 | .861 | .861 | .843 | .842 | .823 | .823 | .810 | .810 | .784 | .785 |
| 2.0 | .873 | .873 | .856 | .855 | .837 | .837 | .824 | .825 | .799 | .801 |
| 2.1 | .885 | .885 | .868 | .868 | .850 | .850 | .837 | .839 | .813 | .815 |
| 2.2 | .895 | .895 | .879 | .879 | .862 | .862 | .850 | .851 | .827 | .828 |
| 2.3 | .905 | .905 | .890 | .889 | .873 | .873 | .862 | .863 | .840 | .841 |
| 2.4 | .913 | .913 | .899 | .899 | .884 | .884 | .873 | .874 | .852 | .853 |
| 2.5 | .921 | .921 | .908 | .907 | .893 | .893 | .883 | .884 | .862 | .864 |
| 2.6 | .929 | .928 | .916 | .916 | .902 | .902 | .892 | .893 | .871 | .874 |
| 2.7 | .935 | .935 | .923 | .923 | .910 | .910 | .901 | .902 | .881 | .883 |
| 2.8 | .941 | .941 | .930 | .930 | .918 | .918 | .909 | .909 | .889 | .892 |
| 2.9 | .946 | .946 | .936 | .936 | .925 | .924 | .916 | .917 | .898 | .900 |
| 3.0 | .951 | .951 | .942 | .941 | .931 | .931 | .923 | .924 | .905 | .908 |
| 3.1 | .956 | .956 | .947 | .947 | .937 | .937 | .929 | .930 | .912 | .915 |
| 3.2 | .960 | .960 | .952 | .951 | .942 | .942 | .935 | .935 | .919 | .921 |
| 3.3 | .964 | .964 | .956 | .956 | .947 | .947 | .941 | .941 | .925 | .927 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE VIII. TABLE OF EXACT AND ASYMPTOTIC LOWER CONFIDENCE BOUNDS FOR $R(t_0)$ (Continued)

$n = 100$
$p = r/n = 1$

| | $\gamma = 0.50$ | | $\gamma = 0.75$ | | $\gamma = 0.90$ | | $\gamma = 0.95$ | | $\gamma = 0.99$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\frac{Z_a}{Z_b}$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ | $L^*\left(\frac{Z_a}{Z_b}\right)$ | $L_A^*\left(\frac{Z_a}{Z_b}\right)$ |
| 3.4 | .967 | .967 | .960 | .960 | .951 | .951 | .945 | .946 | .931 | .933 |
| 3.5 | .970 | .970 | .963 | .963 | .955 | .955 | .950 | .950 | .936 | .938 |
| 3.6 | .973 | .973 | .966 | .966 | .959 | .959 | .954 | .954 | .941 | .943 |
| 3.7 | .976 | .976 | .969 | .969 | .963 | .963 | .958 | .958 | .945 | .947 |
| 3.8 | .978 | .978 | .972 | .972 | .966 | .966 | .961 | .961 | .950 | .951 |
| 3.9 | .980 | .980 | .975 | .975 | .969 | .969 | .964 | .965 | .953 | .955 |
| 4.0 | .982 | .982 | .977 | .977 | .972 | .971 | .967 | .967 | .957 | .959 |
| 4.1 | .984 | .984 | .979 | .979 | .974 | .974 | .970 | .970 | .960 | .962 |
| 4.2 | .985 | .985 | .981 | .981 | .976 | .976 | .972 | .973 | .963 | .965 |
| 4.3 | .987 | .987 | .983 | .983 | .978 | .978 | .974 | .975 | .966 | .968 |
| 4.4 | .988 | .988 | .984 | .984 | .980 | .980 | .977 | .977 | .969 | .970 |
| 4.5 | .989 | .989 | .986 | .986 | .982 | .982 | .979 | .979 | .971 | .972 |
| 4.6 | .990 | .990 | .987 | .987 | .983 | .983 | .980 | .981 | .973 | .975 |
| 4.7 | .991 | .991 | .988 | .988 | .985 | .985 | .982 | .982 | .975 | .977 |
| 4.8 | .992 | .992 | .989 | .989 | .986 | .986 | .983 | .984 | .977 | .978 |
| 4.9 | .993 | .993 | .990 | .990 | .987 | .987 | .985 | .985 | .979 | .980 |
| 5.0 | .993 | .993 | .991 | .991 | .988 | .988 | .986 | .986 | .981 | .982 |

$L^*(Z_a/Z_b)$ is the exact lower confidence bound for $R(t_0)$

$L_A^*(Z_a/Z_b)$ is the asymptotic lower confidence bound for $R(t_0)$

TABLE IX. FACTORS FOR TESTS FOR INCREASING HAZARD RATES

| N/γ | 0.02 | 0.05 | 0.10 | 0.25 | 0.40 |
|---|---|---|---|---|---|
| 5 | 1.656 | 1.464 | 1.305 | 1.052 | 0.896 |
| 6 | 1.605 | 1.435 | 1.285 | 1.067 | 0.926 |
| 7 | 1.565 | 1.410 | 1.274 | 1.075 | 0.944 |
| 8 | 1.531 | 1.389 | 1.263 | 1.080 | 0.957 |
| 9 | 1.504 | 1.372 | 1.255 | 1.081 | 0.966 |
| 10 | 1.479 | 1.355 | 1.247 | 1.082 | 0.973 |
| 11 | 1.458 | 1.342 | 1.239 | 1.082 | 0.978 |
| 12 | 1.439 | 1.330 | 1.233 | 1.082 | 0.983 |
| 13 | 1.422 | 1.318 | 1.227 | 1.082 | 0.986 |
| 14 | 1.408 | 1.309 | 1.221 | 1.081 | 0.989 |
| 15 | 1.397 | 1.299 | 1.215 | 1.081 | 0.992 |
| 16 | 1.383 | 1.290 | 1.211 | 1.080 | 0.994 |
| 17 | 1.374 | 1.284 | 1.206 | 1.079 | 0.996 |
| 18 | 1.362 | 1.276 | 1.202 | 1.079 | 0.997 |
| 19 | 1.353 | 1.269 | 1.198 | 1.078 | 0.999 |
| 20 | 1.346 | 1.264 | 1.193 | 1.076 | 1.000 |
| 22 | 1.330 | 1.253 | 1.186 | 1.075 | 1.002 |
| 24 | 1.318 | 1.242 | 1.179 | 1.073 | 1.003 |
| 26 | 1.305 | 1.234 | 1.174 | 1.072 | 1.005 |
| 28 | 1.295 | 1.227 | 1.168 | 1.071 | 1.006 |
| 30 | 1.285 | 1.220 | 1.163 | 1.070 | 1.007 |
| 32 | 1.277 | 1.214 | 1.159 | 1.067 | 1.007 |
| 34 | 1.269 | 1.208 | 1.155 | 1.066 | 1.008 |
| 36 | 1.261 | 1.202 | 1.151 | 1.065 | 1.008 |
| 38 | 1.255 | 1.198 | 1.147 | 1.064 | 1.009 |
| 40 | 1.248 | 1.192 | 1.143 | 1.064 | 1.009 |
| 42 | 1.244 | 1.188 | 1.140 | 1.063 | 1.010 |
| 44 | 1.238 | 1.183 | 1.136 | 1.062 | 1.010 |
| 46 | 1.233 | 1.181 | 1.134 | 1.060 | 1.010 |
| 48 | 1.228 | 1.176 | 1.131 | 1.059 | 1.010 |
| 50 | 1.224 | 1.174 | 1.129 | 1.059 | 1.011 |
| 52 | 1.220 | 1.171 | 1.126 | 1.058 | 1.011 |
| 54 | 1.216 | 1.167 | 1.124 | 1.057 | 1.011 |
| 56 | 1.212 | 1.164 | 1.122 | 1.057 | 1.011 |
| 58 | 1.209 | 1.161 | 1.120 | 1.056 | 1.011 |
| 60 | 1.205 | 1.159 | 1.118 | 1.055 | 1.011 |
| 62 | 1.202 | 1.157 | 1.116 | 1.055 | 1.011 |
| 64 | 1.199 | 1.155 | 1.115 | 1.054 | 1.011 |
| 66 | 1.196 | 1.152 | 1.112 | 1.054 | 1.012 |
| 68 | 1.193 | 1.151 | 1.111 | 1.053 | 1.012 |
| 70 | 1.190 | 1.148 | 1.110 | 1.053 | 1.012 |
| 72 | 1.189 | 1.147 | 1.107 | 1.052 | 1.012 |
| 74 | 1.186 | 1.144 | 1.106 | 1.052 | 1.012 |
| 76 | 1.183 | 1.143 | 1.105 | 1.050 | 1.012 |
| 78 | 1.182 | 1.142 | 1.104 | 1.050 | 1.012 |
| 80 | 1.179 | 1.139 | 1.102 | 1.050 | 1.012 |
| 90 | 1.170 | 1.132 | 1.096 | 1.048 | 1.012 |
| 100 | 1.161 | 1.126 | 1.092 | 1.046 | 1.012 |
| 110 | 1.155 | 1.120 | 1.087 | 1.044 | 1.012 |
| 120 | 1.148 | 1.115 | 1.083 | 1.043 | 1.012 |

TABLE IX. FACTORS FOR TESTS FOR INCREASING HAZARD RATES (Continued)

| N/γ | 0.50 | 0.60 | 0.70 | 0.75 | 0.80 |
|---|---|---|---|---|---|
| 5 | 0.808 | 0.726 | 0.642 | 0.598 | 0.552 |
| 6 | 0.842 | 0.767 | 0.688 | 0.648 | 0.602 |
| 7 | 0.866 | 0.796 | 0.722 | 0.684 | 0.641 |
| 8 | 0.884 | 0.818 | 0.747 | 0.712 | 0.671 |
| 9 | 0.898 | 0.835 | 0.767 | 0.735 | 0.695 |
| 10 | 0.908 | 0.848 | 0.784 | 0.753 | 0.715 |
| 11 | 0.917 | 0.860 | 0.798 | 0.768 | 0.732 |
| 12 | 0.924 | 0.869 | 0.810 | 0.781 | 0.746 |
| 13 | 0.930 | 0.877 | 0.820 | 0.792 | 0.758 |
| 14 | 0.935 | 0.883 | 0.829 | 0.801 | 0.769 |
| 15 | 0.940 | 0.890 | 0.837 | 0.810 | 0.779 |
| 16 | 0.944 | 0.895 | 0.844 | 0.818 | 0.787 |
| 17 | 0.947 | 0.900 | 0.850 | 0.824 | 0.795 |
| 18 | 0.950 | 0.904 | 0.856 | 0.830 | 0.802 |
| 19 | 0.953 | 0.908 | 0.860 | 0.836 | 0.808 |
| 20 | 0.955 | 0.912 | 0.866 | 0.842 | 0.814 |
| 22 | 0.960 | 0.917 | 0.874 | 0.850 | 0.824 |
| 24 | 0.963 | 0.922 | 0.881 | 0.858 | 0.833 |
| 26 | 0.966 | 0.927 | 0.886 | 0.865 | 0.841 |
| 28 | 0.968 | 0.931 | 0.892 | 0.871 | 0.847 |
| 30 | 0.971 | 0.934 | 0.897 | 0.876 | 0.854 |
| 32 | 0.973 | 0.937 | 0.901 | 0.881 | 0.859 |
| 34 | 0.974 | 0.940 | 0.905 | 0.886 | 0.864 |
| 36 | 0.976 | 0.942 | 0.908 | 0.889 | 0.869 |
| 38 | 0.976 | 0.944 | 0.912 | 0.893 | 0.873 |
| 40 | 0.978 | 0.947 | 0.914 | 0.896 | 0.876 |
| 42 | 0.978 | 0.949 | 0.916 | 0.899 | 0.880 |
| 44 | 0.979 | 0.950 | 0.919 | 0.902 | 0.883 |
| 46 | 0.980 | 0.951 | 0.922 | 0.904 | 0.886 |
| 48 | 0.981 | 0.953 | 0.923 | 0.907 | 0.889 |
| 50 | 0.982 | 0.954 | 0.925 | 0.909 | 0.891 |
| 52 | 0.983 | 0.956 | 0.928 | 0.911 | 0.894 |
| 54 | 0.983 | 0.957 | 0.929 | 0.913 | 0.896 |
| 56 | 0.984 | 0.958 | 0.930 | 0.915 | 0.898 |
| 58 | 0.985 | 0.959 | 0.932 | 0.916 | 0.900 |
| 60 | 0.985 | 0.961 | 0.934 | 0.918 | 0.902 |
| 62 | 0.986 | 0.962 | 0.934 | 0.920 | 0.904 |
| 64 | 0.986 | 0.962 | 0.936 | 0.921 | 0.906 |
| 66 | 0.986 | 0.962 | 0.937 | 0.922 | 0.907 |
| 68 | 0.987 | 0.963 | 0.938 | 0.923 | 0.909 |
| 70 | 0.987 | 0.964 | 0.940 | 0.925 | 0.911 |
| 72 | 0.988 | 0.965 | 0.941 | 0.926 | 0.912 |
| 74 | 0.988 | 0.965 | 0.942 | 0.928 | 0.913 |
| 76 | 0.988 | 0.966 | 0.942 | 0.928 | 0.915 |
| 78 | 0.989 | 0.967 | 0.943 | 0.929 | 0.916 |
| 80 | 0.989 | 0.967 | 0.944 | 0.930 | 0.917 |
| 90 | 0.990 | 0.970 | 0.948 | 0.935 | 0.922 |
| 100 | 0.991 | 0.972 | 0.951 | 0.939 | 0.927 |
| 110 | 0.992 | 0.974 | 0.954 | 0.942 | 0.931 |
| 120 | 0.993 | 0.976 | 0.956 | 0.945 | 0.934 |

TABLE IX. FACTORS FOR TESTS FOR INCREASING HAZARD RATES (Continued)

| N/γ | 0.85 | 0.90 | 0.95 | 0.98 |
|---|---|---|---|---|
| 5 | 0.500 | 0.439 | 0.360 | 0.284 |
| 6 | 0.552 | 0.493 | 0.410 | 0.326 |
| 7 | 0.592 | 0.537 | 0.458 | 0.379 |
| 8 | 0.624 | 0.572 | 0.496 | 0.421 |
| 9 | 0.650 | 0.601 | 0.527 | 0.455 |
| 10 | 0.672 | 0.624 | 0.553 | 0.483 |
| 11 | 0.690 | 0.644 | 0.575 | 0.507 |
| 12 | 0.705 | 0.661 | 0.594 | 0.528 |
| 13 | 0.719 | 0.676 | 0.611 | 0.546 |
| 14 | 0.730 | 0.689 | 0.626 | 0.563 |
| 15 | 0.741 | 0.701 | 0.639 | 0.577 |
| 16 | 0.751 | 0.711 | 0.651 | 0.591 |
| 17 | 0.759 | 0.720 | 0.662 | 0.602 |
| 18 | 0.767 | 0.729 | 0.672 | 0.613 |
| 19 | 0.774 | 0.737 | 0.682 | 0.624 |
| 20 | 0.781 | 0.745 | 0.690 | 0.633 |
| 22 | 0.792 | 0.758 | 0.705 | 0.650 |
| 24 | 0.802 | 0.769 | 0.718 | 0.665 |
| 26 | 0.812 | 0.779 | 0.730 | 0.678 |
| 28 | 0.820 | 0.788 | 0.740 | 0.690 |
| 30 | 0.826 | 0.796 | 0.750 | 0.700 |
| 32 | 0.833 | 0.802 | 0.758 | 0.710 |
| 34 | 0.838 | 0.809 | 0.766 | 0.718 |
| 36 | 0.843 | 0.815 | 0.773 | 0.726 |
| 38 | 0.848 | 0.820 | 0.779 | 0.734 |
| 40 | 0.852 | 0.826 | 0.786 | 0.740 |
| 42 | 0.857 | 0.830 | 0.790 | 0.747 |
| 44 | 0.860 | 0.835 | 0.796 | 0.752 |
| 46 | 0.864 | 0.839 | 0.801 | 0.758 |
| 48 | 0.867 | 0.842 | 0.805 | 0.763 |
| 50 | 0.870 | 0.846 | 0.810 | 0.769 |
| 52 | 0.873 | 0.850 | 0.814 | 0.773 |
| 54 | 0.876 | 0.852 | 0.817 | 0.778 |
| 56 | 0.878 | 0.855 | 0.821 | 0.781 |
| 58 | 0.881 | 0.858 | 0.824 | 0.786 |
| 60 | 0.883 | 0.860 | 0.828 | 0.789 |
| 62 | 0.885 | 0.864 | 0.830 | 0.792 |
| 64 | 0.887 | 0.866 | 0.833 | 0.796 |
| 66 | 0.889 | 0.868 | 0.836 | 0.799 |
| 68 | 0.891 | 0.870 | 0.839 | 0.802 |
| 70 | 0.893 | 0.873 | 0.842 | 0.805 |
| 72 | 0.894 | 0.874 | 0.844 | 0.808 |
| 74 | 0.896 | 0.876 | 0.846 | 0.811 |
| 76 | 0.898 | 0.878 | 0.848 | 0.814 |
| 78 | 0.899 | 0.880 | 0.850 | 0.816 |
| 80 | 0.901 | 0.882 | 0.852 | 0.818 |
| 90 | 0.907 | 0.890 | 0.862 | 0.829 |
| 100 | 0.912 | 0.896 | 0.870 | 0.839 |
| 110 | 0.917 | 0.901 | 0.876 | 0.847 |
| 120 | 0.921 | 0.906 | 0.883 | 0.854 |

*TABLE X. PROBABILITY OF OBTAINING A PERMUTATION WITH $T \leq \overline{T}$ IN PERMUTATIONS OF n VARIABLES**

| n \ T | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 165 | 500 | 833 | | | | | | | | | | | | | | | | | | | |
| 4 | 042 | 167 | 375 | 625 | 833 | 958 | | | | | | | | | | | | | | | | |
| 5 | 008 | 042 | 117 | 242 | 408 | 592 | 758 | 883 | 958 | 992 | | | | | | | | | | | | |
| 6 | 001 | 008 | 028 | 068 | 136 | 235 | 360 | 500 | 500 | 640 | 765 | 864 | 932 | 972 | 992 | 999 | | | | | | |
| 7 | 000 | 001 | 005 | 015 | 035 | 068 | 119 | 191 | 281 | 386 | 500 | 500 | 614 | 719 | 809 | 881 | 932 | 965 | 985 | 995 | 999 | |
| 8 | 000 | 000 | 001 | 003 | 007 | 016 | 031 | 054 | 089 | 138 | 199 | 274 | 360 | 452 | | | | | | | | |
| 9 | 000 | 000 | 000 | 000 | 001 | 003 | 006 | 012 | 022 | 038 | 060 | 090 | 130 | 179 | 238 | 306 | 381 | 460 | | | | |
| 10 | 000 | 000 | 000 | 000 | 000 | 000 | 001 | 002 | 005 | 008 | 014 | 023 | 036 | 054 | 078 | 108 | 146 | 190 | 242 | 300 | 364 | 431 |
| P(c) | 000 | 000 | 000 | 000 | 001 | 001 | 002 | 004 | 006 | 010 | 016 | 025 | 037 | 054 | 076 | 105 | 142 | 186 | 237 | 296 | 360 | 429 |

*Tabular values should be divided by 1000.

$$P(c) = \frac{1}{\sqrt{2\pi}} \int_{\infty}^{-c} e^{-x^2/2} dx, \quad c = \left(\frac{n(n-1)}{4} - T - \frac{1}{2}\right) \sqrt{\frac{2n^2 + 3n^2 - 5n}{72}}, \quad n > 10.$$

**Reproduced from "Nonparametric Tests Against Trends," by H. B. Mann, Econometrica, Vol. 13 (1945) pp. 245-259.

TABLE XI. UNBIASING FACTORS FOR THE M.L.E. OF C

| n | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B(n) | .669 | .752 | .792 | .820 | .842 | .859 | .872 | .883 | .893 | .901 | .908 | .914 |
| n | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 |
| B(n) | .923 | .931 | .938 | .943 | .947 | .951 | .955 | .958 | .960 | .962 | .964 | .966 |
| n | 42 | 44 | 46 | 48 | 50 | 52 | 54 | 56 | 58 | 60 | 62 | 64 |
| B(n) | .968 | .970 | .971 | .972 | .973 | .974 | .975 | .976 | .977 | .978 | .979 | .980 |
| n | 66 | 68 | 70 | 72 | 74 | 76 | 78 | 80 | 85 | 90 | 100 | 120 |
| B(n) | .980 | .981 | .981 | .982 | .982 | .983 | .983 | .984 | .985 | .986 | .987 | .990 |

This table is reproduced from "Inferences on the Parameters of the Weibull Distribution" by D. R. Thoman, L. J. Bain, and C. E. Antle, Techometrics, Vol. 11, No. 3, August 1969, pp. 445-460.



Best Available Copy

# *MISSION*
# *of*
# *Rome Air Development Center*

*RADC plans and executes research, development, test and selected acquisition programs in support of Command, Control Communications and Intelligence ($C^3I$) activities. Technical and engineering support within areas of technical competence is provided to ESD Program Offices (POs) and other ESD elements. The principal technical mission areas are communications, electromagnetic guidance and control, surveillance of ground and aerospace objects, intelligence data collection and handling, information system technology, ionospheric propagation, solid state sciences, microwave physics and electronic reliability, maintainability and compatibility.*

Best Available Copy